Sadhan Kumar Ghosh *Editor*

Waste Management and Resource Efficiency

Proceedings of 6th IconSWM 2016

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Preface

A healthy environment and sustainable living conditions are the basic goals for us and the future generation. To achieve such goals, we need renewable energy resources, sustainable technology and effective waste management, leading towards a circular economy. The sustainable development goals (SDGs) aim for sustainable production and consumption to avoid waste—focusing on production and distribution supply chain in an integrated process rather than on processes in isolation. It is also our duty to ensure that we pose the least harm to the environment by polluting soil, air and water. Since the inception, the International Society of Waste Management, Air and Water (ISWMAW) has been working and committed for sustainable waste management and environmental protection by reducing air and water pollution.

The IconSWM movement was initiated for better waste management and environmental protection in the year 2009 through generating awareness and bringing all the stakeholders together across the world in a bracket for discussion under the aegis of the International Society of Waste Management, Air and Water (ISWMAW). It establishes research projects across the country and in collaboration with the Consortium of Researchers in International Collaboration (CRIC). IconSWM has become significantly one of the biggest international platforms in India for knowledge sharing, awareness generation and encouraging the urban local bodies (ULBs), government departments, researchers, industries, NGOs, communities and other stakeholders to be better in the area of waste management. The conference attracted huge interest from academics, practitioners and policy makers around the world because of the importance of the theme areas and the conference's timeliness in addressing the need for resource utilization.

Resource efficiency can be enhanced if the material is circulated for a number of times of use in the appropriate form. Circulation of materials will help in bringing the circular economy in place, leading to zero waste. Of course, the concept of the circular economy is being demonstrated in some of the countries across the world. The main pillar of the circular economy concept is to conserve resources accelerating waste avoidance, reuse, recycle and driving towards zero landfills. There are many countries where a target of recycling and zero landfill has been set. Initiatives in research and implementation to realize the benefits of circulation of resources have been witnessed across the world. However, research outputs and realization of ideas must converge. This is exactly what IconSWM aimed to achieve through stakeholder's interaction and networking. In the 6th IconSWM, papers received were based on waste management, policy and strategies, recycling, treatment technologies including energy recovery through different routes, nanotechnology, modelling. We have segregated the articles related to research in different fields and covered them in several tracks. The conference offered both the academics and the practitioners the opportunity to share knowledge and experience relevant to the waste management and resource circulation. The overarching question was how we collaborate to facilitate further development in these emerging areas. This book represents the selected papers from the conference.

Part I: Swachh Bharat Mission in India
Part II: Solid Waste Management in Asia-Pacific, African and and European Countries
Part III: Sustainability and Climate Change
Part IV: Policies and Strategies
Part V: Municipal Solid Waste Management
Part VI: City Specific MSW
Part VII: Landfill and Leachate Management
Part VIII: Composting
Part IX: Industrial Waste Treatment and Management
Part X: Sludge Management
Part XI: Waste to Energy
Part XII: W2E Pyrolysis and Gasification
Part XIII: C&D Waste Management
Part XIV: WEEE Management
Part XV: Plastic Waste Management
Part XVI: Chemical Engineering in Waste Management
Part XVII: Waste Utilization and Minimization
Part XVIII: Air Pollution
Part XIX: Modelling in Solid Waste Management
Part XX: Waste Water Treatment
Part XXI: Nano Technology

Kolkata, India
April 2018

Sadhan Kumar Ghosh, Ph.D.

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The Committee expresses gratitude to Mr. Praveen Prakash, IAS, JS(W), UDD, GOI; Mr. Biswajit Roy, Director (BD&HR) of Oil India Ltd.; Mr. Arnab Roy, IAS, Principal Secretary, Department of Environment, Government of West Bengal; Dr. N. Visal, IAS, DMA, Government of Karnataka; Mr. M. P. Singh, GM R&D, IOC Ltd.; Mrs. Dipsikha Deka, Oil India Ltd.; Mr. N. K. Belani, President, CREDAI; Mr. Manjunath Prasad, IAS, Commissioner, BBMP; Mr. G. Kumar Nayak, IAS, MD, Karnataka Power Corpn. Ltd.; Mr. Khalil Ahmed, IAS, Commissioner, KMC; Mr. C. P Marak, Chairman, MSPCB; and Mr. B. K. Barua, ASPCB.

I am thankful to all the members in the core group, International Scientific Committee and Secretariat. Technical Committee members and many of the authors, who served as the referees, are included in this book. Thanks go to all who provided constructive and comprehensive reviews. I must mention the active participation of all the team members in IconSWM across the country with special mention of Ms. Sheetal Singh and her team in CMAK; Dr. Suneel Pandey and his team in TERI; Prof. Deben Barua in Tezpur University, Assam; Dr. V. Kirubakaran in GGRI, Chennai; Mr. Gautam Ghosh and his team, Sampriti Kakati, Biswajit Debnath, Rahul Baidhya, Sannidhya Kumar Ghosh, Suresh Mondal, Bisweswar Ghosh, Gobinda Debnath and the research team members in Mechanical Engineering Department; and ISWMAW, Kolkata HQ, for various activities for the success of the 6th IconSWM 2016. Special thanks go to the team in Springer (India) Private Limited, in particular. Special thanks go to Mr. Aninda Bose and Ms. Kamiya Khatter, whose contribution through the process of this publication has been invaluable. I express my thanks to all the participating delegates and all the members in the Core Committee, International Scientific Committee, National Organizing Committee, Local Working Group members for making the event meaningful.

I must express my gratitude to Pranati, my wife, for her valuable support and suggestions and allowing me to spare time for this work. In closing, I wish to thank all of the authors for their insights and excellent contributions to this book. This book is definitely an effective document for the library, for the researchers and for the implementers.

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About the Editor

Dr. Sadhan Kumar Ghosh who is Professor and Former Head of Mechanical Engineering Department, being the Founder Coordinator of the Centre for QMS at the Jadavpur University, Kolkata-700032, India, is a renowned personality in the field on waste management, circular economy, green manufacturing and TQM. He served as the Director, CBWE, Ministry of Labour and Employment, Government of India, and at the beginning of his career in the Larsen & Toubro Ltd. He is the Founder and Chairman of IconSWM; President of the International Society of Waste Management, Air and Water (ISWMAW); and the Chairman of the Indian Congress on Quality, Environment, Energy and Safety Management Systems (ICQESMS). He received several awards in India and foreign countries including the Distinguished Visiting Fellowship 2012 by the Royal Academy of Engineering, UK, to work on “Energy Recovery from Municipal Solid Waste”. He received Indian patent on “eco-friendly plastics recycling machine and the process thereof” [Patent no. 202532 dated 02/03/2007] and Bangladesh patent “Automatic High Speed Jute Ribboning Machine” [Patent no. 1005146 dated 17/02/2014]. He wrote nine books, more than 26 edited volumes, more than 170 national and international publications and chapters.

He is the (a) international expert of the United Nations Centre for Regional Development (UNCRD)/DESA 2017–18 for the project “State of the 3Rs in Asia and the Pacific”; (b) UNCRD expert under UN DESA in 3R Forum [Adelaide, 2016]; (c) international expert of the Asian Productivity Organization (APO), Japan, and China Productivity Council (CPC) on Green Manufacturing and Green Factory (Taiwan 2014, 2015, 2016); and (d) Indian Leader in the Research Project for GP for the BoP business in APO member countries in Asia (May 2016–July 2018). His very recent international research project as Indian Leader includes Erasmus Plus, UKIERI 2011–13, UKIERI 2012–14, UKIERI 2015–16 and Royal Society—DST 2015.

He has been serving as Member of international steering committees and editorial boards and served as Keynote/Plenary Speaker in many international conferences, namely in Australia, China, Germany, Hong Kong, Italy, Laos, Malaysia, USA, UK and India. He has initiated the movement for worldwide sustainable waste management and research with partners in many countries through the Consortium of Researchers in International Collaboration (CRIC). He was Convener of ISO TC 61 WG24, Member in the Indian Mirror Committee of ISO TC 207 and chaired the ISO TC 61 WG2 meeting in several countries. He has been Principal Investigator of more than 24 research projects. He has been requested to act as Organizing Chair of 4th 3RINC, by Materials Cycles Society, Japan, and Chair-Elect of 7th IconSWM 2017. He was the State-Level Advisory Committee Member of Plastics Waste (Management & Handling) Rules 2011. He is now involved in two important projects—preparation of standards for RDF for utilization in cement plant and other industries as expert members in the Committee set up by the Ministry of Housing and Urban Affairs (MoHUA), Government of India, and collaborative international research project on "Global Implementation Status of Circular Economy (2018–2020)" involving experts from 33 countries. He is available at: sadhankghosh9@gmail.com.

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Part I
Swachh Bharat Mission in India

Swachh Bharat Mission—Implementation and Performance in Rural Areas of Select States

Sadhan Kumar Ghosh, Padma Kant Jha and Yogesh Kumar Singh

Abstract Mahatma Gandhi once said, 'Sanitation is more important than independence' [1]. First Sanitation Programme in India was launched by the Government of India in 1986 which was restructured in 1999 and 2012. But it could not lead to substantial increase in the coverage of rural households with sanitation facilities. After 64 years of independence, Census 2011 revealed that 67.30% rural households had no access to the toilet in India. The present Government which was formed in 2014 put sanitation in its top priorities and launched *Swachh Bharat Mission* (SBM) on 2 October 2014. One of the objectives of this Mission is to achieve open defecation free (ODF) status by 2 October 2019 as a tribute to 'Mahatma Gandhi' on his 150th birth anniversary. The problem of open defecation is not equally distributed among the States of India. This paper tries to evaluate the impact of the Mission considering the increase in coverage of households with sanitation facilities in six States, namely Uttar Pradesh, Bihar, Madhya Pradesh, Rajasthan, Odisha and West Bengal by 31 March 2017 which had 675.02 lakh rural households without access to toilets accounting for 60.75% of total uncovered households with the individual household toilet in India as per the Baseline Survey conducted by Ministry of Drinking Water and Sanitation in 2012–13.

Keywords Swachh Bharat Mission (SBM) · Open defecation · Open defecation free (ODF) · Continual improvement · Rural India

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1 Introduction

According to Census 2011, India's 68.84% population lives in villages and the revelation from Census that only 32.70% households had access to toilets in rural areas stunned the Government and development activists. Open defecation is not only a health hazard but also causes the threat to women residing in rural areas of the country. Mostly, women who do not have access to toilets in rural areas relieve themselves under cover of darkness, i.e. before the dawn or in the evening after sunset.

A UNICEF report also reveals that India has the highest number of stunting cases and the stunting is not the only hazard which comes up with open defecation but there are others too [2]. Water- and sanitation-related diseases remain among the major causes of death in children under five and in India under-five mortality rate in 53 per thousand live births [3]. India is a low-income category country; the diseases due to open defecation caused an added financial burden on poor families due to poor hygiene and leave them in the vulnerable situation.

In 2012–13, the Ministry of Drinking Water and Sanitation (MDWS), which deals with rural drinking water and sanitation programme, conducted a baseline survey (BLS) to estimate the number of rural households not covered with sanitation facilities (baseline survey reveals the data as on March 2013). The baseline survey showed some improvement in coverage of households with sanitation facilities, i.e. from Census 2011 data of 32.70–38.76% (Fig. 1) [4].

The baseline survey statistics also showed that the problem of open defecation was not equally distributed across the country. While looking at the number of households not having access to sanitation facilities, which was 1110.25 lakh, the share of States like Uttar Pradesh, Bihar, Madhya Pradesh, Rajasthan, Odisha and West Bengal was 675.02 lakh accounting for 60.75% of total uncovered households (Table 1).

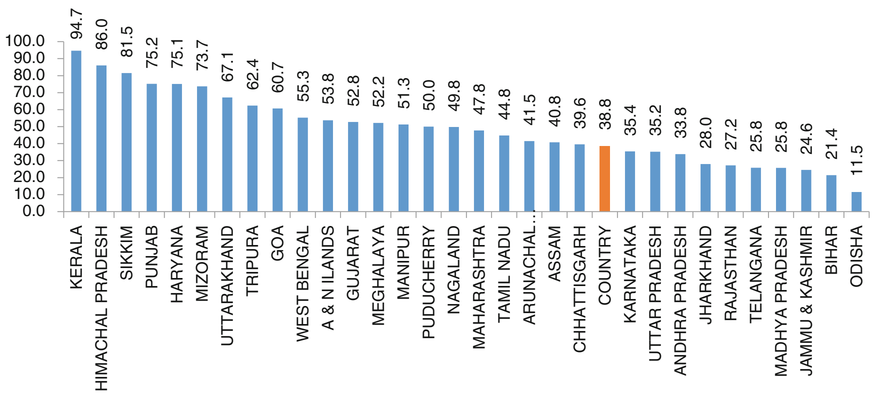

Fig. 1 Households covered with sanitation facilities (percent coverage) as per baseline 2012–13

Table 1 Top six States having highest number of uncovered households with sanitation facilities

State name	No. of rural households without toilet as per BLS 2012–13 (in lakh)
Uttar Pradesh	185.98
Bihar	168.17
Madhya Pradesh	89.68
Rajasthan	83.59
Odisha	79.82
West Bengal	67.78
Total	675.02

Source Ministry of Drinking Water and Sanitation

The present Government, which came into power in 2014, kept access to sanitation facilities as one of its top priorities. In continuation to this, the Government initiated a time bound mission '*Swachh Bharat Mission*' (SBM) on 2 October 2014 to achieve open defecation free (ODF) status by 2 October 2019 as a tribute to Mahatma Gandhi on his 150th birth anniversary after restructuring the earlier sanitation programme—'Nirmal Bharat Abhiyan' (NBA). The assistance by the Government under SBM was increased to Rs. 12,000 from existing Rs. 10,000 (Rs. 4,600 under NBA and Rs. 5,400 under convergence with MGNREGA). The provisions of water storage and hand wash were the main reasons behind this increment in the assistance. The Central Government knew that achieving ODF status is not possible without the active participation of the States; hence a Sub-Group of Chief Ministers on Swachh Bharat Abhiyan was constituted to suggest ways for achieving the Swachh Bharat status by 2 October 2019. The Sub-Group of Chief Ministers submitted its report to the office of Prime Minister of India on 14 October 2015. The recommendations offered by the Sub-Group have been accepted by and large.

To achieve the ODF status by the country, earnest effort and effective implementation of the Mission are required by the States like Uttar Pradesh, Bihar, Madhya Pradesh, Rajasthan, Odisha and West Bengal which were contributing 60.75% of the total target as per baseline survey. Till March 2017, the coverage of households with sanitation facilities was increased to 63.72% at national level. In the further part of the paper, separate analysis for six States has been made to understand the impact of the Mission on the performance of mentioned States since BLS survey.

2 Comparative Analysis for Six Select States

2.1 Statistics Pertaining to the State of Bihar

In Bihar, as per baseline survey, only 21.4% of households had access to sanitation facilities. Till 2 October 2014, the State had coverage of 22.3%, i.e. only 0.9 percentage point improvement in coverage over the baseline survey. During the

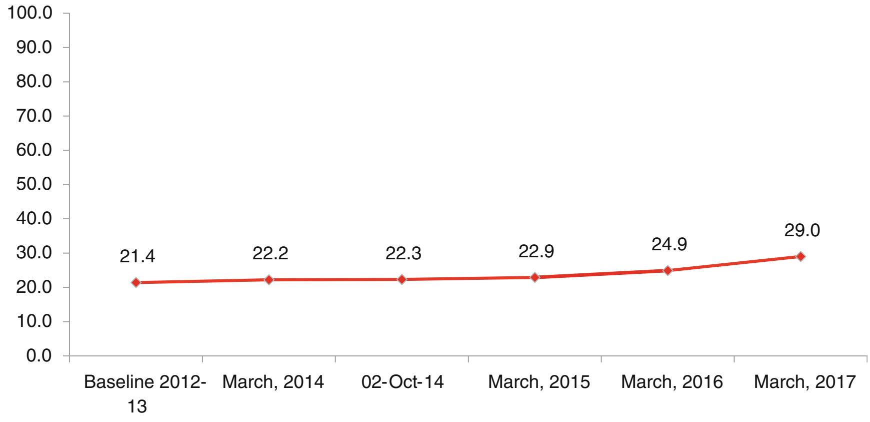

Fig. 2 Percent of households covered with sanitation facilities in Bihar

year 2014–15, before the launch of the Mission, the coverage showed an addition of only 0.1 percentage point. But, in latter part of 2014–15, i.e. after the launch of the Mission, the coverage showed an improvement of 0.6 percentage point. The State witnessed some improvement in next year of launch of the Mission, which took the coverage to 24.9% households. However, the coverage had shown only 2.6 percentage point improvement after the launch of the Mission for the State of Bihar by March 2016. By March 2017, 29% of the households have got the access to sanitation facilities (Fig. 2).

Only 2,177 out of 38,715 villages have declared themselves as ODF village, whereas no district has declared itself as ODF district out of 38 districts in the State (as on 30 May 2017).

2.2 Statistics Pertaining to the State of Madhya Pradesh

In Madhya Pradesh, as per baseline survey, only 25.8% of households had access to sanitation facilities. Till 2 October 2014, the State had shown the coverage of 31.8%, i.e. 6 percentage point increase over the coverage at the time of baseline survey. During 2014–15, before the launch of the Mission, the coverage showed an addition of only 0.8 percentage point. But, in latter part of 2014–15, i.e. after the launch of the Mission, the coverage showed an improvement of 2.5 percentage point. The progress was observed in next year of launch of the Mission, which took the coverage to 42.8% households. The coverage has shown 9 percentage point improvement after the launch of the Mission for the State of Madhya Pradesh by the end of March 2016. The coverage has reached 58.1% by the end of March 2017 (Fig. 3).

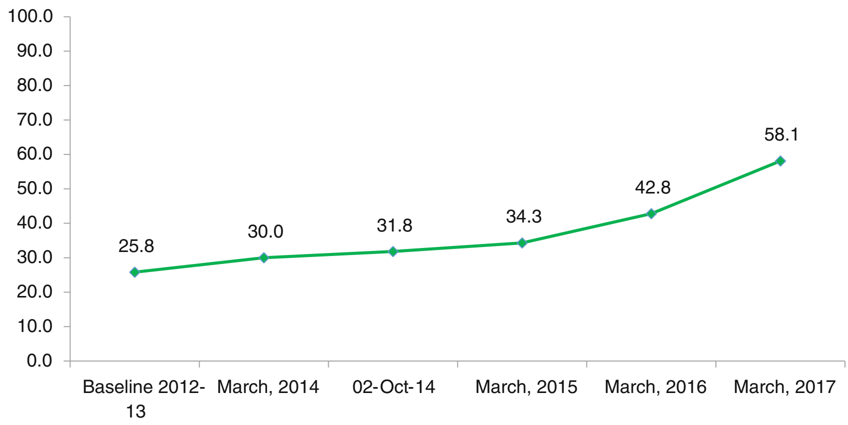

Fig. 3 Percent of households covered with sanitation facilities in Madhya Pradesh

Only 16,566 out of 51,347 villages have declared themselves as ODF village, whereas 4 districts have declared themselves as ODF districts out of 51 districts in the State (as on 30 May 2017).

2.3 Statistics Pertaining to the State of Odisha

In Odisha, as per baseline survey, only 11.5% of households had access to sanitation facilities. Till 2 October 2014, the State has shown the coverage of 12.0%, i.e. 0.5 percentage point improvement in coverage over the baseline survey. During the year 2014–15, before the launch of the Mission, the coverage made an addition of only 0.1 percentage point. But in latter part of 2014–15, i.e. after the launch of the Mission, the coverage showed an improvement of 1.4 percentage point. In 2015–16, the State showed remarkable progress and coverage went up to twice of previous year adding 14.7 percentage point. The coverage had shown 16.1 percentage point improvement after the launch of the Mission for the State of Odisha by the end of March 2016. During 2016–17, the State has shown progress by adding another 14 percentage point to coverage and reaching overall coverage to 42.1% (Fig. 4).

Only 4,871 out of 47,283 villages have declared themselves as ODF village, whereas no district has declared itself as ODF district out of 30 districts in the State (as on 30 May 2017).

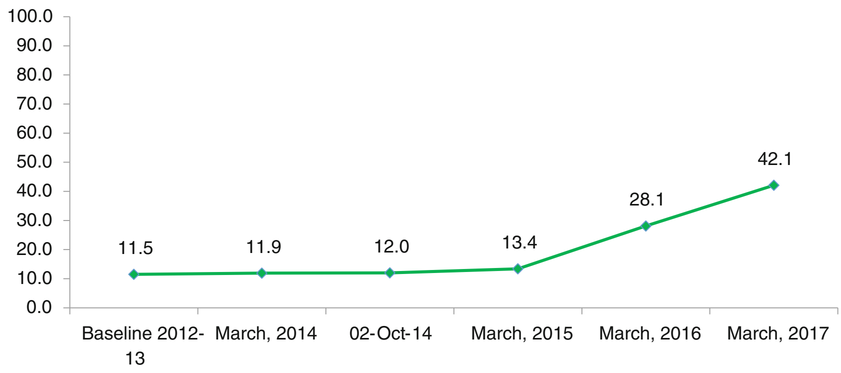

Fig. 4 Percent of households covered with sanitation facilities in Odisha

2.4 Statistics Pertaining to the State of Rajasthan

In Rajasthan, as per baseline survey only 27.2% of households had access to sanitation facilities. Till 2 October 2014, the State had shown the coverage of 29.7%, meaning only an improvement of 2.5 percentage point coverage over the baseline survey. During the year 2014–15, before the launch of the Mission, the coverage showed an addition of only 0.1 percentage point. But, in latter part of 2014–15, i.e. after the launch of the Mission, the coverage showed an improvement of 5.6 percentage point. The progress was remarkable with adding 18.8 percentage point in next year of launch of the Mission, which took the coverage to 54.1% households by the end of March 2016 which has reached to 78.7 by March 2017 (Fig. 5).

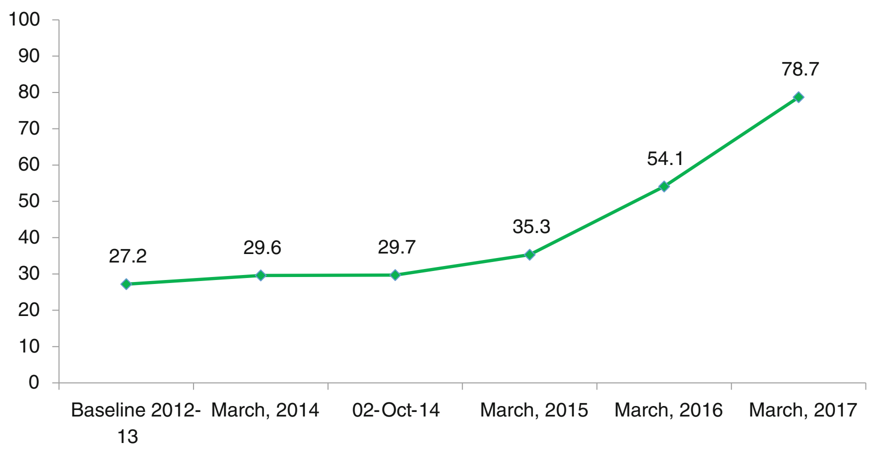

Fig. 5 Percent of households covered with sanitation facilities in Rajasthan

Only 19,918 out of 41,509 villages have declared themselves as ODF village, whereas 6 districts have declared themselves as ODF districts out of 33 districts in the State (as on 30 May 2017).

2.5 *Statistics Pertaining to the State of Uttar Pradesh*

In Uttar Pradesh, as per baseline survey only 35.2% of households had access to sanitation facilities. Till 2 October 2014, the State had coverage of 38.0%, meaning only 2.8 percentage point increase in coverage over the baseline survey. During the year 2014–15, before the launch of the Mission, the coverage was very little. But, in latter part of 2014–15, i.e. after the launch of the Mission, the coverage showed an improvement of 1.8 percentage point. The progress caught some speed in next year of launch of the Mission, which took the coverage to 42.1% households by adding 2.4 percentage point over the coverage as on March 2015. The coverage has shown improvement of only 9.6 percentage point after the launch of the Mission for the State of Uttar Pradesh by the end of March 2017 (Fig. 6).

Only 7,407 out of 99,289 villages have declared themselves as ODF village, whereas only one district has declared itself as ODF district out of 75 districts in the State (as on 30 May 2017).

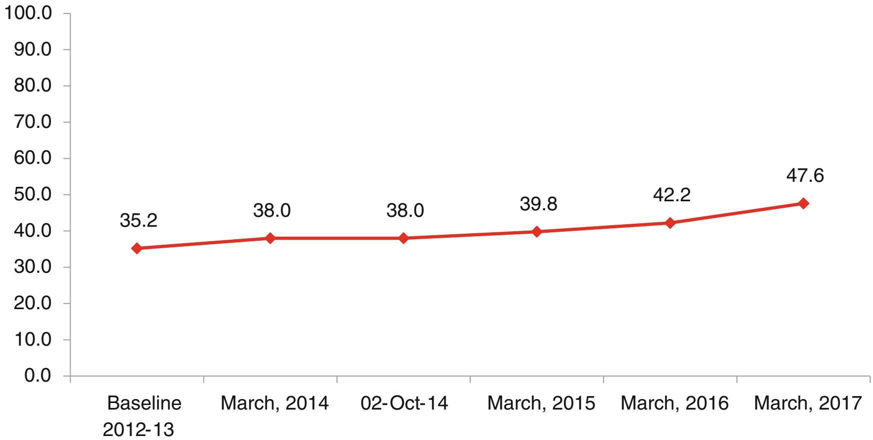

Fig. 6 Percent of households covered with sanitation facilities in Uttar Pradesh

2.6 Statistics Pertaining to the State of West Bengal

In West Bengal, as per baseline survey, 55.3% of households had access to sanitation facilities. Till 2 October 2014, the State had coverage of 60.1%, i.e. only 4.8 percentage point improvement in coverage over the baseline survey. During the year 2014–15, before the launch of the Mission, the coverage showed an addition of only 0.7 percentage point. But in latter part of 2014–15, after the launch of the Mission, the coverage showed an improvement of 4.8 percentage point. The progress caught some speed in next year of launch of the Mission, which took the coverage to 64.9% households. The coverage reached to 74.4% by the end of March 2016 which got an addition of 15.3 percentage point in next year leading coverage to 89.7% (Fig. 7).

Only 21,647 out of 42,076 villages have declared themselves as ODF village, whereas 7 districts have declared themselves as ODF districts out of 20 districts in the State (as on 30 May 2017).

2.7 Comparison Among Six States

Figure 8 clearly shows that States like West Bengal, Rajasthan, Madhya Pradesh and Odisha can surely provide access to toilets to all households by 2 October 2019 with existing pace of performance. But States like Uttar Pradesh and Bihar, which have highest number of households with no access to toilets, have been sluggish so far. Without earnest efforts from these States, the target to achieve ODF status by India seems unrealistic.

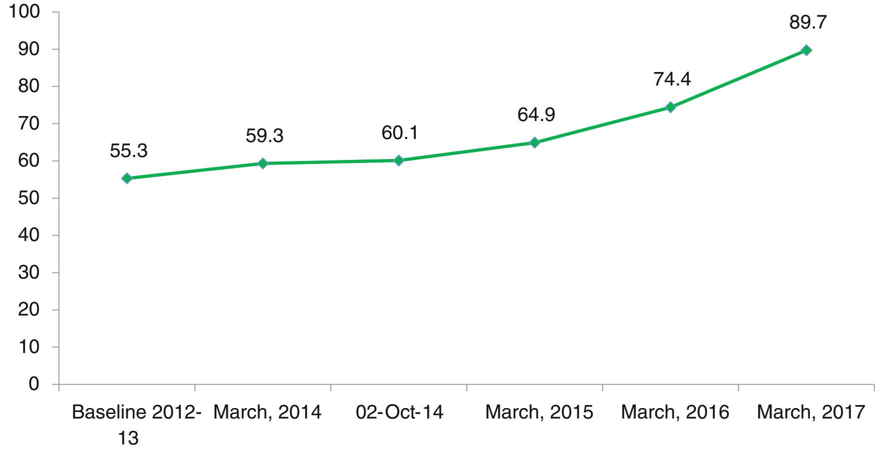

Fig. 7 Percent of households covered with sanitation facilities in West Bengal

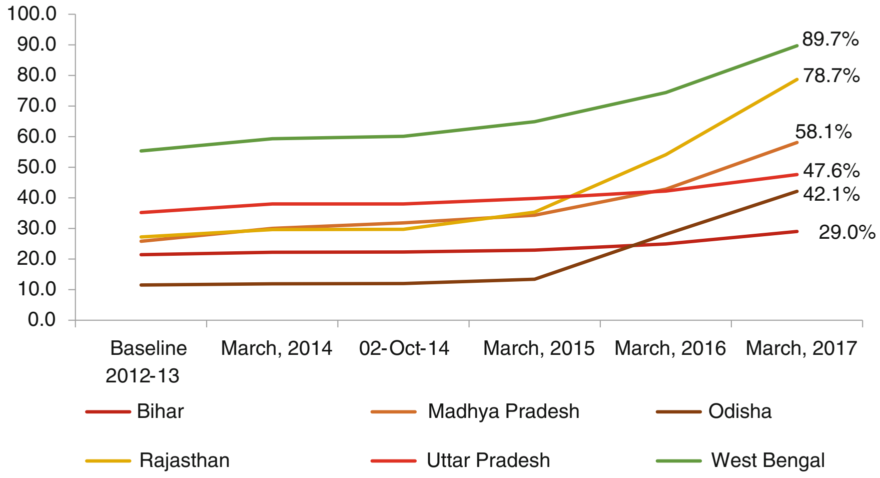

Fig. 8 Percent of household coverage with sanitation facilities

In providing access to sanitation facilities, the State Governments are required to play an important role. This paper also reviewed some case studies to come up with some guiding points for the State Governments which can be followed to replicate the success stories for achieving the open defecation free (ODF) status.

3 Case Studies

1. **Nadia District, West Bengal**
   Nadia was the first district in the country which achieved open defecation free (ODF) status after the launch of the SBM [5]. The district collector strategized the sanitation campaign by focusing on behaviour change of the people living in the district, adopting saturation approach, involving schools and local institutions like Self-Help Groups (SHGs). The teachers, students, SHG representatives, Anganwadi workers, doctors played the role of catalysts for the campaign. This success story highlighted that coordination between village councils (*Gram Panchayats*), district councils (*Zila Parishad*) and district administration could bring the results soon. For the rapid construction of the toilets, the rural sanitary marts were opened to fulfil the demands of construction material for toilets and capacity building of masons was promoted. Behaviour Change Communication (BCC) and Information Education Communication (IEC) also played a crucial role in attaining the ODF status by the district.

2. **Bikaner District, Rajasthan**
   In April 2013, the district collector of Bikaner started the campaign *Banko Bikano* to promote the usage of sanitation facilities by connecting it to sense of the pride at the level of women, family, village and district [6]. The administrative set-up of Bikaner district focused on behaviour change. In this direction, the district collector formed a District Resource Group with technical support from Water and Sanitation Programme for convincing people's representatives who had to motivate the community further. The theme of campaign was community-led and community-driven.
   Many heterogeneous groups were formed to seek and shame those defecating in open in morning. The low-cost technology options for toilets were promoted. On the other hand, poorest of poor were helped by the community in getting household toilet constructed which shows community's sense of pride and dedication to achieving ODF status.
3. The initiatives from the States like Gujarat, by passing a State law which refuses to allow the candidates contesting local elections if they do not have individual household toilet [7] and 'No Toilet, No Bride' slogan by the State of Haryana in 2005, advising brides not to choose the spouse if spouse's household does not have toilet [8], have made the situation better.

4 Conclusion

The analysis of six States shows that the progress in the States, viz. Rajasthan, West Bengal, Odisha and Madhya Pradesh, is significant since launch of the Swachh Bharat Mission whereas the focus is needed to be given by the States of Uttar Pradesh and Bihar. Without efforts by the State Governments of Uttar Pradesh and Bihar which have 3,02,18,284 uncovered households with sanitation facilities, constituting 46.01% households of the total uncovered households at national level as on 31 March 2017, the country cannot achieve ODF status by 2 October 2019. The State Governments should also look for involvement of community, local leaders and better coordination among village councils, district councils and district administration to achieve ODF status and make it sustainable.

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An Effective Mosquitoes–Insects Killing Machine (MIKM)

Sushant B. Wath

Abstract Mosquitoes−insects carry many potentially dangerous diseases like mosquito-borne viral encephalitis, dengue, chicken guinea, yellow fever, malaria, filariasis and affect around one to three million people globally. To minimize risk and to avoid bites, protective measures practiced include mosquito coils, repellent mats, vaporizers, aerosol and body cream or lotions. But there are certain limitations and drawbacks associated with the existing products systems which include health implication on users due to uses of chemicals, fire hazards and safety, effectiveness, ease of handling/operation and economy. Moreover, it does not completely destroy the mosquitoes–insects and just keeps them at bay, in order to provide the temporary relief for limited hours in the specified area. More importantly due to the recent outbreak and spread of deadly ZIKA VIRUS in African and American continent due to mosquitoes, it is urgently required to control the mosquitoes' menace. So, there is a need and market for indigenous, low-cost, eco-friendly efficient mosquito-controlling device. The patented (3013DEL2015) invention describes a use of developed low-cost non-hazardous material in a specially design machine which produces mosquito-insect attractants in more economical and convenient way, which lures the mosquitoes–insects towards the source, i.e. machine, and gets eventually kill by electric field. The invention targeted to be cost-effective for controlling the mosquitoes' problem without any negative implications on user health or environment.

Keywords Bio-sensors · Repellent · Attractant · Lure · Controlling devices

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1 Introduction

Water is the most essential and basic need in the complete life cycle of the mosquitoes. Different types of mosquito species thrive in different kind of climate like hot, humid, dry and aquatic conditions such as fresh water, waste or polluted water, acidic water. They mostly preferred the stagnant water for laying eggs which hatches into larvae within 2–3 days and feed on the organic matter present in the water. A female mosquito can lay around 150–350 eggs each time at least three times in her lifetime. Larvae can be found in variety of places where the stagnant water source is available such as swimming pools, room coolers, flower pots, storm drains, storm drains, septic drainage, rice cultivation area, hollow trees, junked containers, lakes, fabricated containers, and junked vehicle tires. Along with the water, municipal solid waste (MSW) may also be the breeding area for mosquitoes. The presence of organic matter and entrapped water in MSW waste (with plastic, glass, metals, etc.) makes the kind of biotope favourable for vector mosquitoes to breed [1].

Mosquitoes belong to a group of mini, pygmy-like flies and are one of the most harmful insects to mankind. They have bio-sensors to sense heat, carbon dioxide and UV lights. Mosquito can even detect the person in complete dark by sensing CO_2 and body temperature that the person releases from his body.

Worldwide every year about 0.7 billion people get infected due to the transmission of different types of diseases resulting from different species (Table 1) of mosquitoes. And it results in the death of around 2 million people per year (http://tut2learn.com/2016/07/world-mosquito-day/).

Developing country like India shares the big load of mosquito-borne diseases, sharing 34% of dengue and 11% malaria cases worldwide. In India during 2013, around 1.13 million people get infected due to chikungunya, dengue and malaria, resulted in to about 766 death (http://www.downtoearth.org.in/coverage/mosquito-matters-42168).

Table 1 Major classes of mosquitoes and diseases caused in India and worldwide

Genus	World		India		Diseases cause
	Species	Major vector	Species	Major vector	
Anopheles	422	60	58	6	Malaria, filaria
Aedes	888	25	111	1	Yellow fever, dengue, DHF, filaria, chikungunya
Culex	715	12	57	3	Bancroftian filariasis, Japanese encephalitis West Nile Fever, viral arthritis, Polyarthritis
Mansonia	23	7	4	1	Rift Valley fever virus
Total	**2048**	**104**	**230**	**11**	

Amongst the various insect-transmitted human diseases, malaria is the prominent one. Anopheles species is the dangerous mosquito species resulting in the outbreak and spread of malaria in Indian cities and results in many deaths per annum globally, of which majority are children. Further, mosquitoes have developed resistance to various insecticides which makes controlling of these diseases more difficult [2]. India reported 40 million cases due to mosquito-borne diseases, of which 1.07 million cases of malaria and 535 deaths in India during 2015 (http://www.malariasite.com/malaria-india/).

Moreover, India shares sea route/connection with majority of yellow fever (YF) endemic countries. This raises more concern in India to control Aedes mosquito breeding in seaport areas to prevent any potential introduction of YF virus in the country. As per International Health Regulations Act, 2005, all the international airports/seaports, ground crossings, and peripheral areas up to 400 m should be kept free from Aedes mosquito breeding or indices should be kept less than one to eliminate the chance of spreading disease or vectors to any part of the world.

2 Existing Measures, Its Drawbacks and Implications

To minimize risk and to avoid insect or mosquito bites, protective measures have been practiced. Mosquito coil is low cost and commonly use alternative to restrict mosquito bites. It compose of pyrethrum, a powder made from chrysanthemum plants, which undergoes slow combustion providing relief from mosquitoes for few hours. Other measures include use of mosquito-repellent mats, vaporizers, aerosol and body cream or lotions. None of the listed measures completely destroys the mosquitoes and just keeps the mosquitoes at bay, in order to provide the temporary relief for limited hours in the specified area. Moreover, it uses hazardous chemicals/materials which may have following small to very serious health implications in the short and long run on user during the course of its usage [3, 4].

- PM in coils: Asthma, persistent wheeze in children.
- Chemicals (like allethrin, *N*,*N*-diethyl-M-toluamide (DEET, etc.): eyes, skin, respiratory tract, nervous system.
- Prolonged exposure: brain, liver and kidney damage.
- Does not completely destroy the mosquitoes.
- Temporary relief for limited hours and area.
- Mosquitoes have developed resistance to these repellents.

Another conventional way of controlling mosquito menace is usage of ovi-traps, which cater fabricated breeding place for the mosquitoes, followed by manual destruction of larvae. Nowadays, many mosquitoes or flying insect traps or killing machine are available in the market. These machines apply a device which combusts propane, thus producing CO_2, temperature and moisture. These three attractant lures mosquitoes towards source, and then, mosquitoes get collected in net or collection chamber and get dehydrate/get killed. Some trapping system includes electric circuits, fans, light or sound technology to attract mosquitoes and kill them. However, there are certain limitations and draw backs associated with the existing products/systems, which includes health implications on users, fire hazards and safety, effectiveness, ease of handling, operation and economy. Further, these gadgets with hazardous materials-chemicals, may lead to serious environmental implications related to its disposal, after use.

In view of this, there is a need and market for indigenous, low-cost, eco-friendly, efficient mosquito-controlling device. The material to be used for emitting mosquito attractant should be environmental-friendly and is not having any health implications on the person using it as well.

3 Design Basis

Mosquitoes use various types of sensors for detecting its food which include thermal, visual and chemical sensors. Mosquitoes use various types of sensory neurons for the detections of host odour which itself is very complex due to the presence of numerous chemical compounds attributing specific odour [5–7].

Normally, female mosquitoes thrive on the human blood for its need of protein required for reproduction. They locate host by sensing the CO_2,1-octen-3-ol and other body odourant emitted from the host body, and through optical recognition.

Normally, mosquitoes use three types of stimuli using its bio-sensors for sourcing pray which are also used as the basis for design of MIKM.

- Olfactory stimuli (long range 10–50 m): CO_2, octenol
- Visual stimuli (middle range 5–10 m): lights fluorescent, LED, UV
- Thermal stimuli (short range 20 cm): skin temperature/heat, moisture, sweat (amino acid, cholesterol, fatty acid alcohol, esters, lactic acid, propionic acid, etc.)

4 Design and Development

Understanding the challenges and drawbacks/limitations associated with the existing systems and devices, a novel device “Mosquitoes–Insects Killing Machine (MIKM) and its Method thereof” is designed and developed [8] as shown in Fig. 1.

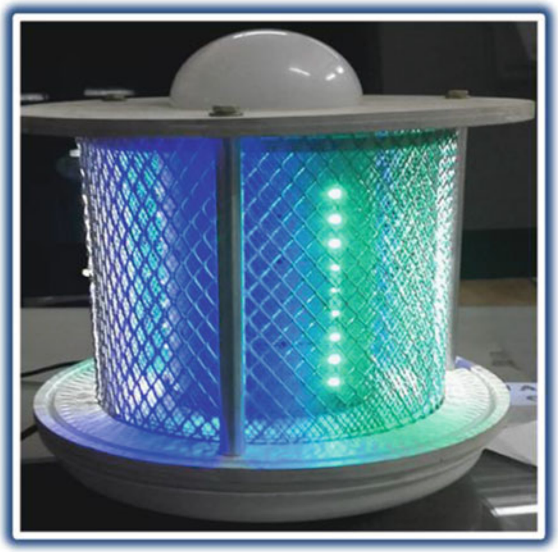

Fig. 1 Mosquito-Insect Killing Machine

The present invention (Fig. 1) describes a device or a machine for luring and killing the mosquitoes–insects. It can be described as a specially designed electrical cum electronic machine and a mechanism for attracting and killing mosquitoes or flying insects. It comprises of a specially developed material essentially comprising parts such as carbonate source, body odorant source, which together releases mosquito-insect's attractants such as CO_2 and other attractant smells (body odour), with or without controlled heating. The machine uses a specially developed low-cost non-hazardous material which can emit controlled amount of requisite CO_2 along with other attractants (body odorant) with or without controlled heating which is placed at the middle of the machine. Heat control mechanism maintains the CO_2 emission rate and heat. LED lights of various specific colours optimizes mosquitoes–insects towards machine. Slow-rotating perforated enclosure helps in evenly dispersion of emissions through the specified channel, fitted with slow-rotating perforated disc which gives the impulse emission simulating the human breathing/respiration pattern. Fan helps in evenly dispersion of emissions through channel, and facilitate suction of mosquitoes–insects in the electric grid as well, which eventually kills them by burning. The ashes of burned mosquitoes–insects gets collected in the detachable cleaning tray. The material use for emitting CO_2 and other attractant is bio-degradable, non-hazardous, environmental-friendly, low cost and is not having any health implications on the user.

5 Advantages

The main advantages of the MIKM are:

- More effective in mosquito—insects control as uses CO_2 along with other attractants such as body odour, heat, lights.
- Does not have any negative health implications on the users as does not use any toxic materials.
- Environmental-friendly.
- Completely destroys the mosquitoes–insects.

6 Conclusion

Thus, the present innovation provides the environmental-friendly alternative for the eradication and killing of the mosquitoes, which are responsible for various diseases and deaths in India and globally. Unlike other mosquitoes controlling devices and methods presently adopted, this not only protects the users from the mosquito's menace but also has no health implications from its uses on users. Moreover, due to use of bio-degradable, cheap and non-hazardous materials, it is environmental-friendly. This innovation has a great societal importance and potential for replication within India and abroad countries which are facing the big threat to human kind due to the outbreak of deadly ZIKA virus, dengue, malaria, etc., and other mosquitoes-related problems. The present innovation is presently at the prototype testing stage, and further, R&D related to design and process optimization are in progress.

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Fabrication of a Low-Cost Water Purifier Incorporating Agricultural Wastes for the Removal of Dyes and Heavy Metals

R. Prabhakar, Y. Bharath and S. N. Singh

Abstract In twenty-first century, due to the advent of industrialization and urbanization, water is polluted with contaminants such as heavy metals, dyes and microorganisms. Dyes and heavy metals are major pollutants of water, which causes micro-toxicity together. Chemical methods of treatment of contaminated water are not economical and are a cumbersome process [1]. It is thereby extremely essential to look for alternatives. One such altercation is to incorporate biological processes as they possess the ability to biosorb dyes and heavy metals from polluted water. India produces 350 million tonnes of agricultural wastes [2]. Agricultural by-products such as sugarcane bagasse, coconut coir and rice husk are among many that can be used. In this pioneering research, the gap between solid waste management and water purification is bridged. The properties of activated and raw forms of sugarcane bagasse and coconut coir were studied for the removal of dyes and heavy metals. It was found that activated forms of biosorbents were more efficient in removal of heavy metals and dyes as compared to raw forms of biosorbents. Various factors such as contact time, doze, pH, temperature affecting the biosorption process were studied, and it was concluded that a steady rise in these parameters improved the biosorption properties. The results from the studies conducted were extrapolated for the fabrication of a low-cost water purifier. These biosorbents were coupled with an ultra-filtration membrane and an ultraviolet chamber. The fabricated unit was tested for its efficiency, economics, effectiveness, etc. Therefore, the use of agriculture wastes for the removal of contaminants is an effective alternative to remove contaminants from water as well as for wise solid waste management.

Keywords Biosorption · Water purification · Agriculture wastes
Solid waste management

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1 Introduction

Water is a major source of life on Earth. It is the constituent part of all living organisms. It forms the integral part of chemical and biological reactions. The human body is made up of 70% water; it is required for the sustenance of the body. The pollution of water is at an alarming level now which is due to the uncontrolled industrialization, urbanization and other similar practices. These processes release harmful contaminants into the water making it unfit for drinking and other purposes [3]. The major contaminants such as heavy metals, dyes and microorganisms are not removed by conventional practices such as decantation and boiling. Modern methods have disadvantages such as high cost of operation, regular maintenance, dependence on after sales services. [4].

A study by Nriagu et al. defines a heavy as a dense metal or metalloid which is toxic in nature. Heavy metals are released into water bodies from processes such as refining ores, tanneries, batteries, fertilizer industries, paper industries, pesticides, mining. These possess an alarming threat to the environment. Heavy metals such as Cr, Fe, Se, V, Cu, Co, Ni, Cd, Hg, As, Pb, Zn are hazardous to humans and cause cancer, rashes, skin-related problems, irritation of the eye, loss of hair, infertility, loss of memory, etc. Heavy metals cannot be destroyed or degraded because they are thermo-stable and hence remain in the environment for a long time. Technologies such as chemical precipitation, ion exchange, membrane processes and adsorption onto activated carbon are used to remove heavy metals from water. These methods are expensive in nature [5].

In a report by Koumanova et al., it was stated that the large number of production and use of dyes generates coloured wastewaters that are a serious environmental concern. Textile industries, dye producing industries, paper and pulp mills, tanneries, electroplating factories, distilleries, food firms and a bunch of different industries discharge coloured waste product into water bodies. Textile industries use large quantities of dyes, thus imparting colour to effluents. Dyes are coloured pollutants which are used in industries as colouring agents. The released dyes are toxic and coloured in nature. It colours the water and makes it unfit for drinking. Majority of dyes are stable to biodegradation and photodegradation. Methods such as membrane filtration, precipitation, coagulation, flocculation are used to remove dyes from water. These methods are not economical and cannot be used on a variety of coloured water [6].

India generates approximately 350 million tonnes of agricultural waste [2]. The waste generated has a huge potential in purification of water. Agricultural wastes are biological compounds possessing the ability of biosorption. Biosorption is the process of passive concentration of contaminants on the dead biological materials by various mechanisms such as surface adsorption, diffusion, chelation, and ion exchange among many others [7].

There has been immense research conducted unlocking the potential of agricultural wastes [8]. Agricultural wastes such as coconut coir, sugarcane bagasse, orange peels, rice husk and peanut shells have been researched upon. It has the capacity to remove heavy metals and dyes from 0.001 to 50 ppm and above [9, 10]. Sugarcane bagasse and coconut coir have been selected for this study, as it is produced in India abundantly and has multiple heavy metals and dyes biosorption ability [11]. It becomes essential to eradicate these contaminants from water in a simple, efficient and cost-effective manner.

The fabrication of a low-cost water purifier is a necessity to address the issues of potable drinking water and solid waste management to benefit the society. The low-cost water purifier named “Jal Samadhan” is fabricated using agricultural wastes, low-cost environment-friendly materials along with recycled materials. The unit mainly works on the principle of biosorption. The unit uses two types of biosorbents in two different forms. The unit once fabricated was capable of removing all three major contaminants such as heavy metals, dyes and microorganisms. The unit is also economically priced and easy to use.

2 Materials and Methods

2.1 Collection of Raw Materials

Biosorbents such as coconut coir and sugarcane bagasse were collected from KR market, Bengaluru, India.

2.2 Preparation of Materials

Coconut coir and sugarcane bagasse are washed with running tap water, followed by a quick wash with distilled water. It is sundried at 70 °C for 60 min [12].

The dried biosorbents are divided into two parts. One part is used as raw biosorbents, while the other is used for the preparation of activated biosorbents. Raw biosorbents are raw sugarcane bagasse (RSB), and raw coconut coir (RCC) and activated biosorbents are activated sugarcane bagasse (ASB) and activated coconut coir (ACC).

2.3 Preparation of Activated Biosorbents

The dried biosorbents are taken and subjected to charring. The process removes all volatile matter. The product obtained is called char. The char obtained is mixed into a solution of 25% of calcium chloride and stored for 24 h. The solution is then filtered and dried. The product obtained is activated biosorbent [13].

2.4 Collection and Analysis of Contaminated Water

Ten litres of dye industry effluent (consisting of methylene blue) was collected. The collected sample was analysed to determine the concentration of dye by subjecting it to standard procedure of UV spectrometer at 660 nm [14]. The heavy metals such as lead and chromium were analysed with atomic adsorption spectrometer (AAS) [15].

2.5 Parameters Affecting Biosorption

2.5.1 Effect of Contact Time

0.1 g of biosorbent was taken in six beakers containing 20 ml of contaminated water. It was kept on orbital shaker for a time period starting with 10 min followed by increments of 10–60 min. The solution was filtered and analysed with AAS and UV. The same was repeated for the other biosorbents [16].

2.5.2 Effect of Doze

The biosorbents were taken in increments of 0.1–0.6 g in six beakers containing 20 ml of contaminated water and kept on orbital shaker for 20 min. The solution was filtered and analysed in AAS and UV for heavy metals concentration and dye concentration, respectively [17].

2.5.3 Effect of pH

0.1 g of each biosorbents in four beakers containing 20 ml of contaminated water was subjected to biosorption for 20 min at different pH ranging from 4, 6, 8, 10. The pH was adjusted using 0.1 M NaOH and 0.1 M HCl. The solution was filtered and analysed in AAS and UV [14].

2.5.4 Effect of Temperature

0.1 grams of each biosorbents in four beakers containing 20 ml of contaminated water was subjected to biosorption for 20 min at different temperature ranging from 10, 20, 30, 40 °C. The temperature was adjusted using cold centrifuge and orbital shaker. The solution was filtered and analysed in AAS and UV [18].

2.6 Fabrication of Water Purifier

A 2 * 2 ft of waste plywood was taken from a construction to mount the components. Food grade bottle was collected. A hole of 1 cm diameter is drilled at the bottom with a driller. A connector is placed at the point and joined using glue. A waste PVC pipe was taken of 25 in. height from the same construction site. The bottom of the PVC pipe was closed using eight layers of muslin cloth/equivalent material. The bottle is mounted on to the plywood using a holder. UV chamber and UF membranes are mounted using holders. The outlet from the bottle was connected to the inlet of UF membrane using pipes. The outlet from UF membrane was connected to UV chamber using pipes. The outlet of UV chamber was placed into a storage tank. Hole of 2 in. is drilled on to the cap of food grade container. The PVC pipe is placed inside the hole made on the cap. The PVC pipe acts as the biosorbent loading area.

3 Results and Discussion

The water laden with heavy metals and dye was subjected to biosorption using raw and activated forms of sugarcane bagasse and coconut coir. The effect of various parameters such as pH, temperature, and dosage and contact time on biosorbents with removal of dye and heavy metals in water were studied and reported as follows.

3.1 Analysis of Contaminated Water

Two heavy metals were detected in the water sample collected using atomic absorption spectroscopy (AAS). The concentrations of heavy metal present are as follows:

Lead: 17.85 ppm
Chromium: 15.58 ppm

The levels of heavy metals present are more than the WHO prescribed limits which are 0.1 ppm for lead and 0.5 ppm for chromium. The UV analysis showed a value of 2.24 units of absorbance.

3.2 Effect of Contact Time on Biosorption

The effect of contact time on biosorption of heavy metals and dyes was studied. It was found that for the biosorption of dyes, on raw sugarcane bagasse (RSB), raw coconut coir (RCC), activated sugarcane bagasse (ASB) and activated coconut coir (ACC), 30 min was the optimum time where maximum biosorption occurred. In the case of biosorption of heavy metals, it was found that after 60 min of time period 98.15% of lead and 98.84% of chromium is removed. As the contact time increases the biosorption slowly moves towards equilibrium as all the sites get occupied.

It can be concluded that amount of biosorption increases with increase in time. This is due to the increased interaction between the contaminant and biosorbent. The probability of biosorption increases with increase in time depending on the available area for biosorption [19]. Figures 1 and 2 depict the same.

3.3 Effect of Biosorbent Dosage

Various doses of biosorbent such as RSB, RCC, ASB and ACC were taken to determine the effect of dosage on the effect of biosorption. It was found that 0.6 g RSB, RCC, ASB and ACC removed 77.6, 82, 82 and 88%, respectively. From Fig. 3, it can be inferred that an increase in the dose of biosorbent increases the efficiency in dye removal. This could be attributed to the large surface area available for biosorption of dye.

From Fig. 4, it can be seen that as the doze of biosorbents increases the biosorption property of the biosorbents increases. This is because of more area provided by the biosorbent to biosorb the heavy metals. Total biosorbent dose of 0.8 and 1.2 g removes 99.90–100% of heavy metals.

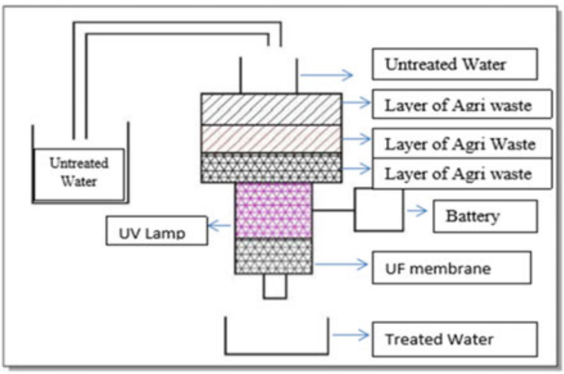

Fig. 1 Jal Samadhan

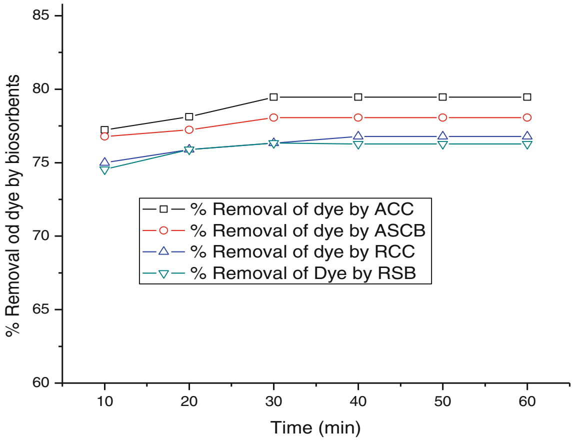

Fig. 2 Effect of contact time on dye removal

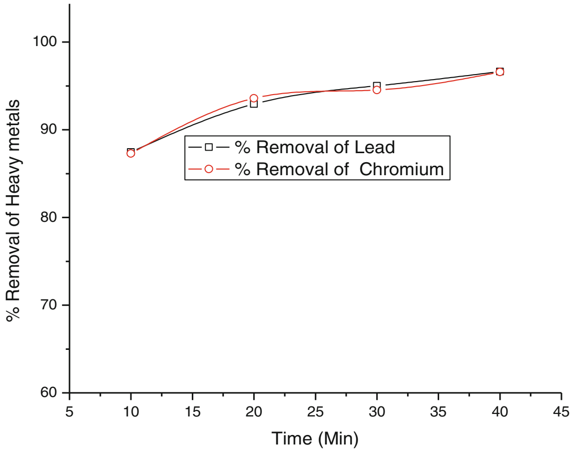

Fig. 3 Effect of contact time on biosorption of heavy metals

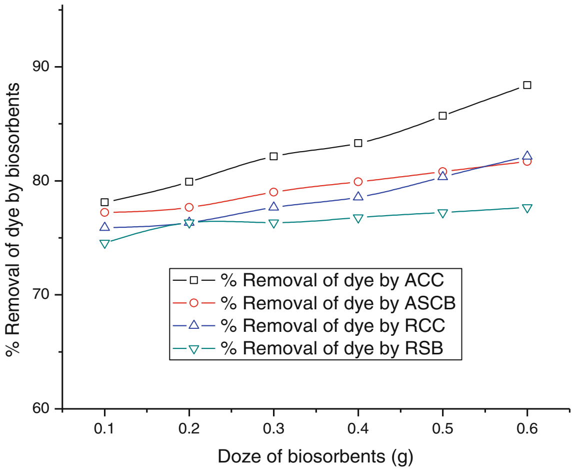

Fig. 4 Effect of dosage on dye removal

3.4 Effect of pH on Biosorption of Contaminants

From Fig. 5 it can be inferred that at lower levels of pH which is the acidic range, the biosorption increases and gradually decreases as there is an increase in pH. This is because in the acidic region, the acid further increases the surface area of the biosorbent resulting in an increase in biosorbent and biosorbate interaction. It is found that at an optimum pH of 4, ASB and ACC removed 82 and 83% of the dye, respectively, while RCC and RSB removed 76.33 and 76.79% of dye at an optimum pH of 7.

An increase in pH results in the decrease of biosorption. This is because of the characteristics of the biosorbent and the heavy metal. The decrease in positive charge on the biosorbent decreases the biosorption property. The maximum % of biosorption occurs at pH 4. This can be inferred from Figs. 6.

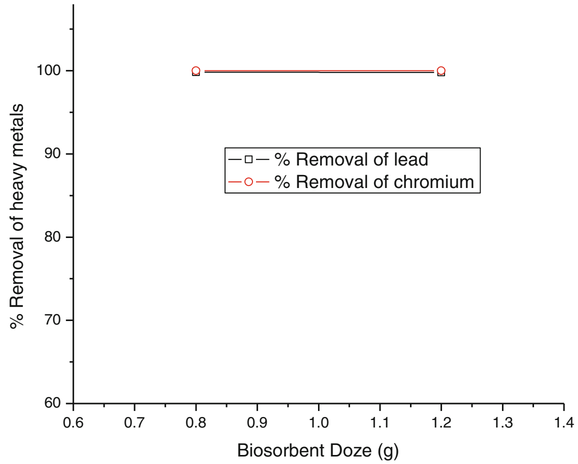

Fig. 5 Effect of dosage on heavy metal removal

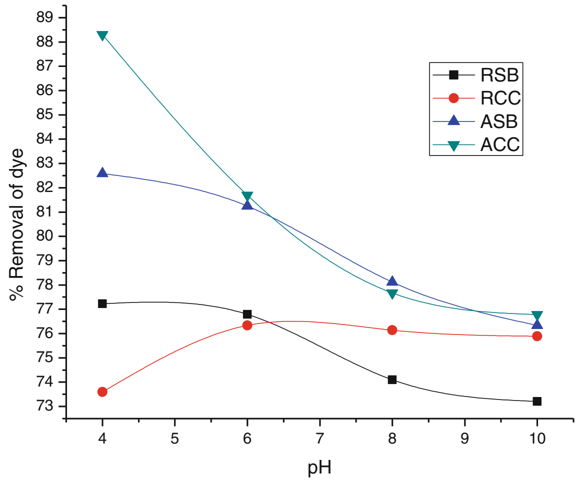

Fig. 6 Effect of pH on dye removal

3.5 Effect of Temperature

From Fig. 7, it can be inferred that there is an increase in biosorption as the temperature increases. This is because at lower temperatures, the surface areas of biosorbent decrease as the molecules are held together closely. It is found that at 40 °C, 77, 76.68, 83 and 82% of the dye was removed by RSB, RCC, ACC and ASCB, respectively.

From Fig. 8, it can be inferred that as the temperature increases the biosorption increases. It is because at lower temperature, there is less area for biosorption to occur as the molecules are tightly packed. The optimum temperature is between 30 and 40 °C. In this temperature range, 94% of chromium and 97% of lead are removed by the biosorbents (Fig. 9).

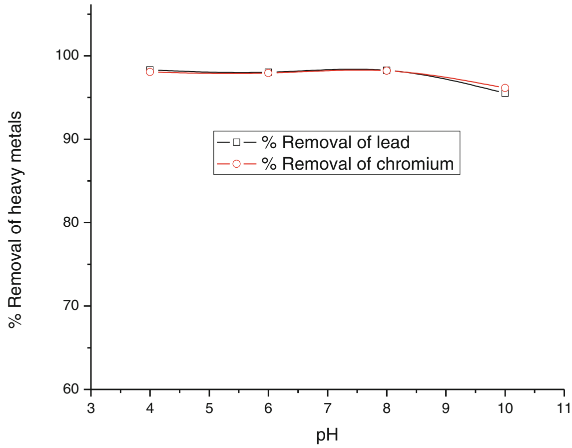

Fig. 7 Effect of pH on heavy metal removal

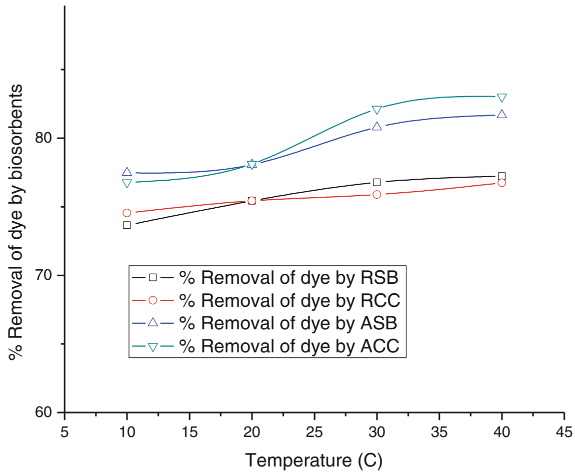

Fig. 8 Effect of temperature on dye removal

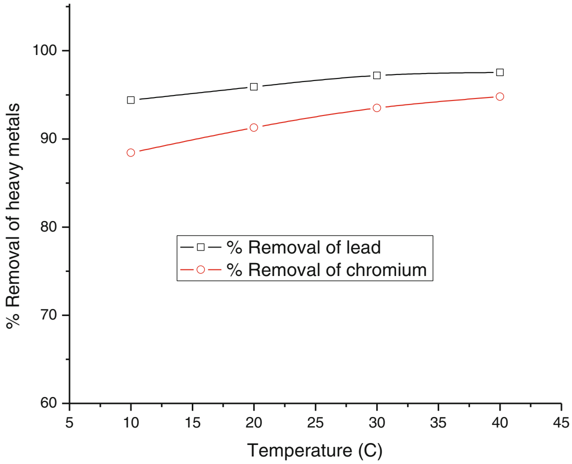

Fig. 9 Effect of temperature on heavy metal removal

4 Conclusions

The study has significantly achieved the use of agricultural waste to treat contaminated water. By employing this method, solid waste management can be effectively achieved by using the agricultural wastes as effective tool for the purification of water. The study displays the efficiency of biosorbents in the removal of contaminants from water. The water filtration unit "Jal Samadhan" can be used at any geographical area catering to the needs of the people. It can be concluded that raw forms of the biosorbents are also effective in the removal of dyes and heavy metals. However, the activated forms of the biosorbent removed the highest contaminants of which activated coconut coir removed the highest percentage of contaminants.

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Part II
Solid Waste Management in Asia-Pacific, African and European Countries

Analysis of Composition and Associated Environmental Impacts of Sludge Generated from Dipped Products Manufacturing Industry in Sri Lanka

R. L. C. Livera and N. J. G. J. Bandara

Abstract The manufacturing of dipped products in Sri Lanka is a growing industry which uses concentrated latex for manufacturing. Sludge from treatment plants of dipped products manufacturing companies is an inevitable solid waste resulting from various stages of concentrated latex processing and treatments that are dumped into landfilling sites which requires a suitable disposal method. The most common techniques of handling sludge are dewatering, disposal in landfills, incineration and application on agricultural lands. Main objective of the study is to conduct an analysis of the composition of seven different types of sludge collected from four dipped products manufacturing factories in Sri Lanka. Other objectives of the study are to identify the associated environmental impacts of present heavy metals in sludge through comparisons based on Sri Lanka Standards 1246:2003 for composting. Collected sludge samples were analysed for selected cations: copper, tin, iron, sodium, magnesium, manganese, potassium, calcium, lead, zinc, nickel, chromium and cadmium. As chemical parameters, phosphate, organic carbon, nitrogen, pH and EC and, as physical parameters, specific gravity, total, volatile and fixed solid content were tested. The data were statistically analysed using one-way ANOVA and Tukey pairwise comparison tests or by Kruskal–Wallis test. According to the results obtained for the chemical analysis, pH of all the sludge types ranged within SL Standards for composting. Total nitrogen content, available phosphorous and organic carbon contents vary above and below the required minimum for standards. In the heavy metal analysis, Zn and Ni were recorded above the maximum permissible level of SLS and CCME standards, and also, Fe was found in comparatively high concentrations. The results of sludge analysed from four different factories in dipped products manufacturing industry can vary based on the manufacturing process, wastewater treatment process and also with time.

Keywords Dipped products · Sludge · Heavy metals · Environmental impacts Standards

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1 Introduction

The manufacturing of dipped products in Sri Lanka is a growing industry which uses concentrated latex for its manufacturing process. Examples of dipped products are gloves for medical, industrial and household use, balloons and condoms.

The Central Environmental Authority (CEA) of Sri Lanka has categorized rubber processing as one of the major polluting industries in Sri Lanka [1]. Effluent generated from rubber processing industry is not suitable for any domestic or industrial use without proper treatment because such effluents are found to be outside the tolerance limits set out by CEA [2, 3], and such effluents result in polluting surface and groundwater sources [3, 4]. To overcome this problem, effective rubber treatment will be necessary [5]. Wastewater treatment process generates different types of sludge such as chemical sludge from chemical wastewater treatment, biological sludge from biological wastewater treatment and centrifuged sludge and mould sludge from natural latex processing.

The composition of sludge from different times and locations may vary according to the manufacturing process, wastewater effluent (seasonality of industries, industrial input, etc.) and wastewater treatment process (lime additions, dewatering, digestion, etc.) [6, 7]. Generated sludge will contain trace elements, organic and inorganic matter, and different heavy metals in different concentrations. Therefore, the composition needs to be known for designing of alternative uses of sludge and for alternative disposal methods of sludge other than incineration. But yet the composition of sludge generated in dipped products manufacturing industry and its timely variation is not identified according to literature. The findings of the study can be used for that purpose since there are only limited researches carried out in this area. The purpose of the study is to determine the composition of different types of sludge through conducting a comprehensive analysis of sludge samples collected from several large-scale glove manufacturing companies.

2 Methodology

Four large-scale glove manufacturing, factories with different ownerships were selected for the analysis. Sludge samples from sludge piles at factories' wastewater treatment plants were collected from June 2015 to November 2015 in monthly basis. Three samples were collected from one sludge type using sampling equipment appropriate to the type of sludge (liquid or solid), and the analysts of interest were well mixed to prepare a composite sample and each parameter was analysed while carrying out three replicates in each month. This method was carried out for all the seven different sludge types.

The pH, electrical conductivity, total, fixed and volatile solids and specific gravity were determined in fresh sludge samples while organic carbon and available phosphorous were tested in air dried (2–3 days) and sieved (2 mm) samples. Total

Table 1 Maximum acceptable trace elements content in composts

Parameter	Testing method
pH	pH meter
EC	Conductivity meter
Total, fixed and volatile solids	US EPA method 1684
Total nitrogen	Micro-Kjeldhal method
Available phosphorous	Olsen method
Organic carbon	Wet oxidation—Walkley and Black method
K, Ca, Na, Mg	Atomic absorption spectrophotometer
Heavy metals (Cu, Ni, Pb, Zn, Cr, Cd)	Atomic absorption spectrophotometer

nitrogen, K, Na, Ca and heavy metals were tested of oven dried (105 °C) sludge samples. Both physical and chemical parameters were tested according to the following methods as shown in Table 1.

The obtained results were interpreted on variations within one category of sludge collected in different months and also on variations in different sludge categories collected from each industry. This was carried out by bar charts using Microsoft Excel, 2010, and statistical analysis was carried out using MINITAB software. Average values for each sludge category were compared with SLS compost standards and least environmental damaging sludge categories were identified and alternative solutions for sludge disposal other than incineration were discussed.

3 Results and Discussion

All the results presented are corresponding to sample types as follows:

F1: S1—Chemical sludge from chemical wastewater treatment plant of Factory 1
F2: S2—Chemical/biological sludge from central wastewater treatment plant of Factory 2
F3: S3—Chemical sludge from chemical wastewater treatment plant of Factory 3
F4: S4—Chemical sludge from chemical wastewater treatment plant of Factory 4
F4: S5—Biological sludge from biological wastewater treatment plant at Factory 4
F4: S6—Mould sludge from natural rubber latex centrifugation process of Factory 4
F4: S7—Centrifugal sludge from magnesium removal process of natural rubber latex of Factory 4

According to the results, highest solids' content (%) was recorded in F4:S7 (36.40–98.76%), F2:S2 (36.61–95.94%), F1:S1 (31.93–94.30%), F3:S3 (29.45–96.33%), F4:S6 (32.70–82.68%) and F4:S5 (20.20–67.73%) sludge types. This is due to effective filter pressing and comparatively low value was recorded in F4:S4 (13.70–44.01%) sludge type as a result of storing without filter pressing in the wastewater treatment plant. According to Kruskal–Wallis test, there is no significant difference between seven different sludge types (*H*-value = 7.26, *P*-value = 0.297).

Fixed solids' content (%) in sludge samples was recorded in F3:S3 (67.80–78.95%), F4:S4 (66.98–74.45%), F2:S2 (23.18–80.94%), F4:S5 (41.96–71.24%), F1:S1 (43.51–61.12%), F4:S7 (40.24–63.79%) and F4:S6 (25.41–56.31%), respectively. These results mean that the F4:S7 and F4:S6 have the highest volatile solids' contents (%). Results of Kruskal–Wallis test show that there is a significant difference between at least one mean of the sludge types analysed (*H*-value = 19.55, *P*-value = 0.003). Total volatile solids' content % was recorded in higher values in F4:S6 (43.69–74.59%) and F2:S2 (19.06–76.82%) sludge types. According to statistical analysis, in Kruskal–Wallis test there is a significant difference between at least one mean of the data set (*H*-value = 19.5, *P*-value = 0.003).

Fixed solid content (%) and volatile solid content are related to each other where fixed solid content is the amount remaining after combustion at 550 °C and volatile solid content. The reason for the high volatile solids' content (%) in F4:S7 and F4:S6 sludge types is that these two types are the results of the centrifugation process of natural rubber latex where organic content is higher than in other sludge types.

Results for the chemical analysis showed that all sludge types analyzed were in the pH range 6.40–10.58 throughout the year according to the results. The required range for pH in SL Standards for compost 1246:2003 is 6.5–8.5 and Kruskal–Wallis test showed that there is no significant difference between seven different sludge types (*H*-value = 8.48, *P*-value = 0.205). pH is a very important factor for the availability of heavy metals in sludge because heavy metal concentrations are generally reduced when soil pH is increased. But heavy metals are not leachable under normal environmental conditions since heavy metals are immobile even at acidic pH of 2 [8]. Therefore, the effects from pH in the seven different types of sludge are very limited according to the results analysed.

According to the results obtained on electrical conductivity, the lowest electrical conductivity (μs/cm) was recorded in F3:F3 (265–463 μs/cm) where there was low water content and F4:S5 (126–494 μs/cm) and highest was recorded in F4:S4 (388–1782 μs/cm) where there was very high water content in sludge. According to the one-way ANOVA test, at the confidence level of 95% there is a significant difference between at least one mean of the data set analysed (*P*-value = 0.011, *F*-value = 3.48).

As illustrated in the Fig. 1, highest total nitrogen content (%) was recorded in F4:S7 (3.64–4.33%) and then in F4:S6 (2.58–3.63%) which are generated as a result of centrifugation process of natural rubber latex, resulting in high amounts of organic matter. All the mean values of F4:S4, F4:S3 and F1:S1 recorded higher values than the required minimum SL Standards for compost (1.0%). Most of the mean values F2:S2 and F4:S5 were recorded above the standard. But F3:S3 and F4:S4 are recorded below the standards. Therefore, these will require addition of nitrogen if used for soil fertilizer or soil conditioner purposes. According to the Kruskal–Wallis test, there is a significant difference between at least one mean of the data set analysed (*H*-value = 29.54, *P*-value = 0.000).

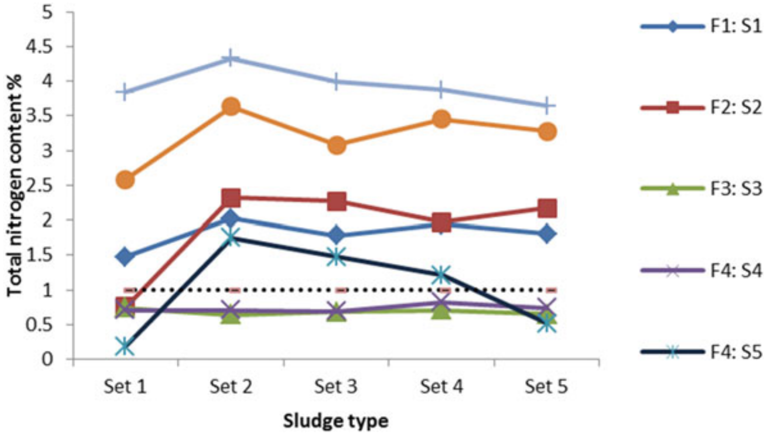

Fig. 1 Variation of total nitrogen content (%) of sludge

As illustrated in Fig. 2, the highest total phosphorous content (%) was recorded in F4:S7 (12.24–14.17%) and then in F4:S6 (9.21–12.38%) and lowest value was recorded in F3:S3 (0.007–0.016%). All the mean values of F4:S7 and F4:S6 were recorded above the required minimum SL Standards for compost (0.5%) which are generated in centrifugation of natural latex and therefore contain very high phosphorous concentrations. In the centrifugation process, chemicals are added to natural latex to remove Mg as $Mg_3(PO_4)_2$. This generates F4:S7 which is also called as $Mg_3(PO_4)_2$ sludge. F4:S6 is also generated in mixing with water; therefore, these show high availability of phosphorous. According to the Kruskal–Wallis test, there is a significant difference between at least one mean of the data set analysed (*H*-value = 32.55, *P*-value = 0.000).

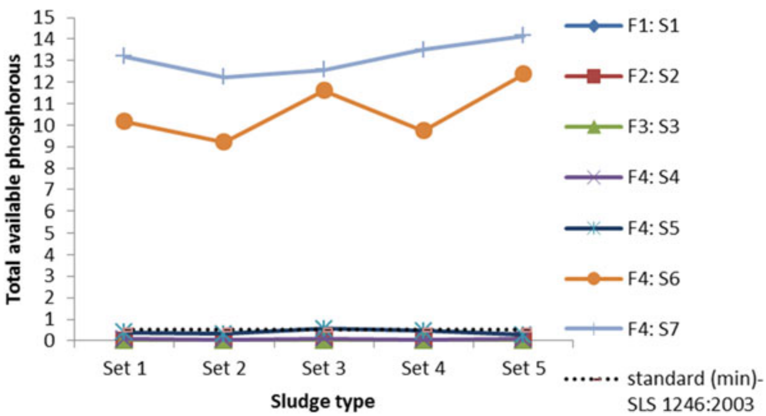

Fig. 2 Variation of total available phosphorous content (%) of sludge

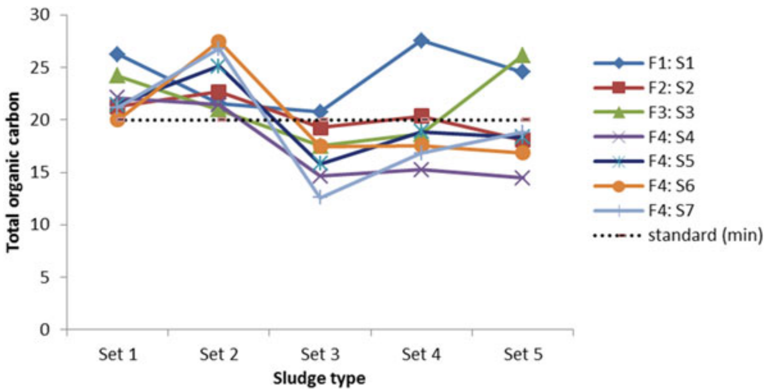

Fig. 3 Variation of organic carbon content (%) of sludge

Figure 3 shows that the organic carbon content of the sludge samples was more or less similar to each other. According to the Kruskal–Wallis test, there is no significant difference between seven different sludge types analysed (H-value = 7.75, P-value = 0.257).

Concentration of heavy metals in sludge affects the options available for sludge disposal. Mean values obtained for heavy metals namely copper (Cu), nickel (Ni), lead (Pb), zinc (Zn), chromium (Cr) and cadmium (Cd) in mg/kg for seven different types of sludge at different times of year are as shown in following tables.

In all types of sludge, mean values of Cu concentrations were recorded below the allowable maximum level of SL Standards for compost (400.0 mg/kg). Therefore, the possibilities for occurrence of environmental problems are limited. According to the one-way ANOVA test, at the confidence level of 95% there is no significant difference between seven different sludge types analysed (P-value = 0.402, F-value = 1.07) (Fig. 4).

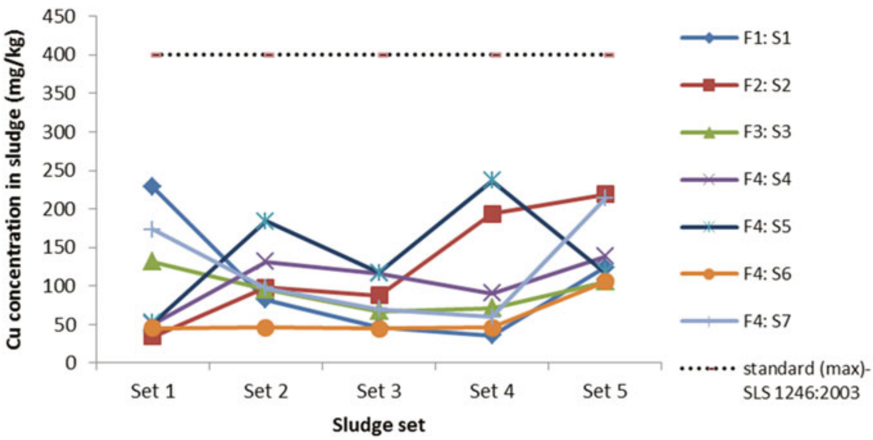

Fig. 4 Variation of Cu concentration (mg/kg) of sludge

All the mean values recorded in different sludge types were above the maximum Ni concentration permitted by SL Standards for compost (100 mg/kg) and by CCME standards (180 mg/kg). This may be due to the use of chemical compounds containing Ni in the industry for the manufacturing process as common activators [9]. High concentrations of Ni in all types of sludge and variation of concentration with time may affect greatly the disposal of sludge into the environment. According to the one-way ANOVA test, at the confidence level of 95% there is no significant difference between seven different sludge types analysed (*P*-value = 0.753, *F*-value = 0.57) (Fig. 5).

When considering the standards, all the mean values of different sludge types were recorded lower than the maximum limit for Pb concentration in SL Standards for compost (250.0 mg/kg) and in CCME standards (500.0 mg/kg). According to the one-way ANOVA test, at the confidence level of 95% there is no significant difference between seven different sludge types analysed (*P*-value = 0.173, *F*-value = 1.64) (Fig. 6).

When considering the standards, all the means were recorded above the maximum permissible limits of SL Standards for compost (1000.0 mg/kg) and CCME standards (1850.0 mg/kg). According to previous literature, Zn is one of the predominant metals in sludge generated from wastewater treatment plants due to the use of TMTD/ZnO before transporting [10], as processing aids for rubber modification, as accelerators to improve vulcanization and to improve properties of the final product [11] and as age resistors to slowdown deterioration of products [9, 12]. According to the one-way ANOVA test, it shows that at the confidence level of 95% there is a significant difference between at least one mean that was analysed (*P*-value = 0.000, *F*-value = 6.64) (Fig. 7).

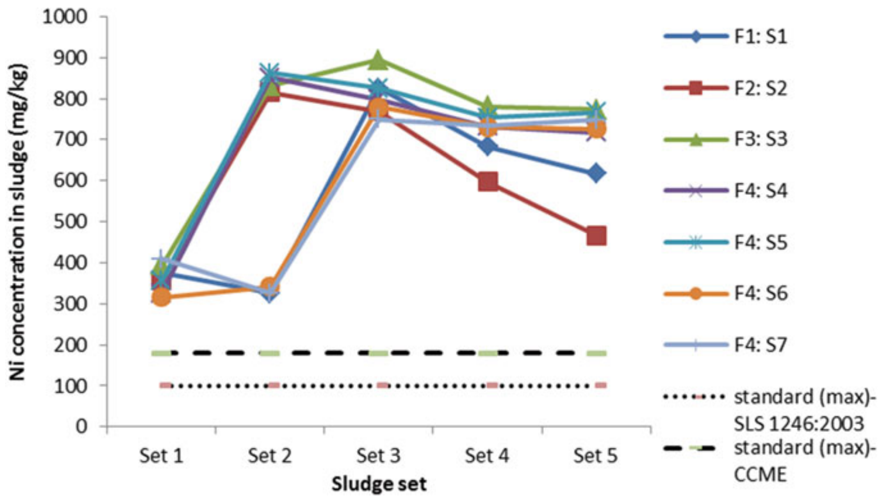

Fig. 5 Variation of Ni concentration (mg/kg) of sludge

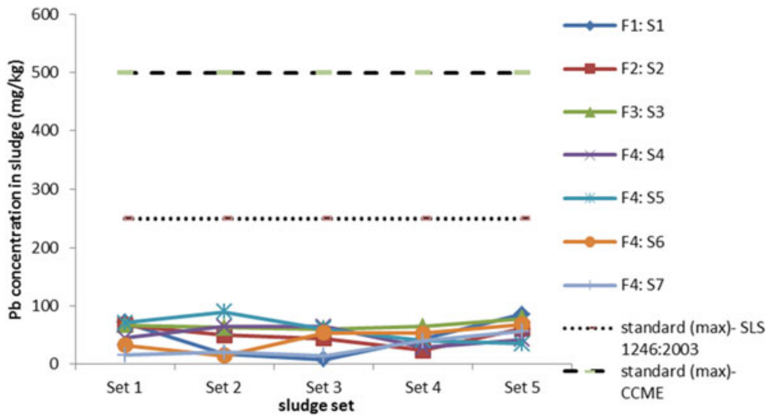

Fig. 6 Variation of Pb concentration (mg/kg) of sludge

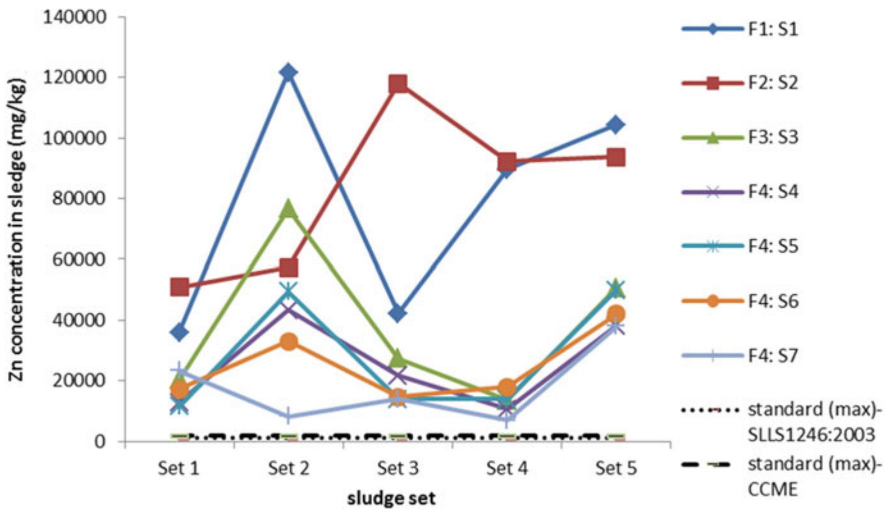

Fig. 7 Variation of Zn concentration (mg/kg) of sludge

All the means of the data set were present below the maximum allowable Cr concentration in SL Standards for compost (1000.0 mg/kg) which minimize the level of possible impacts from release to the environment unless released in very high mass. According to the one- way ANOVA test, at the confidence level of 95% there is a significant difference between at least one mean analysed (P-value = 0.000, F-value = 7.79) (Fig. 8).

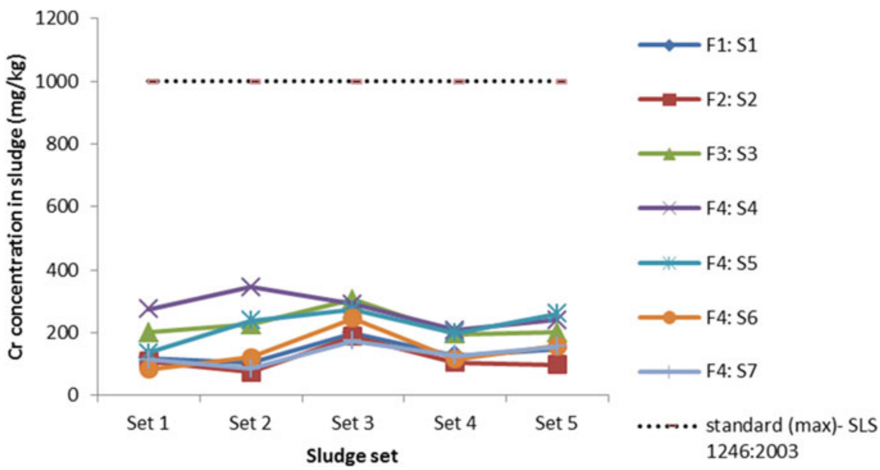

Fig. 8 Variation of Cr concentration (mg/kg) of sludge

In all the sludge samples, Cd was present below the maximum permissible levels of SL Standards for compost (10.0 mg/kg) and CCME standards (20.0 mg/kg).

According to the results obtained, most of the means of the data set were recorded above the minimum required Mg concentration for SL Standards for compost (5000.0 mg/kg). Therefore, the sludge has suitable characteristics as a soil conditioner or as a fertilizer when considering the requirements for Mg content. According to the one-way ANOVA test, at the confidence level of 95% there is a significant difference between at least one mean analysed (*P*-value = 0.000, *F*-value = 10.13) (Fig. 9).

According to previous literature, the potassium content of sewage sludge is low and will not be of concern when sludge is applied on land. Most sources estimate K content to be less than 1% [13–15]. According to the one-way ANOVA test, at the confidence level of 95% there is a significant difference between at least one mean analysed (*P*-value = 0.000, *F*-value = 8.34) (Fig. 10).

Most of the means of sludge types except for sludge type F4:S7 were recorded above the minimum required Ca concentration for SL Standards for compost (7000.0 mg/kg). High Ca content may be due to the use of chemicals containing Ca compounds in wastewater treatment process. According to the one-way ANOVA test, at the confidence level of 95% there is a significant difference between at least one mean analysed (*P*-value = 0.005, *F*-value = 4.05) (Fig. 11).

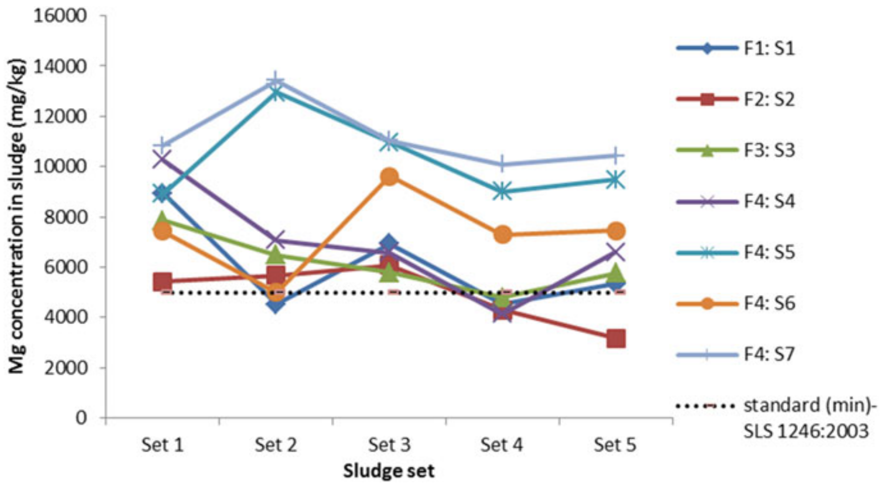

Fig. 9 Variation of Mg content (mg/kg) of sludge

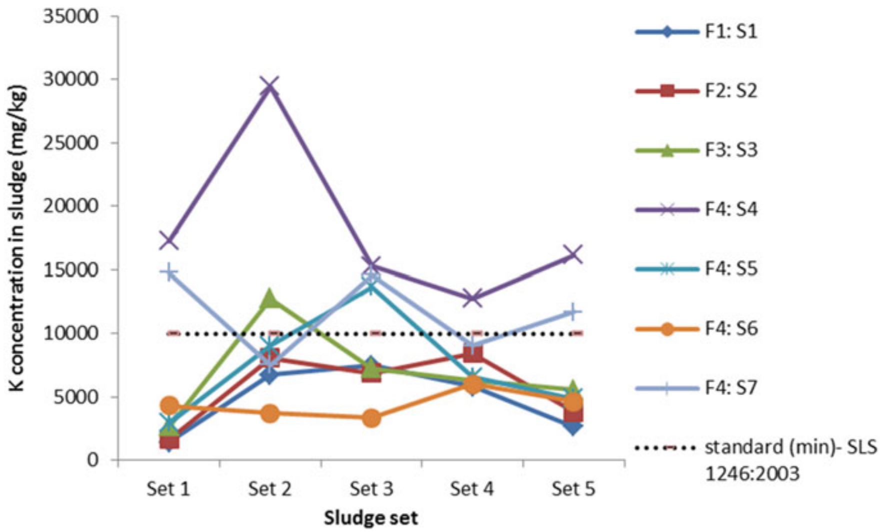

Fig. 10 Variation of K content (mg/kg) of sludge

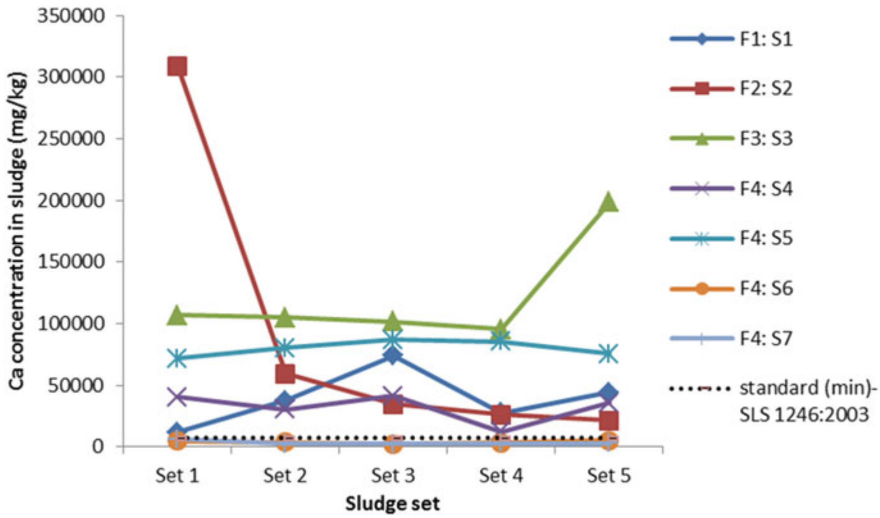

Fig. 11 Variation of Ca content (mg/kg) of sludge

4 Conclusions and Recommendations

According to the results obtained by the analysis of different sludge types generated in glove manufacturing industry in Sri Lanka, it can be concluded that different sludge types have different compositions and also even in the same type timely variations can be observed throughout the year of collection. Therefore, ranking of the sludge types is complex because of the timely variation of chemical parameters. Based on the analysis and the comparison with SL Standards and CCME standards for compost, it can be determined that Zn, Ni and Fe concentrations are present in all seven sludge types in relatively high concentrations and there is a high possibility of causing environmental effects if released to the environment in the sludge disposal process. Thus, it requires removal or stabilization of Zn, Ni and Fe prior to land application using further treatments. It can also be suggested to mix the sludge with organic materials such as soil, sawdust, manure in a ratio which can balance the concentration of heavy metals with the maximum permissible levels set by the standards. The processed sludge (after mixing with organic matter) can be suggested to use for application in crops where there are specific nutrient requirements for improved yield or in areas with nutrient deficiency.

Also in addition, some sludge types do not comply with the required minimum values of total nitrogen content, available phosphorous content and organic carbon contents as implied in the SL Standards for compost; therefore, addition of nutrients before using as a fertilizer or as a soil conditioner is recommended.

The most common techniques of handling industrial sludge are dewatering, disposal in landfills, incineration and application on agricultural lands. The high content of organic matter, phosphorous and nutrients suggests the use of sludge as organic fertilizer in agriculture or as a conditioner for soil and it may benefit municipalities and farmers [16]. However, application may cause potential environmental and public health risks from contamination of chemicals such as heavy metals, organic pollutants and pathogens [17, 23]. As a solution to this issue, removal, extraction or stabilizing of heavy metals prior to land application is likely to be a possible and practical means for reducing metal content in textile sludge [18, 19]. Gasification and pyrolysis are also considered as promising methods to convert sewage sludge (unconventional biomass) into harmless substance by thermal treatment process of both traditional and unconventional biomass [20–22].

Although gasification and pyrolysis are not found in common application in Sri Lanka, they can be a reliable solution to the sludge management issue.

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Emission Characteristics of Gaseous Pollutants from Pilot-Scale SRF Gasification Process

S. W. Park, J. S. Lee, W. S. Yang, J. J. Kang, M. T. Alam, Y. C. Seo, J. H. Oh, J. H. Gu, S. R. Chennamaneni and V. K. Kandasamy

Abstract Municipal solid waste (MSW) contains a significant amount of paper, food waste, wood and yard trimmings, cotton, and leather and is considered as a source of renewable energy. Energy could be recovered from MSW through gasification technology. Gasification experiments were conducted in a pilot-scale plant (8 ton/day) using solid refuse fuel (SRF). SRF was produced from MSW by mechanical biological treatment process consisting of crushing, sorting, and drying. Gasification pilot plant is equipped with various control systems of cyclone, scrubber, wet electric precipitator, and moisture remover for reducing gaseous pollutants and tar. Gaseous pollutants such as NH_3, HCN, and HCl were sampled at inlet and outlet locations of these control units to analyse the concentrations of pollutants with checking their removal efficiencies. Korean standard methods were used for sampling gaseous pollutants. Concentrations of most gaseous pollutants were reduced by control systems. Specially, removal efficiency of wet electric precipitator was the highest in all cleaning systems, and we could calculate the conversion rate of gaseous pollutants. From analysing above results, we can conclude that this gasification plant is good in operation and the research team is now designing a scale-up plant for commercialization.

Keywords SRF · Gaseous pollutants · Gasification · Control system

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1 Introduction

After industrial revolution, climate change and depletion of fossil fuel had been caused by urbanization and industrialization. Following these results, studies about green energy and sustainable development in the world were increased by professionals in various fields. The new and renewable energy stood out as alternative energy of fossil fuel, and categories of new and renewable energy were defined that renewable energy is waste, biomass, solar heat and light, wind, ocean, geothermal, and small hydropower, and new energy are fuel cell, gas to liquid and hydrogen by Korea government.

Portion of waste and biomass to energy is about 70–80% of total renewable energy in Korea, the highest portion in renewable energy [1]. In case of waste, Korea currently recycles 57% of household waste and landfills 26%. The remaining 17% is incinerated, mainly for heat production [2]. In this study, for waste-to-energy (WtE), we produced SRF from MSW of Y city in Korea. Average higher heating value of SRF was 4271 kcal/kg by instrument (LECO co. AC-600) analysis. Results of proximate analysis showed this SRF had low ash contents (6.87%). These results were good evidence for the applicability of thermal application.

In Korea, incineration of MSW feedstock for energy recovery has been adopted long ago. But in this study, an effort was endeavoured to apply gasification process for producing syngas and generation of electricity. Generally, syngas produced from gasification process was used for the production of chemicals like ethanol, ammonia, and synthetic natural gas and for power generation [3]. Gasification of coal is a well-established technology, because of its homogeneous composition it is easy to operate. In case of MSW or SRF, due to its heterogeneous compositions, SRF gasification is difficult. In this study, for economic feasibility, we produced SRF from MSW of Y city and directly put SRF into pilot-scale gasification process.

Specially, we focused on the emission of gaseous pollutants from gasification process. Characteristics of SRF gasification were studied by several researchers already. Gaseous pollutants from gasification are not major issue for gasification plant operation. Emission concentration of gaseous pollutants is very low comparing with incineration. In case of incineration process, main emission gaseous pollutants are NO_x and SO_x from oxidation reaction. But, emission gaseous pollutants in gasification process are NH_3, HCN, HCl, H_2S, and COS from partial oxidation and reduction reaction. In this study, we analysed NH_3, HCN, and HCl from each process and studied about emission characteristics of gaseous pollutant in gasification process.

2 Materials and Method

Figure 1 shows the process for SRF production and pilot-scale gasification. SRF production consists of many steps like crushing and sorting process for achieving high heating value. On-site manufactured SRF was directly sent to the gasification process. After production of syngas, we could operate gas engine for electric power generation.

Figure 2 shows manufactured SRF and MSW of Y city. Table 1 shows the physicochemical characteristics of feedstock such as elementary analysis, lower heating value (LHV) analysis, and proximate analysis. Using these results, we could control experimental condition.

Figure 3 shows sampling train for gaseous pollutants' analysis. Basically, this sampling train was installed in ice bath, and sampling of gaseous pollutants was conducted in stable reaction of gasification. Table 2 shows sampling condition and method of gaseous pollutants and absorbent liquid. After finishing sampling, samples were analysed using ion chromatography process. These sampling methods were based on 'Standard methods for the measurements of air pollution in Korea'. We could take a sample of gaseous pollutants as a representative the of overall gasification process. For calculating of each process, the sampling ports selected were inner gasification reactor (#1), after gasification reactor (#2), after de-nitrification scrubber (#5), after de-chlorination (#6), after de-sulfurization (#7), after wet electric precipitator (#8), and after induced draft fan (#9). Numbering was

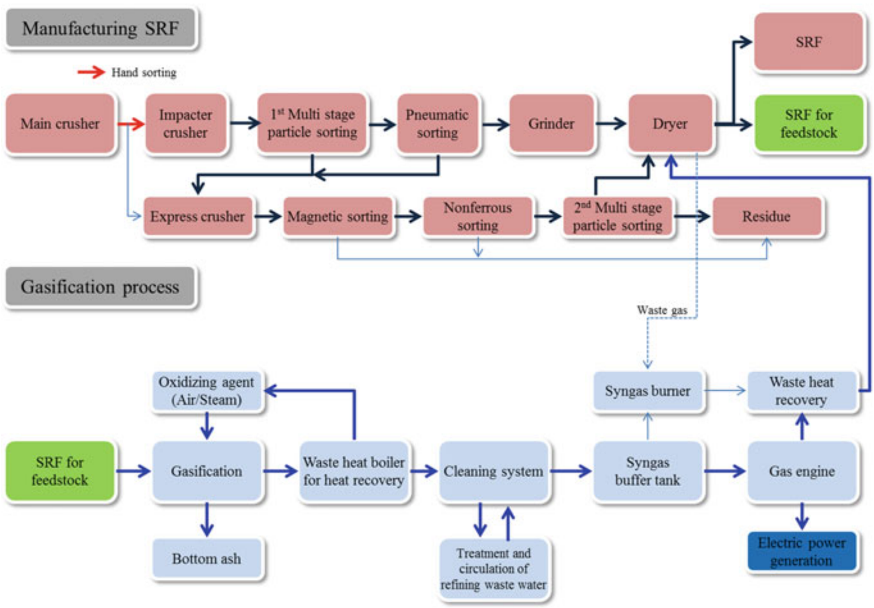

Fig. 1 Process diagram of pilot plant

(a) MSW in Y city (b) Manufactured SRF

Fig. 2 Raw and manufactured feedstocks

Table 1 Characteristics of SRF

		wt%
		SRF
Elemental analysis	C	40.49
	H	5.81
	N	0.61
	O	31.53
	S	ND
	Cl	0.70
Proximate analysis	Moisture	25.36
	Volatile	64.50
	Fixed carbon	3.27
	Ash	6.87
		kcal/kg
LHV analysis	Instrument	3,832
	Dulong eq.	3,481

according to the order of gasification system and for decreasing error rate. We conducted at least three sampling for each condition. Table 3 shows condition of gasification plant. In same temperature range, we conducted gasification experiment on condition 1 and 2. But in case of condition 1, although gasification condition was not good enough, we used the first oxidant only. In case of condition 2, if gasification condition was not good enough, we used second and third oxidant for good turbulence.

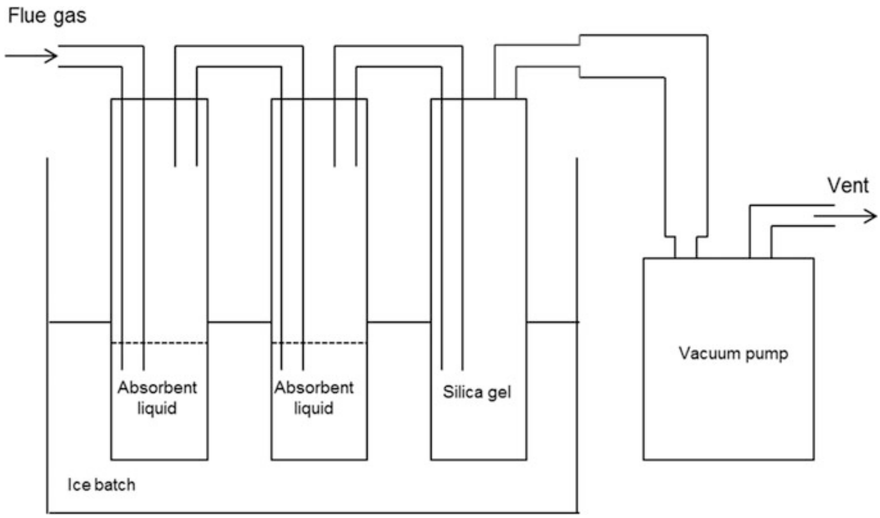

Fig. 3 Sampling train diagram

Table 2 Analysis method of gaseous pollutants

Gaseous pollutant	Absorbent liquid	Sampling condition	Analysis method
NH_3 (ammonia)	10% H_2O_2 (hydrogen peroxide)	Flow rate: 1–2 L/min Sampling time: 10–20 min	Ion chromatography
HCN (hydrogen cyanide)	0.5 mol/L NaOH (sodium hydroxide)	Flow rate: 0.5–1 L/min Sampling time: 10–20 min	
HCl (hydrogen chloride)	0.1 mol/L NaOH (sodium hydroxide)	Flow rate: 1 L/min Sampling time: 40 min	

Table 3 Experimental condition of gasification

	Condition 1	Condition 2
Feeding rate (kg/h)	333.3	
LHV of feedstock (kcal/kg)	3500	
Equivalent ratio (ER)	0.3	
Amount of oxidant (Nm^3/h air)	406	
Oxidant ratio	1st: 100%	1st: 88.77% (360.4 Nm^3/h air) 2nd: 2.5% (10.26 Nm^3/h air) 3rd: 8.73% (35.29 Nm^3/h air)

3 Result and Discussion

Figure 4 shows results of gaseous pollutants' emission from gasification process. The maximum concentration of gaseous pollutants in condition 1 was, respectively, 546 ppm for NH_3, 74 ppm for HCN, and 21 ppm for HCl. In case of condition 2, concentration of NH_3 was 329 ppm, and concentration of HCN was 49 ppm and HCl was about 4 ppm. From Fig. 4 that most gaseous pollutants had decreasing tendency after cleaning, those systems were scrubber and wet electric precipitator. Most of the gaseous pollutants can be dissolved by water, and this might be the reason behind this phenomena. So, after wet cleaning system, tendency of gaseous pollutants' emission was decreased because of it. Emission amount of gaseous pollutants in condition 1 had higher concentration than that of condition 2. We considered that this was because oxidation reactions in condition 1 were less active

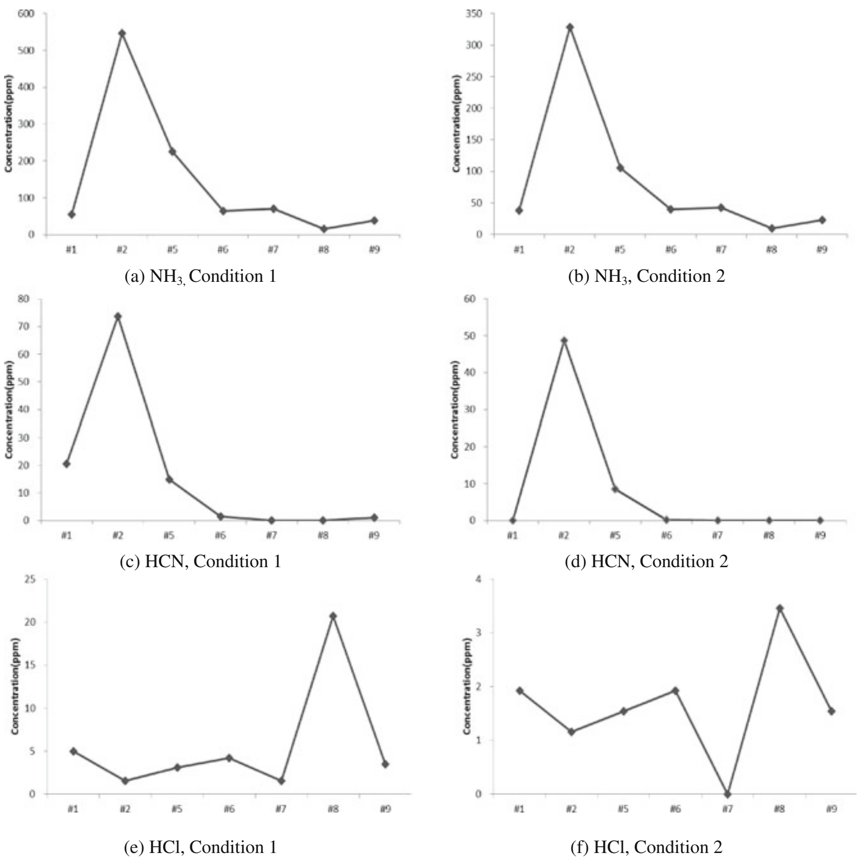

Fig. 4 Results of gaseous pollutants from gasification

than oxidation reactions in condition 2. Generally, injection of auxiliary oxidant made contact with oxidant and feedstock active [4].

In case of emission characteristics by kinds of gaseous pollutants, emission trend of NH_3 and HCN was very similar. For both of the cases, maximum gaseous pollutants were generated at #2. Emission trend of HCl was different from nitrogen pollutants. For HCl, maximum pollutants were generated at #8. Following these results, we could conclude that NH_3 and HCN were directly generated in gasification reactor at high temperature, and HCl was generated in cleaning system at low temperature.

4 Conclusion

In this study, SRF was manufactured from MSW and used as feedstock for gasification experiment in a pilot-scale plant. Gaseous pollutants were sampled for each location of the gasification process to figure out removal efficiencies of them.

(1) Fluff SRF used in this study was useful alternative fuel for fossil fuel. Fluff SRF had disadvantage such as transportation. But in this study, SRF manufacturing system was installed nearby gasification process and this manufactured SRF was fed directly into gasification reactor.
(2) Results of emission characteristics of gaseous pollutants in gasification process showed that NH_3 was the most emitted and HCl was the least emitted gaseous pollutants. Basically, gasification is a reduction reaction and usually reacted at lower temperature than oxidation reaction like incineration process. Due to this, emission of NH_3 was more dominant than emission of NO_x. We considered that the reason behind HCN emission was same. Generally, chlorine in feedstock is a significant factor converted to dioxin in excess air condition. In excess air condition, dioxin is emitted by making precursor. Cl_2 in excess air condition was reacted by Deacon's reaction, $2HCl + 1/2O_2 \leftrightarrow Cl_2 + H_2O$ [5]. Following these results, most of Cl was converted to HCl in gasification process or was not reacted because of lower temperature than incineration process.
(3) All of gaseous pollutant emissions after removal system were less than 10 ppm. Removal system was composed of cyclone, scrubber, and wet electric precipitator. These systems excluding wet electric precipitator were very simple and less costly. From this result, we can conclude that gaseous pollutants' emission could be controlled by simple removal system.

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Using *Sargassum* sp. and Kitchen Waste as Substrates for Vermicast Production

Raymund N. Fantonalgo and Juliet F. Salubre

Abstract Vermicomposting is one of the popular methods or technologies used in reducing the biodegradable waste materials generated by processing it into compost. The most common utilized substrates for this type of technology are plant leaves and kitchen waste. Seaweeds were rarely used as carbon sources; hence, the present study compared the vermicast yield using macroalga *Sargassum* sp. as main substrate with that of kitchen waste using the standard method developed by Solid Waste Management Section of the Environmental Management Bureau, Department of Environment and Natural Resources-Region VI, Parola, Iloilo City, Philippines. The experiment employed two treatments with three replicates. Treatment one used ground *Sargassum* sp. obtained from Isla Nadulao, Guimaras, West Central Philippines, while treatment two utilized the kitchen waste derived from various households. Each replicate had the 2.25 kg substrate and 0.75 kg animal manure. Fifty (50) matured African Night Crawler earthworms (Eudrilus eugeniae) were put for each replicate and allowed to metabolize the substrates for 6 weeks (1½ months). The set-up was regularly monitored and properly maintained. Regular sprinkling of clean water was done in order to provide moisture for

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the organisms. After two months, vermicast was harvested from the two treatments using hand picking and pyramid of Egypt methods and weighed thereafter. The number of the worms in both treatments was also manually counted. Findings of the study revealed that *Sargassum* sp. and kitchen waste treatments yielded 135.5 and 129.4 g of vermicast, respectively. Using student's independent *t*-test ($p < 0.05$), results indicated that there was no significant difference between the amount of the vermicast yielded using ground *Sargassum* sp. and kitchen waste as substrates. This indicates that *Sargassum* sp. is as good as kitchen waste once used as substrate for vermicast production. Furthermore, it was observed that there was greater number of worms in *Sargassum* sp. than in kitchen waste treatment. With these findings, *Sargassum* sp. is recommended to be used as substrate for vermicomposting especially this organism stayed unharnessed during the peak of its growth.

Keywords Kitchen waste · *Sargassum* sp. · Vermicast · Vermicomposting Worms

1 Introduction

Every year the world produces tons of solid waste materials. It has been estimated that the current global municipal solid waste (MSW) generation levels are approximately 1.3 billion tons per year and are expected to increase to approximately 2.2 billion tons per year by 2025. This represents a significant increase in per capita waste generation rates, from 1.2 to 1.42 kg per person per day in the next fifteen years [1]. These materials can intensify the occurrence of the different types of pollution in the community if these will not be properly managed [2]. In some extent, these can potentially degrade the quality of water and air in the environment. The accumulation of these materials over the years and its improper disposal methods have led to the spread of the infectious diseases in the various parts of the world [3]. Due to the problems caused by the accumulation of the solid waste materials in the world, several initiatives have been done by the government agencies, non-government organizations (NGOs), research institutions and academes in order to reduce the amount of these materials and to manage them properly. In the Philippines, the Department of Environment and Natural Resources (DENR) thru the Environmental Management Bureau (EMB) has actively been implementing its Vermicomposting Technology as part of the Solid Waste Management Program in cooperation with the Local Government Units in the different parts of the country. This is part of its agenda on solid waste source reduction, recycling, and management by processing biodegradable waste materials into compost/fertilizer.

In recent years, vermicompost has gained importance to people most especially the organic farmers and flower growers because it contains favorable aerobic bacteria, growth hormones and has higher nutrient value such as nitrogen, phosphorous, potassium [4, 5]. Vermicomposting is a technology which mainly uses worms in order to breakdown the organic materials to generate compost. Worms are widely used in the composting technology because of its capacity to recycle agricultural wastes and to produce good and quality compost. The most common types of worms used in this method are Red Wiggler or manure worm (*Eisensia foetida*), and the Red Worm (*Lumbricus rebellus*), another manure worm. In the process, the worms are consuming the biomass and excreting the undigested materials called worm casts or black gold. The casts are rich in nutrients, growth-promoting substances, beneficial soil microflora, and having properties of inhibiting pathogenic microbes [6]. These substances are highly useful in raising seedlings and crop production because they are stable, fine granular organic manures, which enrich soil quality by improving its physic–chemical and biological properties [7].

Available literature has shown that the common substrates used in vermicomposting are animal manure, wet paper, kitchen waste, fruit and vegetable waste, coffee grounds, and ground yard wastes [8, 9]. These materials are good sources of organic materials and can easily be degraded by worms. Moreover, once these materials are metabolized by the worms, they do not produce substances which are toxic to themselves. Despite of the popularity of vermicomposting, no single study has been done using seaweeds as substrates for this type of technology; however, it has been reported that some seaweeds have been used as fertilizers [10–12]. With this, it is high time to explore to *Sargassum* sp. as substrate for vermicomposting technology in the Philippines, especially this country is considered as one of the "Seaweeds Bowl in Asia."

Sargassum (Family Sargassaceae, Order Fucales) represents the most common species of brown macroalgae in tropical to warm temperate waters with more than 130 described species. *Sargassum* sp. has a wide variety of forms and reproductive strategies [13] that provide important ecological and economical benefits including nutrient cycling. Intertidal and subtidal sargassum beds provide food, habitat, and nursery grounds for a wide array of marine organisms while also providing food, alginates, feed, and bioactive compounds for people who harvest or culture *Sargassum* [14–16].

The present study compared the vermicast yield by using *Sargassum* sp. as substrate with that of the kitchen waste. This also determined the number of African Night Crawler earthworms (*Eudrilus eugeniae*) survived in both treatments after the experiment. So far, this study is pioneer in the use of seaweed *Sargassum* sp. as substrate in vermicomposting in the Philippines, if it is not in the world. This is a practical initiative in maximizing the use of *Sargassum* sp. in the Philippines since most of them remain unutilized during the peak of its growth, thus they are just decomposed in the ocean without any use.

2 Materials and Methods

2.1 Collection and Transport of Sargassum *sp.*

Approximately 30 kg (wet weight) of *Sargassum* sp. was collected in the intertidal zone of Isla Nadulao, Brgy. Igcawayan, San Lorenzo, Guimaras, West Central Philippines. Collection was done using a motorized banca during low tide of the day. Collected seaweeds were washed thoroughly using tap water to remove the debris and salts. The washed samples were later put in a clean table made of bamboo to drain excess water. These samples were packed in the polyethylene plastic prior to transport in the laboratory.

2.2 Drying and Grinding of the Seaweed Samples

Drying was done in Science Research Laboratory, College of Arts and Sciences, Western Institute of Technology (WIT), La Paz, Iloilo City, Philippines. Individual thallus was hanged in a wire to expose the algal body to the air. Semidried seaweeds were cut into smaller pieces using the scissors. After cutting, the seaweeds were dried again at room temperature for one week. Dried algae were grind using a blender (Osterizer Model 4172) at the Research Laboratory of the same institution. Semi-pulverized materials were later used as substrates for the experiment.

2.3 Collection of the Kitchen Waste

Around 30 kg (wet weight) of kitchen waste was gathered from various households. These materials are mixture of the fruits, vegetables, and various types of peelings. Meat and cooked food items were excluded from the mixture in order to prevent the ants to colonize the food items. Liquid components were removed from these materials. The remaining materials after draining were sun-dried until partial dryness. The partially dried materials were used as substrates for the experiment.

2.4 Rearing of the Worms

The worms (African Night Crawler earthworms, *Eudrilus eugeniae*) used in the study were procured from a vermiculturist. The organisms were cultured in the substrates with a 1:1 carbon-to-nitrogen ratio to allow rapid increase in the number of worms. They were stocked in the vermichamber or bins after fermentation period of the substrates. The best way to test whether the substrates had undergone the process of fermentation was by the dropping 3–5 worms to the substrates.

If the worms dug down and stayed in the substrates, meaning the materials had already undergone the said process. On the other hand, if they refused to burrow and they remained on the top or in a corner, stocking should be postponed until the worms would settle down into the substrates. They were allowed to grow until maturity. These worms were the ones used in the experiment.

2.5 Fermentation of Substrates

Fermentation was done to ensure that the worms ate the substrates. The pre-mixed, chopped or shredded and moist substrates were stored in a tightly covered container for 15 or more days. After the fermentation or pre-decomposition phase had been completed, the temperature of the substrates has cool down and it was determined by using the clinical thermometer. Once the temperature had reached to 24–30 °C, stocking could be carried out (worm seeding).

2.6 Experimental Set-Up

The experiment employed two treatments with three replicates each. Each replicate had the 2.25 kg substrate and 0.75 kg animal manure put in a cylinder container with ventilated cover. Fifty (50) matured African Night Crawler earthworms (*Eudrilus eugeniae*) were put for each replicate and allowed to metabolize the substrates for 6 weeks (1½ months). The set-up was regularly monitored and properly maintained.

2.7 Maintenance of Worm Beds

The worm beds were maintained by watering the substrates until they reached the moisture content of 40–60% from the first day of stocking up to fermentation phase until the harvest of the vermicasting. The ventilated top covers were always placed on the top of the chambers/bins to conserve moisture, to keep them cool and dark inside and to prevent the rats, chickens, and other worm predators from entering the containers. The chambers were kept away from the direct sunlight to prevent the worms from scorching and killing.

2.8 Harvesting and Weighing of the Vermicast

After allowing the worms to utilize the substrates within the specified time from two treatments, the vermicast was harvested using the two methods namely: hand picking method and pyramid of Egypt. Those vermicast which could not be collected manually were harvested using pyramid of Egypt. In this method, the pyramid of Egypt was formed to allow the worms to settle down in the remaining substrates. After few days, the surface or upper portion of the pyramid could already be scraped and harvested. The harvested vermicast was stored in a cool dry place away from direct sunlight. This was air-dried, and the impurities were strictly removed thru sieving. The impurity-free vermicast was packed in the unsealed plastic bag and was stored in a cool and dry place. The weight in each replicate was determined using a weighing scale. The average weight per treatment was compared thereafter.

2.9 Counting of the Worms

At the end of the experiment, alive worms were counted manually in each replicate. Data were reported per treatment.

2.10 Statistical Analyses

Statistical Package for Social Science (SPSS) version 17.0 was used to process and analyze the data. Student's independent *t*-test (alpha set at 0.05) was employed in comparing data between treatments.

3 Results

3.1 Number of Worms at the End of the Experiment

During the termination of the experiment, the worms were collected and counted for the determination of the actual counts. The number of African Night Crawler earthworms (*Eudrilus eugeniae*) in two treatments is given in Fig. 1. Findings of

Treatment	Number of Worms after Six Weeks
Sargassum sp	200[a]
Kitchen waste	150[b]

Different letters indicate significant difference between two treatments

Fig. 1 Number of African Night Crawler earthworms (*Eudrilus eugeniae*) in *Sargassum* sp. and kitchen waste substrates the present study indicated that the number of worms after six weeks of substrates utilization in *Sargassum* sp. treatment was 200 worms while the one in kitchen waste treatment was 150 worms. Using student's independent *t*-test (0.05) revealed that there was significant difference between the survival rates of the worms in two treatments.

3.2 Vermicast Yield in Two Substrates

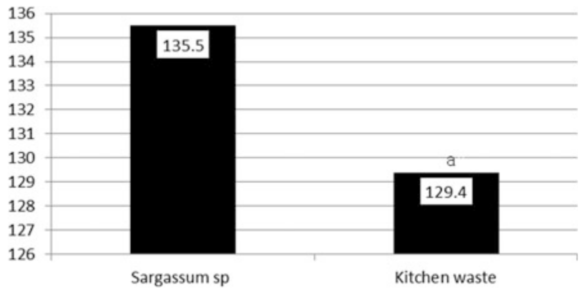
After six weeks, vermicast was harvested from the two treatments using hand picking and pyramid of Egypt methods. The vermicast appeared granulated and blackish in color and cool to the touch. It did not produce any odor, and it did not leach at all (Fig. 2a). It was humus-like with high porosity and good water holding capacity (Fig. 2b).

When the vermicast was weighed, findings of the study revealed that *Sargassum* sp. and kitchen waste treatments yielded 135.5 and 129.4 g of vermicast, respectively (Fig. 3). Furthermore, student's independent *t*-test (0.05) results revealed that there was no significant difference on the vermicast yielded in both treatments.

a. Granulated and blackish in color vermicast   b. Humus-like vermicast with high porosity

Fig. 2 Vermicast produced by African Night Crawler earthworms (*Eudrilus eugeniae*)

Fig. 3 Vermicast yield (g) in *Sargassum* sp. and kitchen waste substrates



4 Discussion

Seaweeds are one of the most diverse organisms in the ocean. They play essential ecological roles in this type of aquatic ecosystem. For a long time, these organisms have been known as good sources of fertilizers. The positive effects of the application of seaweed extracts on the cultivated plants had been reported in the studies of Craigie [17]; Du Jardin [18]; and Calvo et al. [19]. These effects include the enhancement of the plant resistance to frost and drought, improvement of the plant development like flowering and leaf development, and increase in the crop yields [20]. Aside from these benefits, seaweed extracts can also increase the resistance of the plants to pathogens. Craigie [21] indicated that seaweed extracts contribute to the recovery of damages caused by insects and bacterial or fungal diseases.

Among the popular seaweeds used as fertilizers are the brown algae *Sargassum*. In Myanmar, the extracts of *Sargassum trichophyllum*, *S. salicifoloides*, *S. kasyotenese*, *S. tenerrimun*, *S. carpophyllum*, *S. duplicatum*, *S. ilicifolium*, *S. cristaefolium*, *S. plagiophyllum*, *S. swartzii*, *S. polycystum* were attempted to use as organic fertilizer in pot trial of rice [22]. *Sargassum* spp. are rich in polysaccharides like fucoidans and alginates which possess bioactive properties [23, 24]. Sulphated polysaccharides extracted from *Sargassum filipendula* exhibited strong antioxidant properties, with stronger reducing power than vitamin C, and were effective in inhibiting cell proliferation [25].

In this study, *Sargassum* sp. was used as substrate for the vermicast production. Findings of the present study showed that there was no significant difference between the amount of vermicast harvest in *Sargassum* sp. treatment and kitchen waste treatment. This indicates that seaweed *Sargassum* sp. is a good substrate for vermicast production like kitchen waste. These organisms allowed the worms to utilize its carbon compounds although the chemical composition of the fermented *Sargassum* sp. was not determined. This seaweed is rich in carbon-containing compounds like polysaccharides. Ji et al. [26] isolated the sulfated polysaccharide from the *Sargassum pallidum,* and they found out this polysaccharide is constituted by xylose (35.92%), mannose (21.86%), arabinose (15.26%), galactose (13.49%), glucose (9.60%), and others (3.88%).

Findings also revealed that there was significant difference in the number of worms reproduced and survived at the end of the experiment between two treatments. This simply manifests that *Sargassum* sp. supported the reproduction/and survival of the worms more than the way kitchen waste did in the said organisms during the duration of the study. Potentially, this seaweed contains essential substances which support the growth, survival, and reproduction of the worms. Once *Sargassum* sp. was metabolized as substrate, it did not produce toxic substances which could kill the worms. In vermicomposting, the recommended C:N ratio should be 1:1 to allow the rapid increase in their number of worms. This has been practiced by Solid Waste Management Section of Environmental Management Bureau of Department of Environment and Natural Resources-Region VI, Philippines. In the present study, although the C:N ratio used was 3:1, the worms managed to dig down and stay in the substrates and to increase in its number. This response of the worms is indeed a manifestation that the substrates were favorable to the growth, production and survival of the worms. The role of organic carbon and inorganic nitrogen is critical for various activities among living organisms such as cell synthesis, growth, and metabolism. The carbon and nitrogen must be present in the substrate at the correct ratio in order to attain proper nutrition. In vermicomposting, an appropriate carbon-to-nitrogen ratio for optimal earthworm digestion is also necessary [27]. In this study, 3:1 C:N ratio was used in order to expect higher vermicast yield rather than the number of worms. The high amount of vermicast yield was potentially due to the higher amount of carbon present in the seaweeds. Earthworms like African Night Crawler prefer to metabolize substrates which are rich in carbon. They use carbon mainly for energy production.

5 Conclusions and Future Directions

The present study revealed that *Sargassum* sp. reaped significant amount of vermicast compared to kitchen waste. Moreover, it produced higher number of worms in contrast to the kitchen waste. This indicates that this seaweed is a good substrate for vermicast production and worm production or farming. It is therefore recommended that the chemical composition and nutrient profile of the *Sargassum* sp. should be determined in the future studies. Likewise, the chemical composition of the vermicast generated from this substrate should be tested in the next research endeavor.

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Study on the Effective Reuse of Eggshells as a Resource Recovery from Municipal Solid Waste

M. R. Sarder, N. A. Hafiz and M. Alamgir

Abstract Since early period, eggs have been used as food by human being and getting preferred day-to-day because of its nutritious content. The eggshells have been discarded as unfavourable ingredients which are accountable for the deterioration of the environment and also responsible for flies, mosquitoes and smell hassle. The mass of one eggshell is about 11% of an egg and largely produced from households, food companies, hotels and restaurants, etc. Littering of eggshells is a growth medium for microorganisms which can generate various illnesses in human body. Eggshells can become resources by proper management and recycling process. Eggshells are highly calcium-rich substances and have many essential nutritional benefits for vegetation. Powdered eggshells can be utilized directly with soil as well as in composting to assure calcium-rich compost thus valuable in reducing the plant diseases like blossom end root (BER) and also reduces the expense of the plantation. This research shows the management of eggshells at KUET campus. Eggshells have been generally obtained at KUET campus from student dormitories, cafeteria and domestic areas. The study reveals that the generation rate of eggshells is 19.49 kg/month which is the 0.17% of the total solid waste, while the overall generation rate of solid waste in the campus is 0.090 kg/capita/day. The properties of eggshells are measured as the contents of calcium, moisture, organic, carbon and nitrogen are 31.5, 3.23, 23.82, 13.23 and 0.601%, respectively, while the values of C/N ratio are 15.75 and pH is 7.7.

Keywords Municipal solid waste · Eggshells · Resource recovery Plantation

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1 Introduction

There are a large numbers of hen eggs that are broken every day in food plants. The eggshells are often seen as a waste from the industry, whose generation can signify from 0.03 to 0.12 of the mass of the egg items acquired from egg [10]. Recently, Europe created about 10,600 million ton of eggs from which about 30% was directed to the egg breaking handling [4]. Livestock department's available research displays that the household manufacturing of egg in Bangladesh is 7,303 million tons in the fiscal year 2011–2012 against the requirement of 15,392 million tons [6].

The proper management and disposal of this waste have been regarded as an important issue for the food market for the concern of environmental security, due to not only the considerable amounts produced but also to its potential for bacterial growth or progression of pathogens [10]. Appropriate control techniques have not been well recognized for eggshells, and disposal in dumps has been typically used [12]. Even so, recycle and restoration should be examined to avoid the waste of sources. Eggshells are waste products from hatcheries, houses and junk food sectors [1, 9] and can be easily gathered in a lot. Eggshells waste disposal plays a role in polluting the environment. Difficulties associated with disposal of eggshells consist of cost, accessibility of disposal sites, smell, goes and abrasiveness [9]. However, they can be prepared into saleable products like manure, used in paintings, individual and animal nourishment and building components and to generate collagen from the membranes [1, 9].

Eggshells contain calcium and trace amounts of other smaller ingredients, i.e. magnesium, boron, copper, steel, manganese, molybdenum, sulphur, rubber and zinc [3]. Eggshells calcium is possibly the best natural resource of calcium, and it is about 90% absorbable [3]. It is a significantly better resource of calcium than limestone or coral resources. Eggshells contains high amount of calcium. This calcium is helpful for some plants specially for tomato plants to prevent Blossom ends root (BER) disease. For this reason, calcium enriched compost is desirable for such type of plants. Calcium enriched compost can be obtained from the mixture of biodegradable solid waste and eggshells powder with the help of composting process. In reality, the use of rich calcium compost to soil lacking in this nutrient may represent an option to promote eggshells recycling into a value-added item and thus restore a natural source included in this animal by-product [8].

Some vegetation specially tomato plant suffer from Blossom ends root (BER) disease due to lack of calcium in the soil. This BER disease can be prevented by applying calcium enriched compost in the soil. Eggshells, powder with soil is greatly beneficial to prevent BER diseases [5]. The chemical compositions (by weight) of by-product eggshells are as follows: calcium carbonate is 94%, magnesium carbonate is 1%, and calcium phosphate is 1%, while the calcium content is 28.2–41.2% and phosphorus content is 0.102% [2].

Compositionally, eggshells are quite similar to that of our bones and teeth. It is advisable that individual with weak bones takes 400–500 mg calcium daily to complement nutritional resources. The powder should be taken together with some included magnesium, zinc, vitamin D3, K1, K2, strontium and boron for effective usage. Schaafsma et al. [11] revealed a highly positive effect of eggshells calcium supplements (with included magnesium and vitamin D) on bone mineral density (BMD). Previous study shows that the eggshells supplemented group had considerable improvement in bone strength and density in their hip bone after one year [7]. The results indicate that healthy-delayed post-menopausal women with sufficient calcium consumption at baseline may increase bone nutrient density of the hip within 12 months following the use of the chicken eggshells powder-rich supplement [7]. The main objective of this study is to characterize the eggshells and to depict the reuse potential of eggshells as a resource recovery from solid waste generated at KUET campus.

2 Study Area

This study is being conducted on the collected eggshells processed at the waste management plant situated in the campus of Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh. Currently, it has about 4900 students, 18 academic departments under three faculty, three institute and has a count of population which is around 7000 comprising students, teachers, officers, family members and other supporting workers. The university having an area of 101 acre area located at the north-west corner of Khulna City, about 12 km from the city centre as shown in Fig. 1. The university has adopted an on-campus solid waste

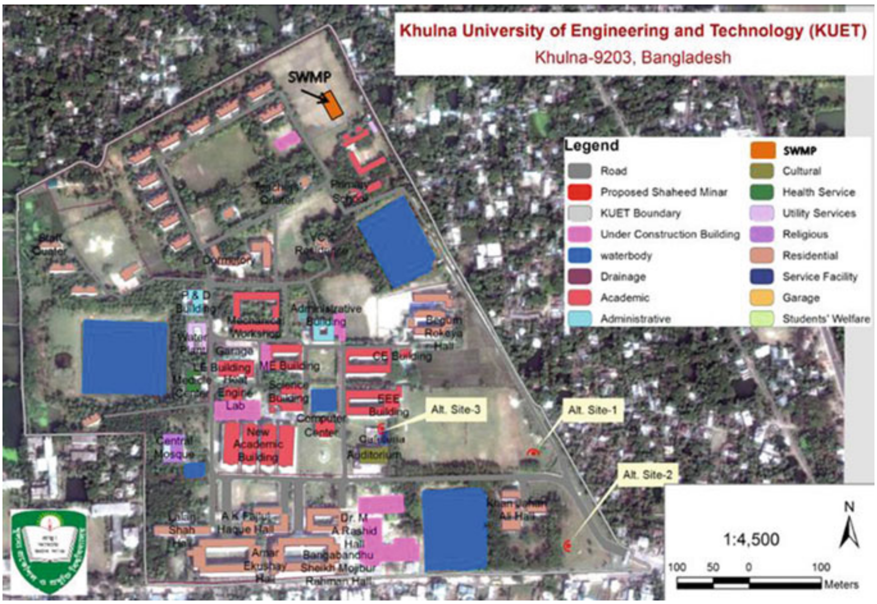

Fig. 1 Layout plan of KUET campus showing the location of WMP

management system with a waste management plant (WMP). The system comprises waste source separation, waste storage, collection, transportation, separation, composting, recycling, burning and disposal process. This initiative has improved the overall environment of the university campus.

3 Materials and Methods

This study has been done by way of field level research, primary data selection and laboratory analyses. To evaluate the effective recycling of eggshells as a source restoration of solid waste, the following technique has been adopted. Two plastic containers have been provided at every student dormitory, residential and academic buildings for the source storage of rapidly biodegradable and slowly biodegradable/non-biodegradable waste separately. Solid wastes from common features have been gathered into containers which are placed into a light and portable concrete block to encounter from tilting and overturning as shown in Fig. 2. These waste materials have been transferred every day to the WMP by using rickshaw van for ultimate treatment method as shown in Fig. 3.

The eggshells mainly produced into student dormitories, residences and cafeteria. The eggshells have been categorized in WMP as shown in Fig. 4 and dehydrated after cleaning through normal water. The dried eggshells have been placed in an oven at a temperature of 105 °C for 24 h. The oven-dried eggshells have been turned into powder and sieved through #100 sieves, and then, necessary assessments have been conducted as shown in Fig. 5.

Fig. 2 Roadside dustbin for the storage of wastes

Fig. 3 Collection and transportation of SW using rickshaw van

Fig. 4 Solid waste management plant including burning unit

Fig. 5 Powdering of eggshells using traditional iron hammer

4 Results and Discussions

Figure 6 describes the total waste generation rate at KUET campus from January, 2016, to May, 2016. The average waste generation rate has been found as 0.090 kg/capita/day which indicates that the waste generation rate is increasing from previous year. However, waste generation rate depends on different factors such as food habit, weather condition, campus vacation and arranging different types of programme.

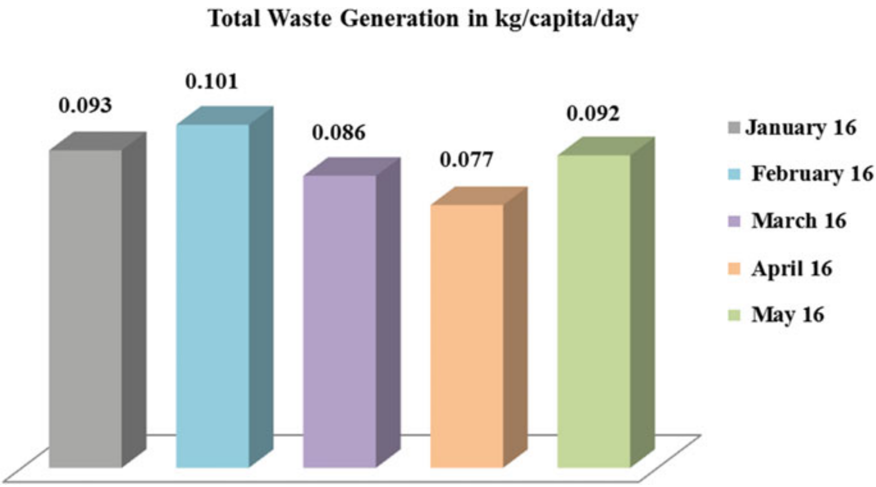

Fig. 6 Total waste generation rate at KUET campus (kg/capita/day)

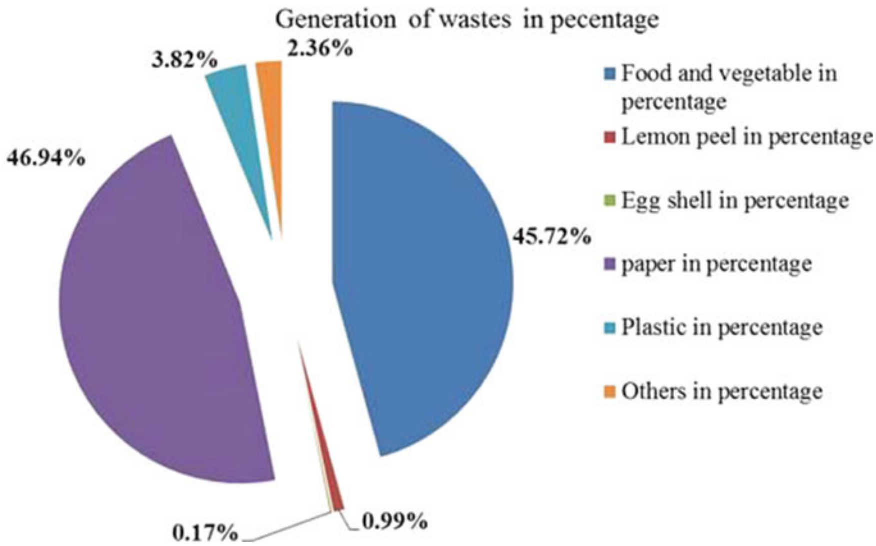

Fig. 7 Composition of solid waste generated at KUET campus

Figure 7 illustrates the composition of solid wastes generated at KUET campus, and it has been observed that paper and food wastes are predominant and also shows a negligible amount (0.17%) of eggshells has been produced, but they are sufficiently enough for environmental deterioration of KUET campus if do not manage properly.

Figure 8 delineates the monthly eggshells production at KUET campus, and it has been noticed that the average monthly eggshells generation is 19.49 kg and mostly generated from students dormitories, residential areas and cafeteria. However, in the month of April, the amount of eggshells is the highest which occurs due to the presence of the new students in the campus before the completion of course of the final year students. However, in average, the rate of generation of eggshells with respect of people is almost constant.

Fig. 8 Monthly production of eggshells at KUET campus

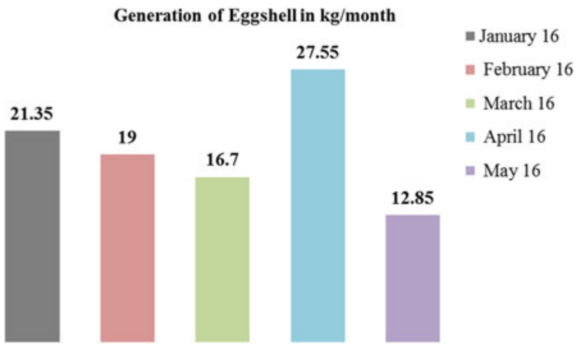

Table 1 Some major properties of eggshells

Properties of the eggshell	Measured values
Calcium content	31.5%
Moisture content	3.23%
Organic content	23.82%
Carbon content	13.23%
Nitrogen content	0.84%
C/N ratio	15.75
pH	7.6

The characteristics of eggshells as measured in the chemistry laboratory of KUET are shown in Table 1. At least three specimens are measured for each element, and the average value is given in the table. From the measured some representative characteristics, it can be seen that the value of calcium content is very high as 31.50%, while the organic, carbon, nitrogen and moisture contents are 23.82, 13.23, 0.84 and 3.23%, respectively. The value of pH and C/N ratio is obtained as 15.75 and 7.6, respectively. As a highly calcium content material, the eggshells are very helpful to provide necessary calcium to the plants if it is mixed with soil. Soil can easily absorb calcium from eggshells powder and helpful for prevention of BER disease and enriched pH of acidic soil and may be used as calcium supplement for human. The decomposition of eggshells has been accelerated in slightly acidic soil and fineness of eggshells.

5 Conclusions

This study reveals that the overall solid waste and eggshells generation at KUET campus are found as 0.090 kg/capita/day and 19.49 kg, respectively, and the eggshells are 0.17% of total solid waste generation. Eggshells contain 31.50% calcium, which is beneficial to increase the calcium in the soil if can be applied properly. The maximum portion of eggshells obtained at KUET campus is coming from boiled eggs. The properties of boiled eggshells may differ from non-boiled eggshells due to elimination of some components during heating. Finally, it can be concluded that eggshells can be used as a valuable soil conditioner.

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Material Stream in the Recycling Process for Spent Compact Fluorescent Lamp (SCFL)

Seung-Whee Rhee and Hyeong-Jin Choi

Abstract Material stream for recycling material and mercury from spent compact fluorescent lamp (SCFL) are fulfilled to estimate material composition in consecutive recycling process by an input–output approach. The system of recycling process for SCFL was established by SCFL crusher, screen separation system, 1st air separator, magnetic separator, 2nd air separator, mercury distillation system, and activated carbon adsorption. From the results of material stream of SCFL, more than 95% of materials of SCFL such as glass, phosphor powder, copper wire, ferrous metals, plastics, paper, and vinyl can be recovered. For material stream on mercury, mercury content in phosphor powder was highest among material compositions and total mercury amount in recycling materials from 1,000 kg of SCFL was estimated to be 47.22 g. In the system of recycling process for SCFL, mercury amount in vapor phase was measured with the result of 3,017 mg in SCFL crusher, and 1,184 mg in screen separation system. Total mercury amount in vapor phase was estimated to be 4,201 mg which was only 8.17% of total mercury amount emitted from the system of recycling process. Hence, it was estimated that total mercury amount from the recycling process system of 1,000 kg of SCFL in material stream was 51.42 g in both recycling materials and vapor phase.

Keywords Material stream · Spent compact fluorescent lamp · Mercury Recycling

1 Introduction

Wastes containing mercury have been significantly considered nowadays because the Minamata Convention on mercury was adopted unanimously to be a global treaty in 2014. In Korea, the management of spent fluorescent lamps (SFLs) among

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wastes containing mercury has been concerned to protect human health and the environment from releases of mercury and mercury compounds [1–3]. In 2014, the generation of SFLs was estimated about 140 million tubes, and the recycling rate of SFLs may be less than 30% in Korea [4]. More than 70% of SFLs were not controlled properly, and most of them were disposed in landfill sites or incinerators without any pre-treatments. Since SFLs contained mercury which is a toxic and hazardous substance, the control of SFLs is very important to prevent its adverse effects on the environment and human health [5]. In order to recycling wastes containing mercury such as SFLs, it is very important to investigate waste stream with hazardous substance to control and remove hazardous substance such as mercury in advance. Using a kind of technique of material flow analysis, waste stream, flow structures, and the amount of materials for recycling process of SFLs are necessary to study in recycling fields.

Material flow analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system defined in space and time [6]. The approach model of MFA may help to develop material flow accounts for usage in official statistics to provide environmental performance data and to evaluate environmental impact assessment. In order to apply material flow analysis to waste recycling stream, closed loop of recycling stream was established with controlling pathways for material usage in recycling processes and estimated input fraction and output fraction to recycling processes with surroundings. Hwang and Jang [3] estimated SFLs management in Korea using material flow analysis [7]. They found that approximately 5.8 million units are disposed and treated in landfills and incineration facilities, and the mercury disposed in landfills and treated in incinerators were found to be 38.3 and 25.5 kg, respectively. Zhang et al. [12] studied the fate and flow of mercury in fluorescent lamps from manufacture to disposal using the material flow analysis (MFA) method in China [8]. The mercury contained in fluorescent lamps for domestic production, export, and import in 2011 was 29.31, 12.81, and 3.95 tons, respectively. [9] investigated mercury emission and mercury concentration in the components of SFL such as glass tube, phosphor powder, and base cap in recycling processes [9].

In this study, material stream in the recycling processes of SCFLs was investigated by using the input–output approach. The recycling processes for SCFL in pilot plant scale consist of SCFL crusher, screen separation system, 1st air separator, magnetic separator, 2nd air separator, mercury distillation system, and activated carbon adsorption. In each recycling process, input–output approach is applied to estimate material stream of the components of SCFL and mercury amount in the components. In the recycling process of SCFL, total materials collected and recycled were estimated. Also, the mercury emission to air phase in each process was evaluated by the measurement of mercury concentration in vapor phase. Finally, it can be found that the total amount of mercury in each SCFL unit was estimated by using the input-output approach.

2 Materials and Method

2.1 Materials

The sample used in this study is 20W-type SCFL, and its components are as shown in Table 1. SCFL is composed of glass, phosphor powder, copper wire, ferrous metals, plastics, vinyl, paper, and others. Out of the components, the glass is 49.27 g occupying the greatest proportion and the phosphor powder is 0.89 g holding the least proportion. In this study, the SCFL recycling process was established as a system and the material stream was performed by establishing 1,000 kg of 20W-type SCFL (10,627 units) as an input material.

2.2 Recycling Process and Experimental Equipment

In this study, the system was composed of seven consecutive processes using the SCFL recycling facilities in pilot plant scale developed by Kyonggi University in Gyeonggi-do, Korea. The recycling process is composed of crushing process, sorting and recovery process, and hazardous material treatment process. The name, capacity, and functions of each process are shown in Table 2. The crushing process is corresponded to Process 1, sorting and recovery processes to Process 2–5, and the hazardous material treatment processes to Process 6–7. For mercury in vapor phase, mercury is controlled by Process 7 and mercury concentration emitted to atmosphere is less than 5 $\mu g/Sm^3$ which is much lower than 2 mg/Sm^3 of the air quality standard in Korea [10].

The measurement of mercury emitted from the SCFL recycling process was performed from the materials and vapor phase generated from each process. In mercury analysis, DMA-80 using the gold amalgamation was used for the materials and the atomic absorption photometry was used in vapor phase based on the ultraviolet ray generated in the 254 nm.

Table 1 Component of spent compact fluorescent lamps

Wattage (W)	20W	
	g	%
Glass	49.27 ± 1.28	52.36
Phosphor powder	0.89 ± 0.05	0.95
Copper wire	4.57 ± 0.32	4.86
Ferrous metals	11.27 ± 0.75	11.98
Plastics	22.45 ± 0.94	23.86
Vinyl	0.71 ± 0.07	0.75
Paper	1.50 ± 0.13	1.59
Others	3.44 ± 0.25	3.65
Total	94.10 ± 3.79	100.00

Table 2 Capacity and function of process in lamp recycling facility

Process No.	Plant	Capacity	Function
1	SCFL crusher	10,000 ea/day	Crushing SCFL
2	Screen separation system	1,000 kg/day	Separation of phosphor powder, glass, and copper wire from crushed materials
3	1st air separator	1,000 kg/day	Separation of paper and vinyl from crushed materials
4	Magnetic separator	1,000 kg/day	Separation of ferrous metals from crushed materials
5	2nd air separator	1,000 kg/day	Separation of glass and plastics from crushed materials
6	Mercury distillation system	100 kg/day	Stabilization of mercury from solid phase
7	Activated carbon adsorption	15 m^3/min	Adsorption of mercury vapor

2.3 Material Stream Method

The material stream of the SCFL recycling process was performed by a basic method using inflow and outflow. In the material stream, overall flowchart for each process of SCFL recycling facility was established as shown in Fig. 1. Since the boundary was set to each process, the material stream was examined in each process. The material stream was performed using basic data such as the amount of

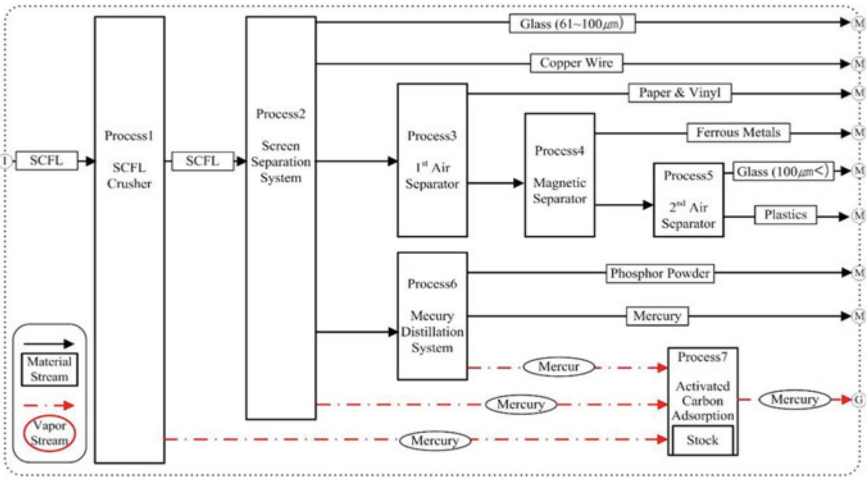

Fig. 1 Overall flowchart in recycling facility for SCFL

input material, type of constituents, amount of substances, disposal materials. In addition, the material stream for mercury was analyzed by dividing into mercury in vapor phase and mercury contained in the output materials.

Since tiny glass particles generated from the SCFL crushing process can be mixed with the phosphor powder, they need to be separated properly. The screen with pore size of 61 μm was built in screen separation system to collect phosphor powder completely because the average particle size of the phosphor powder is approximately 45 μm [9].

3 Results and Discussion

3.1 Material Stream on Spent Compact Fluorescent Lamp

SCFL recycling process was set to entire system, and the material stream for each recycling process was shown in Fig. 2. Process 1 was the crushing process using SCFL crusher to get the products less than 1.0 cm of particle size. The output materials crushed in process 1 were recovered into each material through the sorting and recovery processes (Process 3–5). In Process 2, the glass (61–100 μm), copper wire, and the phosphor powder less than 61 μm in particle size were recovered using screen separation system. In Process 3, the paper and the vinyl were recovered using 1st air separator. And then, in Process 4, the ferrous metals were recovered using magnetic separator, and the glass (100 μm <) and the plastic are recovered using 2nd air separator in Process 5.

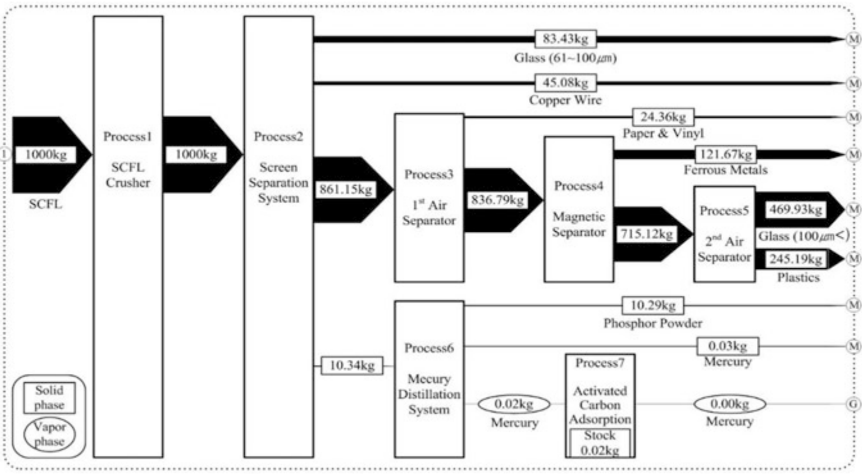

Fig. 2 Material stream in recycling facility for SCFL

Since the phosphor powder recovered in the screen separation system, Process 2, contained the high concentration of mercury, it needs treatment by Process 6–7, which were the hazard material treatment processes. Process 6 was a mercury distillation system to recover mercury from phosphor powder. Material stream for mercury was also evaluated completely in the recycling processes. Mercury in the phosphor powder flowed into Process 6 was vaporized through the thermal distillation process in vacuum condition and was recovered by cooling system. Out of 10.34 kg of input amount of phosphor powder, mercury amount was recovered to be 46.47 g and the discharged amount of phosphor powder was 10.29 kg. The discharged amount of the phosphor powder was directly measured and was the same as the weight subtract the mercury from the input amount of phosphor powder. Almost all mercury flowed into the Process 6 were vaporized and recovered by the cooling system. Since mercury in the phosphor powder discharged almost did not exist, the process efficiency was very good. The recovered amount of mercury by the cooling system was 33.62 g which was showed approximately 72% of the recovery rate. The mercury not recovered in Process 6 can be treated by adsorption with activated carbon in Process 7.

3.2 *Mercury Stream on Spent Compact Fluorescent Lamp*

To examine the material stream of mercury, mercury contents contained in all the materials recovered from recycling processes were analyzed and shown in Table 3. In mercury analysis, three samples were collected, and the average mercury contents and standard deviation were shown by analyzing three times for each sample. The total amount of mercury in Table 3 was calculated without considering the amount of mercury after treating the phosphor powder.

The mercury content in the phosphor powder before treatment was 4,380 mg/kg, and the mercury contents in all materials except the phosphor powder before

Table 3 Mercury content of recovered materials from SCFL

Materials		Amount (kg)	Mercury content (mg/kg)	Mercury amount (mg)
Glass	100 μm<	469.93	1.864 ± 0.360	876 ± 169
	61–100 μm	83.43	4.754 ± 0.521	397 ± 43
Phosphor powder	Non-treated	10.34	4,380.547 ± 365.584	45,295 ± 3,780
	Treated	10.29	0.348 ± 0.127	4 ± 1
Copper wire		45.08	1.691 ± 0.293	76 ± 13
Ferrous metals		121.67	1.382 ± 0.278	168 ± 34
Plastics		245.19	1.485 ± 0.348	364 ± 85
Paper and vinyl		24.35	1.469 ± 0.342	36 ± 8
Total		1,000.00	–	47,216 ± 4,132

treatment were analyzed less than 5.0 mg/kg. Although, in Korea, the standard for the mercury content is not established yet, in USEPA and Japan, it is established as 260 and 100 mg/kg, respectively. And Basel Convention, which prohibits the trans-boundary movement of hazardous wastes, recommends the standard of mercury content less than 5 mg/kg [11, 12]. Since the materials derived from SCFL except the phosphor powder were satisfied with the standard, therefore, they were not subject to mercury treatment. Since the mercury content of phosphor powder is higher than the standard, however, it should be treated properly. In Process 6, phosphor powder was treated by the distillation system and the mercury content in treated phosphor powder is only 0.348 mg/kg.

Mercury in vapor phase generated in each process of SCFL recycling system was treated in adsorption tower with activated carbon in Process 7 because vapor was sent to adsorption tower through cyclone connected with each process. Hence, mercury in vapor phase could not discharge to any other place. In the process of SCFL recycling system, mercury in vapor phase was measured with MVI and its results are shown in Table 4. The mercury amounts in vapor phase from SCFL crusher, screen separation system, and mercury distillation system were 3,017, 1,184, and 11,670 mg, respectively. It was found that mercury concentration in SCFL crusher was relatively high because most mercury was emitted to atmosphere when SCFL was crushed initially. In the mercury distillation system, the mercury concentration in vapor phase was very high because some of vaporized mercury was not recovered by the cooling system.

The mercury amount involved into SCFLs can be estimated by both the sum of the mercury amount in the materials from entire recycling process as shown in Table 3 and the mercury amount emitted to atmosphere as shown in Table 4. Since the amount of mercury contained in all materials was 47.22 g and the amount of mercury in vapor phase except distillation system is 4.20 g, hence, total amount of mercury contained in 1,000 kg of SCFL was estimated as 51.42 g.

The material stream of mercury in SCFL recycling facilities is as shown in Fig. 3. The major mercury stream can be represented by Process 6, in which phosphor powder was treated by distillation process. Since most mercury was contained in phosphor powder, mercury distillation system was very important to control and to recover mercury through the treatment of phosphor powder. The amount of mercury recovered in this system was 33.62 g which was recovered

Table 4 Mercury emission in vapor phase for each process

Process	Flow rate (m^3/min)	Mercury concentration ($\mu g/m^3$)	Mercury emission (mg)
SCFL crusher	4.11	734 ± 130	3,017 ± 534
Screen separation system	3.02	392 ± 58	1,184 ± 175
Mercury distillation system	3.00	3,890 ± 279	11,670 ± 837
Total	10.13	–	15,871 ± 1,546

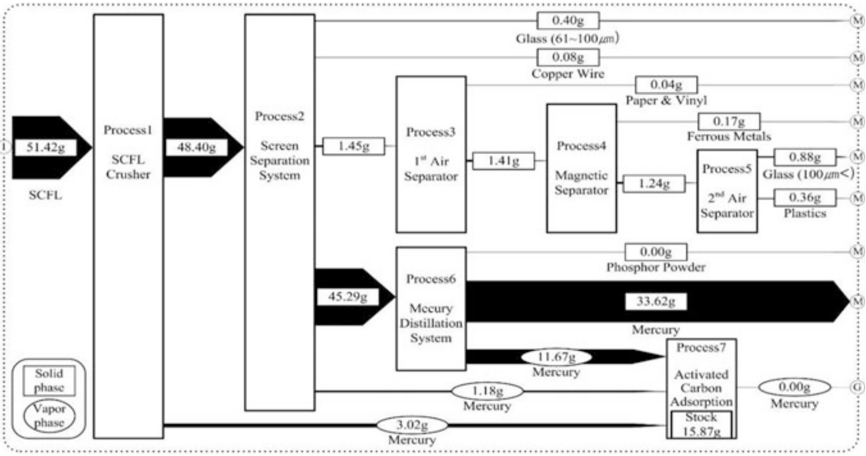

Fig. 3 Mercury stream in recycling facility for SCFL

approximately 74% compared to the input amount. Approximately 26% of the input mercury is not recovered, and this amount is deemed to be flowed into Process 7. Finally, the mercury amount in phosphor powder passed through mercury distillation system was measured to be less than 0.01 g. Hence, it can be shown that the stability of mercury distillation system was satisfied.

3.3 Recovery Rate and Purity of Recycled Materials

In recycling facilities, recovery rate and purity of output components of SCFL were evaluated by separation theory as shown in Table 5. In separation theory, it can be classified by target material and other materials in each process. Since other materials are working as a deteriorating factor, recovery rate and purity can be significantly affected by other materials which are not recovered separately. And recovery rate and purity were very important factors to evaluate the recycle system and recycle system boundary. Since almost all components from the SCFL had very high value of recovery rate and purity, the performance of SCFL recycling facilities was satisfied. Recovery rate of glass, phosphor powder, ferrous metals, paper and vinyl was higher than 95%, but recovery rate of copper wire and plastics was less than 90%. Even though glass can be classified with small particle size (61–100 μm) and large particle size (>100 μm), recovery rate of total glass was about 99%. In case of copper wire, particularly, it is deemed to be necessary to improve the recycling process because recovery rate was around 80%.

With respect to purity, purity of ferrous metals, paper and vinyl was higher than 95%; purity of glass and phosphor powder was higher than 90%; purity of plastics and copper wire was higher than 85%. Generally, the material having high recovery

Table 5 Recovery rate and purity of SCFL materials

Material	Input material (kg)	Output material (kg)	Recovery rate (%)	Purity (%)
Glass	523.59	553.36	99.34	94.00
Phosphor powder	9.46	10.34	99.17	90.73
Copper wire	48.57	45.08	80.11	86.31
Ferrous metals	119.77	121.67	96.54	95.03
Plastics	238.58	245.19	89.54	87.12
Paper and vinyl	23.49	24.36	99.13	95.57
Others	36.56	0.00	–	–
Total	1,000.00	1,000.00	–	–

rate represents high purity. In case of phosphor powder, recovery rate is very high with 99% but the purity is relatively low with 90%. That was the reason why tiny glass particles generated in the crushing process would be included in phosphor powder. From the results of material stream, it can be found readily that more than 95% of materials of SCFL can be recovered and some processes in SCFL recycling facilities should be improved to increase recovery rate and purity of output materials.

4 Conclusion

The entire material stream and mercury stream were performed based on the basic data of components of SCFL and the mercury concentration analysis for the SCFL recycling processes. In the results of analyzing material stream for 1,000 kg of SCFL, components such as 553.36 kg of glass (83.43 kg, 61–100 μm; 469.93 kg, >100 μm), 45.08 kg of copper wire, 24.36 kg of paper and vinyl, 121.67 kg of ferrous metals, 245.19 kg of plastics and 10.34 kg of phosphor powder are recovered. The mercury content in recovered materials and the mercury amount in vapor phase were estimated to be 47.22 and 4.20 g, respectively. Hence, total amount of mercury contained in 1,000 kg of SCFL was estimated as 51.42 g. From the results of evaluating recovery rate and purity through material stream, it can be found readily more than 95% of materials of SCFL can be recovered.

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Conceptual Framework for Municipal Solid Waste Processing and Disposal System in India

A. Aich and Sadhan Kumar Ghosh

Abstract Municipal solid waste processing and disposal in India is a complex task involving numerous waste fractions, a range of technological treatment options, and many environmental, social, and economic issues. Strong systematic frameworks can only facilitate the planning, implementation, and maintenance of sustainable municipal waste processing and disposal systems. The framework helps to define the key considerations for system planning and design, steps for performance and monitoring, and approaches for facilitating continual system improvements. A conceptual framework for municipal solid waste processing and disposal has been developed in this study, by critically examining the literature, data analysis, and survey, for determination of the management approach that would be necessary for the improvement of the present situation of solid waste management system in India. This framework has been established after practical case studies to exemplify how far it is applicable as a systems management tool for complex waste management system, and address the obstacles typically faced by the waste processing plants in India. The benefits of this conceptual framework include the integration of processing and disposal of waste with its collection and transportation.

Keywords Composting · Conceptual framework · Incineration
Municipal solid waste · Supply chain · Source segregation

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1 Introduction

Municipal solid waste management (MSWM) system in India is very complex because of rapid unplanned urbanization coupled with improper waste management practices, inadequate capacity to handle waste, lack of capital investment, poor implementation of legislation, and lack of public concern. Sharholy (2007) found that in India, about 90% of municipal solid waste (MSW) was disposed of unscientifically in open dumps and landfills [1]. Currently, of the estimated 62 million tonnes of MSW generated annually, by 377 million urban people of India, more than 80% is disposed of indiscriminately at dump yards in an unhygienic manner by the municipal authorities leading to problems of health and environmental degradation [2]. Municipal solid waste can be processed, in an environment-friendly manner, into compost manure, gas, electricity, building materials, and other valuable products. Diversion of organic fraction of municipal solid waste (OFMSW), which is more than 65% of total MSW in India [3], to composting plant(s) and anaerobic digestion (AD) plants may reduce more than 50% load at landfill sites. But, due to inconsistent supply of feed material and process management, composting could not be successful at large scale in India. Incomplete separation of non-compostable materials from the feedstock, high cost in operation and maintenance, at the same time higher cost of compost manure in comparison with commercial fertilizers have rendered most of the compost plants, in India, not viable [4]. In India, composting is applied only on 10–12% of MSW [5]. Because of mixing of all types of waste together, majority of the compost manure produced from MSW, in India, contains heavy metals specially Zinc (Zn), Copper (Cu), Cadmium (Cd), Lead (Pb), Nickel (Ni), and Chromium (Cr) in much higher percentage than the standards and having low nutrient value [5, 6]. Incineration or waste-to-energy (WtE) which is the most widely used technology in developed countries for energy extraction from MSW also does not reflect successful stories, in India, due to the following reasons: (i) low calorific value (900–1760 kcal/kg) of waste, typically between 30 and 40% than that of developed countries, and (ii) lot of inert materials in MSW. A ton of MSW can generate about 550 kWh (about 2 MW per 100 MT) of electricity in USA [7] whereas, in India, about 80–100 MT MSW can produce 1 MW of electricity [8]. Again, in spite of numerous advantages of anaerobic digestion (AD) of organic waste, it could not be adopted in India in large scale, because of its long hydraulic retention time (HRT), generally 45–60 days, which eventually leads to a large volume of the digester and hence high capital cost of the system. Mixing of all types of waste together is another obstacle for processing of MSW through AD at large scale. Landfill gas (LFG) extraction is high capital cost intensive and its closure and long-term post closer care require financial assistance for its sustainability. Economic profitability is a key barrier to widespread implementation of LFG project [9]. Landfill gas extraction technology, therefore, may not be sustainable in India due to its high capital cost and monitoring cost unless it is supported by sufficient tipping fee or concession.

The main focus of success of MSWM system remains on processing and ultimate disposal of waste which should be supported by proper collection and transportation of waste. To achieve sustainable and effective waste management system in India, development strategies must go beyond purely technical considerations to formulate specific objectives and appropriate measures for implementation with regard to technical, institutional, social, financial, economic, and political aspects. In this paper, a conceptual framework for processing and disposal of municipal solid waste, for Indian condition, has been developed. This structured conceptual framework will address the key issues of municipal solid waste processing and disposal (MSWPD) system in India.

2 Objective

The objective of this study is to develop a conceptual framework for municipal solid waste processing and disposal system which may eventually promote a sustainable municipal solid waste management system in India. The overall goal of this conceptual framework is to serve as a practical tool for the establishment of sustainable municipal solid waste processing and disposal systems.

3 Literature Review

3.1 Conceptual Framework

Sustainability of MSW processing and disposal technologies depends upon multidimensional factors such as waste characteristics and quantity, climatic conditions, environmental impacts, land criteria, economic and financial conditions, social and political situation. Menon (2013) indicated that an integrated sustainable solid waste management system (ISSWMS) needed a strategic approach to sustainable management of solid wastes covering all resources and all aspects which include generation, segregation, transfer, sorting, treatment, recovery, and disposal of waste in an integrated manner, with an emphasis on maximizing the efficiency of the use of resources [10]. To make the solid waste management system sustainable, it should be technically and financially viable, economically beneficial, and socially accepted [11]. Planning and development of a sustainable municipal solid waste management (SMSWM) system should follow a conceptual framework. Aims and objectives of framework are preparing a conceptual framework that can be likened to planning and monitoring. It addresses specific questions that require answers, and it is used to make conceptual distinctions and organize ideas [12]. Strong conceptual frameworks capture something real and do this in a way that is easy to remember and apply [12]. A conceptual framework defines ‘the way the ideas are organized to achieve a purpose' [10]. It is the way the subject been investigated different to the 'normal' approaches [12]. Technical knowledge, research background, personal experience, and data (particularly primary data) are the inputs required for developing a conceptual framework [12, 13]. Formal hypotheses posit possible explanations (answers to the why question) that are tested by collecting data and assessing the evidence [14–16]. The pieces of the conceptual framework are borrowed, but the researcher provides the structure [12]. Specific forms that might a conceptual framework take include: flowcharts, tree diagrams, shape-based diagrams—triangles, concentric circles, overlapping circles, mind maps, and soft systems.

3.2 Framework for Municipal Solid Waste Management System

A strong framework depicting the goals, strategies, management procedures, and control can only lead to a sustainable SWM system. Effective and sustainable MSWM systems cannot be achieved by focusing on the technical aspects alone; clearly formulated objectives and coordinated actions are also required in the political, institutional, social, financial, and economic fields [17]. The conceptual framework for MSWM briefly defines the main concepts of MSWM and identifies the goals and principles that normally guide MSWM system development. It discusses key objectives and issues which should be addressed by MSWM strategies with regard to technical, financial, economic, institutional, and social aspects [17]. Effective MSWM depends upon an appropriate distribution of responsibilities and authority.

4 Methodology

4.1 Field Survey

There has been considerable excitement about composting of MSW in India. But field survey, for this work, reveals that quite a good number of MSW composting plants which are built and operated by local bodies or by different private agencies are not operating successfully. For example, in West Bengal, India, windrow compost plants at Durgapur (300 TPD) and Kamarhati (200 TPD) could not reach their break-even sales due to problem in waste characteristics and the plants are at the verge of closure. The vermi composting plant at Chandannagar, Kalyani, is running successfully, but the vermi compost plants at Panihati (100 TPD), Bhadreswar (20 TPD), and Khardah (30 TPD), all in the state of West Bengal, are at total dismal condition due to wide fluctuation of quality of waste and lack of initiative for quality control of the product. A 50 TPD vermi compost plant at Bidhannagar, West Bengal, could not be commissioned due to lack of initiative and faulty planning. A 200 MT windrow compost plant of Kolkata Municipal Corporation is operating intermittently at less than one-fourth of its capacity due to heavy fluctuation of waste quality and other reasons. Compost plants at Mysore (400 TPD), Mangalore (300 TPD) both in Karnataka and 500 TPD plant at Nasik in Maharashtra are operating with low plant capacity. A 50 TPD vermi compost plant at Mangalore, Karnataka, is presently closed due to huge inventory of compost manure.

A good number of waste-to-energy (WtE) facilities have been created, in India, over a period of time at the initiative of both private and government sectors, but the success story is not so encouraging. Most of the waste processing plants in India either have been shut down or not being operated as per their designed capacity. Field survey suggests that incineration of MSW in India is still at experimental stage. Present situation of some of the WtE plants surveyed for this study in India is given below:

S. No.	Project details	Present situation	Problem encounter	Remarks
1	16 MW WtE plant (2000 TPD feed material) at Okhla, in Delhi, commissioned in the year 2010	Unable to meet emission standards	High moisture content, low calorific value waste	Delhi Government has recently decided to shut down the plant
2	WtE plant of 6.0 MW capacity at Shadnagar, Hyderabad, (700 TPD feed material)	Utilizing 150–200 TPD while the rest of it is dumped in nearby fields	Feed material containing lot of inerts/CD waste. Low calorific waste requiring auxiliary fuel (rice husk is being mixed)	Unsegregated waste causing severe environmental damages
3	RDF plant at Hyderabad (at Gandhamguda)	The plant remains shut most of the days, and actual recovery of pelletizable fuel waste is below 20%	Variation in the heat content of [waste pellets] 1,000 kcal to over 4,000 kcal per kg	The rejected quantity dumped outside the plant is causing severe environmental damages
4	750 TPD pyrolysis plant at Pune, Maharashtra	Yet to receive the environmental clearance	Double stage segregation of waste and pre-drying are incurring extra cost	Performance data not disclosed by the plant authority

Various reports suggest that two incineration plants, one at Narela and other at Ghazipur, in Delhi are found to be expensive and not viable. In Lucknow, a 15 MW waste-to-energy plant was commissioned in 2003 but it never operated on full capacity and closed down in 2004.

From the field survey, it has been transpired that in India the waste processing and disposal (WPD) system is not supported by any long-term strategic plan for its sustainability. In most of the cases, the waste processing plants did not receive the guaranteed volumes of desired characteristics of MSW. Waste management practice followed is not based on the practical field situation but based on technology. Thorough introspection on the practical field situation and the management system is not being done for strategy formulation. Extensive field survey reveals that there is conspicuous lack of accuracy regarding estimation of municipal solid waste. Waste quantification and characterization are posing a serious problem in technological assessment and feasibility studies. Further, most of the technologies selected require high level of segregation of waste which is completely absent in the practical field.

4.2 Data Collection

Data collection and analysis reveal that almost every city there remains a number of bulk sources which individually or clubbing with two or more other sources can create a sustainable supply chain for feed materials of the waste processing plant(s). A summary of the experiences of waste generation pattern of the urban centers is appended below, though many more examples can be cited in this regard:

Case I The Kolkata Municipal Corporation (KMC), India, generates about 5115 ton/d i.e., 1.10 kg/cap-d of MSW daily [18]. In Kolkata, there are about 397,890 domestic holdings which contributes about 1700–1850 MT of waste [18]. KMC also generates about 1600–1800 tons of waste from institutions, commercial establishments, and market areas [19] which is basically paper, plastic, metals, textiles, cardboard, straw, and other waste. About 1165–1250 MT waste comes from street sweepings [18]. List of some bulk waste generators in Kolkata Municipal Corporation area is given below:

Source	Daily waste generation (MT)
Daily markets (total number 252, out of which 20 are owned by KMC)	700–800
Slaughterhouse at Hog Market	5.0
Wholesale fish markets (8 No.)	30
Wholesale flower market (Kashi Vishwanath Ghat Flower Market)	10
Wholesale fruit (known as Mechua Falpatty) and vegetable market (known as Koley Market)	50

(continued)

(continued)

Source	Daily waste generation (MT)
Royal Calcutta Turf Club (basically from horse dunk from stable and garden and kitchen waste)	7–9
Kitchen waste of big clubs (27 No.)	15–18
Eastern Command HQ Fort William basically garden and paper and plastic waste	15
Kitchen waste from 5-star hotels (8 No.) and 4- and 3-star hotels (22 Nos.)	15–25
Rabindra Sarobar, Subhash Sarovar Eden Gardens, Victoria Memorial, Citizen Park, Millennium Park	40–50/week
Ceremony houses/banquet halls (2500 Nos.)	450
Kalighat Temple (purely flower, leaf, and fruit waste)	2

Case II Haldibari Municipality, a small town of population 14,989, in the district of Coochbihar, WB, generates about 29 tons of MSW daily; out of which about 21 MT, which is purely agricultural/vegetable waste (more than 90% biodegradable), is generated from a daily wholesale vegetable market or popularly known as 'Paikari Bazar.' This is a unique case where a town having population less than 15,000, has a daily wholesale vegetable market which generates 21 MT of agricultural waste daily whereas the total domestic waste generation is only 2.9 MT.

Case III Udupi City Municipal Council, a small town of population 125,350, in the district of Udupi, Karnataka, generates about 60 tons of MSW daily, out of which about 10–12 MT, which is purely flower, fruit, and food waste (more than 95% biodegradable), is generated from three temples named Kadiyali Temple, Sri Krishna Temple, and Sri Mahalingeshwara Mahaganapathi Temple.

Case IV Tirupati Municipal Corporation (MCT), a small hill town in the Chittoor district of the Indian state of Andhra Pradesh, having population 287,035, generates 140 MT of MSW and out of which 40–45 MT purely biodegradable waste is generated at Tirumala Venkateswara Temple, Sri Venkateswara Zoological Park, and other temples like Govindarajaswami temple. About 50,000–100,000 pilgrims visit daily in the town.

The examples given above are very few of the observations made during the course of field survey and data collection. During the study, it has been transpired that the waste management authorities have no vision and long-term planning for waste processing and disposal. The local bodies have never conducted any macro-level analysis of waste generation patterns. There is complete absence of segregation of waste at source.

5 Analysis

5.1 Structure and Content of the Framework for MSWPD System

The first goal of the framework of the municipal solid waste processing and disposal (MSWPD) system is to protect the health of the population. Other goals include promotion of environmental quality and sustainability, support of economic productivity, and employment generation. The framework of the MSWPD system is the major part of the conceptual framework for integrated sustainable municipal solid waste management (ISMSWM) system. This framework for MSWPD system has been structured, in this study, along with five principle dimensions as follows:

(1) Selection of right technologies for processing and disposal of MSW,
(2) Waste sources and its characteristics,
(3) Strategy for waste collection and transportation,
(4) Management structure and responsibility centers for implementation of plans and programmes, and
(5) Management approach for planning and development of system and procedures.

5.1.1 Selection of Right Technologies for Processing and Disposal of MSW

Waste management system cannot be made sustainable only with the technical end-of-pipe solutions but an integrated approach is necessary. A sustainable waste processing technology is one which is technically suitable, financially viable, economically beneficial, socially acceptable, and environment-friendly. Apart from the quantity and quality of waste, the waste processing plants are to be decided on the basis of strength, weakness, opportunity, and threat (SWOT) analysis. Identification of SWOTs in SWM processing and disposal project is important because they help in planning to achieve the objective. First, the decision makers should consider whether the objective is attainable, given the SWOTs. If the objective is not attainable, a modified or different objective must be selected and the process is to be repeated. After the SWOT analysis report is completed, the SWOT list becomes a series of recommendations for developing a strategic plan. The brainstorming season of the participants and stack holders, on the SWOT reports, to identify the obstacles and formulation of strategy for the solutions to those limitations helps to select the technology for a sustainable processing and disposal of MSW. The SWOT analysis will also help to identify the raw material feed mix, raw material supply chain, product mix, product market, business model and business risk and social barrier. The framework of the selection of technology for the processing and disposal of MSW developed in this study is presented in Fig. 1.

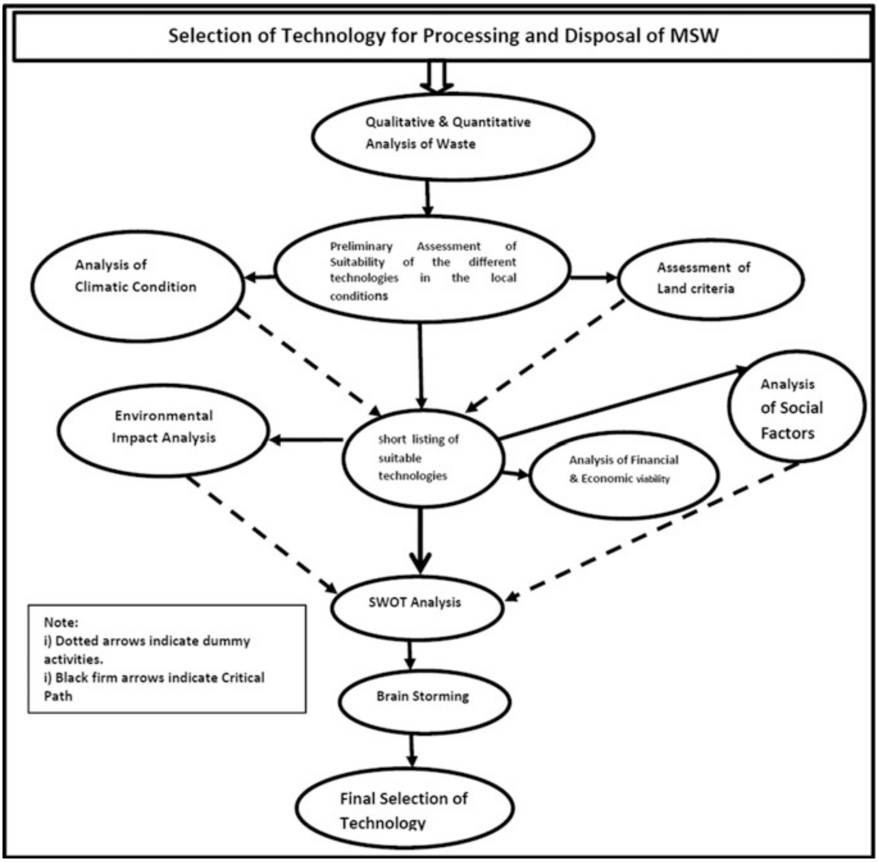

Fig. 1 Framework of the selection of technology for processing and disposal of MSW

5.1.2 Waste Sources and Its Characteristics

Quantity, characteristics, and frequency of generation of waste are important, both for selection of technology for processing and disposal of waste and also for designing of collection and transportation system. Guided by the experience and the knowledge obtained from field survey and data analysis, a new concept 'segregation of sources' has been evaluated in this study. In the absence of 'segregation of waste at source,' this new concept may help to segregate the major portion of waste if implemented systematically, in India. 'Segregation of source' means the separation of different bulk waste sources as per their waste characteristics and clubbing them with other sources which generate similar characteristics of waste. A color coding system may be introduced, as follows, to segregate the major parts of different types of waste, viz. degradable, non-degradable, and inert waste (Table 1).

Table 1 Color coding of sources

Sources of waste (waste generated at)	Color coding
Daily markets, wholesale (vegetable, fruit, flower, and fish) markets, slaughterhouse, kitchen (of big hotels, hostels, big clubs) food canteen/plaza, restaurants, banquette halls, religious places, ceremony house, stables, poultry, piggery, milk dairy, parks and gardens, zoo, fruit and food processing industries, sugar industry, agricultural industry, cesspool waste, waste from sewage treatment plants	Green
Domestic[a]	Blue
Shopping mall, market complex (other than daily market), commercial complex, offices, school, college, university or any other institutions, airports, railway stations, bus terminus, housekeeping waste of big hotels, amusement park/stadium/fairground	Yellow
Construction debris	Orange
Road sweeping	Black

[a]'Blue,' i.e., domestic waste and street sweeping waste are common for all areas

5.1.3 Strategy for Waste Collection and Transportation

To support the concept of segregation of sources, two paradigms: (i) part-to whole approach and (ii) bottom-up approach of planning have been established in this paper.

(i) Part-to-Whole Approach

In '**part-to-whole**' approach, the concept of centralized processing of MSW may be changed to decentralized processing, wherever possible. In this approach, in the event of absence of segregation of waste at source, on-site (near the generation point) processing of MSW should be encouraged rather than the single centralized system; i.e., 'try to take care of the waste near the point of generation and push the excess quantity to the central system.'

(ii) Bottom-Up Approach of Planning

In this approach, transportation and collection system should be planned and designed based on the ultimate processing and disposal destination of the waste, i.e., '**bottom-up approach**.' Area-wise allocation of collection and transportation vehicles should be replaced by allocation of vehicles as per waste characteristics, quantity, and disposal destiny. Resources are to be allocated as per the (i) types of waste, (ii) quantity of waste to be transported, (iii) frequency of generation of waste, (iv) vehicle type, (iv) haul distance, (v) frequency of collection, (vi) number of sources clubbed together, (vii) distance of plant where the waste is to be transported, and (viii) maximum time limit by which the transportation of waste can be delayed.

5.1.4 Management Structure and Responsibility Centers for Implementation of Plans and Programmes

Sustainability of integrated sustainable municipal solid waste management system (ISMSWM) depends on the level of efficiency of the functioning of the various responsibility centers of the organizational structure responsible for MSWM system and their elements. SWM services can be performed effectively only if its administration is adequately decentralized as per their size. According to size of the city, decentralization is to done in 2–4 tiers as shown below.

Size of city	Administrative divisions
Large	Ward level, zone level, sector level, city (central) level
Medium	Ward level, zone level, city level
Small	Ward level, city level

Decentralization of responsibilities of MSWM system requires a corresponding distribution of powers/authorities and capacities. Framework for responsibility centers has been formulated in Fig. 2.

5.1.5 Management Approach for Planning and Development of System and Procedures

The waste management planning process runs in cycles; i.e., in principle, it is a continuous process, where the plan or strategy may be required to be revised at regular intervals. Developing and implementing ISWM requires comprehensive data on present and anticipated waste situations, supportive policy frameworks, knowledge and capacity to develop plans/systems, proper use of environmentally sound technologies, and appropriate financial instruments to support its implementation. Considering the concept of 'segregation of source' as an alternative to 'segregation at source' and application of bottom-up approach, a systematic collection and transportation frameworks have been developed in this study which are given in the following sections.

Planning and development

The five basic steps to be followed for planning and designing a system for sustainable processing and disposal of municipal solid waste, following the 'bottom-up approach' as have been classified in this study, are given in Fig. 3.

Flowchart for responsibilities of various responsibility centers for planning and development of municipal solid waste processing and disposal system as have been developed in this study is given in Fig. 4.

Framework for planning and designing of vehicles for collection and transportation of MSW following the concept of bottom-up approach, as have been developed in this study, is given in Fig. 5.

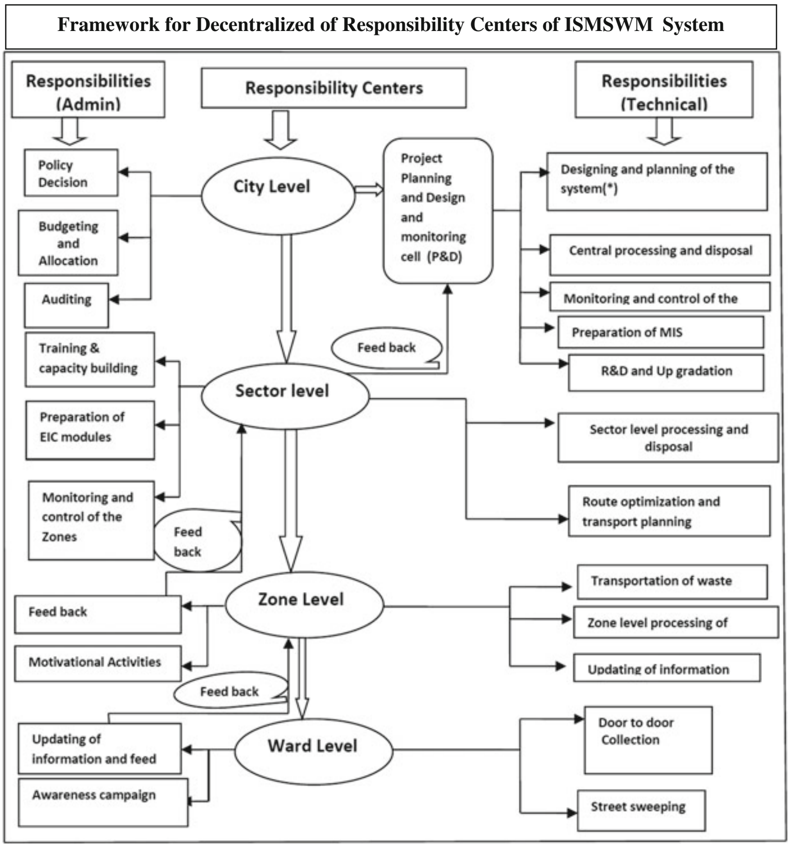

Fig. 2 Decentralized responsibility centers for ISMSWM system

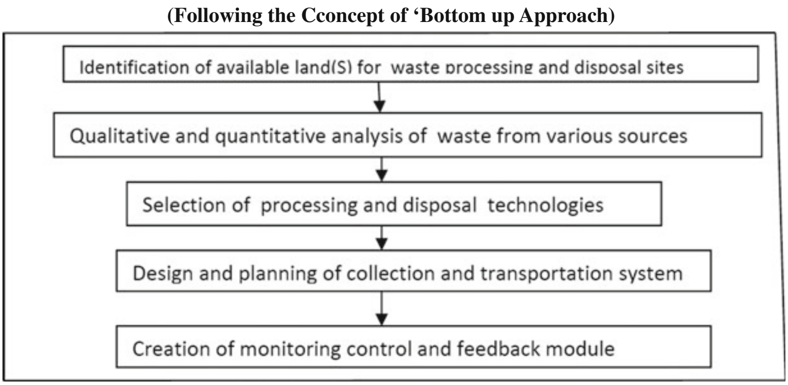

Fig. 3 Flowchart for planning of MSW processing and disposal system

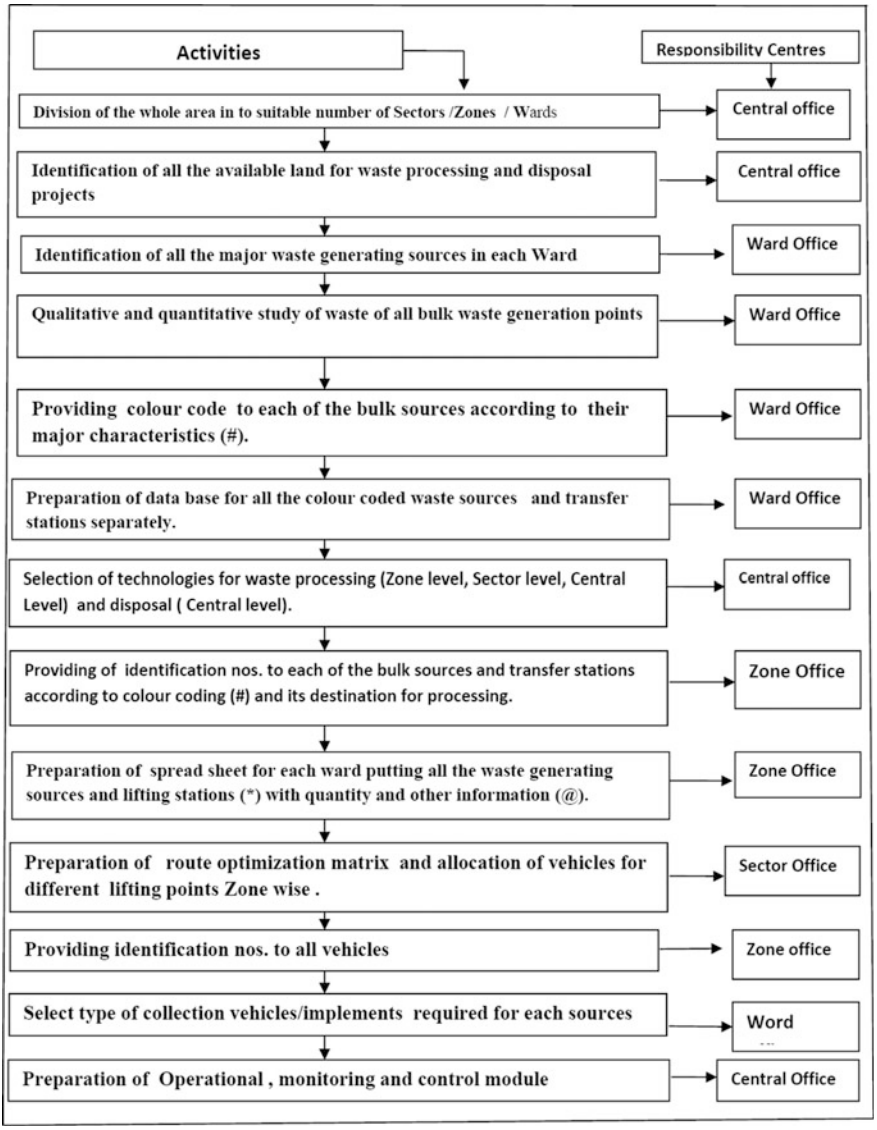

Fig. 4 Flowchart for activities of responsibilities for planning and development of MSWPD system. (@) Information such as location, color code, approximate quantity of daily waste, distance from the disposal ground, vehicle type, vehicle’s garage. (*) Also locate all the major sources in ward maps as per their color code. (#) Color code as prescribed above

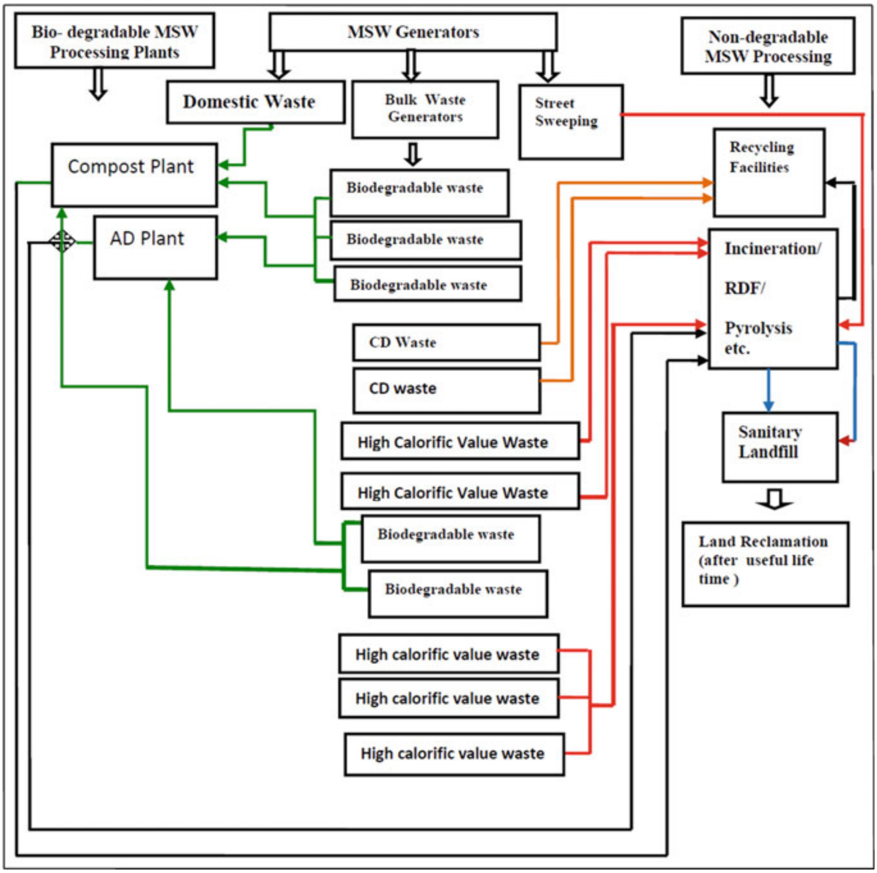

Fig. 5 Framework for planning and designing of vehicles for collection and transportation of MSW. BWG—bulk waste generator, CD waste—construction and demolition waste, red arrows indicate transportation of high calorific value waste, green arrows indicate transportation of high biodegradable content waste, saffron arrows indicate transportation of CD waste, black arrows indicate transfer of screenings, and blue arrows indicate transfer of bottom ash (color figure online)

5.1.6 Establishment of Supply Chain for Feed Materials for MSW Processing and Disposal

Selection of technology for processing and disposal of municipal waste largely depends on the characteristics of feed materials, i.e., MSW. It is, therefore, essential to establish a sustainable supply chain of right kind and right quantity of feed materials for the waste processing plants for its sustainability. The 'bottom-up approach' and 'part-to-whole approach', as explained above, will provide a systematic collection and transportation model to support a sustainable supply chain

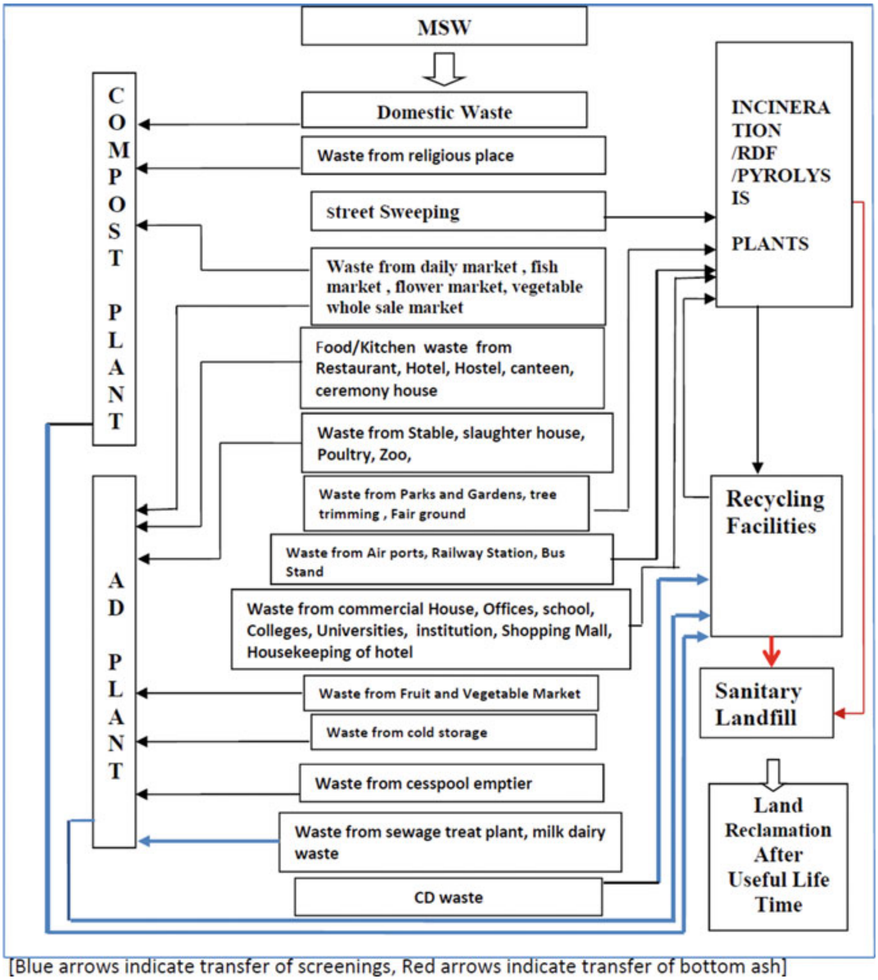

Fig. 6 Typical framework for feed materials supply chain for waste processing and disposal system

for feed materials for MSW processing and disposal plants. The framework for feed materials supply chain for the processing and disposal of MSW, evaluated in this study, is given in Fig. 6.

6 Discussion

This conceptual framework has briefly defined the main concepts of MSWPD system and has identified the goals and principles that will guide the MSWPD system development. It has highlighted the key objectives and issues which should be addressed by MSWM strategies. This conceptual framework for MSWPD system would remove the key obstacles encountered by the waste processing plants in India. This framework paper has concluded by outlining possible directions for development planning of a sustainable solid waste processing and disposal system in India.

7 Conclusion

This conceptual framework is dynamic in nature and requires continuous evaluation within the principle of framework. The framework for MSWPD will be the guiding tool of the planning process and will provide the direction for strategic plan if used by itself. This conceptual framework is not a finished product; it requires further collaborative actions by the stakeholders and its partners.

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Selection of Suitable Landfill Site for Municipal Solid Waste Disposal: A Fuzzy Logic Approach

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Abstract A fuzzy-based model was developed in the proposed work to evaluate the suitability of landfill sites for disposing municipal solid waste considering 32 attributes as proposed by Central Pollution Control Board (CPCB). The work is demonstrated with reference to Asansol Municipal Corporation (AMC) area in West Bengal, India, as a case study. The attributes include both quantitative and qualitative variables. These attributes were assessed qualitatively by the experts related to solid waste management. The weightage of each attributes and sensitivity index of each attributes related to alternative sites were defined in the form of triangular fuzzy membership functions based on the intuitions and data related to available literatures. The fuzzy decisions provided by the experts were then defuzzified by Yager's unit interval method to get the crisp weightage corresponding to each attribute and sensitivity index for attributes corresponding to each proposed sites. At a time the experts were to evaluate one attribute for both weightage and sensitivity index calculation. The performance of the model was checked by determining relative percentage error considering the model obtained weightage and CPCB mentioned weightage. From the results, it was clear that for most of the attributes the weightage obtained by the two methods was more or less same except for the attributes distance from collection area, distance to nearest drinking water source, public acceptability, distance to nearest surface water, depth of ground water and job opportunities. This implies that during decision-making, experts provide more emphasize to economic viability and social acceptability of the sites along with environmental sustainability. The attributes are mainly qualitative attributes describing socio-economic conditions; hence, fuzzy interpretation of those attributes can capture the ambiguity in the meaning of the attributes and overcome the imprecision and uncertainty of the related data more effectively.

Keywords Landfill site selection · Fuzzy-based model · Attributes
Weightage · Sensitivity index

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1 Introduction

Global economic prosperity and changing consumption pattern lead to mountainous Municipal Solid Waste (MSW) generation. At the same time, indiscriminate urbanization decreases land for assimilating the huge amount of MSW. Municipal Solid Waste Management (MSWM) has now become an important challenge for the decision makers worldwide. For the developed countries, the quantity and characteristics of solid wastes, and the lack of disposal sites have caused a greater concern for MSWM. While for the developing countries, the quantity and characteristics of MSW combining with scarcity of land and lack of public awareness have made the problem of MSWM a critical public issue.

Disposal of MSW in either open land or secured landfill is the most common practice for MSWM due to its simplicity and inexpensiveness [6, 8]. Limited space availability for waste disposal and growing environmental awareness are mainly responsible for continuously increasing negative public opinion towards landfilling process. The "Not In My Back Yard" (NIMBY) and "Not In Anyone's Back Yard" (NIABY) phenomena are becoming more popular nowadays creating tremendous pressure on the decision makers involving in the selection of a landfill site.

Inefficient landfill site selection causes several problems related to society, ecology, economics, environment and public health [3, 7, 9]. The selected location must comply with the requirements of the existing government rules and regulations while minimizing environmental, health and social costs [10].

The determination and evaluation of positive and negative characteristics of one location relative to others is a difficult task and can be considered as a Multi Criteria Decision-Making (MCDM) process that involves both crisp and linguistic variables. It is very difficult to develop a selection criterion that can precisely describe the preference of one site over another.

Many methods have been developed so far to select the best landfill site among the available alternative sites. Methods based on geographical information system (GIS), analytical network process (ANP), analytical hierarchy process (AHP), ordered weighted average (OWA), Boolean logic (BL), Delphi technique (DT), Site Sensitivity Index, etc., have been used either alone (with various modifications) or in combination of two or more for selecting landfill site. Most of these methods involve complex mathematical models that have been developed based on the concepts of accurate measurements and crisp evaluation. In Indian context, due to lack of fund and proper management it is difficult to obtain accurate crisp data. At the same time, most of the selection attributes cannot be described precisely. The data related to selection attributes and the weightages of the attributes are usually expressed in linguistic terms.

To deal with the attributes' uncertainties arising during the evaluation process with imprecise linguistic descriptions, fuzzy set theory [12] appears to be a good complimentary approach. Once the attributes are represented by fuzzy sets, there are several fuzzy techniques that can be used to facilitate formulation and calculations of uncertainties associated with these fuzzy indicators.

In this paper, a fuzzy logic-based model was developed to select suitable landfill site considering 32 attributes related to accessibility, receptors, environment, socio-economic, waste management practice, climate and geology. Asansol Municipal Corporation (AMC) area, India, was considered as case study to check the suitability of the model.

2 Methodology

2.1 Description of the Study Area

Asansol Municipal Corporation (AMC) area (Fig. 1), having geographical position latitude 23° 40′N and longitude 87°E and lying between river Ajay in the north and river Damodar in the south, is an industrial-cum-mining town in the Burdwan district of West Bengal, India. The total area of AMC is 127.23 km^2 with a generally flat terrain. With its mineral rich resources and heavy industrial development, Asansol is a fast growing town with population 563,917 (Census 2011). Though there are vast area of agriculture lands within Asansol, due to rocky soil and low rainfall, the inhabitants have to harvest their crops once a year, mainly in rainy seasons. AMC is responsible for MSW management, and total MSW handling is 220 MT per day. Presently, MSWM is done under four headings: storage; sweeping and collection; transportation; and disposal. MSW are collected without any source segregation and are disposed in unscientific manner in open dump yard devoid of

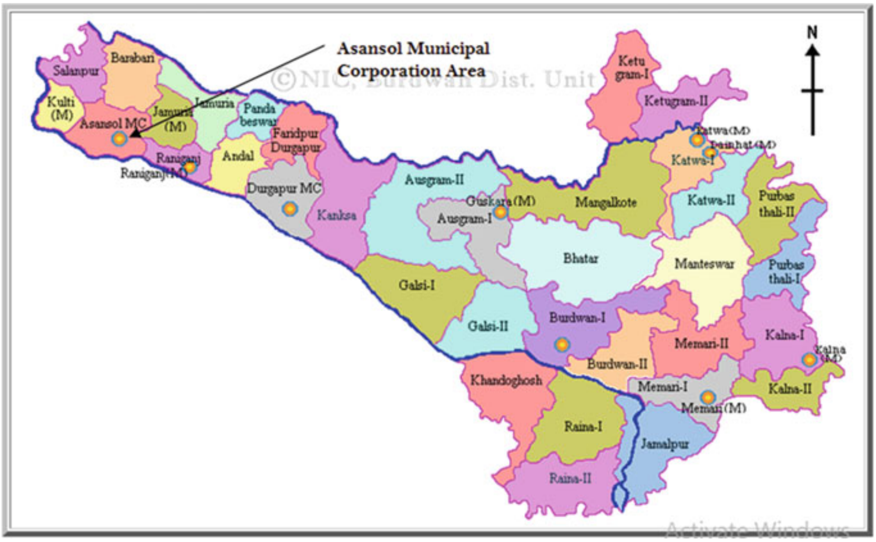

Fig. 1 Map of Burdwan district showing different administrative units

any proper treatment. Presently, two open dump sites are used for MSW disposal, one at Kalipahari (having area 10 Acre) and another is located at Samdihi, Burnpur, covering an area around 3 acres [2]. The landfill sites were selected without any suitability study, and both of them are verges to be exhausted and force the decision makers to select suitable landfill sites to construct sanitary landfill.

2.2 Calculation of Area for Landfill Site

One of the primary criteria of the landfill site selection is to calculate the required landfill area to accommodate the disposable MSW for the design period. To make the selected site economically viable, the design period was assumed 30 years (2015–2045). To calculate the required area, it was assumed that:

- Rate of population increase is 10% per year (from trend analysis of population of 1951–2011, Census Report).
- Per capita solid waste generation is 0.41 kg (as per Asansol Durgapur Development Authority (ADDA) report [1]).
- Disposable MSW fraction is 40% (worst case) of the total SW generation based on the physical characterization report [5]. For simplification of the project work, it was assumed that the characteristics of the solid wastes would be remained same for the designed period.
- Density of SW after compaction in the landfill site is 1000 kg/m^3 [5].
- Maximum height of the landfill is 20 m (Manual on Solid Waste Management by CPHEEO [5]).
- Area required is 1.2 times as area calculated [5].

Adopting the method proposed by CPHEEO Manual [5] for landfill site area calculation, it was obtained that the total area required for the landfilling operation for AMC area is 53.66 ha for the design period.

2.3 Selection of Attributes

Multiple factors should be considered for selection and evaluation of a landfill site. In this study, the factors used for the analysis of landfill site suitability were grouped into seven main categories considering the classification recommended by CPCB [4]:

- Accessibility
- Receptor
- Environmental
- Socio-economic

- Waste management practice
- Climatological
- Geological

Each main categories were included several attributes, and ultimately total number of attributes considered for landfill site selection were 32.

2.4 Data Collection

Data were collected for three purposes:

- Identification of landfill sites based on preliminary survey considering guidelines of CPHEEO Manual [5] and Municipal Solid Waste (Management and Handling) Rules, 2015 for landfill site selection.
- Formulation and validation of fuzzy-based model, for calculating weightage and sensitivity index for the selected attributes.
- Identification of suitable landfill site for the study area using the proposed model.

Two sites were selected near Asansol area for landfill site based upon the following factors:

- Within 2 km from suitable main road
- Economical travel distance (30 km) from origin of waste
- Not a flood plain

Attribute-related data were collected to calculate the sensitivity of the site.

2.5 Development of Model

A fuzzy-based model was developed to integrate various attributes with respect to each available alternative site for landfilling operation. After identifying the attributes and possible landfill sites, the weightages and sensitivity index of each attributes were calculated based on expert opinions. All the attributes were assigned linguistic term and were expressed as triangular membership function. The formulation of the proposed model is presented schematically in Fig. 2.

2.5.1 Fuzzification of Attributes

Weightage and sensitivity index of each attributes have been defined in the form of triangular membership functions $(a, \mu(a))$, $(b, \mu(b))$, $(c, \mu(c))$ as shown in Fig. 3, where $\mu(x)$ is the membership value for any input variable x.

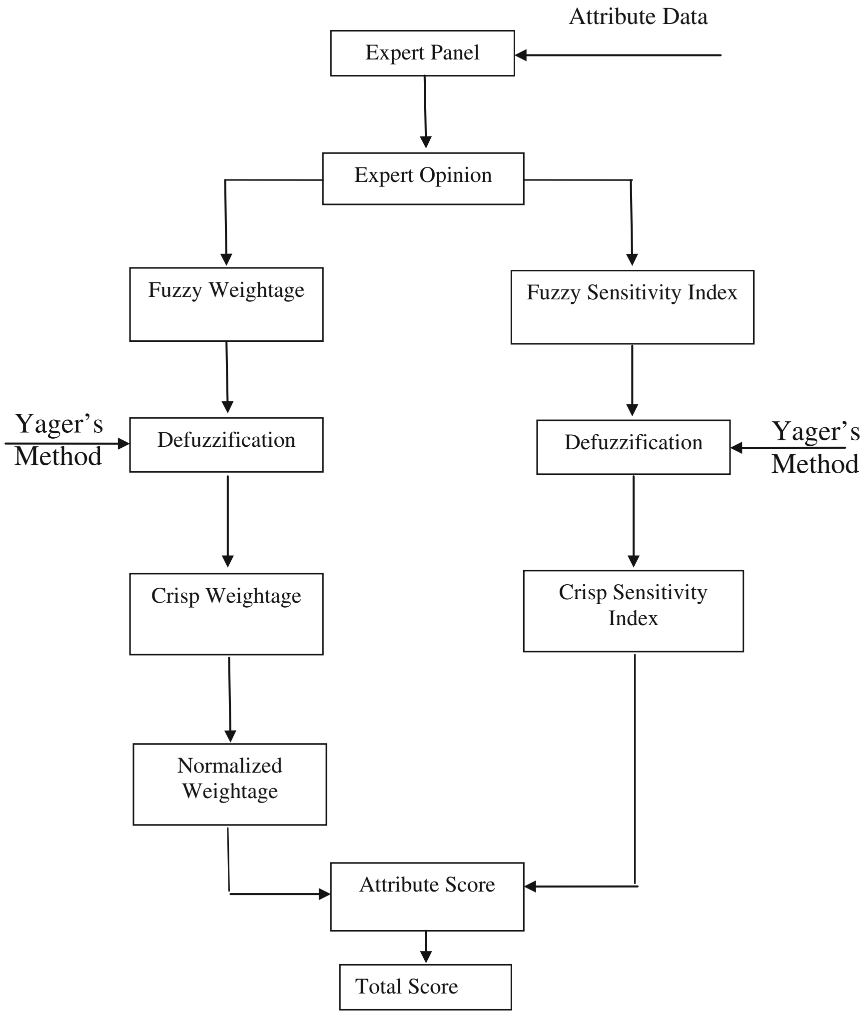

Fig. 2 Flow chart of proposed model

The membership functions for the triangular fuzzy numbers were calculated based on Eq. 1

$$\mu(x) = \begin{cases} 0, & \text{for } x < a \\ \frac{x-a}{b-a} & \text{for } a \leq x \leq b \\ \frac{c-x}{c-b} & \text{for } b \leq x \leq c \\ 0, & \text{for } x > c \end{cases} \tag{1}$$

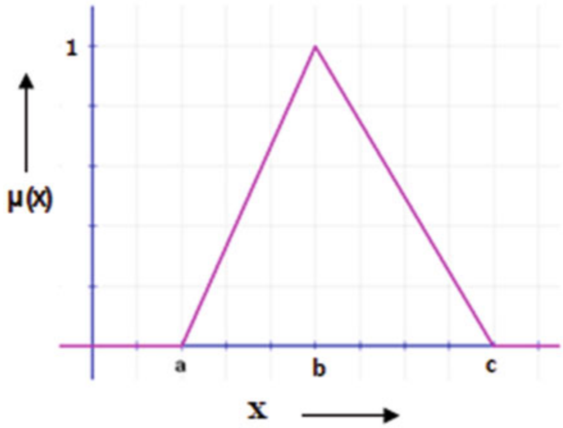

Fig. 3 Triangular membership function

Tables 1 and 2 present the triangular fuzzy numbers and corresponding membership functions for weightage and sensitivity index, respectively. For weightage calculations, each attributes were divided into seven groups while for sensitivity index calculation, each attributes were divided into five groups. The fuzzy values and corresponding membership functions for the attributes for calculating weightages and sensitivity index were assigned intuitionally based on the related works obtained in the published literature. Figures 4 and 5 present the triangular membership functions of weightage and sensitivity index, respectively, for each attributes.

2.5.2 Collection of Expert Opinion

A questionnaire was prepared to collect data regarding expert opinion for each attributes and alternative sites regarding their weightages and sensitivity index. The attributes were expressed linguistically to the experts.

Table 1 Membership functions for weightages

Linguistic descriptions of the attributes	Fuzzy values and corresponding membership functions for weightages
Very very low (VVL)	(0, 0) (0.05, 1) (0.1, 0)
Very low (VL)	(0.05, 0) (0.1, 1) (0.3, 0)
Low (L)	(0.1, 0) (0.3, 1) (0.5, 0)
Medium (M)	(0.3, 0) (0.5, 1) (0.7, 0)
High (H)	(0.5, 0) (0.7, 1) (0.9, 0)
Very high (VH)	(0.7, 0) (0.9, 1) (0.95, 0)
Very very high (VVH)	(0.9, 0) (0.95, 1) (1, 0)

Table 2 Membership functions for sensitivity index

Linguistic descriptions of the attributes	Fuzzy values and corresponding membership functions for sensitivity index
Very good (VG)	(0, 0) (0.1, 1) (0.3, 0)
Good (G)	(0.1, 0) (0.3, 1) (0.5, 0)
Fair (F)	(0.3, 0) (0.5, 1) (0.7, 0)
Poor (P)	(0.5, 0) (0.7, 1) (0.9, 0)
Very poor (VP)	(0.7, 0) (0.9, 1) (1, 0)

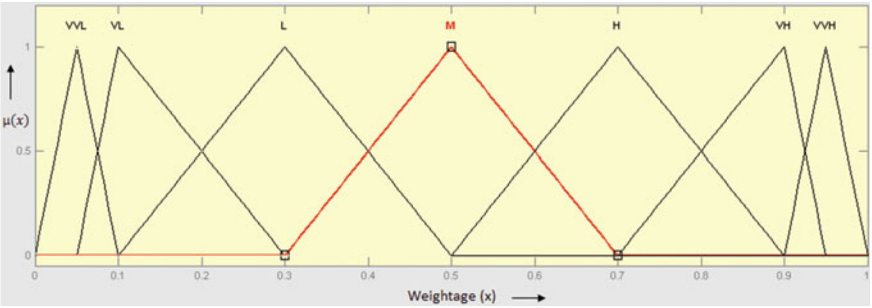

Fig. 4 Different membership functions for weightages

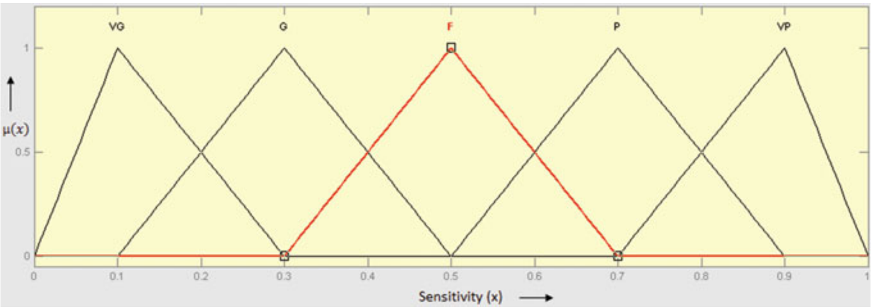

Fig. 5 Different membership functions for sensitivity index

A group of four experts (E_1, E_2, E_3, E_4) were decided based on their experiences and expertise in the Solid Waste Management fields. Expert opinions corresponding to importance of each attributes and sensitivity of each attributes were collected by face-to-face questionnaire survey. To make data more reliable, Delphi method was adopted.

$$\text{Let } A_i (i = 1, 2, \ldots, m) \text{ represents the } i\text{th attribute}$$
$$E_j (j = 1, 2, 3, 4, \ldots, n) \text{ represents the } j\text{th expert}$$

2.5.3 Calculation of Weightage

Let w_i^j represents the individual weightage assigned for ith attribute by jth expert.
$\tilde{w}_i$ represents net weightage for ith attribute.
$\tilde{w}_i$ is in the form triangle written as $\tilde{w}_i = (a, b, c)$
where a, b and c are calculated using following formulae

$$\tilde{w}_i = \frac{\sum_{j=1}^{n} w_i^j}{n} \tag{2}$$

2.5.4 Defuzzification of Weightage

After getting the weightages in the form of triangular fuzzy numbers, defuzzification was done to get the corresponding crisp value using Yager's unit interval method [11] as per Eq. 3.

$$\text{Crisp weightage, } \bar{\bar{w}}_i = \int_0^1 \frac{a_\alpha^L + a_\alpha^U}{2} \mathrm{d}\alpha \tag{3}$$

where,

$$a_\alpha^L = (b - a)\alpha + a$$
$$a_\alpha^U = c - (c - b)\alpha$$

2.5.5 Normalization of Weightage

After getting the crisp weightages corresponding to each attributes, normalization was done to convert the crisp weightage with respect to 1000 so as to compare with the results of CPCB [4]. Normalization of crisp weightage is done using following formulae

$$W_i = \frac{\bar{w}_i}{\sum_{i=1}^{m} \bar{\bar{w}}_i} \times 1000 \tag{4}$$

2.5.6 Calculation of Sensitivity Index

s_{ki}^{j} represents the individual sensitivity as triangles assigned for ith attribute of kth alternative by jth expert.
$\tilde{s}_i$ represent net sensitivity for ith attribute.
$\tilde{s}_i$ is in the form of triangle written as $\tilde{w}_i = (a, b, c)$
where a, b and c are calculated using following formulae

$$\tilde{s}_{ki} = \frac{\sum_{j=1}^{n} s_{ki}^{j}}{n} \tag{5}$$

2.5.7 Defuzzification of Sensitivity Index

After obtaining the triangular fuzzy values of sensitivity related to each attributes, defuzzification was done using Yager's unit interval method [11] as per Eq. 6.

$$\text{Crisp weightage, } \bar{\bar{s}}_{ki} = \int_{0}^{1} \frac{a_{\alpha}^{L} + a_{\alpha}^{U}}{2} \mathrm{d}\alpha \tag{6}$$

where,

$$a_{\alpha}^{L} = (b - a)\alpha + a$$
$$a_{\alpha}^{L} = c - (c - b)\alpha$$

2.5.8 Calculation of Attribute Score

Attribute score (AS) is calculated using Eq. 7

$$\mathrm{AS}_{ki} = W_i \times \bar{\bar{s}}_{ki} \tag{7}$$

Table 3 Decision criteria for landfill site selection

Total score	Site description
<300	Less sensitive to the impacts (preferable)
300–750	Moderate
>750	Highly sensitive to the impacts (undesirable)

Source CPCB [4]

2.5.9 Calculation of Total Score

The weighted linear aggregation method was used to calculate total score for a particular site by using Eq. 8

$$\text{Total score for a particular site} = \sum_{i}^{n} W_i \bar{\bar{s}}_{ki} \tag{8}$$

where W_i is the weightage of the particular attribute and $\bar{\bar{s}}_{ki}$ is the sensitivity of the particular attribute for the corresponding alternative site.

Table 3 presents the decision criteria for landfill site selection based on total score obtained by Eq. 8 [4].

3 Results and Discussion

Satellite image of two sites that were selected near Asansol area for landfill site based upon the following factors:

- Within 2 km from suitable main road
- Economical travel distance (30 km) from origin of waste
- Not a flood plain

is presented in Fig. 6.

The data related to 32 attributes used for landfill site selection were presented in Table 4.

The expert opinion obtained for weightage calculation for each attribute is presented in Table 5.

The weightages were calculated from the triangular fuzzy numbers by applying the formulae presented in Eq. 2. After getting the fuzzy weightages, the crisp weightages were calculated applying Yager's defuzzification method using Eq. 3. All the weightages were normalized by using Eq. 4.

To evaluate the performances of the proposed model, the relative percentage error between CPCB proposed weightages and model obtained weightages were calculated as presented in Table 5.

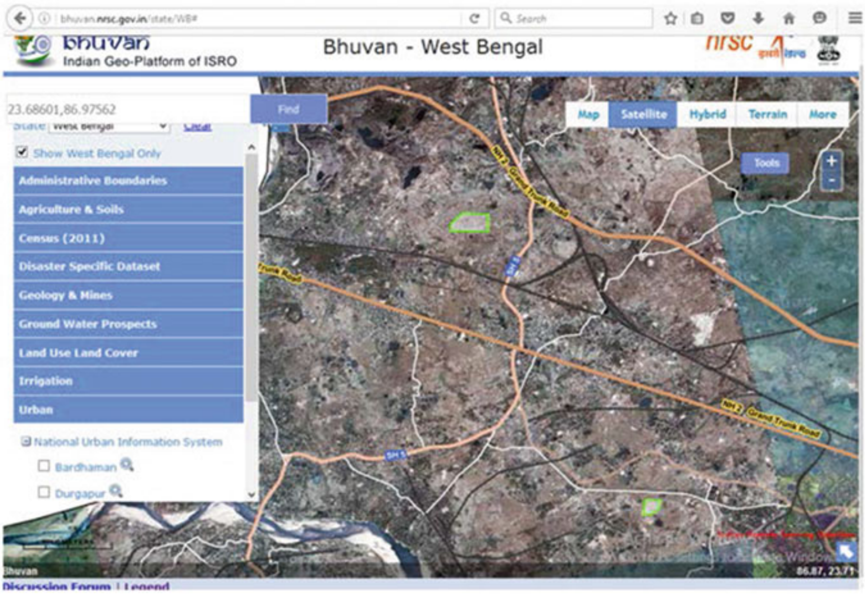

Fig. 6 Satellite images of proposed landfill sites

From Table 5, it is clear that the weightages for different attributes obtained from the proposed model and weightages obtained from CPCB [4] proposed Site Sensitivity Index (SSI) method are more or less same except for the attributes:

- Distance from collection area
- Distance to nearest drinking water source
- Public acceptability
- Distance to nearest surface water
- Depth of groundwater
- Job opportunities

In Site Sensitivity Index (SSI) method proposed by CPCB [4], the weightages were assigned by the experts by pairwise comparison method. The distance from collection area, from nearest drinking water source, nearest surface water, and depth of ground water are quantitative attributes while public acceptability and job opportunities are qualitative attributes. SSI technique may tend to be less effective in dealing with the imprecise or vague nature of the linguistic attributes and at the same time not deal with human reasoning for both qualitative and quantitative attributes as mentioned above. Therefore, a great variation may be observed in terms of percentage relative error in the weightages of attributes regarding accessibility and socio-economic condition. In the proposed method, the attributes were presented to the experts as ordered linguistic terms. All the attributes were described as fuzzy variables defined on the variable domain which is more close to human

Table 4 Attribute-related data for the proposed sites

S. No.	Attribute	Site 1	Site 2
1	Type of road	0.15, district main road	0.850, state highway
2	Distance from collection area (Km)	7.9	13.3
3	Population within 500 m	0–100	0–100
4	Distance to nearest drinking water source	<1000 m	<1000 m
5	Use of the site by nearby residents	Not used	Moderate
6	Distance to nearest building	400 m	200 m
7	Land use/zoning	(Built-up, urban and barren/unculturable/ wastelands, scrublands and agriculture, crop land)	(Built-up, urban and agriculture, crop land)
8	Decrease in property value with respect to distance from where property value get affected	No decrease	1 km
9	Public utility facility within 2 km	Industry, school	Industry, resort and water park, petrol pump and commercial shops
10	Public acceptability	Not accepted	Acceptance with minor suggestions
11	Critical environments	Not a critical environment	Not a critical environment
12	Distance to nearest surface water	Stagnant, 500 m	Stagnant, 500 m
13	Depth of ground water (m) table below ground surface	>0.73	>0.73
14	Contamination (Environmental element already contaminated)	Air	Air
15	Water quality	No fluoride and arsenic contamination	No fluoride and arsenic contamination
16	Air quality	Critical (SO_2 L, NO_2 C and PM10 C)	Critical (SO_2 L, NO_2 C and PM10 C)
17	Soil quality	Organic carbon—low (<0.4%) phosphate—low (45–22 kg/ha) potash low (<180 kg/ha) pH moderately acidic (4.5–5.5)	Organic carbon—low (<0.4%), phosphate—low (45–22 kg/ha), potash low (<180 kg/ha) pH moderately acidic (4.5–5.5)
18	Health	No problem	No problem
19	Job opportunities	<100 workers	<100 workers
20	Odour in terms of distance to nearest habitation	<600 m	<600 m

(continued)

Table 4 (continued)

S. No.	Attribute	Site 1	Site 2
21	Vision (% area visible from nearest habitation)	50–75%	0–25%
22	Waste quantity (ton/day)	220	220
23	Life of site	5 yrs	12 yrs
24	Precipitation effectiveness index	Sub-humid (P-E = 60)	Sub-humid (P-E = 60)
25	Climatic features contributing to air pollution	Temperature inversion during winter	Temperature inversion during winter
26	Soil permeability (based on the % of clay present)	Clay (0–20%)	Clay (0–20%)
27	Depth to bedrock	3–12 m	3–12 m
28	Susceptibility to erosion and run-off (based on soil loss per year)	Moderate (10–15 t/ha/yr)	Moderate (10–15 t/ha/yr)
29	Physical characteristic of rock	Soft-to-medium rock	Soft-to-medium rock
30	Depth of soil layer	Shallow (25–50 cm)	Shallow (25–50 cm)
31	Slope pattern	2–8%	2–8%
32	Seismicity (based on position in seismic zone)	III	III

reasoning. Since in this method, an expert is judging one attribute at a time therefore, the proposed method is flexible enough so that some partial conclusion can be made. At the same time, it is clear that experts gave more weightages to the attributes “distance from collection area” and “public acceptability”. That means experts were concerned not only about environmental sustainability of the sites, but they gave more importance to economic viability and social acceptability of the sites.

The data related to attributes corresponding to the proposed sites are already presented in Table 4. These data were presented to the experts to obtain the sensitivity related to each data.

The calculated sensitivity index of the attributes related to each alternative site proposed for AMC area calculated by using Eqs. 5 and 6 are presented in Table 5. Attribute scores for the two sites along with total scores as determined using Eqs. 7 and 8 are presented in Table 6.

From Table 7, it is clear that the Total Score (TS) for site 1 is 427.734 and site 2 is 400.054. Therefore, site 2 is less sensitive than site 1 and is the best suitable site for AMC area. As per CPCB [4] classification as presented in Table 3, both the sites are moderately suitable for landfilling operation.

Table 5 Crisp and normalized weightages of each attribute

S. No	Attribute	Fuzzy weights			Crisp weightage	Normalized weightage	CPCB weightage	% relative error
		a	*b*	*c*				
1	Type of road	0.300	0.500	0.700	0.500	27	25	10
2	Distance from collection area	0.600	0.800	0.925	0.781	43	35	22
3	Population within 500 m	0.700	0.900	0.950	0.863	47	50	−5
4	Distance to nearest drinking water source	0.700	0.900	0.950	0.863	47	55	−14
5	Use of the site by nearby residents	0.250	0.450	0.650	0.450	25	25	−1
6	Distance to nearest building	0.088	0.250	0.450	0.259	14	15	−5
7	Land use/zoning	0.450	0.650	0.850	0.650	36	35	2
8	Decrease in property value wrt distance	0.088	0.250	0.450	0.259	14	15	−5
9	Public utility facility within 2 km	0.250	0.450	0.650	0.450	25	25	−1
10	Public acceptability	0.650	0.850	0.938	0.822	45	30	50
11	Critical environments	0.650	0.850	0.938	0.822	45	45	0
12	Distance to nearest surface water	0.700	0.900	0.950	0.863	47	55	−14
13	Depth of groundwater	0.700	0.900	0.950	0.863	47	65	−27
14	Contamination	0.500	0.700	0.900	0.700	38	35	10
15	Water quality	0.550	0.750	0.913	0.741	41	40	2
16	Air quality	0.500	0.700	0.900	0.700	38	35	10
17	Soil quality	0.400	0.600	0.800	0.600	33	30	10
18	Health	0.550	0.750	0.913	0.741	41	40	2
19	Job opportunities	0.075	0.200	0.400	0.219	12	20	−40
20	Odour	0.350	0.550	0.750	0.550	30	30	1
21	Vision	0.200	0.400	0.600	0.400	22	20	10

(continued)

Table 5 (continued)

S. No	Attribute	Fuzzy weights			Crisp weightage	Normalized weightage	CPCB weightage	% relative error
		a	*b*	*c*				
22	Waste quantity/day	0.600	0.800	0.925	0.781	43	45	−5
23	Life of site	0.550	0.750	0.913	0.741	41	40	2
24	Precipitation effectiveness index	0.300	0.500	0.700	0.500	27	25	10
25	Climatic features contributing to air pollution	0.100	0.300	0.500	0.300	16	15	10
26	Soil permeability	0.500	0.700	0.900	0.700	38	35	10
27	Depth to bedrock	0.150	0.350	0.550	0.350	19	20	−4
28	Susceptibility to erosion and run-off	0.100	0.300	0.500	0.300	16	15	10
29	Physical characteristic of rock	0.100	0.300	0.500	0.300	16	15	10
30	Depth of soil layer	0.350	0.550	0.750	0.550	30	30	1
31	Slope pattern	0.088	0.250	0.450	0.259	14	15	−5
32	Seismicity	0.150	0.350	0.550	0.350	19	20	−4

Table 6 Crisp sensitivity index of attributes

S. No.	Attribute	Site 1					Site 2				
		E_1	E_2	E_3	E_4	Crisp sensitivity index	E_1	E_2	E_3	E_4	Crisp sensitivity index
1	Type of road	G	G	VG	VP	0.400	G	G	VG	G	0.256
2	Distance from collection area	VG	VG	VG	VG	0.125	VG	G	VG	F	0.263
3	Population within 500 m	G	G	F	G	0.350	G	G	F	G	0.350
4	Distance to nearest drinking water source	G	G	G	G	0.300	G	G	G	G	0.300
5	Use of the site by nearby residents	VG	VG	VG	VG	0.125	F	F	VG	F	0.406
6	Distance to nearest building	F	G	G	F	0.400	VP	P	F	P	0.694
7	Land use/zoning	G	G	G	G	0.300	G	G	G	G	0.300
8	Decrease in property value wrt distance	VG	VG	VG	G	0.169	VG	VG	VG	G	0.169
9	Public utility facility within 2 km	F	F	P	G	0.500	F	F	P	G	0.500
10	Public acceptability	VP	VP	VP	VP	0.875	G	G	VG	G	0.256
11	Critical environments	VG	VG	VG	G	0.169	VG	VG	VG	G	0.169
12	Distance to nearest surface water	P	F	P	G	0.550	P	F	P	G	0.550
13	Depth of groundwater	VP	VP	VP	VP	0.875	VP	VP	VP	VP	0.875
14	Contamination	F	G	G	G	0.350	F	G	G	G	0.350
15	Water quality	P	F	F	P	0.600	P	F	F	P	0.600
16	Air quality	VG	VG	VG	G	0.169	VG	VG	VG	G	0.169
17	Soil quality	G	G	G	G	0.300	G	G	G	G	0.300
18	Health	G	VG	F	G	0.306	G	VG	F	G	0.306
19	Job opportunities	VP	P	F	F	0.644	VP	P	F	F	0.644
20	Odour	F	VG	VG	G	0.263	F	VG	VG	G	0.263

(continued)

Table 6 (continued)

S. No.	Attribute	Site 1					Site 2				
		E_1	E_2	E_3	E_4	Crisp sensitivity index	E_1	E_2	E_3	E_4	Crisp sensitivity index
21	Vision	P	P	P	F	0.650	F	G	F	G	0.400
22	Waste quantity/day	VG	VG	VG	G	0.169	VG	VG	VG	G	0.169
23	Life of site	G	G	G	F	0.350	VG	VG	VG	G	0.169
24	Precipitation effectiveness index	F	G	F	G	0.400	F	G	F	G	0.400
25	Climatic features contributing to air pollution	VP	P	P	P	0.744	VP	P	P	P	0.744
26	Soil permeability	P	P	F	P	0.650	P	P	F	P	0.650
27	Depth to bedrock	F	VP	F	F	0.594	F	VP	F	F	0.594
28	Susceptibility to erosion and run-off	P	P	G	F	0.550	P	P	G	F	0.550
29	Physical characteristic of rock	F	F	F	F	0.500	F	F	F	F	0.500
30	Depth of soil layer	P	F	F	F	0.550	P	F	F	F	0.550
31	Slope pattern	F	F	F	F	0.500	F	F	F	F	0.500
32	Seismicity	VP	P	P	F	0.694	VP	P	P	F	0.694

Table 7 Attribute scores and total scores of alternative sites in AMC area

S. No.	Attribute	Weightage	Site 1		Site 2	
			Crisp sensitivity index	Attribute score	Crisp sensitivity index	Attribute score
1	Type of road	27	0.400	10.974	0.256	7.030
2	Distance from collection area	43	0.125	5.358	0.263	11.253
3	Population within 500 m	47	0.350	16.564	0.350	16.564
4	Distance to nearest drinking water source	47	0.300	14.198	0.300	14.198
5	Use of the site by nearby residents	25	0.125	3.086	0.406	10.031
6	Distance to nearest building	14	0.400	5.693	0.694	9.873
7	Land use/zoning	36	0.300	10.700	0.300	10.700
8	Decrease in property value wrt distance	14	0.169	2.402	0.169	2.402
9	Public utility facility within 2 km	25	0.500	12.346	0.500	12.346
10	Public acceptability	45	0.875	39.459	0.256	11.556
11	Critical environments	45	0.169	7.610	0.169	7.610
12	Distance to nearest surface water	47	0.550	26.029	0.550	26.029
13	Depth of groundwater	47	0.875	41.409	0.875	41.409
14	Contamination	38	0.350	13.443	0.350	13.443
15	Water quality	41	0.600	24.383	0.600	24.383
16	Air quality	38	0.169	6.481	0.169	6.481
17	Soil quality	33	0.300	9.877	0.300	9.877
18	Health	41	0.306	12.445	0.306	12.445
19	Job opportunities	12	0.644	7.727	0.644	7.727
20	Odour	30	0.263	7.922	0.263	7.922
21	Vision	22	0.650	14.266	0.400	8.779
22	Waste quantity/day	43	0.169	7.234	0.169	7.234
23	Life of site	41	0.350	14.223	0.169	6.858
24	Precipitation effectiveness index	27	0.400	10.974	0.400	10.974
25	Climatic features contributing to air pollution	16	0.744	12.243	0.744	12.243

(continued)

Table 7 (continued)

S. No.	Attribute	Weightage	Site 1		Site 2	
			Crisp sensitivity index	Attribute score	Crisp sensitivity index	Attribute score
26	Soil permeability	38	0.650	24.966	0.650	24.966
27	Depth to bedrock	19	0.594	11.403	0.594	11.403
28	Susceptibility to erosion and run-off	16	0.550	9.053	0.550	9.053
29	Physical characteristic of rock	16	0.500	8.230	0.500	8.230
30	Depth of soil layer	30	0.550	16.598	0.550	16.598
31	Slope pattern	14	0.500	7.116	0.500	7.116
32	Seismicity	19	0.694	13.323	0.694	13.323
TS			**427.734**		**400.054**	

4 Conclusions

Landfill site selection is very important for developing countries as there is scarcity of land nearby the urban areas from where majority of solid waste is generated. Selected landfill site must be economically viable, socially acceptable and environmentally sustainable. Several methods are already used for landfill site selection but those methods have limitations in their usage as it is a multicriterion decision-making process and involves crisp as well as linguistic variables as input in decision-making. Not well-established relationship between attribute data and sensitivity index further adds degradation to the performance of those methods. Therefore, in this study a fuzzy-based model was developed to identify a suitable landfill site to incorporate uncertainty associated in specifying various attributes which are often imprecisely defined to the decision makers by the data handler. Sensitivity of the proposed model was validated by the data provided by CPCB [4], and from the percentage relative error analysis, it was found that the model was good fit.

The proposed model was also applied to select suitable landfill site for Asansol Municipal Corporation (AMC) area. Two sites were first selected based on the preliminary constraints like within 2 km from suitable main road, economical travel distance (30 km) from origin of waste and not a floodplain. Applying the proposed model, site 2 was found to be most suitable with total score 400.054 and falling under the category moderately sensitive as defined by CPCB [4].

Though context specific, the proposed model can be easily used as an effective tool by planners and decision makers in the process of initial screening to select a suitable landfill site for long-term operation.

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Biofuels from Indian Lignocellulosic Wastes Through Pyrolysis: A Review with Some Case Studies

Ranjana Chowdhury

Abstract This review presents the current status of the pyrolytic conversion of lignocellulosic waste to biofuels in India. The yields and characteristics of pyro-products from Indian lignocellulosic wastes have been discussed and the challenges in this conversion technology with respect to Indian wastes have been identified. Two case studies—one on catalytic co-pyrolysis and another on environmental analysis pyrolysis plant of waste jute, have been discussed and recommendations have been made.

Keywords Indian lignocellulosic waste · Thermal characterization
Biofuel generation · Pyrolysis · Catalytic and co-pyrolysis

1 Introduction

The issues related to global warming and climate change have raised the arguments for the development of biorefining processes, particularly liquid biofuel production as a substitute for petroleum-derived transportation fuels. Indian government has planned to achieve a target of 20% blending of fossil fuels with ethanol and biodiesel by 2017 [1]. Due to concerns like high food prices, competition of land for food production, acceleration of deforestation, scarcity of water resources, negative impact on biodiversity and so on [2] involved in the first-generation biofuel, the interest in developing second-generation liquid biofuels from nonfood lignocellulosic materials has increased. Lignocellulosic biomass is the only economically sustainable source of carbon for production of renewable liquid fuels or chemicals [3]. However, the effective utilization of lignocellulose is not always practicable due to the recalcitrance of lignocellulose to hydrolysis. Lignocelluloses are mainly

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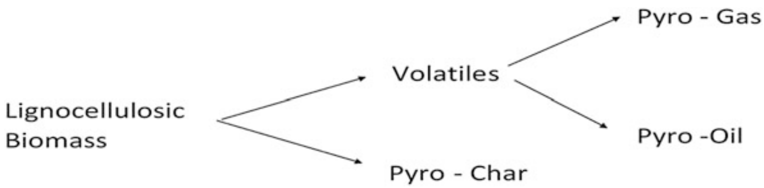
composed of cellulose, hemicellulose and lignin, in addition to a small amount of pectin, starch, ash and extractives. Unlike biochemical processes, the conversion through thermochemical routes is not restricted by the recalcitrance of lignocellulosic feedstocks. The thermochemical processes namely combustion, gasification and pyrolysis can utilize all components of lignocellulosic including lignin. Among all the thermochemical processes, pyrolysis can generate all forms of fuels, namely solid, i.e., pyro-char, liquid, i.e., pyro-oil and gas, i.e., pyro-gas through a single step. The yield of solid, liquid and gaseous products from pyrolysis can be adjusted by the manipulation of pyrolysis temperature. The pyro-oil generated through pyrolysis of lignocellulosic feedstocks is considered as a second-generation biofuel which may be upgraded to be used in automobile sectors as well as for power generation. The pyro-gas can either be used for power generation or can be converted to green liquid fuels through Fischer–Tropsch process. The pyro-char can either be used for power generation or for soil amendment to avoid greenhouse gas (N_2O) emission. Pyrolysis also serves as the precursor process for both combustion and gasification. Understanding the versatility of pyrolysis process to address the challenges of waste management and mitigation of greenhouse gas emission, this article will focus on the review of research studies and the present status of pyrolytic conversion of Indian lignocellulosic wastes to energy sources with special emphasis on the characteristics of Indian wastes being pyrolyzed, the trends and characteristics of pyro-products and the challenges of the process. Two case studies, one on catalytic co-pyrolysis and the other on environmental impact analysis of large pyrolysis plant, based on waste jute, will be discussed to elucidate the ways of mitigation of challenges in this area. Some recommendations will be made based on the overall survey and analysis.

2 Pyrolysis

Pyrolysis can be defined as a thermochemical decomposition of organic matters at elevated temperatures in absence of oxygen or any halogen compounds [4–9]. In the first step, the pyrolyzing feedstock is decomposed to char and volatiles. The condensable part of volatiles is called pyro-oil, and the non-condensable part is called pyro-gas. This reaction step is known as primary pyrolysis. In the second step, the components of pyro-gas react among themselves to generate new products. This reaction step is known as secondary pyrolysis. The reactions of primary and secondary pyrolysis processes may be represented as follows:



(1)

3 Reaction Scheme for Primary Pyrolysis

The secondary pyrolysis reactions are as follows:

$$C + H_2O \leftrightarrow CO + H_2 \tag{2}$$

$$C + CO_2 \leftrightarrow 2CO \tag{3}$$

$$(-CH_2-) + H_2O \leftrightarrow CO + 2H_2 \tag{4}$$

$$(-CH_2-) + CO_2 \leftrightarrow 2CO + H_2 \tag{5}$$

$$CO + H_2O \leftrightarrow CO_2 + H_2 \tag{6}$$

$$CO + 3H_2O \leftrightarrow CH_4 + H_2O \tag{7}$$

According to reaction conditions, the pyrolysis may be categorized as follows: fast, flash and slow pyrolysis [10, 11]. The detailed difference among the three is listed in Table 1.

From the table, it is clear that slow pyrolysis is widely accepted since all the conditions are more widely viable than the others and the product formation is higher than among the others. Fast and flash pyrolysis processes are however followed when the oil yield is to be maximized.

Table 1 Different pyrolysis processes with operating parameters and products

Pyrolysis process	Solid residence time (s)	Heating rate (K/s)	Particle size (mm)	Temp. (K)	Product yield (%)		
					Oil	Char	Gas
Slow	450–550	0.1–1	5–50	550–950	30	35	35
Fast	0.5–10	10–200	<1	850–1250	50	20	30
Flash	<0.5	>1000	<0.2	1050–1300	75	12	13

4 Agricultural Residues in India

The lists of different agricultural residues which are significantly available in India are provided in Table 2 [12].

From the analysis of the table, it is evident that agricultural residue available from rice is at the top of the list, followed by banana, wheat, sugarcane, maize, millets and others including residues from spices, cassava, coconut, cotton, pulses, nuts, coffee, etc. Additionally, about 56% of 159 MT of green bamboo produced in India appear as waste [13]. All these residues belong to lignocellulosic category and are suitable for thermochemical conversion. Although the pseudo-stems of banana plants are suitable for thermochemical conversion, the peels, etc., are more suitable for anaerobic digestion. Hiloidhari et al. [14] have categorized the Indian crop residues as follows: (a) Cereal, namely rice, wheat, maize, bajra, barley, small millet, jowar and ragi; (b) Oilseeds, namely mustard and rapeseed, sesame, linseed, niger, soy bean, safflower, sunflower and groundnut; (c) Pulses, namely all types of gram viz. blackgram, redgram, pigeon peas and lentil; (d) Sugarcane; (e) Horticultural, namely coconut, banana and areca nut and others namely cotton, jute. They estimated that national potential of surplus agro-residues available for bioenergy is 234 MT, which is 34% of the gross quantity of residue of 686 MT. The difference in the data is observed between this estimate and that projected by Muruganan and Gu [12]. The cereals contribute the maximum (89 MT) followed by sugarcane (56 MT), others (47 MT), horticultural (23 MT), oilseeds (14 MT) and pulses (5 MT). The annual national potential of bioenergy is 4.15 EJ from the surplus agro-residues, which is equivalent to 17% of India's total energy consumption. The agricultural residues which are suitable for thermochemical conversion can be processed through pyrolysis.

Table 2 Availability of agricultural residues in India

S. No.	Agro-waste	Quantity (GT/Year)
1	Rice (husk + straw)	246.59
2	Banana (stem, peels, etc.)	240.00
3	Wheat (stalks + pod)	140.40
4	Sugarcane (bagasse + leaves and top)	104.97
5	Maize (stalks and cobs)	42.55
6	Millets (bajra, etc.) (stalks, cobs, husks)	35.07
7	Spices including ginger, garlic, chilly, cumin, coriander, etc. (stalks, sheath, etc.)	15.61
8	Cassava (starch in roots, other wastes)	14.55
9	Coconut (husk, pith, shell)	9.84
10	Cotton (balls + husk)	6.60
11	Pulses including arhar and urad dal (stalks and husks)	0.44
12	Others (areca nut, coffee, etc.) (husks)	0.30

5 Municipal Solid Waste (MSW) in India

There is an obvious relationship between the size of population and the amount of waste generated in a city. Among all Indian cities, the metropolitan area of Kolkata generates the highest volume of MSW of 4.2 million TPY. Overall, the Northern and Eastern India generate the highest (30%) and the least (17%) quantities of MSW, respectively [15]. The composition of MSW of Indian metro cities, Kolkata in particular, is depicted in Fig. 1. It is revealed from Fig. 1 that the major constituent of municipal solid waste is lignocellulosic in nature [16, 17]. The lignocellulosic MSW is mainly composed of food and garden wastes (55%), followed by paper (38%) and textile wastes (7%) [16, 17].

6 Thermochemical Characteristics of Indian Lignocellulosic Agro-Residues and MSW

The elemental analysis with respect to carbon (C), hydrogen (H) and oxygen (O) contents of different Indian lignocellulosic wastes, as available in the literature [18–28], is provided in Table 3 along with their higher heating values.

From the analysis of the table, it is evident that while the values of carbon and hydrogen content of the lignocellulosic residues lie in the range of 36.8–49.8 and 4.7–10.1%, respectively, the content oxygen is as high as 39–55.1%. The higher heating value is distributed over a very narrow range from 14.6 to 22.6 MJ/kg.

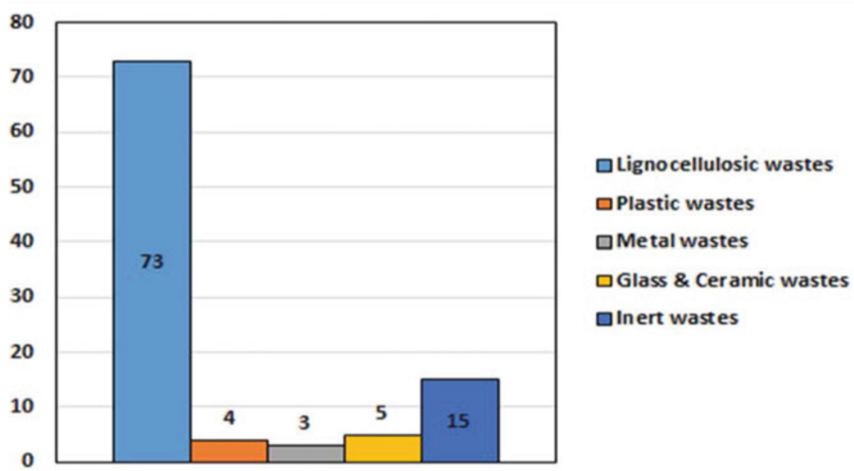


Fig. 1 Composition of MSW in Indian metro city (Kolkata)

Table 3 Properties of Indian lignocellulosic agro-residues and MSW

Properties	Indian lignocellulosic wastes												
	RS	B	BPS	MPC	SOC	SCB	PP	JW	LW	CC	WS	CS	TW
C (%)	43.2	46.9	40.4	40.6	45.2	41.5	36.8	49.8	46.4	47.6	46.6	48.0	40.0
H (%)	5.62	5.85	6.1	6.03	7.6	10.1	5.4	6.0	8.0	5.0	6.1	5.9	4.7
O (%)	48.8	47.0	53.5	46.1	39.3	47.7	42.6	41.4	44.6	44.6	46.6	45.2	55.1
HHV (MJ/kg)	16.0	17.7	15.5	14.6	19.8	16.5	18.0	16.7	22.6	15.6	18.8	19.5	15.0

HHV higher heating value; *RS* rice straw; *B* bamboo; *BPS* banana pseudo-stem; *MPC* mustard press cake; *SOC* sesame oil cake; *SCB* sugarcane bagasse; *PP* printing paper; *JW* jute waste; *LW* lime waste; *CC* Corn cob; *WS* wheat straw; *CS* coconut shell; *TW* textile waste

7 Pyrolysis of Indian Lignocellulosic Wastes

Among the lignocellulosic agro-residues, the pyrolysis of husks, shells bamboo and bagasse has been studied extensively up to the temperature range of 500 °C [12, 18]. On the other hand, pyrolysis of Indian lignocellulosic municipal solid wastes, namely vegetable waste of municipal markets, paper wastes, textile wastes, mustard oil press cake sesame oil cake, lime waste and jute wastes, has been studied by the present group [19–28] in the temperature range of 300–900 °C. In most of the cases, slow pyrolysis has been studied.

8 Reactors Used

Most of the research studies on pyrolysis of Indian lignocellulosic wastes have been performed using packed bed semi-batch reactors under vacuum or N_2 atmosphere [12, 18–28].

9 Product Trends

Pyro-oil yield of up to 60% from the pyrolysis of Indian lignocellulosic agro-wastes has been reported [12]. Maximum and minimum yields of 60.5–13% have been obtained through the pyrolysis of eucalyptus wood and soy bean stalks, respectively. No report is available on the yields of pyro-char and pyro-gas from these wastes. Analyses of yields of different products of pyrolysis of lignocellulosic MSW have been reported by the present group [19–28]. As per these reports, char yield decreases as pyrolysis temperature is raised from 573 to 673 K for all lignocellulosic materials except mustard press cake (MPC) and sesame oilcake (SOC) studied by the present group. Above 673 K, there is no change in the char yield for these materials except printing paper and textile wastes for which the char yield shows a second decline as pyrolysis temperature is raised from 873 to 973 K. For MPC, there is no change in char yield over the feasible pyrolysis temperature range 673–1173 K. Sesame oil cake shows an initial decreasing trend from 673 K onwards and reaches a constant value at 1073 K. The decrease of char yield with increasing pyrolysis temperature may be attributed to an increase in thermal degradation of the solid hydrocarbons in the char. However, the reason behind the occurrence of two declining trends in the plots of textile waste and printing paper is not clear. According to Erta et al. [29] either due to secondary decomposition of the solid product or due to huge amount of primary decomposition of the raw material at higher temperature, the char yield decreases at increased pyrolysis temperature. Partial gasification of the carbonaceous residue is suggested as another reason behind this behavior [30].

Table 4 $T_{max,\ oil}$ for Indian lignocellulosic MSW

Pyrolysis feed	Maximum oil yield	$T_{max,oil}$
Packing paper	54.8	873
Newspaper	42.6	773
Printing paper	35.8	773
Textile waste	60.2	773
Mustard press cake	46.4	973
Sesame oil cake	43.8	873
Jute waste	25.0	973
Lime waste	31.0	873

In case of pyro-oil yield, there is an increasing trend up to a certain temperature beyond which there is a declining trend. The values of the temperature $T_{max,oil}$ corresponding to the attainment of maximum oil yield are different for different feedstocks. These are provided in Table 4 [31].

From the table, it is evident that for most of the lignocellulosic MSW, the maximum yield of pyro-oil is achieved at 773 K. Similar trends of oil yield have been observed by many others researchers namely Phan et al. [32], Yang et al. [33], Bhuiyan et al. [34] and Volli and Singh [35] in case of pyrolysis of cardboard, newspaper, textile waste, mustard press cake, sesame oil cake and wood wastes, respectively. In different research studies, it has been claimed that the reason behind the declining trend of oil yield at higher pyrolysis temperatures is due to secondary decomposition of volatiles above 773 K [36, 37]. The gas yield increases gradually with increase in temperature. It is observed that there is an increasing trend of gaseous products right from the minimum feasible pyrolysis temperature. This may be due to the secondary cracking of the pyrolysis vapors at higher temperature

10 Pyrolysis Kinetics

The lumped kinetics of pyrolysis of different Indian lignocellulosic MSW, namely vegetable waste of municipal markets, paper wastes, textile wastes, mustard oil press cake and sesame oil cake, lime waste and jute wastes, have been reported [19–28]. According to lumped kinetic scheme, the pyrolyzing MSW is assumed to be converted instantaneously to active complex which, in turn, is decomposed to volatiles and char. Both the decomposition of the feedstocks and generation of volatiles and char follow first-order kinetics.

11 Characteristics of Pyro-Oil

The contents of carbon, hydrogen and oxygen of the pyro-oil from different Indian lignocellulosic wastes are provided in Table 5 [18–28].

Table 5 Properties of pyro-oil from Indian lignocellulosic agro-residues and MSW

Properties	Indian lignocellulosic wastes									
	T	RSB	B	MPC	SOC	NP	PP	JW	LW	TW
		>773 K	>773 K	673–	673–	573–	573–	573–	573–	573–
		1173 K	1173 K	1173 K	1173 K	1173 K	1173 K	1173 K		
C (%)		41.0	35.0	48.8–54	59.2–35.8	20.0–30.0	25.0–26.0	65.0–49.0	67.0–45.0	63.0–62.0
H (%)		2.4	1.8	9.0–6.0	9.2–8.5	4–1	8.0–8.3	10.0	10.0	3.2
O (%)		56.0	61.5	32.0	21.9–9.6	64.0–66.0	65.0	10.0–40.0	10.0–35.0	33.4

From the analysis of the table, it is evident that while the carbon content of pyro-oil from all Indian lignocellulosic waste, as reported in the literature, lies in the range of 20–67%, the values of hydrogen and oxygen content are, respectively, in the ranges of 1.8–10 and 10–66%. According to the reported observations, for most of the lignocellulosic MSW, except textile waste, carbon content of pyro-oil decreases with pyrolysis temperature. The hydrogen content is almost insensitive to pyrolysis temperature. From the analysis of the data, it appears that while for most of the wastes, the oxygen content of pyro-oil is invariant with temperature, for jute and lime waste the oxygen content increases with the increase in pyrolysis temperature. For sesame oil cake, the oxygen content decreases with the increase with pyrolysis temperature. The higher heating values of pyro-oil obtained from rice husk and bamboo waste at pyrolysis temperature >773 K are 18.6 and 17.4 MJ/kg. The higher heating values of pyro-oil obtained using jute and wastes vary from 35–17 to 35–17 MJ/kg as the pyrolysis temperature is varied in the range of 573–1173 K. For different Indian lignocellulosic MSW, the patterns of dependence of higher heating values of pyro-oil on pyrolysis temperature are depicted in Fig. 2.

From Fig. 2, it is clear that there is a decreasing trend of heating values with temperature. Overall the heating values of pyro-oil obtained from lignocellulosic MSW lie in the range 17–32 MJ/kg. As observed by researchers, pyro-oil obtained from Indian lignocellulosic wastes contains alcohols, aromatic hydrocarbons, esters, alkyl phenols, oxy phenols, furan, carboxylic acids, ketones, aldehydes which are suggested to be formed through depolymerization and fragmentation of cellulose, hemicellulose and lignin.

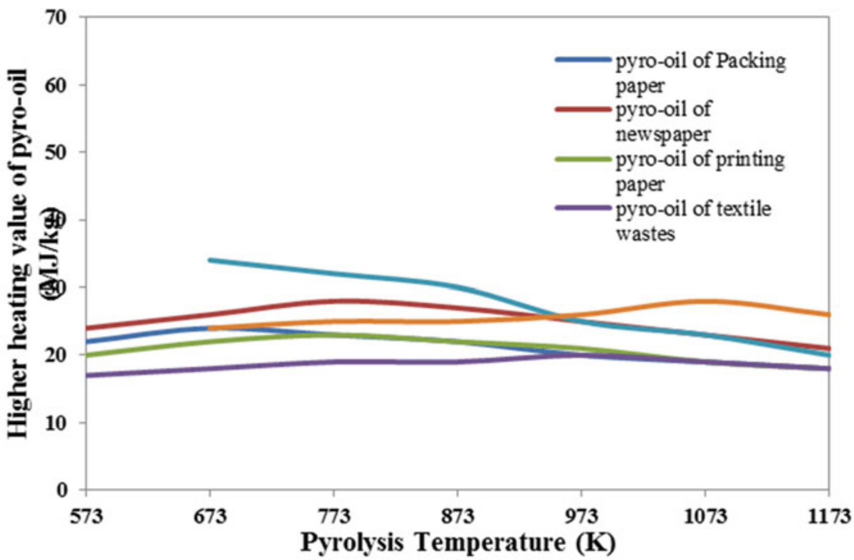


Fig. 2 Dependence of higher heating values of pyro-oil on pyrolysis temperature

12 Characteristics of Pyro-Char

From the studies on pyrolysis of Indian lignocellulosic MSW [19–28], the values of carbon and oxygen content, respectively, increase and decrease with the increase with pyrolysis temperature. As a consequence, there is, in general, an increasing trend of heating value of pyro-char, obtained from all lignocellulosic MSW, with pyrolysis temperature.

13 Characteristics of Pyro-Gas

The gas chromatographic analyses of pyro-gas obtained from pyrolysis of sesame oil cake, jute waste and lime waste of Indian origin have been performed. In all cases, the main constituents are CO, CH_4, H_2 and CO_2.

14 Catalytic Pyrolysis

Only one study [28] has been reported on the effect of catalysts on the pyrolysis of Indian lignocellulosic wastes. Alumina has been reported to be the best catalyst for the pyrolysis of jute waste. The activation energy of jute pyrolysis reduces from 9.15 to 3.5 kJ/mol in presence of 10% (w/w) alumina with respect to the quantity of jute being pyrolyzed. There is an overall increase of yield and decrease of oxygen content of pyro-oil obtained from Indian jute waste in presence of alumina.

15 Co-Pyrolysis

Co-pyrolysis of mustard press cake [27] and Indian paper wastes have been performed by the present group. The bio-oil yield has been optimized through response surface analysis using the ratio between paper waste and mustard press cake as parameters. The following equation has been reported:

$$\begin{aligned}\text{Energy Yield}(\%) = {} & +51.72 + 0.77 * A - 10.21 * B - 0.88 * A * B + 2.50 * A^2 \\ & - 15.40 * B^2\end{aligned}$$

where A is the ratio of PW to MPC, and B is the pyrolysis temperature (K).

$$\text{EY}(\%) = \text{POY} * \frac{\text{HHV}_{\text{PO}}}{\text{HHV}_{\text{MSW}}}$$

EY Energy yield;
POY Fractional yield of pyro-oil;
HHV_{PO} Higher heating value of pyro-oil;
HHV_{MSW} Higher heating value of pyrolyzing MSW.

The maximum energy yield of 56.51% has been reported at temperature of 812 K and paper waste to MPC ratio of 8.80:1.

16 Challenges

The reported results on research studies on pyrolysis of Indian lignocellulosic wastes reveal that although pyrolysis is an attractive route for the generation of biofuels from Indian lignocellulosic wastes, there exist a few burning challenges which need research attention. These are: (a) high oxygen content of pyro-oil; (b) scale-up of small-scale pyrolysis unit based on laboratory data; (c) necessity for the development of knowledge base on catalytic co-pyrolysis to handle different types of waste materials together; (d) investigation on pretreatment processes for the upgradation of quality of pyro-products; (e) necessity for the assessment of environmental impact of large pyrolysis plants.

17 Case Studies

In view of the challenges still remaining in the field of pyrolysis of Indian lignocellulosic wastes, results of two studies conducted by the present group appear encouraging.

17.1 Case 1: Catalytic Co-pyrolysis of Jute Waste and Sesame Oil Cake

Method: Jute waste and sesame oil cake were co-pyrolyzedia a semi-batch pyrolyzer in the temperature range of 573–1173 K. Alumina, ZnO, KCl, NaCl and sodium aluminosilicate were used as catalysts.

Result: Results on the effect of catalysts on the pyro-oil yield at different pyrolysis temperature are shown in Fig. 3. Alumina shows the highest catalytic effect and there is a large increase in the pyro-oil yield in presence of alumina, particularly up to 773 K. Thus, the catalytic pyrolysis can be followed to improve the performance of energy generation from the mixed feed of jute waste and sesame oil cake.

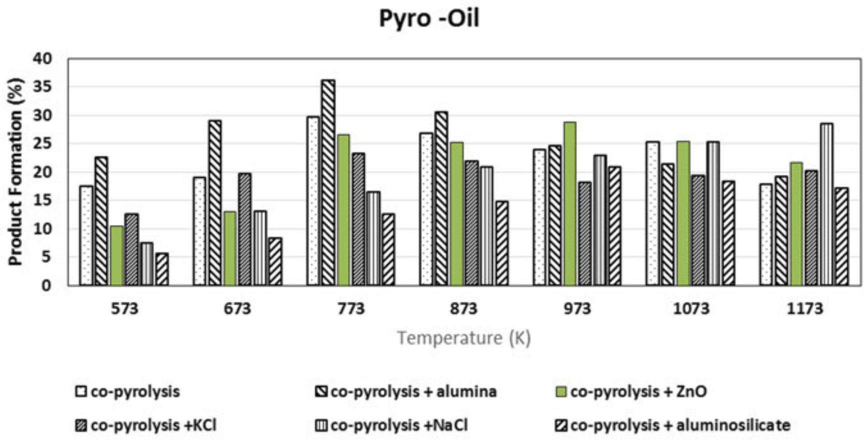


Fig. 3 Effect of catalysts on the pyro-oil yield

18 Environmental Analysis of a Large Pyrolysis Plant Based on Jute Waste

Environmental analysis of a 100 tpd jute waste pyrolysis plant was performed based on the kinetic data generated in the laboratory scale. Aspen Plus® was used for the modeling. A scheme for the utilization of pyro-products was as follows: (a) Utilization of Pyro-gas and a fraction of pyro-char for the substitution of energy needed for drying and pyrolysis; (b) Utilization of residual fraction of Pyro-char for amendment of soil of an agricultural field situated at 20 km from the pyrolysis plant, (c) Utilization of pyro-oil in a power plant using combined heat and power cycle. Total avoidance of CO_2 is possible due to (1) utilization of char and gas for the supply of energy for pyrolysis and drying and thereby replacing grid electricity which is generated in coal-based power plants in India, (2) replacement of diesel oil in the power plant by pyro-oil and (3) reduction of N_2O (Equivalent CO_2) emission by the replacement of nitrogen-based fertilizer by pyro-char. Conversely, the emission of CO_2 caused by transportation of pyro-oil and pyro-char from the pyrolysis plant to the power plant and agricultural field, respectively, has been debited.

Avoidance of $CO_{2,}$ A CO_2 has been correlated to pyrolysis temperature (T) and fraction (f) of pyro-char deposited in agricultural field and has been maximized with respect to these factors using response surface methodology. The maximum value of A_{CO2} of 1081 g/kWh has been obtained at T = 590 °C and f = 0.25.

19 Recommendations

From the review, it is clear that although research studies are being conducted on slow pyrolysis of Indian lignocellulosic wastes, more knowledge base should be developed. The pyrolysis of agricultural residues should be studied more thoroughly. More emphasis should be given to solutions for the identified challenges faced by the process. The scale-up exercise and environmental analysis should be started for more feedstocks using process simulation software.

20 Conclusions

The article has dealt with the research findings on pyrolysis of different Indian lignocellulosic feedstocks, both agricultural and municipal wastes. Detailed analysis of thermochemical characteristics of different feedstocks has been made. Trends of yield of different pyro-products along with their characteristics have been discussed. Finally, challenges of this process have been identified and some recommendations have been made highlighting some encouraging results on two case studies on catalytic co-pyrolysis and environment analysis from the perspective of avoidance of CO_2. The recommendations may be useful for commercial utilization of pyrolysis process for the valorization of Indian lignocellulosic wastes for the generation of second-generation biofuels.

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Improvement of Solid Waste Management Code of Practice Development Through Effective Public Consultation

S. T. El Sheltawy, Nisreen Boghdady and M. M. K. Fouad

Abstract As society continues to demand for clean environment and municipal solid waste is produced and accumulated due to industrial development and human activities, severe ecological contamination will result unless a MSW code of practice is developed and applied. In this context, many challenges will be encountered unless effective public participation without enforcement is realized. Stakeholders' responsibility will be defined, and awareness program and alternative regimes were studied. Structured interview and public consultation were designed and analyzed. It was found that users must recognize the limitations and risks of adopting less representative management regimes and of applying uncontrolled MSWM system. Benefits of public participation in design, implementation, and review of MSWM code of practice are summarized to meet specific objectives and to gain a better understanding of the MSW hierarchy.

Keywords MSWM · Public consultation · Code of practice

1 Introduction

Municipal solid waste management (MSWM) has undergone rapid development in recent decades. In most cases, the development has resulted in waste management with optimum sustainability applying the four well-known pillars: environmental, social, economic, and culture elements.

In Egypt, the development can be attributed to a large extent to new national policy instruments such as laws, regulations, code of practice, responsible ministries, and authorities. From the perspective of local decision makers, the main problem in this context is the public responsibility which may be developed through

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public consultation and disclosure plan (PCDP) reported by the International Finance Corporation (IFC) [5].

The purpose of PCDP is to ensure that any activity affected people and other interested parties are provided with clear information about this activity and are given opportunities to provide feedback and make suggestions as to how the implementation of this activity could reduce adverse impacts or otherwise be improved by minimizing social risk.

1.1 Social Baseline

History of Egypt dates back to 3000 BC. Egyptian modern history goes back to 1801 when Mohamed Ali Basha was declared as the first Wali of Egypt. Till 1952 revolution, Egypt was under royal rule after which it turned to Republican rule. Recently, Egypt has undergone two revolutions, 25th January 2011 followed by 30th June 2013 declaring Egypt as a democratic state confirming the role of citizens as a base of democratic verification.

This historical background in addition to international requirements has enforced social participation as the foundation on which all development must depend.

Open houses and public meetings have been centered on the democracy trends and are typically conducted confidentially to cope with stakeholder requirements [6].

1.2 Social Responsibility (SR) and Municipal Solid Waste Management System (MSWMS) Link

The main underlying link between SR and MSWMS is the environmental issues which may be regulated with policy, regulations, laws, and codes of practice. This link may be summarized through measuring of MSWM code challenges and opportunities, benefits, enforcement, and SR may be clarified waste-wise by different producer's responsibility scenarios and Pay-As-You-Throw (PAYT) programs.

According to stakeholder consultation guidelines [2], public consultation should not be considered as procedural step or as a tool to validate the depth of the MSWM code but rather as an opportunity to collect external views—including critical ones—for code development, to measure expectations and identify alternatives. Any issue of concern identified in the consultation phase can help shape the proposal during the early code preparation phase when changes may still be easier to make.

Public consultation cycle may be summarized in Fig. 1.

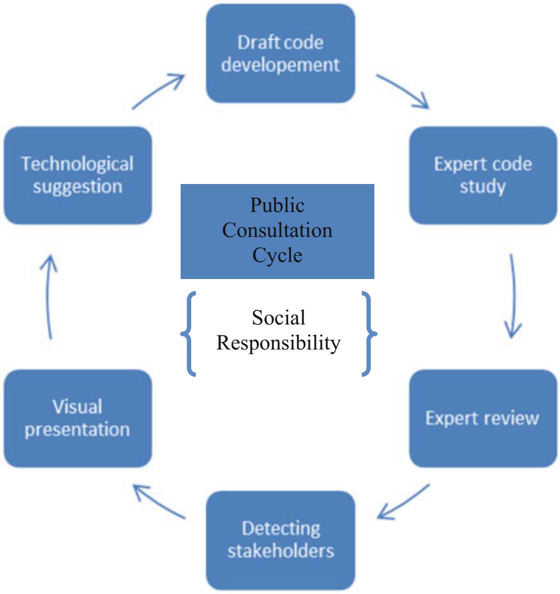

Fig. 1 MSWM public consultation cycle and social responsibility

1.3 Initial Primary Data Collection

The initial social survey is performed during draft development of the MSWM code of practice and was based on particular objectives, including:

- Identifying different types of stakeholders and their various interests.
- Initiating a dialogue with key stakeholders.
- Identifying key social issues concerning MSWM code implementation.
- Informing methodology development for the full social responsibility and participation in MSWM.
- Understanding how the most vulnerable groups can benefit from the positive social impacts of a controlled MSWMS implementation.
- Understanding how negative social approach can be avoided or mitigated with development of a MSWM code for maximizing positive benefits through PCD.

2 Methodology

The PCDP seeks to define a technically, socially, and culturally appropriate approach to consultation and disclosure. Stakeholder consultation must be ongoing during planning and implementation of any MSWM activity.

2.1 Tools Used

The tools used for public consultation and disclosure phase are:

- In-depth interview.
- Structural interview.
- Group discussion.
- Public hearing.

The national and regional authorities, community leaders, and main concerned authorities were selected to form a consortium for an Egyptian MSWM code.

More than 100 meetings were organized weekly from July 2012 to January 2016 after which the draft was ready to be disclosed and presented to the public.

2.2 Consultation Procedure

2.2.1 Preparation of Handouts

The first step of consultation organization was the preparation of handout documents composed of: workshop program, presentation materials, and attendance roll.

2.2.2 PCD Announcement

The public consultation workshop was open to the public. A large announcement poster was placed in the front of the National Center for Housing, where the event was held, to announce the event to the public. In addition, the code scientific committee members and the supporting teams have mailed a soft copy of the code draft to all stakeholders, ministers, and managers concerned with MSWM as well as service providers "Zabaleen," at the national, regional, and local levels, one month before the workshop. One day before the consultation, reminders were made by phone.

2.2.3 PCD Structure and Consultation Process

Consultation process was performed according to the steps illustrated in Fig. 2.

During the PCD, each participant has received written information documents as well as a note paper. The consultation was carried out through three sessions as shown in Fig. 2. The first part consisted of presentations related to the 11 chapters of the MSWM code of practice with an estimated time of 40 min. The second part consisted of a socioeconomic analysis conducted by the social consultant with an estimated time of 15 min. The third part consisted of interaction with the

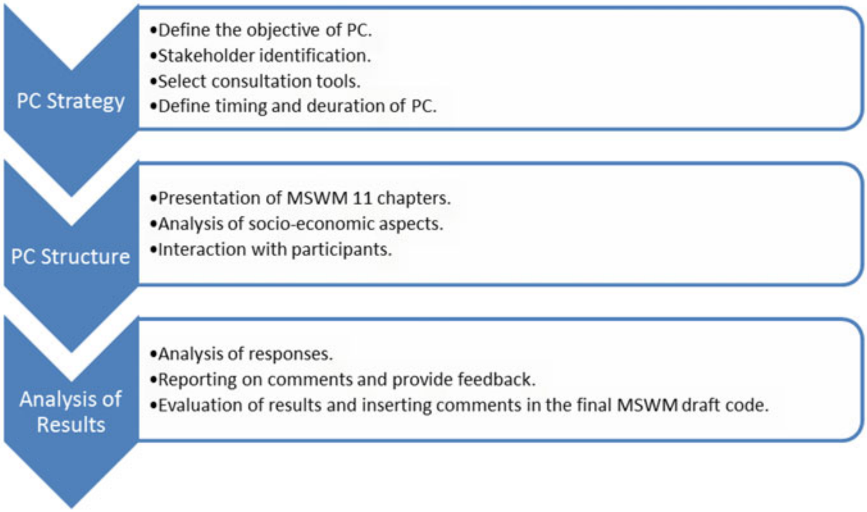

Fig. 2 Public consultation (PC) process steps

participants of the workshop by a question and answer session and the opportunity for opinion to be expressed. The duration of this session was estimated to be 2 h.

After termination of the workshop, a feedback response must take place to answer for participant's opinion.

3 Results and Discussion

Community input into the preparation of the MSWM code draft report is essential to its success. At each phase in the process, there will be an opportunity for input into the report, in order to help ensure that the code is reflective of the existing characteristics of the community while looking forward to the future of MSWM system.

As previously mentioned, many tools were designed to accommodate the Egyptian Society. Speeches and meetings were organized with high rank and trustful stakeholders and leaders. The most effective tool was the public consultation workshop held at the Center for Housing Research on March 22, 2016, and scheduled according to item 2.2.3.

3.1 Stakeholders Attendance

Any project must be initiated with stakeholders' seminars and consultation, and a standard list of participants relevant to MSWM were selected [1]. Table 1 illustrates

Table 1 Classification of stakeholders according to the field of interest

Stakeholder group	Field of interest	No. of participants	% of attendance
G 1	Policy makers and scientific committee	17	14
G 2	Recruiting collectors	5	4
G 3	Paying for the service	14	12
G 4	Service providers	8	7
G 5	Research centers and universities	19	16
G 6	New cities environmental affairs	23	19
G 7	Private sector and experts	5	4
G 8	NGO	5	4
G 9	Government department	12	10
G 10	Others	12	10
Total		120	100

a summary of attendance for the PC workshop (March 22, 2016), and Fig. 3 shows the composition of stakeholders attending to the PC workshop.

3.2 PCD Techniques

As reported in EPA (1990) [3], public involvement was conducted as two-way communication that involves both presentation of the 11 chapters of the MSWM

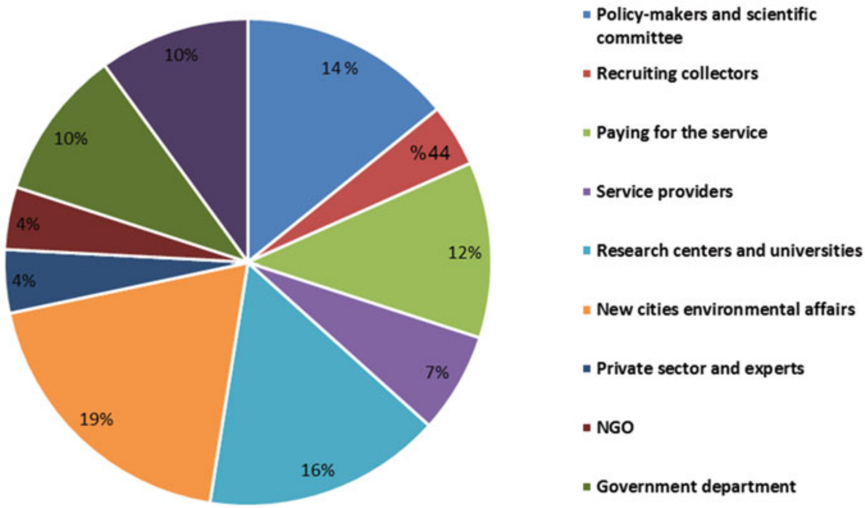

Fig. 3 Stakeholders attending the consultation

code draft to the public and getting back from the public ideas, issues, and decision. This process was realized through disclosure, listening, and collaborative techniques.

Below is a brief description of techniques used in public involvement and their circumstances.

3.2.1 Stakeholders Participation in the PC Workshop

According to WELL Study (1999) [7], the stakeholders are analyzed by taking into account those groups who may directly or indirectly be affected by the MSWM code both positively or negatively. The workshop has begun with an introductory speech from the committee chain followed by experts' presentation for the 11 code chapters.

The event covered a lot of topics, and input was requested on the draft guiding principles.

A number of questions were answered in situ during the workshop. The first question was related to the neglection of the hazardous waste followed by question related to the time necessary for code implementation, many suggestions were about pollutant pay principle, and limited concerns are about environmental aspects of the management steps and monitoring of the process.

Participation rates decreased as the time proceeds, so it was found to be important to ensure that the participation instrument is of a reasonable length.

Debriefing was found to be helpful in the workshop, and it was appropriate to ask participants to write their suggestion and what they thought of the disclosure instrument on a distributed paper note, and all responses and reply will be modified.

The answers to specific questions were used to update later versions of MSWM code of practice.

3.2.2 PCD Participants' Reflections on MSWM Code

The highest level of public involvement is to give the public a recorded role in making the code draft revision and share in decision making.

Next to public consultation workshop, the technique used was collaborative technique through received reporting suggestions and comments from participants and responses of advisory groups about these comments. Figure 4 illustrates the number of participants collaborating in the work.

Table 2 summarizes some of the topics raised in written form during public participation and disclosure workshop and committee responses. Many advisory groups undertake the raised topics through steering committee of elected members. These groups have proposed and mailed responses to participants as illustrated in Table 2.

Finally, a group composed of leaders of all the interested groups was set up to post the final version of the Egyptian MSWM code of practice for board's approval.

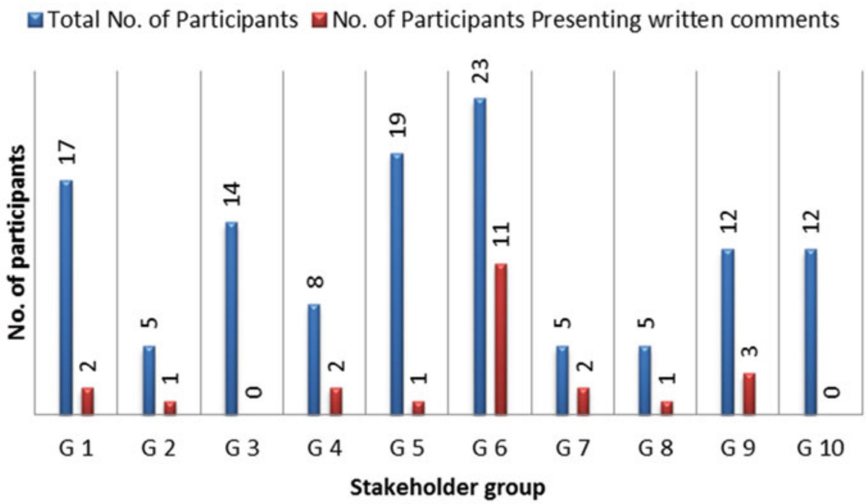

Fig. 4 Participants presenting written comments

Table 2 Topics raised during the PCD workshop

Key topic	Stakeholder group that raised the topic	Specific aspects and reflections	Committee response
Insights regarding the code	G 1	• Adding maps to baseline and actual dates as well as earthquakes history	• Done
	G 5	• Adding workshop to intermediate states	• Done
	G 6	• Wording replacements	• Done
	G 9	• Minimum cleaning standards excluding washing	• Done
		• Needs specific rates	• Difficult to apply
	G 4	• Why other wastes are neglected	• According to government requirement
		• Define legal responsibility	• Out of scope
	G 9	• Need of average generation rates	• Varies with demographic status
	G 5	• Adding some definitions	• Done
		• Adding notes of rainfall in landfill design	• This is included in other codes
	G 7	• Re-naming of MSWM code	• This was named according to ministerial decree
	G 6	• Needs for rewarding specially for management responsibility	• Done

(continued)

Table 2 (continued)

Key topic	Stakeholder group that raised the topic	Specific aspects and reflections	Committee response
Utilization success	G 1	• Needs of checklist	• Responsibility of EEAA
		• Landfill closure schedule	• Other codes
	G 6	• Needs more amendments of law 4/1994 before implementation	• This will be given as recommendation
	G 8	• Taking into account social aspects and training requirement as well as awareness raising	• Done
	G 4	• Performing annual social survey with predesigned questionnaire of check success	• Recommended and done
	G 2	• Importance of inspection	• Done
Outcome success	G 9	• Adding more experts to the committee	• This will be recommended for phase II
	G 6	• Increasing awareness upraising and monitoring success	• Recommended
	G 4	• Revising cleaning rate	• Done
	G 7	• Continuous public consultation	• Done
Analytical approach	G 1 G 6	• Requirement of EIA before implementation	• Done • EEAA responsibility
		• Use of alternatives and selecting the best available option	• Done • Out of the scope
		• Analysis of service provider specification	• See SWM department at EEAA
	G 7	• Use of service management instead of waste management	• This is the responsibility of EEAA
		• Develop a new strategy	

3.2.3 Authors' Reflections on MSWM Code Implementation

The authors have concluded some key principles concerning social participation in MSWM code implementation. These principles are in conformity with IFC guidelines (2007) [4] and suitably modify to align with the cultural specifications of the selected activity and area according to EU principles [2].

These principles are:

- All stakeholders must be consulted in a two-way method.
- Consultations should be continuous processes.
- There must be specific and transparent mechanisms concerning the implementation of the MSWM code of practice to continuously improve the service.

4 Conclusion Remarks

Public Consultation Disclosure Plan (PCDP) continues to be a high priority for communities in the twenty-first century. The consultation process for the MSWM code implementation had a positive perception by all stakeholder groups. The public expressed the wish that all MSWM activities are carried out in the same way of social consultation and study, with a transparent information dissemination with respect to the activity to be developed before the beginning of any implementation step. The PCD workshop has proven particularly effective in resolving issues. The workshop was very interactive, and the stakeholders showed special interest since their recommendations were instantaneously verified, especially concerning tolerance, cost and quality of disposal facilities as well as environmental issues. The topics addressed by the population are directly related to "pollutant pay" issue. Collection rate, disposal sites, and segregation approaches are the topics causing the most expectations within the population since they imply a solution for one of the main social problems.

The PCD performed here is not going to be of academic quality, but is useful for policy making. However, any efforts to demonstrate the validity of the code will justify public opinion with greater confidence showing the reasoning of respondents.

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Characterization of Municipal Solid Wastes from Lagos Metropolis, Nigeria

O. M. Ojowuro, B. Olowe and A. S. Aremu

Abstract This study examines the characteristics of solid waste from different parts of Lagos metropolis, southwestern Nigeria. Solid wastes from the four main disposal facilities in Lagos State were sampled and analyzed. Samples were taken from trucks mainly operated by Private Sector Participation contractors so as to stratify the wastes according to land use type, population density, and income. A total of 286 samples, each weighing 90 kg were stratified into ten material classes and weight recorded. The results of the study show slight disparity in all the solid wastes samples sorted by land use type, population density, and income level. In all solid wastes from residential land use types contain mainly organics (33.06–46.25%), plastics (12.73–20.7%), paper (4.61–10.3%), and textiles (1.66–12.33%). On the other hand, solid wastes from commercial land use types are composed majorly of 29% plastics, 22% organics, and 14% each of paper and textiles. Source separation of these wastes is recommended, and technologies for resource and energy recovery are required for sustainable solid waste management in Lagos State.

Keywords Municipal solid waste · Components · Lagos State Nigeria

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1 Introduction

Solid waste is a non-liquid, non-gaseous material which is no longer of use or unwanted by the owner. It consists of discards such as food wastes, plastics, paper, wood, glass, textiles, cans, and other miscellaneous unwanted items. Municipal solid waste (MSW) is an embodiment of all forms of solid waste dumped in municipal receptacles and the responsibility of collection and disposal falls on the government, city or local authorities, or an appointed organization/agency. MSW originates from households (apartments, estates, compounds, and multi-storey buildings), commercial areas (markets, business complexes, hotels, and motor parks), institutions (schools, jailhouses, recreational centers, hospitals and government offices, or establishments), industries and municipal services such as street sweepings, litter pickup, and drainage debris evacuation. Municipal solid wastes in developing countries are highly heterogeneous in terms of composition with 55–80% generated from households, 10–30% from commercial or market areas while the rest are from streets, industries, and institutions [1].

There is an apparent unevenness in the generation rates and composition of solid wastes across the globe, even within a given neighborhood. Solid waste composition is influenced by several factors such as area (i.e., residential, commercial), geographical location, standard of living (income level), culture, energy source, and season/weather [2, 3]. Land use (area) and income level tend to prevail over other factors. Residential land use types generate wastes as a result of household activities such as food preparation, unwrapping, sanitation, gardening, and food/beverage consumption. Commercial waste is heterogeneous in itself, and it is related to the kind of commercial activity such as trading in goods or products, small-scale manufacturing, and provision of professional services.

Income plays a significant role in solid waste composition as constituents of solid waste may even vary within the same country or city because of income disparity. The World Bank Atlas classification system classifies the economy of countries with low income, lower middle income, upper middle income, and higher income based on Gross National Income per capita. According to the World Bank [4], MSW from low-income countries is mainly organic in nature consisting of food scraps, yard waste, wood, and process residues while MSW from high-income countries consists mainly of paper, plastics, and other inorganic materials. This is also relevant within a classified country as wealthier individuals consume more packaged products resulting in a higher percentage of inorganic materials in the waste stream [5].

Information on the composition of solid wastes is important in management programs/plans and determining equipment needs [6]. The in-depth knowledge of MSW composition is an insight for policy change in most instances, i.e., moving from landfill-based to resource-based waste management systems [7]. An accurate knowledge of the quantity and composition of the waste input is equally essential to the success of a resource recovery project as quantity and quality of the input must be assured [8]. It is observed that higher volumes of waste and a changing composition have a profound impact on solid waste management practices thereby necessitating policy changes in developing countries [5]. Also, solid wastes composed of high inorganic materials could have a significant impact on human health and the environment. Hence, the composition of solid waste at any particular time may influence several decisions in solid waste management. The aim of this study is therefore to determine the characteristics of solid waste from different parts of Lagos metropolis, southwestern Nigeria.

2 Methodology

2.1 Study Area

The study area, Lagos is a megacity located in the southwestern part of Nigeria. Lagos is Nigeria's economic focal point with Gross Domestic Product of about $131 billion. It lies between latitude 6° 34′ 60″N and longitude 3° 19′ 59″E along the West African coast and covers a total area of 3,475.1 km^2. It was the administrative capital of Nigeria for a long time before the capital was moved to Abuja in 1991. Lagos State is subdivided into twenty administrative Local Government Areas, and its 2015 population is in excess of 23 million [9]. The city has also been distinguished as the nation's commercial nerve center with 65% of the nation's commercial activities, over 2,000 industries and having two of the nation's largest seaports for import and export activities [10].

It is estimated that about 13,000 metric tonnes of solid waste is generated daily in Lagos State from various human activities. The Lagos State Waste Management Agency (LAWMA) has been in existence since 1991, and the agency is responsible for solid waste storage, collection, disposal, and management of landfills in Lagos State. The agency is also responsible for sanitation of major highways and street sweeping activities, monitoring of contractors' (Private Sector Participants) activities, and establishment of performance standards on waste management activities in Lagos State. The inclusion of private waste collectors under the Private Sector Participant (PSP) scheme has tremendously improved solid waste collection within the megacity. Therefore, there is the need to characterize solid wastes coming from different parts of the city so as to obtain baseline information for its efficient management.

2.2 Method

In line with the aim of this research, identification of specific characteristics of waste generated in waste sector make it a different sample of the waste stream. Waste can be separated into two major land use types:

1. Residential—waste collected mainly by both private haulers called Private Sector Participants (PSP) and LAWMA from residences across the state. These wastes are primarily collected by skip trucks, double and single dino trucks, trailer trucks, open-back trucks, and mammoth compactors.
2. Commercial and Institutional—waste generated by businesses, government/education institutions, markets, and motor parks. These wastes are collected by a variety of vehicles including those described above.

Solid wastes with similar characteristics were identified by similarities in population density and economic characteristics. The metropolis was divided into six subsectors based on these two criteria. The sampling areas and the corresponding Local Government Area (LGA)/Local Council Development Area (LCDA) are listed in Table 1.

Industry standard formed the basis for our sampling method, while for the sampling size, D5231 was chosen as the standard.

Field officers were used in the selection of samples from trucks arriving at the dumpsite. Waste disposal trucks were randomly selected, and samples were gotten from the tipped waste at designated points.

A total of 286 samples were obtained from PSP collected solid wastes at the four existing solid waste disposal facilities in Lagos State. The samples consisted of approximately 90 kg of waste and were then sorted into ten material classes; Paper, plastics, glass, metals, organics, construction and demolition wastes, inorganic, and textiles. Materials within these ten fundamental classes were further split into 87 individual material groups:

(a) Paper—Newsprint, High-grade Office Paper, Magazines, Uncoated OCC/Kraft, Boxboard, Mixed Paper—Recyclable, Compostable Paper, Other Paper;
(b) Boxboard—Cardboard boxes, Package boxes;
(c) Plastics—Pet Containers and Packaging, HDPE Bottles and Packaging, Expanded Polystyrene Packaging (EPS), All Other Rigid Plastic Products, Trash Bags, Commercial and Industrial Film, Other Film, Remainder/Composite Plastic;
(d) Glass—Recyclable Glass Bottles And Jars, Flat Glass, Other Glass;

Table 1 Density income and locations within the study area

Category	LGA/LCDA	Specific location
High density, low income (HDLI)	Ajeromi, Ebute Metta	Ajegunle, Otto
Low density, high income (LDHI)	Ikoyi Obalende, Iru Victoria Island	Ikoyi, Lekki, VI
Medium density, high income (MDHI)	Ikeja, Kosofe, Oshodi Isolo	Ikeja GRA, Ogudu GRA, Ajao Estate
Medium density, low income (MDLI)	Alimosho, Lagos Mainland	Alimosho, Ebute Metta
Low density, low income	Imota, Ikorodu North, Epe	Imota, Isiu, Agbowa, Epe

(e) Metals—Can, Other Aluminum, HVAC Ducting, Ferrous Containers (Tin Cans), Other Ferrous, Other Non-Ferrous, Other Metal;
(f) Organics—Yard Waste (Compostable), Food Scraps, Bottom Fines And Dirt, Diapers, Other Organic;
(g) Construction and Demolition (C&D)—Clean Dimensional Lumber, Clean Engineered Wood, Wood Pallets, Painted Wood, Treated Wood, Concrete, Reinforced Concrete, Asphalt Paving, Rock and Other Aggregates, Bricks, Gypsum Board, Composition Shingles, Other Roofing, Plastic C&D Materials, Ceramics/Porcelain, Other C&D;
(h) Inorganic—Televisions, Computer Monitors, Computer Equipment/ Peripherals, Electronic Equipment, All types of batteries, Fluorescent Lights/ Ballasts;
(i) Household Hazardous Waste (HHW)—Latex Paint, Oil Paint, Plant/Organism/ Pest Control/Growth, Used Oil/Filters, Other Automotive Fluids, Mercury-Containing Items, Sharps and Infectious Waste, Ash, Sludge, and Other Industrial Processed Wastes, Sewage Solids; and
(j) Textiles—Carpet, Carpet Padding, Clothing, Other Textiles.

The weighing of each material category was carried out after sorting of samples had been made. Details of each sample were documented. Plate 1 shows weighing of a sample at one of the landfills.

Plate 1 Weighing of sorted organic fraction of the waste at a landfill

3 Results and Discussion

Figure 1a–e shows the top ten constituents of the separated wastes from residential land use types based on density and income. The constituents tend to follow the same trend; having the greatest proportion of organics followed by paper and textiles. Organics account for 33.06–46.25% of the waste stream, plastics 12.73–20.7%, paper 4.61–10.3%, and textiles 1.66–12.33%. As shown in the

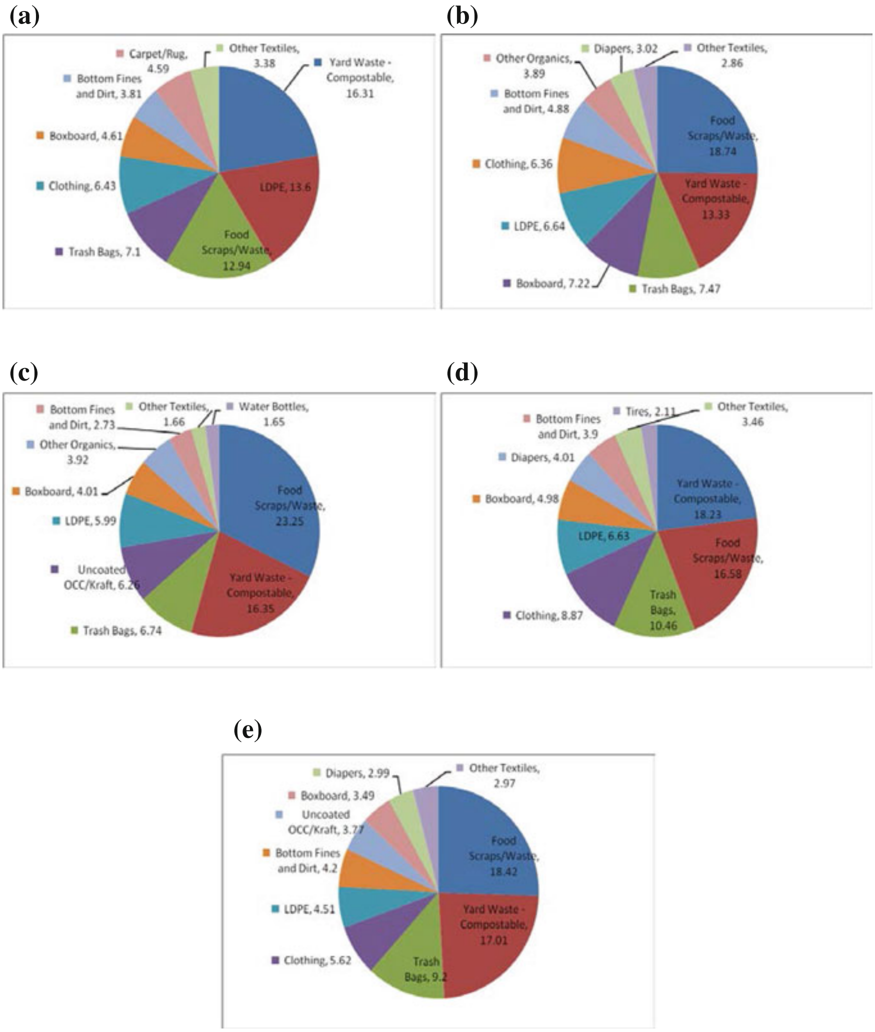

Fig. 1 **a** Composition of residential wastes from HDLI areas. **b** Composition of residential wastes from HDMI areas. **c** Composition of residential wastes from MDHI areas. **d** Composition of residential wastes from MDLI areas. **e** Composition of residential wastes from LDHI areas

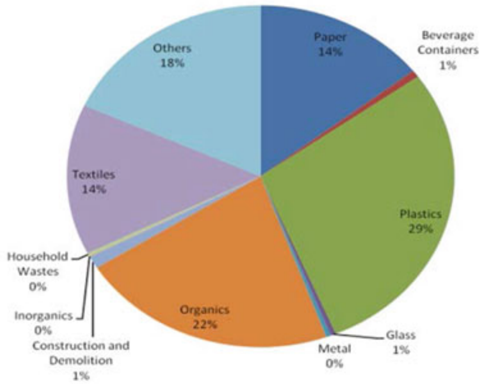

Fig. 2 Composition of wastes from commercial areas

Figures, there is a slight variation in the constituents with respect to population density and income level. However, there is no general trend in this variation more so they are insignificant according to population density or income level.

The percentage by weight of each of the various ten different material classes for commercial wastes arriving at the dump sites is shown in Fig. 2. The wastes coming from commercial areas consists of plastics (29%), organics (22%), others (comprising mainly factory dust) (18%), paper (14%), and textiles account (14%).

In comparison with residential wastes (Fig. 1a–e), commercial wastes contain more of plastics than organics. Perhaps this may be attributable to the reduction in household wastes as a result of food preparation, gardening, sanitation, and some other household activities. It may also be due to increased unpackaging activities, use of pet containers, and by-products of small-scale manufacturing process.

4 Conclusion

Solid wastes from different parts of Lagos metropolis, southwestern Nigeria, consist of identical components as solid wastes from other parts of world. Samples taken from trucks mainly operated by Private Sector Participation contractors and stratified according to land use type, population density, and income show slight disparity in composition. Irrespective of the population density and income level, solid wastes from residential land use types are composed mainly of organics (33.06–46.25%), plastics (12.73–20.7%), paper (4.61–10.3%), and textiles (1.66–12.33%). On average, solid wastes from commercial land use types are composed mainly of 29% plastics, 22% organics, and 14% each of paper and textiles. The increase in plastics and reduction in organics may be attributable to decrease in household wastes and commercial activity-based wastes resulting from small-scale manufacturing and unwrapping of products. Source separation of these wastes is recommended, and technologies for resource and energy recovery are required for sustainable solid waste management in Lagos State.

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Waste to Energy: Developing Countries' Perspective

Adeniyi Saheed Aremu and Habeeb Oladimeji Ganiyu

Abstract About 4.2 million tons of solid waste is generated daily from urban centres in developing countries, most of which are disposed in open dumps and uncontrolled landfills. These wastes are composed of renewable energy materials with energy value of about 9.87×10^9 kWh/day. Capturing the energy embedded in these wastes is one of the sustainable ways of reducing the quantity of wastes to be landfilled while producing electricity, heat and fuel to meet basic needs. Investment in Waste to Energy (WTE) sector has increased over the years in developed countries, and its applicability to developing economies has been hampered by several constraints such as lack of records of waste quantity and composition, low calorific heating value, financial incapability, unsupportive local policies, and technological know-how and adaptability. For a start, there is need to conduct feasibility studies, upgrade the predominant open dumps in developing countries to sanitary landfills and later seek financial and technical assistance. Establishment of a vibrant WTE market in developing countries will have enormous social, economic and environmental benefits.

Keywords Solid waste · Management · Energy and developing countries

1 Introduction

Energy is vital for socio-economic development while several human activities result in the generation of materials which are no longer of use otherwise called solid wastes. Global energy demand is continuously increasing due to rapid population growth and urbanization [6], and it is projected to keep rising especially

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in developing countries [8]. Consequently, energy affordability and energy poverty are two major challenges facing developing countries. According to the UK Parliamentary Office of Science and Technology report of December 2002, about 1.6 billion people in developing countries are still without access to energy services, 80% of which live in rural areas of sub-Saharan Africa and South Asia. Fossil fuels remain the principal form of energy powering global expansion by providing about 60% of the additional energy requirement and in future, may account for almost 80% of total energy supplies in 2035 [1]. In view of rising long-term energy demand, renewable energies and energy efficiency play vital roles particularly in fulfilling climate targets and commitments towards energy access and security [25].

Managing the enormous amount of municipal solid waste generated has being a challenging task to municipal authorities in both developing and developed countries. Population increase, changing lifestyle, industrialization, economic development and a host of other variables are responsible for the worldwide increase in solid waste generation. The urban population of the world is expected to increase from 3.6 billion in 2011 to about 4.6 billion in 2025 [20], while world cities generate about 1.3 billion tonnes of solid waste per year, and this quantity is expected to increase to 2.2 billion tonnes by 2025 [7].

Over the years, several methods which seek to effectively and efficiently manage these wastes have been proposed. Solid waste management activities involve technologies associated with the control of waste generation, handling, storage, collection, transfer, transportation, processing and transformation, and final disposal [18]. Throughout the world, there is growing emphasis on the integrated solid waste management hierarchy which places an order of preference for waste management actions according to what is desirable for human beings and the environment. The European Union's five-step waste management hierarchy places prevention as the best option followed in decreasing order of priority by reuse, recycling, recovery, and disposal as the least preferred option [3, 4].

Obviously, it is advisable to prevent or reduce the generation of wastes. However, if waste is inevitable, it is desirable to reuse or recover materials from the waste stream. Chalmin and Gaillochet [2] observed that only 25% of the total quantity of municipal solid waste produced yearly in the world is recycled or recovered. In developed countries, landfilling and thermal treatment are disposal methods of waste that cannot be used or recycled. Wastes that cannot be practically reused or recycled or those that escape the predatory claws of scavengers in developing countries end up in open dumps and uncontrolled landfills.

As the global level of solid wastes and demand for energy continue to rise, Waste to Energy (WTE) technology plays a dominant role in solving these two challenges. WTE technologies consist of methods/processes to extract valuable energy contained in waste streams for the production of electricity, heat or transport fuel [24], and it is a vastly underutilized resource throughout the world [11]. Presently on a global scale, there are over 1200 WTE plants in operation across more than 40 countries [10]. WTE as a thermal treatment option in many countries of the Organization for Economic Cooperation and Development (OECD) has replaced the traditional incineration of waste, in addition yielding energy in form of electricity or heat [22].

2 Income Classification of Economies

The classification of economies by the World Bank in July 2016 according to 2015 Gross National Income (GNI) per capita is presented in Table 1. From this classification, 31 countries are low-income countries, 52 are lower-middle income countries, 55 are upper-middle income countries, while 79 are high-income countries. This criterion (economic status) forms a key indicator of a country's development and may reflect similar solid waste generation rate, composition, and management technique of a group of countries in the same class. In this study, any country that falls within the low, lower-middle or upper-middle income group is termed a developing country. Hence, there are a total of 5.861 billion people living in 138 developing countries and having GNI per capita less than $12,476.

3 World Energy Situation

The total energy consumption in the world between 1997 and 2015 is illustrated in Fig. 1. Energy consumption has continuously grown over the years. It grew from 9,530 Mtoe in 1997 to 13,778 Mtoe in 2015 representing 30.8% increase in demand. This increase in energy consumption may be as a result of the expanding world economy which is associated with higher levels of activities and living standards. Therefore more energy will be required in the next twenty years to support world economy growth and prosperity [1]. In developing countries, demand for energy services is expected to increase considerably and primary energy demand presumed to triple and form up to two-thirds of total global demand by 2050 [15].

Table 1 Classification of economies based on income and associated population

World Bank classification	Low income	Lower-middle income	Upper-middle income	High income
No. of countries	31	52	55	79
GNI ($)	1,025 or less	1,026–4,035	4,036–12,475	Above 12,476
Population (billion)	0.622	2.878	2.361	1.398

Adapted from http://siteresources.worldbank.org/DATASTATISTICS/Resources/CLASS.XLS

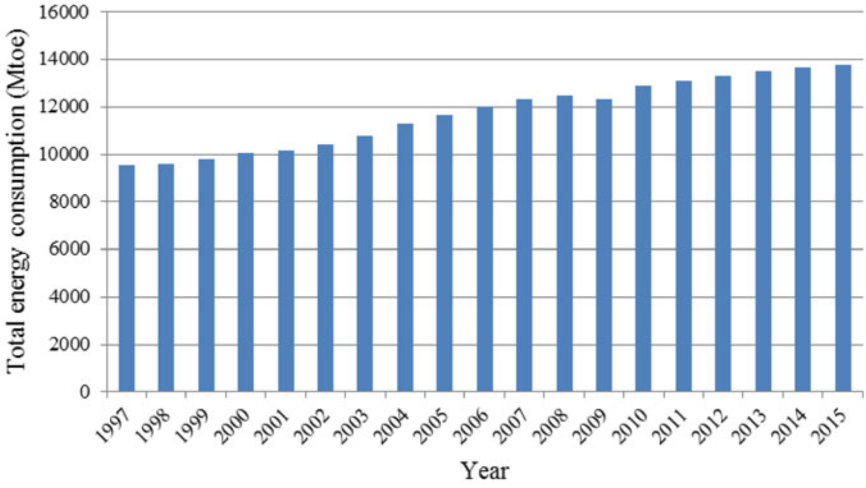

Fig. 1 World energy consumption. Adapted from Enerdata [5]

4 Generation and Composition of Solid Wastes from Developing Countries

Solid waste is generated primarily as a result of productive and consumptive activities from households, commercial establishments, institutions and industries. Several factors have been known to affect the output and characteristics of solid wastes in developing countries. Urban solid waste generation rates for developing countries are shown in Table 2. The per capita generation rate of solid waste is highest for upper middle income countries, followed by lower middle income countries, while low income countries have the lowest per capita generation rate. Specifically, the rate of generation of solid waste in upper middle income countries is almost double the amount generated by low-income countries. However, lower

Table 2 Waste generation in developing countries

Income level	Urban population	Waste generation rate (kg/capita/day)	Total (tons/day)
Low income	676,000,000	0.86	581,360
Lower-middle income	2,080,000,000	1.3	2,704,000
Upper-middle income	619,000,000	1.6	990,400

Source Hoornweg and Bhada-Tata [7]

Table 3 Waste composition by income level in developing countries

Income level	Composition					
	Organic (%)	Paper (%)	Plastic (%)	Glass (%)	Metal (%)	Other (%)
Low income	62	6	9	3	3	17
Lower-middle income	55	10	13	4	3	15
Upper-middle income	50	15	12	4	4	15

Source Hoornweg and Bhada-Tata [7]

middle income countries will have the highest total waste generation because the urban population is more than triple the upper middle income countries and low income countries. In totality 4,275,760 tons of solid waste is expected daily from developing countries.

Table 3 shows the composition of a typical solid waste from developing countries. It contains more organic materials, and less glass and metal. The organic materials have high moisture content (about 20–70%); hence, these wastes have low calorific heating value.

5 Energy Content of Solid Wastes from Developing Countries

Energy content of solid wastes from developing countries was calculated using established moisture content and calorific energy value of waste components contained in Tchobanoglous et al. [17] and Kamuk and Haukohl [10]. The calculated energy content based on dry matter of solid wastes from the three income groups that make up developing countries is presented in Table 4. The total energy potential of these wastes is 3.55×10^{13} kJ/day. This energy content translates to approximately 9.87×10^{9} kWh energy per day (i.e. 1 kWh = 3600 kJ).

Table 4 Overall energy content of urban solid waste from developing countries on dry matter basis

Income level	Energy[a] (KJ/kg)	Total energy[a] ($kJ \times 10^{12}$)
Low income	11381.90	3.96
Lower-middle income	13568.70	22.89
Upper-middle income	13794.20	8.69

[a]Excluding metals and glass

6 Constraints and Prospects of WTE Facilities in Developing Countries

6.1 Lack of Fundamental Records/Data

Planning for a WTE plant requires knowledge of the expected quantity and composition of solid wastes, potential WTE sites, funding opportunities and a host of other parameters. The net effect of lack of these fundamental statistics are often a source of confusion and cast doubt in the minds of investors who may want to do business or provide services in the waste management sector [14]. Hence, feasibility studies are necessary to assess waste characteristics, present solid waste management system, energy value, energy sales, existing laws and standards, potential stakeholders, WTE organization options/setup, ownership, needed expertise, and project economy, finance and implementation.

6.2 Composition of Wastes

Lower calorific value and high moisture content of waste from developing areas may attract extra heating fuel and put the facility at risk. Also, the composition of wastes is influenced by several factors which in the long run may affect its calorific value. Little variation in calorific value for a short period may be tolerable but wide variation will affect operation cost and performance of the WTE facility. However, from this study, wastes from developing countries have calorific value of approximately 11–13 MJ/kg which is greater than an annual minimum of 7 MJ/kg or seasonal minimum of 6 MJ/kg recommended by Kamuk and Haukohl [10].

6.3 Financial Constraints

Developing countries are known to have limited foreign exchange resources and financial sustainability of solid waste management systems. Most developing countries are debt ridden. According to the World Bank [26], at the end of 2014, the total external debt of developing countries stood at $5,294 billion with 28.8, 34.5 and 36.7% representing short term, private non-guaranteed, and public and publicly guaranteed debt respectively. The combined stock of external debt of low-and middle-income countries was $5.4 trillion at the end of 2014, the net debt flows totalled $464 billion, and Foreign Direct Investment (FDI) was $576 billion [27]. Half of the top ten foreign direct investment recipients in the world (in 2014) are from developing countries and multinational enterprises continue to acquire foreign affiliates in the developing world [21]. FDI's significance to developing countries is in the area of transferring production technology, skills, innovative capacity, and organizational and managerial practices between locations, as well as of accessing international marketing networks in primary, manufacturing and services sector [12].

WTE plants in the USA and Europe require a capital cost of 2.90–7.70 million$/MW, operating cost of 90,000–200,000 million$/MW/year and the levelised cost of electricity is 80–210 million$/MWh [24]. Also, the World Bank estimates the costs associated with WTE facilities in lower middle-income and upper-middle income countries as $40–$100 per ton and $60–$150 per ton respectively [7]. More so, a modern WTE incinerator may require costs to maintain pollution control equipment and additional costs on supplementary fuel to burn a typical high-organic and relatively wet waste from developing countries [19]. This amount is on the high side for developing countries when compared to budgetary allocations to the waste management sector which is an average of $29,620,553 [19] representing 5.89% of municipal budget for the referenced cities. Years back the sharpest increase in investment flows into clean energy was through venture capital and equity, and investment in public capital markets [23]. Today, the same investment flow or partially/entirely donor funded assistance may be valid for WTE technologies.

6.4 Education/Training and WTE Technology Transfer

Several qualified and skilled staff are required for all the sections in WTE facilities. These staff include on-site and off-site workers as direct or indirect staff during plant construction, and permanent staff for operation and maintenance of these facilities. Majority of WTE facilities run 24 hours in a day and 7 days in a week. The pool of employees differs from facility to facility, but the pool normally comprises operative staff, technical staff, administrative staff and contractors. However, WTE technology should match existing local socio-economic conditions in developing countries in order to be successful. In the early 1987, the WTE plant set up in India by technical assistance from a Danish firm failed due to mismatch of quality of incoming feed with plant design. The waste that was available for the plant could not sustain combustion due to the difference in its composition in relation to design parameters [9].

Staff in WTE facilities require general training such as gas treatment, maintenance/operation optimization, asset management, regulatory compliance, emission monitoring, job ethics and safety. Also, some staff in waste handling, conversion and pollution control sections need advance training to acquire skills and knowledge to meet specific job requirements.

6.5 Government Policies

In reality, capital and operating costs of WTE facilities are more than other disposal methods. Several government initiatives such as tax credit, subsidies, emission restrictions, and renewable energy legislations/policies/targets are required to encourage domestic growth of WTE technology [8]. Also, infrastructure for waste collection and sale of energy is required for sustainability of WTE facilities.

6.6 Key Prospects

WTE offers three key benefits: reduction of waste volumes by at least 90%, recovery of metals and other materials, and the generation of renewable base load energy [11]. Proper investment in WTE technology has the potential to yield significant economic and environmental benefits in terms of revenues, employment, and pollution and greenhouse gas emissions reduction in many parts of developing countries. Revenues come from tipping fees, and sales of energy and recyclables. Though WTE is not yet financially competitive in a number of markets, the global market for thermal and biological WTE technologies may grow to about $29.2–$80.6 billion by 2022 [11].

In the USA, the WTE industry employs about 5,350 people nationwide and every dollar of revenue generated by the industry puts a total of 1.77 dollars into the economy through intermediate purchases of goods and services, and payments to employees [13]. Developing countries are characterized by cheaper labour costs than the USA; hence, there are opportunities for more earnings from WTE plants.

Also, the WTE process is CO_2 neutral because it saves fuel that would have been used in traditional plants, and it is relatively cheap in comparison with biomass, wind and photovoltaic power; i.e., the WTE process costs only EUR 7–12 to save one ton of CO_2 [16].

Other advantages of WTE facilities are [10]:

- Most efficient way of reducing waste volume and the demand for landfilling.
- Flexibility in location thereby reducing the need for transportation.
- Sustainable renewable energy source to substitute fossil fuels.
- Environmentally beneficial without greenhouse gas generation.
- WTE facility bottom ash can serve as substitute for virgin aggregate.

7 Conclusion

Waste to energy (WTE) technologies play a significant role in solving waste disposal and energy shortage challenges. In WTE technologies, wastes are combusted for the production of electricity, heat or transport fuel. These technologies provide tremendous socio-economic value and less negative environmental impacts on host communities. Over 4.2 million tons of solid wastes with combined energy content of approximately 9.87×10^9 kWh are generated daily from developing countries. There is also the availability of cheap labour to meet some specific semi-skilled or unskilled job demands.

However, composition variability, high moisture content and low calorific value of solid waste from developing countries affect its combustibility. WTE applicability to developing economies is hampered by lack of records on waste quantity and composition. Huge capital cost is also needed to start up and maintain a WTE facility. Local policies are equally unsupportive and technological know-how and its adaptability to local conditions is a prerequisite. Today, the same investment flow or partially/entirely donor-funded assistance may be valid for WTE technologies. To invest in WTE technologies, developing countries need to upgrade the predominant open dumps to sanitary landfills, closely followed by collection optimization, and education/training before WTE technology transfer.

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The Technological Level of Equipment of Participants in the ELV Recycling Process in Serbia and the Region

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Abstract The technological level of equipment used by recyclers in the process of end-of-life vehicle (ELV) recycling depends mainly on the following four factors: legislation, desired economy of the process, socioeconomic characteristics of the surroundings, and the number of ELVs. ELV depollution technologies are strictly defined by the national and regional legislation, but technological processes of recycling depend mostly on the requested type of output. Due to that, we differ shredders with various capacities and dismantling centers that separate used parts to be placed on the market while the rest of material is prepared for melting process. This paper proposes the analysis of economical parameters that are important for the adoption of technologies that are applicable in Serbia and the Region from the economical and ecological aspects for the process of ELV depollution.

Keywords Technology · Recycling · ELV

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1 Introduction

Superior equipment enables superior work quality, which relates especially to the branches where hazardous situations are possible. Motor vehicles are one of the greatest polluters of the Earth, starting from the production process to the end of their life cycle. We will focus on the recycling of ELVs at the end of their life cycle, and the equipment that enables recyclers to make the process as environmental friendly as possible. The increasing number of ELVs is a significant issue in many countries nowadays. The Republic of Serbia and the Region also face with this problem. The amount of waste generated from the motor vehicles enlarges constantly through the dynamics of buying new vehicles and from the regular production and maintenance activities. Serbia and other less developed countries in the Region also face a problem of the large number of old vehicles (about one million in Serbia) that should have been recycled by now. Romania, Greece, and Croatia have more modern vehicles due to the higher life standard. It is estimated that the number of ELV ranges from 4 to 6.7% of the number of registered vehicles and that the total number of generated ELVs in Serbia per year is about 100,000, there is no precise data for this estimate [1].

The interest of the recyclers is to implement the recycling process at the national and international levels through the different approaches to the ELV recycling and conduct the process in the best possible manner. This means that some of the recyclers, predominately microenterprises will focus on the collection, storage, partial dismantling, and trade with the collected reused parts. Higher level recyclers are those who have the higher level of specialization. The highest level of the ELV recycling is gained at the specially designed recycling lines that only specialized recyclers own. A general approach to the problems of ELV recycling is needed to obtain the sustainability of the process, due to the high significance of the process itself in technical, environmental, and economic aspect [2]. One of the most important parts of the system is the equipment applied in the recycling process as well as the trained and well-educated recyclers. An example for this is the certification of experts that may conduct depollution process, where the use of mobile drainage equipment plays a crucial role. This type of depollution process is widely accepted in Romania. The model for choosing the proper equipment for ELV recycling requires the consideration of many parameters that combine aspects from natural, economical, social, and technical field [2]. If the recycling process is conducted according to the national legislation acts and the EU directive 2000/53/EC, vast amount of waste that can harm the environment can be used as a resource for new products.

Environmental friendliness is one of the prerequisites for the sustainability of one national ELV legislation system in general. In order to obtain the environmental friendly ELV scrapping, it is necessary to implement proper depollution process, which is a complex one due to the complexity of hazardous materials contained in a motor vehicle. Because of that, the most suitable way of accomplishing this is by using specially designed equipment for removing fluids, batteries, and other hazardous materials from ELVs [3]. This equipment prevents the leakage and pollution of environment. In order to reuse the fluids, it is necessary to organize separate collection and storage of various fluids, what can be achieved by using a single tank for each fluid type. Fluids are contained in the interior of the ELV, inappropriate housings, tanks, or devices, which is the reason why fluids are usually hard to approach. The use of specialized depollution equipment makes the process more efficient. Due to its importance, we will focus on the equipment for fluid removal from an ELV stable or mobile ones. The use of professional equipment facilitates the manipulation of the vehicle during the depollution process that enables reduction of the negative impacts on the environment and the health of employees to a minimum [4].

2 The ELV Depollution Process and Specialized Equipment

The process of depollution is the most important one for obtaining the environmental sustainability of the ELV recycling process. Due to its nature, this process is not economically sustainable on its own, because of that strong government measures have to be implemented, especially in developing countries. Otherwise, this process will be neglected and hazardous components and materials may reach the environment, causing negative consequences. Due to their nature, fluids may become the most dangerous of all hazardous components. They may leak into the environment, while the solid ones are restricted within their borders [2].

Fluids that are contained in used vehicles are very toxic, and this is the reason why the high level of their removal is needed. There is the equipment available on the market that is specifically designed for professional removal of hazardous materials from used vehicles. The usage of this equipment enables recyclers to conduct the removal of fluids very effectively and efficiently (up to 30 min per an ELV and up to 98% of removed fluids). Alternative methods can be used, but it is necessary to achieve the same level of efficiency. Even when alternative methods are used, both the health and safety requirements must not be compromised [5].

The specialized equipment for ELV depollution process has already been available on the market for a while. The widely known producers are Vortex [6] and SEDA [7], while the national metal processing industry and academic institutions try to design competitive equipment. This paper focuses on the proper selection of the available equipment from different aspects based on the current technological and economical situation in Serbia and the Region.

The complete depollution process of the ELVs consists of several stages. First, it is necessary to take so-called preliminary activities [8]. The second stage is the removal of all the liquids from a vehicle. After that comes the removal or deployment of air bags and finally the last stage. In the last stage, ELV is classified as a non-hazardous waste. This paper is primarily oriented toward the selection of the available equipment for the second stage of depollution process. The equipment is divided into four groups, namely:

– Stable equipment—domestic made;
– Stable equipment made—EU made;
– Mobile equipment made—domestic made;
– Mobile equipment made—EU made.

The selection of proper equipment based on market needs and economy possibilities is conducted using the TOPSIS method (**T**echnique for **O**rder **P**reference by **S**imilarity to **I**deal **S**olution) as explained in the next chapter.

3 The Application of the TOPSIS Method for Selection of Proper Equipment

The TOPSIS method (**T**echnique for **O**rder **P**reference by **S**imilarity to **I**deal **S**olution) is a widely used as multiple criteria decision-making method. Authors of the method are Hwang and Yoon [9]. The TOPSIS method has considerable similarities to the ELECTRE method (also multiple criteria decision-making method), so it can be considered as one of the often used variants of the ELECTRE method. Authors of the ELECTRE method (**EL**imination and **E**t **C**hoice **T**ranslating **RE**ality) are Benayoun et al. [10]. The essence of the TOPSIS method is to define the ideal (best) solution and the worst possible solution, after which the choice of the most suitable action is conducted with the demand that this action should be similar mostly to the ideal solution (to have the least distance of the best action), and to differ from the worst possible solution (to have the highest distance of the worst action). The TOPSIS is applied through an iterative process that means that the procedure has a certain number of steps.

4 Selection of Equipment for Depollution of ElVs

The selection of the equipment is done among four possible actions, namely:

– a_1: Stable equipment—domestic made;
– a_2: Stable equipment made—EU made;
– a_3: Mobile equipment made—domestic made;
– a_4: Mobile equipment made—EU made.

The selection is conducted through seven attributes (criterions):

– A_1: Costs of equipment (€), (demanding minimum);
– A_2: Costs of human resources per an ELV (€/ELV), (demanding minimum);
– A_3: Energy costs (kWh/ELV), (demanding minimum);
– A_4: Reliability of equipment;
– A_5: Attainability of services and maintenance;

- A_6: Effects of equipment operation;
- A_7: Safety.

The first decision-making matrix contains marks of all actions according to each attribute. The marks may be qualitative or quantitative. In the given example, the first decision-making matrix has next values:

		A_1	A_2	A_3	A_4	A_5	A_6	A_7
$O =$	a_1	14,000.00	1.20	6.20	High	Very high	Average	Very high
	a_2	39,500.00	5.00	3.00	Very high	Average	High	Very high
	a_3	25,000.00	3.25	9.30	Average	Very high	Very high	High
	a_4	49,990.00	13.5	4.50	High	Average	Very high	High

Quantification of qualitative attributes is done using next scale: 1—very low level, 3—low, 5—average (medium), 7—high, and 9—very high level. Quantified decision-making matrix has next values:

		A_1	A_2	A_3	A_4	A_5	A_6	A_7
$O =$	a_1	14.00	1.20	6.20	7	9	5	9
	a_2	39.50	5.00	3.00	9	5	7	9
	a_3	25.00	3.25	9.30	5	9	9	7
	a_4	49.99	13.50	4.50	7	5	9	7

Step 1. Calculation of the decision-making matrix N that contains normalized values.

In this step, each element vector (column of the quantified decision-making matrix) is divided by a related vector norm. The normalized decision-making matrix N is created of the normalized values n_{ij} that read:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}},$$

where indices are:

- $i = 1, 2,\ldots, m$—number of an action,
- $j = 1, 2,\ldots, n$—number of an attribute.

For a change from minimization A_j to maximization A_j, the following expression is used:

$$n_{ij} = 1 - \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}.$$

The decision-making matrix for the analyzed problem has next values:

		A_1	A_2	A_3	A_4	A_5	A_6	A_7
$N =$	a_1	0.800	0.919	0.501	0.490	0.618	0.325	0.558
	a_2	0.435	0.662	0.758	0.630	0.343	0.456	0.558
	a_3	0.642	0.781	0.251	0.350	0.618	0.586	0.434
	a_4	0.284	0.088	0.638	0.490	0.343	0.586	0.434

At attributes A_1, $A_{2,}$ and A_3, the latter expression for transfer min A_j to max A_j is used. Examples of calculating some of the normalized values are presented:

$$n_{11} = 1 - \frac{14}{\sqrt{14^2 + 39.5^2 + 25^2 + 49.99^2}} = 0.800$$
$$n_{24} = \frac{9}{\sqrt{7^2 + 9^2 + 5^2 + 7^2}} = 0.630$$

Step 2. Calculation of the normalized decision-making matrix V with weights

First, we define weights of all attributes as:

$$w_1 = 0.20;\ w_2 = 0.09;\ w_3 = 0.12;\ w_4 = 0.15;\ w_5 = 0.12;\ w_6 = 0.17;\ w_7 = 0.15$$

Then the normalized decision-making matrix V with weights is calculated that may be presented as:

$$V = \begin{bmatrix} w_1 \cdot n_{11} & w_2 \cdot n_{12} & \cdots & w_{\mathrm{n}} \cdot n_{1\mathrm{n}} \\ w_1 \cdot n_{21} & w_2 \cdot n_{22} & \cdots & w_{\mathrm{n}} \cdot n_{2\mathrm{n}} \\ \cdots & \cdots & \cdots & \cdots \\ w_1 \cdot n_{\mathrm{m}1} & w_2 \cdot n_{\mathrm{m}2} & \cdots & w_{\mathrm{n}} \cdot n_{\mathrm{mn}} \end{bmatrix} = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix}$$

The normalized decision-making matrix for the analyzed problem has following values:

		A_1	A_2	A_3	A_4	A_5	A_6	A_7
$V =$	a_1	0.1600	0.0827	0.0601	0.0735	0.0742	0.0552	0.0837
	a_2	0.0870	0.0596	0.0910	0.0945	0.0412	0.0775	0.0837
	a_3	0.1284	0.0703	0.0301	0.0525	0.0742	0.0996	0.0651
	a_4	0.0568	0.0079	0.0766	0.0735	0.0412	0.0996	0.0651

Step 3. Defining the best and worst solution

In general, determination of the ideal (best) solution is conducted using the expression:

$$a^{*} = \{(\max v_{ij} | \max A_j),\ (\min v_{ij} | \min A_j),\ i = 1, 2, \ldots, m\}$$

In general, determination of the negative ideal (the worst) solution is conducted using the expression:

$$a^{-} = \{(\min v_{ij} | \max A_j),\ (\max v_{ij} | \min A_j), i = 1, 2, \ldots, m\}$$

During normalization, it has already been transferred min A_j in max A_j, so we observe only max a^{*} and min a^{-} for determination of ideal and negative ideal solution:

$$a^{*} = \{0.1600;\ 0.0827;\ 0.0910;\ 0.0945;\ 0.0742;\ 0.0996;\ 0.0837\}$$
$$a^{-} = \{0.0568;\ 0.0079;\ 0.0301;\ 0.0525;\ 0.0412;\ 0.0552;\ 0.0651\}$$

Step 4. Determination of partial distances

In this step, we calculate distances from ideal and negative ideal solution for every action. Euclidian distances are used of this operation.

The distance of the action a_i to the ideal solution is given by the expression:

$$S_i^{*} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{*}\right)^2},\ i = 1, 2, \ldots, m$$

The distance of the action a_i to the negative ideal solution is given by the expression:

$$S_i^{-} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{-}\right)^2},\ i = 1, 2, \ldots, m$$

Partial distances to the ideal solution are (example for action a_1):

$$S_1^{*} = \sqrt{(0.1600 - 0.1600)^2 + (0.0827 - 0.0827)^2 + (0.0910 - 0.0601)^2 + (0.0945 - 0.0735)^2 + \cdots}$$
$$S_1^{*} = \sqrt{\cdots + (0.0742 - 0.0742)^2 + (0.0996 - 0.0552)^2 + (0.0837 - 0.0837)^2} = 0.058027$$
$$S_2^{*} = 0.086255$$
$$S_3^{*} = 0.083493$$
$$S_4^{*} = 0.135382$$

Partial distances to negative ideal solution are (example for action a_1):

$$S_1^- = \sqrt{(0.0568 - 0.1600)^2 + (0.0079 - 0.0827)^2 + (0.0301 - 0.0601)^2 + (0.0525 - 0.0735)^2 + \cdots}$$
$$S_1^- = \sqrt{\cdots + (0.0412 - 0.0742)^2 + (0.0552 - 0.0552)^2 + (0.0651 - 0.0837)^2} = 0.137917$$
$$S_2^- = 0.099503$$
$$S_3^- = 0.109912$$
$$S_4^- = 0.067636$$

Step 5. Determination of the distance of the ideal (best) solution

The distance of the action a_i from the ideal (best) solution is determined by the formula:

$$C_i^* = \frac{S_i^-}{S_i^* + S_i^-}, \; i = 1, 2, \ldots, m$$

Based on the previous expression, one may conclude:

$$1 \geq C_i^* \geq 0$$
$$a_i = A^* \Rightarrow S_i^* = 0 \Rightarrow C_i^* = 1$$
$$a_i = A^- \Rightarrow S_i^- = 0 \Rightarrow C_i^* = 0$$

The best action is determined by the value of C_i^*. More precisely, the higher the value of C_i^* the action is closer to the ideal (best) solution, meaning the better one. So we choose the action with the highest value of C_i^*.

Relative closeness to the ideal solution is:

$$C_1^* = \frac{S_1^-}{S_1^* + S_1^-} = \frac{0.137917}{0.058027 + 0.137917} = 0.7038$$
$$C_2^* = \frac{S_2^-}{S_2^* + S_2^-} = \frac{0.099503}{0.086255 + 0.099503} = 0.5356$$
$$C_3^* = \frac{S_3^-}{S_3^* + S_3^-} = \frac{0.109912}{0.083493 + 0.109912} = 05683$$
$$C_4^* = \frac{S_4^-}{S_4^* + S_4^-} = \frac{0.067636}{0.135382 + 0.067636} = 0.3332$$

Step 6. Determination of ranks of actions

The TOPSIS method enables ranking of actions in complete order. That is conducted using the value C_i^*. Namely, the first range takes the action that has the highest value of C_i^*, the second rank to the action that has the second highest C_i^*, etc.

For the given example, the ranks of actions are:

1. rank: action a_1
2. rank: action a_3
3. rank: action a_2
4. rank: action a_4

According to the TOPSIS method, the optimal solution is the action a_1—stable equipment—domestic made, for the studied case. It is obvious that the buying costs of the equipment are the key contributor to this selection. Its price is much lower than the price of the other actions and the attribute A_1—buying costs of the equipment have the highest weight in the model.

5 Conclusion

The stricter legislation acts harmonized with EU norms, and the increased number of ELVs has created possibilities for the development of equipment for depollution and ELV scrapping, where national metal processing industry and academic institutions work together in implementing competitive domestic-made equipment to existing brands. The analysis conducted in this paper shows that the domestic-made stable equipment may have the advantages to the established brands, precisely the presented model (14,000 EUR) for the ELV recycling in Serbia and the Region of the similar economic structure and standard.

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Part III
Sustainability and Climate Change

The Influence of Municipal Solid Waste of Georgia on Climate Changes

Natela L. Dvalishvili and Mariam Sh. Tabatadze

Abstract Currently, the improvement of municipal solid waste (MSW) management is an ongoing process in Georgia. Up to 90% of wastes generated in the country are disposed without any separation procedures. Unfortunately, information on amount and morphological composition of waste generated in Georgia does not exist, and methodology of waste accounting is not elaborated that creates great problems during drawing of international scientific projects, determination of energy efficiency of waste and possibility of waste processing. One of the important issues of technogenic impact of waste on the environment is produced greenhouse gases and its impact of global climate change. After disposal of replaces waste, a large amount of landfill gas is produced in landfill. The formation of landfill gas depends on the natural conditions (geographical, climatic and meteorological factors) and landfill management and the composition of the waste as well. The goal of our project was determination of morphological composition of MSW and identification of the total amount of waste, generated from the domestic and commercial facilities of Georgia (including all cities and villages of each municipalities of State) by uses of gravimetrical analyses and obtained data from the effectiveness questionnaire of waste. The results show that the main fractions of municipal solid waste are paper, plastic and food waste. The character of Georgian waste defines the generating big amount of methane. The impact of waste on global climate change was identified based on the IPCC methodology.

Keywords Municipal solid waste · Morphological composition of MSW
Influence of GHG · Climate changes · Inventory of GHG

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1 Introduction

As of today, the study of quantity and morphological composition of municipal solid waste (MSW) is topical, since there is no policy of waste segregation (sorting) and no information on the composition of waste located at the landfills is available in the country. Besides, there is no full-value service of waste accumulation and disposal in the regions of Georgia, lots of villages are not provided with trash cans, and due to this, fact population is forced to dispose the waste at the territories voluntarily selected by people. Up to 52% of waste generated in the country is thrown away without any control to the gorges adjacent to residential places, on the riverside and other illegal, informal dump sites.

Study of quantity and morphological composition of municipal solid waste (MSW) is important in the process of elaboration of National Communication. In 1994, Georgia signed the United Nations Framework Convention on Climate Change (UNFCCC) and later on the 16 June 1996 Kyoto Protocol, according to which Georgia is obliged to prepare National Communications on Climate Change. The goal of the mentioned document is the study of current state in the area of climate change in the country and assessment of quantity of greenhouse gases emission [1, 2].

The goal of our work was the determination of quantity and morphological composition of MSW generated in Georgian cities and villages with the use of quantitative method of sociological researches and gravimetric analysis and calculation of methane emission on the basis of obtained data using the IPCC methodology [3].

2 Literature Review

The management of municipal solid waste (MSW) in Georgia is at the initial stage. Up to 90% of waste generated in country is thrown away to the landfills without segregation. In January 2015, the law—Waste Management Code—came into force in Georgia, the basic goal of which is reduction of influence of waste on the environment and human health that implies waste minimization and their processing [4]. On the basis of this law, “The National Waste Management Strategy for 2016–2020” and “The National Waste Management Action Plan for 2016–2020” [5] were approved by the Resolution #160 of the Government of Georgia, basic goal of which is the assessment of current situation in the country and implementation of modern model of waste management—improvement of waste collection system, segregation (sorting) of waste, its processing and landfill gases reduction.

3 Results and Discussion

With the purpose of determination of quantity and composition of waste generated in the country throughout a year, during 2015 was conducted the research in the regions, population of which is 62% of total population domiciled in Georgia.

In each region with the purpose of acquisition of statistical information on waste were held meetings with representatives of governances of municipalities.

Study of quantity and morphological composition of MSW in Georgian cities and villages was carried out with the use of quantitative method of sociological research and gravimetric analysis.

For quantitative analysis was composed experimentally tested questionnaire, on the basis of which was acquired statistical information from governances of municipalities, also the population domiciled in each region of Georgia was interviewed for gathering the information on quantity and composition of waste generated by people, also the interviews with commercial facilities and governmental bodies of regions were envisaged by the study.

Determination of SDW composition using gravimetric method was made according to preliminary elaborated stages:

- Two hours before the emptying of containers, they were weighted at portable digital auto weights;
- Contents of containers were dumped at plain surface, on the canvas cover 5 × 7 m in size;
- Empty container was weighted again. Difference between full and empty containers was the weight of waste;
- Waste disposed on the canvas cover was segregated (sorted) using the shovel according to fractions;
- Each fraction of segregated waste was bagged and weighted, and height and circumference of bags were measured;
- All data were entered in the workbook.

As the result of integrated processing of statistical data, information acquired from the questionnaire and data obtained using gravimetric method identified the quantity of municipal solid waste generated in each region per capita and morphological composition of MSW (Tables 1 and 2).

On the basis of obtained results, using the IPCC-2006 methodology was made the forecast of methane emission from waste sector until 2030 by the example of Adjara Autonomous Republic (Table 4), which is one of the most important regions of Georgia [6] according to strategic, natural and touristic-recreational potential. According to The National Waste Management Strategy of Georgia (2016–2030) on a nationwide scale was scheduled the stage-by-stage implementation of segregation of municipal solid waste, as a result of which the fractional composition of MSW will be changed along with reduction of quantity of MSW (Table 3).

Table 1 MSW composition in some regions of Georgia

Region	Glass	Paper	Metal	Plastic	Hygienic	Rubber/textile	Wood	Waste fine fraction	Hazard	Food	Total
Tbilisi	3.47	13.15	1.70	15.24	8.00	2.20	0.74	3.66	0.79	51.05	100.00
Samtskhe–Javakheti	2.75	12.00	3.23	13.80	6.80	0.77	0.78	10.80	0.37	48.70	100.00
Kakheti	2.81	11.15	2.85	11.50	5.04	1.00	0.25	22.58	0.50	42.32	100.00
Shida Kartli	3.13	11.30	2.84	15.56	5.18	0.53	0.73	16.69	0.30	43.74	100.00
Adjara	2.78	15.50	2.48	15.36	7.24	1.70	0.22	9.80	0.80	44.12	100.00
Guria	2.19	11.59	3.48	15.48	5.74	0.38	0.50	17.74	0.75	42.15	100.00
Mtskheta-Mtianeti	1.51	9.93	3.78	15.48	5.92	1.81	0.67	16.01	1.00	43.89	100.00
Average	2.66	12.09	2.91	14.63	6.27	1.20	0.56	13.90	0.64	45.14	100.00

Table 2 Average annual quantity of MSW (2015–2016) collected by municipal services in Georgia

Region	Kg/per capita/year	Waste disposal service enjoying the percentage of population,%
Tbilisi	318.35	100
Samtskhe–Javakheti	245.93	40
Kakheti	170.10	30
Shida Kartli	274.82	40
Adjara	270.45	100
Guria	165.30	30
Mtskheta-Mtianeti	169.12	40

Table 3 Segregation of solid domestic waste according to National Waste Management Strategy of Georgia scheduled on a nationwide scale (2016–2030)

Fraction of MSW	2020 (%)	2025 (%)	2030 (%)
Paper	30	50	80
Glass	20	50	80
Metal	70	80	90
Plastic	30	50	80
Food[a]	10	35	60

[a]Assumption is made by the authors, since the National Waste Management Strategy (2016–2030) does not consider the mentioned fraction

4 Conclusion

Under conditions of scheduled changes of waste quantity and fractional composition and also for Adjara Autonomous Republic was made the forecast of methane inventory until 2030. Results and corresponding forecast are given in Table 4, from which is seen that reduction of disposal of some fractions of waste at the landfills starting with 2020 will cause reduction of greenhouse gases in the period of 2021–2030:

(a) Removal of part of paper, plastic, metal and glass fractions—by 6, 8% in average (1.3–12.65%);
(b) Removal of paper, plastic, metal, glass and food waste fractions—by 16, 8% in average (2.63–32.26%).

Research results confirm that waste segregation and reduction of paper and the most important food waste fractions in MSW entering the landfills will reduce methane emission by 32, 26% for 2030.

Table 4 Forecast of methane emission from waste sector of Adjara Region for current conditions and under conditions of changed quantity and composition during MSW segregation

Year	Present conditions	a		b	
	Gg	Gg	% (reduce)	Gg	% (reduce)
2015	1.69	1.69	0.00	1.69	0.00
2016	2.17	2.17	0.00	2.17	0.00
2017	2.62	2.62	0.00	2.62	0.00
2018	3.02	3.02	0.00	3.02	0.00
2019	3.40	3.40	0.00	3.40	0.00
2020	3.75	3.75	0.00	3.75	0.00
2021	4.08	4.03	1.30	3.97	2.63
2022	4.39	4.28	2.53	4.15	5.47
2023	4.69	4.51	3.73	4.29	8.47
2024	4.97	4.73	4.92	4.40	11.58
2025	5.25	4.93	6.09	4.47	14.78
2026	5.52	5.11	7.27	4.52	18.05
2027	5.78	5.28	8.51	4.54	21.45
2028	6.03	5.44	9.83	4.53	24.97
2029	6.28	5.58	11.21	4.49	28.57
2030	6.53	5.71	12.65	4.42	32.26

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Identify and Assess the Impact of Climate Change and Sea Level Rise to the System of Landfills and Solid Waste Treatment Facilities in the Central Coast Region of Vietnam

Nghiem Van Khanh

Abstract The impact of the phenomenon of climate change and sea level rise to the provinces in the central littoral region of Vietnam is going on clearer every day, whereby the solid waste treatment plants become one of the factors which caused serious ecological environmental pollutants. In particular, in this context, most of the provinces in the central littoral region have made the planning of solid waste management. But in fact, the local is still difficulty in preparing the "Report action plan to respond to climate change in the province". Therefore, the paper offers the results of studies identifying, assessing the impact of climate change and sea level rise for the landfill system, the treatment plants in the central littoral region. It is a factual basis to assist the work of the proposed plan of action in solid waste management activities in the province to cope with climate change, and rising sea levels are appropriate and effective.

Keywords Climate change · Landfill · Solid waste treatment facilities

1 Introduction

The importance of adaptation to climate change (CC) in the planning of solid waste management (SWM) is currently very large, and it deserves more attention in the process of urban planning, the planning policy, for several reasons: urban SWM system has now been proven vulnerable by the due to floods, landslides and storms everyday. It was interrupted for a certain period of time due to the extreme weather events; SWM system is considered most vulnerable in the development and expansion of urban, when the infrastructure system and the suitability of the

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location of the SW treatment facilities play an important role. The high environmental and healthful risk from the potential disaster happening on a large scale, from unsanitary and without planning landfills, which is directly related to the SWM has not been determined in responding to climate change objectives. In the modern city, the test and consider the likely impact of climate change scenarios according to the position of planning, building new and old landfills is essential. The old landfills, even when closed, will cause pollution risk, if located in flood-prone areas. The new landfills are the most vulnerable part of SWM chain, capable of causing environmental damage is very high, especially in the case of erosion or flooding. Therefore, the article is written with the research on the methods and results of the evaluation, identifying the impact of climate change on the system of solid waste treatment facilities in the central coastal provinces.

2 General Introduction to the Central Coastal Region [1]

Central Coast region has 90,790 km^2 natural area, accounts for 28% of the country's natural and divided into two sub-regions: North Central Region and Central Coast.

2.1 Natural Features

The height of the region descending from the mountains down to the midland hills, down to the plains in the coastal sand dunes and out to the coastal islands. Coastline is about 1000 km.

It has the most harsh climatic conditions in Vietnam. Annually, more frequent natural disasters such as storms, floods, Laos wind, droughts, the underlying cause by location, terrain structure are created.

Thua Thien-Hue is one of the provinces with the most rainfall in Vietnam with annual average rainfall in excess of 2.600 mm, where up to 4.000 mm. The coastal plain of Thua Thien-Hue least rainfall, but also the annual average from 2700–2.900 mm.

- Every year from 200 to 220 days of rain in the mountains, 150–170 days of rain in the coastal plain area. In the rainy season, each month, there are 16–24 days of rain. The rains lasted several days usually caused widespread large flooding.
- The topography of the west, from Ha Tinh to Thua Thien-Hue, includes high mountains; rivers flow towards the NW-SE empties into the sea; the river is narrow, steep, small catchment area with relatively large amount of rain will pour down floods born, rise quickly and cause flooding for areas low eastern plains. Example: Song Huong—Bo River, upstream height is 1.318 m, the length is over 100 km and basin area is 2.690 km^2, flowing from north to south

near the sea poured in Thuan An. Since the entire area of the river basin over 80% is mountainous, plains mostly remaining lower than sea level, most will be inundated during the flood on alert level 3 (equivalent to 3.5 m).

- Due to the rainfall from 68 to 75%/year should normally cause major flooding damaging production, property, human life, the negative impact on the environment and ecology. In contrast, during the dry season, the water supply was not enough for living and production in a number of localities in the region.
- As flood season in the North Central occurs from July to October, in the South Central Coast usually occurs from October to December.
- The massive floods that occurred in central in the years 1952, 1964, 1980, 1983, 1990, 1996, 1998, 1999, 2001, 2003 …. At one point flooding as waves superimposed flood floods in November, 12, 1999; October, 11, 2010.

2.2 Economic and Social Characteristics

The total population of the region in 2015 is about 20 million people, the urbanization rate is of 32%, and average population growth rate is of 1.1%. Region which has some strength in economic development is mining and marine aquaculture. In addition to fishing operators are shrimp, squid, crab …. In technology, mainly construction materials industry which notably cement and brick production, distributed in all provinces. On agriculture, the strength of the region is to develop industrial crops such as peanuts annually, straw, sugarcane, mulberry, pineapple, recently the development of tea, rubber, coffee, cocoa.

2.3 Infrastructure Systems

Regional transportation infrastructure is being renovated and is a new construction. Technical Infrastructure Central Coast region is stable with 6 airports, 13 seaports (7 ports Type 1), 14 highway, railway north–south running through, evenly distributed in the provinces, connecting cities, economic zones and industrial parks in the region.

3 Summary of Status Report, the Planning of Landfills, Solid Waste Treatment Facilities in Central Coast Provinces [1]

The total number of existing landfills in ten provinces is 165, of which:

– Number of active landfills is 141
– The number of closed BCL is 22

– The sanitary landfills are 22 (approximately 13.3% of the existing landfills and 15.6% of the total number of active landfills).

The volume of discharged solid waste currently and the collection, treatment of solid waste in each province particular are shown in Table 1.

- Now, the main technology to treat the solid waste in the province is landfill, in which the provinces have the highest rate of sanitary landfills which are Da Nang (100%) and Hue (55.6%); the lowest rate is Quang Binh, Quang Tri (no sanitary landfills)
- The percentage of sanitary landfill compared to the total is low, especially rural areas (only 2/10 provinces had ratios of over 50% sanitary landfills).

Table 1 Situation of treatment, solid waste landfills in the central coastal provinces 2014–2015 [1]

Name of province	The volume of discharged solid waste (Ton/day)	Rate of collection, % (*)	Landfill		Main treatment technologies
			Sanitary/ total	Operating/ total	
Thanh Hoa	421.28	60–100	2/31	25/31	Landfill 100%
Nghe An	402	70	0/22	20/22	Landfill + compost
Quang Binh	500		0/9		Landfill 100%
Quang Tri	518.3	90 (10–15)	0/33	31/33	Landfill 96% + 4% incineration
Thua Thien-Hue	453.1	85–100 (30)	5/18	18/18	Landfill 60% + production of renewable materials 20% + compost 20%
Đa Nang	242.33	93	2/2	1/2	Landfill 100%
Quang Nam	600	55	5/16	15/16	95% Landfill + 5% incineration
Quang Ngai	186.8	70–75 (20–35)	4/14	14/14	Landfill 60% + compost 20% + incineration 20%
Binh Thuan	501	80	2/12	12/12	Landfill 83.3% + incineration 14.7%
Phu Yen	785	90 (50)	2/8	8/8	Landfill 100%

Note The values in parentheses are the percentage of solid waste collected at the district and rural areas

4 Trends and Forecast Impacts of Climate Change—Sea Level Rise for Landfills System in Central Coast Provinces

Based on the National Strategy on Climate Change of the Prime Minister in 2011 [2], the scenarios of climate change and sea level rise by the Ministry of Natural Resources and Environment, 2012 (medium emissions scenario B2) [3], the report assessment the impact of climate change and rising sea levels in the provinces and an action plan to cope with climate change and sea level rise in the coastal central provinces [4], the paper forecasts the areas most influenced by climate change and sea level rise impact landfills systems, and treatment facilities are operating and planned in the future in the Central Coast provinces, and the detail is shown in Table 2.

Table 2 Synthesis of climate change trends and forecast the impact of climate change, sea level rise on landfill system in the central coastal province [1, 5]

Province/city	Areas most influenced by climate change and sea level rise	Landfills/treatment facilities impacted	
		Currently operates	planning
Thanh Hoa	D. Nga Son, C. Thanh Hoa, D. Quang Xuong, D. Hau Loc (commune Thanh Đinh, Thanh Kim, Thanh Hung, Kim Tan)	Landfill in wards Phu Son, C. Thanh Hoa	Treatment facilities (T.F.) in townships Hau Loc
		Landfill in townships Quang Xuong	
		Landfill in townships Nga Son	
Nghe An	T. Cua Lo, D. Nghi Loc, D. Dien Chau và D. Quynh Luu	Landfill in Nghi Yên, Nghi Loc	T.F. in Nui Go Doc, commune Quynh Loc, Quynh Luu
		Landfill in townships Dien Chau	Composting Plant Vung Trai Eo, commune Dien Yen, Dien Chau
		Landfill in commune Ngoc Son, Quynh Luu (khu LH)	
Quang Binh	D. Quang Trach, C. Đong Hoi	Landfill in Quang Long, D. Quang Trach	Landfill in Quang Tien, D. Quang Trach
TT Hue	D. Phu Vang, D. Phu Loc, D. Quang Dien, D. Huong Thuy, D. Phong Dien, townships Thuan An	Landfill Thuy Phuong, Huong Thuy	Sanitary landfill in commune Quang Loi, D. Quang Đien
		Landfill Lang Co, commune Lang Co, D Phu Loc	Landfill in commune Phu Xuan, D. Phu Vang
		Landfill Loc Thuy, D. Phu Loc	

(continued)

Table 2 (continued)

Province/city	Areas most influenced by climate change and sea level rise	Landfills/treatment facilities impacted	
		Currently operates	planning
Đa Nang	Riverside plains Vinh Dien, Co Co, Cam Le và Cu De	Landfill Khanh Son (old)	Landfill Khanh Son (new)
Quang Nam	C. Hoi An (Cam An, Duy Nghia, Cam Ha, Cam Kim, Phuoc Dung, Vinh Thanh, Cam Thanh, Cam Nam); Tam Ky, Nui Thanh (Tam Hoa, Tam Xuan 2, Tam Giang, Tam Nghia, Tam Hiep); Thang Binh; Dien Ban	Landfill Hoi An	T.F. Tam Xuan 2
		Treatment facility Tam Xuan 2	Landfill Tam Nghia
		Landfill Tam Nghia	Composting plant Cam Ha
Quang Ngai	East of D. Binh Son, D, Tu Nghia; D. Mo Duc (townships Mo Duc), Southeast of D. Duc Pho (townships Duc Pho), D. Son Tinh (townships Son Tinh), C. Quang Ngai, townships La Ha, townships Song Ve	Landfill Nghia Ky, C. Quang Ngai	Landfill Duc Lan, D. Mo Duc
		Landfill townships Mo Đuc	T.F An Dien, commune Pho Nhon, D. Duc Pho
		Landfill in townships Duc Pho	
		Landfill in townships Son Tinh	
Phu Yen	T. Song Cau, D. Dong Hoa, C. Tuy Hoa	Landfill Tho Vuc C. Tuy Hoa	T.F C. Tuy Hoa (commune Hoa Kien)
			Landfill in commune Xuân Binh—T. Song Cau
			Landfill in commune Hoa Xuan Tay, D. Dong Hoa
Binh Thuan	Phan Ri—Bac Binh; Phu Thuy, Minh Hoa—Tuy Phong, C. Phan Thiet (Phong Nam, Tien Loi); D. Ham Thuan Nam (commune Hiep Phuoc, Cay Gang, Ke Ga); T. La Gi	Landfill Hai Ninh/landfill unsanitary, Hai Xuan, commune Hai Ninh, D. Bac Binh	T.F Da Loc, commune Tan Binh, T. La Gi
		Landfill Phuoc Tan, commune Tan Phuoc, T. La Gi	Landfill Hai Ninh, commune Hai Ninh, D. Bac Binh
		Landfill Ganh Hang, D. Island Phu Quy	Landfill Song Luy, commune Song Luy, D. Bac Binh

Note: *D* District; *C* City; *T* Town

5 The Impact Assessment of Climate Change—Rising Sea to the Landfill System in Central Coast Provinces

5.1 *Evaluation Methods [5]*

5.1.1 Assess the Possibility of Phenomena, Events

The event is classified based on the statistics data on current climate variability, weather conditions in the past of each province and mainstreaming climate change trend under climate change scenarios of Vietnam. Evaluate the possibility of phenomena, events for landfills, solid waste treatment facilities in each province using qualitative methods, based on the possibility of a measure under five levels: It is very hard happens, hard happens, Uncertain happen, able happen, certain happen. Depending on the degree (strong, weak) and the frequency of occurrence of the factors related to climate change, the level of risk will be from "low" to "very high" (Table 3).

5.1.2 Evaluate the Impact of These Phenomena, Events

The evaluation was carried out according to the documentation assess the impact of climate change and identify adaptation measures of the Academy of Hydrometeorology Sciences and Environment. The method evaluated in matrix is commonly used and the most effective tools to assess the impact and the ability vulnerability due to climate change and sea level rise. Details of method assessment matrix are presented in Tables 4 and 5.

Consequences of climate change must be examined on tolerance effects of the climate change factor for each landfill or solid waste treatment facility.

To determine the impact of the climate change factors may use multiple assessment methods: qualitative and quantitative difference. However, for landfills and treatment facilities in the Central Coast provinces, using qualitative methods of

Table 3 Evaluation of the likelihood of climate change factors [5]

Numerical order	The factors related to climate change	Evaluated by scoring the possibility of annual happen	
1	Changing rainfall	Certain	5
		Able	4
2	Temperature fluctuations	Uncertain	3
		Hard	2
3	Sea level rise	Very hard	1
4	Storms, depressions and tropical cyclones		

Table 4 Quantitative measure to determine the risks posed by climate change impacts [5]

The ability of impacts occur	The loss—damages				
	Trivial	Medium	Important	Serious	Disaster
Barely	Low	Low	Low	Low	Low
Unlikely	Low	Low	Medium	Medium	Medium
Ability	Low	Medium	Medium	High	High
More likely	Low	Medium	High	High	Very high
Almost certainly	Low	Medium	High	Very high	Very high

Table 5 Quantitative measurement to determine the ability vulnerable [5]

Risk level	Capacity to adapt		
	Low	Medium	High
Very High	High	High	Medium
High	High	Medium	Medium
Medium	Medium	Medium	Low
Low	Low	Low	Low

assessment. Qualitative methods of measurement on the quantitative measure of the ability to influence the subject of planning. The degree of impacts is assessed through five steps: very small, small, medium, large, very large (Table 6).

Table 6 Assess the influence level of climate change on landfills, solid waste treatment facilities (SWTF) [5]

Numerical Order	Level of impact	Properties	Landfill, SWTF
1	Very high	Increased rainfall	Affect people's lives. The high risk of major epidemics spread. The high ability landslide surrounded walls of landfills
2	High	Increased temperature	Increases the decomposition of organic components, potentially large smelly, costly deodorizing chemical used in landfills
3	Medium	Sea level rise	Damage to infrastructure on a large scale, increasing the risk of flooding, landside surrounded walls of landfills and SWTF
4	small	Tropical cyclone	Large-scale damage and requiring expensive repair costs, regular and hinder the collection, transportation and treatment of solid waste
5	Very small	Drought	Damage to speed the decomposition of waste in landfills was slower

5.1.3 Assess the Level of Risk Due to Climate Change to Landfills, SWTF

Risk assessment to landfills and treatment facilities due to the impact of climate change and sea level rise are assessing losses, damages, potentially affecting landfills, SWTF due to the impact of climate change.

The level of risk is considered through the integration scenarios of climate change of the Ministry of Natural Resources and Environment and orientation construction planning landfills, SWTF on the provinces of Central Coast, including consideration to factors such as natural conditions, topography, climatic conditions, environmental, residential area at the location of each landfill, SWTF identified in the plan (Table 7).

Risks to landfills, SWTF due to the impact of climate change and sea level rise are determined by the extent of damage (from low to high) based on the suitability of the location landfills, SWTF and process technology used. To assess the level of risk to the effects of climate change on landfills, SWTF can be divided into four levels of risk as follows:

Determining the extent of climate change risk in general solid waste management and in particular landfills, SWTF, based on the study of a number of organizations such as the Intergovernmental Panel on Climate Change (IPCC), ACCCRN, handbook of climate change impact assessment and adaptation strategies (UNEP) … Assessing the level of risk is aggregated by "ability/events" and "the consequences of the climate change phenomenon".

Weights are determined in order to evaluate and compare the importance and the impact of the consequences of climate change on landfills, SWTF. Weights are determined as follows:

- For landfills, SWTF, flooded issue is big problem, which often occurs when there is rain; compared to other consequences, flooding should be considered to evaluate, so the importance is determined accounting for 35% (0.35) compared with other risks.

Table 7 Relationship level of risk and the response [5]

Level	Properties	The subjects are affected	The response activities for landfills, SWTF
1	Low (L)	– Activities in the process of operating landfills, SWTF – The suitability of the location of the SWTF, the treatment technology	Requires regular maintenance work
2	Medium (M)		Requires regular maintenance and adjustments in the design
3	High (H)		Requirements on design adjustments, changes in technology and need to research, specific plans to integrate climate change adaptation
4	Very high (VH)		Need to change the solid waste management method, change the position of SWTF

- The possibility of landfills flooding in the rainy season is large, consequently causing pollutants from leachate into the environment easily spread soil, surface water, groundwater, so the importance is determined accounting for 30% (0.3) compared with other risks.
- Ability to generate odours from landfills, SWTF has a major impact on the surrounding environment, but caused no major consequences, so the importance is determined accounting for 20% (0.2) compared with other risks.
- Environmental consequences from the risk of landside surrounded walls, embankments of landfills and SWTF, risk a major impact on environmental quality, but the likelihood is low due to the construction of landfills; SWTF process has taken into account the technical solutions, minimizing the risk of landside surrounded walls, embankment so the importance is determined accounting for 15% (0.15) compared to other risks.

→ The consequences of climate change and sea level rise to landfills, SWTF corresponding to each level of risk as follows: The level of risk is very high: 4–5; a high level of risk: 3–4; the average risk level: 2–3; lower-risk level: 1–2; very low-risk level: 0–1.

5.1.4 Assess Response of Landfills, SWTF

To assess the response of the landfill, SWTF to the elements due to climate change, the need to determine the impact indicators as:

- The level of investment in equipment systems, machinery, raw materials, chemicals and manpower, ensuring operation of the landfill: this is the economic resources to ensure enhanced response risks due to climate change and sea level rise.
- Technology and technical use to treat solid waste: in which, unsanitary landfill capable lowest response, compared to the recycling technology, composting, burning.

Assess response of landfills, SWTF is a combination of factors economic investment, human resources, engineering, technology used. Based on the above factors can assess the degree of impact or damage to the landfill, SWTF as follows:

Adaptability:			
Very good	4–5	Normal	2–3
Good	3–4	Not good	1–2
		Weak	0–1

5.1.5 Integrated Assessment of the Impact of Climate Change to Landfills, SWT

The degree of impact or damage caused by climate change to landfills, SWTF is a synthetic elements, including: degree of risk; Ability to cope (response) and is determined by the function:

$$\text{The degree of impact} = \text{f}(\text{degree of risk; ability to respond})$$

Based on the average score of the above factors, assess the vulnerability and the impact of climate change and sea level rise on technical infrastructure system in five levels: level of impact high: 0–1; high impact level: 1–2; the average level of impact: 2–3; low impact level: 3–4; very low level of impact: 4–5.

5.2 The Result of the Climate Change—Sea Level Rise Impact Assessment to Landfill System of the Central Coast Provinces

Currently, most of the central coast provinces have reported up plans to cope with climate change and sea level rise in the province, but no specific assessment on the impact of climate change and sea level rise on with landfills in the province, only a general assessment of the environmental field [4].

(1) The degree of the impact of natural disasters on the landfills was surveyed as follows:

- No impact: Quang Binh, Da Nang, Quang Ngai.
- From mild to low impact: Nghe An, Quang Tri, Hue.
- From moderate to severe: Thanh Hoa, Quang Nam, Phu Yen, Binh Thuan.

(2) Ability to respond of the construction items of landfills in coping with climate change and sea level rise as follows:

- From 0 to 50% of the construction item cannot respond: Thanh Hoa, Quang Binh, Da Nang, Quang Nam, Phu Yen, Binh Thuan.
- Over 50% of the work construction item cannot respond: Nghe An, Quang Tri, Hue, Quang Ngai.
- Synthetic assessment on the situation of climate change and sea level rise impacts on landfills in the Central Coast provinces are presented in Table 8.

Table 8 Synthetic assessment on the situation of climate change and sea level rise impacts on landfills, SWTF in the Central Coast provinces

Numerical order	Province/landfill, SWTF	Risk level	Ability to cope	The overall vulnerability	
	Thanh Hoa				
1	Landfill in Phu Son, C. Thanh Hoa	**3**	**3.6**	**3.3**	Low
2	Landfill in Quang Xuong town	**2.65**	**3.25**	**2.95**	Medium
3	Landfill in Nga Son town	**2.85**	**2.7**	**2.78**	Medium
4	SWTF of Hau Loc town	**2**	**3.0**	**2.5**	Medium
	Nghe An				
1	SWTF of Nghi Yên, Nghi Loc	**3.35**	**2.95**	**3.15**	Low
2	Landfill in Dien Chau town	**3.3**	**3,25**	**3,28**	Low
3	Landfill in Ngoc Son, Quynh Luu	**2.5**	**3,85**	**3,18**	Low
4	SWTF of Nui Go Doc, Quynh Loc, Quynh Luu	**2.0**	**3,3**	**2,65**	Medium
5	Composting plant Vung Trai Eo, Dien Yen, Dien Châu	**2.35**	**3,25**	**2,8**	Medium
	Quang Binh				
1	Landfill in Quang Long, Quang Trach	**3.2**	2	**2,6**	Medium
2	Landfill in Quang Tien, Quang Trach	**2.85**	3	**2,93**	Medium
	Thua Thien-Hue				
1	Landfill in Thuy Phuong, Huong Thuy	**1,85**	**3,65**	**2,75**	Medium
2	Landfill in Lang Co, Phu Loc	**2**	**3,35**	**2,68**	Medium
3	Landfill in Loc Thuy, Phu Loc	**2,5**	**3,15**	**2,83**	Medium
4	Landfill in Quang Loi, Quang Dien	**2,85**	**3**	**2,93**	Medium
5	Landfill in Phu Xuan, Phu Vang	**3,3**	**2,4**	**2,85**	Medium
	Da Nang				
1	Landfill in Khanh Sơn (new)	2,15	2,65	**2,4**	Medium
2	Landfill in Khanh Sơn (new)	2,45	2,05	**2,25**	Medium
	Quang Nam				
1	Hoi An Landfill	**3,3**	**2,4**	**2,85**	Medium
2	SWTF of Tam Xuan 2	**2,55**	**3,0**	**2,78**	Medium
3	Tam Nghia Landfill	**2,25**	**2,7**	**2,48**	Medium
4	Cam Ha compost plant	**1,7**	**3,0**	**2,35**	Medium
	Quang Ngai				
1	Nghia Ky landfill	**2,5**	**3,3**	**2,9**	Medium
2	Landfill in Mo Duc town	**3,55**	**2,55**	**3,05**	Low
3	Landfill in Duc Pho town	**3,55**	**2,8**	**3,18**	Low
4	Landfill in Son Tinh town	**3,85**	**2,25**	**3,05**	Low

(continued)

Table 8 (continued)

Numerical order	Province/landfill, SWTF	Risk level	Ability to cope	The overall vulnerability	
	Thanh Hoa				
5	Landfill in Duc Lan, Mo Duc	**2,85**	**3**	**2,93**	Medium
6	SWTF in An Dien, Pho Nhon, Duc Pho	**2,35**	**3,55**	**2,95**	Medium
	Phu Yen				
1	Landfill in Tho Vuc, Tuy Hoa City	**2,8**	**3,6**	**3,2**	Low
2	SWTF in Hoa Kien, Tuy Hoa City	**2,55**	**3,25**	**2,9**	Medium
3	Landfill in Xuan Binh – Song Cau	**3,2**	**2,4**	**2,8**	Medium
4	Landfill in Hoa Xuan Tay, Dong Hoa	**3,5**	**2,7**	**3,1**	Low
	Binh thuan				Low
1	Landfill Hai Ninh, Bac Binh	**3,7**	**2,4**	**3,05**	Low
2	Landfill Phuoc Tan, La Gi	**2,45**	**3,0**	**3,73**	Low
3	Landfill Ganh Hang, Phu Quy Island	**2,85**	**2,4**	**2,63**	Medium
4	SWTF Da Loc, Tan Binh, La Gi	**2,0**	**3,3**	**2,65**	Medium
5	landfill Sông Luy, Bac Binh	**3,2**	**2,7**	**2,95**	Medium

6 Conclusion

Climate change really did affect the planning, development planning: Disaster, floods and droughts is increasing along with the increase in global temperature, the planned economic development planning, urban planning and land use planning and other disciplines, including the planning of solid waste management needs to adapt to the impact of current, as well as the potential impacts of climate change.

The management of solid waste plans in the local normally is not considered the impact of climate change. It only focus on risks posed by climate change at the present time or even mentioned climate change but the lack of guidelines give. In all cases, the planning of solid waste management does not integrated the impact of climate change will be very difficult to change in the future to adapt to climate change. Results of the study have initially contributed actively in proposing policy solutions, economic and technical development towards environmental sustainability, reduce environmental pollution caused by impact of climate change on the system of solid waste treatment facilities in Vietnam.

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The Development of Sustainable Materials Management (SMM) and Circular Economy in Taiwan

Leon Tzou, Kun-Hsing Liu and Allen H. Hu

Abstract After a series of policy measures and economic incentives imposed by the government in the early 90s, the waste management in Taiwan has achieved an impressive result and the national recycling rate was increased from 21 to 62% during 2003 to 2012. However, waste management problems still may happen when a new business trend emerges such as a new technology, product, or a consumption pattern. The government thus began to adopt the concept of sustainable materials management (SMM) brought by OECD to manage all materials in a systematic way. Other than SMM, the initiates of circular economy emerge as a new trend recently in Europe to transform the conventional linear economy practice into a circular one and the prospect of circular economy in Taiwan is discussed herein.

Keywords Waste management · Sustainable materials management
Circular economy

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1 Background

1.1 The Municipal Waste Management in Taiwan

To begin, with regards to the municipal solid waste (MSW) management, the municipal waste currently in Taiwan is 0.6–0.8 kg per capita/day, which is comparatively lower than that of 2 kg capita/day in the USA. The development of MSW management in Taiwan started from dumping (before 1984) through sanitary landfill (1984–1990) and incineration (since 1990) to resource recycling and recovery (since 2004). The respective MSW initiatives included Extended Producer's Responsibility, Large Incinerators (1991), Four-in-one Recycling program (1997), Per-bag Trash Collection Fee in Taipei (2000), Food Waste Recycling (2001), Source Reduction (2002), Zero-waste Policy (2004), Garbage Sorting/ Recycling (2005–2006), and Sustainable Material Management (2011). More specifically, in the Four-in-one Recycling program, implemented since 1997, four categories are established (Fig. 1). These categories include recycling industries to collect recyclable from citizens, communities and local sanitary crews, local authority to collect and further sorting MSW, community residents to promote MSW sorting in the community, and recycling fund to provide financial incentive. Moreover, the resource recycling management fund currently has three working committees included which are the Resource Recycling Fee Rate Review committee, Management Fund Committee, and the Auditing/Certification Group

Fig. 1 Four-in-one Recycling program. *Source* Environmental Protection Administration, Executive Yuan, R.O.C. (Taiwan)

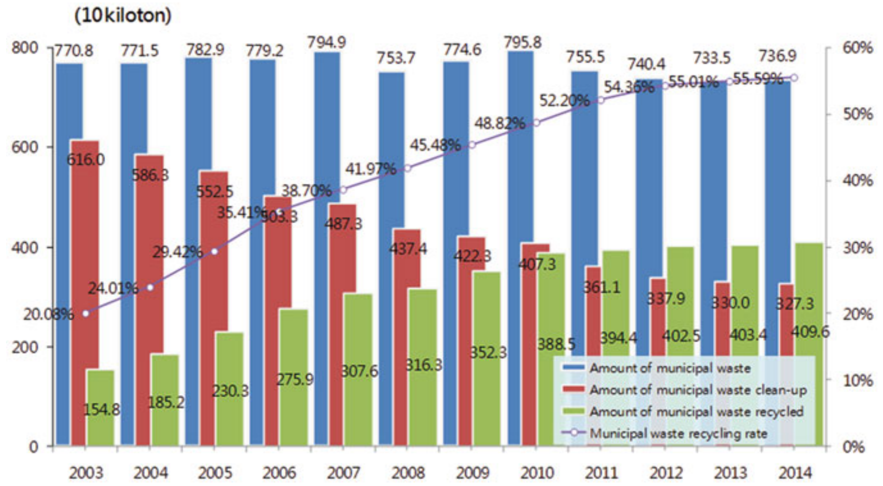

Fig. 2 MSW quantity and recycling rate. *Source* Environmental Protection Administration, Executive Yuan, R.O.C. (Taiwan)

Supervisor Committee, in order to assure independent, coherent as well as authoritative scientific assessments.

For the municiple waste management, the Extended Producer's Responsibilities (EPR) principle states the regulations of producers should take physical and financial responsibility of recycling post-consumer products in most EPR program, and that producers only need to pay recycling fees to Taiwan Environmental Protection Administration (EPA), that then uses the fees to subsidize collection and recycling. That being said, the per-bag trash collection fee is regulated in several areas for further reduction of waste. In Taipei, the per-bag trash collection fee is NT $0.36/L, which results in a decrease in waste volume by 67%, and an increase in recycling volume by 48%. As a result, the municipal waste recycling rate grew from 20.08% in 2003 to 55.59% in 2014 (Fig. 2), which clearly shows successful strategies and approaches in municipal waste treatment. In sum, the amount of municipal waste as well as the amount of municipal waste clean-up tends to decrease, while the amount of municipal waste recycled has increased accordingly.

1.2 The Industrial Waste Management in Taiwan

Secondly, moving on to the industrial waste treatment, the development of approaches in industrial waste management started from disposal (before 1990), through reduction (mid-1990s), and reuse/recycling (mid-2000s) to sustainable materials management (after 2010). After mid-2000s, the management established an efficient industrial waste report and management system in comparison with

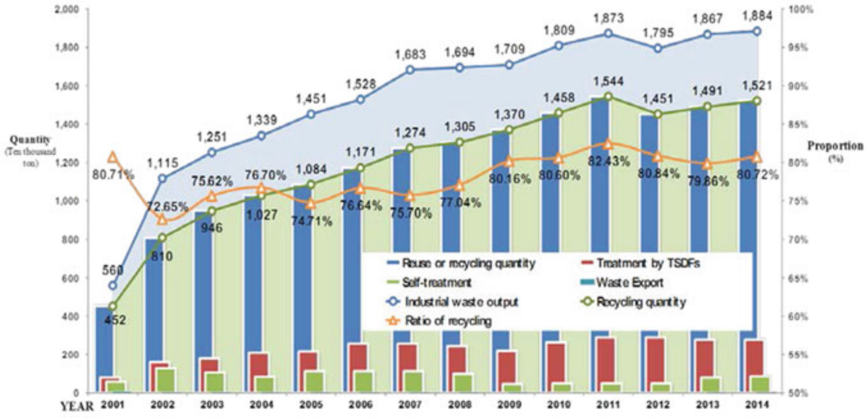

Fig. 3 Amount of industrial waste management in Taiwan. *Source* EPA Taiwan. [3]

using paper for reporting before mid-1990s. In 2004, the recycling rate of 80.72% and industrial waste amount of 18 million tons were reported while the strategy of industrial source reduction was implemented (Fig. 3) [3]. In regard to the industrial waste control and tracking, 100% of hazardous industrial waste and 90% of industrial waste are transported by vehicles that are equipped with GPS devices to prevent illegal dumping. While the strategy of industrial source reduction was implemented, the industrial waste output value reached NT$65.9 billion in 2013.

2 Sustainable Materials Management in Taiwan

Sustainable materials management (SMM) is defined by OECD [5] as an approach to promote sustainable materials use, integrate actions targeted at reducing negative environmental impacts, and preserve natural capital throughout the life cycle of materials, taking into account economic efficiency and social equity. The journey from waste management toward SMM illustrates that, at present, the "Waste Disposal Act," which is the traditional "end-of-pipe" treatment, functions as the management acts for waste clearance and treatment. On the other hand, the "Resource Recycling and Reuse Law" emphasizes on the resource efficiency for recycling of substances. Due to an increasing complexity and the volume of waste generated, the Taiwan government is making effort to integrate the "Waste Disposal Act" and the "Resource Recycling and Reuse Law" into the "Cyclic Resource Usage Act," which aims to bring about materials usage and re-usage with more productivity over their entire life cycle, while reducing environmental impacts and increasing resource efficiency.

In addition, Taiwan's material use per capita for Domestic Material Consumption (DMC) in 2013 was 13.3 tons [4], which was close to European

Union's (28 countries) average, 13.2 tons as shown in Fig. 4. Also, in 2013, Taiwan had lower DMC material use per capita figure than Austria, Belgium, and the USA, but higher than Japan and Netherlands.

The main scheme of SMM has evolved from past end-of-pipe treatment to current zero waste and resources recycling, which is more sophisticated to 3R practice of recycle and reuse of resources and source reduction, to achieve maximum resource efficiency and minimum impacts on the environment, including the supply risk reduction, the production efficiency increase, the efficient consumption creation, and the MFA tool development, as shown in Fig. 5. To sum up, the key objectives of SMM in Taiwan in 2011 were established in three phases as follows: (1) Short-term (0–3 years), to identify the critical materials and relevant industries. (2) Mid-term (3–6 years), to plan and promote the cooperation mechanism of industries, and (3) Long-term (6–10 years), to formulate imperative rules of law and enhance the mechanism. Currently, the Sustainable Materials Management Policy Framework has been drafted and 10 types of prioritized materials and 30 critical materials had been tentatively identified based on three screening criteria, namely economic importance, supply risk, and environmental impact. A schematic framework for SMM in Taiwan can be seen in Fig. 5.

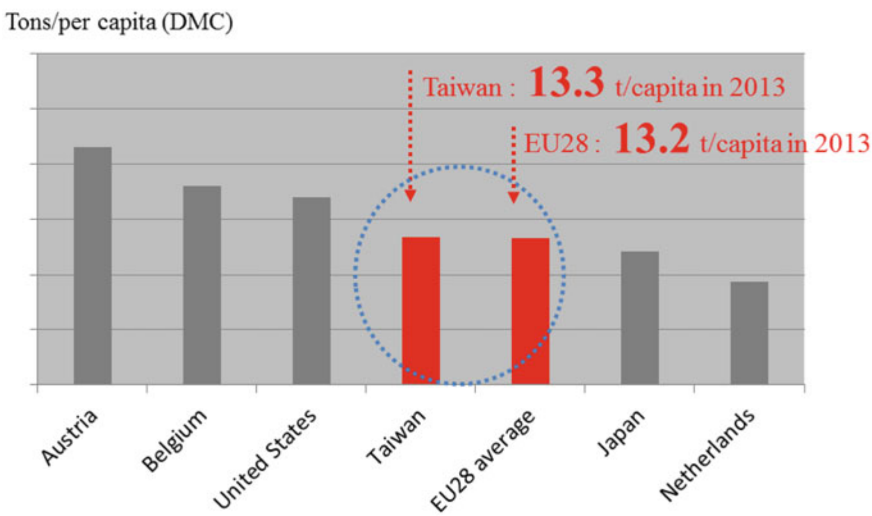

Fig. 4 DMC per capita in Taiwan and other area/countries.

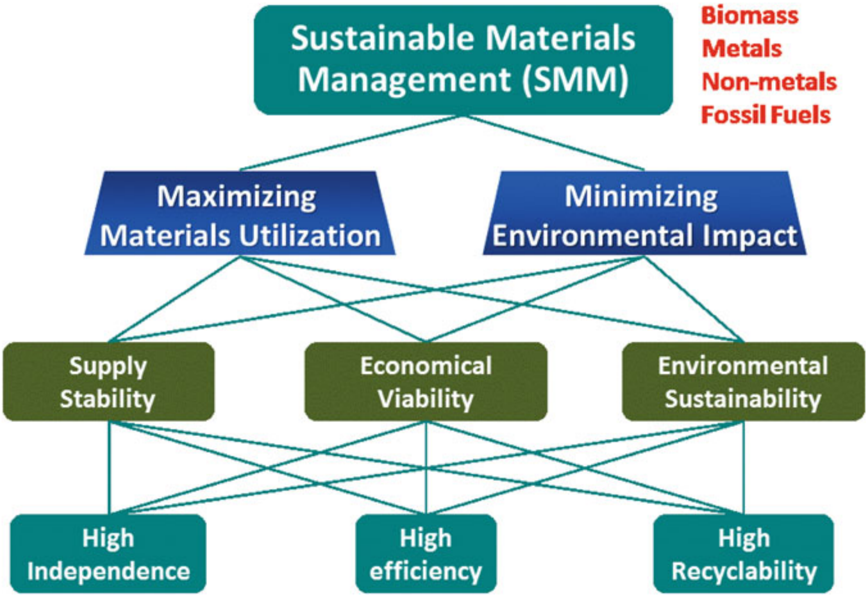

Fig. 5 Sustainable Materials Management Framework. *Source* Environmental Protection Administration, Executive Yuan, R.O.C. (Taiwan)

3 Circular Economy Prospect in Taiwan

3.1 The Definition of Circular Economy

"Circular Economy" can be a generic term for the reducing, reusing, and recycling activities conducted throughout processes of production, circulation, and consumption. In addition, "Circulation" refers to the fulfillment of changes in demand and improvement of resource efficiency with limited resources; "Economy" refers to the additional economic activities and value from research, manufacturing, and service derived from the circulation of resources. The concept of circular economy has been seen as the tool against the triple challenges of economic development, resource scarcity, and environmental degradation.

In another sense, circular economy is an industrial system that is restorative or regenerative both by intention and design. "It replaces the end-of-life concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impairs reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, with this, business models" [1, 2]. During recent years, circular economy has become an international hot topic and is expected to help finding ways for next economic development in both national and corporate level.

For many people, circular economy is similar to what were known as "low carbon economy," "green economy," or "eco-economy" from past campaigns. In reality, circular economy is evoked from the "take–make–dispose" linear economic model and transforms to the resource cycling modes to reach sustainable economic development. Circular economy has given a new meaning to 3R's in implement and is therefore viewed as an upgraded version of green economy. For Taiwan, as linear economy still remains the core of its manufacturing industry, the economy development is thus still interconnected to resource usage. Facing pressures from both within and abroad, industries are facing dilemma choosing between making profit and enforcing environmental protection. Considering the unique characteristics that the circular economy entails both industrial development and environmental preservation, it is worth further learning from Taiwan.

To begin, the basic principle demonstrates the "Minimization" concept which has shifted from end-of-pipe prevention of waste generation into reduction demand for material and energy during production and consumption stage, through improvement in resource efficiency. The most essential major driving force for minimization is "profitability" which can be seen through reusing and recycling. Reuse refers to extending the product life cycle to minimization waste generation through multiple usages during the "use" stage. Hence, "technology" is regarded as the solution to the issue and often conducted through R&D in design and raw material selection. However, to allow for "reuse" of product, one needs to overcome the conflict with the conventional business strategy to pursue higher profit and taking consumer behavior into consideration. Recycle refers to the cycling directly or indirectly after regeneration. Recycling technology and system are the basis for resource recycling, but government intervention and consumer behavior can make significant difference in recycling rate.

Under a circular economy, the "pay-per-use" concept is becoming more acceptable by consumers or users. By selling the use of the goods, companies retain the ownership of their goods, which means the owners can repair, re-manufacture, or recycle them; hence, companies have an incentive to implement green design and improving resource efficiency for their products.

3.2 What Can Be Done in Taiwan for the Circular Economy

Materials such as metal, PET, paper, and glass are in the mainstream for the material circulation development; materials such as PE, PP that are technologically feasible for recycling but rooms for improvement in terms of quality and recycling system; materials such as concrete, CO_2, and food waste that are large in quantity and have yet to be effectively utilized; materials for 3D printing material will transform the future manufacturing, and the application of the biological (renewable) material is the solution to the resource scarcity issue.

In the business viewpoint, the new and emerging business models indicate the following elements that have been identified through evaluation of the successful business models, including: (1) Strengthening customer relationship: through fulfillment of demand instead of providing a production, such as leasing or product sharing. (2) Converting product utilization rate into income, such as AirBnB. (3) Life cycle thinking of product-service integration: Formulating product design and market strategy through integration of product sales and service, in order to establish an effective recycling system. (4) Creating stable income and added value: Business model such as pay-per-service unit does create competitive advantage with competitors. (5) Mainstreaming of sharing economy: Regulatory system needs to be revised to establish a “sharing friendly” environment that will encourage both the consumers and product manufacturers to adopt such business model. The Uber and AirBnB services are now in the beginning level in Taiwan. In opposite to Uber or AirBnB, the leasing of photocopy machine is a successful business in Taiwan. The successful factors, or the challenges, of circular economy, are discussed in the next section.

3.3 The Challenges

Some critical issues outlined from various perspectives highlight the problems faced associated with circular economy. From the industrial level, the costs and risks associated with circular economy are listed below: (1) Costs: The price for some portion of materials might be higher than their market price; a working circular economy requires close collaboration among artery industry, venous industry and reverse logistics system and recycled raw materials might have an impact on product quality control. (2) Risks: Supply for recycled raw materials might be insufficient and unstable as well as consumers may have low acceptance for renew, reproduction, and reuse products, and thus, the market of recycled products needs to be expanded. From the perspectives of consumers, the reasons for consumers for and against of buying circular production service can be categorized into pros and cons. The pros includes: gaining value—renting is more cost-effective than buying for the seldom-used high-priced goods; holder of goods can earn extra income by renting out the goods, buying services helps to avoid maintenance fees and consumable material expenses and the gaining of approval from green consumers. In addition for other additional value, if circular economic products have more cost-reductive performance than liner economic products, the durability, and upgradability of a product, sharing economy creates virtual communities and retaining salvage value by selling high for unused goods/parts.

For the successful future of circular economy development in Taiwan, the four essential elements for circular economy are the four points: (1) Technology Development: The what, who, when, and how in the technology development. (2) Regulatory Framework and Economic Incentive: Government plays the role of establishing an enabling environment for circular economy as well as supporting measures such as stakeholder engagement, government procurement, standardization, and certification scheme, to create market incentive for the transition.

(3) Stakeholder Engagement: Stakeholders include consumer, producer, and government; and some of the engagement forms include, but are not limited to, inter-departmental and inter-industrial. (4) Business Model and Consumer Behavior: Requiring significant transition in business model as well as acquiring consumer acceptance in product-service systems, such as sharing economy.

4 Conclusion and Future Perspective

The progress of waste management in Taiwan has built a firm foundation for the development of SMM and circular economy. The main scheme of SMM is the evolution of the 3R in the waste management concerning the supply risk, production efficiency, consumption efficiency, circular management improvement, and the MFA tool development. Some of the recommendations for circular economy development in Taiwan includes strengthening investment in technologies and equipment, letting raw material prices truly reflect the real cost in order to enhance its use-efficiency, integrating artery and vein industry, as well as inter-departmental collaboration in government authorities, enhancing market acceptance of goods and services in circular economy, circulating scarce metal 3R information; to upgrade 3R technologies; to increase economic incentives and enhancing the quality of information for fundamental environment. SMM and circular economy are both to seek a best solution of resource use effectiveness under a systematic management.

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Integration of Environmental Impacts in Sustainable New Product Development

S. Roy, N. Modak and P. K. Dan

Abstract Introduction of new products has become a strategic area globally for sustaining a competitive advantage. There are several factors contributing to new product development (NPD) success known as critical success factors which are essential for firms' ultimate success. As per the survey, environmental concern should greatly be increased in magnitude in Indian manufacturing companies for success and survival. This study concerns about the identification of manifests used to signify the environmental impacts on NPD success where the success of firms has also been expressed by the environmental aspects. As empirical data and experiences have accumulated, manifests of environmental factor are eco-friendliness of the product, adverse effect of the product on environment, sustainability of the product, the environmental goal achievement rate of the new green products, compliance of new green products with the consumers' preference, meeting government policies for product development, recycling rate of the new green products, and hiring responsible employees. Same as the factor, environment-related measure is expressed by reduced cost, healthy relationship with investors, regulatory approvals, life-cycle analysis, and customer satisfaction. A semi-structured questionnaire has been developed, and detailed research interviews have been collected from design and development experts of Indian manufacturing companies. Reliability of the survey data has been tested by Cronbach's alpha reliability testing using IBM SPSS 21.0 software. The main objective of this study is to develop a framework using structural equation modeling (SEM) approach by IBM SPSS AMOS 21.0 software to analyze the effects of environmental impacts on NPD success. The hypothesis testing performed by using SEM approach proves that the environmental impact is positively related to product development success. In addition, identification of obstacles faced by manufacturing companies to implement environmental factor adds an extra novelty in this empirical research which will help to overcome the problems in future days.

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Keywords New product development · Critical success factors
Success measures · Environmental impact · Structural equation modeling

1 Introduction

NPD practice has become one of the necessary parts of the firms and organizations for sustainability in the competitive market environment. This situation has been enhanced by rapid escalation in global market and unpredictable market environment [1]. According to previous researches, there are various factors expressed as critical success factors as they are critical for success and survival of the firm [2, 3]. So, identification of these factors has become one of the most challenging areas of interest for researchers for confirming sustainability of NPD success. Various factors such as technology [4–6], research and development (R&D) [6–10], top management support [7, 11–17], cross-functional team collaboration [7, 8, 17–20] are mostly discussed by researchers in existing literature. This research concerns environmental impacts on sustainable NPD. Environmental impacts on product development are another issue which has been considered as one of the vital factors by researchers [21–25]. In the present scenario, globally manufacturing companies are facing a pressure for developing products which are less harmful to the environment [26]. This study is focusing on environmental impacts for sustainable new product development. Same as the success factors, there are various success measures identified by researchers which have been used to measure the NPD success of firms and organizations. These success measures have been manifested by various manifest variables such as market success, meeting budgets and schedules, speed-to-market [27], success rate, percentage of sales by new products, profitability relative to spending, technical success rating, sales impact, profit impact, meeting sales objectives, meeting profit objectives, profitability versus competitors [7], customer acceptance, customer satisfaction, meeting revenue goal, revenue growth, meet market share goal, meeting unit share goal, break-even time, attaining margin goal, attaining profitability goal, attaining return on investment goal, development cost, launch on time, achieving product performance goal, meeting quality guideline, and percentage of sales by new product [28] as described by researchers.

In this study, we consider environmental impacts as success factor and environment-related measures as success measure of new product development success (PDS) to develop a framework using structural equation modeling to build relationships among them and identify the obstacles to implement this factor in terms of its manifest variables, so as to overcome those issues in future.

2 Methodology

Structural equation modeling (SEM) is a methodology for representing, estimating, and testing a theoretical network of (mostly) linear relations between variables, that is, measured variable and latent constructs [29]. The SEM approach is used here to develop the relationship among factors which are critical for organizational success and survival and correlate them with the new product development success. It is a comprehensive statistical approach for analyzing hypotheses about relations among manifest and latent variables [30]. This study concerns about the role of the environmental factor and its manifests and sets hypothesis to relate this factor with the product development success (PDS) which is again measured by environment-related measures. This empirical research considers the Indian manufacturing industries for the survey purpose, and data has been collected from their NPD personnel, design and development experts and managers. The statistic used in this work is obtained from the respondents of 36 engineering product development companies, especially electrical manufacturing and structural fabrication companies in India. Cronbach's alpha reliability testing has been performed for testing the reliability of the survey data by calculating the value of alpha (α) [31] using IBM SPSS 21.0 software. Structural equation modeling (SEM) approach has been used to develop the framework of the interrelationship of environmental constructs and product development success (PDS) and their manifest variables. IBM SPSS AMOS 21.0 software package has been used to perform the analysis.

This work involves formulation of the hypothesis which has been tested using structural equation modeling (SEM) on primary data set obtained from survey. The hypothesis is mentioned below:

H1: Environmental factor (E) positively influences the product development success (PDS) which is again measured by environment-related measures.

3 Results

3.1 Analysis of Measurement Validity

A thorough data survey has been carried out from Indian manufacturing industries for the accomplishment of the research objectives. Here, the manifests of the constructs have been divided into two segments, i.e., importance of that manifest to measure the latent construct and another is implementation which is the degree of execution of that manifest in practical scenario. This segmentation adds an extra novelty to this study. All measures are based on 7-point Likert scale where 1 denotes strongly disagree and 7 denotes strongly agree for importance, whereas 1 denotes very low and 7 denotes very high for implementation and in case of the output latent construct which is PDS here. The reliability of the collected data has been tested by Cronbach's alpha reliability test using IBM SPSS 21.0 software package, and the reliability values of each construct have been enlisted in Table 2. As values of α for all variables are above threshold value which is 0.8, it proves that the collected data is reliable [31, 32]. Now, for developing the interrelationship of the constructs and estimating the hypothesis, the structural equation modeling (SEM) analysis has been conducted using IBM SPSS AMOS 21.0 software package (Table 1).

The path diagram displayed in Fig. 1 demonstrates the hypothesized relationships among the latent constructs and their manifests. The values over the arrows indicate the associated standardized regression weights obtained after execution of SEM analysis using IBM SPSS AMOS 21.0 software package.

The statistics of path estimates which are the factor loadings of the manifest variables are listed in Table 2. Same as the statistics of path estimates to relate latent constructs is stated in Table 3. Different fitness measures such as goodness of fit index (GFI), adjusted goodness of fit index (AGFI) and root mean square error approximation (RMSEA), chi-square statistics, and degree of freedom estimates were computed to validate the developed model. The standardized values of the fit indices are listed in Table 4, and the values obtained from the test are also listed in Table 5. As per the data of Table 3 where statistics of path estimates of constructs have been listed, it can be interpreted that the hypothesis which has been considered is proven right. The inferences drawn here are on the basis of the path estimate value which shows that the hypothesis is significantly and effectively correct.

In the proposed model, the fit indices are above the accepted level of 0.90 as shown in Table 3. The chi-square value is also satisfactory, the value of χ^2/df is also considerable, and RMSEA value is quite small as it should be. As the values of all fitness parameter indices are well within permissible range, it can be said or proved that integration of environmental factor for successful new product development plays a vital role for industrial sustainability of Indian manufacturing companies.

Table 1 List of manifest variables of latent constructs including results of reliability testing

Latent variables	Measurement variables	Cronbach's alpha (α)
Environmental factor (E)	1. Eco-friendliness of the product (EF1) 2. Adverse effect of the product on environment (EF2) 3. Sustainability of the product (EF3) 4. The environmental goal achievement rate of the new green products (EF4) 5. Compliance of new green products with the consumers' preference (EF5) 6. Meeting government policies for product development (EF6) 7. Recycling rate of the new green products (EF7) 8. Hiring responsible employees (EF8)	0.863
Product development success (PDS)	1. Reduced cost (PDS1) 2. Healthy relationship with investors (PDS2) 3. Regulatory approvals (PDS3) 4. Life-cycle analysis (PDS4) 5. Customer satisfaction(PDS5)	0.985

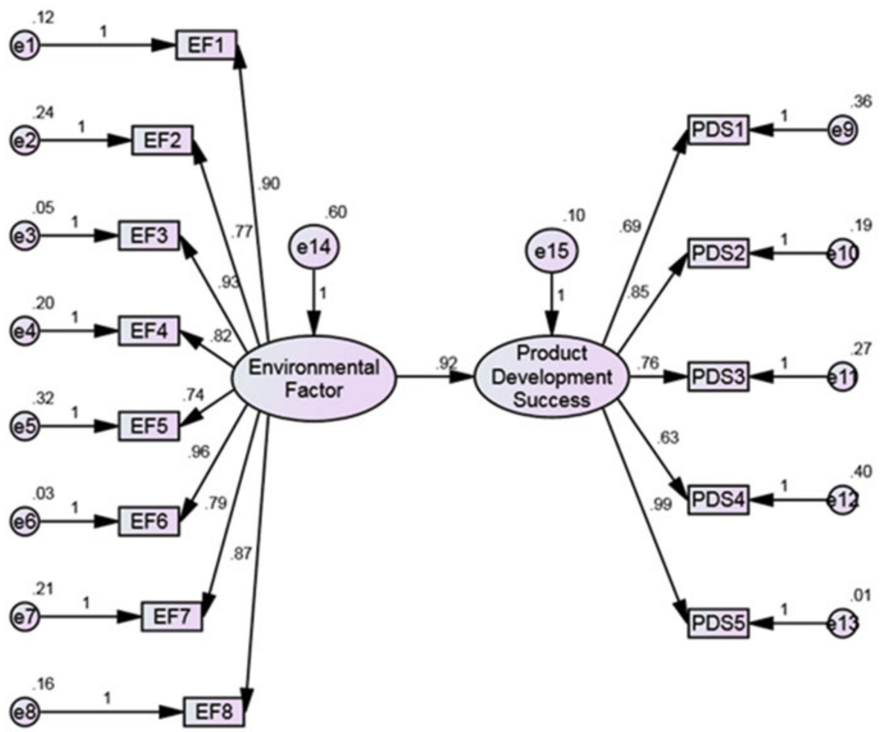

Fig. 1 Structural equation modeling (SEM) model after execution

Table 2 Statistics of path estimates

Latent variables	Manifest variables	Factor loadings
Environmental factor (E)	1. Eco-friendliness of the product (EF1)	0.90
	2. Adverse effect of the product on environment (EF2)	0.77
	3. Sustainability of the product (EF3)	0.93
	4. The environmental goal achievement rate of the new green products (EF4)	0.82
	5. Compliance of new green products with the consumers' preference (EF5)	0.74
	6. Meeting government policies for product development (EF6)	0.96
	7. Recycling rate of the new green products (EF7)	0.79
	8. Hiring responsible employees (EF8)	0.87
Product development success (PDS)	1. Reduced cost (PDS1)	0.69
	2. Healthy relationship with investors (PDS2)	0.85
	3. Regulatory approvals (PDS3)	0.76
	4. Life-cycle analysis (PDS4)	0.63
	5. Customer satisfaction(PDS5)	0.99

Table 3 Statistics of path estimates

Description	Path	Hypothesis	Cronbach's alpha (α)	Estimate	Inference drawn
Environmental factor and product Development success	E-PDS	H1	0.893	0.92	Supported

Table 4 Fitting indices

Fit indices	Desired range
χ^2/degrees of freedom	≤ 2.00
RMSEA (root mean square error of approximation)	Values less than 0.05 show good fit Values as high as 0.08 represent reasonable fit Values from 0.08 to 0.10 show mediocre fit Values > 1.0 show poor fit
Goodness of fit index (GFI)	≥ 0.90
Average goodness of fit index (AGFI)	$\geq$ 0..90

Table 5 Model fitting parameters

Chi-square (χ^2)	Df	χ^2/df	GFI	AGFI	RMSEA
85.152	64	1.330	0.960	0.943	0.033

4 Discussion and Conclusion

This study recognizes the impact of environmental factor on PDS in Indian manufacturing industries. The manifest variables to quantify the success factor which is environmental factor in this case have been identified from previous literature as well as from the experts' opinion from 36 manufacturing companies through a detailed survey from Indian manufacturing companies. Same as the success factor, the manifests of success measure which is PDS in terms of measures related to environmental aspects have been identified. Addition of experts' opinion based on their real-life experience adds an extra novelty to this research. Though environmental effects of newly developed products have long-term impact on companies' success and survival as well as it affects the human life, they often remain neglected. This study emphasizes on environmental factor and quantifies this factor by eco-friendliness of the product, adverse effect of the product on environment, sustainability of the product, the environmental goal achievement rate of the new green products, compliance of new green products with consumers' preference, meeting government policies for product development, recycling rate of the new green products, and hiring responsible employees. Though the importance of these variables has been admitted, still the practical implementation somehow remains ignored. This research concentrates on importance as well as implementation of manifests of environmental factor for companies' betterment which will improve their performance by reducing cost of development with lesser environmental risks, healthy relationship with investors, ease of regulatory approvals, life-cycle analysis, and customer satisfaction. In case of implementation of environmental factor, companies have to face various obstacles in real-life scenario. The limited number of government-approved eco-waste recycler in India is one of the problems for recycling. But, in present days, government has become strict and conscious for restricting the environmental hazards for the sake of nature and humanity as well.

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Decentralised Waste Management System for Sustainable Habitat Development

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Abstract Municipal Solid Waste plays a vital role in creating pollution to the environment. The present scenario shows that household waste contributes nearly 35% from the total MSW generation in India, in which more than 25% of waste is biodegradable. By considering 127,285 metric tonnes per day MSW generation in India, this paper concentrates on the household solid waste management in a cluster level which reduces the overall collection and transportable energy and cost. The wastewater generated in the cluster particularly spent was water from the kitchen, and washing has been effectively worked for Colocasia and Cana Indica. The main advantage of Colocasia is that it can be used for medicinal purposes such as strengthening bones and teeth. For the biodegradable solid waste, effective micro-organisms' method has been adopted to convert the waste into fertiliser at fast rate.

Keywords Municipal solid waste (MSW) · Metric tonnes per day (MTD) Effective micro-organisms (EM)

1 Introduction

The population of India is crossing more than 1.25 billion, the solid waste generated by the people are gaining its scale to wide range of 500–600 g per capita waste per day. This accounts for 188,500 tons per day and added to 68.8 million tons per year. Due to the rapid urbanisation, the cities are flooded with people migrating from village which increases population density on cities and also the waste generation every year. At this rate, the per capital waste generation potential of cities will expected to be 1–1.5 kg per day by 2030. Even though, Government of India

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(GoI) took immense steps to provide effective tool and techniques to organise and handle municipal solid waste (MSW). The Ministry of Urban Development (GoI) fails on municipal solid waste management (MSWM) due to various factors. The Urban Local Bodies (ULB) people finding it obscure to dispose the municipal solid waste as per the guidelines of "Municipal waste (management and handling)" Rule, 1999. In due course of time, MSW growing to be the serious threat to nation policies and disposal scrutiny upon human welfare. So it is the right time for developing countries like India to concentrate on effective solid waste management as low and middle-income countries generate more organic waste constituents in municipal solid waste than the developed countries. In India, around 339 ULB's active units employed their people on collection, segregation and disposal of MSW. The MSWM in most cities didn't score the expected results of the Ministry of Urban Development and Ministry of Environmental and Forest to recuperate the soil condition preventing the soil quality degradation due to improper handling of MSWM.

2 Composition of MSWM

The solid waste generated from various sectors like domestic, industrial, institutional, medical, and commercial together constitute MSW. The domestic waste from residential houses comprises of organic waste in major of food junks, vegetables remains, and stationeries. The industrial waste consists of more toxic, heavy metals, and non-biodegradable contents. The institutional waste generated probably of office materials like paper, plastics, dyes, remains of furniture. The commercial and medical wastes combined as mixed waste and find its way into MSW. Therefore, MSW forms major portion of organic matters which are biodegradable when compared to the per cent of heavy metals and other non-degradable matters. The lifestyle of the people continuously changes due to the rapid urbanisation and modernisation aggravated the generation of the level of MSW. The developing countries mostly use organic matters which added to 50–60% of MSW. The domestic waste from the residential areas constitute mostly of food waste, vegetable waste, slaughtered remains, and part of miscellaneous products.

2.1 Impacts of Improper Handling of MSW

- Air pollution due to the putrefaction of MSW.
- Land pollution due to the mixed waste composition of plastics, heavy metals, industrial waste, etc.
- Water pollution due to the methane gas and Leachate percolation.
- Spreading of epidemic diseases and pose threat to human health.
- Breeding of mosquitoes and parasitic microbes.

- Greenhouse gas emission into the environment due to the decomposition of organic waste.
- Clogging of MSW in sewage channels and causing flood during rain.

2.2 Obstacles on Handling and Disposal of MSW

There are many numbers of factors affecting the function of ULB for handling MSW.

- The lack of organised system and proper guidelines for collection, storage, transport and disposal of MSW.
- Lack of strict rules to be imposed on spot penalties for not cooperating with the compliance of MSW rule, 2000.
- Lack of awareness among the people generating the waste and their negligence to segregate solid waste into biodegradable and non-biodegradable categories.
- Lack of technology to separate the MSW using automation and providing human handling and segregation techniques due to the financial burden.
- The insufficient amount of transport facility and manpower to participate in this system.

3 Methods of Handling MSW

Composting or mechanised biological technology is the method of allowing organic contents of MSW to biological undergo degradation. This method involves two categories;

- Aerobic treatment: Degraded in the presence of air usually the by-products are carbon dioxide, nitrates, nitrite, and compost used as natural manure.
- Anaerobic treatment: Degraded in the absence of air acted upon bacteria and microbes by-products are methane gas and Leachate.

It is one of the effective methods chosen by the most of the developing countries which is simple and easy to practice in no-time. Even though it is simple but open windrow dumping attracts the breeding of microbes and insects. It also makes it hard for the people to observe hand picking of non-biodegradable during rainy season. The probation period is around 36–42 days of interval for the bacterial action to completely decompose the MSW. Then, the manure is silted out into fertile soil and returns the values into ground. Proper checking and continuous monitoring are required for frequent turnover of the compost to mix it uniformly, and this process kills most pathogens and parasites. The heat released due to the exothermic reaction and ranges from 60 to 80 °C. The thermophilic bacteria can digest the MSW organic constituents within shorter period of time.

4 Leachate Management

The choices to be reflected for leachate management are:

(a) **Discharge to Lined Drains**: This choice is habitually not practicable. It can only be embraced if the leachate feature is shown to convince all wastewater discharge standards for lined drains, constantly for a period of years.
(b) **Release to Waste Water Treatment System**: For landfills close to a wastewater treatment plant, leachate might be passed to such a plant after some pre-action. Deduction is organic content which is regularly required as a pre-action.
(c) **Recirculation**: One among the approaches for handling of leachate is to recirculate it through the landfill. This has two valuable effects:

    (i) The method of landfill stabilisation is enhanced and
    (ii) The ingredients of the leachate are diminished with the landfill by the biological, chemical, and physical changes occurring. Recirculation of a leachate needs the strategy of a spreading system to ensure that the leachate passes equally all the way through the intact waste. Since gas production is faster in such a route, the landfill should be prepared with a well-aimed gas retrieval system.

(d) **Evaporation of Leachate**: one of the methods used to handle leachate is to spray it in ruled leachate ponds and agree the leachate to vaporise. Such ponds need to be concealed with geomembranes during the high rainfall times. The leachate is uncovered during the summer months to allow vaporisation. Odour control needs to be practiced at such ponds.
(e) **Treatment of Leachate**: The way of treatment facilities to be carried out based on the leachate characteristics. Normally, treatment will be needed to deduce the concentration of the following prior to discharge: organic materials which are degradable and non-degradable, explicit hazardous ingredients, ammonia and nitrate ions, sulphides, odorous mixtures, and adjourned solids. Handling processes may be biological methods (such as activated sludge, aeration, nitrification (dentrification), chemical methods (such as oxidation, neutralisation), and physical progressions (such as air stripping, activated adsorption, ultra filtration.). The canned leachate may be squared to surface water bodies.

4.1 Scope of Work for Waste and Leachate Investigation Are

(a) New waste will be categorised once it is collected from bins.
(b) Old waste composed from various depths in present waste dumps or sanitary landfills will be categorised.

(c) Assortment and laboratory analysis of at least 6 samples of leachate from just under existing waste landfills or sanitary dumps.
(d) Evaluation of leachate eminence from laboratory analysis.

Biological Oxygen Demand of Leachate from Municipal Solid Waste landfills has upper limit of 195 g/l and lower limit as zero which was specified in the classic data on features of leachate reported by Bagchi [2], Tchobanoglous et al. [9] and Oweis and Khera [6]. Leachate quality data set has not yet published in India. However, studies led by NEERI-Nagpur, IIT-Delhi, and some State Pollution Control Boards have publicised groundwater adulteration potential beneath sanitary landfills.

5 Treatment of Brackish Water in a Habitat

There is one simple, eco-friendly and economical method that involves neither mechanics nor chemicals. It imitates a process that is part of most traditional households even today, where kitchen water is diverted into a clump of banana trees. Here, the water is freed of all its organic constituents by the combined effort of the plants and soil bacteria. As the water passes through the soil and reaches the family well, soil bacteria polishes the water fully and renders it fit for all uses.

The method can be adapted by individual houses and apartment complexes even today. Greywater can be diverted to a soil bed of water-loving plants, which must be exposed to at least moderate sunlight so that they grow healthily. You can use *Canna indica* (Indian shot), *Hedychium coronarium* (white ginger lily), and any variety of Heliconia, the cyperus plant (umbrella plant), Colocaesia, or banana. There is a widespread impression that today's soaps and detergents contain a lot of chemicals that are harmful to the body. However, both the organic and inorganic constituents are present only in minute quantities and all the organic ingredients are biodegradable and will be removed by the plant–soil bacteria combination. Soil bacteria, of course, do not have the ability to remove any inorganic salts but these are so little that they don't matter.

5.1 Methodology

On a level bed of garden soil, plant the saplings giving at least 2.5 sq. ft. per plant and leaving one-foot gap between plants. They can be planted laterally and longitudinally. The level of the soil bed should be uniform so that the greywater spreads over the entire bed, and the entire area is available for cleaning the water. Otherwise, water will tend to flow towards the lower areas and the purification will be incomplete.

Water the plants with freshwater for two or three weeks till they take root and stabilise; then divert the greywater into the bed in progressively increased volumes over a week. Thereafter, the process is practically self-sustaining. No smell will originate from the bed. There may be some stream of a couple of inches during the peak usage period in the mornings but this will go down in 30–45 min. No mosquitoes will be generated. The water seeping into the soil augments the shallow water table and can be drawn for reuse through a dug well.

The process can be decentralised in multi-storeyed complexes where the bathrooms on all floors are generally one above the other. If some soil space is available near one such bathroom, only its greywater can be diverted and treated here. A centralised system will involve bringing the greywater from all the bathrooms to be treated in one single soil bed. One can collect the treated water and use it for flushing and gardening. This aspect will be covered in the next article.

5.2 Plumbing

An elbow is connected to the outflow pipe and extended to reach the soil bed. No gum or glue piping is used so that for any temporary shutdown, the elbow can be just pulled out to let the water flow into the regular gully and reach the internal sewage line.

If planned during construction, the pipes taking the greywater to the soil bed can be easily concealed underground in the driveways. Since they have to be laid at a slope of 1 in 120, the terminal pipe on the bed will be at a lower level than the abutting ground level. Therefore, the level of the soil bed has to be protected by means of curbing. In one campus, the treatment bed was 4.5 ft. below the abutting ground level but it still worked smoothly.

5.3 Maintenance

The process is self-sustaining and requires minimal maintenance. If canna plants are used, plants that have borne fruit should preferably be removed but this does not require any skills. For other plants, even this is not necessary. Prevent mounds forming around the plants since these impede the smooth flow of water across the entire bed and the process may have to be begun afresh. If water stagnates, it is either an indication that the plant density is inadequate or the area provided is insufficient. In such cases, the water supply must be disconnected and remedial action is taken (Fig. 1).

A simple water treatment practice using canna plants (Tamil: “Kalvazhai”) was experimented in a habitat which filters the wastewater particularly soap water.

The greywater is conceded through the canna bed, which is shaped over layers of blue metal and soil. The canna plants assist in decomposition of the suspended

Fig. 1 Way of greywater recycling by using canna plants will be money-spinning and simple

solids. The soil layers beneath filters the water. The rest water can be allowed to flow to garden area which consists of flower and fruit plants. There is no mosquito breeding or stench from the canna beds as water is absorbed quickly. However, it needs periodical maintenance.

6 EM Treatment

Extensive research has been conducted with the decisive goal to protect soils by developing diverse cultures of compatible positive micro-organisms. The critical goal is to alter the soil microbiological steadiness (i.e. the population equilibrium) and forms an atmosphere that flatters the growth and activity of these publicised organisms and to improve their valuable effects on the growth and health of crop plants. The research completed successfully by using the mixed cultures of effective micro-organisms (EM).

In effect, EM technology provides

(a) Resources of governing soil micro-organisms to the improvement of the plant, and
(b) An added element that improves the possibility for successful conversion from conventional to nature farming ways.

EM technology is not only but a step ahead of plant production and protection. Research has revealed that EM is highly efficient in purifying waste waters and sewage emissions; promoting soil structure and accumulation; overturning malodours in livestock and poultry buildings; and improving the conversion efficiency of animal fodders. Such a widespread function of micro-organisms enormously increases the possibility of developing an energy-efficient, economically viable, and eco-friendly system of organic farming for mankind now and forever. Many of the basic problems related to agriculture, human health, and the environment can be solved to a significant level by the application of EM technology.

6.1 Methodology

The MSW can be stored effectively in generation source itself and properly treated. This reduces the cost of transport and tedious collection process of the urban local bodies. There are 5 pits of same dimension, and domestic waste is evenly distributed. One litre of EM (enhanced microbes) water is taken for this experiment. One of the waste loaded pits is left without addition of EM water. The remaining pits are supplied with EM in the ratio of 1:2:3:4 concentrations mixed with the remaining per cent of water to make it one-litre solution. Then, the waste is left for degradation under the microbial actions in the aerobic environment for the period of 5 days. In each day, the waste is turned top to bottom for even mixing. As it is an exothermic reaction which generates heat and increases the temperature about 50–60 °C, it kills most of the parasites and pathogenic bacteria. Then, the soil is taken for BOD testing at regular intervals and corresponding values are noted down (Figs. 2, 3 and 4).

Fig. 2 Five trenches formed

Fig. 3 MSW with EM water is mixed

Fig. 4 After 5 days of decomposition, the status of MSW

7 Results and Discussion

Through the results in Table 1, by adding 100 mL of EM treated water to MSW will give an optimum generation of BOD to the soil.

Table 1 BOD result of five samples using OxiTOP system is shared. Units of the results are to be considered as mg/L

Samples with EM	BOD level of samples in mg/L				
	Day 1	Day 2	Day 3	Day 4	Day 5
MSW + 100 mL	20	40	60	80	80
MSW + 200 mL	0	20	40	40	40
MSW + 300 mL	0	20	20	40	40
MSW + 400 mL	20	40	40	60	60
MSW alone	20	20	40	40	40

8 Conclusion

The BOD results show that the EM water treatment with one ratio proportion in the MSW will improve the quality of the soil by means of increasing the BOD level and hence protect the land from the issues through Leachate. Also the greywater treatment in each habitat will protect the soil and water quality level by means of increasing vegetation in habitat area.

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Environmental Risk Assessment for Beneficial Reuse of Coal Combustion Residues

D. V. S. Praneeth, V R Sankar Cheela and Brajesh Dubey

Abstract The present paper deals with need for establishing common protocol for evaluating risk assessment for reuse of coal combustion residues (CCR) in the name of "Leaching Environmental Assessment Framework" (LEAF). The process involved in the industries produces large quantities of by-products, and CCR is one of such wastes which is rarely categorized as hazardous, but it cannot be dumped on the landfill. The current and most accepted tool for environmental evaluation in terms of leaching is toxicity characteristic leaching procedure (TCLP) and synthetic precipitation leaching procedure (SPLP). But these tests cannot provide the complete site-specific decision on beneficial reuse of the materials. In this paper, trends of coal combustion residue especially fly ash across world is explained and present different leaching tests available and need for common protocol LEAF is explained with stating its advantage, and disadvantages is explained.

Keywords Leaching · Reuse · TCLP · SPL · USEPA

1 Introduction

Balancing the impacts on human and environment with promoting reuse and resource conservation is difficult challenge [1], "Reuse" term has gaining the importance due to over discharge of waste, over usage of raw materials that is affecting environment and human. Solid waste disposal has becoming a major problem for industries, especially in developing countries due to proper availability of land for disposal and improper waste management regulations [2]. Certain waste has potential benefits to reuse for same processing unit or building process of other unit. The problem lies in identifying which residue has potential use and what is the fate of that residue when it is used in the other work. There are certain wastes which are not defined by RCRA as solid waste such as coal combustion residues, drinking

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water sludge, sewage sludge; they are rarely described as hazardous waste for which we cannot simply dump to the landfill [3]. The risk associated with the waste to the environment and human is the important criteria for different management options such as reuse, dump in landfills.

The two typical ways considered in the risk assessment of waste materials are

1. Direct exposure through the ingestion, dermal contact and [4].
2. Contamination through the contamination of groundwater [4]. The common pathway way of evaluating risk of waste on environment and human is leaching to the groundwater. This risk assessment helps us in managing option, and it gives the information regarding need to clean-up contaminated sites which represents the greatest threat and to what level sites must be remediated. One of such major industrial wastes is coal combustion residues (Fig. 1).

In this paper, my objective is to discuss the trend of coal combustion residues especially fly ash in world, common ways of risk to environment, present following tests to evaluate that risk and its disadvantage, need to have new framework to evaluate risk with stating its advantages and limitations.

Coal combustion residues are the major industrial waste producing in the world which has many beneficial reuse options, but it contains constituents of chemical concern which is harmful to environment and human. As globally coal production is increasing every year, residues producing from the combustion are also increasing and need for proper management options also increasing.

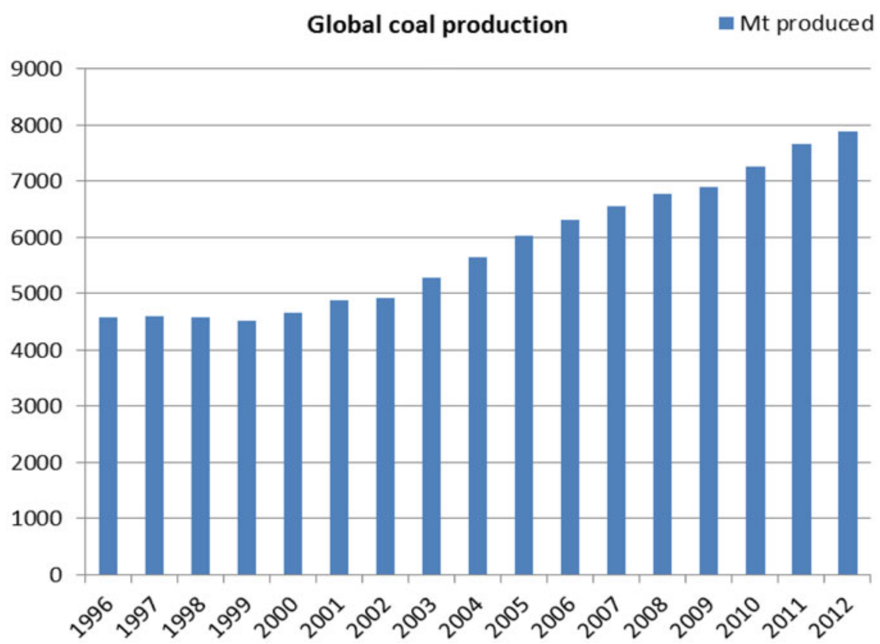

Fig. 1 Global coal production [5]

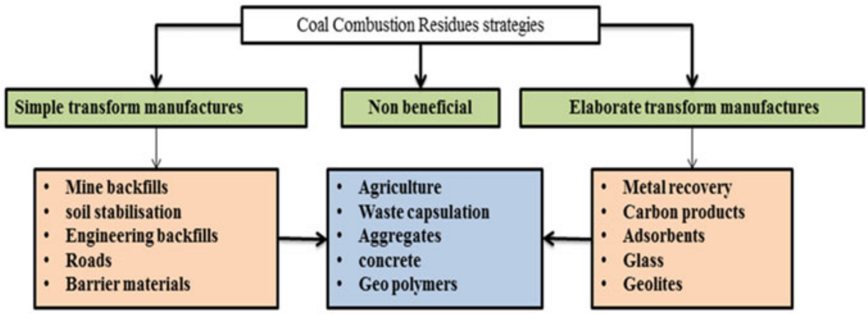

Fig. 2 Coal combustion residue strategies

In Fig. 2, non-beneficial is considered as economical burden to the generator, viewed as limited value added. Simple transform manufactures are value-added products that can be obtained by simple transform strategies like blending, processing. Elaborate transform manufactures are high value-added products extracted by advanced processing strategies [6].

Comparing the generation and utilization of coal combustion residues of main countries during the year of 2009, 2010 and 2011, the China had generated highest coal combustion residues around 375 Mt in year 2009 and 480 Mt in 2011 with percentage of utilization is 60 in 2009 and 68 in 2011. Israel is the only country with 100% of utilization in these years (Fig. 3).

Figure 4 indicates the fly ash generation which is increased from 57 Mt in 2014–65.77 Mt in 2008 and decreases to 45 Mt in the year 2014, and similar trend follows for bottom ash too. Regarding India, Indian coal consumption of 1300 million tonnes of coal equivalent (Mtce) in 2040 is 50% more than the combined

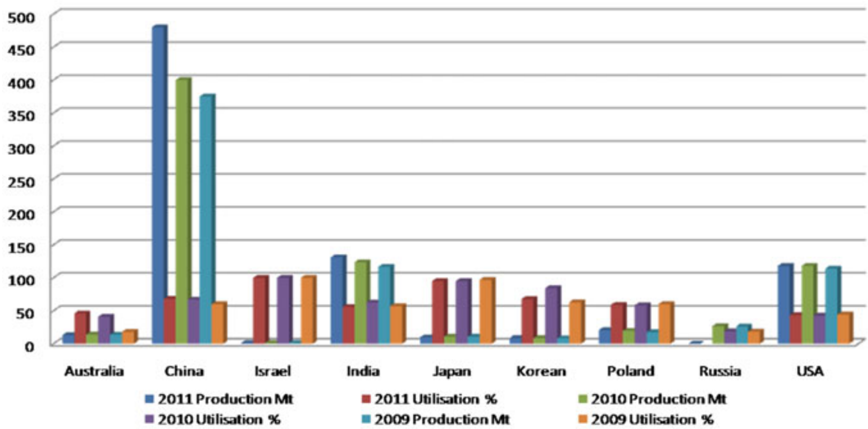

Fig. 3 Countries with their production and utilization of CCR in the years of 2009, 2010, 2011 [4]

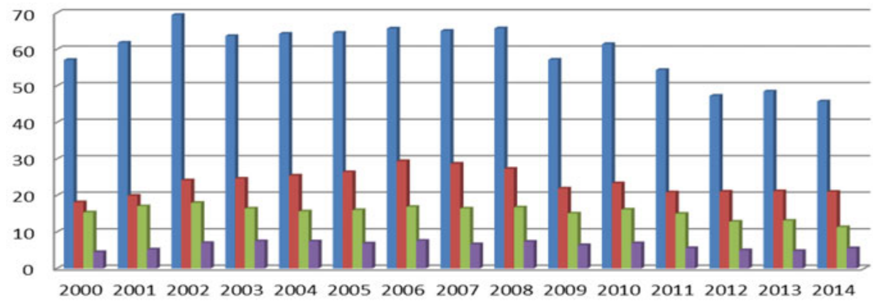

Fig. 4 Fly ash and bottom ash generated and utilization from the year 2000 to year 2014 in the USA [8]

demand of all OECD countries and second only to China in global terms. India coal contains 30–55% of ash [7].

As seen from above figure, majority of the fly ash is reused in cement and followed by reclamation of low-lying areas, etc. The common risk associated when the disposed waste comes to contact with moisture in the form of precipitation, surface water, and water present in the fill itself, and this process is explained through leaching. When this moisture contacts with industrial waste, the soluble solid constituents will start dissolving into liquid by percolation or diffusion, but the extent of the dissolving depends on the many conditions [9] (Figs. 5 and 6).

This process is known as leaching and moisture that leaches or formed is known as leachate, forms when liquid percolates through permeable material and it contains suspended, dissolved material. So, the general way of evaluating risk is pathway of leaching to the groundwater and for evaluating this risk, we need to understand the process and factors that affect and controlling the leaching process [3].

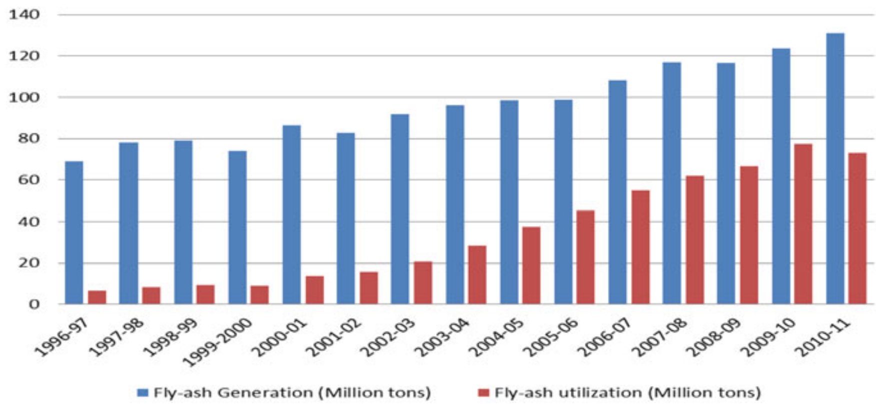

Fig. 5 Indian fly ash generation and utilization [10]

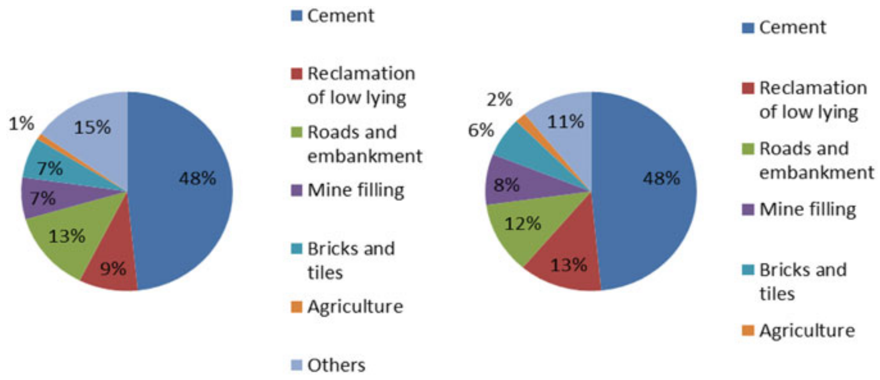

Fig. 6 Utilization of fly ash in India in the year of 2010 and 2011 [11]

Table 1 Factors controlling leaching

Chemical factors	Physical factors
pH	Particle size
Liquid to solid ratio	Porosity
Redox	Rate of mass transport
Sorption	Temperature
Complexation	Fill geometry

1.1 Controlling Parameters

There are different factors controlling the leaching process, and they are grouped them in form of physical factors and chemical factors. Some of the important factors controlling leaching are Table 1.

1.2 Different Leaching Tests

While calculating the risk through leaching, the test should be done such that all factors should be included. Leaching tests are majorly classified into two types [9].

1.2.1 Batch Tests

These tests are known as static tests; in these tests, specific amount of waste is allowed to contact with specific amount of liquid which acts as leaching fluid for fixed time, and contaminant release mechanism is found using chemical analysis to the obtained leachate. The major assumption made in these batch tests is attaining of equilibrium at the end of fixed time, where it does not happen in actual field scenario [3], and for this reason, these are known as short-term tests, where long-term release scenario cannot be predicted using these tests. These batch tests are used to simulate specific environmental scenarios and will not inform about release mechanism in various environmental scenarios.

Some of the batch tests followed worldwide are [9]:

- Extraction Procedure Toxicity (EP-TOX, US EPA Method 1310).
- California Waste Extraction Test (WET, California, 1985).
- Multiple Extraction Procedure (MEP, US EPA Method 1320).
- Synthetic Precipitation Leaching Procedure (SPLP US EPA Method 1312).
- American Society for Testing and Materials (ASTM D 3987-85) extraction.

1.2.2 Flow-Through and Flow-Around Tests

These tests are known as dynamic tests; in these tests, leaching fluid is allowed to flow through the waste material or fluid is allowed to flow-around tests which depends on waste materials (monolith and granular samples) and resulting leachate is continuously or intermittently collected [9]. These tests are used to simulate long-term releasing scenarios and give information regarding kinetics of contamination mobilization.

In flow-through tests, liquid is allowed to pass through the compacted granular waste sample in open container and resultant leachate is collected and examined for parameters of interest like L/S, time-releasing mechanism.

Some of the flows through tests are [9]:

- prEN 14405, Up-flow percolation test.
- ASTM D 4874, Standard Test Method for Leaching Solid Waste in a Column Apparatus.
- NEN 7343, Column Test.

The most common acceptable tools for leachate assessment are toxicity characteristic leaching procedure (TCLP) and synthetic precipitation leaching procedure (SPLP); these are generally basic characterization tests. Generally, TCLP was designed to simulate material sitting in a landfill for number of years and determine the mobility of organic, inorganic contaminants that present in the waste/residue, and TCLP is used to determine whether a solid waste is a toxicity characteristic hazardous waste (40CFR261), and it is used to determine whether hazardous waste is sufficiently treated prior to land disposal (40CFR268) [12], whereas SPLP simulates the material sitting in situ exposed to rainfall, actual field conditions and determines the movement of organic, inorganic contaminants. SPLP is commonly used by regulatory agencies to assess leaching risk from beneficially used waste materials.

Major disadvantages of using these basic characterization tests are

- Site-specific decision-making cannot be done.
- Both are single-point tests, as pH maintained in these is specific. We can rarely observe this pH happening in natural conditions.
- In the span of 18 h, the equilibrium cannot be reached.
- Data generated is not enough to analyse the material-specific property [12].
- These tests are sometimes overestimated or underestimated [12].

We need to have a much more comprehensive way to look all factors that affect the leaching and standard protocols in form of framework that addresses all concerns of the regulatory tests and helps to take site-specific decision-making easier. These leads to development of the leaching environmental assessment framework (LEAF) an USEPA research-funded framework, which provides a large data and insight into leaching process. The LEAF consists of leaching tests, data management tools, mass transferring model and QA/QC for material production [13].

2 LEAF Leaching Tests

See Table 2.

2.1 Method-1313

This is a parallel batch extraction procedure which determines the liquid–solid partitioning as a function of pH on which metal concentration depends. This test consists of preparing of extract solutions whose pH target ranges from 2 to 13, on addition of sulphuric acid/potassium hydroxide, material to be tested. The l/s ratio is to be maintained at 10 mL extractant/g-dry sample (g-dry), and they are rotated around 28 ± 2 rpm for certain time which depends on particle size, and this method is not applicable for characterizing the release of volatile organic analytes (e.g. benzene, toluene and xylenes) (Table 3).

Table 2 Different LEAF tests

Test name	Description
Method-1313	Liquid–solid partitioning as a function of pH using a parallel batch procedure
Method-1314	Liquid–solid partitioning as a function of liquid–solid ratio (L/S) using an up-flow percolation column procedure
Method-1315	Mass transfer rates in monolithic and compacted granular materials using a semi-dynamic tank leaching procedure
Method-1316	Liquid–solid partitioning as a function of liquid–solid ratio using a parallel batch procedure

Table 3 Rationale of different pH used in LEAF 1313 [14]

pH target	Rationale
2 ± 0.5	Provides estimation of total or available COPC content
4 ± 0.5	Lower pH limit of typical management scenario
5.5 ± 0.5	Typical lower range of industrial waste landfills
7 ± 0.5	Neutral pH region; high release of oxyanions
8 ± 0.5	Endpoint pH of carbonated alkaline materials
9 ± 0.5	Minimum of LSP curve for many cationic and amphoteric COPCs
12 ± 0.5	Maximum in alkaline range for LSP curves of amphoteric COPCs
13 ± 0.5	Upper bound (field conditions) for amphoteric COPCs
10.5 ± 0.5	Substitution if natural pH falls within range of a mandatory target

2.2 *Method-1314*

This method is designed to liquid–solid partitioning as a function of liquid–solid ratio (L/S) using an up-flow percolation column procedure This method is intended to obtain a series eluates of granular method which is used to show cumulative release of concentrations of COPS as function of L/S ratios [15] (Fig. 7).

This method consists of packed granular material in a percolating column of 30 cm long and 5 cm diameter and allowing reagent water through the packed material and collecting the eluates of different L/S ratios of 0.2, 0.5, 1, 1.5, 2, 4.5, 5.0, 9.5 and 10 ml/g-dry material [15].

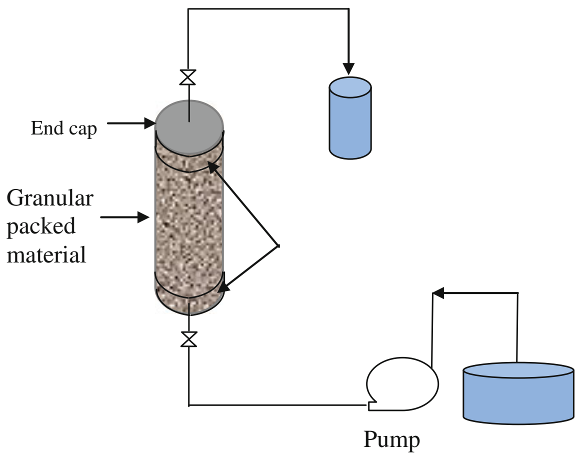

Fig. 7 LEAF 1314 column apparatus

2.3 Method-1315

Place a layer of sand to fill the remaining gap between the sample packing and the interface between the column and inflow end cap. When enough test material is available to pack a full column, the sand layer at the inflow end of the column should be approximately 1 cm. This gap may be larger if less test material is used.

This is a semi-dynamic tank test that is intended to know the mass transfer behaviour and rate as function of leaching time for COPS. This test deals with two types of materials, namely monolithic (brick) and compacted granular material. The test consists of immersing the material in eluate (reagent water) for specific period of time, and for monolithic, all faces are exposed, whereas for compacted granular material, only one face is exposed and compacted to optimum moisture content when immersed.

When material is contact with reagent water for definite contact period, the mass transfer takes till equilibrium is achieved, and then sample is removed and periodic renewal of water should be taken, difference in weight is noted as mass transfer, which tells the amount of eluant absorbed into the solid matrix at the end of each leaching interval. This leaching characterization method provides intrinsic material parameters for release of inorganic species under mass transfer-controlled leaching conditions. This method is not applicable to characterize the release of organic analytes with the exception of general dissolved organic carbon [16].

For a compacted granular material, the minimum size should be 5 cm, in the direction of mass transfer should be done and L/A must be maintained at 9 ± 1 mL/cm^2.

2.4 Method-1316

This method consists of five parallel extracts of L/S 10.0, 5.0, 2.0, 1.0, 0.5 mL/g-dry and a blank without solid materials which is used to identify any interferences. In total, six bottles are tumbled in an end-over-end fashion for a specified contact time based on the maximum particle size of the solid. Extract pH and specific conductance measurements are then taken. The eluate constituent concentrations are plotted as a function of L/S and compared to QC and asses. This method provides solutions that are considered to be indicative of leachate under field conditions only where the field leaching pH and L/S ranges are encompassed by the laboratory extract final conditions, and the LSP is controlled by aqueous-phase saturation of the constituent of interest. This method is not used for characterizing release of volatile organic analytes [17] (Table 4).

Table 4 Advantages and disadvantages of LEAF

Advantages	Disadvantages
Large data will be available which include all leaching controlling factors	No specific method (guidance) is there to handle such large data
Testing can be done according to site-specific condition like limited pH	There is worry about repeatability as limited number of laboratories available and cost
Decision regarding beneficial reuse, site remedial measures, effectiveness of treatment can be made easy	Wide range of pH range used in the tests does not represent site conditions
A site protocol can be developed by LEAF [12]	May contradict SPLP data [1]

2.5 Guidelines for Interpreting and Compiling Leaf Test Results

As mentioned above, TCLP and SPLP are just screening tools to decide whether waste is hazardous or not. It is single-point tests, and we can know just that we can dump waste or not. But LEAF is an integrated framework which considers all factors affecting leaching deep. As large amount of data is generated from the test, it may or may not reflect potential problem of using a CCR as beneficial use in actual site conditions [12]. Therefore, before developing such large data certain guidelines are followed:

- If a large amount of data required, first find all site-specific characteristics like pH, hydraulic conductivity, hydraulic gradient and soil type. This can be used for calibration of LEAF results.
- If a single concentration level of contaminant is required for Yes or No decision of leachability, it is best to go for risk-based approach where the site-specific maximum contaminant level is developed according to accepted scientific protocol [12].
- First define the objective clearly, what tests are required to perform to reach specific goal. Based on that, consult geo-environmental and industrial experts who can interpret data from LEAF.

2.6 Considerations for an Integrated Leachability Test Program

The following are a few items that should be considered when attempting to develop an integrated leachability test program for CCRs:

- Continue to use the TCLP or SPLP tests as the screening methods, and use the appropriate LEAF method on tiered basis as information is needed about the leaching characteristics [12].

- Work with engineers who can interpret TCLP, LEAF, SPLP results in various industries.
- Develop a larger body of data, over a period of years using a combination of the TCLP and SPLP results and applicable LEAF methods
- Try to know the limitation and value of TCLP, LEAF, SPLP for given material.

3 Conclusions

Huge amount of industrial waste in the form of coal combustion residues are generated all over world which has some potential beneficial reuse. But when they are used for another process, there is maximum chance of contaminating environment when it contact with water through process of leaching. The most common tools for leaching assessment are SPLP and TCLP, but these tests are single point tests; that is it considers single-pH conditions, site-specific decision such as beneficial reuse of secondary materials cannot be done using these tests. This leads to the leaching environment assessment framework (LEAF) for the evaluation of the physical and chemical properties of industrial wastes and secondary materials, which considers all factors that affect leaching in deep. The LEAF methods are expected to provide useful information, additional guidance, and research is needed before they can be used to make and/or influence site-specific decisions about leaching from a CCR beneficial reuse site.

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Arsenic Contamination of Groundwater in West Bengal: A Report

Reetushri Sen and Sutripta Sarkar

Abstract Water pollution is a major problem faced by modern societies. Industrial and domestic wastes are dumped into water bodies making them unsuitable for human utilization. Most of the city dwellers in India draw underground water for domestic consumption. However, high quantity of heavy metals like arsenic is a major contaminant of underground aquifers especially in the eastern state of West Bengal (renamed Bengal). It has been reported that around 50 million people living along the Ganga–Brahmaputra basins are affected by the high levels of arsenic in drinking water. Besides causing hyperpigmentation and 'black foot disease', it affects several human systems leading to cancer. A total of 59 samples were collected from tube wells in domestic dwellings covering six districts in West Bengal, and pH, iron, phosphate and arsenic content were measured using field testing kits (Nice Chemicals Pvt. Ltd., India). The presence of microbial contaminants was detected by plating water samples in EMB agar medium. Relative abundance was calculated for arsenic, iron, phosphate and microbial contaminants. While arsenic was found to be most abundant in Burdwan District, iron was highest in Nadia District. However, in both the cases sample size was small. Highest arsenic content of 1 mg/ml was reported from Dumdum area in North 24 Parganas and Chetla area in Kolkata. High content of iron and phosphate along with arsenic was found in Haripal (Hooghly District). Coliforms were also detected in a few samples. Despite a lot of awareness being raised about safe drinking water, many people are oblivious of the fact that it is critical to a healthy living. In the current study, most of the samples were collected from domestic or community tube wells. Water was still being drawn from sources which were found to be contaminated by high level of arsenic. There is an urgent need of implementation of technologies which effectively remove arsenic and other heavy metals.

Keywords Water pollution · Heavy metal contamination · Arsenic content

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1 Introduction

Water is considered polluted if some substances or conditions are present in such a degree that it renders the water unsuitable for use [1]. Human activities have lead to pollution of water sources including groundwater. Human groundwater contamination can be related to waste disposal (private sewage disposal systems, land disposal of solid waste, municipal wastewater, wastewater impoundments, land spreading of sludge, brine disposal from the petroleum industry, mine wastes, deep-well disposal of liquid wastes, animal feedlot wastes, radioactive wastes). Large quantities of organic compounds are manufactured and used by industries, agriculture and municipalities which pollute the underground aquifers. Arsenic contamination of groundwater is estimated to be affecting 144 million people across the world [2]. Exposure to arsenic causes dermal changes like pigmentation, hyperkeratoses, ulceration, skin cancer. Acute and chronic exposure also affects liver, kidney, heart and lungs. It also has significant effect on gastrointestinal, haematological, neurological, developmental, reproductive and immunologic health due to mutagenic, genotoxic and carcinogenic properties [3]. A dose–response relation between cumulative arsenic exposure and prevalence of diabetes mellitus was observed [4]. According to the World Health Organization, permissible limit of arsenic in drinking water should not exceed 10 ppb [5]; however, it has been reported that the risk of arsenic toxicity remains even at that low level [6].

The present study was undertaken to assess the current status of water pollution in groundwater in West Bengal. Samples were collected from six districts from domestic and community tube wells. Samples were analysed for arsenic, iron, phosphates, total hardness and microbial contamination.

2 Materials and Methods

2.1 Sample Collection

The samples were collected from the areas of Howrah, Liluah, Belur, Bally in Howrah District. Uttarpara (Makhla), Hindmotor (Dharmatala), Konnagar, Nabagram, Rishra, Sreerampore, Mahesh (Sreerampore), Haripal, Dankuni in Hooghly District. Burdwan, Bandel in Burdwan District. Madhyamgram, New Barrackpore, Leningarh, Dumdum, Panihati, Sodepore, Ghola (Sodepur), Barrackpore college, Kolepara (Barrackpore), Naihati, Ichapur, Shyamnagar, Basirhat, Barasat, Keventer (Barasat), Amtala (Barasat), Selempore (Nilgangue) in North 24 Parganas district. Kalyani, Kalianibash and Halisahar in Nadia District. Garia, Tollygunge, Chetla, Behala, Thakurpukur Joka, Ruby, Rajpur, Deshapriya Park, M. G. Road, Sector 5, Baguihati, Science City in Kolkata. Total of 59 samples of which 5 were from Howrah, 15 from Hooghly, 2 from Burdwan, 21 from North 24 Parganas, 13 from Kolkata and 3 from Nadia were collected in triplicate in 50-mL-sterilized container. Samples were stored in −20 °C until analysed.

2.2 *Detection of Arsenic, Iron, Phosphate and Total Hardness*

Arsenic, iron, phosphate and total hardness were detected by water analysis field kits manufactured by Nice Chemicals Pvt. Ltd., India. Arsenic was detected by using the classical Gutzeit method [7] based on the reaction of arsine gas with mercuric bromide.

2.3 *Microbial Contamination Determination*

Water samples were plated in EMB agar plates (Eosin Methylene Blue Agar) to estimate the quantity of faecal coliforms. Its composition is as follows—Peptic digest of animal tissue—10 gm/L, Dipotassium phosphate—2 gm/L, Lactose—5 gm/L, Sucrose—5 gm/L, Eosin-Y—40 gm/L, Methylene blue—0.065 gm/L, Agar—13.50 gm/L, pH 7.2. 100 μL of sample was plated in triplicate and incubated at 37 °C for 24 h.

2.4 *Statistical Analysis*

Tests were carried out in triplicate. Standard deviation was calculated on triplicate values. Relative abundance (%) was formulated by:

$$\frac{\text{No.of samples containing arsenic/ phosphate/ iron} \times 100}{\text{Total no. of samples}}$$

3 Results and Discussions

Access to safe drinking water is essential to health, a basic human right and a component of effective policy for health protection. Groundwater can be contaminated through various pollutants, one of them is arsenic. The groundwater arsenic problem has raised widespread concerns in different parts of the world, and results reported by various agencies are alarming. According to Guha Mazumder [4], more than six million people in West Bengal, India, are exposed to arsenic-contaminated groundwater. Singh [8] observed that elevated concentrations of arsenic exist in groundwater of nine districts of West Bengal, namely Murshidabad, Malda, Nadia, North 24 Parganas. South 24 Parganas, Burdwan, Howrah, Hooghly and Kolkata. In this study, high content of arsenic has been found in the underground water in the districts of North 24 Parganas, Burdwan, Howrah, Hooghly, Kolkata and Nadia

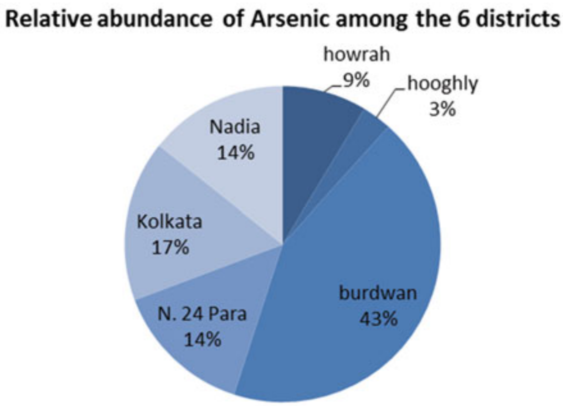

Fig. 1 Depicts the relative abundance of Arsenic found in the samples of the study areas

(Table 2). The relative abundance of arsenic was found highest in Burdwan followed by Kolkata (Fig. 1). However, sample size was small from these districts. Highest arsenic content of 1 mg/mL was reported from Dumdum area in North 24 Parganas and Chetla area in Kolkata.

Relative abundance of iron was highest for Nadia District followed by Hooghly and Kolkata. Many of the technologies which remove arsenic depend on the co-precipitation of iron and arsenic. A linear co-relationship has been found in the arsenic and iron removal by treatment plants [9] (Fig. 2).

Mc Arther et al. [10] reported that West Bengal has high arsenic and phosphate in some wells. In this study, the sample from Haripal, Hooghly, showed high arsenic along with high phosphate and iron content (Table 2). Relative abundance of phosphate was highest in Burdwan and North 24 Parganas Districts. Samples from Uttarpara (Makhla), Rishra and Haripal in Hooghly District, Burdwan in Burdwan District, Madhyamgram, New Barrackpore, Leningarh, Panihati, Barrackpore, Naihati, Halisahar, Ichapur, Kalianibash, Shyamnagar, Basirhat in

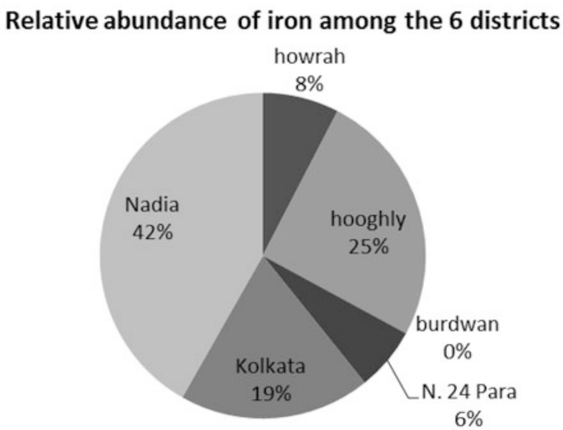

Fig. 2 Relative abundance of iron found in the water samples

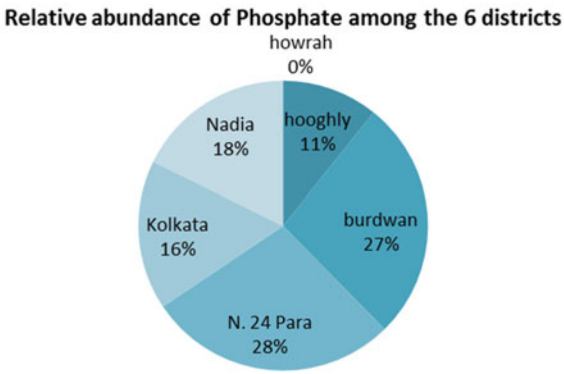

Fig. 3 Percentage of Phosphate found in the the water samples

North 24 Parganas District, and Tollygunge, Behala, Rajpur, Sector 5 in Kolkata have marked level of phosphate in groundwater (Fig. 3).

Microbial contaminations are also present in quite a few samples. These are may be due to unhygienic environment of water source or storage of water. Microbes mainly *E. coli* are found in the area of Howrah in Howrah District, Uttarpara (Makhla), Rishra, Sreerampore (Mahesh) in Hooghly District. Barasat (Amtala) in North 24 Parganas and Garia, Chetla M. G. Road, Baguihati in Kolkata (Fig. 4).

Water hardness was found to be maximum in at least three samples from Kolkata (around 400 ppm in terms of $CaCO_3$) (Table 1). This may be due to the presence of insoluble calcium, magnesium and phosphate salts (Table 2).

Most of the samples were collected from domestic and community tube wells. It was appalling to note that people were using water from contaminated sources. Water sources where treatment plants were installed or filtration facility was available where not necessarily free from heavy metal contamination.

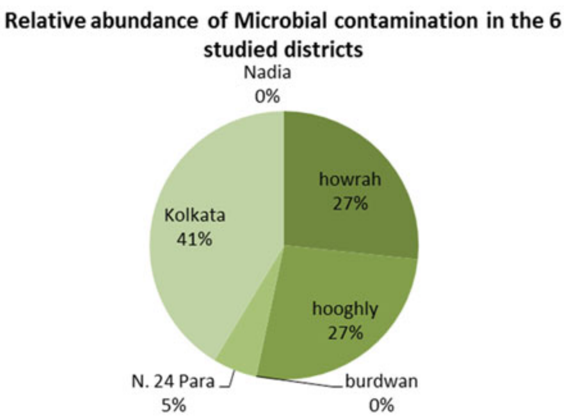

Fig. 4 Percentage of samples which had microbial contamination

Table 1 pH, temperature and hardness of the samples collected from the six districts covered under the study

District	Area	pH	Temp. (°C)	Hardness (ppm of $CaCO_3$)
Howrah	Howrah	7.1	28	58
	Liluah	6.41	23	22
	Belur 1	7.15	25	224
	Belur 2	7.1	25	140
	Bally	7.06	25	46
Hooghly	Uttarpara (Makhla)	7.58	31	96
	Hindmotor (Dharmatala)	7.15	20	42
	Hindmotor	8	30	156
	Konnagar 1	6.1	20	80
	Konnagar 2	7.2	31	142
	Nabagram 1	6.9	20	234
	Nabagram 2	7.2	25	72
	Nabagram 3 (filter)	7.3	25	58
	Rishra 1	7.9	29	180
	Rishra 2	6.92	20	264
	Sreerampore 1	8.28	20	57
	Sreerampore 2	7.56	25	174
	Sreerampore (Mahesh)	6.49	31	84
	Haripal	6.7	25	262
	Dankuni	6.36	20	90
Burdwan	Burdwan	6.93	25	140
	Bandel	7.28	25	48
North 24 Parganas	Madhyamgram	6.99	18	68
	New Barrackpore	6.86	30	124
	New Barrackpore (filter)	8.23	29	144
	Leningarh	7.2	30	26
	Dumdum	7.02	25	56
	Panihati	7.2	20	84
	Sodepore	7.03	25	250
	Sodepore (Ghola)	7.39	29	180

(continued)

Table 1 (continued)

District	Area	pH	Temp. (°C)	Hardness (ppm of $CaCO_3$)
	Barrackpore		20	198
	Barrackpore college (filter)	7.12	20	36
	Barrackpore college	6.32	25	160
	Barrackpore 3	6.95	18	146
	Nihati	7.11	20	200
	Ichapur	6.24	20	146
	Shyamnagar	6.52	29	160
	Basirhat 1	7.61	30	32
	Basirhat 2	7.3	25	258
	Barasat	7.26	30	120
	Barasat, Keventer area	6.43	20	260
	Barasat (Amtala)	9	29	126
	Selampore (Nilgunge)	7.1	25	98
Kolkata	Garia	7.19	29	400
	Tollygunge	6.88	30	200
	Chetla	7.5	20	58
	Behala	7.35	30	200
	Joka, Thakurpukur	7.4	25	136
	Ruby	6	29	480
	Rajpur	6.58	20	200
	Deshapriya Park	7.5	25	220
	Deshapriya Park (filter)	7.1	25	114
	Science city	7.81	20	380
	M. G. road	7.65	31	84
	Sector 5	6.8	30	106
	Baguihati	6.59	20	200
Noida	Halisahar	7.2	25	206
	Kalianibash	7.1	29	144
	Kalyani	6.12	29	100

Table 2 Quantity of iron, phosphate, arsenic and microbial contamination in the samples obtained from the six districts

District	Area	Iron	Phosphate	Arsenic	Microbial contamination**
Howrah	Howrah	BDL*	BDL	BDL	Detected (mean-17, sd-8.88)
	Liluah	BDL	BDL	BDL	Not detected
	Belur 1	BDL	BDL	BDL	Not detected
	Belur 2	1 mg/mL	BDL	BDL	Not detected
	Bally	BDL	BDL	BDL	Not detected
Hooghly	Uttarpara (Makhla)	BDL	0.5 mg/L	BDL	Detected (mean-23.33, sd-9.291)
	Hindmotor (Dharmatala)	BDL	BDL	BDL	Not detected
	Hindmotor	BDL	BDL	BDL	Not detected
	Konnagar 1	BDL	BDL	BDL	Not detected
	Konnagar 2	BDL	BDL	BDL	Not detected
	Nabagram 1	BDL	BDL	BDL	Not detected
	Nabagram 2	BDL	BDL	BDL	Not detected
	Nabagram 3 (filter)	BDL	BDL	BDL	Not detected
	Rishra 1	0.5 mg/L	BDL	BDL	Detected (mean-5.33, sd-3.51)
	Rishra 2	BDL	0.25 mg/L	BDL	Not detected
	Sreerampore 1	BDL	BDL	BDL	Not detected
	Sreerampore 2	0.5 mg/L	BDL	BDL	Detected (mean-14.66, sd-7.50)
	Sreerampore (Mahesh)	BDL	BDL	BDL	Detected (0.607)
	Haripal	1 mg/L	1 mg/L	0.05 mg/L	Not detected
	Dankuni	BDL	BDL	BDL	Not detected
Burdwan	Burdwan	BDL	1 mg/L	0.05 mg/L	Not detected
	Bandel	BDL	BDL	0.05 mg/L	Not detected

(continued)

Table 2 (continued)

District	Area	Iron	Phosphate	Arsenic	Microbial contamination**
North 24 Parganas	Madhyamgram	BDL	0.5 mg/L	BDL	Not detected
	New Barrackpore	BDL	0.5 mg/L	0.5 mg/L	Not detected
	New Barrackpore (filter)	BDL	0.5 mg/L	BDL	Not detected
	Leningarh	BDL	0.5 mg/L	BDL	Not detected
	Dumdum	BDL	BDL	1.0 mg/L	Not detected
	Panihati	BDL	0.5 mg/L	BDL	Not detected
	Sodepore	BDL	BDL	0.1 mg/L	Not detected
	Sodepore (Ghola)	BDL	BDL	0.05 mg/L	Not detected
	Barrackpore	BDL	0.5 mg/L	0.5 mg/L	Not detected
	Barrackpore college (filter)	BDL	BDL	BDL	Not detected
	Barrackpore college	BDL	BDL	BDL	Not detected
	Barrackpore 3	BDL	BDL	BDL	Not detected
	Naihati	BDL	0.5 mg/L	BDL	Not detected
	Ichapur	BDL	0.5 mg/L	BDL	Not detected
	Shyamnagar	BDL	0.5 mg/L	BDL	Not detected
	Basirhat 1	0.05 mg/L	BDL	0.1 mg/L	Not detected
	Basirhat 2	BDL	2 mg/L	BDL	Not detected
	Barasat	BDL	0.5 mg/L	0.05 mg/L	Not detected
	Barasat, Keventer area	BDL	BDL	BDL	Not detected
	Barasat (Amtala)	BDL	BDL	BDL	Detected (mean-4.33, sd-2.081)
	Selampore (Nilgunge)	BDL	BDL	0.05 mg/L	Not Detected

(continued)

Table 2 (continued)

District	Area	Iron	Phosphate	Arsenic	Microbial contamination**
Kolkata	Garia	BDL	BDL	BDL	Detected (mean-12, sd-6.557)
	Tollygunge	BDL	0.5 mg/L	0.5 mg/L	Not Detected
	Chetla	BDL	BDL	1.0 mg/L	Detected (mean-25.33, sd-5.507)
	Behala	BDL	0.5 mg/L	BDL	Not detected
	Joka, Thakurpukur	BDL	BDL	BDL	Not detected
	Ruby	BDL	BDL	0.75 mg/L	Not detected
	Rajpur	BDL	0.5 mg/L	0.75 mg/L	Not detected
	Deshapriya Park	BDL	BDL	BDL	Not detected
	Deshapriya Park (filter)	BDL	BDL	BDL	Not detected
	Science City	BDL	BDL	0.5 mg/L	Not detected
	M. G. Road	0.5 mg/L	BDL	BDL	Detected (mean-9, sd-3)
	Sector 5	BDL	0.5 mg/L	BDL	Not Detected
	Baguihati	5 mg/L	BDL	BDL	Detected (mean-10.66, sd-7.76)
Nadia	Halisahar	BDL	0.5 mg/L	BDL	Not detected
	Kalianibash	BDL	BDL	BDL	Not detected
	Kalyani	0.5 mg/L	BDL	BDL	Not detected

**BDL* Below detectable level
**Colony count given is that obtained per 100 μL

4 Conclusions

All the districts covered in the study showed high level of arsenic in groundwater which has been reported earlier as well. Water is an indispensable part of human life, and its pollution or contamination can lead to several diseases. Strong policy framework, better management techniques, awareness and community involvement are needed to deal with this critical problem.

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Part IV
Policies and Strategies

Socioeconomic and Demographic Profile of Waste Pickers in Brazil and India

M. S. Borges, V. R. Cruvinel, L. H. P. de Lira, A. C. S. Martins and S. K. Ghosh

Abstract In Brasilia, the capital of Brazil, we still have the biggest open dump in the Americas. There are more than two thousand waste pickers working in bad conditions without safety. In India, all over the country the waste pickers work for the collection and segregation of waste from different places including dump sites. The socioeconomic condition and the occupational health and safety hazard of the waste pickers are very bad conditions though they are the agent that makes the environment livable for the citizens. The purpose of this research is to show the reality of the socioeconomic profile, demographic, and social security conditions of these workers and compare the waste pickers in Brasilia, the capital of Brazil, Bangalore and Kolkata, India. This is a narrative review and a cross-sectional study. The following socioeconomic data found in Brasilia were: 65.4% of waste pickers receive less than US$250 per month; just 33.20% receive financial support from the federal government. Only 12.7% contribute to social security. The demographic data indicate that most waste pickers (60%) are women; 36.5% of the sample has only primary education. The average age is 39.4 years. Most of these workers are associated with organizations. In Bangalore and Kolkata, the capital city of the state

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of Karnataka and West Bengal, respectively, there are nearly 20.000 waste pickers; 25% of them are formally organized. A significant number of them are between 18 and 40 years of age; the majority are women and illiterate; 70% earn between US $44.7–89.4 per month. Both groups are economically and socially vulnerable. Their access to water, sanitation and housing facilities in the city is inadequate. Most waste pickers from both countries are exempt from a number of benefits, such as retirement for length of service, maternity pay, sick leave, among others. One of the main needs of waste pickers of India is the inclusion of informal workers in the social protection service, making them part of the universal security system. In Brazil, it is necessary to reinforce the importance of the contribution of social security, which can guarantee assistance in case of disability. Therefore, this reality demonstrates the need to strengthen strategies to improve the quality of life, income, and working conditions of these trash pickers.

Keywords Solid waste segregators · Social security · Socioeconomic factors Solid waste collection · Sanitary landfill · Health effect · Demographic profile Waste pickers

1 Introduction

The environment has suffered from inadequate waste disposal worldwide. With the industrialization process and changes in the population's consumption pattern, and the increase in the quantity and variety of waste generated is causing soil, water and air pollution from toxic waste, as well as providing the proliferation of vectors that cause diseases.

According to data released by the Brazilian Geography and Statistics Institute (IBGE) in 2015, Brazil, located in South America, currently has 204.450 million of inhabitants. India is a country located in South Asia and is characterized by having the second largest population in the world, with 1.21 billion people. The population of India is six times greater than that of Brazil. According to a document prepared by the Department of Economic and Social Affairs of the United Nations, India will overtake China as the most populous country in the world in 2022, with approximately 1.4 billion people.

According to the National Information Sanitation, in 2013, Brazil generated approximately 193 tons of waste daily, but only 169 were collected, which shows that of all waste produced in Brazil, 87% was collected. The southern region is the most covered by solid waste collection with 99.5% coverage. The northern region is the region with the lowest waste collection rate, with 96.3%. According to the Business Commitment for Recycling, in Brazil, 40% of waste is mainly destined to dumpsites and landfills without the necessary environmental care [1]. According to Institute of Applied Economic Research (IPEA), in a new study released in 2010, Brazil loses about 2.4 billion dollars due to burying waste that could be recycled.

India generates 14 million tons of garbage every day by the 377 million people living in urban India. It is considered the world's third-largest garbage generator [2]. According to Central Pollution Control Board of India and Centre for Science and Environment, of the total Municipal Solid Waste (MSW) generated in India daily, only 83% of what is generated is collected and only 29% of the MSW collected is treated [3, 4].

Among the issues related to sustainable development, recycling is seen as a possibility for recovering solid waste and maintaining healthy environments. In this context, in many developing countries, the waste pickers are the workers who provide utility services, acting in the grooming, sorting, transport and packaging waste for processing into new materials involving the saving of natural resources, and promoting healthy environments.

The proper management of solid waste is a common problem among the two emerging countries, causing large dumpsites in the cities that cause negative impacts to the environment and health of the population and especially the collectors. Landfills pollute the air, causing numerous respiratory problems, pollute the soil, preventing planting activities and still pollute streams, rivers, water table, and the seas, often making the water unfit for consumption.

This study aims to present a comparative analysis of socioeconomic and demographic profile of solid waste pickers in Brazil and India. The specific objectives are: Identify the demographic profile of the collectors of both countries; describe the socioeconomic profiles of the collectors in both countries; address advances and discussions that seek the improvement of working conditions in both countries.

2 Part 1—National Policies on Waste Management in Brazil

In Brazil, with the approval of the National Policy on Solid Waste in 2010, the responsibility for solid waste has to be shared among the government, companies, and the population, setting goals and guidelines that must be met by each sector. In addition, the policy determined that all dumps throughout Brazil had to be closed by the year 2014 and landfills would be opened, which would be discarded all that what could not be recycled.

The policy has several objectives to be followed by the sectors involved in the management of solid waste.

The Public Sector:

- Cities should make integrated solid waste management plans with the prioritization of collectors and environmentally sound disposal of waste;
- Cities should close the bins and creating landfills receiving organic waste;
- Municipalities must organize the separate collection of recyclable materials that serve the entire population, supervise, and control the costs of this process;

- Municipalities should encourage the participation of collectors in associations and cooperatives to improve their working conditions;
- The government should conduct campaigns to encourage people to separate recyclable materials from organic waste;
- Public agencies should allocate the recyclable materials cooperatives.

The Companies:

- Companies should invest in proper waste treatment;
- More accessible beneficiation of raw resources for recycled materials;
- Support the creation of voluntary and cooperative delivery stations.

The Collectors/Cooperatives:

- Accession to the cooperatives in order to improve the working environment, reducing health risks and increased income;
- Always look for partnerships with companies and the public sector to carry out the selective collection and recycling;

The Population:

- Individual responsibility to separate recyclables in the residence;
- Participate in educational campaigns on waste sorting;
- Supporting strategies to strengthen the pickers' work.

According to Dias [5], in Brazil a worker with a formal employment is covered by a labor laws which contains rules for fair labor relations, including a minimum wage, work hours a day, 30 days of vacation per year, entitlement to insurance, retirement pay, six months' unemployment wages, and other rights. Unfortunately, all the waste pickers in Brazil still don't have these rights.

Compulsory membership divided opinions of collectors, on the one hand the collectors will have access to the pension plan, fixed working hours, among other privileges that the Consolidation of Labor Laws of Brazil provides, on the other hand, workers will be removed from the informality that it is one of the attractions for part of collectors. Some collectors see the garbage dump as the opportunity to work the day and time that is convenient, to obtain monthly income or to supplement income. Faced with this impasse, the government together with the cooperatives tries to seek a way to solve the problem.

In Brazil's capital, there are now about 33 organized institutions that make the selective collection; these institutions are associations and waste pickers' cooperatives. When a collector is part of these organized institutions, it is seen as part of a group that seeks to improve working conditions, also seeking greater visibility in society and the importance of the work performed by the collector. The collector is seen as a responsible worker to withdraw from nature what can be recycled.

In 2002, the collectors have obtained a great victory when they were legally recognized as a professional category, made official by the Brazilian Classification of Occupations (CBO). The recyclable materials are recorded by the number 5192-05.

3 Examples of Inclusive Laws and Policies in Brazil and India

In 2010, the National Policy on Solid Waste Pickers recognizes them as public utility service providers, with initiatives to support cooperatives and municipalities that are part of the workers in the solid waste systems. In this sense, the collectors have access to the National Health System, as well as all Brazilian citizens, although only minority receives enough to pay the national pension system. A Social Security Bill under discussion in the House of Parliament, if approved, will allow collectors to contribute 2.3% of their income to the national pension scheme.

The Cataunidos Network, together for waste Selective Collection, was created with the aim of promoting better living conditions and work for the pickers. Cataunidos has sought alternatives to facilitate the increase in the income of these workers, the education, and training of their members and family while preserving the environment. Social Venture Network Cataunidos is formed by 650 (four hundred and fifty) waste pickers of 25 (twenty-five) associations and cooperatives in the Greater Belo Horizonte [6].

In India, national policies clearly recognize the informal recycling sector. The National Environmental Policy 2006 states the need to strengthen the collection of waste and recycling, as well as increased access, financing, and implementation of technologies. The National Action Plan on Climate Change, 2009, and other policy documents also refer to the collectors and progressive regional legislation has been enacted in many states [7].

Number of waste pickers; socioeconomic profile, demographic, and social security condition in Brazil

	Brazil	India (Bangalore and Kolkata)
Number of waste pickers	229.568	20.000
% of men	67%	Minority
% of women	33%	Majority
Contribute to security	15.4%	–
Average age	39.4	Between 18 and 40 years
Average income per month	US$151.5	Between US$44.7 and US$89.4
Illiteracy rate among collectors	20.5%	Majority is women

Source 2010 Census (IBGE), PNAD (2012)

4 Situation About the Waste Management in Brasilia, the Capital of Brazil

This open dump is located in the Federal District, in the vicinity of the Brasilia National Park (BNP), about 20 miles from the Presidential Palace, and is approximately 147 ha (429.963 acres) in area. It was named "Estrutural Open Dump" because of its proximity to the road between the Pilot Plan and the administrative regions. The open dump was created more than 50 years ago, along with the construction of Brasília, and for decades there has been the promise of its deactivation. There are 45,000 people living in its surroundings, and 15% of them survive on the collection of recyclable solid waste on the "Estrutural Open Dump."

According to data from the Solid Waste Diagnostic Report, the Federal District, a region which is the capital of Brazil, produces about 8,500 tons of garbage a day, 6,000 tons from construction and 2,500 tons from homes and trade. Among all this amount of garbage, only approximately 5% is recycled. The recycled waste is the main source of income of many people working autonomously or associated with cooperatives.

The Federal District government has been trying to change the destination of the waste produced in the region. The garbage that has been disposed in the Estrutural Open Dump (the largest in Latin America, currently) goes directed to landfills and warehouses managed by recycling cooperatives. Approximately 3000 people crowd at the dump in search of any material that can be sold. With the closure of the open dump, only cooperatives have access to recyclables. Therefore, it is necessary that the self-employed join, ensuring that they will continue surviving on the recycled material.

5 Part 2—The profile of Waste Pickers in Brasilia, Brazil

It is important to know the profile of waste pickers to implement effective measures for education and protection to ensure improvements in the quality of life of workers. This is a cross-sectional study. Table 1 shows the profile of waste pickers in Brasilia, Brazil, according to the variables: gender, age, race, education, number of children, and marital status. We used database of responses that were collected by investigators of Institute for Socioeconomic Studies in 2014. As this was secondary data without access to any personal data of waste pickers like name, address, ID number, telephone, this stage of the research was not submitted to the Ethics Committee. It was only made authorization for release of the data for this research. There were interviewed 1686 waste pickers which correspond to 85% of the total of collectors of Brasilia, Brazil.

Table 1 Distribution of waste pickers in Brasilia according to demographic variables of the groups studied; Federal District

Variables		*n*	%
Number of waste pickers	Total	1,686	100
Gender	Male	647	38.4
	Female	1,039	61.6
	Total	1,686	100
Age	18–25	220	13.3
	26–35	522	31.7
	36–45	465	28.3
	46–55	305	18.4
	56–65	129	7.8
	66 or more	24	1.5
	Total	1,665	100
Race	White	231	13.9
	Black	373	22.5
	Brown	983	59.3
	Yellow	47	2.8
	Indian	23	1.4
	Total	1,657	100
Schooling	Illiterate	155	10.1
	Incomplete elementary school	490	31.8
	Complete elementary school	563	36.5
	High school	262	17.0
	Technical education	56	3.6
	Undergraduate	14	0.9
	Graduate	1	0.1
	Total	1,541	100
Children	Yes	1,482	88.6
	No	190	11.4
	Total	1,672	100
Number of children	1	274	18.5
	2	362	24.5
	3	331	22.3
	4	235	15.8
	5	121	8.2
	6	64	4.3
	7	47	3.2
	8 or more	49	3.3
	Total	1,483	1.5
Married	Yes	571	34.2
	No	1,099	65.8
	Total	1,670	100

Table 2 Distribution of study participants as socioeconomic variables of the groups studied. Distrito Federal, Brazil 2015

Variables		*n*	%
Average monthly income	<US$200	1,074	65.40
	US$200–400	526	32.00
	US$400–600	25	1.50
	US$600–800	16	1.00
	US$800–1,000	2	0.10
	Total	1,643	100.00
Average family income	<US$200	829	53.00
	US$200–400	624	39.90
	US$400–600	71	4.50
	US$600–800	25	1.60
	US$800–1,000	15	0.90
	Total	1,564	100,00
Other occupation	Yes	260	15.60
	No	1,405	84.40
	Total	1,665	100.00
Another source of income	Yes	486	33.20
	No	976	66.80
	Total	1,462	100.00
Social security	Yes	211	12.70
	No	1,453	87.30
	Total	1,664	100.00

Table 2 shows the distribution of participants who answered the study questions according to the variables: average monthly income, average family income, other occupation and social security.

6 Discussion

Regarding the sex of the partners, the prevalence of women is higher (62%) compared to the amount of men. In studies conducted by Gonçalves [8] and Dias et al. 9] in the Brasilia, it was noted that women constitute the majority of waste pickers.

Regarding age, the collectors are on average of 38 years. This fact shows convergent with respect to the results found by the situational survey conducted by the Institute of Applied Economic Research (IPEA) [10] on the collectors that reveals the average age of collectors 39.4 years in Brazil.

Regarding race and color, in this study 81% of the collectors say they are brown and black. As census survey data conducted by IBGE (2010), the Brazilian population has 42% of mulattos and 6% self-described blacks, which represents almost half the total population. Moreover, in the study by IPEA in 2013, 66.1% of waste pickers of Brazil declared black or brown [10].

Regarding the level of schooling, most collectors only completed primary education. Thus, the data obtained in this study have better schooling conditions for collectors of Brasilia in relation to Brazil, because according to the study by IPEA [10], 20% of collectors of recyclable materials in the country are illiterate, while 24.6% have completed primary education and 11.4% completed high school. In this study, only about 10% of collectors are illiterate. In this study, many workers perform their work activities on the night shift and still have other occupations, which can be a factor that hinders the access of workers to education, as well as stigma and social exclusion of the profession [10].

When asked if they had children or not, 88.2% of collectors said also have children. The group had an average of three children. This data can be divergent when compared to population groups of professions and similar socioeconomic conditions. In another study with DF collectors, we found an average of four children [10].

Regarding marital status, the collectors had a higher percentage for the variable does not have spouse with 65.6% of respondents in this condition. This factor can be attributed to the difficulty in finding partners because of the strong social discrimination that exists on the profession of groomer.

In relation to family income, 65.7% has a lower concentration of income than 200 dollars monthly. The same value is repeated to family income, showing that the waste pickers play the role of breadwinners, reinforcing the importance of grooming for the livelihood of families. In addition, the scavenging is characterized as the only occupation in most of the respondents. This fact shows that the work done in an organized manner in a better position to infrastructure such as press, shed, and machinery can generate more income for the scavengers.

From receiving the family allowance, it was realized that the benefit does not have good coverage in these communities not reaching 30%. The “Family Income Program,” a form of income transfer is linked to social rights such as health and education [11]. The program benefits poor and extremely poor families. Regarding social security contributions, most collectors said they did not contribute to social security (88%). The contribution rates show the low level of social protection, as collectors become exempt from a number of benefits, such as retirement for length of service, paid maternity leave, among others. According to the survey conducted by IPEA in 2013 [10], the recyclable material collectors comprise part of the population that is not in the pension system.

7 Conclusions

7.1 Issues and Challenges in Tabular Form for Indian and Brasil

One of the biggest challenges of India and Brazil is facing the government and the unions to adapt the working conditions of collectors, so they can join the new form of formal employment. Many collectors are drawn to the collection of waste precisely for the informality; it is important to note that the formalization of the arrangement of collectors' work is a means of making the class stronger, bringing benefits and better working conditions.

One of the biggest problems faced by the Governor of Brasilia is the allocation of the population whose main source of income is the "Estrutural Open Dump," in the neighborhoods of trash family homes, built with minimal access to infrastructure.

In 2013, the National Movement of scavengers in Brazilian representatives went to the House of Representatives to request the approval of the Senate bill (PL 3997/12), which includes the category of special social security benefits, so that collectors to start to contribute at a rate of about 2% of their own revenues to receive benefits when they need to. This type of contribution is adopted for other professions, such as fishermen and rural residents. In 2013, again MNCR met with government officials seeking the incorporation of the draft Constitution amendment (PEC 309/13), which aims to work together with the PL 3,997/2012, in order to speed the process of inclusion of waste pickers such approval as special beneficiaries of social security. Despite all the movement of struggle of these workers, said Bill is still in progress. This fact is extremely worrying and requires urgent state stance to reverse this to ensure the labor rights of collectors [10, 12, 13].

Even with all the adversity faced, the collectors seek social organization through cooperatives, associations, networks, and national and regional movements in order to achieve better working conditions through cooperation with public and private sectors. The National Policy on Solid Waste (PNRS) highlights the role of scavengers and the need to implement selective collection. In addition, the Federal Government of Brazil instituted in 2009 CATAFORTE Program—Sustainable Business in Solidarity Network aimed at investment in training and qualification for the collectors, and the acquisition of equipment and technical consulting contract for autonomy and income generation to collectors [12, 14].

In Brazil, the selective collection initially organized by the private sector has contemplated the collectors of recyclable materials, for example, Brasilia, which in 2016 hired 04 recycling cooperatives for the provision of the selective collection and community education service.

Finally, it is expected that this study can contribute to aggregate qualified information to this debate, in order to foster discussion about the proper disposal of solid waste, in line with respect for human dignity especially the appreciation of the activities carried out by waste pickers and recyclable material collectors.

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The Indian Resource Panel: A Mechanism to Promote Resource Efficiency Policy Throughout the Indian Economy

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Abstract India's rapid economic growth necessitates rapidly increasing resource consumption. However, resource extraction, processing, use and disposal typically have considerable environmental impacts. In addition, there are concerns about the adequate and affordable supply of resources in the future, especially for certain critical resources for which India is highly import dependent. Therefore, resource efficiency is critical for sustainable development in India going forward. While considerable resource reuse and recycling is already existent in the Indian economy, there is no overall strategic approach to resource efficiency such as those adopted by European Union nations. The Indo-German bilateral cooperation project "Resource Efficiency and Sustainable Management of Secondary Raw Materials", funded by the German Ministry of Environment, Nature Conservation, Building and Nuclear Safety, is being jointly implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and the Indian Ministry of Environment, Forest and Climate Change (MoEFCC). The project aims to promote policy and institutional frameworks that improve resource efficiency and secondary material reuse. In addition to demonstrating successful resource efficient practices in selected sectors, the project has also supported the MoEFCC to institute an Indian Resource Panel (InRP), the first of its kind in India, with the mandate to advise the Government of India on implementation of resource efficiency strategy and policies throughout the Indian economy. One of the first tasks of the panel was to undertake a baseline assessment of the policy landscape in India related to resource use. A detailed analysis was undertaken of all existing policies at different stages of the life cycle—mining, design, manufacturing, consumption and waste management. Gaps and potential synergies were identified that would be the basis of policy recommendations to promote resource efficiency across the entire value chain. This paper presents the objectives of the InRP and highlights results of this comprehensive policy assessment, including a case study of the automotive sector.

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1 Introduction and Background

India's rapid economic growth necessitates rapidly increasing resource consumption. Even though per capita resource consumption in India is still relatively low compared to developed countries, in absolute terms India was already the third largest consumer of materials in 2009 after China and the USA [1]. From 1.7 billion tonnes per year in 1980, India's total material consumption increased to 4.8 billion tonnes in 2009 [2] and is projected to increase dramatically to 14.2 billion tonnes in 2030 [1]. However, resource extraction, processing, use and disposal typically have considerable environmental impacts [3]. In addition, there are concerns about the adequate and affordable supply of resources in the future, especially for certain critical resources, for example, cobalt, nickel, copper, phosphate, on which India is highly import dependent [1]. Therefore, resource efficiency (RE) is critical for sustainable development in India going forward. While considerable resource reuse and recycling is already existent in the Indian economy, there is no overall strategic approach to resource efficiency such as those adopted by European Union nations [4]. In 2009, India's resource productivity was USD 716 per tonne of material used versus a global average of USD 953 per tonne. While resource productivity increased significantly in India between 1980 and 2009, the increase was well short of what was achieved in China and Germany [1].

2 Objectives of the Indian Resource Panel

The Indo-German bilateral cooperation project "Resource Efficiency and Sustainable Management of Secondary Raw Materials" (in short: Resource Efficiency), funded by the German Ministry of Environment, Nature Conservation, Building and Nuclear Safety (BMUB), is being jointly implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and the Indian Ministry of Environment, Forest and Climate Change (MoEFCC). The project aims to promote policy and institutional frameworks that improve resource efficiency and secondary material reuse. In addition to demonstrating successful resource efficient practices in selected sectors, the project has also supported the MoEFCC to institute an Indian Resource Panel (InRP), the first of its kind in India, with the mandate to advise the Government of India on implementation of resource efficiency strategy and policies throughout the Indian economy. The panel is comprised of ten experts from government, academia, industry and civil society, and is supported by a Secretariat housed in the Central Pollution Control Board (CPCB).

The InRP has been set up to advice the Government of India (GoI) and relevant stakeholders on the potential for enhancing resource efficiency and productive use of secondary raw materials in the Indian economy. As part of its advisory role, the Panel is expected to underscore resource efficiency in the context of the existing policies and programmes of the Government of India like “Make in India”, “Clean India” and “Smart Cities”. Additionally, as mentioned earlier, the Panel is also required to analyse and draw conclusions on existing policies related to resource efficiency and secondary raw materials like the National Environment Policy (NEP), Waste Management Rules and R&D schemes for better management of secondary resources.

One of the first tasks of the panel was to undertake a baseline assessment of the policy landscape in India related to resource use. A detailed analysis was undertaken of all existing policies at different stages of the life cycle—mining, design, manufacturing, consumption, and waste management. Gaps and potential synergies were identified that would be the basis of policy recommendations to promote resource efficiency across the entire value chain. This paper presents highlights of this comprehensive policy assessment.

3 Methodology of the Policy Analysis Paper

The policy analysis has been conducted in three steps:

Step 1: Identifying Policies at Stages of Life Cycle and Overarching Policies

An inventory of policies that are applicable to the different stages in the life cycle of products (except for the mining/extraction stage where the focus will be on metal ores and non-metallic minerals)—design of products, manufacturing process, consumption phase of the product and post-consumption (or end-of-life phase) of the product was prepared. National-level environmental policies, for instance, the Environment Protection Act, 1986, NEP, etc., have been analysed as overarching policies, but different stages have also addressed specific concerns/gaps from their respective analysis, which are applicable to the overarching policies.

Step 2: Gaps and Opportunities in Existing Policies

The second step involves identification of gaps and opportunities in existing policies in the context of resource efficiency and secondary resource management (SRM).

Step 3: Gaps in Policy Landscape

This analysis highlights the linkages between different policies and programs and the impact of those linkages on emphasizing the role of resource efficiency and secondary resource management. Overlaps in gap and opportunities of different policies have been identified and linked to the landscape policy analysis.

Figure 1 summarizes the methodology.

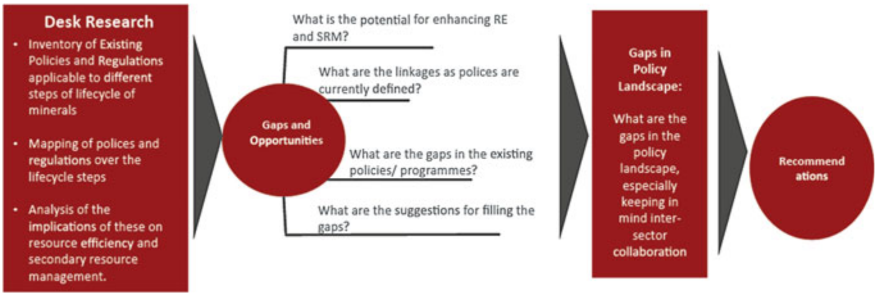

Fig. 1 Schematic representation of the methodology of the policy analysis paper

4 Key Results of the Life cycle Gap Analysis

The key findings of the life cycle gap analysis are summarized below.

4.1 Mining

Gaps:

The policy analysis exercise conducted for the mining stage revealed that although the framework exists, it has a limited focus on resource efficiency at the mining stage. Further, best available techniques/technologies (BAT) for efficient mining are missing. Mine closure plans do not address social issues and lack scientific rigour during the closing down process. Currently, the mine sector administrators or environment sector regulatory mechanisms do not adequately take into consideration regional environmental and social impact assessments or studies based on carrying capacity for planning mine leases and overall mine development in regions. Also, the plans do not focus on linking mining and mine closure plans.

Opportunities:

The National Mineral Policy could look into aspects related to co-production of metals as by-products from the base metal ores extracted, thereby maximizing resource recovery and minimizing waste, this would promote resource savings. Emphasis also needs to be given on promoting Research and Development for technologies that maximize this co-production of by-product metals from base metal ores. This would enhance raw material security on the one hand and give the country's manufacturing sector a competitive edge on the other. Cooperative legislation should enable mining of minor minerals wherever feasible by local cooperatives and reviving the traditional cooperative societies at the state level; this would in turn enable drawing out a mining framework through understanding local perspectives on various aspects of extraction and damages.

4.2 Design

Gaps:

Currently, the policies pertaining to the design of products, the National Design Policy (2007) for instance, do not address RE and SRM and have no environmental standards and guidelines for the same. The Eco-Labelling Scheme of the Government of India, ECO-Mark, does not cover resource intensive products like building materials (extensive use of sand and soil), car manufacturing (steel, aluminium, critical metals) etc.

Opportunities:

An integrated approach in the Science, Technology and Innovation Policy of 2013 and the inclusion of RE and SRM as key elements in the policy can go a long way in achieving the goal of sustainable and inclusive growth. Life cycle impact assessments of production and product designs, with emphasis on resource efficiency and promotion of the use of secondary raw materials, can be incorporated in design policies. The Bureau of Indian Standards (BIS) can mandate emphasis on RE and SRM standards and guidelines for product designers and manufacturers.

4.3 Production/Manufacturing

Gaps:

While flagship programmes like Make in India provide special assistance to energy efficient, water efficient and pollution control technologies through Technology Acquisition and Development Fund (TADF), there is no mention of RE and SRM issues in any of the national-level manufacturing policies. Additionally, industrial infrastructure promotion policies also do not address the need for emphasizing RE and SRM towards a sustainable industrial economy. The BIS standards, although widely referred to in the manufacturing industry, lack standards for RE and SRM.

Opportunities:

Voluntary Standards like the MoEFCC's Corporate Responsibility for Environmental Protection (CREP), 2003, could have significant positive impact on the adoption of RE and SRM, but needs appropriate accompanying measures like dissemination and awareness generation in partnership with industry bodies and chambers of commerce. Agencies similar to the Bureau of Energy Efficiency (BEE), which designs instruments for energy efficiency, need to be institutionalized for the promotion of RE and SRM tools in industry. Capacity building of regulatory bodies as well as small and medium enterprises should be a core focus area to promote RE and SRM in the production phase. Helpdesks may be created in a public–private partnership (PPP) mode between Industry Associations and State Pollution Control Boards to create awareness regarding benefits of RE and SRM to industry.

4.4 Consumption

Gaps:

The analysis for the consumption stage revealed that consumption decisions are largely influenced through taxation. Taxation rates are not differentiated, as a result, consumption of resource efficient products or products that use secondary resources are not incentivized. Eco-Mark scheme has not been successful in creating awareness towards the use of environmental products. The Public Procurement Bill (2012), although a step in the right direction towards creating markets for sustainable products, does not promote the consumption of products made using resource efficient practices or secondary resources.

Opportunities:

Given that consumption is behaviour dependent, most opportunities lay in awareness and capacity building programmes. Nationwide media campaigns like the *Jaago Grahak Jaago* campaign of the Ministry of Consumer Affairs could be key in this regard. Another way to curb consumer attention towards RE and SRM products is by introducing incentives through tax systems. Differentiating the tax rate between regular products and products made in a resource efficient manner and with secondary resources is a good technique to get the customer's buy-in. The Public Procurement Bill could also introduce the concept of RE and SRM and the importance of purchasing such goods. This would enable the space for new RE and SRM product markets.

4.5 Post-Consumption (or End-of-Life)

Gaps:

The post-consumption stage is most vital for SRM, especially in a country like India, where high economic growth rates are accompanied with rising incomes and increasing consumption resulting in the generation of large volumes of waste (valuable and non-valuable). As existing policies relevant to this stage of the life cycle are revisited and revised to adapt to the current scenario, there is a relatively greater emphasis on issues related to RE and SRM; yet none of the policies close the loop as they mostly adopt approaches which are not comprehensive and leave vagueness with regards to responsibilities, ownership and financing tools. It is well known that the informal sector is the backbone of efficient waste recycling in India; however, all the waste rules (except solid waste and plastic waste rules) have failed to incorporate this underprivileged section of society in the formal waste management mechanism.

Opportunities:

The introduction of standards for resource efficient recycling is a requirement that is essential to all existing relevant policies/programmes. Furthermore, the efficiency criteria should be balanced with the social criteria as a large part of the recycling occurs in the informal sector. Therefore, RE should not be used as a barrier for the informal sector mainstreaming. To the contrary, focusing on the comparative advantages of the informal (in collection, segregation and dismantling) and formal sectors (in advanced technological solutions for scientific disposal and recovery of materials and energy), models promoting cooperation between the two could be developed. Extended producer responsibility must be used as a fundamental principle for waste management, especially for material-rich waste streams like e-waste, end-of-life vehicles, packaging waste, etc. Further, waste management should be made a key element of industrial policy as it would contribute to acquiring low-cost raw materials for industrial development.

5 Result of Sectoral Analysis Using the Automotive Sector as a Case Study

Examination of potential policy interventions at a particular stage of the life cycle allows us to identify the existing policies and the potential instruments that have been used to address the different stages of the life cycle. However, to identify the gaps in ensuring that the life cycle thinking is embedded in policymaking, there is a need to examine policies that have an impact on the same sector throughout the different stages of the life cycle. This step is critical because a sector is influenced by policies drawn up by different Ministries at the national level, as well as the policies promoting the sector at the state level. Mainstreaming RE and SRM into policy making needs a holistic approach whereby all the stages of the life cycle need to be considered by the different Ministries involved in policymaking in a particular sector. This would imply that a coordinated approach needs to be developed for policies that influence the sectors. Four sectors of key importance to India, where the existing policy landscape can be improved by incorporating RE and SRM issues by linking policies influencing different stages of the life cycle, were selected for analysis: Information Technology (IT), Automotive, Cement, and Iron and Steel. The results of the Automotive sector analysis are briefly summarized below.

5.1 Raw Material Production

The mine exploration technologies being used in India are obsolete, and substantial technology gaps exist in exploration techniques and equipment which has implications on resource extraction and resource use in extraction. Given the energy- and water-intensive nature of mineral extraction, there are provisions laid down by the National Mineral Policy 2008, Minerals and Mining Development Regulatory Act 2015 and the Sustainable Development Framework 2011 that encourage efficient extraction of minerals. But these policies/frameworks do not put emphasis on specific minerals including those important for the automotive sector.

5.2 Manufacturing and Assembly Stage

Foreign Direct Investment: Automatic approval for foreign equity investment up to 100% in the manufacturing of automobiles and its components under the Auto Policy of 2002 brings new intermediate goods, additional capital for production, technology transfers (for more efficient technologies and those enhancing use of secondary raw materials) and skills in the form of externalities and technology spillovers. The technological spillover effects on domestic manufacturers can be in the form of enhanced efficiency and diffusion of knowledge in the long-run.

Incentives for R&D: The Auto Policy 2002 also allowed for weighted tax deduction under the Income Tax Act, 1961 for sponsored research and in-house R&D expenditure. Further, for every 1% of the gross turnover of the automobile manufacturing company that is expended during the year on Research and Development for adoption of low emission technologies and energy-saving devices, there is a rebate on the applicable excise duty. The 12th Five Year Plan of the Government of India emphasizes the need to achieve global standards in operational efficiency and for this the government also seeks to promote international cooperation in emerging areas of automotive technologies. It is important that there are incentives designed that would encourage the use of resource efficient technologies and promote the use of secondary raw materials in production of automobiles.

5.3 Use and Service Stage

Auto Fuel Policy, 2003, provided the base to the Government for drafting a road map on long term emission and fuel availability. The road map focuses on the availability and usage of various auto-fuels (including LNG, hydrogen and biofuels) for emission control, energy security and fuel efficiency. It also promotes eco-friendly cars in the country such as CNG-based vehicles, hybrid vehicles, electric vehicles, and mandatory blending of 5% ethanol in petrol.

Safety Regulations:

The Automotive Mission Plan 2016–26 (AMP 2026) recognizes that vehicles need to comply with global standards of safety in line with the UNECE World Forum for Harmonization of Vehicle Regulations. These standards, while ensuring safety, do not compromise on improvements in fuel efficiency. Similarly, there should be identified standards and labelling that not only promote fuel efficiency, but also establish quality and environmental criteria to promote resource efficiency and use of secondary raw materials in production of automobiles.

5.4 End-of-Life Management Stage

Even though there is no specific regulation in India governing end-of-life vehicles (ELVs), the issue is slowly gaining prominence. Currently, retired vehicles in India usually end up in the informal sector where, after dismantling, the auto components are either refurbished or sent for recycling. Not surprisingly, the efficiency of material recovery is quite low as the workers are not trained and lack the equipment to dismantle and recycle auto components [5]. While some aspects of ELV recycling are addressed by vehicular policy, environmental policy as well as the different wastes management rules, other aspects are not yet covered by the law.

6 Recommendations from the Analysis

Based on the detailed analysis of the existing policies and discussions amongst the Panel members and its Secretariat, the following recommendations have been put forward as initial steps to promote RE and SRM in the Indian context.

Overarching Framework for Resource Efficiency and Secondary Resource Policy:

There are policies related to different stages of the life cycle but most of these policies do not explicitly take into account RE or SRM issues. Rather than introducing policy changes one by one on a case-by-case basis, we need an overarching framework for Resource Efficiency and Secondary Resource Policy. This could take the form of a National Policy for Promotion of Resource Efficiency and Secondary Resources Management. The policy document would outline the fundamental principles for RE and SRM applicable for the Indian economy. It would then identify the key themes relevant to the Indian context and outline those thematic strategies. The policy could then be a reference point for the different line Ministries while developing their future strategic plans. Like the National Environment Policy, it can recommend measures that will trigger policy and implementation level changes in different stages of the life cycle across sectors which need not be legislative in nature. In addition, once an overarching framework is in place, it could trigger amendments to relevant regulations like the Mining Act, programmes like Make in India, Digital India, etc. and other relevant policies. An overarching framework can reduce the time required to achieve the desired objective significantly.

Development of Standards for RE and SRM:

Standards are the cornerstone of any economy and act as tools to enhance the resource efficiency and use of secondary resource management across sectors. In the absence of standards, ministries and departments can't recommend specific targets for RE and SRM. Whereas, if standards are available, enterprises can be asked to follow the standards and achieve the desired target of RE and SRM. The main advantage of introducing RE and SRM concepts through standards in India is the existing fairly successful system of following BIS standards for quality and safety. A significant level of compliance to BIS standards exists for a variety of goods and widespread public awareness regarding BIS standards will ensure awareness creation about RE and SRM issues. The BIS can be encouraged to develop standards for products by including RE and SRM concerns covering the different stages of the life cycle. A starting point could be an industry wide dialogue on developing industry initiated voluntary standards for RE and SRM. Once voluntary standards are introduced, the next step could be incentives for following the standards, and once RE and SRM issues are mainstreamed, even mandatory compliance with RE- and SRM-related BIS standards could be introduced.

7 Conclusion

The first task of the Indian Resource Panel is to take a holistic view of the Indian economy from the perspective of resource efficiency and identify gaps in the existing policy landscape. The key results of the analysis were summarized in this paper, and recommendations were made that were deemed to be most logical first steps. As engagement on resource efficiency policy increases, the Panel will consider more detailed and sector-specific analyses and recommendations.

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Knowledge and Practices of Municipal Solid Waste Workers: Findings from Focused Group Discussions

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Abstract Solid waste workers are exposed to substantial levels of physical, chemical and biological toxins from the point waste is generated and collected to the point it is disposed. They are at risk of developing allergic diseases, respiratory infections, musculoskeletal disorders, gastrointestinal infections and injuries due to work-related accidents. The high exposure statistics highlight the nether prevention methods, under utilization of preventive measures such as using personal protective measures, lack of education and training. The workers can be protected from work hazards and prevented from various diseases and conditions by employing safety procedures and ensuring effective and adequate use of personal protective measures. There is a huge gap between knowledge and practices of safe handling of municipal solid waste among workers in India. With this background, a qualitative study was conducted to understand the knowledge and practices of municipal solid waste handlers in Bangalore city. The study highlighted fair good knowledge about waste segregation and different types of waste but a few lacked knowledge about sanitary waste. Almost all the workers were provided with safety gears but a very few used them as they were not comfortable. Most of the workers suffered from common ailments but utilized private healthcare facility and ended up spending high for health care. Workers lacked the facilities like drinking water, toilets and restrooms. Findings of the study have been employed to design a survey for the entire solid waste workers of Bangalore and to develop occupational health and safety manual and behaviour change interventions.

Keywords Municipal solid waste workers · Segregation · Occupational health hazards

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1 Introduction

1.1 Background

Municipal solid waste workers are generally exposed to variety of occupational health hazards and conditions [1]. Solid waste workers are exposed to substantial levels of physical, chemical and biological toxins from the point waste is generated and collected to the point it is disposed [2]. There is a lot of evidence available to prove the fact that the municipal solid waste handlers are at risk of developing allergic diseases and disorders, respiratory infections, musculoskeletal disorders, gastrointestinal infections and injuries due to work-related accidents [3–6]. The most evident pathway for infectious diseases is by activation of faeco-oral route basically by eating, drinking water and smoking, without adhering to the universal precautions [7]. The communal waste is basically comprised of organic and bio-aerosol usually stuffed with micro-organisms like bacteria, fungi, viruses, endotoxins and various organic and inorganic chemicals which are potentially hazardous [8–10].

There is a huge body of research to assess the impact and morbidity data about occupational exposure to solid waste among municipal solid waste workers. Identification and assessment of occupational health risks among the solid waste workers are receiving increasing importance because of reported statistics on exposure among the solid waste workers [2]. These exposure statistics highlight the nether prevention methods, under utilization of preventive measures such as using personal protective measures, engineering controls, lack of education and training and other such interventions.

However, control of these conditions at work and enforcement of appropriate hygiene measures is difficult due to lack of hygiene standards, especially in developing countries like India. It is evident that workers can be protected from work hazards and prevented from various diseases and conditions associated with the waste handling by employing safety procedures and ensuring effective and adequate use of personal protective measures [5].

With urbanization and industrialization, the volume of the waste generated is drastically increasing. With increase in the waste generation, there is a lot of attention paid on the occupations that are associated with waste management. Most of the jobs associated with solid waste management are dangerous. In USA, collection of refuse and recyclable material was considered as world's sixth most dangerous occupation in 2016 with the rate of 27.1% deaths per 100,000 workers [6].

People employed in collecting waste, cleaning sewage pits and drains, sweeping roads and collecting and disposing of human and animal excreta, and animal corpses are called pourakarmikas (these also include manual scavengers, sewer workers, sanitation workers) [11].

There are few studies that emphasize the health risks and magnitude of the disease burden among the solid waste workers in India. Very little is known about the utilization of the healthcare facility for the health problems associated with solid waste handling and its occupational hazards. The occupational health problems also have synergistic effect of poverty and malnutrition and habits like alcoholism. Alongside this, the socio-economic factors such as poverty, lack of education, poor housing conditions, poor diet, meagre pay and inadequate health facilities and benefits pose high risks for various diseases [11].

In industrialized countries, the occupational health impacts have been significantly brought down with the result of introduction of standard norms for solid waste management, but the burden in the developing countries is still very high and needs to be addressed. There is a little knowledge about the hazards of solid waste to the workers in developing countries. The protection for the workers is also very minimal. There remains a significant difference in knowledge and practices of safe handling of municipal solid waste among the waste handlers in India. Workers do not follow safety precautions but rarely use personal protective gears to protect themselves. With this background, a qualitative study was conducted to understand the knowledge and practices of municipal solid waste handlers in Bangalore city.

Bangalore generates nearly about 4000 tons of solid waste every day. BBMP is carrying out collection, street sweeping, transportation, processing and disposal of municipal solid waste. BBMP has a system of door to door collection for collecting the municipal solid waste. About 80% of the collection and transportation activities have been outsourced. About 23,000 municipal solid waste workers (pourakarmikas) are being utilized for municipal solid waste management. Among these, around 3000 are directly employed by BBMP and around 20,000 are employed by contractors. These solid waste workers'/pourakarmikas' major role is

- Collection and transportation of household waste by auto tippers and pushcarts;
- Sweeping of roads, streets, footpaths and pavements, cleaning of roadside drains, uprooting of vegetation;
- Gangmen are employed for intensive cleaning of public areas like playgrounds, burial grounds.

The present study has highlighted the knowledge and practices of solid waste handlers about waste segregation, occupational problems prevalent among them. This study has highlighted the risks and gaps in knowledge and practices of municipal solid waste workers and untoward health problems, to suggest possible measures to safeguard the health of the workers.

However, control of these conditions at work and enforcement of appropriate hygiene measures is difficult due to lack of hygiene standards, especially in developing countries like India. It is evident that workers can be protected from work hazards and prevented from various diseases and conditions associated with the waste handling by employing safety procedures and ensuring effective and adequate use of personal protective measures.

2 Methodology

To critically assess the working conditions, knowledge about waste segregation, practices of the solid waste workers and to gain an insight into the occupational health problems among these workers, a qualitative study was conducted among the municipal solid waste handlers in Bangalore city.

2.1 Aim

The primary aim of this qualitative study was to understand the nature of work of solid waste workers, the knowledge, practices, occupational hazards and health problems associated with their work.

The secondary aim of the study was to develop occupational health and safety manual for the solid waste workers.

2.2 Objectives

(1) To assess the knowledge of municipal solid waste workers regarding waste segregation;
(2) To assess the protective measures used by solid waste workers while collecting the waste;
(3) To know the occupational hazards and health problems prevalent among solid waste workers;
(4) To assess the health facilities utilized by solid waste workers.

2.3 Qualitative Study

Focus group discussions to understand the nature of work, the knowledge, practices, occupational hazards and health problems were conducted among municipal solid waste workers in Bangalore. Total of seven focus group discussions were conducted in four zones of Bruhat Bengaluru Mahanagar Palike (BBMP).

Among the eight zones and 198 wards of BBMP, Yelahanka, Hebbal, Peenya and Rajarajeshwari Nagar zones were selected based on the convenience. Two focused group discussions each (one for pourakarmikas directly employed by BBMP and another for pourakarmikas employed by contractors) were conducted in all the four zones which were selected. The participants were representative of the wards that were to be covered. The participants consisted of pourakarmikas including sweepers and auto drivers, gangmen, water man, inspectors and supervisors. Each focused group discussion had around 20–25 participants.

The broad themes of enquiry for the focused group discussion are as follows.

- Nature of work;
- Safety at workplace;
- Knowledge on waste segregation;
- Health status and occupational health problems;
- Awareness and utilization of health facilities.

The responses of the participants were recorded in writing and in an audio recorder.

3 Findings

3.1 Nature of Work

The municipal solid waste workers comprised of both employed directly by BBMP and employed by private contractors. Most of them were from poor socio-economic status. Both the government and contract employees work from 6 am till 12 pm on everyday basis. Some of workers had recently joined the job, and some were working since the inception of BBMP the then corporation. The range of employment was between 3 weeks and 25 years. Most of them were illiterate, and only a few had primary education. Most of them reported that they had 3–4 children and said they had maximum of primary education. Most of them expressed that they never wanted their children to be in this job.

The worker employed directly by BBMP was paid around 200/-, and the one employed by contractor was paid 250/- per day. All these workers were provided with health cards and with the medical facilities such as free medical services and insurance. Both the group were provided with gloves, shoes, uniforms and safety equipments. But the facilities such as pay for the work, provision of safety equipments, uniforms, gloves, shoes were found to be better with the employees with contractors.

Most of the workers, both under BBMP and contractors, responded that illiteracy, poverty and helplessness were the main reason to choose the job. Even though they were not happy with the kind of the work and the pay for their work, they were helpless to be in the job. For some of the families, it was a vicious cycle where their children were also forced to be in the same job because of lack of alternative job and poverty.

3.1.1 Garbage Collectors

Auto tipper/autos and pushcarts are used for the primary collection of garbage. An auto tipper was provided for every 1000 households and a pushcart for every 200 households. Daily collection and transportation of waste are done with auto tippers only with driver and helper. Pushcart collection only is done in slum areas. The waste collected by the auto and pushcart is collected at an assigned point, and the waste is then transported by tractors or compactors for disposal. Sometimes, the drivers of the auto tippers have to carry the dead animals along with the waste. The solid waste also contains wastes from toilets, wastes from establishments like hospitals which include contaminated instruments like blades, needles and sharp instruments.

On an average, garbage collector by auto tippers (door to door) would cover around 800–1000 houses a day. Street sweepers would cover the stretch of the street allotted to each sweeper. They dump the segregated waste at a specified point for further transportation. These points would be identified by health inspectors or by contractors.

3.1.2 Street Sweepers

These workers basically sweep the roads, streets, footpaths and pavements. They also trim the plants and public gardens. The waste is collected and dumped at the assigned point and further transported for the disposal.

3.1.3 Drain Cleaners/Slit Cleaners

The men are involved in cleaning the drains from 6 am in the morning. Each worker is expected to clean 2–4 drains by 2 pm in the afternoon. During the rainy season, the amount of waste in the drains is quite high and may clog the drains and hence the cleaning of drains would be more frequent during rainy season. Sometimes, they even lift the stone slabs and open the drain to clear the block.

3.2 Safety at Workplace

In order to safeguard the workers, provisions of safety measures like masks, gloves, boots and uniforms are mandatory. Each pourakarmika is provided with apron, gloves, boots and masks. In addition to this, each worker is provided with an ID card which has to be displayed during their working hours. Many of the BBMP employed workers stated that the gloves were torn within a week and are not been replaced. The situation was same with the employees under private contractors. But the common finding was that most of them were comfortable to wear the apron and uniforms but the mask and gloves were not comfortable. Some of them also complained that they will not get a new one when they request.

Most of the women sweepers said that they do not wear mask, gloves during the working hours. The common reason for not using gloves and masks was that the workers feel very uncomfortable and hot in them and hence refuse to wear it during the long working hours.

Mr Prasad, 28-year-old slit remover, said “we are provided with gloves, shoes and uniforms, but it is uncomfortable to wear. We sweat and it is itchy”.

Even though everyone was aware of the safety measures and their benefits, none of them were practicing the use of personal protective gears. This may cause exposure to various toxic wastes and inhalation of noxious gases. Adding to this, most of them also said that to tolerate the foul odour they often consume alcohol.

3.3 Knowledge and Practice About Waste Segregation

BBMP emphasizes segregation at source. Various IEC activities have been conducted intensively to embark the importance of segregation. The households are required to segregate their wastes into two categories, namely wet and dry waste. At the later stage, household hazardous waste like discarded medicine, sanitary napkins, diapers, batteries paints is proposed to be collected separately. When enquired about the knowledge on segregation, almost everyone had a fair knowledge about segregation.

Mrs. Latha, garbage collector—door to door, said that “segregation is separation of different waste substances into different groups”.

Mrs. Dyavamma said “separating plastic covers, bottles, milk covers from other waste like paper, wooden pieces is segregation”—a garbage collector.

Both the workers under BBMP and private contractors had a fair knowledge about segregation of waste. They also had an understanding about the importance of segregating the waste. Some of the workers said they separate the waste into different categories which helps simplifying the process of waste management. Some of them quoted that they separate different wastes which have resale value like plastics, paper, cardboard, metals, sell them to waste pickers and use coconut shells as firewood. Most of the workers quoted that they separate the plastics materials, sell it and get money out of it.

Mrs. Latha said, “we collect plastic covers, toothbrush, buckets, and we sell to the factories and get money for breakfast and tea”.

Mrs. Manjula stated that “plastics and paper if separated can be recycled, whereas papers and vegetable waste can be used as manure; other dry waste can be dumped or burnt”; the clarity about the importance of segregation was not appreciated much.

Both the employees under BBMP and under private contractors were able to define dry and wet waste.

Mr. Ramachandra quoted that “dry waste means which is dry like plastic, paper, iron pieces, wooden pieces, and wet waste is like household waste, waste from hotels, vegetables, leftovers”.

Sanitary waste was perceived as wet waste and was disposed with wet waste by some of the workers who were newly appointed. But a few of them were also able to describe hazardous waste. They mentioned that they separate the medical waste such as needles, medicines and other medical waste separately.

3.4 Status of Health and Healthcare Utilization by the Pourakarmikas

3.4.1 Health Status and Problems

The common health problems stated by the workers were fever, headache, weakness, vehicle hits, joint pains, itching, difficulty in breathing, skin rashes, workplace accidents and injuries such as needle pricks, wounds and cuts from equipments, insect bites.

Mrs. Lingamma, 45-year-old lady, said that “it often happens that we have minor cuts and injuries, we bleed also, but nothing will happen; we will wash the wound and start going”.

Most of them feel that injuries and health problems are a part of their job as their job is to handle waste which is hazardous. Most women complained of joint pains and back aches. They take painkillers regularly and will continue to work.

3.4.2 Alcohol-Related Illnesses

Most of the workers both men and women disclosed the widespread consumption of alcohol and were a major health concern and a major risk for their health. They feel the necessity of consuming alcohol during work as it makes them feel unconscious about the flighty sight and odour. On an average, they spend around 50/- on alcohol. Compounded with this is the use of beedis and tobaccos by both men and women which also is a health concern. Alcohol use is a serious mental illness but also has devastating influence on other systems of the body.

Mr Murugan said “everybody consumes alcohol before work. It is very common. Alcohol gives strength to tolerate the dirt, filth and smell while working it masks our pain”.

Mr Mohan quoted about his fellow colleague that his colleague was consuming alcohol for almost every day for more than 20 years and had liver disease, but still he continues to consume because without alcohol none of them can work in that nauseating place.

3.4.3 Utilization of Health Facilities

Most of the workers were not satisfied with the health facilities provided. Most of the workers visit a private clinic for any of their ailments. They responded that they wish to go to the private clinics as they are nearby and they charge less money. Some of them also stated that government and private do not make any sense because they need to pay to both the places. A very few said that they avail the health services at ESI hospitals. Some of them completely denied utilizing Employees State Insurance (ESI) facilities because they have to wait for a long and would lose a day's pay which they cannot afford to. They felt that government doctors are careless about the poor people and do not respond aptly to their ailments. They also said that the procedure to get an approval for any health facility under ESI is time consuming and if illiterate it may be complicated for them.

A few felt the distance of the facility as a barrier for utilization of the services. But in contrast, a few of them had utilized ESI facility and were happy. Most of them opined that the health facility is for major diseases, but for minor ailments they have to spend out of their pocket.

Mrs. Ratnamma quoted that her husband has a surgery and was appreciating the facility provided to her. She quoted that "I went with my card, everything was free for my husband, and he is well now".

Use of alcohol, tobacco and harsh working environment are the risk factors for premature deaths of waste handlers. Most of the workers felt that their health has deteriorated because of the present job. Along with this, under inadequate healthcare facilities and under utilization of free healthcare facilities for various reasons finally put them in such a position that they end up paying a huge amount on their health.

3.5 Occupational and Health Facilities

Municipal solid waste workers were denuded with basic facilitates like toilets and drinking water. Only a few of them responded that they were able to use pay and use toilets. But most of them said that they go in open places or near the bushes or in open sites for toilet. Those who work near ward offices were fortunate enough to use the office toilets. Drinking water was also a concern for the workers. A few of them said that they ask in nearby houses/hotels or bakeries for drinking water. Some of them pathetically quoted "sometimes we ask drinking water but they will not give drinking water; rather, they collect water from washroom taps and give".

Most of the workers stated that they do not have any provisions to keep their food during their working hours. Hence, most of them do not carry food along with them during work. Mrs Shanthi quoted that "if some of the residents give them leftover food, either we eat it then and there or we keep it near a clean place so that they can carry when they go back to home, but still they are not sure of stray dogs snatching the food". Most of the workers said they are also devoid of water to wash their hands before they eat food. Some of them stated that "we do wash our hands but not properly because we may not get enough water and sometimes we ask soap from hotels or residents to wash."

3.6 Expectations and Improvements in Occupational and Health Facilities

Almost everyone expected water facility for drinking and provisions to wash the hands. They also expressed the need for toilet facilities at the workplace and restrooms to change after work.

Mr. Anand pathetically quoted that "we stink badly when we finish our work, and we feel humiliated and hesitant to sit next to others while travelling back home. If we are given a restroom at least we can sit with comfort along with others".

They also insisted that the health facilities should be made available free of cost for all kinds aliments and disease and should be treated with dignity by the doctors at government facility. They also expressed for the hike in their salary.

4 Remarkable Points from the Group Discussions

(1) Nature of the work and exposure to potentially hazardous environment for the workers under BBMP and under private contractors were similar.
(2) The workers have sufficient knowledge on waste segregation and about wet and dry waste. But a few of them were unaware about the sanitary waste and its segregation which needs to be emphasized.
(3) Almost everyone is provided with protective gears like gloves, masks, boots and uniforms, but they are not being used either because they are of low quality or they get worn off easily or the workers feel uncomfortable using. Hence, there is need to emphasize on the importance of using the protective gears and to provide better quality protective gears.
(4) Both the workers were facing the same financial problems and issues and have feel of hopelessness for their current job.
(5) Various health problems are common among them, and these problems are complicated with alcohol consumption.
(6) Even though healthcare facility is been provided, it is not reaching the people and they end up paying a huge amount of money on health care.
(7) There is urgent need to provide these workers with basic facilities like drinking water, facilities to wash their hands and restrooms to change after their work.

(8) Awareness programmes should be planned about the healthcare facilities availability and how to utilize them as most of them were illiterate and were not familiar with the system.
(9) Awareness programmes about various disease and conditions due to their work and how to prevent them should be proposed.
(10) Regular health monitoring of the workers, thorough screening camps and check-ups should be initiated to safeguard the health of the workers.

5 Future Scope of Work

Survey—With the findings of the present study, a large-scale survey for around 23,000 municipal solid waste workers in Bangalore is proposed to understand the common occupational health problems and to assess the working environment of these workers. The study will also bring out the needs of the workers and help in improving the facilities for the workers.

Manual for occupational health and safety—Health and safety manual for training the municipal waste workers on various health problems and measures to prevent them is developed and is under the process of approval.

Behaviour change communication activities—Behaviour change communication activities and modules are developed for emphasizing the importance of using personal protective gears and to bring in a behaviour change in effectively using the protective gears.

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Viability-Gap Assessment for Municipal Solid Waste-Based Waste-to-Energy Options for India

Suneel Pandey, Nidhi Maurya and Anjali Garg

Abstract Most of the urban local bodies in the country are grappling with the problems of proper management of municipal solid waste. With limited finances at their disposal, they are unable to provide proper treatment and disposal to the waste collected in cities. As the solid waste streams in most cities contain around 50% of organic waste, waste-to-energy projects provide viable option for treating this waste. This paper examines the viability of two waste-to-energy options (biomethanation and RDF-based projects) which have been implemented with some degree of success in the country. The projects with capacities—3, 5 and 10 MW—were considered for biomethanation route, and single project with capacity 6.5 MW was considered for RDF-based option. The viability-gap analysis shows that there exists a funding gap of Rs. 0.24, Rs. 0.82 and Rs. 1.51 per kWh, respectively, for the three biomethanation options and gap of Rs. 2.35 per kWh for RDF-based option. The funding gap to some extent can be met by availing certified emission reductions (3 MW projects would not require any more funding) but would require more support in terms of subsidies for these projects to be financially viable in Indian context.

Keywords Waste-to-energy · Biomethanation · RDF · Certified emission reduction · Financial viability · Levelised unit cost of electricity

1 Introduction

There are close to 7000 cities and notified towns across India representing an urban population of around 300 million, generating almost 115,000 TPD (tonnes per day) of municipal solid waste (MSW) [4]. The solid waste generated in the country has grown in a rapid manner over the last decade. This is mainly due to rapid

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urbanisation, rising consumption patterns, related increase in MSW generation, change in waste characteristics over the year and lack of awareness and public apathy towards the seriousness to deal with the issue. In India, the characteristics of MSW vary place to place and season to season as it is a large country with varied climate. Bulk of this waste is being dumped in the open in an uncontrolled manner, resulting in pollution of water bodies and land and causing uncontrolled emission of methane. It is estimated MSW generated would require about 1240 ha of land every year if it is disposed on land [2]. If all the treatable waste is processed biologically or thermally, it is estimated that land requirement for disposal of waste will reduce by 90%, thus reducing the load on landfills substantially.

The calorific or fuel value in the MSW is due to biodegradable waste such as food waste and horticulture waste and non-biodegradable waste such as leather, wood, plastics, paper, rubber. This variability coupled with higher moisture content in the MSW in India affects combustion of waste in waste-to-energy (W2E) processes. The waste generation varies on the daily basis and hence has to be homogenised before feeding to W2E processes like incineration. Presence in high inert which is abrasive in nature can also cause wear and tear in waste processing units and combustion chamber. Combustion of MSW can also result in formation slag and fused ash deposits in the equipment employed in W2E system, thus reducing the efficiency of combustion and higher cost of operation. Additionally, higher moisture content and halogen in waste can form acidic gases in the flue and cause corrosion in the W2E systems.

Urban local bodies (ULBs) in India—responsible for municipal solid waste management—have been under pressure to safeguard public health and maintain compliance with the legislative framework as provided by the Municipal Solid Waste (Management and Handling) Rules of 2000 and now 2016 notified by Ministry of Environment and Forests, Government of India.

ULBs in recent years have developed and launched various initiatives for transforming service levels and for improving compliance with these rules. Despite these efforts, the situation of MSW management and compliance of ULBs with the MSW Rules remain far from satisfactory. Resource, capacity and financial constraints have resulted in poor collection, transportation and safe disposal of MSW. In addition, clandestine disposal of biomedical waste and electronic waste has not made the task of ULBs easy. While daily collection efficiency is typically 50–60% (except for metro cities like Delhi and Mumbai where it has been reported in the range of 80–90%), only around 13% of waste is treated/processed and literally nothing is disposed as per the provisions of MSW Rules [2].

The problem of treating organic portion of MSW can be addressed by adopting W2E technologies for treatment and processing wastes before disposal. This will not only divert the waste from landfill sites but also recover some energy and other resources like manure while treating the waste. As per the draft National Master Plan (NMP), 2006 by MNRE (Ministry of New and Renewable Energy, Government of India), there is potential to generate around 2200–2300 MW of the power in the urban areas of the country if this waste can be properly segregated. Biomass and municipal solid waste (MSW) have widely been accepted as important, locally available renewable energy sources with low carbon dioxide emissions [6].

2 Objective of the Research

The availability of source-segregated waste and cost of infrastructure both in terms of capital and operation and maintenance costs remain major barriers for gainful implementation of such W2E options in Indian cities. There is therefore a need to look at various non-regulatory barriers, particularly technological and financial aspects and to evaluate mechanisms that could make such projects viable and attractive in the future.

3 Current Scenario

As of now, as per the MNRE regarding energy recovery from MSW, three projects, namely at Hyderabad, Vijayawada and Lucknow with total capacity of 17.6 MW had been set up in India. The projects at Vijayawada and Hyderabad were based on use of refuse-derived fuel (RDF), while the Lucknow one was based on anaerobic digestion.

The plant was shut down only after a year of operation at much lower capacity despite biomethanation being identified as most attractive option for W2E in NMP of MNRE. Only operating project based on MSW to energy is 16 MW project at Okhla in Delhi. Other non-MSW-based projects include a 1-MW biomethanation project using cattle dung as feedstock at Ludhiana; a 0.5-MW project for sewage treatment plant at Surat; and a 150-kW project using vegetable market and slaughterhouse wastes at Vijayawada.

4 Energy Generation Potential

Any one or all W2E technologies, landfill with gas recovery, biomethanation, gasification or incineration, can be considered to be applicable for W2E projects utilising sorted MSW as the feedstock. Among these options, landfill with gas recovery is excluded as a potential technology option in view of the Solid Waste Rules, 2016, which state that landfilling of waste will only be allowed for non-biodegradable, inert waste and waste not suitable for material recovery and recycling or for biological processing. Landfilling will be allowed for disposal of pre-processing reject and residues from waste processing facilities. The Rules also state that landfilling of mixed waste will be allowed only if it is found unsuitable for waste processing.

As per the average waste characteristics for MSW in India, reportedly around 50% of waste is organic. Considering past poor performance of W2E projects in Hyderabad and Vijayawada and for the limited period of operation in Lucknow, it is safe to assume that every 150 tonnes of organic waste would produce around 1 MW of power which would be minimum requirement for the projects using above-mentioned technologies to be technically and financially viable. So cities generating at least 300 TPD of MSW would be candidate for W2E projects in the country on stand-alone basis. As per CPCB assessment, there are at present 31 such cities producing around 36,000 TPD of MSW. The annual power generation potential of these cities processing MSW would be around 36,000 MW.

5 Financial Viability

W2E projects provide for a beneficial way of disposing off MSW. Technology options like incineration, biomethanation, use of RDF, gasification and pyrolysis have been considered possible solution to recover energy from MSW. However, conventional MSW incineration while considered as an important sustainable solution for waste management and energy recovery, apart from being cost-intensive, provides low overall efficiency due to emission of acidic flue gases in the boiler [3, 5]. On the other hand, projects based on biomethanation and uses of RDF have proven to be commercially viable in Indian market. Hence for the sake of assessing the cost of power generation from such projects, we have considered only two options (biomethanation and RDF-based projects) for financial analysis.

In case of biomethanation, three cases are developed depending on the capacity of plant to process the waste. In case the waste generated in the city is around 450 tonnes per day (TPD) of organic waste, then a small-capacity plant (3 MW) would be sufficient. On the other hand, if the waste generated in the city is around 1500 TPD of organic waste as in large cities like Delhi, then a higher-capacity plant would be needed. Thus, three cases are developed, i.e. 3-MW plant that can process up to 450 TPD, 5-MW plant that can process up to 750 TPD and 10-MW plant that can process 1500 TPD of organic waste.

While in case of RDF, it is necessary to operate it minimum waste input feed level. Based on experience of previous projects in India, such projects would be economical only for the cities generating at least 500–700 TPD of organic waste, such as Hyderabad. Thus in case of RDF, only one capacity plant is taken of 6.5 MW that can process up to 700 TPD of organic waste.

5.1 Inputs and Assumptions

5.1.1 Technical Parameters

The technical inputs and assumptions used for estimating the levelised cost of power generation using biomethanation and RDF-based waste-to-energy plants are summarised in Table 1.

5.1.2 Generation

For computing annual generation for each case, assumptions regarding parasitic consumption during the plant operations and annual operating hours are assumed on the basis of the NMP for development of W2E projects in India as prepared by

Table 1 Technical inputs and assumptions

Particulars	Units	Biomethanation			RDF
Plant capacity	MW	3	5	10	6.5[b]
Organic waste processed	TPD	450[a]	750[a]	1500[a]	700[b]
Life of plant[a]	Years	15	15	15	15
Capital cost	Rs. Crores	40.25[a]	57.30[a]	102.00[a]	60.00[b]
Land cost[b]	Rs. Crores	0.3	0.5	0.6	0.4
Operation and maintenance cost	Rs. Crores	2.72[a]	4.13[a]	8.25[a]	3.00[b]
Yearly escalation in O&M cost[c]	%	4.83	4.83	4.83	4.83
Debt–equity ratio[d]	Ratio	70:30	70:30	70:30	70:30
Interest rate[d]	%	12.00	12.00	12.00	12.00
Repayment period (including 1 years moratorium)[d]	Years	10	10	10	10
Return on equity[e]	%	14.00	14.00	14.00	14.00
Discount rate (weighted average cost of capital, i.e. WACC)	%	12.60	12.60	12.60	12.60
Capital recovery factor	%	15.16	15.16	15.16	15.16

Sources [a]Based on National Master Plan for Development of Waste-to-Energy in India, Ministry of Non-Conventional Energy Source now Ministry of New and Renewable Energy (MNRE), Government of India; details available at: www.mnre.gov.in, accessed on 25th July 2008
[b]As per discussion with stakeholders
[c]Based on average wholesale price index (WPI) for last three years, i.e. 2005–06, 2006–07 and 2007–08; details available at: https://reservebank.org.in/cdbmsi/servlet/login/, accessed on 25th July 2008
[d]Based on financing norms as given by IREDA
[e]Based on CERC norms for return on equity for power generating plants

Table 2 Estimation of annual generation

Particulars	Units	Biomethanation			RDF
Plant capacity (*A*)	MW	3.00	5.00	10.00	6.50
Parasitic consumption (*B*)	MW	0.45[a]	0.75[a]	1.50[a]	1.00[b]
Net electricity for sale ($C = A - B$)	MW	2.55	4.25	8.50	5.50
Annual hours of generation (*D*)	Hours	7920[a]	7920[a]	7920[a]	6132[a]
Annual generation [$E = (C * D)/10^3$]	MU	20.20	33.66	67.32	33.73

Sources [a]Based on National Master Plan for Development of Waste-to-Energy in India, Ministry of Non-Conventional Energy Source now Ministry of New and Renewable Energy (MNRE), Government of India; details available at: www.mnre.gov.in, accessed on 25th July 2008
[b]As per discussion with stakeholders

MNRE. The assumptions as well as computation of annual generation are being presented in Table 2.

5.2 *Levelised Cost of Power Generation*

In order to estimate the levelised cost of power generation, the annutised capital cost (i.e. the capital cost levelised over the life of the project, i.e. 15 years for each technology), annual O&M cost and annual fuel cost are estimated.

5.2.1 Levelised Capital Cost

Levelised capital cost is estimated by multiplying the capital cost of each type of plant with the discount factor and capital recovery factor (CRF).

Determination of the Discount Rate

The discount rate has been arrived at based on the weighted average cost of capital (WACC). For arriving at the WACC, the debt–equity ratio and the rate of interest for the debt have been assumed to be 70:30 and 12%, respectively, based on the financing norms specified by Indian Renewable Energy Development Agency (IREDA). The rate of return on equity is taken as 14% which is based on norms for rate of return on equity for generation companies as given by Central Electricity Regulatory Commission (CERC).

Capital Recovery Factor (CRF)

Power generation involves substantial upfront capital commitments. Thus, for computing fixed cost of a project over its whole life, there is a need to provide for a discount factor, which would convert this one-time investment into costs, distributed equally over the life of the system, i.e. 15 years in this case. For this purpose, CRF is computed. CRF is ratio of a constant annuity to the present value

Table 3 Levelised capital cost

MSW technology	Plant capacity (in MWs)	Levelised capital cost (in Rs. Cr)
Biomethanation	3	6.15
	5	8.75
	10	15.55
RDF	6.5	9.15

Source TERI estimates

Table 4 Annual O&M cost

MSW technology	Plant capacity (in MWs)	Annual O&M cost (in Rs. Cr)
Biomethanation	3	1.60
	5	2.43
	10	4.86
RDF	6.5	1.77

Source TERI estimates

of receiving that annuity for a given period of time. CRF in case of MSW projects, for each type of technology, at 12.6% discount rate and life of 15 years comes out to be 15.2%. Table 3 summarises the levelised capital cost for each type of MSW technology.

5.2.2 Annual Operating and Maintenance (O&M) Cost

The O&M cost for each case is taken as per the estimates presented by the NMP. These have further been raised at the rate 4.83% per year. Escalation factor has been determined based on the average of the wholesale price index (WPI) for last three years. Table 4 summarises the annual O&M cost for each type of MSW technology.

5.2.3 Annual Fuel Cost

Fuel cost in case of W2E projects includes the cost of waste as well as the cost of collection and transportation of such waste[1] from source of generation to the plant site. As per national practice, however, the waste is available free of cost in case of biomethanation plants, while in case of RDF projects, the cost of waste includes the cost of processing the waste into fluff which is then used for power generation. Thus, fuel cost in case of biomethanation plants is solely the collection and

[1]The cost for collection and transportation of MSW from source of generation to the plant site also includes salary and wages of the staff involved.

Table 5 Collection and transportation cost of MSW

Particulars	Units	Biomethanation			RDF
Plant capacity	MW	3	5	10	6.5
Quantity of organic waste processed	TPD	450	750	1500	700
MSW collection and transportation charges	Rs./tonne	250	475	675	475
Total collection and transportation cost	Rs. Cr	2.48	7.84	22.28	8.50
Quantity of fluff generated	TPD	–	–	–	200
Cost of fluff	Rs./tonne	–	–	–	130
Annual fuel cost (including fluff cost)	Rs. Cr	2.48	7.84	22.28	9.16

Source Based on discussion with stakeholders including Municipal Corporation of Hyderabad

transportation cost of waste, while in case of RDF plants, cost of fluff is also included. The cost of collection and transportation, in actual, varies from Rs. 250 to 700 per tonne depending on the size of city and quantity of waste generated, collected and transported. Table 5 summarises the fuel cost assumed for each case.

5.2.4 Revenue from Sale of By-Product

The levelised cost on case of plant based on biomethanation technology is further reduced as it earns extra revenue from sale of by-products. Biofertiliser is produced as a by-product of biomethanation process, which in itself is useful manure. Table 6 summarises the levelised unit cost of electricity (LUCE) generated from MSW-based plants for each type of technology.

5.3 Viability-Gap Analysis

This section presents the result of viability-gap analysis for the scheme. Viability gap is computed by comparing the LUCE generation from each type of MSW technology and the benchmark tariff for MSW projects already existing in the country. The LUCE for each type of MSW technology ranges between Rs. 3.84 and 5.11 per kWh in case of biomethanation plants and is Rs. 5.95 per kWh in case of RDF plant. While for purposes of computing the viability gap, benchmark tariff for MSW projects is assumed as Rs. 3.60 per kWh. This is the existing highest tariff approved for MSW projects by Andhra Pradesh Electricity Regulatory Commission (APERC) in FY 2006/07. Table 7 summarises the viability gap for each type of MSW technology.

Table 6 Levelised unit cost of electricity (LUCE) generation from MSW plants

Technology type	Plant capacity	Levelised capital cost[a]	Annual O&M cost	Annual fuel cost[b]	Total levelised cost	Less: sale of by-product[c]	Net levelised cost	LUCE
Units	MW	Rs. in Cr	Rs. in Cr	Rs. in Cr	Rs. in Cr	Rs. in Cr	Rs. in Cr	Rs. per kWh
Biomethanation	3	6.15	1.60	2.48	10.22	2.48	7.75	3.84
	5	8.75	2.43	7.84	19.02	4.13	14.89	4.42
	10	15.55	4.86	22.28	42.68	8.25	34.43	5.11
RDF	6.5	9.15	1.77	9.16	20.07	Nil	20.07	5.95

Source TERI estimates

Note [a]Total capital cost is considered including land cost

[b]Total fuel cost consists of collection and transportation charges and cost of fluff (in case of RDF only)

[c]Power generation from a biomethanation plant results in generation of biofertiliser which can be sold in market to earn additional revenue and hence reduce cost

Table 7 Viability gap (per unit) for each type of MSW technology

Technology type	Plant capacity	LUCE of MSW	Benchmark tariff	Viability gap[a]
Units	MW	Rs./kWh	Rs./kWh	Rs./kWh
Biomethanation	3	3.84	3.60	0.24
	5	4.42	3.60	0.82
	10	5.11	3.60	1.51
RDF	6.5	5.95	3.60	2.35

Source TERI estimates
[a]Viability gap = LUCE of MSW plants − Benchmark tariff

5.3.1 Mechanisms to Bridge the Viability Gap

A combination of capital and interest subsidy along with funds from CDM benefits through CERs is used for bridging the above gap to make the MSW technology viable. Given the current low rates of CERs, most projects would require additional funding support to make them viable.

Role of Government for Financing the Gap

As these technologies are new and would also help in management of waste, government can finance the remaining gap in case of medium–high-capacity biomethanation (5 and 10 MW) and RDF (6.5 MW) plants through a combination of capital and interest subsidy. Further as the per unit gaps are marginal, this funding may be provided in initial period only and can be removed after the technology becomes fully viable vis-à-vis conventional power systems.

Capital Subsidy

Since the main barrier for power generation from waste-to-energy plants could be the high initial capital cost, it is necessary that this cost should be reduced. Thus giving upfront subsidy in the form of reduction in capital cost can go a long way in promoting W2E to energy plants. In order to make biomethanation plant of high capacity, i.e. 10 MW viable, a capital subsidy of 15% is proposed. While medium-capacity biomethanation plant of 5 MW may not be given any upfront support through capital subsidy as per unit viability gap in this case is very small Table (7). Such plants may be given benefit of subsidised loans which can make the plant viable vis-à-vis conventional plants without putting any upfront burden on government. RDF plant, on the other hand, involves huge initial capital cost; thus, a higher capital subsidy is proposed to be provided to such plants, i.e., of 45%.

Interest Subsidy

Along with capital subsidy, it is proposed to provide subsidised loans to reduce upfront investment by promoter. In the base case, 70% of the remaining capital cost (after subsidy) is considered debt at an interest rate of 12%. To improve the viability, a subsidised interest rate of 7% is proposed (i.e. interest subsidy @ 5%) for both medium-to-high biomethanation and RDF plants. Table 8 summarises the mechanisms used for bridging the viability gap in case of MSW-based plants.

5.4 Fund Requirement (Per Plant)

In case of low-capacity biomethanation plant, i.e. 3 MW, there is no need for government financing as projects become viable after availing benefits through CERs alone, which would imply no additional burden on government. Further, use of funds from CERs and from government in the form of capital and interest subsidy makes the medium-to-high-capacity biomethanation (i.e. 5 and 10 MW) and RDF (6.5 MW) plants viable, by reducing the gap to zero. Table 9 summarises the additional funds required from the government for providing capital and interest subsidies to high-capacity biomethanation and RDF plants.

Further to have a more effective implementation of the MSW-based projects and ensuring that waste is utilised in useful manner, a scheme is to be implemented in phased manner.

It would be of utmost importance to implement the MSW-based W2E options in various cities grappling with day-to-day waste management problems in a fast-track manner. This would also ensure faster compliance of cities with the provisions of MSW Rules. It has been estimated earlier that larger cities generating at least 450 TPD of organic waste can generate around 3600 MW of power annually by processing their organic waste. The present generation capacity is around 11 MW

Table 8 Mechanisms to bridge the viability gap for MSW-based plants

Particulars	Units	Biomethanation			RDF
		3 MW	5 MW	10 MW	6.5 MW
LUCE	Rs./kWh	3.84	4.42	5.11	5.95
Less: benchmark tariff	Rs./kWh	3.60	3.60	3.60	3.60
Viability gap (VG) I	**Rs./kWh**	**0.24**	**0.82**	**1.51**	**2.35**
Less: funds through CERs (per unit)	Rs./kWh	0.50	0.50	0.50	0.50
VG II	**Rs./kWh**	**−0.26**	**0.33**	**1.02**	**1.85**
Less: funds through government					
Capital subsidy	%	–	–	15%	45%
Interest subsidy	%	–	5%	5%	5%
VG III	**Rs./kWh**	**−0.26**	**0.00**	**0.00**	**0.00**

Source TERI estimates

Table 9 Fund required from government towards subsidy (per plant)

Technology type	Plant capacity	Fund required for capital subsidy	Fund required for interest subsidy	Total Fund required for subsidy per plant
Units	MW	USD millions	USD millions	USD millions
Biomethanation	3	–	–	–
	5	–	3.3	3.3
	10	5.1	7.4	11.2
RDF	6.5	6.8	1.9	8.7

Source TERI estimates
Note Assuming exchange rate as 1 USD = 68 INR

based on RDF projects. The wet waste in the cities can be processed by biomethanation process, and the dry organic wastes like paper, plastics, rags, leather can be used for RDF-based power generation.

Further, the fund required from government, to implement the targeted capacities, would depend on whether small-capacity biomethanation plants are commissioned (in this case, there would be no implications on government) or high-capacity biomethanation or RDF plants are being commissioned (in this case, there would arise financial implications for the government).

6 Conclusions

The financial viability-gap assessment shows that among the selected waste-to-energy options (biomethanation and RDF-based projects), the projects with capacities—3, 5 and 10 MW were considered for biomethanation route and single project with capacity 6.5 MW was considered for RDF-based option. The viability-gap analysis shows that there exists a funding gap of Rs. 0.24, Rs. 0.82 and Rs. 1.51 per kWh, respectively, for the three biomethanation options and gap of Rs. 2.35 per kWh for RDF-based option. The funding gap to some extent can be met by availing certified emission reductions but would require more support in terms of subsidies for these projects to be financially viable in Indian context.

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Part V
Municipal Solid Waste Management

Municipal Waste Management and Resource Recovery Towards Green Growth in Vietnam

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Abstract Vietnam has achieved remarkable socio-economic development in the last 30 years. Economic growth has been maintained since 1990 until now. However, economic growth has been unsustainable, caused environmental pollution and depletion of natural resources. On the other hand, Vietnam is one of the most seriously impacted countries by the climate change. In this context, there is a need to change the growth paradigm, to promote Green Growth. This paper identifies potential as well as solutions and recommendations of integrated solid waste management including resource recovery from municipal waste for Green Growth in Vietnam.

Keywords Municipal waste · Waste management · Resource recovery
Green Growth

1 Introduction

Since 1986, after 30 years of adopting the Renovation policy, Vietnam has achieved remarkable success in economic growth. The country has maintained GDP growth from 5.2 to 8.5% in 2004–2014 period, GDP per capita has reached to around 2,000 USD, and Vietnam has joined the middle-income group of countries. However, together with economic growth, environment of Vietnam has been being degraded; surface water in urban area is polluted; air quality in cities is degraded; biodiversity is declined in terms of ecosystem, species and gene resources. Besides that impacts of climate change have become increasingly serious; Vietnam is one of the most badly impacted by climate change in the world [1].

Facing these challenges, Vietnam has adopted Green Growth development pathway, in which integrated solid waste management is one of the area.

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2 Waste Management and 3Rs in Green Growth Policies and Strategies

Vietnam Green Growth direction has been set in a number of policy documents, which emphasized the importance of 3Rs and resource recovery. In the *Party Resolution 24/NQ-TW on proactive responding to climate change, strengthening natural resources management and environmental protection,* adopted in 2013, it has been emphasized with a variety of tasks including: (i) promote transformation of growth pattern associated with restructuring the economy towards Green Growth and sustainable development; (ii) promote waste reuse, recycling and energy production and recovery from waste.

In 2012, *National Green Growth Strategy* was approved by the Prime Minister with the goal: "Green Growth, towards the low-carbon economy and enriching natural capital will become the dominant trend in sustainable economic development; reduction of greenhouse gases (GHG) emissions and increase of capability for capturing GHG are gradually becoming essential and mandatory indicators in social-economic development". The strategy requires implement solutions of promoting fast development of green economy sectors for creating more jobs, increasing income and enriching natural resources including promotion of waste recycling and reuse activities. To implement the strategy, the *Green Growth Action Plan* for the period 2014–2020 has also been issued by the Prime Minister in 2014.

The Strategy for Sustainable Development in Vietnam for the period 2011–2020 set the overall objective of "sustainable and effective growth must come along with social progress and equality, national resources and environment protection, socio-political stability, firm protection of independence-sovereignty-unification and territorial integrity of the country". In order to ensure effective management of solid and toxic wastes, the strategy requires development of solid wastes management system in which solid wastes are separated at source, collected, reused, recycled and absolutely treated with advanced and suitable technologies.

National Strategy for Environmental Protection to 2020 and vision towards 2030 also provided directions of activities and measures to increase rates of solid waste collection, recycling and reuse; gradually reducing the production and use of bags and packaging made of non-biodegradable materials. The strategy has set a vision towards 2030 of "trends in increasing environmental pollution, natural resources degradation and biodiversity decline should be halted and reversed; the quality of living environments should be improved; climate change should be proactively addressed; and basic conditions should be created to develop a lower waste, low-carbon green economy aiming at achieving economic prosperity and sustainable development of the country".

National Strategy for Integrated Solid Waste Management to 2025 and vision towards 2050 provides a vision towards 2050 of "strive all types of solid waste generated to be collected, reused, recycled and thoroughly treated with technology which is advanced, environmentally friendly and suitable with the real conditions of each province; restrict volume of solid waste land filled at a minimum level".

Moreover, *National Strategy on Climate Change* has also set up many directions for GHG reduction, including effective waste management by increasing waste collection, reuse, recycling and energy recovery.

3 Potentials for Resource Recovery from Waste to Promote Green Growth

Vietnam has a lot of potentials for implementation of 3Rs to promote Green Growth. *Firstly, amount of municipal solid waste is increasing in coming years* which will become a big resource for recovery activities. The total volume of municipal solid waste (MSW) generated nationwide increases an average of 10–16% per year. The MSW generation quantity per capita increases with living standards. In 2010, the urban SW generation quantity per capita in Vietnam was 1 kg/person/day with total volume of municipal SW generated of 26,224 tonne/day [2]. In 2015, total volume of municipal SW generated was 37,176 (tonne/day) [1]. It is estimated that the volume of urban municipal solid wastes will increase 2.37 times in 2020, and 3.2 times in 2025 compared to 2010 [2] (Table 1).

Average collected MSW rate in 2015 was approximately 85% with total volume of collected MSW generated of 31,600 tonne/day [1].

Besides that, there are many components in MSW which can be reused and recycled into products such as livestock feed, compost from organic waste; recycled products from paper, metal, plastic, glass, …. The component can be used to produce organic fertilizers accounts for 54–77.1%; followed by plastics: 8–16%; metals 2% [2]. In large urban areas, the rate of urbanization and commercial activities is higher than it is in small urban areas, and the proportion of organic waste is lower while the proportion of hazardous waste and non-biodegradable waste such as plastic, glass, metal is higher [3].

Secondly, recycling rate is still low and recycling activity has been implemented mainly by the informal sector in craft villages. The rate of recycling waste for composting and recycling paper, plastic, glass, metals such as iron, copper, lead, aluminium, … is still very low, only 8–12% of the urban solid wastes collected [2]. Recycling has been implemented very little by formal and mostly by informal sector. For formal sector, by the end of 2015, there are about 35 MSW treatment facilities

Table 1 Estimated urban solid waste generation until 2025

Year	2015	2020	2025
Urban population (million people)	35	44	52
Share of the urban in total population (%)	38	45	50
Urban solid waste generation (kg/person/day)	1.2	1.4	1.6
Total volume of MSW (tonne/day)	42,000	61,000	83,200

Source MONRE [2]

using different technologies with total design capacity of 6,500 tons of waste per day. In these facilities, there are 12 composting facilities, some remaining facilities used combined composting and burning technology, some facilities use combined plastic recycled and bricks manufacturing technology, … [1]. There are two main types of recycling technologies: (i) domestic technology, such as An Sinh, Seraphin, MBT-CD.08, Betid technology and; (ii) foreign technology from France, Belgium, South Korea, Spain, Denmark, the USA, China, … Currently, there are no suitable composting technologies for local practice, produced compost is usually with low-quality and does not meet the requirements of the market. In addition, the high selling price of compost due to high production costs as well as limited product advertisement of composting businesses have left the compost market undeveloped [4].

A big volume of waste is recycled in craft villages including paper, metal and plastic recycling craft villages, for example Duong O paper recycling craft village and Da Hoi iron recycling craft village in Bac Ninh province; Minh Khai plastic recycling craft village in Hung Yen province… However, the recycling technology in the villages is mostly manual, backward and causing severe environmental pollution, affecting people's health and life [5]. While wastewater and air emission generated from the recycling activity are mostly not treated but discharged directly into the environment, solid waste is collected together with municipal waste to the landfill. And most of landfills in Vietnam are not sanitary, only 31% of landfills are sanitary in 2015 [1].

Thirdly, greenhouse gas (GHG) emission from waste is increasing and there is a need of reducing. In the period of 1994–2010, total GHG emissions in Vietnam (with LULUCF) increased sharply from 103.8 to 246.8 million tonnes of CO_2 equivalent, of which the emission from waste sector showed a sharp increase from 2.6 to 15.4 million tonnes of CO_2 equivalent [6]. Vietnam has committed to reduce 8% of GHG emission by 2030 compared to business-as-usual (BAU) scenario in the Intended Nationally Determined Contribution (INDC). 3Rs and waste-to-energy activities can be implemented for promoting GHG emission reduction such as: recovery of gas from landfills for electricity or industrial processes or for other purposes; waste incineration to generate electricity and; composting which reduces emissions from landfills by reducing the amount of organic waste moved to the landfill.

Finally, 3Rs and resource recovery generates green job, improves income and Vietnam also receives supports from international community. Recycling activities help reduce cost spent for waste disposal activities and make a chance for the private sector to have considerable income from recycling activities, thereby they create jobs and income. Recycling in the craft villages has contributed a lot in poverty reduction and income improvement. Furthermore, as international cooperation on waste management has been strongly promoted in the last years, Vietnam has been supported and cooperated with many countries such as Japan, Korea, … and a lot of international organizations. This helps Vietnam to have more resources in finance and technique for better integrated waste management. Vietnam is one of members of 3R Regional Forum in Asia and the Pacific, which has been established by UNCRD and Japan MOEJ. This makes opportunities for Vietnam to share, learn and cooperate in waste management and 3Rs (Fig. 1).

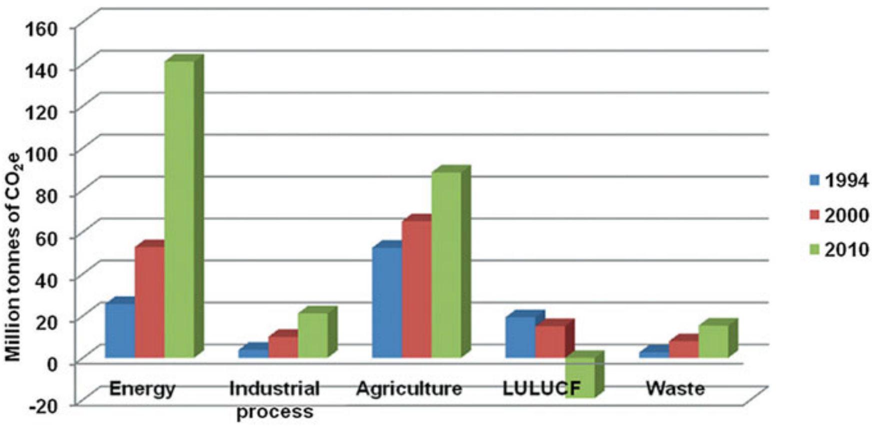

Fig. 1 Total GHG emissions in 1994, 2000 and 2010 by sector. *Source* The Government of Vietnam [6]

4 Some Solutions for Promoting 3Rs and Resource Recovery Towards Green Growth Vietnam

To promote resource recovery activity from municipal solid waste, specific solutions needed to implement include (i) promotion of solid waste sorting at-source: it is necessary to mobilize community's participation and develop proper infrastructure, separately collect and treat each kind of waste after sorting; (ii) promotion of solid waste collection and transport: strengthen the capacity of solid waste collection and transportation; to expand network of solid waste collection and; promote to mobilize participation of private sector into collection, transport activities; (iii) improvement of solid waste reuse and recycling: improve reuse of solid waste; develop waste market, waste economy; develop recycling industry; encourage procurement of recycled products; develop recycling laws and apply preferential policies for recycling activities and; establish recycling funds.

Beside specific solutions, it is necessary to implement other general solutions including (i) development and improvement of policies on integrated solid waste management with focus on resource recovery from waste such as volume-based solid waste fee, implementing extended producer responsibility (EPR); (ii) develop legislations/regulations on different types of wastes such as e-waste, construction and demolition waste, food waste; (iii) promote active and efficient implementation of existing policies and master plans on waste management; (iv) development of a consistent and time-series database on waste management; (v) enhancing scientific researches and technology transfer on resource recovery and waste management; (vi) awareness raising and creating behaviour change in lifestyle of people; (vii) strengthening close global and regional collaboration on resource recovery from waste.

5 Conclusion

Being a developing country at low stage of development, Vietnam is still facing a lot of environmental issues, including waste management. The country has adopted Green Growth policies, in which the 3Rs and resource recovery have been addressed. However, to bring these policies into play, there is a need of resources in terms of finance, technologies and labour, which are still limited.

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Mycoremediation of Contaminated Soil in MSW Sites

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Abstract Solid waste management has been given the topmost priority in the recent times. Solid waste dumping has increased drastically in the past few years. Accumulated garbage dumping has resulted in the contamination of soils that lay below the pile of municipal solid waste or MSW. The outcome of long-term accumulation of MSW on soil is the intensification of contaminants such as heavy metals and other metals in the soil. The presence of pollutants in soil makes it unsuitable for agriculture and as grazing pastures. The heavy metals from the soil are absorbed by the plants/produce, and these when consumed enter the never-ending food chain causing damage to animals and human beings. The yield of produce is also affected by the presence of heavy metals. The dire need of the hour is for technologies to remediate the soils. Bioremediation is an emerging technology that utilizes natural means to remediate soil, thus proving to be economical and efficient as compared to conventional chemical technologies. Mycoremediation and phytoremediation of soil incorporate the use of fungi and plants to alleviate the soil conditions. This study focuses on the effect and efficiency of mycoremediation and phytoremediation on MSW soil. In this research, *Pleurotus ostreatus* was used and was incubated with appropriate nutrition with MSW soil for 25 days. The phytoremediation of MSW soil was performed by sowing fenugreek seeds on MSW soil and allowing the growth for 25–29 days Almost 82% of the nickel was removed from the soil at the end of 25 days. The phytoremediation yielded only 55% removal of lead and 92% of nickel. Thus, mycoremediation is a promising technology that can be incorporated to treat soil adulterated due to solid waste dumping or MSW. This research compares the two technologies with regard to efficiency of the process, cost-effectiveness, and deduces a more suitable technology.

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Keywords MSW soil/sites · Mycoremediation · Phytoremediation
P. ostreatus

1 Introduction

In today's world, fossil fuels are continuously being utilized to meet the ever-growing energy demands. This has resulted in the depletion of the natural resources and is causative of environmental damage. The following consequences are evident from increased pollution, rise is sea level, global warming and climate change. The main effects of pollution are on air, water, and land.

Solid waste and improper usage of leftovers create abundance in garbage causing major environmental concerns. Improper disposal techniques, lack of space requirements, and many other factors have contributed to the rising concern of waste management. Long-term consequence of garbage dumps and the effect of aged garbage on soil accumulate innumerable contaminants in soil. Chemicals such as nitric acid, sulfuric acid, cyanides, heavy metals are used in mining processes, and degrade and empty the nutrients and fertility of the soil subjecting it to contamination. Industrial sewage, agricultural runoffs, urban wastes, industrial discharge are some of the very conventional sources of land pollution [1]. The agricultural runoffs include manure, fertilizers, chemicals, irrigation water, and pesticides. Accumulation of disposed heavy metal wastes such as copper, zinc, lead, chromium, nickel, cadmium [2], mine wastes, and sewage sludge are equally responsible for the pollution of soil [3].

Municipal solid waste is proportional to the density of population rising in all the fast-growing cities. The heaps of garbage scattered across scream to throw light on handling and processing of the littered waste which is the need of the hour. Ineffective policies, lack of awareness, inadequacy of treatment facilities, and many other factors have given rise to the never-ending crisis of garbage disposal and waste management. In a country like India, major cities such as Delhi, Bombay, Bangalore, Kolkata generate large quantities of waste. This waste includes inorganic and organic components. Inorganic components may be glassware, plastics, toiletries, debris, and other dry matter. Organic components may be papers, cardboards, kitchen wastes, garden wastes, etc. MSW dumping on soil leads to accumulation of chemical elements such as heavy metals, inorganic, halogenated organics in the soil.

The presence of contaminants in the soil makes it unfit and unsuitable for growth of crops/plants and other activities. Growing and harvesting on contaminated sites will lead to a contaminated produce. Consumption of the adulterated produce by various life forms has adverse effects such as cancer, respiratory, and other disorders in human beings and genetic modification of the flora fauna. Most adverse effects are observed when rainwater leaches these pollutants in the soil. These runaway waters on its way pollute the groundwater tables and other water bodies, thus propelling forward toward water pollution.

In order to improve the conditions of the soil contaminated with municipal solid waste, many chemical treatment methods such as vitrification, containment, extraction, precipitation and bioremediation [4]. But these methods have been proven to be cost ineffective and non-environment friendly. Thus, this makes it inevitable to look for alternate technologies. Mycoremediation is an upcoming bioremediation technique that uses fungal species. Fungi have the capacity to act on long-chain compounds and break them to smaller ones.

Fungi have the potential to absorb heavy metals as they can grow under any extreme condition. Fungi secrete enzymes that break and cleave bonds of large compounds by removing atoms such as halogens and breaking hydrogen and carbon bonds. The other microbes such as bacteria further degrade the contaminants to produce simple small compounds such as carbon dioxide (CO_2), methane (CH_4), water. There are two specific types of Basidiomycetes group of fungi that can grow in any environment. These are white rot fungi and the brown rot fungi. The brown rot fungi degrade wood polysaccharides. White rot fungi can act on a wide range of chemicals and contaminants [5].

Some of the white rot species that are widely known and used are *Pleurotus ostreatus, Lentinus edodes, Agaricus bisporus* [6]. Fungi are better bioremediators than yeast and bacteria due to the mycelial nature of the fungi. Fungal species such as *P. ostreatus* are found to be versatile and effective bioremediators [7]. In another study, it was found that these fungal species can biosorb heavy metals such as lead, chromium possessing absorption capacity of 13.6 mg/kg for copper, 3.4 mg/kg for lead, 9.8 mg/kg for zinc [8]. Different soil conditions such as pH result in an increased accumulation of heavy metals in the fruiting body of these oyster mushrooms [9].

Phytoremediation of soil employs the use of plants to alleviate soil conditions. Herbaceous species such as *Stackhousiaceae* and members of *Acanthaceae*, *Brassicaceae*, etc., are found to be nickel remediaters [10]. In this research work, soil from MSW dumping and oil spills was remediated using *Trigonella foenum-graecum* (fenugreek). Fenugreek being a herbaceous plant grows fast and is found to be a better accumulator [11].

In this research study, the mycoremediation of soils contaminated with municipal solid waste using *P. ostreatus* was analyzed and studied. The mycoremediation of the soil contaminated with MSW is compared with phytoremediation of the MSW soil.

2 Materials and Methods

2.1 Procurement of Materials

The soil contaminated with municipal solid waste was obtained from an MSW dump site in Kathriguppe, Bengaluru, Karnataka. The mushroom species, namely

P. ostreatus, was procured in the form of spawns from Institute of Horticulture, Hulimavu, Karnataka, for the mycoremediation process. Fenugreek seeds were obtained from Hybrid Seeds, Siddapura, Bengaluru, Karnataka, for the phytoremediation.

2.2 Mycoremediation of MSW Soil

The soil was subjected to mycoremediation using *P. ostreatus* species for 22 days. Straw was used as the nutrient source for the fungi. The soil, nutrient, and spawns were packed in a sandwich permutation to offer the maximum contact between the spawn, soil, and nutrients. The heavy metals in the MSW soil were analyzed at regular intervals. Layering of soil, spawn, and hay were packed in polypropylene (PP) bag and plastic trays.

2.3 Phytoremediation of MSW Soil

Soil contaminated with MSW was subjected to phytoremediation by sowing fenugreek seeds and incubating for 25–29 days. The plant was allowed to grow, and the heavy metals in the spoil were analyzed periodically.

2.4 Analysis of Heavy Metals in Soil

The soil contaminated with MSW was analyzed for heavy metals such as lead, nickel. The soil was sampled out at regular intervals of 7 days. The soil was first oven dried and digested with 2 mL of 65% nitric acid (HNO_3) along with 6 mL of hydrochloric acid (HCl) per gram of soil using a microwave digester (600 W). The heavy metals were determined by atomic absorption spectroscopy [12].

3 Results and Discussion

The soil subjected to mycoremediation was analyzed for different heavy metals, out of which lead and nickel were detected. Soil was analyzed for every 7th, 14th, and 21st day of incubation. The soil subjected to phytoremediation was analyzed for heavy metals at regular intervals of 5 days.

The effect of mushroom on soil is seen in Figs. 1, 2, 3, and 4. These figures represent the mycelia and mushroom from the MSW soil on the 7th, 14th, and 21st

Fig. 1 Mycelia on MSW soil in PP bag

Fig. 2 Mycelia on MSW soil in tray

day from a PP bag setup and plastic trays, respectively. The effect of phytoremediation on soil can be observed from Fig. 5.

The contaminants in the soil were studied periodically and represented graphically in Figs. 6 and 7. Figure 6 represents the % reduction in heavy metals in soil contaminated with MSW by mycoremediation, and Fig. 7 corresponds to that by phytoremediation.

Fig. 3 Mushroom in MSW soil in PP bag

Fig. 4 Mushroom in MSW soil in tray

From Fig. 6, it is seen that the lead concentration in soil has decreased in PP bag and plastic tray setup at the end of 21 days yielding a 68.86% removal of lead from soil. Similarly, 81.25% removal efficiency was observed for nickel from soil at the end of 21 days by the mushrooms. This suggests that the mushrooms have accumulated the heavy metals present in soil onto their fruiting bodies.

Figure 7 elucidates the effect of fenugreek on soil contaminated with MSW. It is found that at the end of 29-day period, the fenugreek has a removal efficiency of 55.97 and 92.5% of lead and nickel from soil, respectively. This suggests that the fenugreek biosorbs the contaminants.

Fig. 5 Phytoremediation of soil

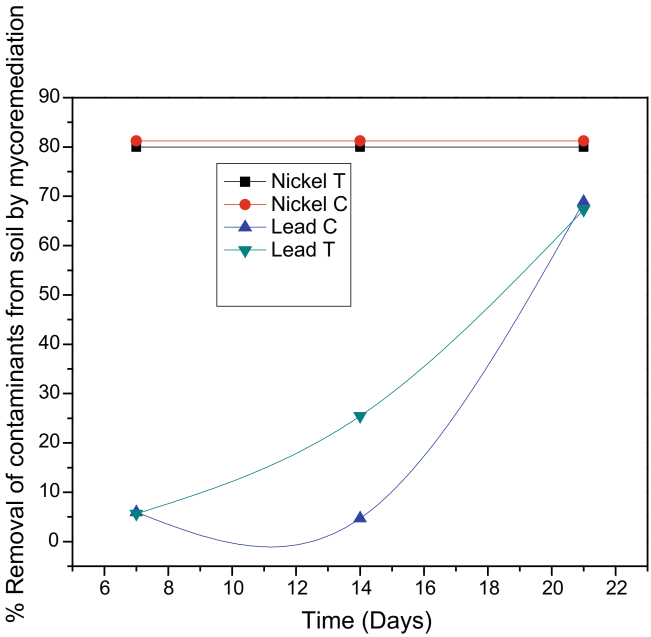

Fig. 6 % removal of contaminants from soil by mycoremediation

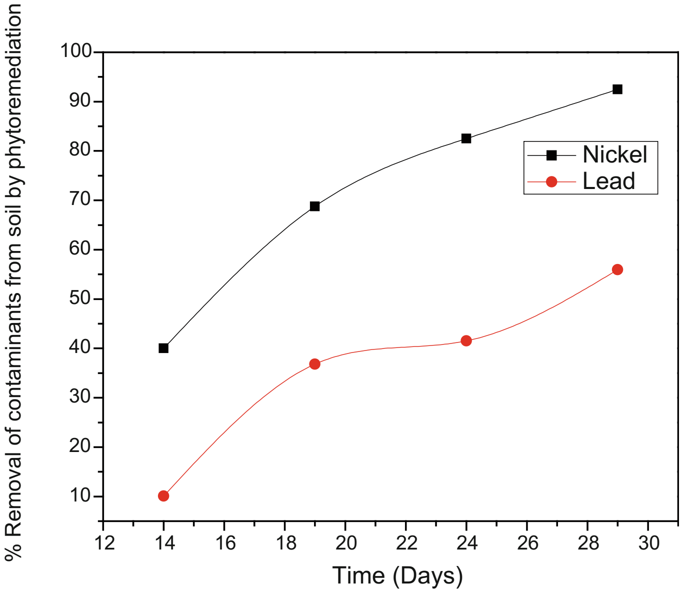

Fig. 7 % removal of Nickel and Lead by Phytoremediation

4 Conclusions

Efficient removal of lead was observed in mycoremediation process as compared to the removal of lead by phytoremediation. It is seen that 68% of lead and 81.25% of nickel were removed from MSW soil after incubation with oyster mushroom for 21 days. This indicates the efficiency of the mycoremediation process. The phytoremediation process resulted in a highly contaminated produce (fenugreek contamination). The uptake of lead from the soils by the fenugreek was found to be high, thus making the plant unsuitable for consumption.

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Developing a Decision Support System for Municipal Vacant Land and Waste Management with Optimized Route Technique

Ankita Das and Sadhan K. Ghosh

Abstract Environment pollution is a global problem and MSW adds fuel to this problem. Modern science finds the way out of this mess to have a cleaner pollution-free habitation. In this paper, we have developed a decision-making support system for municipal vacant land with an optimized route technique. This paper is made on the basis of data collected from 12 municipalities of West Bengal. These municipalities are having tons of garbage and wastes and their in a fix to find out the way for effective solution of the problem. Here, we have proposed a DMSS where in a support system is made by which the municipalities can have the optimized route for collection of wastes and its scientific disposal through an economic time saving. The support system may be helpful in calculation of total quantity of waste and finding out its characteristics. Simultaneously, it can help the measurement of nearest vacant land and advise the possibility of taking decision regarding the installation of new plant. This system will also help to calculate the calorific value of waste. We think successful running of this system may usher a new hope in the tools of fighting the waste management problem in West Bengal. The adoption of this support system is of great importance for our municipalities of West Bengal. Therefore, the presented methodology is thought to have an effective potential for concerned people and authorities here and elsewhere.

Keywords Decision support system · Municipal vacant land · Waste management Optimized route technique

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1 Introduction

Nowadays waste management is a major problem for the modern society in the developing countries. On the other hand, population has been on the rise and according to their needs the pace of increase in urbanization has also been increasing. As urbanization has been flourishing, the density of population of waste management becomes the headaches of municipal authorities. Not only in our country, has municipal waste generation becomes worldwide issue which deserves immediate attention thereby making our habitat pollution free, healthy, airy, and eco-friendly.

The generation of MSW depends on various factors including our food habits, commercial activities. These sorts of activities lead to generate complete wastes in the municipal areas. Here examples of Kolkata Municipal Corporation can be cited. It is evident from the municipal records that present quantity of solid waste generation and disposal per day is 3520 MT(as per 2013–14) are threefold than the wastes generated in 1981 [1, 2]. It is certainly due to the increasing urbanization and changes in the lifestyle of the inhabitants. Statistical data clearly shows that the increase in per capita generation of MSW has been ranging from 0.75 to 1.25% annually [3, 1].

It is true that generation of MSW in small towns is lower than metro cities like Kolkata. With an urban population of 14.12 million, the volume of stock pilled MSW was 4837 metric ton/day in 2013 and the per capita generation rate of a Calcutta was 0.35 kg/day [1, 4, 5]. Kolkata being one of the largest metropolitan cities having a resident of 4.5 million, the urban agglomeration comprising its suburbs with home to approximately 14.1 million thereby making it the third most populous metropolitan area of the country [1, 6]. The adjacent mofussil areas are stricken with overpopulation, socioeconomic problems and itself Kolkata confronts with traffic congestion, urban pollution, poverty and huge garbage and wastes. There is a rate of change in waste management which is increasing day by day (0.2 kg/capita in 1981 and 0.47 kg/capita will be in 2035) for many reasons [1]. From the published data, it is observed that approximately 17.6 lakh metric ton of waste is generated per year with per capita generation ranging between 0.2 and 6 kg per person per day [1, 6, 7]. Such is the case with the municipalities in West Bengal. Municipalities have been showing the indication of increasing population with increased household, transportation and various commercial and industrial activities. They have paucity of funds; they lack proper personnel and techniques to deal with the day-to-day increasing MSW problems. The density of wastes varies from 280 to 660 kg/m^3 in Indian cities, whereas KMC's estimation stands at 600 kg/m^3. Simultaneously, the municipalities face the problem of storage of MSW [1, 6–9]. KMC has storage capacity of around 23,400 m^3 but most of the municipalities lack proper dumping ground as well as storage capacity [1]. In this study, attempts are made for finding out a feasible and economic solution towards MSW problem. By using the decision-making support system, optimized route can be traced towards dumping ground of the municipality. At the same time, database of the municipality relating to the collection of MSW and it is dumping towards available vacant land can be easily available and the authority can test within the system for the practical implementation.

This study will definitely help the municipal authorities in this direction for selection of a maintainable support system for municipal vacant land with optimized route technique thereby giving them economic relief as well as ushering in new vistas of eco-friendly habitation. In this connection, many contemporary works have been done so far but it fails to connect the whole idea but our approach will definitely help to have the real application for solving it out.

2 Literature Review

Now we can discuss the related work in this field. A study has been made on the estimation of municipal solid waste generation and future trends in greater metropolitan regions in Kolkata attempts are made to outline the major trends and challenges that will shape the future of waste management in major cities like Kolkata [1]. In this study, correlation analysis of different factors of MSW has been made. A separate study on an overview for solid waste bin monitoring system shows that an integrated system combined of radio frequency identification, GPS, GIS, which helps to show the real-time image processing waste estimation [10]. On the other hand, a review on technologies and their usage in solid waste monitoring and management system has been published wherein attempts are made about the basics of available ICTs and applications in SWM to facilitate the search the planning and design of a sustainable system [11]. The study on solid waste collection vehicle route optimization for the city of Redlands, California, has shown that major portion of municipalities' waste budget goes for the collection and transportation phase, and they have proposed to use GIS model to determine optimal routes for small collection routes, etc. [12]. It is revealed in another contemporary study on a method for optimizing waste collection using mathematical programming in a Buenos Aries Case Study that operations research technique has been used to optimize the roots of waste collection vehicle servicing dumpster, etc. [13]. The application of the proposed method helps to minimize the distance root of the collection vehicle, etc. In another survey on an overview for solid waste bin monitoring system, it is observed that identification of climate protection potentials of waste recycling provides additional background information about waste recycling targets. Under the title of optimal solid waste collection routes identified by the ant colony system algorithm, the proposed MSW system is based on database supported by GIS which takes account of all the required parameters of solid waste collection. Finally, the result of ALS algorithm has been compared with the empirical method which has been used by Municipality of Athens [14]. In another specific study on vehicle route optimization for RFID integrated waste collection system wherein RFID technology has been used and a single vehicle with predetermined capacity and multiple tours, etc., with deterministic waste quantities are given and system runs via DASH optimization Xpress solver to find an optimized route [15]. In case study of Barreiro, Portugal, the study has been done on by operation costs and pollutant emissions reduction by definition of new collection scheduling and optimization of MSW collection routes using GIS, the feature of the study is that it has combined vehicle route optimization with waste collection scheduling with the help of GIS, and it is seen that the operation cost including labour and vehicle maintenance and fuel consumption are also relevant in optimizing timing [16]. But in this paper, a separate study has been made on a decision-making support system which has its practical real application with optimized route technique.

3 Methodology

The most creative and challenging phase of the support system is design. The term 'design' describes the final system and process by which it is developed. It refers to the technical specification that will be applied in implementing proposed system. The goal of the design phase is to transform the requirements specified into structures that are suitable for implementation in programing language. It involves decomposing the system into modules and then invoking relationships among them (Table 1).

Table 1 Shows the optimized route from the municipality to the nearest dumping ground

S. No.	Name of the municipality	Nearest dumping ground	No. of ways (time, distance)	Optimized way
1.	Khardaha	NDDM	1. Via Kalyaniexp (24 min, 10.7 km) 2. Via Duttapukur (27 min, 12.8 km) 3. Belghoria Station to old Nimta post office (56 min, 18 km)	Via Kalyaniexp (24 min, 10.7 km)
2.	New Barrackpore	NDDM	1.Via Kalyaniexp (11 min, 5.3 km) 2. Via Sodepur Barasat road (9 min, 5.8 km) 3. Via Sumitbannerjee road (19 min, 4.9 km)	Via Kalyaniexpy (11 min, 5.3 km)
3.	Budge Budge	Narkeldanga	1. Via BBT road (7 min, 1.9 km) 2. From municipality to Sarangabad via Budge Budge plaster more (12 min, 3.2 km)	Via BBT road (7 min, 1.9 km)
4.	North Dumdum	NDDM	1. Via barrackpure trunk road (44 min, 12.8 km) 2. Via Jessore road (38 min, 12.5 km)	Via Jessore road (38 min, 12.5 km)

3.1 The Steps Involved

- To determine how the output is to be produced and in what format.
- Input data and master files (database) have to be designed to meet the requirement of the proposed system.

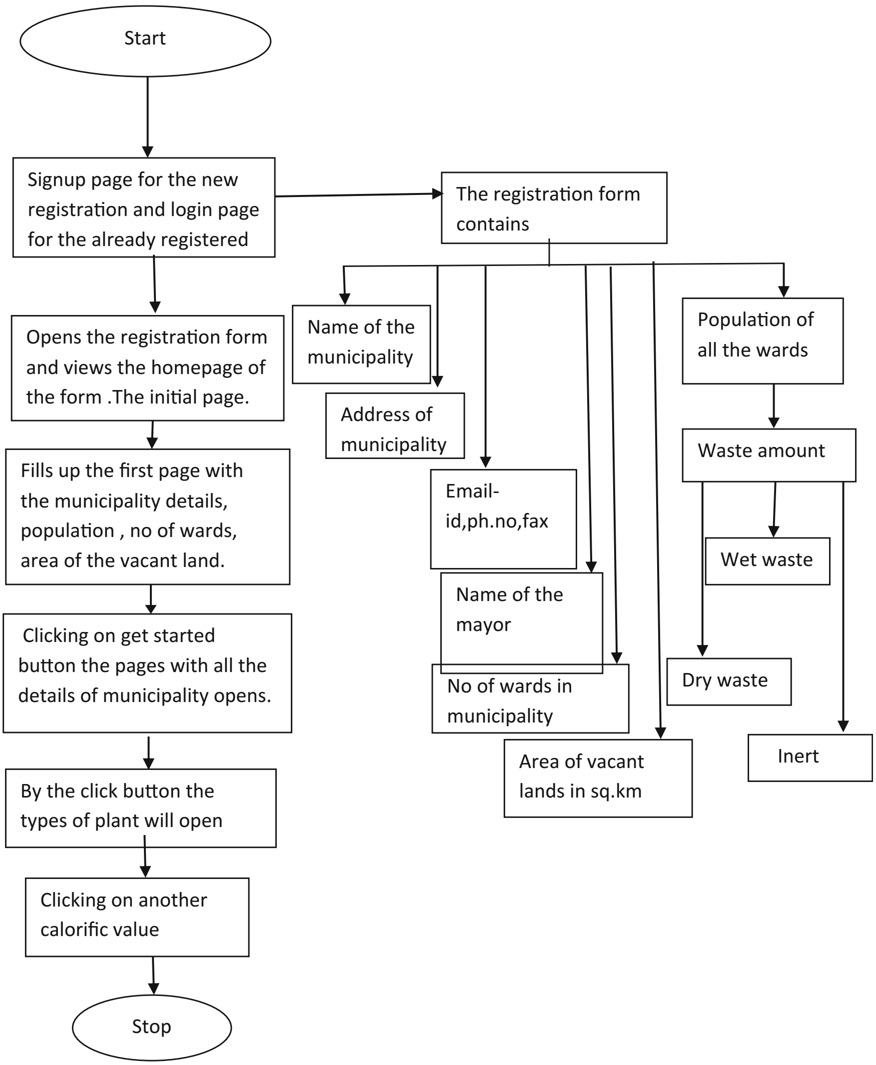
3.1.1 Following Steps Are as Followed

- Using sturts2 (for coding), postgresql (for database), hibernate(for database connectivity), it has been developed a signup page for the new registration page of admin municipality and a login page for the already registered municipalities.
- By the unique user id and password admin of the municipality side can open the startup page and fill the registration page of municipality.
- In that page, system can also find the waste amount and the percentage of wet waste, dry waste, inert for each of the specific municipality.
- After filling all the fields of the municipal registration page by clicking on the get started button it can move to the next page of the system where it shows all the information about each and every municipality of West Bengal.
- The system can be able to search the vacant lands which are located nearby the according municipalities.
- From the area of the vacant lands and the characteristics of municipal wastes, it can also give the information about which type of plant can be made from those vacant lands.
- The system can also be able to calculate the calorific value of the municipalities waste by using the Dulong's formula for GCV calculation where we have to put the different value of hydrogen, sulphur, carbon.
- From the municipality to the nearest vacant land, this can also be able to find out the shortest optimized path by using the algorithm mentioned in appendix1.

The most important design structures are program structure, system flow chart, data flow diagram (DFD). These help us to thread together all the details that are to be embedded in the modules. Here, the steps have been described as a way of the system flow chart in the below.

System Flow Chart:

System flow chart for the database design of the decision support system



3.2 System Design: Design of the Decision-Making Support System

In Figs. 1 and 2, a system has been developed a signup and login page for the new registration of municipality. After filling all the required details of that page, system can calculate waste amount from population by using formula amount of

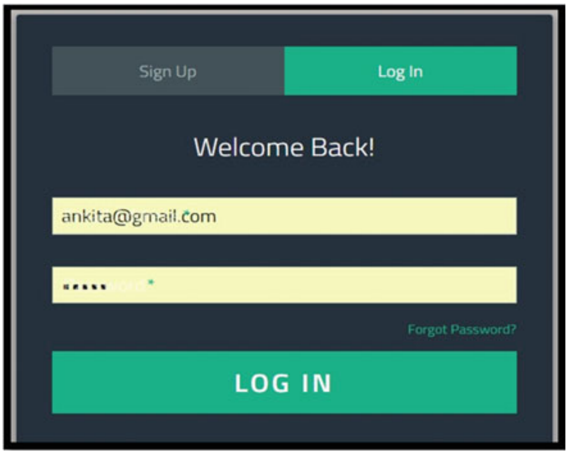


Fig. 1 Sign up and login option for the municipality registration

Fig. 2 Login page for the already registered admin of the municipality

waste = population * 0.5%. The system can also find out the amount of wet, dry, inert by calculating the percentage on above the total waste. Calorific value will be found by using the formula Dulong's calorific value GCV = $((35.5 \times C + 114.8 \times H + 9.5 \times S - 14.5 \times O) \times 1000)/(100 \times 4.1868)$. Each multiple of carbon, hydrogen and sulphur represents heat generated by its one [17]. From the area of vacant lands and characteristics of wastes, it can able to show the types of plant will be made on those lands like waste to energy plant, biomass plant. The system can also be able to find the most cost-effective optimized route from the municipality to the dumping ground by using the Pallottino's graph growth algorithm implemented with two queues (TQQ) [13]. The basic procedure in constructing a shortest path tree as shown below (Figs. 3, 4 and 5)

Pseudocode:
Procedure *ShortestPathTreeConstruction(s)*
Step-1: begin *Queue_Initialization(Q);*
Step-2: for *i* = *1* **to** *n* **do** *d(i)* = + *infinite; d(s)* = *0;*
Step-3: while *(Q ! = Null)* **do** *Queue_Removal(Q, i);*
Step-4: for *each successor node j of node I* **do**
Step-5: if *d(j) > d(i) + l(i, j)* **then**
Step-6: begin *d(j) = d(i) + l(i, j); Queue_Insertion(Q, j)*
Step-7: end; **end**

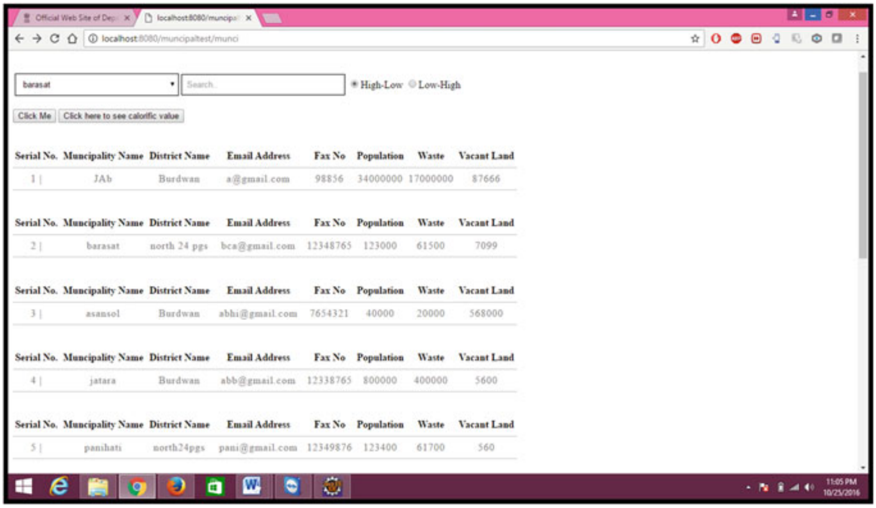


Fig. 3 Details of all municipalities and the optimized route

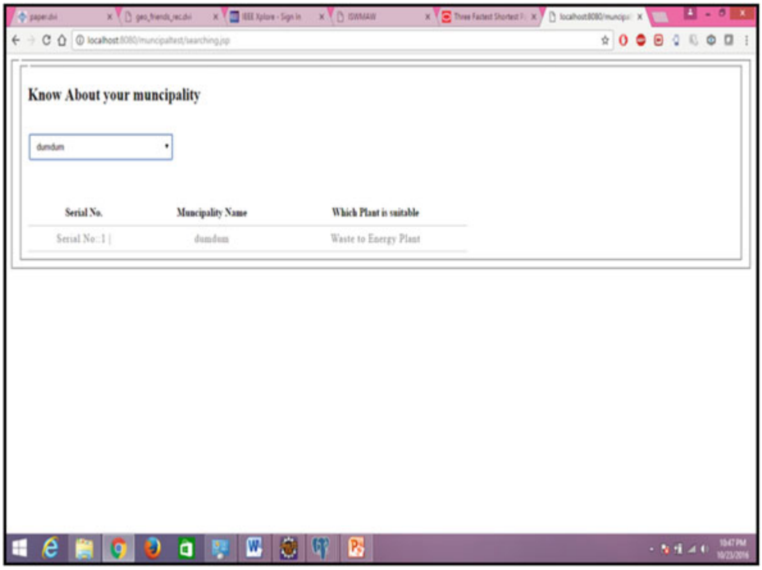


Fig. 4 Types of plant can be built in the vacant land

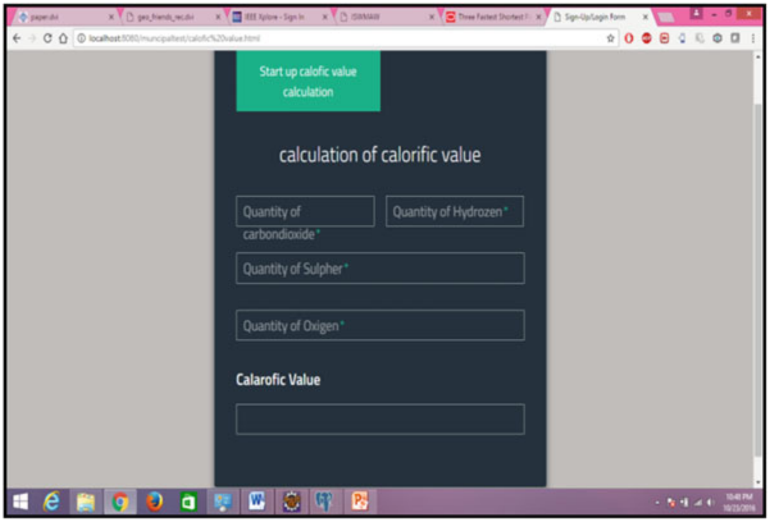


Fig. 5 Calculation of calorific value

4 Result and Discussion

Municipalities are duty bound to collect garbage and after wastes and store them for ultimate disposal. Sometimes, municipalities select some sites and use them for dumping wastes day by day. The decision behind the selection of the site may be filling low lands or producing bio-fertilizers or generating energy. The onerous task of the municipal authority is to collect wastes and make further arrangements for its scientific disposal. We can thus help the municipal authorities through strategy of route optimization. If they follow this technique of route optimization, they can collect the wastes from different corners quickly and economically. Time will be saved. The distance will be lessened. They can easily save their precious fuel by following the optimized route. This technique is also eco-friendly as the municipal cars take less oil and less quantity of polluted smoke is emitted.

This technique is also having a decision support system which guides the car puller to calculate the quantity of total carrying wastes, and it can be emerged from this system which can verify the characteristics of wastes. In consequence to this, the characteristics of the wastes are can be easily known whether it is of dry quality or wet or inert waste etc. In this system, the optimization algorithm runs very well and it shows the optimized distance from the municipality to the dumping ground via the collecting points. This system helps in optimizing distance and at the same time transportation cost will be lessened. The support system has a unique feature for searching out of nearby vacant land, whereas the municipal authority may initiate eco-friendly plant or take decision for initiating biomass projects for tackling with the increasing wastes problem. This will automatically help the authorities to have the account measurement of the land. At the same time, it will be possible of calculating calorific value of wastes and it will clearly indicate how much energy can be generated from this amount of wastes.

5 Conclusion

In this study, we have dealt with data of 12 municipalities in West Bengal and it is proved that this support system is being used here successfully and proved effective. In this respect, it is expected that in the coming future total 100 municipality will be effective through this support system. These municipalities are being chosen as per needs of waste management, and accordingly necessary data has been collected [18]. We see that the system has been successfully run on the basis of our collected data and its implementation as per guidelines.

One thing may kindly be noted it should be made a live project so as to implement in all the municipalities through their database and it will be utmost helpful for the waste management in municipalities of West Bengal. In future, the system will work on GPS-based cyber-physical system. In this connection, one thing is to be noted that the Google Map be embedded so that the system will automatically filter and scrutinize the location of dumping area and vacant lands properly.

Today, we are a need of so many viable effective techniques to deal with the municipal wastes problems. This study will definitely help to manage the MSW stocks efficiently in an eco-friendly way. If we further take the help of GPS-based cyber-physical system through cloud computing, it will be a one step further towards better MSW management.

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Part VI
City Specific MSW

Characterization of Urban Waste Management Practices in Brazil: A Generic Sustainable Framework Based on Waste Characteristics and Urban Dimension in the Country

M. S. Borges

Abstract For a city to be sustainable, the waste management system must have as one of its goals to reduce the generation as well as the amount of materials to be destined for final disposal. To reduce the volume of solid waste is necessary to promote the reuse of materials through reuse and recycling. The benefits of reduction and reuse of solid waste are reflected in environmental protection, less exploitation of natural resources, and economy on the import of raw materials; recycling that contributes to the generation of employment and income; lower consumption of energy and water in manufacturing processes; lower occurrence of environmental problems arising from the disposal of solid waste. The city of Curitiba was one of the pioneers in Brazil and the world in ecological and human urbanism. To have a continuous improvement in all aspects of the city, the process involves education, awareness, and participation of all in society. The objective of this study is to assess the characterization of urban waste management practices in Brazil: A generic sustainable framework based on waste characteristics and urban dimension in the country and shows the city of Curitiba: a successful case in Brazil.

Keywords Characterization · Waste management · Sustainable city
Education · Social inclusion

1 Introduction

Brazil is the largest and the most populated country in Latin America with a population of 202,799,518 habitants.

The total MSW generation in Brazil in 2014 was 195,233.00 tons, and the index of daily waste generated by a person is 0.963 [1, 2, 4, 5]. The waste is sent to

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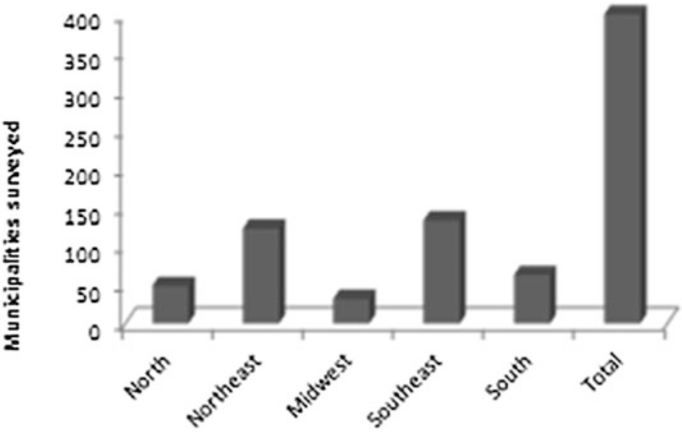

Fig. 1 Country is divided into five regions

landfill sites without adequate pre-treatments. Figure 1 provides information concerning the country regions.

Collection of information on the SW: Fig. 2 provides data related to the population from regions and municipalities surveyed. In Fig. 3, it is shown the generation of municipal waste by region. Figure 4 shows the percentage of waste fractions in Brazil.

The country is divided into five regions according to Fig. 1.

Total population of the regions and the municipalities surveyed according to Fig. 2.

Generation of municipal waste by the region according to Fig. 3.

Percentage of waste fractions in Brazil according to Fig. 4.

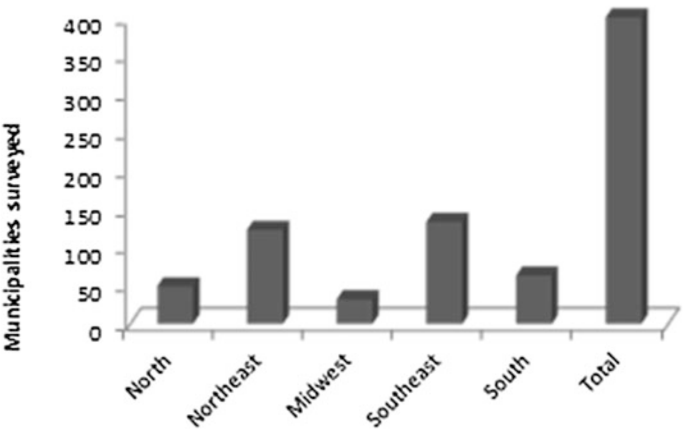

Fig. 2 Total population of the regions and municipalities surveyed

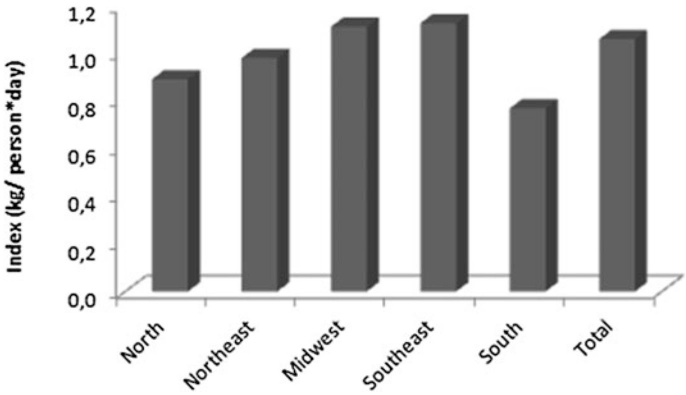

Fig. 3 Generation of municipal waste by region

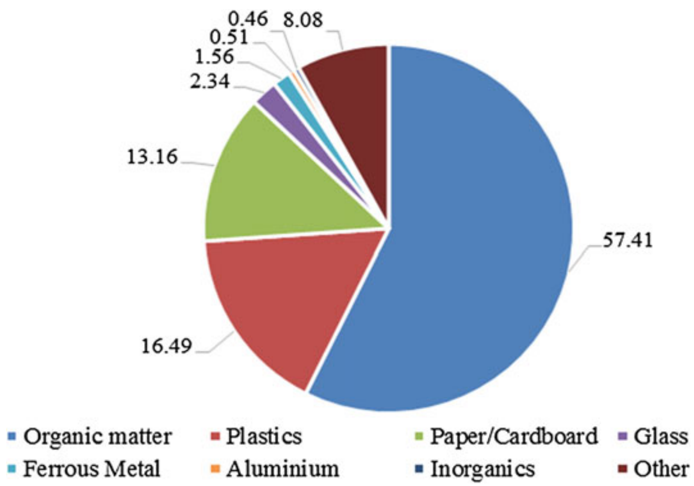

Fig. 4 Percentage of waste fractions in Brazil

The disposal of waste in landfills is currently a common practice in MSW management in Brazil.

Processes such as collection, transportation, sorting, and separation that occur during the various stages, from the generation of waste up to its final processing (recycling, incineration, use as refuse derived fuel (RDF) or disposal (landfill), included also losses that occur during the various steps of waste processing.

2 Recycling

There are several hurdles in Brazil for waste recycling, such as: government support is not consistent, lack of access to regular garbage collection systems, and small numbers of recycling stations. In order to have a better waste recycling model, the combination of efforts from citizens, policy and decision makers, research and development must be integrated together.

The recycling rates for specific materials are relatively high. For instance, aluminum recycling is reported to be about 96%, and recycling rates for paper, glass, and PET plastic are reported to be around 50%.

3 Issues and Challenges

Brazil has emerged from agricultural to an industrial country. However, several factors, such as social inequality, quality of life, per capita income, income distribution, and others, have prevented more advances in the country.

Just as it has happened in other countries, the Brazilian government has created mechanisms to implement the urbanization as a national strategy and in this way, drive economic development, and reach balanced development between urban and rural areas. However, people continue moving to the cities to seek a better life and economic opportunities, and as a result, with the population growth, the volume of waste generation in the cities increases gradually.

4 Possible Solution

An intervention proposal can provide integration between economic and environmental interests, as part of an overall master plan. It proposed the creation of a consortium of private investors seeking to invest in viable projects.

The projects will generate employment and income with socio-environmental impacts for any administrator who develops one of these facilities—which would be noteworthy even on a global level.

To clearly understand a regional problem, how it affects poor and vulnerable cities in developing countries, and how sustainable solid waste management practices can offer an innovation that may provide solutions, it is necessary to confront development challenges such as major public health problems, low quality of vital services (such as sanitation, electricity, education, or financial services), or supply chain problems that affect smallholder farmers.

To propose an integrated and innovative vision for these developing cities, it is necessary to bring significant value to poor and vulnerable cities, and address similar problems and the barriers for regional growth and improve urban sustainability performance (social, environment, economic, and governance).

The results of the integration of the best waste management practice as an intervention method to reduce poverty and environmental problems in different cities in Brazil are presented as an involvement of the society in waste processing that brings income, creates job opportunities, and reduces negative impacts at large scale.

As an increasing population, waste amounts keep increasing and waste management is becoming more and more complex, the need for waste management plans is vital. For an implementation to be successful, it should be in compliance with other national plans directly related to waste management, which are:

Environmental Plans,
Energy Plans,
Health Plans,
City Planning,
Sanitation Plan.

5 Highlights

Trends can be depicted based on waste characteristics in Curitiba in Southern Brazil: a case study.

6 Curitiba: A Successful Case in Brazil

Curitiba is the capital of Paraná State, one of the most important cities in the southern part of Brazil, The city of Curitiba has 1,879,355 inhabitants, and the municipality gives emphasis to programs that encourage recycling and selective collection: "Eco-citizen program," "Garbage is not Garbage Program," "Green Exchange Program" that is a result of partnership between Curitiba and the Social Action Foundation (FAS), Curitiba Pro Citizeship Institute (IPCC), Parana Federation of Farmers Associations (FEPAR), and the CATA PARANÁ, in consonance with the PNRS (National Policy on Solid Waste) Law 12305/2010 [6].

The city has recycled waste since the late 1980s, well ahead of its time globally in terms of waste disposal. It has an organized waste disposal system the rival of any first world city. The garbage is separated into two categories—organic and non-organic, which are collected by two separate trucks.

The separation of system final and disposal of waste methods in Curitiba:

Household waste—Landfill
Recyclable waste—Recovery plant tailings
Waste Vegetable—Iguaçu Nautical Park
Residue Health Service—“Septic Trench”/Incineration.

7 Methodology of Waste Disposal in Curitiba

7.1 Conventional Collection Door to Door

This service refers to the collection of organic waste and tailings. It is performed in the maximum quantity of 600 L per week. This amount should be divided by the number of collections offered by the municipality to the citizens. The waste must be delivered in front of their properties as regulates the Municipal Decree No. 983/2004.

Conventional collection is performed by 68 compactor trucks and each collection team consists of one compactor truck, one driver, and three collectors.

The door to door conventional collection plan of Curitiba has been prepared taking into consideration the type of equipment used, frequency of collection, away from the disposal site, discharge time, waste volume estimated to be collected, traffic, road traffic legislation, topography, hours of collection teams, optimizing the fleet, among other factors.

Currently, the home collection plan consists of 236 sectors collection, 108 day and 128 sectors night.

Daytime collection begins at 7:00 am and the night at 7:00 pm. In the daytime collection, there are six sectors in which it is held daily from Monday to Saturday and the other, 102 sectors, is held three times a week on alternate days. The night collection, there are 28 sectors in which it is held daily from Monday to Saturday and in other sectors, 100 industries, are held three times a week on alternate days [3].

8 Indirect Collection

Indirect collection consists of an alternative form of regular collection of wet waste in sub-housing areas and with difficult access to the collection trucks (very narrow streets and no infrastructure).

This service is performed by four drivers, four catchers, four truck cranes, and eighty stationary buckets of 7 m^3. The buckets are removed three times a week or according to demand. Indirect collection also supports the cleaning service of the communities with more five debris collection teams, each formed: by one driver, two collectors, and one truck.

Currently, they are available 25 buckets in communities and 20 buckets in municipal own [3].

9 Recyclables Collection Door to Door

The recyclable selective collection meets 100% of the Municipality of Curitiba. It consists of the collection and transport of potentially recyclable waste such as paper, plastics, metals and glass, among others that are collected in a door to door collection services named “lixo que não é lixo” (Garbage That Is Not Garbage program), or in the “cambio verde” (Green Exchange Program) or in the sustainability stations, those two last ones explained ahead. For the realization, these collections are available 34 straight truck 40 m^3, 59 drivers, and 146 collectors, this quantitative is equivalent to 59 teams.

This service is also provided for maximum quantity of 600 L per week as the same as conventional collection. This amount must be divided by the number of collections offered by the municipality to the citizen. The recyclable materials must be delivered in front of their properties as regulates the Municipal Decree No. 983/2004.

The recyclable collection plan of the Municipality of Curitiba has been prepared taking into consideration the type of equipment used, collection frequency, distance of the recovery units, discharge time, waste volume estimated to be collected, traffic, topography, hours of collection teams, optimizing the fleet, among other factors.

The recyclable collection plan is divided into 171 sectors collection, 89-day sectors, and 81 sectors in the afternoon and one nighttime sector. Daytime collection begins its activities at 7:00 am and the evening at 4:00 pm.

The collection is performed three times a week for 32 sectors twice a week in 98 sectors, once a week at 40 sectors, and 1 sector on a daily basis.

Segregation, packaging, and disposal of waste to the public collection are the responsibility of the generator according to the days provided for recyclable collection plan.

10 Collection in Exchange Points Program—“Cambio Verde”

The program consists of local policy, to fight hunger, which covers questions related to the waste disposal, the generation of income, ecological preservation, and encouragement of farmers groups. Institutional purchase derives from trading with producers’ associations organized as small and medium producers in the Metropolitan Region of Curitiba.

Direct effects of this program are placing on the metropolitan area, the crop surpluses of Curitiba market, at the same time that helps food quality improvement of the low-income population, in addition to contributing to the cleaning and preservation of the environment.

The exchange points are located in public places, and the exchange in these points happens each 15 days. For approximated each four Kilograms of recyclable materials, the participant receives about one kilogram of groceries. Since 2007 it is possible to exchange vegetable or animal oil for food. Each 2 L of oil packaged in PET worth for 1 kg of food [3].

11 Collection Service of Pruning, Rubbish, and Unserviceable Furniture

The collection of plant residues (pruning trees and gardens cleaning) offered by the municipality is held in the maximum 1,000 L per month. To collect unserviceable furniture, there is no limit. The city performs collecting debris and waste construction to the maximum of 500 L (five wheelbarrows), each 2 months.

Currently, this service is performed by three contractors and these provide daily in two shifts, a total of 75 teams are: 48 trucks body of 15 m^3, 75 drivers, and 220 collectors, and the wastes are sent to companies that perform processing for the purpose of use material [3].

The plant residue collected by the city is currently sent to two destinations: processing in order to be transformed into energy source for furnaces or boilers and to be used as dunnage material for equipment traffic on parts of the site with low bearing capacity or as ancillary elements of the access roads to the work front.

12 Questions and Challenges

Although it has been created the full scope of garbage collection services and the creation of social inclusion programs like "Ecocidadão" (echo-citizen), the city still has many points of improper disposal of waste from the informal working collectors; these conditions cause a negative image of the collector to the population caused by conflicts in traffic, improper handling of waste (material scattered on the sidewalks), and sometimes being the collector indirectly linked to marginality.

The support for waste pickers who carry out the collection of recyclable is materialized in "Ecocidadão" (eco-citizen) Program according to the Brazilian Federal Law 12305/2010, establishing the National Solid Waste Policy.

The Recycling Parks Program Ecocidadão are spaces endowed with physical, administrative, and managerial infrastructure for receiving, sorting, and selling the material collected by waste pickers organized into associations and cooperatives system. In 2013, the Ecocidadão Program Recycling Parks received 7.889,53 ton of garbage collection of material that is not Garbage and in 2015 was 16.387,68 ton.

From the environmental point of view and health, most of the collectors associated with the failure to carry your stuff program for your house, because many of their homes were true waste dumps, enabling the proliferation of vectors of diseases for their families.

However, the city still has a lot of waste pickers working in their own residences, in unsanitary conditions, with child labor, sometimes, making the separation of materials at the edge of rivers and that resist joining the program. This is a great demand of the city; eliminate situations like this because they are both harmful to the environment and the surrounding community.

Another important question is that due to the high cost of providing waste collection services in the city, the managers are seeking for alternatives and proposals in order to improve the services that enable reduce the cost of the city, reducing the mileage driven by collection vehicles, employee overtime without impacting the quality of service and environmental preservation.

Another challenge is the implementation of reverse logistics of hazardous waste in which we face great resistance from manufacturers in return for continued generation and improper disposal of these by the population according to the Brazilian Federal Law 12305/2010, establishing the National Solid Waste Policy.

13 Example of Solutions

13.1 Sustainability Station

In November 2014, it was launched as the first Sustainability Station, located in the Boa Vista neighborhood, north of the Curitiba. The station is a prepared place for voluntary delivery of recyclable waste by residents. The new model aims to involve citizens in the management of solid waste, improve the selective collection, and create more a mechanism of social inclusion, to delegate the management of waste for recycling associations.

The Boa Vista Sustainability Station started the Voluntary Delivery System Recyclable Waste, which provides for the implementation in the coming years, at least one station in each of the 75 districts of Curitiba.

The station serves the residents located in a 300 m radius of the site. The goal is to create another mechanism to prevent irregular waste disposal and consequent environmental and health problems and reduce the path taken by recyclable collection trucks.

There are five models of sustainability stations developed, which will be used as the profile of the region where the unit is installed and class waste that will receive, as specified below.

Type 1—Container with dividers for glass reception, plastic, paper, and metal;
Type 2—Container with the same divisions Type 1 plus buckets for construction waste and vegetable waste;
Type 3—Recycling Parks (improvement of the barracks of Ecocidadão Program);
Type 4—Sites previously determined to receive construction waste;
Type 5—Truck with container of Type1 Station to collect in large events.

14 Support for Recyclers and Social Inclusion—Ecocidadão Program

Support for waste pickers who carry out the collection of recyclable is materialized in Ecocidadão Program. Information on the informal system of collection and recycling target were raised by research conducted in 1999 by the Department of Public Cleaning of the Environment Municipal Secretariat, in partnership with the Municipal Health Department, who registered at the time 2.769 pickers of recyclable materials.

Social and environmental vulnerabilities were identified in the survey were the use of housing as a deposit; dependence on the part of the collectors for those that provide the collection cart; dependence on the part of collectors such as housing and the concentration of collectors and deposits in areas of habitations and nearby valley.

The Ecocidadão Program was a City Hall initiative to reverse this situation, which began in December 2007. The project intends to empower and provide activity of strengthening conditions, with special emphasis on the Recycling Parks Deployment.

The Environment Municipal Secretariat is responsible for managing the Ecocidadão Program and for operational management.

15 Curitiba's Waste Policies and Legislation

Curitiba has an integrated solid waste:

- Organic Waste;
- Waste Recycling;
- Waste Plants;
- Waste of Health Services;
- Wastes of Construction;
- Hazardous Waste.

The collection of recyclable waste was established in Curitiba in October 1989, entitled "Waste Program that is not garbage."

The collection covers 99.7% of households in 108 areas of collection:

- Twenty-two sectors with the collection three times a week;
- Forty-six sectors with collection twice a week;
- Forty sectors with collection once a week.

The Environmental legislation in Curitiba is one of the best in Brazil. Nevertheless, there are still gaps that require completion.

16 Exposing the Social Attitudes to Waste

The Green Exchange Program was established in 1991 and is the exchange of waste horticultural products for recycling at the time. Currently, there are 78 exchange points, where each month is benefiting some 7,000 people and distributed approximately 44 tons of food.

The recyclable waste is collected by 23 trucks for chests exclusively for demining. Part of recyclable waste collected by the municipality is forwarded to the Waste Recovery Unit Recyclable. Located in Campo Magro, 30 km distant from Curitiba, the Unit is responsible for sorting waste and subsequent sale to the recycling industry.

17 Waste Program that is not Garbage

"Waste Program that is not Garbage," released in March 2006, aims to increase the separation of recyclable waste at source, in order to reduce the material destined for the landfill Caximba and increase recycling rates.

Garbage is not garbage in condominiums advise residents and employees of residential and commercial about the importance of previous separation of household waste.

The special collection service was implemented in the hospital in the city of Curitiba on December 1, 1988, simultaneously with the deployment of the Ditch Septic, located in Industrial City of Curitiba (Cidade Industrial), where it was intended the volume collected. In 1994, it was noted the need to reduce the volume for the Vala and ensure a better control of contamination, waste has suffered an infective process of incineration.

18 Waste Management of Construction (WMC)

Waste Management of Construction—WMC was established in Brazilian municipalities by CONAMA Resolution 307 of 2002. In the city of Curitiba, however, it began in 1992 when it published the Municipal Law 7972. Municipal Decree introduced the Integrated Management Plan for WMC in the municipality, guidelines regulating the CONAMA Resolution 307.

Collection Program Household Special Waste (Hazardous Waste) was created on September 21, 1998. The following special collection is accepted in 24 bus terminals in the city of Curitiba, batteries, toners, inks, packaging of insecticides, medicines and fluorescent lamps.

The program was expanded to include cooking oils. The volume collected from this waste is sent for recycling, where it is transformed into soap, detergent, and raw material for making other products.

18.1 Description

This initiative began in 1989, the "Garbage That Is Not Garbage," started with an environmental education in schools. Then, a booklet was distributed to the population and they began collecting household and supermarkets, where recyclables are exchanged for vouchers purchased. The city assumes the cost of collection and the material collected is donated to a health care entity, which processes and markets, allocating the profits to care activities.

Selective collection created technical conditions for the implementation of a recycling plant and composting in the city, much of the inorganic material (metal, glass, etc.) are separated, reducing the costs of plant operation.

18.2 The Green Exchange Program

It was established in 1991 and consists of exchanging recyclable waste for horticultural products of the season. Currently, there are 78 exchange points, where each month is benefiting about 7,000 people and distributed approximately 44 tons of food.

Exchange of Recyclable: is the exchange recyclable waste for horticulture. Four pounds of garbage is worth a pound of fruits and vegetables. It can also be exchanged for vegetable oil and animal: Every 2 quarts of oil is 1 kg of food. The exchange is made on a fortnightly service unit deployed in the city of Curitiba, according to annual schedule established by the Municipal Environment.

18.3 As a Result

The amount of 45,125 tons of recycled material represents a savings of 195,252,646 litres of water that would be used if 45,000 tons of new material had to be produced.

Comparing the costs of natural resources in the production of consumer goods from virgin raw material, with recycled metal saves a ton about four thousand gallons of water. The Green Exchange sent for recycling 15,793 tons of scrap metal, which represents a saving of 63,172,000 L of water.

Recycling one ton of paper saves approximately 29,202 L of water. In 16 years, the Green Exchange has collected and sent for recycling 4,523 tons of paper, which represents a savings of 132,080,646 L of water.

Recycling returns to the productive cycle wasted materials, as well as saving precious environmental resources for living beings, such as water, minerals, and energy.

Recycling paper saves trees. Every 50 lb of recycled paper avoids the cutting of a tree. The 4,513 tons of paper sent by the Exchange for the Green Recycling prevented the cutting of 90,263 trees.

Another savings from recycling is the oil. Recycling plastic saves 50% oil compared to the production of plastic from virgin raw material. Green Exchange was collected in 10,379 tons of plastic sent for recycling, which represents savings of 5,190 tons of oil.

The Green Exchange contributes to the preservation of the environment, prevents the trash is dumped in streams, streets, and empty lots. The time of decomposition of metal, plastic, and glass varies from one hundred years to five thousand years. Recycling is an alternative to mitigate the consequences of waste generated by society. The city of Curitiba offers the population able to collaborate with the preservation of the environment. These programs and services address all areas of the city.

18.4 Environmental Education

Environmental education is a way to integrate the actions of government, and elsewhere, and to build a balanced environment. Environmental issues are addressed in order to rescue the city's history and maintain the identity of the residents who live in the middle allowing the incorporation of values related to environmental protection along with the sustainability of local development. Brochures, leaflets, posters, and videos geared to local help, sustain the educational concepts and disseminating appropriate environmental practices. In addition to these educational tools, a mobile environmental education, a bus equipped with video and stereo, photo exhibition and mock circulating in the city schools, parks, squares, and events held by the city.

18.5 In Communities

Education is the aspect of change, and knowledge provides a change of attitude, commitment, and action, both individually and collectively, of the population. In

Curitiba, an important program such as the Trash is not Trash, Exchange and Purchase of Green Waste has been possible due to the participation of the population as a partner at City Hall. Other actions as well as the planting community educational lectures have been held for the development of environmental awareness by residents of the city.

The rapid rate of urbanization has caused a tremendous amount of change in Curitiba city.

Using a qualitative and descriptive approach, this paper gives an attempt to review the success story Curitiba (Brazil) in hope of re-learning sustainability practice.

In this way, the sustainability principles in Curitiba are being discussed and an adaptive proposal according with Boras is being analyzed based on its contextual opportunities.

The matching process of applying and achieving sustainability strategies is a proposal for the city of Curitiba, which addresses the medium- and long-term sustainability education and practice.

19 Final Remarks

To ensure proper management of MSW in a city, the problem must be approached from its roots. It is necessary to determine the role of partnerships between universities, companies, federal, state and local governments in Brazilian cities in waste management problem solving and evaluate the benefits of alternative techniques for managing municipal solid waste.

Finding alternatives to capitalize on the complementary expertise of research centers and working staff throughout the solid waste management spectrum, and studying the pre-collection waste, it is possible to establish the foundations on which the organization will make the later collection, because the collection of waste is an important part of total costs for waste management.

At the same time, the organization should adapt waste disposal points for improving subsequent waste collection routes. Optimizing the elimination of waste becomes an easy task for citizens and will contribute to building a healthier and a more sustainable city.

This successful case in Brazil presents a structured methodology that allows local authorities or private companies dealing with municipal solid waste, to design their own pre-collection of municipal solid waste systems in order to facilitate the removal of waste to the population, increase selective recovery of materials, and improve waste collection work.

For these reasons, this method is used to distribute the storage area to the points of study. Literature related to the distribution boxes in many cities is scarce, despite being a key step in designing a waste management system. In fact, there are plenty of methodologies to assess and optimize waste collection routes, but there are no studies on the type of storage and distribution boxes. In this sense, the present study attempts to fill the gap in the scientific literature in terms of this type of studies.

In the city of Curitiba, the selective collection of municipal solid waste began with children from public and private schools in the region of Curitiba. They first learned about sellective collection and only than they taught their parents to separate their garbage. Curitiba has had a selective collection for 20 years, and between 60 and 70% of Curitiba citizens practiced separation, which was important to reduce by two-thirds of the production of waste in urban space. Waste should not be viewed as an expense to the city; it needs to be turned into income, encouraging recycling actions and reuse. Small projects like that reflected in major changes in the city.

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Prospect of Climate Mitigation by Integrated Solid Waste Management: A Case Study of Khulna City, Bangladesh

T. K. Roy, S. M. Haque, S. T. Hossain, T. Islam and S. Sikder

Abstract Municipal solid waste (MSW) is considered as one of the significant sources of greenhouse gas (GHG) emission that contributes to global climate change. Waste sector is accountable for 5% of the global GHG emission, which consists of methane (CH_4) and carbon dioxide (CO_2) emission. At present, about 3 billion world urban population generate 1.3 billion tons of MSW per year at the rate of 1.2 kg per capita per day. By 2025, the urban population will likely increase to 4.3 billion and will generate 2.2 billion tons of MSW per year at the rate of about 1.42 kg per capita per day. Integrated solid waste management (ISWM) is a system that considers the prevention and recycling of wastes in most effective way for the protection of human health and environment. Under the ISWM, most appropriate and suitable waste management technologies are selected based on the evaluation of local needs and local environmental conditions towards reducing energy consumption, GHG emissions and carbon storage. Khulna is one of the topmost climate vulnerable coastal cities in the world. The area of Khulna City is 45.65 km^2, where more than 1.5 million people live. About 520 tons of MSW is produced per day in Khulna City. Nearly 79% of the produced waste is organic in nature. The city has its own waste management system including door-to-door (DtD) waste collection and dumping into the ultimate disposal or landfill sites. The study estimates that the anaerobic digestion of organic waste and recycling together can reduce the emission of 19,588 tons CO_2 equivalent and composting with recycling can reduce 22,838 tons CO_2 equivalent per year in Khulna City. The paper highlights the existing solid waste management system in Khulna City with the prospect of ISWM system for climate mitigation of Khulna City.

Keywords Khulna City · Integrated solid waste management · Climate mitigation

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1 Introduction

Waste sector, which is 20% of the global anthropogenic sources, generates about 5% of the total greenhouse gases (GHGs). Though the contribution is minimal, still it matters and requires special attention for mitigation. Since the world population is increasing day by day, the per capita waste generation is also getting amplified consequently. It leads to failure of proper waste disposal practices, especially in the developing countries. The unscientific method of waste disposal continuously emits GHGs, which is ultimately contributing to the global climate change. Hence, mitigating GHG emissions from proper waste management practices is to be given priority in developing countries. Compared with the other 15 sectors which are listed under Kyoto Protocol, controlling and reducing GHG emissions from waste sector seems to be cost-effective through Clean Development Mechanism (CDM) [14].

Currently about 1.3 billion tons of MSW is generated per year in the world, which is expected to increase at 2.2 billion tons by the year 2025. This shows a significant increasing trend of per capita waste generation, from 1.2 to 1.42 kg in the coming fifteen years [15]. Municipal solid waste contains different organic and inorganic components such as food and vegetables, paper, glass, plastics. The amount and percentage of this matter varies from country to country based on the use of resources. Besides, alternative uses or recycling reduce the percentage of certain amount of matter in the total produced waste. The amount of organic waste in Bangladesh is much more than many countries. In fact, it is more than double compared to Japan or India. Japan has popular recycling process of produced municipal waste that reduces the percentage of organic waste.

Solid waste management system is not up to the satisfactory level in Bangladesh, especially in urban areas like Dhaka, Chittagong, Khulna, where huge amount of organic waste is generated daily. Due to lack of managing capacity and well-developed system, a great opportunity of making compost is continuously being underestimated as well as these unused and unmanaged waste is putting up a great environmental threat. In Bangladesh, some non-governmental organizations (NGOs) and community-based organizations (CBOs) introduced door-to-door (DtD) waste collection system in the late 90s with payment of little amount of service charge. But, the DtD waste collection service covers an insignificant portion of its population. Actually, a minor fraction of wastes is managed by the DtD collection system [7, 8]. Khulna is a divisional metropolitan city in Bangladesh. It is also the third largest industrial and second largest port city. Every day about 520 tons of solid wastes are produced in Khulna City [13]. Because of unsatisfying solid waste management system in Khulna City, some common problems are found to occur such as diseases, fire hazards, odour nuisance, air, water and soil pollution and consequent economic losses. On the other hand, those wastes have a potential value of burnable biogas and generate electricity and organic bio-fertilizer [2]. So, the alternative use of organic waste can be very useful to minimize the environmental threat, and the proper utilization will help to produce more compost that can be used in agricultural sector. Eventually, the city will remain clean and also be economically strong.

2 Objectives of the Study

The study has the following objectives:

- To highlight the existing solid waste management system in Khulna City; and
- To investigate the prospect of integrated solid waste management (ISWM) system for climate mitigation of Khulna City.

3 Methodology

The research is conducted based on the solid waste and its management database of Khulna City. The information of solid waste is collected from secondary sources like journal paper, conference paper and also from interview with concerned personnel. Method followed by Visvanathan [14] is followed to develop the climate mitigation scenario from the ISWM perspective. The method considers the total amount of wastes that include different individual waste components, conversion factor and correction factor. The conversion factors originate from US Environmental Protection Agency (USEPA), 2002, and Intergovernmental Panel on Climate change (IPCC), 2006. The emission is calculated to represent the mitigation scenario for anaerobic digestion; aerobic composting; waste reduction, reuse and recycling.

4 Khulna City as the Study Area

Khulna City of Bangladesh is the study area for this paper. It is the third largest industrial city of Bangladesh. The divisional city Khulna acts as regional hub for the administrative, commercial, institutional, and academic affairs. The city stands on the banks of the River Rupsha and Bhairab. About 1.5 million people live in its 45.65 km^2 area. The city lies between 22° 47′ 16″ to 22° 52′ north latitude and 89° 31′ 36″ and 89° 34′ 35″ east longitude. The city is divided into 31 wards, and every ward consists of different *mahalla*s (locality). The total number of *mahalla*s of the city is 143. Khulna Municipality with an area of 12.02 km^2 was established in 1884 [9]. Khulna became an important town from the late 1950s to the early 1960s mainly for its industrial development. The city progressed further after the establishment of Mongla port, just about 40 km of its south. Numerous industries were set up with the increase in manifold commercial activities in Khulna. Khulna became the main centre of jute industries and jute-based trades in Bangladesh. Population of Khulna City rose significantly after the liberation. Introduction of shrimp farming in Khulna and its surrounding coastal region and establishment of shrimp processing industries in Khulna again strengthened the economy of Khulna City. Average household size of the city is 4.5, and the rate of literacy is around 94%. Monthly income of employed 66% people is within Tk. 5,000. About 30% employed people, who have their monthly income within Tk. 2,500, live below poverty level. Only 3.5% employed people have monthly income Tk. 15,000 and above [10].

5 Sources, Category and Amount of Solid Wastes in Khulna City

Khulna City has a numerous sources of waste generation. The sources include buildings, establishments and activities under different land uses namely residential, commercial, industrial, institutional, construction, manufacturing, agricultural. About 520 tons of solid waste is generated from these sources, which does not always go through waste management system as the amount is much more than the management capacity. Table 1 shows that the percentage of food and vegetables is higher (78.9%) in the generated waste of Khulna City Corporation (KCC) area. Amount of institutional waste such as paper and paper product is in the second higher position (9.5%).

Table 1 Composition of municipal solid waste in Khulna City

Composition of MSW	Percentage
Food and vegetables	78.9
Paper and paper products	9.5
Polythene and plastics	3.1
Textile and woods	1.4
Rubber and leathers	0.5
Metal and tins	1.1
Glass and ceramics	0.5
Brick, concrete and stone	0.1
Dust, ash and mud products	3.7
Others (bone, rope, etc.)	1.2
Total	100

Source Afrin et al. [3]

6 Solid Waste Management System in Khulna City

The Khulna City Corporation Ordinance, 1984, in its Chapter One titled “Public Health” under the Part II of “Functions in Detail” has the directives on “Removal, Collection and Disposal of the Refuse of the Municipal Area”. The section 75 and its subsections are as like as “75. (1) The Corporation shall make adequate arrangements for the removal of refuse from all public streets, public latrines, urinals, drains, and all buildings and land vested in the Corporation, and for the collection and proper disposal of such refuse. (2) The occupiers of all other buildings and lands within the Corporation shall be responsible for the removal of refuse from such buildings and lands subject to the general control and supervision of the Corporation. (3) The Corporation may cause public dust-bins or other suitable receptacles to be provided at suitable places and where such dust-bins or receptacles are provided, the Corporation may, by public notice, require that all refuse accumulating in any premises or land shall be deposited by the owner or occupier of such premises or land in such dust-bins or receptacles. (4) All refuse removed and collected by the staff of the Corporation or under their control and supervision and all refuse deposited in the dust-bins and other receptacles provided by the Corporation shall be the property of the Corporation” [6].

Khulna City Corporation (KCC) and community-based NGOs–CBOs are taking care of 60% of the total waste generated, while the rest of them are unattended. In fact, the wastes mostly collected under the DtD collection system are not sorted. They are dumped either in open space or poorly managed landfill sites. Thus, the city is facing serious health risk for this uncollected domestic wastes that are indiscriminately dumped on streets and public places. The wastes are responsible for the prolonged waterlogging and contamination of urban water bodies due to clogging of the existing drainage system by wastes. The population of KCC area as per the population census was 0.62 million in 1991. Considering the medium projection, it was estimated as 0.92 million for 2000 and it would be 2.05 million by 2020. Waste generation in the city area depends on its population. The Structure Plan estimated generation of solid wastes in the KCC area for the year 2000, 2010 and 2020 was 411 tons, 624 tons and 922 tons.

Solid waste management system in KCC area is found improved mainly after 1998, the initiation of the community-based DtD waste collection intervention by PRODIPAN, an NGO [12]. In the DtD waste collection system, 2–3 waste collectors with a non-motorized rickshaw van collect wastes from the households. At present, about 10 NGOs and CBOs are involved for this DtD waste collection system. The NGOs and CBOs work in collaboration with the Conservancy Department of KCC [13]. The NGOs and CBOs are BRIC, CHD, Clanship Association, MuktirAlo, Nabarun Sangsad, Rupayan, RUSTIC, Samadhan, SEIAM and SPS. The collected household waste is dumped into the nearest secondary disposal sites (SDSs). Later, KCC waste transfer trucks collect waste from those sites and dump into the ultimate disposal site (UDS) in Rajbandh. The UDS in Rajbandh has an area of 30 acre. Two new sites are currently being prepared for waste dumping. These sites are located in Mathabanga mouza and Solua mouza having an area of 25 acre and 16 acre, respectively [7, 8].

KCC collects waste by its 20 trucks and 200 wheel carts [4]. Apart from households, the carts also carry waste from commercial buildings either going door to door or collecting from a nearby place where the waste is dumped. Besides, the waste from market is dumped into a nearby dustbin where KCC waste-collecting trucks go and collect organic waste in a particular time of the day. There are no separate carts or trucks for collecting clinical waste. In fact, the clinical wastes are carried away in the same vehicles that carry other wastes from dustbins and later dump together twice a day [4]. Currently, 520 tons of solid waste is produced daily in Khulna City, but the collection capacity of the responsible local public authority KCC is about 65–70% [5]. The Conservancy Department of KCC has lack of technical manpower, i.e. engineers, town planners and environmentalists. This is why, performance of the department is not up to the mark.

7 Contribution of Solid Waste in GHG Emission and Climate Change

Waste sector is accountable for 5% of the global GHG emission consisted of methane (CH_4) and carbon dioxide (CO_2). Anaerobic decomposition of solid waste emits CH_4, while wastewater produces CO_2 during decomposition [14]. Landfilling, composting and incineration (thermal treatment) are the most common treatment of municipal solid waste. Among them, landfilling is most popular as it is comparatively easy and cost-effective even though it is not always the first choice as it can cause the infertility of the soil. Though the global warming potential (GWP) considers release of CO_2, in case of practices of solid waste management release of only CH_4 is accounted to estimate the GHG emission. This is mainly for the general consensus of considering CO_2 as biogenic origin [14].

7.1 Emission from Landfilling

Landfilling is a popular way of waste management in developing countries, even though in developed countries too. All the waste matter cannot be recycled or composed. A certain portion is needed to be either burned or used for landfilling. Emission of greenhouse gas is considerably higher in the waste decomposition process on landfill sites than of composting [11]. But, the emission of GHG from landfilling depends upon various factors such as waste composition, surrounding environment, soil composition.

7.2 Emission from Composting

Composting of organic waste has been widely popular in recent times as it is an easy and popular technology and also it has economic value. At present, it is used in many countries as an alternative to landfilling considering the impact of landfilling on climate change. Small-scale composting is also popular in Khulna City. Composting of organic fraction of MSW avoids the methane (GHG) emissions directly [14]. Even a well-managed composting plant in aerobic decomposition method for MSW produces carbon dioxide that eventually contributes on global climate.

7.3 Emission from Incineration or Thermal Treatment

It is the most climate threatening method for MSW management. This method is followed both in developing and developed countries. But, the open burning or absence of proper burning technology in the developing countries like Bangladesh is putting a direct threat to the environment. Most of the developed countries use different technologies to reduce the emission of gases or decomposition of emitted gases. The common technologies are burn pile, burn barrel, rotary kiln, fluidized bed, specialized incineration, etc. The combustion process nearly emits all the CO_2 in the atmosphere present in the waste. The mass fraction of carbon in MSW is approximately equal to CO_2 itself (27%); therefore, 1 ton CO_2 is considered to be generated from the incineration of 1 ton MSW. Waste incineration is widely applied in many of the developing and developed countries, where space for landfill site is limited. Japan and many European countries are such countries that follow incinerations. The amount of global annual combusted waste is 130 million tons in over 600 plants of 35 countries. The UNFCCC has also approved three municipal waste incinerators with 450,813 tons CO_2-eq reductions by treating MSW from developing countries in recent years [14].

8 Climate Mitigation Through Integrated Solid Waste Management (ISWM) in Khulna City

The amount of waste discharge increases along with the explosion of population and economic development of a country or region. But, improper and poor waste management system is subject to the risk for environmental health. It causes various problems such as water pollution due to contamination of water with dumped wastes, creation of breeding grounds for insects and rodents, and increased waterlogging and flooding due to blockage of canals, drains or gullies by the wastes dumped. Besides, increased rate of GHG emission due to improper management of wastes contributes significantly to climate change. Integrated solid waste management (ISWM) is a system that considers the prevention and recycling of wastes in most effective way for the protection of human health and environment. Under the ISWM, most appropriate and suitable waste management technologies are selected based on the evaluation of local needs and local environmental conditions. The components of ISWM are waste prevention, recycling, combustion and proper disposal of wastes to the technically sound constructed landfill sites. The ISWM process can greatly contribute to climate change mitigation by reducing the emission of the GHG from the environment. The prospect of ISWM system for climate mitigation has been investigated by developing three possible scenarios based on the methods of composting; anaerobic digestion; and reduce, reuse and recycling.

Khulna City produces almost 520 tons of solid waste a day that means 189,800 tons in a year. The results from the developed scenarios clearly state that emission of the GHG reduces if the ISWM system is followed. Anaerobic digestion (AD) for organic waste can reduce 3,040 tons of GHG emission in each year where aerobic composting can reduce 6,290 tons in the same timeline. Waste reduction and reuse can reduce up to 10,534 tons of GHG where waste recycling can reduce 16,548 tons of GHG in each year. So, it concludes that anaerobic digestion (AD) for organic waste and recycling will together reduce the emission of 19,588 tons CO_2 equivalent into the atmosphere per year and composting along with recycling will reduce 22,838 tons CO_2 equivalent. The detailed calculation and description of the scenarios are shown in Table 3.

A scenario of CO_2 mitigation is developed considering different methods of resource recovery from solid waste such as anaerobic digestion (AD), aerobic composting, waste reduction and reuse, and waste recycling. As stated earlier, almost 520 tons of solid waste is generated daily in Khulna City. So, in each year near about 189,800 tons of waste is generated. The waste stream contains different individual components such as organic, plastic, paper, metal. According to the percentage distribution, the amount of different components is calculated and presented in Table 2.

Table 2 Amount of solid wastes in Khulna City with different components

Waste components	Total waste generated in each day	Distribution (%)	Total amount of waste (ton/day)	Total amount of waste (ton/year)
Organic contents	520 tons	78.9	410.28	149752.2
Paper		9.5	49.4	18,031
Plastics		3.1	16.12	5883.8
Glass		0.5	2.6	949
Metal		1.1	5.72	2087.8
Wood		1.4	7.28	2657.2
Green waste		3.7	19.24	7022.6
Inert materials		1.8	9.36	3416.4
Total		100.00	520	189,800

8.1 Climate Mitigation Scenario by Composting

Method of composting from municipal waste is followed in many countries. In fact in the study area Khulna City, the method of composting is followed by an NGO named RUSTIC, who produces a small amount of compost using a certain amount of municipal waste. But composting is not the first choice when the climate is considered as a major concern.

Biodegradable organic contents are assumed to be completely stabilized in this scenario. Biological conversion factor for composting is assumed (i.e. 0.084) for the GHG emission calculation. Estimated CO_2 is 12,580 ton which will be emanating from the complete biological conversion of organic components from the MSW under aerobic conditions. But generally composting process will be extended between 30 and 45 days until getting C/N ratio of less than 20, since the complete biological conversion of C content will take long time [14]. Hence, the correction factor is considered 0.5 that is only 50% of organic content is converted under composting technology in the field. So, final amount of emitted CO_2 is 6,290 ton per year and remaining C content will be applied to the C sink soil.

8.2 Climate Mitigation Scenario by Anaerobic Digestion

The biological action where biodegradable materials are broken down by microorganism in absence of oxygen is known as anaerobic digestion. Biogas is the end product of this biological action. Biogas is normally combusted for producing heat and electricity, but further processing can turn it into transportation fuels or renewable natural gas [1].

The organic conversion factor of 0.029 along with the correction factor of 0.7 (70% of organic fraction converted into biogas) is considered to calculate equivalent CO_2 emission [14]. The calculated CO_2 mitigation is 3,040 tons per year which is less than emitted CO_2 from composting method.

8.3 Climate Mitigation Scenario by Reduce, Reuse and Recycling

The reduce, reuse and recycle (3R) method is the most common and used method in the developed countries. The method needs more technological advancement and utilization. The valuable materials either reduced/reused or source segregated for recycling is considered in this scenario. It is assumed that 50% of the waste is reduced/reused or 100% recycled from the waste stream [14]. The conversion factors considered for paper, plastics, glass and metal are also different as the use of the waste differs. Total 10,534 tons CO_2 emission can be reduced by reducing or

Table 3 Integrated solid waste management options and GHG mitigation for Khulna City

Integrated solid waste management options	Total amount (ton/year)	Conversion factor	Correction factor	GHG emission (t CO_2)
Anaerobic digestion (AD)	149752.2 (organic)	0.029	70% (0.7)	3,040
Aerobic composting		0.084	50% (0.5)	6,290
Waste reduction and reuse				
Paper	18,031	0.8	50% (0.5)	7,212
Plastic	5883.8	0.4		1,177
Glass	949	0.12		57
Metal	2087.8	2		2,088
Waste recycling				
Paper	18,031	0.6	100% (1)	10,820
Plastic	5883.8	0.3		1,765
Glass	949	4.0		3,796
Metal	2087.8	0.08		167
AD + Waste Recycling	176703.8			19,588
Aerobic Composting + Recycling	(Organic + Recyclables)			22,838

Note Calculations based on [14] using conversion factor from USEPA, 2002, and IPCC, 2006

reusing, and 16,548 tons can be reduced by recycling of materials from solid waste. Besides, the 3R system mitigates GHG emission lowering required energy for production and substituting recycled feedstock for new materials.

Table 3 represents that anaerobic digestion (AD) for organic waste and recycling will together reduce the emission of 19,588 tons CO_2 equivalent into the atmosphere per year and composting along with recycling will reduce 22,838 tons CO_2 equivalent. The result clearly shows that the integrated approaches for waste management will certainly reduce a portion of CO_2 from the atmosphere that will eventually contribute on climate mitigation.

9 Conclusion

Climate Change is a burning issue in the present world, especially for the disaster-prone countries like Bangladesh. In case of climate vulnerable Khulna City, it is found that integrated solid waste management system can significantly reduce GHG emission and eventually contribute to climate mitigation. The waste management system of Khulna City should be developed in a systematic and sustainable way to reduce the impact of solid waste on climate change towards a safe and secured environment for the future generation.

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Identification of Types and Source-Specific Characterization and Quantification Study of Solid Waste in Guwahati City, Assam, India

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Abstract Study was conducted for the identification of types of solid waste along with the source-specific characterization and quantification of Guwahati city. Different types of solid wastes were classified as organic, paper, plastic, glass, metal, rubbish and others. Sources of solid wastes generation were identified as regular and occasional source which is essential for proper quantification study. Regular solid waste-generating sources are households, commercial areas, marketplaces, hotels, restaurants, hospitals and nursing homes, educational institutes, cinema halls, offices, railway stations, bus stations, industries, street sweeping and drain cleaning, etc. On the other hand, occasional sources are 'Bihu', 'Durga Puja', 'Kali Puja', 'Idd', 'Book fair', 'Trade fair', 'Expo', etc. The 'Total Generation of Solid Waste' from Guwahati City was found to be 390 tons/day. The 'Combined Per Capita Generation of Solid Waste' was calculated as 379 gm/cap/day. Characterisation of the waste revealed that out of the total solid waste generation in Guwahati City, organic waste contributes 57.4% followed by paper 18.2%, others 11.3%, plastic 5.6%, rubbish 2.8%, glass 2.6% and metal 2.2%. The average per capita generation of household waste worked out to be 0.175 gm/day, out of which 73.93% was organic followed by paper 15.35%, plastic 2.54%, glass 0.83%, metal 2.41%, rubbish 1.23% and others 3.70%.

Keywords Organic · Paper · Plastic · Glass · Metal · Rubbish
Regular source · Occasional source

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1 Introduction

Generally, municipal solid waste management (MSWM) in most of the cities is not planned rationally due to the non-availability of authentic or relevant information on waste generation and its characterization [11]. Presently, majority of urban local bodies (ULB) do not weigh their waste, but the quantities are estimated on the basis of the number of trips of trucks which carry the waste to the disposal sites. Since MSWM handles huge quantity of waste, it becomes necessary to have detailed information on sources of solid waste generation, their characterization and quantification so as to plan different elements for handling the wastes. The source-specific solid waste characterization and quantification are helpful in predicting the waste quality and quantity from various waste-generating sources in a city, and this can be used as a basis for the planning of a solid waste management system.

Different types of solid wastes were classified as organic, paper, plastic, glass, metal, rubbish and others. Sources of solid wastes generation were identified as regular and occasional source which is essential for proper quantification study. Regular solid waste-generating sources are households, commercial areas, marketplaces, hotels, restaurants, hospitals and nursing homes, educational institutes, cinema halls, offices, railway stations, bus stations, industries, street sweeping and drain cleaning, etc. On the other hand, occasional sources are 'Bihu', 'Durga Puja', 'Kali Puja', 'Idd', 'Book fair', 'Trade fair', 'Expo', etc. The 'Total Generation of Solid Waste' from Guwahati City was found to be 390 tons/day.

2 Reviews on Characterization and Quantification of Solid Waste

Daskalopoulus et al. [2] pointed out that since the municipal solid waste management (MSWM) system handles huge quantity of waste, it becomes necessary to have detailed information on the sources of solid waste generation, their quantification and characterization. The source-specific solid waste quantification and characterization is helpful in predicting the waste quantity from various waste-generating sources in a city and this can be used as a basis for the planning of a system [17]. Parizeau et al. [14] conducted study on the need of waste characterization for successful waste management planning in Siem Reap, Cambodia. On the other hand, Mor et al. [12] studied on municipal solid waste characterization to assess the potential methane generation from the landfill sites. Sharma et al. [15] tried to develop a methodology for solid waste characterization based on diminishing marginal returns. Deshpande [4] pointed out that the municipal solid waste contains vegetable market waste, glass, paper, plastic and other organic fractions and inert matter from different sources, such as residential, commercial and institutional areas. Harilal et al. [8], on the basis of their study in quantification, characterization and management of solid waste from Mahe, union territory of Pondicherry, commented that since the magnitude of issues related to solid waste varies with location and time. Even et al. [5] in their study reported that 20 collection routes serving the nine road lanes were chosen which covered 88% of the city's population. Selected 20 collection routes were comprised eight Monday-Thursday routes, eight Tuesday-Friday routes and four Wednesday-Saturday routes. The original data was from weight-scale readings at the landfill site in operation. Jeevanrao and Shantaram [9] selected three landfill sites in their quantification and characterization study in Hyderabad. Samples of fresh urban solid waste as well as stabilized solid waste were collected from different locations of each landfill sites. The study revealed that fresh solid waste represented the material disposed of at the landfill sites within eight days of the date of collection, whereas stabilized solid waste represented the materials disposed of at least 180 days before the date of collection. Major portion of waste generated was from market yard and public eating places like hotels, tea shops and residential area. As per the study, weight–volume relationship of the wastes for Hyderabad City was varied from 365 to 410 kg/m^3 for fresh solid waste and 265–480 kg/m^3 for stabilized waste.

Yu and Maclaven [17] compared two waste streams quantification and characterization methodologies which contained direct waste analysis for determining the waste quantity and waste composition by questionnaire survey. In contrast to DWA and the questionnaire survey, methodology was normally restricted to collection of data at the point of generation. David and Lipt'ak [3] had been detailed out characterization methods where represented samples are sorted into separate sections such as organic matter, glass, paper, rags, metal, plastic, fine earth and others and weighed. These fractions are then represented as percent by weight. From this, the total percentage of different solid waste was calculated. Ojeda-Benitez et al. [13] also studied the characterization and quantification of household solid wastes in Mexican City.

Gawaikar et al. [6] pointed out some commonly used methodology to assess the quantities of solid waste. The most important aspect of solid waste management is the quantity of waste to be managed. The quantity determines the size and number of functional units and equipments required for managing the waste. The quantities are measured in terms of weight and volume. The weight is fairly constant for a given set of discarded objects, whereas volume is highly variable. In the characterization study of solid waste, Kumar et al. [11] segregated various components such as plastics, paper, metal, organic fractions from the 12.5 kg samples and weighed, and these fractions were expressed as a percentage of the total weight. The Waste Wise Resource Centre [16] also carried out a study on quantification.

Bolaane et al. [1] conducted some research work related on sampling of household waste at source in Gaborone, the capital city of Republic of Botswana. Gawaikar et al. [6] also pointed out in their study that the source-specific solid waste quantification and characterization will be helpful in predicting the waste quantity from various waste-generating sources in a city and this can be used as a basis for the planning of the system. This will also enable in saving of time, manpower and financial inputs required to be spent for estimating the waste quantity for the entire city. Such a developed methodology can be very easily adopted by the municipal agency and would help them in managing the system in a befitting manner. Gomez et al. [7] studied seasonal characterization of municipal solid waste (MSW) in the city of Chihuahua, Mexico, while Khatib et al. [10] studied the same in Nablus district of Palestine.

3 Study Area

Guwahati, the capital city of Assam, is one of the large and densely populated cities in India and largest city in the north-east region of India. Geographically, Guwahati City is located in 26° 5′N to 26° 12′N latitudes and 91° 34′E to 91° 51′E longitudes. The area under the jurisdiction of the municipal corporation of the city called as Guwahati Municipal Corporation is limited to 216 km^2. Mighty Brahmaputra River is on the northern boundary of the city. The southern and the eastern boundaries of the city are made by some small hills of comparatively low heights. On the west, Jalukbari constitutes the border of the city. The city spreads around 27–28 km. in the east west direction and about 10–12 km. in the north south direction. For administrative purposes, the city is divided into 60 wards as shown in Fig. 1.

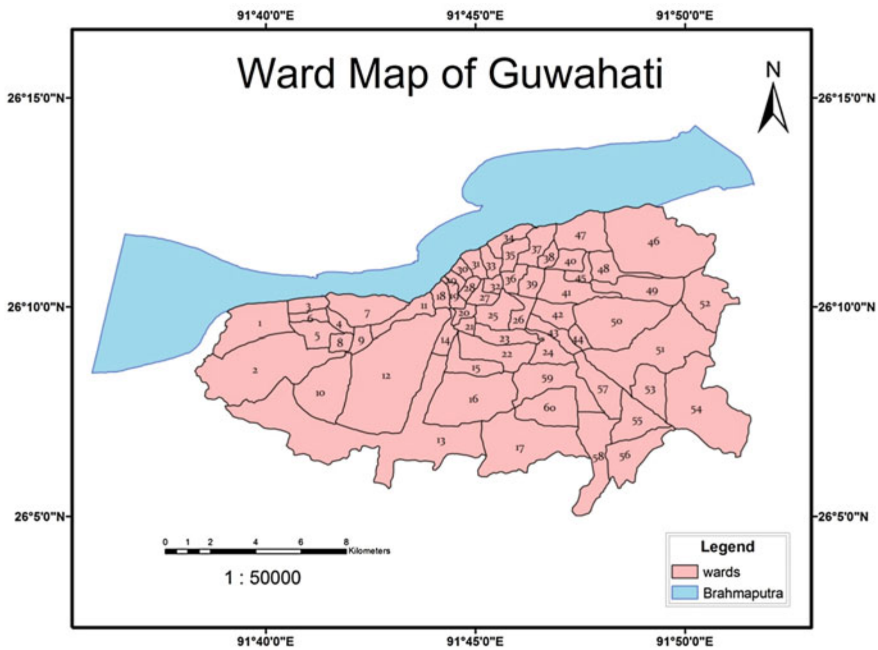

Fig. 1 Ward map of Guwahati City. *Source* Guwahati Municipal Corporation

4 Population Distribution Pattern

Guwahati is one of the most rapidly growing cities in India. The city's population grew from just two lakhs in 1971 to more than five lakhs in 1991. In the census of 2001, the city's population was estimated at 809,895 out of 189,524 households which were found to be 1,028,563 in 2012 out of 208,476 households. On the average, population density in the city was 4,762 persons per km^2.

5 Methodology

A. Identification of types of solid waste of different sources

To know about the different types of solid waste and its different sources, three steps were followed. These include:

Survey: Survey was carried out in greater Guwahati to identify the different sources of solid waste. In this respect, each of the solid waste-generating sources was investigated for proper identification.
Fieldwork: Information and data of various solid waste-generating sources were identified, classified and listed. Primarily, 50 samples were collected from all the identified sources for classification of the different types of solid waste generation.
Laboratory investigation: Samples from respective locations were brought to laboratory and separated into different components and accordingly classified the different types of solid waste.
Organic—includes kitchen waste, vegetable and fruit peels including coconut shell, flowers and garden waste, agricultural waste, leaves, wooden pieces, dead animals and waste from slaughterhouse.
Paper—newspapers, hard papers, books, poster and leaflets, sweet boxes, carbon papers, laminated papers, etc.
Plastic—thermoset, thermoplastic including PS, LDPE, PET, HDPE, PVC and PP and other multi-layered plastic, etc.
Glass—used for building construction, windows for vehicle, mirror, medicine and cosmetic bottles, liquor bottles, etc.
Metal—all type of metals especially tin, iron, aluminium, etc.
Rubbish—stones, bricks, concrete and ceramic, etc.
Others—include sand and soil, batteries, hazardous waste, clothes and woollen items, thermo coal, rubber and leather.

B. Source-specific characterization and quantification of solid waste

The method followed in this study is based on the characterization and quantification of solid waste collected from different sources. Samples were collected from different sites selected randomly covering all the 60 wards of the city. For this purpose, all the sixty wards of greater Guwahati were grouped into five zones as presented in Table 1.

Table 1 Ward-wise study area as per the zones

Zone	Ward No.
East	41, 45, 46, 48, 49, 50, 51, 52, 53, 54, 55, 56
West	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
North	18, 19, 29, 30, 31, 33, 34, 35, 37, 38, 40, 47
South	13, 14, 15, 16, 17, 22, 23, 24, 57, 58, 59, 60
Middle	20, 21, 25, 26, 27, 28, 32, 36, 39, 42, 43, 44

For household sampling, each ward was again farther divided into five sampling points. In this process, all the 60 wards of Guwahati City were stratified into 300 nos. sampling points. On the other hand, rests of the sampling points of different sources were selected and classified as per the generation of waste, and accordingly, all the sample points and the number of samples were identified and stratified for systematic study as presented in Table 2.

Four different coloured litter bins (L_1, L_2, L_3 and L_4) were supplied to each sampling point for the collection of different segregated waste (Fig. 2) and informed about the source segregation process for farther investigation in the laboratory. In this process, altogether 20 (5 of each colour) litter bins were used. Collection and laboratory analysis of the samples were performed on daily basis.

The waste was collected from the source by the hand-picking method and it was segregated at source as organic; plastic, paper, glass and metal; rubbish and other solid waste and kept in four different coloured litter bins which were marked as L_1 (Green colour), L_2 (Blue colour), L_3 (Yellow colour) and L_4 (Red colour).

$\mathbf{L_1}$: Used for collection of organic waste.
$\mathbf{L_2}$: Used for collection of plastic, paper, glass and metal.
$\mathbf{L_3}$: Used for collection of rubbish like stones, bricks and concrete.
$\mathbf{L_4}$: Used for collection of all the other solid waste like sand and soil, batteries, thermocoal, rubber and leather, clothes and woollen items, etc.

Size of the litter bins (L_1, L_2, L_3, L_4**)**:
Volume: 60 L
Breadth = 18 in. and
Length = 22 in.

After selection of sample points and sampling numbers, following methods were adopted for systematic characterization and quantification of different types of solid waste at their generating sources.

(a) **Analysis of household Solid Waste**

Segregated solid waste collected from five different selected points (household) of each ward was mixed as per their category and kept in four different heaps.

(b) **Analysis of commercial and institutional Solid Waste**

The MSW samples were collected through stratified random processes and accordingly fixed the sampling points based on population density, generation of

Table 2 Sample points and numbers of sample

S. No.	Sample points	No. of sampling points	No. of samples	Description of sampling numbers
Regular sources				
1	Household	60	300	5 nos. stratified random samples from each ward
2	Commercial areas	19	95	5 nos. stratified random samples from selected location
3	Marketplaces	17	118	Stratified random samples of different nature from all the 17 nos. market
4	Hotels	32	32	Single sample from each hotel
5	Restaurants	60	120	2 nos. stratified random samples from each ward
6	Hospital and nursing homes	20	40	2 nos. samples from all the 20 nos. hospital and nursing home
7	Educational institutes including hostels	60	180	3 nos. stratified random samples from each ward
8	Cinema halls	15	15	Single sample from each cinema halls
9	Offices	20	100	5 nos. stratified random samples from 20 nos govt. offices
10	Railway stations	2	10	5 nos. samples from all the 2 nos. railway stations
11	Bus stands (long distance)	3	15	5 nos. samples from all the 3 nos. long-distance bus stands
12	Industries	250	250	Single sample from each industries of all the 3 industrial estate
13	Street sweepings and drain cleanings	32	32	Single sample from each ‘carrier truck’
14	Other sources	60	180	3 nos. samples from each ward
Occasional sources				
1	Bihu	30	30	10% stratified random samples
2	Durga Puja	50	50	10% stratified random samples
3	Kali Puja	60	60	10% stratified random samples
4	Idd	10	50	5 nos. stratified random samples from 10 wards
Different fair				
a	Book fair	06	30	5 nos. samples from 6 different book fair
b	Trade fair	03	15	5 nos. samples from 3 different trade fair
c	Expo	03	15	5 nos. samples from 3 different Expo

Fig. 2 Litter bins used for collection of source-segregated solid waste

waste and location. It was ensured that establishments were intimated about the waste sampling process. At each establishment, segregation and collection of the sample were done [6].

(c) **Analysis of Solid Waste of Railway Station and long-distance Bus Terminus/Stand**

All the daily generated solid wastes were first divided into five different heaps in each station. Accordingly, samples were collected from all the five nos. sample point (heaps) for systematic analysis of different component of solid waste to measure the total daily generated solid waste.

(d) **Analysis of solid waste of Street Sweepings and Drain Cleaning**

Samples were collected from each truck and weights were measured as per the methodology adopted by Guwahati Municipal Corporation. Samples were collected from each truck for determination of different types of waste and its weight. Accordingly, average weight of each waste type was calculated and finally distributed the average weight of each waste type in whole amount of waste to measure total generation.

Finally, following steps were adopted for systematic study:

Step 1: Organic solid waste was air and oven dried to remove the water component.
Step 2: After proper mixing, all the samples heaps were farther segregated to different components.
Step 3: The weight of the different segregated waste components was taken on weighing scale of 1 and 5 kg, respectively, for accuracy of weight measurement.
Step 4: The waste characteristics from various categories are averaged and weighed against the number of population and different sources to analyse the average solid waste generation rates which were farther differentiated in the different components. These fractions are then represented as percent by weighed. From these, the total generation and percentage of generated MSW was calculated. Secondary data sources (Guwahati Municipal Corporation; Guwahati Metro Development Authority; Directorate of Population Census, Assam).

6 Results and Discussion

After systematic analysis, total solid waste generated from household was found 180.00 tons/day which was followed by from commercial establishments 56.62 tons/day, markets 17 tons/day, hotels 2.68 tons/day, restaurants 9.4 tons/day, educational institutions 23 tons/day, hospitals and nursing homes 4.81 tons/day, cinema halls 0.65 tons/day, offices 5.35 tons/day, railway stations 2.4 tons/day, long-distance bus stations 1.09 tons/day, industries 3.5 tons/day, street sweeping and drain cleaning 48 tons/day, other sources 15.45 tons/day and from occasional sources 19.75 tons/day (Table 3). Percentage of solid waste generated from different sources in Guwahati City/day is shown in Fig. 3. Thus, the 'Total Generation of Solid Waste' from Guwahati City was found to be 390 tons/day. The 'Combined Per Capita Generation of Solid Waste' was calculated as 379 gm/cap/day. Category-wise breakup of solid waste reveals the total generation of different types of solid waste was—organic waste 223889.83 kg/day followed by paper waste 70831.49 kg/day, plastic waste 21872.85 kg/day, glass waste 9934.48 kg/day, metal waste 8386.64 kg/day, rubbish 10943.55 kg/day and 'other' waste 44078.10 kg/day. The percentages of different types of solid waste generated in different sources are tabulated in Table 4. It shows that the contribution of organic waste was 73.93% in case of waste generating from household which was above 80% in case of the waste generated from markets, hotels and restaurants. It was observed that most of the solid

Table 3 Total quantity of solid waste generated from different sources in Guwahati/day

S. No.	Source	Unit generation per day	Total solid waste tons/day	In % of total
1	Household	0.175 kg/person	180.00	46.20
2	Commercial establishments	1.49 kg/unit	56.62	14.53
3	Markets	2 to 15 kg/unit	17.00	4.36
4	Hotels	83.75 kg/unit	2.68	0.69
5	Restaurants	16.50 kg/unit	9.40	2.41
6	Educational institutions	0.153 kg/person	23.00	5.90
7	Hospitals and nursing homes	1.035 kg/bed	4.81	1.23
8	Cinema halls	43.33 kg/unit	0.65	0.17
9	Offices	0.05 kg/person	5.35	1.37
10	Railway stations	800 kg/unit	2.40	0.62
11	Long-distance bus stations	363.33 kg/unit	1.09	0.28
12	Industries	14 kg/unit	3.50	0.90
13	Street sweeping and drain cleaning	1500 kg/truck	48.00	12.31
14	Other sources	15.45 kg/unit	15.45	3.96
15	Occasional sources		19.75	5.07

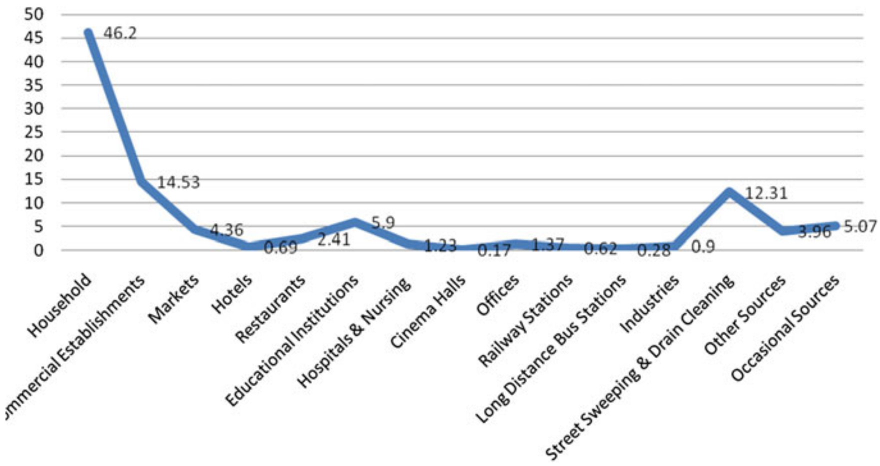

Fig. 3 Percentage of solid waste generated from different sources in Guwahati/day

Table 4 Percentage of different types of solid waste generated in different sources

Source	Organic	Paper	Plastic	Glass	Metal	Rubbish	Others
Household	73.93	15.42	2.60	0.84	2.42	1.21	3.58
Commercial establishments	41.86	44.71	7.36	1.00	1.36	1.14	2.50
Markets	83.75	5.58	6.12	0.71	1.00	0.79	2.04
Hotels	81.50	6.75	3.25	8.50	0	0	0
Restaurants	81.50	6.75	3.25	8.50	0	0	0
Hospitals and nursing homes	45.67	7.17	6.67	6.33	2.00	0	1.00
Educational institutes	57.80	26.40	5.00	5.80	0.30	1.70	3.00
Cinema halls	2.60	1.00	96.40	0	0	0	0
Offices	30.00	64.50	5.00	0	0	0	0.50
Railway stations	51.35	15.75	24.50	4.40	1.00	0.50	2.50
Bus stands (long distance)	32.33	15.67	43.67	4.00	0	0	2.67
Industries	5.00	6.00	7.00	3.00	60.00	4.00	15.00
Floating population	70.90	6.50	7.00	15.60	0	0	0
Street sweeping and drain cleaning	10.00	2.00	10.00	5.00	0	3.00	70.00
Other sources	44.19	5.00	9.00	0.50	3.00	37.31	1.00
Occasional sources	59.40	16.70	6.70	10.05	2.17	1.20	3.78

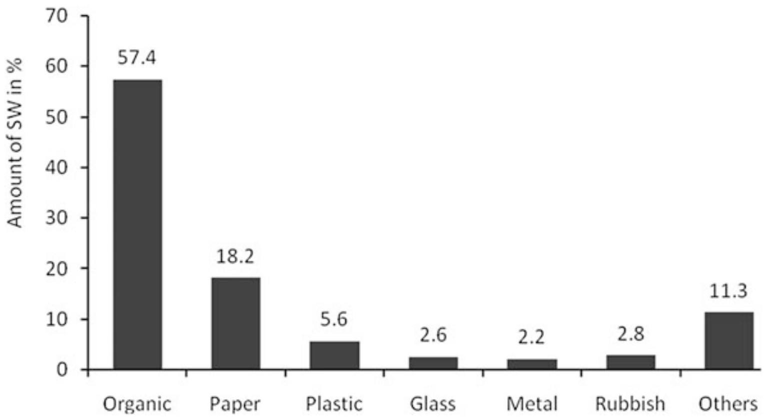

Fig. 4 Overall percentage-wise distribution of solid waste generated from Guwahati City/per day

wastes generated in the city were organic type (57.4%). The average per capita generation of household waste worked out to be 0.175 gm/day, out of which 73.93% was organic followed by paper 15.35%, plastic 2.54%, glass 0.83%, metal 2.41%, rubbish 1.23% and others 3.70%. Out of the total generating sources, household generating the highest amount of waste (46.20%) followed by commercial establishments (14.53%), street sweeping and drain cleaning (12.31%), educational institutions (5.90%), occasional sources (5.07%), markets (4.36%), different other sources (3.96%), restaurants (2.41%), offices (1.37%), hospitals and nursing homes (1.23%), industries (0.90%), hotels (0.69%), railway stations (0.62%), long-distance bus stations (0.28%) and cinema halls (0.17%). Characterisation of the waste revealed that out of the total solid waste generation in Guwahati City, organic waste contributes 57.4% followed by paper 18.2%, others 11.3%, plastic 5.6%, rubbish 2.8%, glass 2.6% and metal 2.2% (Fig. 4).

7 Conclusion

Investigation was made for collection of detailed information regarding solid waste generation in Guwahati City as per the methodology with the help of Guwahati Waste Management Company Private Limited. From the study, it was revealed that overall generation of organic waste in the Guwahati is 57.4% and plastic waste is 5.6%. On the other hand, households generating 73.93% organic waste followed by only 2.54% plastic waste. Though the amount of plastic waste was found to be comparatively less, due its huge volume and mixing with the organic waste, different problems are occurring. To reduce the problem, segregation of solid waste at source is most essential followed by the source reduction practice. The study is opening a path for designing a successful solid waste management plan not only for Guwahati but also for the other Indian urban habitat.

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Integrated Solid Waste Management Turns Garbage into Gold: A Case Study of Jabalpur City

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Abstract Solid waste generation is an inevitable consequence of anthropogenic activities, which needs an enormous effort for its proper management to avoid filthy situation in the city and around the residential areas, but unfortunately the responsible authorities as well as residents do not pay heed to cope with the deteriorating situation. Rapid urbanization and speedy population growth have accelerated the problem, and the circumstances are more grim and severe in developing countries. India is also experiencing a dire state due to the lack of proper disposal of burgeoning solid waste, and the situation in Jabalpur is also about to skid from grip of the authorities. The study attempts to explain the current scenario of solid waste management (SWM) in Jabalpur city, which is known as 'Sanskardhani' (capital of etiquette). Depiction of the running system of SWM in the city, identification of the causes for inefficient solid waste collection and its improper management and derivation of ideas to mitigate the problem and to improve living conditions are the objectives of the study. The information and relevant data have been compiled from Municipal Corporation of Jabalpur (MCJ), related stakeholders supplemented by field observations and self-administered questionnaire. An intensive review of related literature has been embraced too to have a sound knowledge of the problem and to augment solutions of this catastrophe. Finally, the study will deliver concrete insights to the policy makers to enrich the plans, which could assist them in the battle field of integrated and sustainable management of solid waste.

Keywords Anthropogenic activities · Filthy · Urbanization · Burgeoning Mitigate

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1 Introduction

Human activities and its consequences do not seem to cease the generation of solid waste, and the ever increasing amount of waste has now been a trouble and cause of anxiety for the whole world. Speedy growth of the population, changing pattern of our lifestyle, rapid urbanization and industrialization have significantly contributed to deteriorate the situation. Solid waste and the discarded items are inevitable by-products of anthropogenic activities, and because of the hazardous nature, it is a major cause of concern for the health of environment and human being in the urban areas of developed and developing countries. Moreover, some by-products and discarded items are not exactly wastes but 'secondary resources, they are collected for reuse as recovered products or for recycling as recovered materials [1]. Hence, if the discarded items are collected at source and channelized in an appropriate way, the waste material can be modified for the reuse and it will preserve the very precious natural resources, but regrettably, the waste items are brought together in mixed form and fails to attain its apposite value. The situation is more severe and stern in developing countries owing to the insufficient infrastructure and financial constraints.

The condition of waste management in India is almost in the same state. The urban local authorities, which have been assigned to undertake the task of solid waste management, are unable to furnish the services proficiently and at times, some private players are involved to mitigate the situation with its own staff, equipment and funds but unfortunately illegal disposal of the waste and sludge becomes a common practice, and it has been a challenge for the urban local body to cope with this situation. Although, the municipal corporation of Jabalpur is trying hard to improve the current waste management practices, yet the present scenario of waste management is no better.

The current study attempts to portray the existing state of waste generation and its management in Jabalpur city. Therefore, the aim of the paper is to focus on the practices done by the local authorities to augment the contemporary situation of waste management, and it also tries to underline the loopholes and lacunas which are still being an impediment in the betterment of the running picture.

2 Study Area

The study has been organized in Jabalpur city, which is known as 'Sanskardhani' (capital of etiquette) and recognized for the world famous 'Dhuandhar' waterfall situated in the way of the River Narmada. Geographically, the city is located at 23° 10′ North latitude and 79° 57′ East longitude, at an altitude of 393 m above mean sea level (MSL) [2]. Keeping in view the convenience of waste management services, the city has been divided into 15 zones and these all zones constitute 78 wards and cover the area of 265 km^2.

2.1 Research Design

Information and solid waste management (SWM) related data have been compiled from various sources, and to enhance this data, an intensive questionnaire interview have been embraced with various municipal corporation personnel of Jabalpur, who are involved in the waste management followed by the natives' interview of few wards on simple random sampling basis. Besides it, a thorough study of related literature, field visits of the study area, direct observation of the hot spots of the waste have been also operationalized to validate and certify the facts.

2.2 Objectives

The paper is an attempt to visualize existing model of waste management in Jabalpur city, and it correspondingly endeavours to strengthen the knowledge for the better management of waste to heave and live in a pollution free environment. Some specific objectives of the paper are:

- To reveal the real information about waste generation of the study area.
- To be familiar with current waste management programme in the city.
- To figure out the complications and hurdles, which obstruct the track of mitigation in waste management programme.
- To develop ideas, which can minimize waste amount and pollution.
- Finally, to propose such master plan including institutional changes and integrated policies of waste management that could attain desired result and make the city litter free.

3 Waste Generation and Its Management in Jabalpur City

On an average, the city generates 400–450 tonnes solid waste every day and local households, marketplaces, commercial institutions, hotels, restaurants and hospitals are the primary sources of solid waste generation in the city. Waste from all these sources are brought to primary dumping centres (PDC), and these PDCs are the secondary collection points. The Health Department, headed by a Health officer, of the Municipal Corporation of Jabalpur (MCJ), is authorized for the collection and disposal of solid waste within the Corporation limits, except the untreated bio-medical waste and hazardous industrial waste, which is the responsibility of respective generators. Earlier, the condition of solid waste management in the city was pitiable, but, since when the city has been selected to be transformed as 'Smart City' and has secured seventh rank in the first list of top 20 cities released by the Central Government of India, which will be developed as smart city, the change can be acknowledged in the behaviour of city dwellers and local administration. At least, elite group of the population, students and some of mature citizens have been aware of their moral duties and they co-operate local urban body in the management of solid waste. However, the percentage of such persons is very low, and they can be counted on fingers and a huge part of total sum of population is still miles away from the consequence of this transformation. Few posh areas, i.e. Civil lines, Sadar, Cantonment area, Vijay Nagar, Wright town, Napier town and Russell Chowk, receive full flash attention of growth, but on the contrary of this progress, dwellers of the peripheral areas and slums of the city (viz. Adhartal, Raddichowki, Ranital etc.) are forced to reside in filthy atmosphere. Door-to-door collection of solid waste is being practiced in only 10 wards, but no source segregation of solid waste and no expertise are being incorporated in the city. Collection operation is organized in two shifts—one in morning at 7 a.m. and another in afternoon at 2 p.m. (Fig. 1).

Collected waste from all these sources are transported for final disposal at Kathonda, 15 km far away from the city, and the mode of the final disposal of the waste is open in nature. The dumped solid wastes at Kathonda putrefy and create fetid smell, which is extremely obnoxious for the surrounding region. Keeping in view, MCJ has laid the foundation of a 'Waste-to-Energy Power Plant' in a joint venture with ESSEL Group to generate electricity from solid waste. The total cost of the plant is ₹2,000 million (approximately 300 million US $), and its full swing capacity to generate electricity is 11.5 MW and the future of the plant will be seen when it will be commissioned, but before that there are number of strategies, which can be practiced for the better management of solid waste in the city.

Fig. 1 Open dumping of solid waste at Kathonda dumping ground and at the road side

4 Integration of Different Solid Waste Plans for the Overall Management of Waste

As the composition of solid waste is very complex in nature, that is why comparatively more integrated and well-organized set of ideas would be required for a long term and efficient management of solid waste. An integrated approach to waste management consisting of a "hierarchical and coordinated set of actions" [3] seeks to reduce pollution, maximize recovery of reusable and recyclable materials, and protects human health and the environment. Hence, the set of actions to achieve desired result are as follows:

- Any plan or policy cannot meet its aim until it receives the encouragement and support from the beneficiaries, whom the scheme is being implemented for. Therefore, at the very beginning, assistance and incorporation of local residents into the solid waste management plan is much needed for its success and for that an intensive awareness campaign for the clean and hygienic environment can be introduced by local authorities. This campaign can also be initiated with the help of non-governmental organisations (NGOs) and local administration in schools and colleges to establish active participation of the students, who are the future of the nation.
- Segregation of degradable, non-degradable and hazardous waste at the source is next step for an enhanced waste management system, and to achieve this goal, the responsible officials will have to exercise a rigorous crusade in stages such as to create awareness among the people about importance of segregation of waste, to position various dustbins of different colours and caution at public places to avoid mixing of waste and the bins must be tipped frequently. This may assist source segregation, and it will create community participation.
- Owing to the vulnerability of slums and slum dwellers their inclusion is much needed part of waste management and to incorporate them, the officials may begin intensive cleanliness and awareness campaign through street plays in addition to screening of documentary movies based on the theme 'sanitation and waste management practices'.
- Waste management strategies of the government are very efficient and extremely successful on paper, but to know the ground reality, their assessment is necessarily required, and this will help the executives to find out the omissions, and therefore, rectification in policies can be executed.
- Global positioning system (GPS) and geographic information system (GIS) are really nifty tools at present, and these technologies can be introduced for data collection of solid waste, their analysis and visualization [4]. Real-time monitoring of vehicles, used for solid waste collection, transportation, and dumping, can be experienced by the authorities from the control room, if the vehicles are under the GPS tracking system.
- Geo-informatics can assist the city planners to give suitable location for transfer stations of solid waste storage, designing short routes for waste collection,

creating databases for households that pay and those who have not paid for the services, arranging time tables for trucks to collect waste, etc. [5]. Hence, inclusion these technologies may turn the municipal solid waste management practices over a new leaf.

- The areas, which are not under door-to-door collection system in the study area, must be brought under it and while collecting the solid waste, the municipal staffs should take care of not to mix the waste to promote source segregation. The sanitary workers should also have a separate data of physically challenged and old age persons to include this section into house-to-house collection scheme.
- Most of the staffs and officials involved in waste management are not skilled and trained in their work, therefore, workshops and seminars based on solid waste management theme can be organized by MCJ to train them to execute waste management operation proficiently.
- Waste pickers, who carry out their job in inhuman circumstances and receive no identity, belong to the informal sector, can also be included officially into waste management practices. Since, they are efficient in waste picking and sorting; therefore, they can perform the job in handy way, but they need safety measures to work in such hazardous atmosphere. Hence, the Municipal Officials of Jabalpur should consider incorporating the waste pickers into waste management course. Besides it, they can also be trained to work more proficiently (Fig. 2).
- Plastic, which is firmly embedded in our modern life and contribute significantly into solid waste, has been a cause of annoyance for everyone and the scientists are still not getting any permanent solution of this catastrophe. We can only minimize its use as much as possible and can reuse it again and again. Few fungi, i.e. *Aspergillus niger, Aspergillus Japonicus* [6], have been identified, which could decompose plastic up to some extent.
- Polystyrene foam (another trade name 'Thermocol'), which is very suitable and convenient in packing of different products, is a major part of solid waste and owing its non-degradable nature it is a great challenge to be managed. Besides it, huge quantity of cups, plates and other items are manufactured from

Fig. 2 Waste pickers are more vulnerable and performing the job without any safety gears

polystyrene foam and plastic, and when hot as well as cold beverages, edible food items are served in these cups and plates, respectively, styrene and other chemicals migrate in our drinks and foods, which extremely harmful for human health.

- Therefore, the polystyrene foam products can be replaced by bio-cradles (made of used stem of sugarcane and dry straw) for packaging purposes and cups and plates made of old and waste paper pulps. These all products are degradable and non-toxic in nature (Fig. 3).

– Segregation of waste at source is the best way of managing it. Vellore's (Tamil Nadu, India) Mr. C. Nivasan's model [7] is extremely effective if the discarded items are collected in segregated form. He has introduced cattle, fish, earthworms, ducks and hens in waste management and the outcome is amazing. Domestic and stray cattle can be used for the vegetable and fruit market waste and in response we will obtain cow dung. The cow dung can be utilized in biogas plant to gain methane gas, and finally, 99% methane gas free cow dung slurry will come out from the plant, and immediately earth worms can be put into that slurry, which will be eaten by them and the excreta, will be the rich manure for agricultural practices.

– One more part of Nivasan's model [7] is hen. Hens are suitable for rotten items which cannot be eaten by cattle. Maggots appear at the time of decomposing rotten waste. Hens can pick those tiny creatures as their food and lay eggs. Ducks are the best creatures for the waste generated from fish markets and slaughter house. After consuming these wastes, ducks lay more eggs than normal. If Nivasan's model is executed transparently and waste is collected separately, most of the waste may disappear by the end of day.

– Our development will not be sustainable until the environment and the natural resources are not conserved for the future. That's why, the concept of 4Rs—reduce, reuse, recycle and recover—comes into existence. The integration of 4Rs into waste management system can reduce the size of waste and can preserve the resources for the next generation.

Fig. 3 Replacement of polystyrene by bio-cradles

5 Conclusion

Ultimately, the study concluded that the developing countries, including India, are running short of resources, i.e. financing, infrastructure, appropriate strategy and management as well as leadership and the lack of stated means are the major obstacles in the way of municipal solid waste management services. The rapid population growth and burgeoning solid waste have further intensified the acuteness of the situation and the pressure of the garbage and refused item necessitates a herculean endeavour to cope with the challenge of solid waste management. Hence, it can be said that seeking the severity and complexity of the solid waste management related issues more integrated course of action is required and all the action plans may be fruitful only if they are executed collectively and candidly with the whole hearted effort of the involved stakeholders and individuals of the study area and if it is achieved the garbage which is considered as waste, will be a resource and worth of gold.

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Urbanization and Tourism Induced Challenges in Waste Management in Hill Towns: Case of Gangtok

Beran Rai and Subhrangsu Goswami

Abstract Rugged mountains, difficult terrain, and slope pose major challenges for development of Gangtok city. However, despite these challenges, Gangtok has experienced an unprecedented population growth during last two decades. It has created tremendous pressure on the basic infrastructure services and environment, especially when it comes to waste management. On the other hand, tourism is the main economic base of the state. Gangtok City alone receives approximately five lakhs tourists annually (both foreign and domestic). It is also evident from the city-level data of solid waste that in a given year tourism sector alone generates more solid waste than the waste generated by city's own population. It should be noted that Gangtok Municipal Corporation (GMC) is the sole responsible authority for MSWM since its inception in 2010. The primary objective of this research study is to examine the existing solid waste management system in the city in the context of increasing pressure from urbanization and tourism. The methodology of the study included reviewing of relevant literature and examining case studies of hill towns. At the city level, six wards out of fifteen wards of the city were selected based on its land use, population, terrain, road network, economic base, and existing waste management practices. Thereafter, primary survey was carried out after systematic selection of samples from hotels/restaurants, residential, shops, and ragpickers. Detailed study was conducted to understand the existing waste management practices and its challenges through stakeholder consultation. Major stakeholders such as GMC, Tourism Department, Urban Development and Housing Department, and local citizens were interviewed. Analysis of the primary and secondary data revealed surprising findings which include the issues and challenges faced by the local body due to difficult terrain, lack of manpower, lack of resources, inefficient collection process, and most importantly lack of willingness from citizens and tourists.

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Tourism

1 Introduction

Rugged mountains, difficult terrain and slope pose major challenges for development of Gangtok City. However, despite these challenges, Gangtok has experienced an unprecedented population growth during last two decades. It has created tremendous pressure on the basic infrastructure services and environment, especially when it comes to waste management. On the other hand, tourism is the main economic base of the state. Gangtok City alone receives above about five lakhs tourists annually (both foreign and domestic). It is also evident from the city-level data of solid waste that in a given year tourism sector alone generates more solid waste than the waste generated by city's own population. The primary objective of this research study is therefore to examine the existing solid waste management system in the city and its linkages with the natural environmental setting of the city.

2 Study Area

Gangtok is the capital of Sikkim located in the Eastern Himalayan range at an elevation of 1,650 m with rugged mountainous and hilly terrain. Gangtok Municipal Corporation (GMC) is the Urban Local Body, responsible for development and management of city since its inception in 2010. Gangtok located at the center of Sikkim has potential command area over different tourist spots in East Sikkim, which are directly linked by a network of roads centering Gangtok and are perfectly accessible for one-day trips. The tourist attractions of East Sikkim are clustered mostly in and around Gangtok (Fig. 1).

In the north of Gangtok town, there are hills, which gradually gain their altitude leading up to the ranges of the Kanchendzonga, which are toward the northwest of Gangtok and the third highest mountain of the world. Trade and commerce are the most important functional linkages between Gangtok and its neighboring regions. As a result, the entire state of Sikkim depends on Gangtok to meet its economic and administration requirements. Gangtok, as base town, offers the best infrastructural facilities to visiting tourists [12].

The tourist attraction in Gangtok can be classified under (i) natural sightseeing, (ii) monasteries, (iii) sanctuaries of different kinds viz., alpine and wildlife sanctuaries, (iv) man-made sightseeing, and (v) cultural and historical places. The tourist attraction places of Gangtok and its surroundings are shown in Table 1.

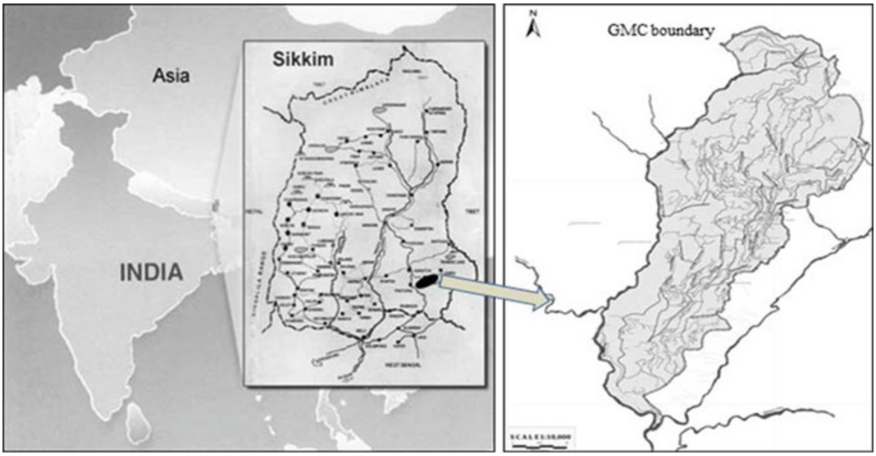


Fig. 1 Location of the study area

Table 1 Tourists attraction sites of Gangtok

Natural sightseeing	Monasteries	Sanctuaries	Man-made sightseeing	Cultural and historical attraction
1. Tsomgo Lake 2. Tashi View Point 3. Bridge B2 waterfalls 4. Nathu La pass	1. Rumtek Monastery 2. Enchey Monastery	1. Fambong Lho Wildlife Sanctuary 2. Kyongnosla Alpine Sanctuary	1. Ganesh Tok 2. Hanuman Tok 3. Flower show 4. Saramsa Garden 5. JLN Botanical Garden 6. Tourist village, Rumtek 7. Zoological Garden 8. Coronation Garden and Deer Park	1. Directorate of handicraft and handloom 2. Do-drul Chorten 3. Tibetology 4. Sa-Ngor-Chotshog Centre

Source Civil Aviation and Tourism Department Govt. of Sikkim

3 Approach and Methodology

The primary objective of this research study is to examine the existing solid waste management system in the city in the context of increasing pressure from urbanization and tourism. Approach and methodology adopted to achieve the objective are explained in the section below.

Through comprehensive literature review, an effort was made to comprehend the nature of municipal solid waste management scenario at global, national, and local levels. It helped to understand various issues and challenges of municipal solid waste management in hill cities of India, the nature of the problem, its causes, and consequences. The literature review and case studies helped developing a robust framework for data collection and analysis. Both primary and secondary data were collected. Secondary data was collected from various government departments like Gangtok Municipal Corporation, State Pollution Control Board, Physical Health Engineering Department, Rural Development Department, Urban Development and Housing Department, and Tourism Department.

As far as primary data is concerned, it was collected through primary survey with systematic selection of sample. It was important to select municipal wards which are strategically located and are observed to be more active in terms of tourist activities. Therefore, six wards, namely Ranipool, Diesel powerhouse, Lower MG Marg, Arithang, development area, and Deorali, were selected out of total fifteen wards of GMC on the basis of population density, area coverage, number of hotels, number of households, and significant land use pattern for primary survey. Selected wards have been shown in Fig. 2. It is important to note that the survey was conducted during the month of February which is off-tourist season (Table 2).

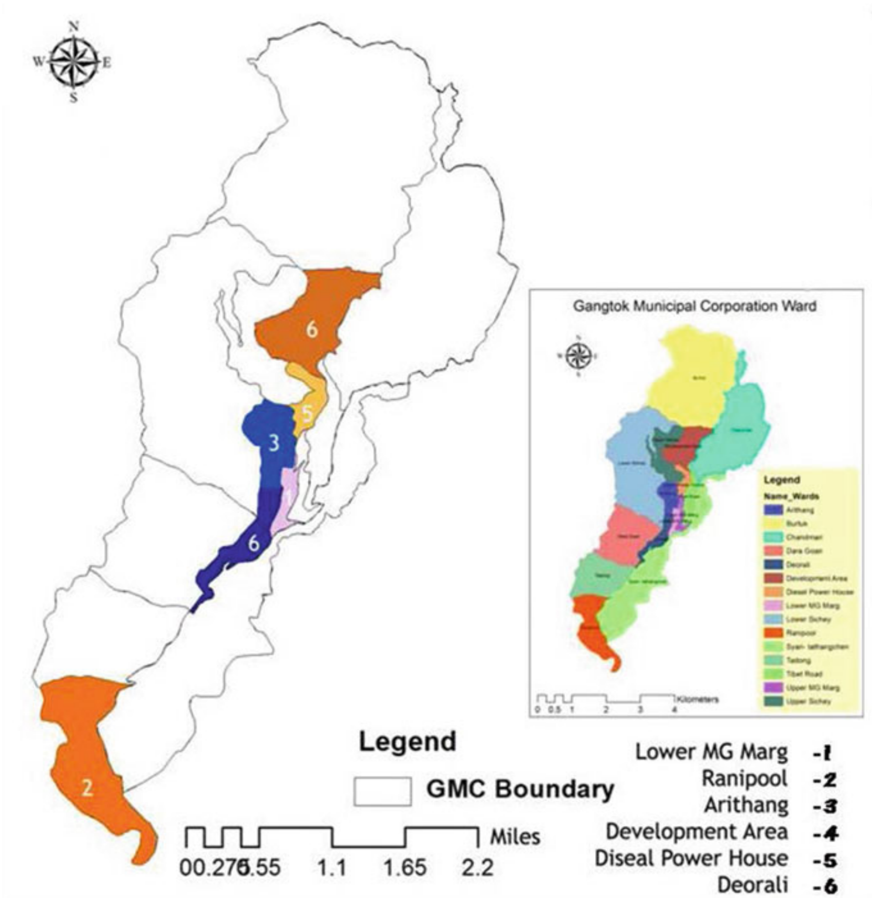


Fig. 2 Location of six selected wards of GMC

Table 2 Important characteristics of the selected wards

Name of wards	Area (ha)	Population density (Census 2011)	Number of hotels	Physical features	Land use
Ranipool	108.52	52	10	Open forest, Gentle slope	Commercial and residential and industrial park
Arithang	34.8	253	24	Steep slope	Commercial and residential
Diesel powerhouse	17.52	293	49	Steep slope	Commercial and residential
Development Area	73.98	96	31	Gentle slope	Commercial, residential, and institutional
Deorali	28.2	256	22	Steep slope	Commercial, residential, and institutional
Lower MG Marg	13.41	413	42	Steep slope	Commercial and residential. Densely populated

Primary survey was conducted to capture data from households, tourists, restaurants, shopkeepers, hotels, ragpickers to examine the status of waste management, perception of different stakeholders about waste management services, level of satisfaction and different issues, and challenges in management and disposal of waste. Distribution of sample and sample size in different selected wards is given in Table 3.

Table 3 Ward-wise distribution of sample

Name of wards	Number of households surveyed	Number of hotels/ restaurants surveyed	Number of shops/ market surveyed
Ranipool	30	4	10
Arithang	30	11	10
Diesel powerhouse	30	5	10
Development area	30	10	10
Deorali	30	11	10
Lower MG Marg	30	13	10
Total	180	54	60

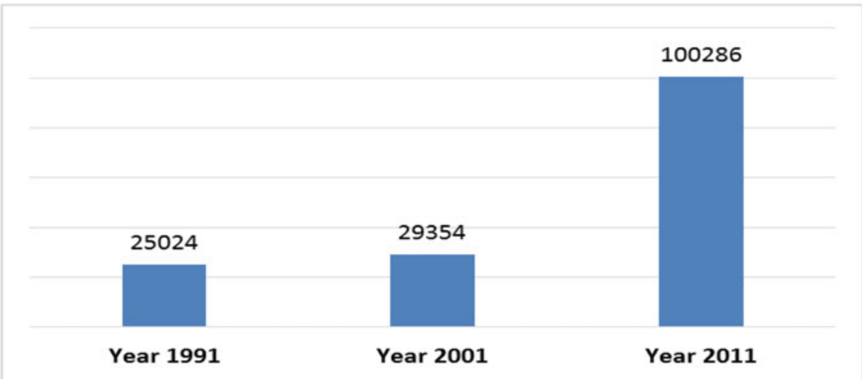
4 Analysis and Observation

4.1 Unprecedented Urban Growth

Urbanization in Gangtok has been acknowledged even during 1950s when it was a capital of Sikkim Kingdom (a separate country ruled by monarchy). Later Sikkim Kingdom was merge with India, and the 22nd state of India was formed in 1975. The pace of migration from rural areas to the capital is being observed from 1991. Due to facilities such as banking, education, hospitals, administration, commercial, and important economic activities and employment opportunities, Gangtok has always attracted more and more population. However, it is observed that the city experienced unprecedented population growth during the last decade, due to addition of new wards into Gangtok Municipal Corporation (GMC) in 2010. It is evident from the graph below that the city experienced a threefold jump in absolute population during 2011 census (Fig. 3).

4.2 Increasing Pressure of Tourism

While hill towns in India are already facing tremendous pressure due to lack of infrastructure, unfavorable climatic condition, difficult terrain, and public apathy toward waste management, tourism induced challenges further aggravate the issue. Although in case of hill towns tourism has a profound impact on the economy of the town, it comes with new challenges in terms of waste generation resulting into negative impacts on the sensitive hill environment [1]. Similar is the case with Gangtok City. In the year 2013, the city received about above five lakhs domestic tourists, whereas about 29,000 tourists were international tourists. The graph below



Source: Census of India

Fig. 3 Trend in population growth of Gangtok. *Source* Census of India shows that there was a steady yearly increase in tourist flow till 2010; however, since 2011 the number seems to be stable with minor yearly variation (Fig. 4).

However, it is important to note that maximum number of tourist comes during the months of March, April, May, and June. Significant number of tourists comes during the month of October and November too due to Diwali, Durga Puja, Losar (Buddhist festival), and Christmas. Figure 5 shows the average monthly tourist flow during last ten years (2009–2013). It is important to note that maximum number of international tourists visit Gangtok during October.

4.3 Status of Waste Management

Gangtok Municipal Corporation (GMC) is the responsible authority for management of solid waste in the city. Table 4 shows a quick status of waste management in the city based on the data provided by GMC.

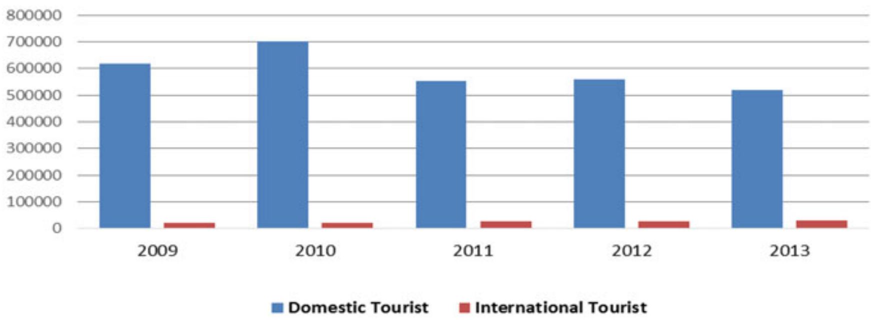


Fig. 4 Domestic and international tourist flow in Gangtok (2009–2013). *Source* Civil Aviation and Tourism Department Government of Sikkim (2015)

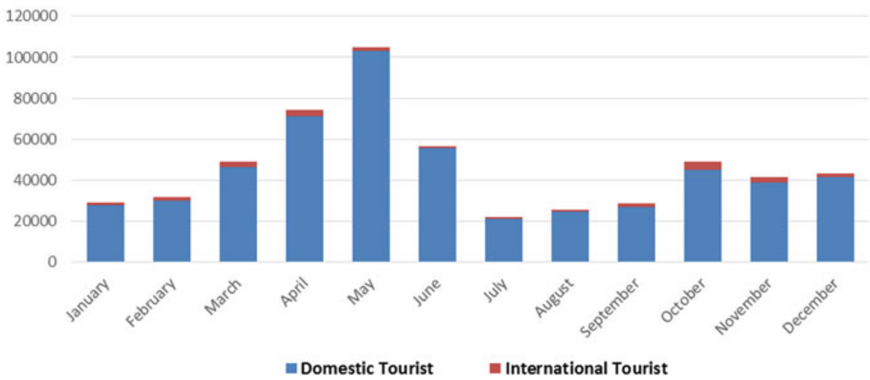


Fig. 5 Average monthly tourist flow of Gangtok during 2009–2013. *Source* Civil Aviation and Tourism Department Government of Sikkim (2015)

Table 4 Profile of solid waste management administrated by GMC

Municipal area	19.02 km^2
Number of wards	15
Total households	23,773
Total waste generated per day	20–25 tons of garbage every day which goes up to 40–45 tons per day during tourist seasons
Street sweeping	2 rounds (6 am–8 am and 3 pm–4 pm)
Dumpsite	At Martam 24 km away from Gangtok (located between forestland and village along the national highway)
Transport infrastructure	27 Tipper, 01 Tractors, 02 Pickup
Dustbins	Community bin = 16 Small bins = 10
Sweepers/drivers/ safaikarmachari/khalasi	105 (contractual employment)

Source Gangtok Municipal Corporation (GMC)

4.4 Collection of Waste

Figure 6 shows the frequency of waste collection in the wards. It is evident from the survey data that daily collection is not observed by all households. Daily collection is reported by maximum percentage of households from Ranipool (80%), whereas in Arithang and in the development area, daily collection has been reported by only 60% households. Low frequency of collection in the development area is essentially due to lack of good road network and steep slope, resulting into poor access. Community bins were observed only in Ranipool ward (Figs. 7 and 8).

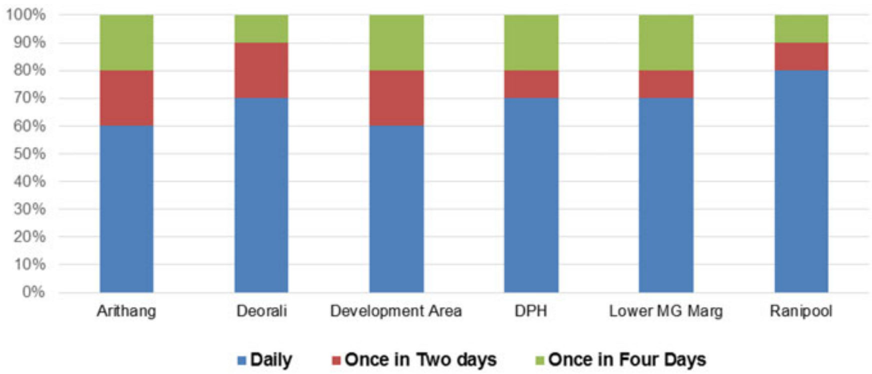


Fig. 6 Ward-wise frequency of collection of waste as reported by surveyed households. *Source* Primary survey, 2016

Fig. 7 Waste collection system in Gangtok. *Photograph Courtesy* Author

Fig. 8 Community bins located along the national highway. *Photograph Courtesy* Author

4.5 Segregation of Waste

While segregation is the key to good solid waste management practice, primary survey data of households reveals that only in case of Ranipool ward segregation is practiced by as high as 93% households; however, not a single household from other five wards reported about proper segregation.

It should be noted that this exceptional observation at Ranipool is essentially because of the pilot work under the zero waste mission of the Urban Development and Housing Department (UDHD) of Sikkim. As can be seen from the photographs below, households were given two separate dustbins to segregate waste at household level (Fig. 9).

When it comes to segregation of waste by the commercial establishments like hotels and restaurants, it was observed that about 20% of surveyed establishments do practice segregation. At the ward level, a variation has been observed. Interestingly, maximum percentage of establishments from development area (30%) practice segregation; however, this practice is reported to be the lowest in Lower MG Marg (Fig. 10).

Fig. 9 Distribution of dustbins to residents in Ranipool ward. *Photograph Courtesy* Author

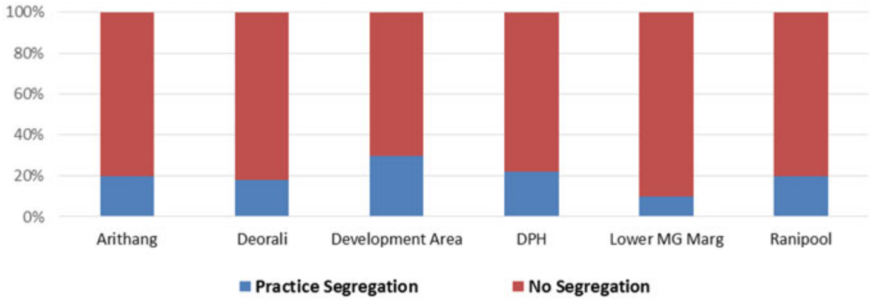


Fig. 10 Bar diagram showing segregation of waste in hotels/restaurants. *Source* Primary survey, 2016

4.6 Direct Collection and Reuse of Food Waste

It is important to note that there is an interesting parallel waste management practice exists in the city. It was observed during the study that nearby villagers do collect food waste daily from the eateries, hotels, and restaurants during the peak tourist season which is from March to June. Villagers use this food waste as fodder for their livestock. It is evident from the graph below that this practice is most prominent in Deorali ward, which is due to proximity to villages. As high as 73% hotels and restaurants at Deorali reported existence of this practice (Fig. 11).

4.7 Reuse and Recycle of Inorganic Waste

When it comes to recycling of waste, it is important to note that *kabadiwala* and *ragpickers* are active in almost all the wards. However, it was observed that they are not getting enough support from GMC. This informal sector does not even get proper space for segregation of recyclable waste. As can be seen in the photographs below, most of such segregation activities happen in the open space available along the national highway. It is also important to note that informal sector is not equally

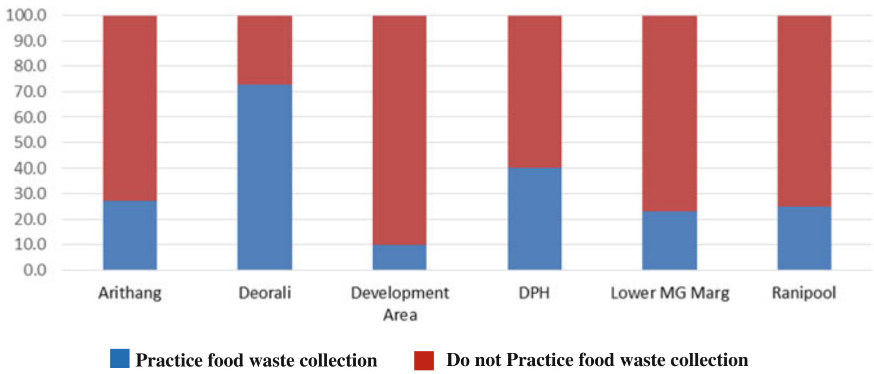


Fig. 11 Ward-wise status of collection of food waste by villagers. *Source* Primary survey, 2016

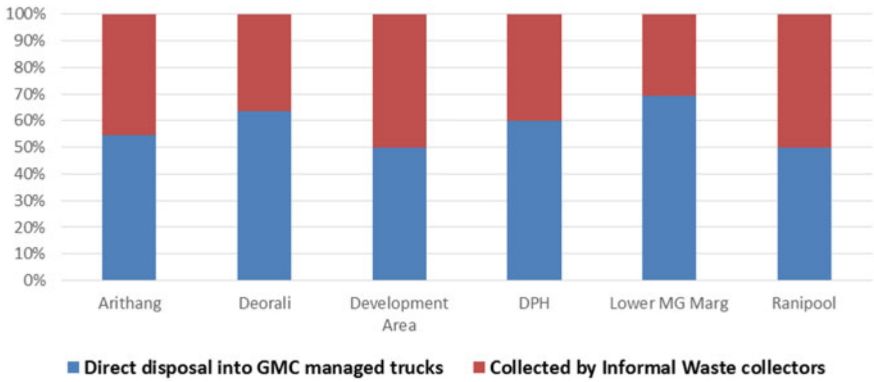


Fig. 12 Formal versus informal collection system for inorganic waste. *Source* Primary survey, 2016

active in all the wards. The analysis of responses from the commercial establishments is shown in the graph below. It is important to note that as high as 50% establishments from Ranipool and development area reported that informal waste collectors do collect or by inorganic waste from them (Figs. 12 and 13).

4.8 Open Dumping and Unscientific Disposal of Waste

It is important to note that in the absence of proper collection system in many places waste is conveniently dumped directly at open places. As can be seen from the photographs below, most of the time waste is dumped along the natural streams called *Jhora*. This practice in turn pollutes the surface water bodies and deteriorates environmental condition (Fig. 14).

Fig. 13 Segregation process managed by informal waste collectors along the national highway. *Photo Courtesy* Author

Fig. 14 Open dumping of garbage in and around *Jhoras*. *Picture Courtesy* Author

The entire waste collected by GMC is dumped at *Martam*, 24 km away from the city. This dump site is not scientifically designed or maintained. More importantly, the dump site is located along the *Ranikhola* River in east district, which is not at all a scientifically identified site. Burning of waste is a common practice at dump site. There are about 200 households saying at nearby villages such as *Nimtar, Martam, Changtang*. These villagers experience the nuisance of smoke and bad smell. They have protested several times in past.

Recently, government has started working on a scientific landfill site with the funding support from Asian Development Bank for the North Eastern Region Capital Cities Development Investment Program (NERCCDIP) (Fig. 15).

Fig. 15 Solid waste dump site at Martam. *Picture Courtesy* Author

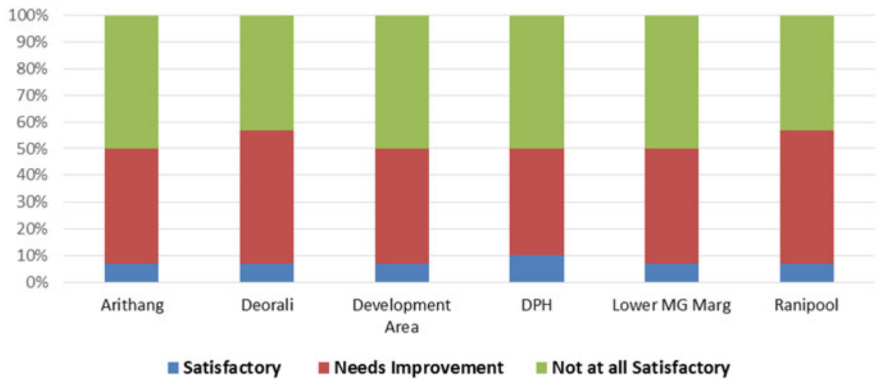


Fig. 16 Ward-wise variation in level of satisfaction about waste management. *Source* Primary survey, 2016

4.9 Level of Satisfaction

Level of satisfaction is an important indicator to understand the level of any basic service. Hoteliers, shopkeepers, and residents were therefore surveyed, in order to understand their level of satisfaction about solid waste management system of the city. They were asked to rank their satisfaction level into three categories as shown in the graph below. It is unfortunate that only about 7.5% of the surveyed population reported that they are satisfied with the level of service. Ward-wise variation of response is given in the graph below. Major reasons for lack of satisfaction as reported were irregular collection of waste and open dumping of waste. When the GMC officials were interviewed, it was observed that GMC is facing issues like lack of manpower and financial constraints. It was also reported that steep slope and poor access also reduce the collection efficiency (Fig. 16).

5 Summing Up

Inappropriate and inefficient management of municipal solid waste is one of the root causes of degradation of the hill town environment in India. In the absence of adequate capacity of the local bodies, seasonal tourism further aggravates the situation. At national level, various policies and programs have been formulated from time to time for improving sanitation services in urban India. But most of such policies and programs remained silent about the special character of the hill cities which demands special attention to the problem of waste management [1].

It is evident from the study that the Gangtok City has also experienced unprecedented population growth during the last decade. At the same time, the city received considerable number of domestic as well as international tourists.

While GMC is facing tremendous challenges in managing its municipal waste, tourism is adding to the problem to great extent, especially during peak tourist season.

Efficient collection system is the key to achieve better waste management; however, GMC has not been able to achieve cent percent collection system. Regularity of collection is another issue which creates high level of dissatisfaction among the citizens. Second most important component is segregation of waste. However, the study shows limited segregation practice in the city. It is important to note that informal sector plays very important role in collecting waste, in turn, helps in better process of reuse and recycle. While collection of food waste from commercial establishments by nearby villagers demonstrates a good sustainable practice in the city, it was unfortunate to observe that the informal waste collectors are not getting the support that they deserve.

In the absence of proper collection system, at many places open dumping prevails along the natural drains, resulting into environmental degradation. However, it should be noted that like any other hill towns of the country, GMC has its own constraints. While steep slope and lack of access at many places poses challenge for efficient collection system, lack of financial resources does not allow the local body to procure better technology and manpower. Therefore, technical and financial capacity building of the local body seems to be one of the most important steps toward achieving a better waste management system in the city.

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Dumping Yard-Free Society Through Sustainable Solid Waste Management: A Case Study of Varanasi City

Awadhesh Kumar

Abstract Municipal solid waste is an inevitable by-product of anthropogenic activities, and it is leading to pollute the urban atmosphere. Poor urban service delivery incorporating inadequate and inefficient solid waste management has deteriorated and grimed the situation in urban areas of developing countries. Varanasi, the city of temples and prominent religious place of Uttar Pradesh in India, has been incorporated as the study area to conduct the research work. On an average, the city generates 650 metric ton of solid waste each day and approximately 480 metric ton of it is dumped at Ramna dumping ground in mixed form under open sky and rest remains unattended. Dearth of expertise, lack of skilled manpower, insufficient waste vehicles and waste bins are certain flaws, which have been identified in the current solid waste management practices. Thus, the paper would augment the prudence to be familiar with the real scenario of waste management practices in the city. The thorough study of the related literature has been established to understand factors affecting waste management systems. Data related to waste management has been compiled from municipal office, and randomly, 45 wards have been opted to conduct the household survey. The stakeholders have been recruited using simple random sampling method and have been interviewed with a proper set of questionnaire. The survey reveals that solid waste management service delivery is in stressed condition, and thus, immediate actions are required to mitigate the problem in the area. Finally, concluding the research work, it can be stated that if an integrated waste management plan and the recommendations are implemented candidly, the waste generated from urban areas may be a great resource for different sectors and would no more be a headache for the local authority.

Keywords Municipal solid waste · Domestic wastes · Integrated waste management · Simple random sampling · And developing countries

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1 Introduction

Numerous daily use stuff, which fail to accomplish its economic value and significance to the first user after its consumption, is discarded and treated as waste materials, i.e. various papers, cans, plastic bottles, polythene bags, kitchen refuse, domestic garbage, broken glasswares. It may be categorized into organic and inorganic waste according to its texture or toxic, non-toxic, radioactive, infectious, etc., and according to its hazardous nature. Processing of the raw materials is the first stage when wastes are generated, and waste generation continues thereafter at every step in the process as raw materials are converted into final products for consumption [1]. After consumption, the products drop its economic importance to the first owner and become waste. In this way, enormous waste items are generated and dumped in the locality of an area. Solid waste management (SWM) encompasses the activities, which minimize waste generation and enhance the way of waste collection, transportation, storage, processing and final disposal of waste. The overall stages of SWM should be in a manner that it is in accordance with the best principles of public health, economics, engineering, conservation, aesthetics, public attitude and other environmental considerations [1].

Overburdened and bourgeoning solid waste has shaped a staggering problem before the mankind. Improper and ineffective solid waste management in urban areas is causing environmental hazard and health-related issues, e.g. air and water pollution, soil contamination, mushrooming of flies, rodents and other disease vectors in and around of waste dunes. Deterioration of urban environment owing to solid waste has created a new chapter of concern before the government and the local authorities.

1.1 Success Stories

Pune Municipal Corporation (PMC) signed an agreement for Public–Private Partnership (PPP) between PMC and Solid Waste Collection and Handling (SWaCH or, officially, SWaCH—Seva Sahakari Sanstha Maryadit, Pune) to institutionalize door-to-door collection formally. The SWaCH door-to-door collection model has benefited PMC by saving approximately ₹15 crores per annum in waste handling and transportation costs, and it has reduced carbon emission to save the environment. PMC is also claiming for Certified Emission Reductions (CERs) (a type of carbon credits) issued by the Clean Development Mechanism (CDM) body [2].

'Shimla Environment Heritage Conservation and Beautification' (SEHB) society was formed by Shimla Municipal Corporation in 2009. The scheme was operationalized in April 2010. Personal protective equipment like raincoats, gumshoes and gloves has also been given to all sanitary staff [2].

Centre for Pollution Control Board (CPCB) funded Vrindavan Kuda Prabandhan PariYojana (VKPP) was introduced in Vrindavan as a pilot model in 2005. Under this programme, Friends of Vrindavan (FoV), a non-governmental and non-profit making organization, started door-to-door collection of segregated waste in two wards of the city. The VKPP encouraged source segregation of waste and retrieved recyclables claiming ₹100,000 when sold to scrap dealers. Five composting units yield one metric ton manure weekly, and FoV is marketing the compost successfully [3].

1.2 Waste Management in the Study Area

The study has been conducted in Varanasi City, which is situated along the left crescent-shaped bank of the River Ganges valley [4]. With respect to waste management services, the city has been divided into five zones—*Varunapar, Adampur, Kotwali, Dashashwamegh* and *Bhelupur*. All these zones constitute 90 wards collectively and cover an area of 81.02 km^2 with the population [5] of 1,201,185. The urban area [6] is stretched between 82° 56′ East–83° 03′ East longitude and 25° 14′ North–25° 23′ 30″ North latitude.

Waste is a visible concern in Varanasi City. Being a developing country, India has trouble in waste management and in Varanasi; it is a great challenge for the local authorities to cope with the problem of solid waste. Varanasi Municipal Corporation (VMC) is the sole responsible body for the waste management in the city, and the VMC is performing its duty without sagacity. The garbage is being dumped under the open sky at Ramna dumping ground without any expertise. Hence, the aim of the study is to depict current waste generation scenario, techniques and ideas, which are being exercised for waste management in the study area and to prepare a strategy for better management of wastes. The outcome of the work may act as a curtain-raiser from the hidden facts of waste management practices, and it may reveal the causes behind inadequate expertise and practices for the ineffective and inefficient management of solid waste in the city. By getting the information about the condition of solid waste pollution potential of the research area, the policy makers can use the study findings in regulating and planning activities to make the city litter and garbage-free, so that the dream of having dumping yard-free society may come true.

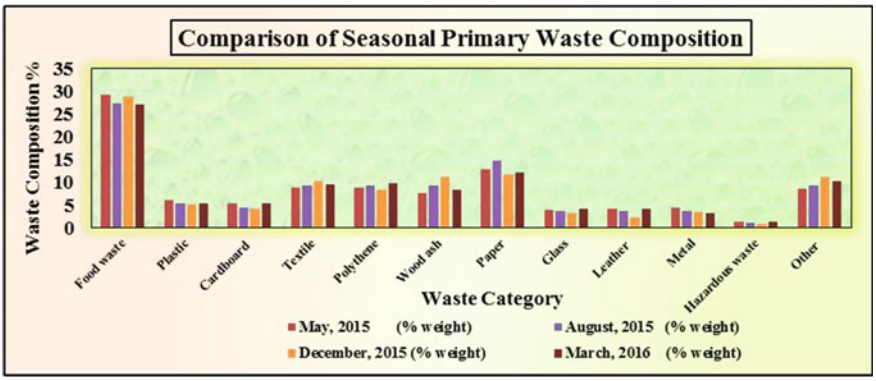
2 Research Design

A thorough study of solid waste-related literature has been incorporated to enhance the knowledge about the magnitude and severity of the problem. In the next step, the methodology which has been incorporated in few parts of the work to organize the research operation is ‘Solid Waste Analysis Tool’ (SWA Tool), User Version developed as part of the European Commission Fifth Framework Programme [7]. The methodology has established the knowledge to conduct questionnaire interview with VMC personnel, i.e. health officer of the district, veterinary officer, contractors assigned for waste collection and disposal, residents of various wards to elicit relevant information associated with SWMS. Besides it, to understand the quantity and composition of waste, which varies season-to-season, an intensive fieldwork has been performed from May 2015 to March 2016 to obtain the waste-related information. Out of 34 waste collection depots (WCDs) of the city, 20 were selected on simple random sampling basis to know the composition of waste in the months of May 2015, August 2015, December 2015 and finally in March 2016. For the purpose, first three working days have been opted for initial ten WCDs and last three days for the rest of the WCDs. The result has been presented in the Table 1 and futher it has been depicted below in the graphical form.

Table 1 Comparison of seasonal primary waste composition in the study area

Waste category	May 2015 (% weight)	August 2015 (% weight)	December 2015 (% weight)	March 2016 (% weight)
Food waste	29.23	27.27	28.65	27.10
Plastic	06.02	05.45	05.05	05.32
Cardboard	05.23	04.45	04.25	05.41
Textile	08.68	09.09	10.12	09.33
Polythene	08.69	09.08	08.28	09.59
Wood ash	07.38	09.09	11.02	08.31
Paper	12.65	14.55	11.65	11.92
Glass	03.98	03.64	03.25	04.06
Leather	04.05	03.64	02.36	04.09
Metal	04.44	03.64	03.49	03.29
Hazardous waste	01.25	01.01	00.89	01.37
Other	08.39	09.08	10.98	10.20

Source Personal survey



Secondary data has been compiled from various published materials and Municipal Office of Varanasi to authenticate the information. Google Map and Arc GIS 9.1 techniques have also been exercised for the tracking of dumping sites, waste collection routes and mapping of the area for the effective management of solid waste. Incremental increase method has been applied for population projection.

2.1 Objectives

The paper endeavours to contribute an understanding of the actual and potential roles of MSWM plan in Varanasi City. The objectives of the paper are:

- To study the present condition of solid waste management programme in the city,
- To identify the causes behind inadequate solid waste management in the city,
- To derive ideas, which can reduce waste generation and pollution and can improve living conditions, and
- To suggest the action plan including institutional changes and resource management policies to achieve optimal solid waste management in the city.

3 Current Scenario of Solid Waste Management in Varanasi City

The 12th Schedule of the 74th Constitutional Amendment Act of India (1992) defines 18 new tasks in the functional domain of the Urban Local Bodies (ULBs) [8] and solid waste management is one of them. Therefore, the health department of VMC has been assigned the charge of SWMS in the city. The current scene of solid waste management in the city is in no-win situation. No source segregation of waste and no door-to-door collection are in practice in this temple city. Residents and shop owners throw refused items at primary collection points or in or around the dustbins positioned at specific places. At times, few residents put the leftovers in polythene bags and hurl it from the windows or balconies without consideration and become invisible in no times just after performing the job. Hotel and restaurant owners, marriage hall managers and confectioners discard their waste items at primary or secondary collection points and get rid of their onus. Wastes, viz. blood, bone, tendons, leather, fur and viscera from slaughterhouses and butcher shops, are not appropriately managed and regulated. After slaughtering and butchering, undesirable body parts of the animals are dumped and mixed with general waste, which is ultimately carried to the Ramna dumping yard. Besides this, blood and other liquid wastes are drained into the conduit, which leads to the River Varuna and pollutes it. Destiny of religious offerings is also no better, and once these items are offered to please the God, they become part of garbage.

An NGO named 'Centre for Pollution Control (CPC)' has a tie-up with VMC to manage and process hospital wastes. The NGO has expanded its operations to over 18 government hospitals and more than 350 private hospitals/nursing homes/pathology for managing hospital waste, and it has installed an incinerator near to the *Mohan Sarai Bypass.* Yet, the hospitals, which are not under the coverage of CPC, throw and mix their waste with common waste, which is extremely perilous. Other hazardous wastes, such as batteries, cell phones, discarded electrical lamps and pesticide's containers, are also thrown away and associated with other household waste. Its consequences are extremely precarious for the workers, for example rag pickers and VMC staff who are involved in handling and dealing with the waste materials (Fig. 1).

On an average, the city generates 650 tonnes waste per day and only 480 tonnes of the total amount is collected each day by the authorities [9] and rest of the waste remains unattended and it often spills over which is both horrid and unhygienic.

Finally, municipal authorities carry the mixed waste for disposal without embracing any expertise and scientific approach at Ramna dumping yard approximately 25 km from the city near the River Ganges. ₹851.84 hundred thousand is the annual budget allocated to the VMC in financial year 2016–17 for solid waste management in the city, and ₹1–1.25 hundred thousand is spent for transportation only. In spite of spending such handsome amount of money, the real scenario of solid waste treatment is contemptibly pitiable.

3.1 SWM—Service Level Benchmarking

Service level benchmarks (SLBs) are a minimum set of standard performance parameters to evaluate and create accountability in urban service delivery. It involves the measuring and monitoring of service provider performance on a

Fig. 1 Women and the children are involved in waste picking without any safety gear. *Source* Images taken during field work

Table 2 In quest of SWM-SLB [10] in Varanasi City, the divulged facts in tabular form

S. No.	Perform a nee parameter	MoUD benchmarks (%)	Varanasi performance (%)
1	Household level coverage of SWM services	100	0
2	Efficiency of collection of municipal solid waste (*waste collected*—480 *TPD; generated*—650 *TPD*)	100	73.8580.00
3	Extent of segregation of municipal solid waste	100	0
4	Extent of municipal solid waste recovered	80	0
5	Extent of scientific disposal of municipal solid waste	100	0
6	Extent of cost recovery in SWM services	100	0
7	Efficiency in redressal of customer complaints	80	8581
8	Efficiency in collection of SWM-related user charges	90	0

Source Varanasi City development plan, 2041, pp 109

systematic and continuous basis [9]. It encompasses four broad areas—water supply, waste water management, solid waste management (SWM) and storm water drainage—and comprises 28 momentous performance indicators declared by Ministry of Urban Development (MoUD). The following SLB report shows an absolute dearth of door-to-door collection system in the study area. No source segregation and scientific treatment of discarded items are in practice in the city. Waste is being collected and dumped in open without any technical augmentation (Table 2).

3.2 Population Projection and Escalation of Waste Generation in the City

The population projection assists the planners to envisage impending requirements for the city, i.e. demand for water supply, sewerage facilities and proper disposal of solid waste and development of other infrastructures in the ensuing years [10]. Census 2011 figures out that 1,201,815 residents dwell in the city, and if we consider per capita waste generation, it is 0.540 kg per day and total amount of waste is approximately 650 tonnes every day. Population projection and escalation of waste production will indicate approaching peril and will caution us to develop proper infrastructure for sustainable management of waste. Table 3 will facilitate us to realize overall scenario of the threat.

The above data clearly shows a significant increase in population and waste generation. Hence, an immediate step is needed to manage increasing solid waste in the city to alleviate the hazard.

Table 3 Projection of population growth and increase in waste generation

Year	2011	2021	2031	2041
Population	1,201,815	1,431,842	1,705,896	2,032,404
Per capita/ day waste generation	0.540 kg	0.545 kg	0.550 kg	0.560 kg
Total waste generation (TPD)	650	780	938	1,138

4 Encountered Problems and Suggestion to Root Out Them

After being familiar with the existing situation of MSWM in the study area, now it is time to explore the ideas and consolidated plans, which are applicable and relevant in the Indian context. Some very crucial strategies that need to be considered for the overall improvement of the waste management system in the city are given below:

- The first step in the way of MSWM may be to kindle civic sense among the residents of the city, and at the very outset, local authorities will have to educate the people to keep the surroundings, locality and public places clean. To achieve desired target, ward-wise cleanliness campaign can be launched and local authorities can also approach different NGOs, schools and colleges in this connection.
- If the budding kids and school children are taught in schools not to promote polythene and plastic, not to throw the garbage in open and to make their parents aware of squalid atmosphere, filth and litter, it may be fruitful. Street plays, based on the theme of solid waste management, can also establish awareness among the general public. Both these ideas can achieve success if they are perceived by the individuals in a genuine way.
- Segregation of waste at source is one of the most important and effective part of efficient MSWM. If degradable, non-degradable and hazardous wastes are segregated at their generation point in different bins, it would be easy to handle and manage them. This target can be achieved in phases, if the local administration does it once again with the help of NGOs and school children. Both these institutions can make the residents of Varanasi City aware through rallies, street plays and cleanliness campaign.
- Litter bins constitute a basic requirement for the control of litter. The bins should meet the following criteria [11]: 1—practical and inexpensive design; 2—should be spaced at convenient intervals; 3—emptied frequently; 4—easy to empty, clean and repair or replace and 5—separate bins for different types of waste with different colours and cautions. Inhabitants are also expected to cooperate to keep the city clean respecting the rules implemented for their betterment.
- After constructing awareness, it is time to bring institutional transformation. The plans and guidelines issued by the government are getting success on paper, but while implementing them on ground level, results are often unsatisfactory.

Hence, an immediate audit of the initiatives, technologies and methods implemented by the government can identify and bring out the lacunae and the loopholes in the current system and reasons behind the failure of the plans, and in this series, modification and adjustment in plans can be enforced.

- The questionnaire interview of VMC personnel revealed that rectification of the government's machinery and the implementers of the proposal is an essential requirement. Until we have a smart, skilled and genuine system with transparency and accountability, we cannot achieve desired objectives. All the liable stakeholders in MSWM must be brought under strict scrutiny and liability of the assigned work. If the work is not found good enough, high authorities should not hesitate while taking extreme steps and actions against them.
- Data management is also a part of MSWM. Authentic data will enhance in monitoring the efficiency of collection, transportation, process and final disposal options [12]. Global positioning system (GPS) and geographic information system (GIS) are important tools in this connection. These technologies work for spatial and attribute data acquisition, storage, analysis and visualization. If the vehicles, used for solid waste collection, transportation and dumping, are brought under GPS tracker system, it will be easy to assess and monitor their routes, real time of waste collection and dumping from the control room [13] and the employees cannot swindle the high-ranking authorities.
- Geo-informatics would help in monitoring the unauthorized activities, by keeping the vigil's eye over the number of trips made by trucks to the specified disposal site. It can assist the city planners to give suitable location for transfer stations for solid waste storage, designing short routes for waste collection, creating databases for households that pay and those who have not paid for the services, arranging timetables for trucks to collect waste, etc., [14]. Therefore, embracing the use of technical advancement in MSWM will bring positive results and it will be confirmed as a milestone in city.
- Waste pickers may also be integrated into this job officially. They sort the wastes efficiently and reduce a huge amount of waste and finally sell to the scrap dealers for recycling. In this way, they help the VMC indirectly and save VMC's time, money and energy. Therefore, the government and the local authorities should also train them with the help of experts to promote their job. The waste pickers should also be provided safety gears such as: wellington boots, hand gloves and masks to work in such unhygienic conditions.
- The use and throw culture are generating waste in enormous quantity. If the government launches the scheme to offer discount at the time of returning empty bottles, cans, wrappers, small boxes of different products, etc., it will reduce waste volume and it can be reused. Many other items, like plastic, glass, metals, can be recovered and recycled. This strategy will conserve our very precious natural resources for the future generations and sustain the earth for a long time.

- Segregation of waste at source is the best way of managing it. Vellore's (Tamil Nadu, India) Mr. C. Nivasan's model [15] is extremely effective if the rejected items are collected in segregated form. He has introduced cattle, fish, earthworms, ducks and hens in waste management, and the outcome is amazing. Domestic and stray cattle can be used for the vegetable and fruit market waste, and in response, they will give cow dung. The cow dung is appropriate for biogas plant, and finally, 99% methane-free cow dung slurry will come out and immediately earthworms can be put into that slurry, which will be eaten by them and the excreta and will be the rich manure for agricultural practices.
- One more part of Nivasan's model [15] is hen. Hens are suitable for rotten items which cannot be eaten by cattle. Maggots appear on the decomposing rotten waste. Hens can pick those tiny creatures as their food and lay eggs. Ducks are the best creatures for the waste generated from fish markets and slaughterhouse. After consuming these wastes, ducks lay more eggs than normal. If Nivasan's model is executed transparently, most of the waste will disappear by the end of day.
- Kitchen waste is also a good source of energy. Biogas can be produced from kitchen waste by the inoculation of microorganism, viz. *thermophilic* and *methanogenic bacteria* [16] in anaerobic atmosphere, and in response, methane and carbon dioxide gases and high quality manure can be obtained from the waste.
- Since 50–55% of the total waste of the city is biodegradable, therefore inoculation of fungi is one more option to decompose the waste in odourless and controlled manner. *Aspergillus niger, Curvularia lunata, A. nidulans, A. fumigatus, Penicillium sp., Fusarium roseum, and Trichoderma viride* [17] are the fungi, which can be used to achieve desired result. An in vitro experiment should be done before executing it on a large scale to get a positive outcome.
- If result of the above experiment is positive, it can be operationalized in the existing Ramna dumping yard to decompose the waste. In this process, biodegradable items will turn into manure and other non-degradable waste can be separated out. Ferrous-containing waste can be sorted by magnetic separation. In this way, landfill site can also be garbage-free.
- Plastic is an unavoidable part of solid waste, but everyone is running short of any proper solution. The only solution is to reduce its use as much as possible. Some fungi, for example *Aspergillus niger, Aspergillus Japonicus* [18], have been identified, which could degrade plastic up to some extent. Besides this, Prof. R. Vasudevan [19] from Thiagarajar College of Engineering in Madurai (India) has introduced a concept of using plastic in road construction, and owing to the use of plastic, roads are more durable and water resistant and any municipality can have the technique free of cost.

- Scientists and researchers from Indian Institute of Petroleum (IIP), Dehradun, have invented an innovative technology to extract high-grade petrol, diesel or aromatics from plastic waste, and the invented fuel will cost only ₹30–40 L [20]. If the technology is successful, it will remove the gigantic burden of plastic from our back. IIP director M. O. Garg has claimed that the fuel will be of high quality owing to almost nil sulphur particles and it will increase the mileage of vehicles up to 2 km as compared with the regular fuel. If the technology is successful, it will remove the gigantic burden of plastic from our back.
- Decentralization of waste can also be a tool in waste management. If total 650 tonnes waste, which will increase in future, is piled high at a place, it will be inconvenient to handle and manage it. So, if the waste is divided into two parts and dumped at two different places, it will reduce waste volume and transportation cost. The following maps depict the statement explicitly (Fig. 2).

The first map portrays existing waste collection route, which is time- and money-consuming, and the huge mounds of waste are not easy to handle. In the second map, a short route has been proposed, which can reduce transportation cost, and comparatively lesser amount of waste can be managed in an easy way.

- In this temple city, a number of devotees visit every year and that is why a huge amount of religious offerings, e.g. flowers and petals, turn into waste and these wastes can be used to prepare incense sticks, perfumes and room spray. Other waste of temples can be decomposed by the above methods.
- Last but not least, entire plans, suggestions, recommendations and projects will embrace its target, when all stakeholders and players involved in it vow to put their maximum effort to synchronize each method in different phases to make Varanasi a garbage-free city.

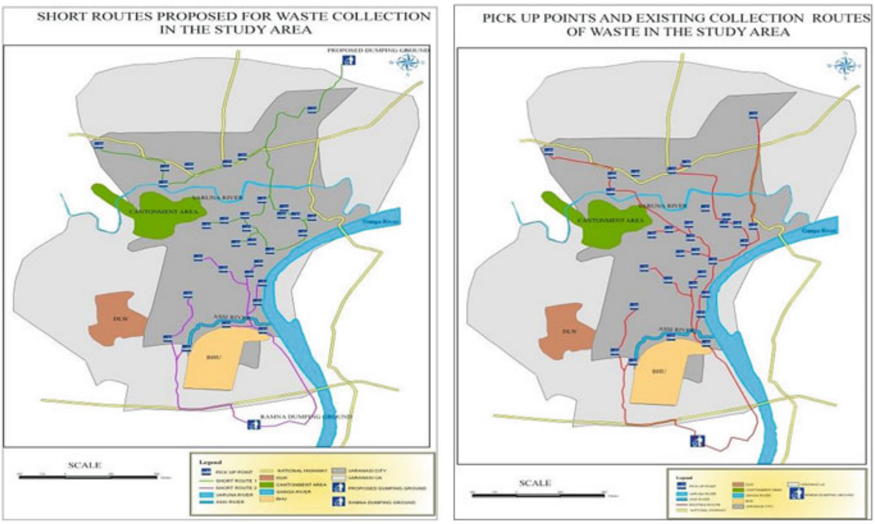


Fig. 2 Existing and proposed routes for waste collection in the study area

5 Conclusion

Developing countries, including India, have no substitute but to draught their strategy for sustainable development admitting the current problems and future challenges with a committed involvement of the individuals and officials. Economic boom and rapid industrialization cannot overshadow the terrible concern of accelerating solid waste. Proper disposal and management of the ever-increasing solid waste require a colossal effort to deal with the challenge to mitigate its adverse impact on development. The acute pressure of garbage needs different methods, technologies and strategies to cope with this catastrophe. Hence, the best possible way for solid waste management may be to execute an integrated and sustainable method of solid waste management, which could facilitate an uncontaminated environment and a good health of society and enthusiastic participation of everyone to dwell in a 'dumping yard-free' society.

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A Study on the Heavy Metal Concentration in Waste Dumping Sites in Titabar, Jorhat, Assam, India

Jafrin Farha Hussain and Sabitry Bordoloi

Abstract Heavy metal contamination of the environment is a worldwide phenomenon that has attracted a great deal of attention [10]. Heavy metal contamination from soil is a cause of serious concern due to potential health impacts, and there have been studies that have shown that heavy metals are potentially toxic to crops, animals and humans [9]. Although heavy metals naturally occur in various concentrations in the ecosystem, even low concentrations are of major concerns to health since the long term of cumulative effects go with it [1]. The presence of heavy metals in the environment is of great ecological significance due to their toxicity at certain concentrations, translocation through food chains and non-biodegradability which is responsible for their accumulation in the biosphere [15]. The present study is aimed at assessing heavy metal concentration in the soil around the hospital wastes and municipal wastes dump sites in Titabar of Jorhat district of Assam. The soil of such wastes dumping sites are contaminated with various heavy metals which are hazardous to life. The present study was aimed at analysing the concentration of Nickel (Ni) and Arsenic (As) in the soil of these dumping grounds. Three sites were chosen for the collection of samples and collections were made on a seasonal basis. The minimum and maximum values of Ni were recorded within a range of 0.25–0.8 ppm, while that in As, the values were within a range of 0.03–0.8 ppm. The maximum values of As obtained in the present study exceeded the permissible limits of Central Pollution Control Board CPCB [5] and WHO. Keeping in view the hazardous impacts Nickel and Arsenic toxicity can lead to; the present study was initiated to assess the soil quality in the area. The present study outlines Ni and As concentration in soil with an aim to strengthen the database on heavy metal contamination which may be helpful in assessing soil quality for maintenance of a healthy environment.

Keywords Heavy metals · Hospital wastes · Arsenic · Nickel

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1 Introduction

Heavy metals naturally occur in the ecosystem and are present in various concentrations. Some of these concentrations may rise in the ecosystem owing to various activities, and exceeding certain limits may become harmful to life. In modern times, anthropogenic sources of heavy metals, i.e. pollution from the activities of human beings, have introduced some of these heavy metals into the ecosystem [11]. With the advancement of global economy, the type of heavy metals in the soil has gradually increased that has resulted in the deterioration of the environment [14]. Studies have shown that heavy metals are potentially toxic to crops, animals and humans when contaminated soils are used for crop production, because these get easily accumulated in vital organs to threaten crop growing and later human health [12].

Excess heavy metals in the soil may originate from many sources, which may include atmospheric deposition, sewage irrigation, improper stacking of industrial solid wastes, mining activities. [14]. However, a major portion of the heavy metal accumulated in the soils is due to the improper handling of solid wastes generates from hospitals and municipal dumps. Heavy metals like Arsenic which is considered as one of the most dangerous element for human life are found in elevated levels in ground water in many regions. Singh [13] carried a study on the Arsenic contamination in ground water throughout the North-eastern part of India and found out that the districts of Jorhat, Golaghat and Lakhimpur in Assam have the highest concentration of Arsenic. Solid wastes handling and management becomes a major challenge in many small towns and cities nowadays in India. In many places, wastes generated from household and domestic stores are simply dumped into open municipal dumping grounds. Hence, there arrives every possibility that the harmful chemicals released from these untreated wastes make ways to enter the food chain. Food chain contamination by heavy metals has become a burning issue in recent years because of their potential accumulation in biosystems through contaminated water, soil and air [8].

There have been several related studies in this field that have shown that heavy metals with a higher atomic density >6 g/cm^3 generated from wastes can accumulate and persist in soils at environmentally hazardous levels [2]. Plants grown on such soils lead to an increased level of metal ion content, and if the consumption of these metals through plant sources is not regulated, it may lead to accumulation in man and other grazers with attendant health hazards [2].

The present study deals with documenting the heavy metal accumulation in waste dumping grounds in Titabar, a small town located in the Jorhat district of Assam, India. There have been several studies related to Arsenic level in ground water of Jorhat district but surface soil analysis for accumulation of Arsenic as a result of unsorted hospital waste and household waste dumping has been investigated in the present paper. Till date, no studies on Nickel concentration have been carried out in the district. The municipal wastes that are generated on a daily basis are dumped into open dumping grounds. The enormous wastes generated from the

Primary Health Centre (PHC) are dumped into open grounds in the vicinity of nearby residential areas. Municipal wastes include household wastes and domestic wastes, while hospital wastes contain blood samples, tissues, syringes, needles, medicines, drug packets and certain other substances that are generated from the nearby hospital. Studies related to groundwater Arsenic contamination carried out by Chetia et al. [6], Buragohain and Sarma [4] in Golaghat and Dhemaji districts of Assam reported high levels of As in these areas. Till date, limited studies related to heavy metal contamination in Jorhat district are being carried out. The present study deals with the concentration of Arsenic and Nickel in Titabar of Jorhat district, as a result of unsorted wastes dumping practices. A control site was also selected so that the study can be compared. This study can help in providing a baseline data for the provision of further research in this field. Three sites were selected for collection of soil, and collections were done on a seasonal basis. The heavy metals that are discussed in the present study are Arsenic (As) and Nickel (Ni).

2 Materials and Methods

Surface soil samples were collected from three sites in Titabar, viz. municipal solid waste disposal site (Site 1), dumping ground near Primary Health Centre (Site 2) and garden area site (Site 3), which was taken up as the control site, during December 2012 to October, 2013. The samples were collected on a seasonal basis up to a depth of 15 cm from the surface layer and were brought to the laboratory. They were air dried and after complete drying, were sieved using sieves of 2 mm mesh size for removal of large-sized pebbles and stones. Standard procedures as per APHA [1] were followed for digestion of the soil samples. Samples were acid digested by taking 1 g of soil sample and digesting it with triacid mixture of sulphuric acid (H_2SO_4), hydrochloric acid (HCl) and nitric acid (HNO_3) in the ratio 4:2:1. After proper digestion and formation of a white powdery precipitate, samples were cooled and then filtered with filter paper (Whatman no. 40) using double distilled water and the final volume was made up to 50 mL. Determination of Nickel was carried out in Atomic Absorption Spectrophotometer (Thermo fisher iCE3000 series), while Arsenic was carried out in the same instrument with VP 100 vapour system (Thermo Scientific).

3 Results

The values of As and Ni obtained from the soils of the three sites are listed in Table 1 below. Values of As and Ni have been represented in bar diagrams in Figs. 1 and 2, respectively.

Table 1 Seasonal variations of As and Ni concentration in different sites represented in ppm

Seasons	Arsenic				Nickel			
	Site 1	Site 2	Site 3	Mean ± SD	Site 1	Site 2	Site 3	Mean ± SD
Winter	0.52	0.78	0.21	0.5 ± 0.3	0.5	0.6	0.25	0.45 ± 0.2
Pre-monsoon	0.39	0.42	0.34	0.38 ± 0.04	0.27	0.3	0.26	0.28 ± 0.02
Monsoon	0.09	0.06	0.005	0.05 ± 0.04	0.28	0.28	0.66	0.4 ± 0.2
Post-Monsoon	0.026	0.23	0.06	0.11 ± 0.11	0.63	0.79	0.55	0.66 ± 0.1
Mean ± SD	0.26 ± 0.2	0.37 ± 0.3	0.15 ± 0.2		0.4 ± 0.2	0.5 ± 0.2	0.4 ± 0.2	

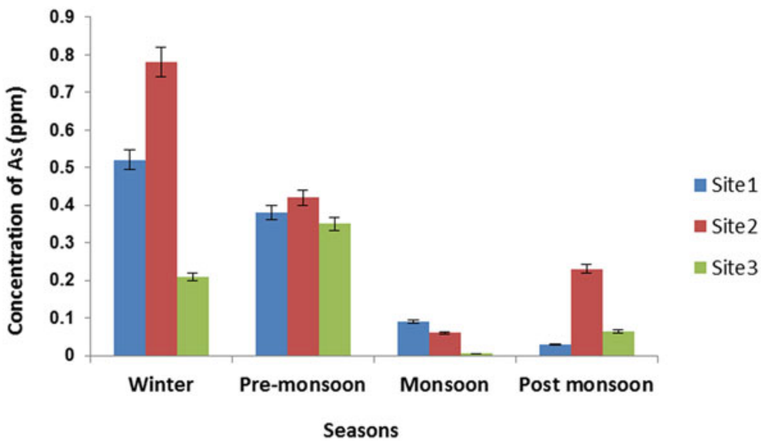

Fig. 1 Bar diagram showing the seasonal variation of the values of As (ppm)

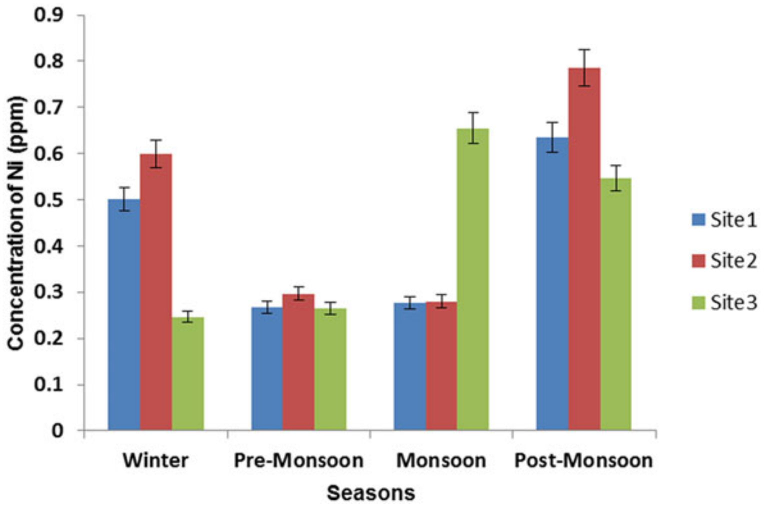

Fig. 2 Bar diagram showing the seasonal variation of the values of Ni (ppm)

1. **Arsenic (As)**

The values of Arsenic (ppm) ranged from 0.026 to 0.52 (Site 1), 0.06 to 0.78 (Site 2) and 0.005 to 0.34 (Site 3). It was observed that the values in the sampling sites remained comparatively high during the winter season (0.5 ± 0.3) followed by the pre-monsoon season (0.3 ± 0.04). It was also observed that the concentration of

Arsenic remained high in the medical solid waste disposal site (Site 2) during the winter season (0.78 ppm).

2. **Nickel (Ni)**

The values of Nickel (ppm) ranged from 0.28 to 0.63 (Site 1), 0.28 to 0.79 (Site 2) and 0.25 to 0.66 (Site 3). It was observed that the values remained comparatively high in the three sites during the post-monsoon season (0.66 ± 0.1). The concentration of Nickel remained comparatively high in the hospital waste disposal site (Site 2) during the post-monsoon season (0.79 ppm).

4 Discussion

Arsenic is a toxic element and is naturally found in soils. However, beyond a certain limit, it poses threat to living organisms. Meharg and Rahman [9] carried out a study in Bangladesh concluding that groundwater contaminated with Arsenic leads to elevated levels in crops if it is used for irrigation purposes. Reports suggest the contamination of Arsenic in the groundwater of several districts in Assam, Jorhat district being one of them. In the present study, it was observed that the concentration of Arsenic in soil was high in the municipal (Site 1) and medical (Site 2) but were within the hazardous levels in Control site (Site 3). The values of As observed here exceeded 0.2 ppm and 0.01 ppm, which are the standards set by the Central Pollution Control Board CPCB [5], World Health Organization WHO [16] and Hussain and Bordoloi [7].

The values of Ni observed in the present study were comparatively higher during the post-monsoon season in the hospital waste dumping site (Site 2). However, the values of Ni observed were lower than 1 ppm, the tolerable limit set by the World Health Organisation (WHO). Although the values do not exceed the tolerable limits, it is high time to take care of such waste disposal sites and the management of wastes taken up by authorities, so that the soil is not polluted by such toxic metals and reduces the accumulation of elements that are harmful for living organisms.

Biomedical waste management and handling rules of Ministry of Environment and Forests MOE&F [3] has proper guidelines for management of hospital wastes and dumping of such wastes after treatment. The rules also suggest that irrespective of the quantum of biomedical waste generated, every PHC must be strictly responsible for grant of authorisation from the respective authority, regarding proper disposal of such wastes.

The World Health Organization (WHO) estimates that about a quarter of the diseases facing mankind today occurs due to prolonged exposure to environmental pollution (UNEP Report Summary). The present study has revealed that soil in the vicinity of dumping grounds receive higher dose of these metals and spread to neighbouring areas with runoff water.

5 Conclusion

Biomedical and any other forms of wastes pose serious threat to life. The above study carried out in Titabar has revealed the accumulation of heavy metals like Arsenic and Nickel in the soils in which unsorted dumping practices are carried. Although this study reports on heavy metal accumulation in the soils of waste dumping sites in the area by providing a baseline data, deeper and elaborate studies may further enhance the strength of research in this field.

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Screening and Characterization of Pyrene-Degrading Bacterium from Oil-Contaminated Sites Around Chandigarh

Bulbul Gupta, Sanjeev Puri and Jaspreet Kaur

Abstract Polyaromatic hydrocarbons (PAHs) are organic compounds with two or more conjoined benzene rings having low solubility in water. They are widely distributed contaminants that have detrimental biological effects, toxicity and carcinogenicity. PAHs persist in the environment for many years because of their hydrophobicity and adsorption to solid particles. Their occurrence in the environment is largely a result of anthropogenic emissions such as incomplete combustion of fossil fuels, accidental oil spills, motor vehicles, waste incineration, pipe leakages. Due to their ubiquitous occurrence, bioaccumulation potential, recalcitrance, carcinogenic and mutagenic activity, the PAHs have aroused significant environmental concern. In the present study, isolates capable of utilizing pyrene at higher concentrations were screened and one strain found to have good growth at 20 mg/L was identified on the basis of its morphology and biochemical characteristics. The isolate was gram-negative, rod-shaped and non-spore-forming bacteria. At its optimized conditions (pH 7, temperature 30 °C), the novel strain *Acinetobacter* sp. Nfl showed good ability to degrade pyrene (84.6%), after 30 days of incubation in minimal medium, as determined by gas chromatography. Strains belonging to the genus of *Acinetobacter* are least studied for degrading polyaromatic hydrocarbons, but they showed ability to degrade HMW-PAHs with high efficiency. These findings indicate a great potential of these species for oil pollutants degradation.

Keywords *Acinetobacter* · Polyaromatic hydrocarbons · Pyrene
Solvent

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1 Introduction

Polycyclic aromatic hydrocarbons (PAHs) are pollutants, often carcinogenic, mutagenic or toxic, found in most terrestrial ecosystems that arise from industrial operations and from natural events such as forest fires. Major components of petroleum, they are continuously released into natural environments, posing a serious risk to human health [1, 2]. Polyaromatic-, nitrogen- and halogen-containing organic compounds are recalcitrant and hydrophobic compounds which are difficult to degrade by microorganism. Their hydrophobicity and recalcitrant nature further increase with the increase in the number of aromatic rings [3–5]. These compounds have higher bioaccumulation and biomagnification potency when enters into the biotic entities. A number of physiochemical processes including adsorption, incineration and absorption can be used to treat PAHs but the costs for chemicals and fuels as well as further treatment or disposal of secondary wastes are increasingly inhibiting adoption of these solutions. The processes leading to the eventual removal of hydrocarbon pollutants from the environment has been extensively documented and involves the trio of physical, chemical and biological alternatives. The biodegradation of pollutants is not a new concept as it has been intensively studied in controlled conditions [6, 7] and in open field experiments [8, 9], but it has acquired a new significance as an increasingly effective and potentially inexpensive cleanup technology.

Although biodegradation processes include indigenous microorganisms for degradation of these pollutants, yet the time taken for transformation is a major concern [10, 11]. Few studies investigating the potential of these natural isolates reported low degradation rate when studied with PAHs as the only carbon source. The degradation rate reduces with HMW-PAHs, mainly due to increase in toxicity with the number of aromatic rings. Thus to improve the biodegradation rate of these recalcitrant in soil or aqueous medium, reports demonstrated the use of solvents, surfactants and other carbon or nitrogen source along with PAHs in the system [12–14]. Phenanthrene degradation when studied with *Pseudoxanthomonas* in minimal medium having peptone as additional nitrogen source showed 90% removal of the compound [15]. In another report by Eibes et al. [16], up to 88% of enzymatic degradation of anthracene was observed with white-rot fungus *Bjerkandera adusta,* when compound dissolved in silicon oil was used along with a non-ionic surfactant (Triton X-100) in the medium [16]. Similarly, when PAHs dissolved in other biocompatible vegetable oils and solvents were added in the two-phase partitioning bioreactor system, improved rate of enzymatic degradation was observed [17, 18].

Pyrene with four benzene rings has been used as model compound for biodegradation studies of HMW-PAHs. Although it is difficult to completely metabolize these compounds, few indigenous microbes such as *Pseudomonas*, *Mycobacterium*, *Rhodococcus* have been reported to degrade pyrene and other HMW-PAHs, to some extent [19, 20]. Bishnoi et al. [21] reported degradation of phenanthrene and pyrene after 42 days of incubation with *Pseudomonas Putida,* isolated from contaminated soil samples. *Mycobacterium frederiksbergense* has been used in two-phase partitioning bioreactor (TPPB) for degradation of pyrene and had shown promising results when pyrene dissolved in solvent was used in the system [22]. Another study with immobilized *Mycobacterium* cells showed better results than free cells for a wide range of pyrene in silicon oil [23]. Pyrene degradation with extracellular polymeric substances (EPSs) isolated from bacteria as well as fungi was also studied by Jai et al. [24] to reduce the degradation time.

Intensive research is required for screening and identification of the species having higher potential of degrading these recalcitrant in a short span. Thus, in this study aim is to screen novel strains showing higher capability of transforming pyrene and further optimization of various physical factors affecting the process, for enhancing the efficiency of the strains for faster degradation of one of the most potent carcinogen, pyrene.

2 Methodology

2.1 Isolation and Screening of Pyrene-Degrading Bacteria

Pyrene-degrading microorganisms were screened on Bushnell Hass medium with minor modifications containing [(g/L) of KH_2PO_4 1.0, K_2HPO_4 1.0, NH_4SO_2 1.0, $MgSO_4{\cdot}7H_20$ 0.02, $FeSO_4{\cdot}7H_2O$ 0.007, $MnSO_4{\cdot}7H_2O$ 0.0001], by enrichment culture technique. Petroleum oil contaminated soil samples were collected from different locations in and around Chandigarh, India. Contaminated soil (2 g) was added to 100 mL of minimal medium containing pyrene (10 mg/L) as sole source of carbon and was incubated at 37 °C on a rotary shaker at 100 rpm. Active inoculum was subsequently subcultured with pyrene in the minimal medium, at regular intervals. Morphologically different bacteria showing consistent growth with pyrene present as sole source of carbon were selected and maintained on minimal agar plates.

2.2 Identification of the Selected Bacteria

2.2.1 Morphological and Biochemical Characterization

Selected strain was characterized by colony morphology, gram staining and biochemical characterization. Tests were performed using microbes from exponential phase of growth according to Bergey's Manual of Determinative Bacteriology [25]. For biochemical characterization, indole, nitrate, oxidase, MR-VP, citrate, carbohydrate and amino acid utilization was tested.

2.2.2 Optimization of Growth Parameters

Growth of the strain under different temperatures (28, 30, 35 and 40 °C) and pH (4, 5, 6, 7, 8, 9, 10, 11 and 12) was investigated in minimal medium with pyrene as sole source of carbon. 100 µL from stock of pyrene (25 mg/mL) was transferred into sterilized Erlenmeyer flask. Minimal medium (25 mL) was added into the flask after complete evaporation of the solvent and inoculated with 1 ml of the inoculum. Culture was incubated at different temperatures (28–40 °C) and growth was determined, after 7 days of incubation. For pH optimization, experiment was performed in minimal medium with adjusted pH (4–11) at its optimized temperature. Effect of solvent on the growth was also checked with ethyl acetate, added to the system as non-aqueous phase liquid (NAPL). Flask with pyrene (10 mg/L) dissolved in ethyl acetate added to 25 mL of minimal medium and one with pyrene (10 mg/L) added without any solvent was inoculated with 0.5 mL of inoculum and incubated at 30 °C for 30 days. After every third day, growth was checked by counting CFU/mL.

2.2.3 Pyrene Degradation

Degradation was studied with 20 mg/L concentration of pyrene in minimal medium with no other carbon source. Flasks were inoculated by transferring 1 mL inoculum of the strain and were incubated at optimized temperature (30 °C) in rotary incubator at 100 rpm. After every third day, growth was determined by CFUs for 30 days. Degradation efficiency was detected after 30 days of incubation by gas chromatography. Concentration of pyrene in samples was calculated by comparing the peak area of sample with the peak area of standard.

$$\text{Biodegradation efficiency } (\%) = [(\text{Co}-\text{Ce})/(\text{Co})] \times 100$$

where

Co: initial concentration of pyrene (mg/L);
Ce: final concentration of pyrene (mg/L).

3 Results and Discussion

3.1 Identification of the Strains

Out of the ten colonies selected, one strain designated as 'Nfl' showed good growth and degradation ability with pyrene as sole source of carbon. The strain was identified by their morphological and physiological properties, shown in Tables 1 and 2. The strain is gram-negative, non motile and non-spore forming. Colonies of Nfl were

Table 1 Morphological characteristics of the isolate

Bacterial strain	Gram stain	Shape	Colour	Spore stain	Motility
Nfl	Negative	Short rod (Coccobacilli)	Pale yellow	Negative	Negative

Table 2 Biochemical characteristics of the isolate

Isolate → Characteristic↓	Nfl	Isolate → Characteristic↓	Nfl
Oxidase reduction	–	Esculin hydrolysis	+
Nitrate reduction	–	Arabinose	–
Indole test	–	Rhamnose	+
Hydrogen sulphide production	+	Raffinose	–
Citrate utilization	+	Trehalose	–
Methyl red test	+	Glucose	–
Voges proskauer	–	Lactose	–
Catalase	+	MacConkey agar	+

convex with glistening surface and pale yellow in colour with entire margin. On the basis of their morphology and biochemical characterization, Nfl showed close relatedness to *Acinetobacter* sp.

3.2 *Effect of Temperature*

Effect of temperature on growth was studied at 28, 30, 35 and 40 °C, and optimum for the isolate 'Nfl' was found to be at 30 °C. A significant reduction in growth was observed at higher temperatures. As shown in Fig. 1 and Table 3, rise in temperature from 30 to 35 °C reduced the cell count from 3.8×10^8 to 1.87×10^8. The strain showed fall in growth, when the temperature was above or below of its optimum value. Rise in temperature increases the availability of the compound, but decreases oxygen solubility that reduces the metabolic activity of aerobic microorganisms. Same growth pattern was demonstrated by Lu et al., [26] for *Pseudomonas* sp. [26].

Fig. 1 Effect of temperature on the growth of the isolate (Nfl) in minimal medium supplemented with pyrene (10 mg/L), as determined by CFU/mL

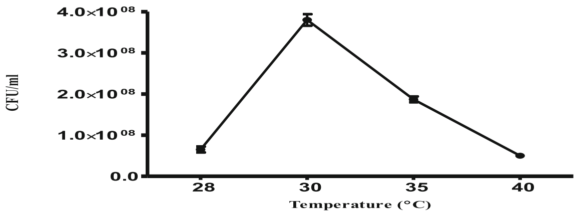


Table 3 Growth of the isolate (Nfl) in minimal medium supplemented with pyrene (10 mg/L), at different temperatures

Temperature (°C)	CFU/mL
28	6.50e+07
30	3.80e+08
35	1.87e+08
40	5.00e+07

3.3 *Effect of pH*

Growth was also checked at different pH (4–11) in minimal medium with pyrene as sole carbon source. For the isolate (Nfl), maximum growth was observed at pH 7.0, shown in Fig. 2. Isolate showed marked reduction in growth from 9.0×10^6 to 1.9×10^4 when pH was more towards the acidic range (pH 5 and 4) (Table 4). However, gradual fall in cell number was observed above pH 7. Difference in growth at different pH values may be because of the enzymes that are released for metabolism of pyrene, have their optimal activity at different pH.

3.4 *Effect of Solvent*

Solvent system was tested to increase the availability of the compound to the microbes. In this study, the strain showed two fold to four fold increase in their growth within 14 days of incubation, when pyrene dissolved in ethyl acetate was used (Fig. 3 and Table 5). Acting as an additional carbon source that is being

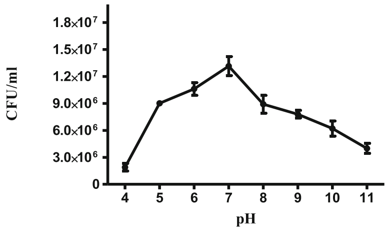


Fig. 2 Effect of pH on the growth of the isolate (Nfl) in minimal medium supplemented with pyrene (10 mg/L), as determined by CFU/mL

Table 4 Growth of the isolate (Nfl) in minimal medium supplemented with pyrene (10 mg/L), at different pH

pH	CFU/mL
4	1.9e+04
5	9.0e+06
6	1.06e+07
7	1.31e+07
8	8.9e+06
9	7.8e+06
10	6.2e+06
11	4.0e+05

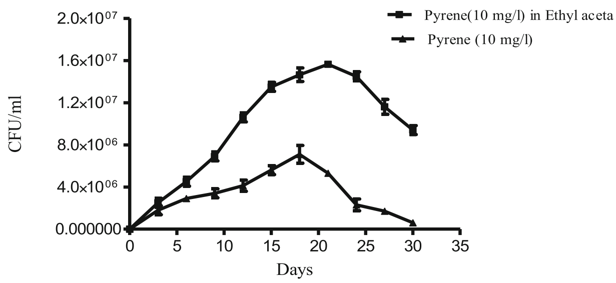


Fig. 3 Growth of the isolate (Nfl) in minimal medium supplement with pyrene (10 mg/L) and with pyrene (10 mg/L) dissolved in ethyl acetate, determined by CFU/mL

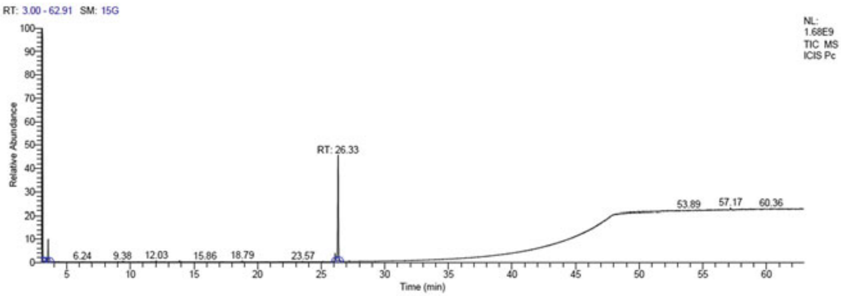
Table 5 Growth of the isolate (Nfl) in minimal medium supplemented with pyrene (10 mg/L) and with pyrene (10 mg/L) dissolved in ethyl acetate

Days	Pyrene (10 mg/L) in ethyl acetate	Pyrene (10 mg/L)
0	0.00	0.00
3	2.5e+06	1.8e+06
6	4.5e+06	2.9e+06
9	6.9e+06	3.4e+06
12	1.06e+07	4.1e+06
15	1.35e+07	5.6e+06
18	1.47e+07	7.2e+06
21	1.55e+07	5.3e+06
24	1.46e+07	2.3e+06
27	1.16e+07	1.71e+06
30	9.4e+06	6.0e+05

utilized more easily than pyrene, ethyl acetate helps in reducing the lag phase of the isolates. Arca-Ramos et al. [18] also reported higher degradation rate in the presence of solvent systems, mainly due to the increased availability of compound to the microorganism.

3.5 Pyrene Degradation

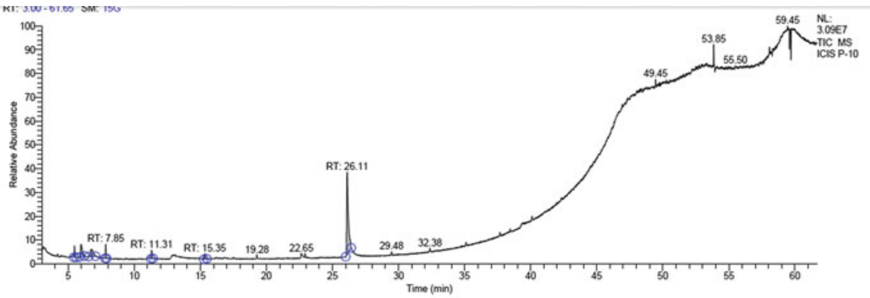
Pyrene degradation was studied with the isolate under optimum conditions, at 20 mg/L concentration in minimal medium with pyrene as sole source of carbon. The biodegradation efficiency of the strain after 30 days of incubation was found to be 84.6% (Figs. 4 and 5). A report with a halophilic bacteria *Thalassospira* sp. strain TSL 5-1 showed only 41.4% utilization of pyrene with an initial concentration of 20 mg/L over a period of 25 days [27]. Based on the extent of degradation, the isolate showed better performance than the reported ones. It indicates potential of the isolate to remediate pyrene-contaminated sites and can be used in bioremediation.



Qual Peak Table

RT	Peak Area	Area %	Peak Height
3.10	2961660410.77	46.67	1671647321.86
3.54	384202301.97	6.05	163952856.90
26.33	3000041914.24	47.28	756550007.25

Fig. 4 Chromatogram of standard of pyrene



Qual Peak Table

RT	Peak Area	Area %	Peak Height
5.48	3571719.09	2.60	1564426.19
5.97	15756741.80	11.46	1613581.11
6.76	14250018.63	10.36	957514.05
7.85	4475292.37	3.25	1831089.41
11.31	3589282.58	2.61	1131251.05
15.35	3292259.93	2.39	730763.95
26.11	92569367.11	67.32	10764183.69

Fig. 5 Chromatogram of pyrene after 30 days of incubation with the isolate (Nfl)

$$\text{Pyrene concentration} = [(92569367.11)/(3000041914.24)] \times 100 = 1.54$$
$$\%\ \text{Degradation} = (1.54)/(20-1.54) = 84.6\%$$

4 Conclusion

The novel strain isolated from the oil spilled area near Chandigarh showed good ability to degrade pyrene at a higher concentration (20 mg/L) in a short span. To the best of our knowledge, the isolates belonging to the genus of *Acinetobacter* have not been studied previously for degradation of PAHs. However, this genus exhibits excellent potential of degrading HMW-PAH in a condition when no other carbon source was provided for growth. Thus, this strain can be exploited further for bioremediation of these pollutants in the natural environment.

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Part VII
Landfill and Leachate Management

Effects of Landfill Leachate on Aquatic Organism: A Case Study of *Leptobarbus hoevenii*

S. H. Fauziah, A. B. NurKamilah and C. U. Emenike

Abstract Aquaculture is one of the main contributors of protein sources to the world population. Yet, the aquaculture sector may be threatened with the ever-increasing pollution coming from various sources. Among others, landfill releases leachate into water bodies which eventually may come into contact with water supplied to the aqua farms. Unfortunately, the toxicity effects from leachate differ from one species to another. As a result, some organisms that come into contact with contaminants can accumulate the pollutants in their system, and the contaminants biomagnify as it travel higher in the food chain. Thus, it is critical to understand the level of exposure of leachate to the aquatic organism, namely freshwater fishes. This research is aimed to determine the mortality of leachate exposure on *Leptobarbus hoevenii*, a genus of cyprinid fish which are native to freshwater habitats in Southeast Asia. The fish was exposed to different concentration of leachate collected from two non-sanitary landfills in Klang Valley, Malaysia. Finney's probit method was used to calculate the lethal concentration (LC_{50}). Both leachate samples have an average BOD_5 and COD of 195 and 734 mg/L, respectively, which exceed the limit allowed by the Malaysian Environmental Quality Act 1974. Observation during the exposure recorded some abnormal changes to the fish in terms of its swimming pattern and breathing. From the results, the lethal concentration of leachate from the two landfills ranged from 6.3 to 7.1% v/v. Leachate collected from an active landfill recorded higher mortality than the leachate from the non-operating landfill. This is so as leachate concentration used for the definitive test was 2–10% v/v for the active landfill while it was 6.4–8% v/v from the non-active landfill. Hence, leachate from active landfill is more toxic to the fish than the non-active landfill.

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Keywords Biomagnification · Toxicity · Municipal solid waste landfill
LC_{50}

1 Introduction

Aquaculture is one of the main contributors of protein sources to the world population. It has been supplying more than 150 million tonnes (live weight) of food products in 2014 [1]. Figure 1 illustrates the utilization of world fisheries production in 2014. It is obvious that developing countries have higher dependency on fisheries products than that of developed nations.

Fish has always been the main source of animal protein for the greatest number of resource-poor and vulnerable people [2]. Thus, aquaculture industry is crucially important to cater the demand and supply of food to the population. The top five producers in aquaculture are China, Japan, India, Norway and Vietnam [3]. Not only aquaculture ensures food security for the world population, the industry also contributes significant benefits in the countries' economy. Thus, the industry has always been promoted by the local government for economic reasons.

Yet, the aquaculture sector may be threatened with the ever-increasing pollution coming from various sources. There have been various reports on contaminations due to trace metal, polychlorinated biphenyls (PCBs), organochlorine pesticides (OCPs) and antibiotics [4, 5]. The main source of contamination is anthropogenic pollution including urbanization, pollutions from transportation, waste disposal activities and industries.

Among others, landfill releases leachate into water bodies which eventually may come into contact with water supplied to the aqua farms. This has been repeatedly

Fig. 1 Utilization of world fisheries production in 2014 [1]

reported in many publications particularly in developing countries [6, 7]. Landfill leachate has been known to contain various contaminants which sourced from the heterogeneous input of municipal solid waste [6–8]. Once landfill leachate contaminates a water bodies, the effect can be disastrous and unpredictable. This is because landfill leachate has a wide range of contaminating level where leachate from active landfill would be different in term of its toxicity from a non-active landfill [7]. As a result, the toxicity effects from leachate differ from landfills to landfills and from one species to another [8–10]. As a result, some organisms that come into contact with contaminants can accumulate the pollutants in their system, and the contaminants biomagnify as it travel higher in the food chain. Thus, it is critical to understand the level of exposure of leachate to the aquatic organism, namely freshwater fishes. This is important since the contaminants may find its way into human food chain via the consumption of contaminated fish. Therefore, this research is aimed to determine the mortality of leachate exposure on *L. hoevenii*, a genus of cyprinid fish which are native to freshwater habitats in Southeast Asia. This fish is commonly found in rivers and small ponds in Malaysia and has been one of the main sources of edible freshwater fish.

2 Materials and Method

For the purpose of this study, raw leachate was collected from two non-sanitary landfills in Klang Valley, Malaysia, where one represents an active landfill (operating) while the other represents a non-active (closed) landfill. Leachate characterization was conducted to determine the pollution intensity namely for pH, chemical oxygen demand (COD), biochemical oxygen demand (BOD) and metals. The analysis was conducted according to USEPA and APHA standard protocols.

Toxicity test on *L. hoevenii* was conducted through three stages of analysis, namely acclimatization, range finding test and definitive test. In definitive test, ten fishes in triplicate containers were exposed to five different concentrations of leachate determined from the range findings test as indicated in Table 1 for active and non-active landfills.

Experiments were conducted for 96 h where mortality and behavioural changes of fishes were recorded every 12 h. Finney's probit method was used to calculate the lethal concentration (LC_{50}).

Table 1 Concentration of leachate exposed *L. hoevenii* determined from the range finding test

Set-ups	*A*	*B*	*C*	*D*	*E*
Concentration of leachate from active landfill (%)	8.0	7.6	7.2	6.8	6.4
Concentration of leachate from non-active landfill (%)	10	8.0	6.0	4.0	2.0

3 Results and Discussion

Leachate samples from both landfills were analysed, and the results obtained is shown in Table 2. Both leachate samples have an average BOD_5 and COD of 195 and 734 mg/L, respectively, which exceed the limit allowed by the Malaysian Environmental Quality Act 1974.

BOD/COD ratio of both landfills is 0.26, which indicate a high biodegradability rate of the organic matter since a ratio of 0.2–0.5 is amenable to biological treatment. As for metal concentrations, Zn was found to be higher in the leachate from active landfill (236 mg/L) as compared to the non-sanitary landfill (24.3 mg/L) and

Table 2 Physico-chemical characteristics of leachate from active and non-active disposal sites

Component	Unit	Quantity BBL	Quantity TBL
BOD_5	mg/L	259	127
COD	mg/L	985	482
Dissolved oxygen	mg/L	5.20	5.30
TDS	mg/L	860	2146
Suspended solid	mg/L	87	14
Oil and grease	mg/L	3	4
Chloride	mg/L	4830	2780
Total organic carbon	mg/L	70.0	42
Sulphate	mg/L	92.3	65.3
Mercury	mg/L	0.04	0.03
Cadmium	mg/L	0.4	0.4
Chromium	mg/L	17.3	6.2
Copper	mg/L	2.62	0.5
Nickel	mg/L	12	0.85
Zinc	mg/L	236	24.3
Arsenic	mg/L	0.10	0.05
Lead	mg/L	0.1	0.01
Manganese	mg/L	5.1	3.1
Iron	mg/L	7.13	4.89
Calcium	mg/L	91.2	72.3
Potassium	mg/L	530	390
Magnesium	mg/L	25.5	20.4
Sodium	mg/L	40.3	35.2
Phosphate	mg/L	100	92
Nitrate nitrogen	mg/L	40.1	35.2
Nitrite nitrogen	mg/L	23.3	20.1
Cation exchange capacity	meq/100 mL	8.21	8.10
Ammoniacal nitrogen	mg/L	720	650
BOD/COD	–	0.26	0.26

both exceed the permissible level of Malaysian EQA 2005 Standard. Similarly with Cr, higher concentration (17.3 mg/L) was detected in the active landfill than the concentration detected in the non-active landfill leachate.

Figures 2 and 3 illustrate the mortality rate of *L. hoevenii* exposed to leachate from active and non-active landfill, respectively.

The LC_{50} values of the landfill leachate from non-active and active landfill were 7.1 and 6.3% v/v, respectively. The higher the value of LC_{50} indicates lower toxicity level because it requires greater concentration to cause 50% mortality. Thus, from the results obtained, the active landfill leachate is of higher toxicity to *L. hoevenii* than the leachate from non-active landfill. This result contradicts Emenike et al. [10] that reported that exposure of closed landfill has higher toxicity than that of active landfill. This contradiction implies that the toxicity level is highly dependent of the physico-chemical characteristic of the leachate which has been known to vary greatly from one landfill to another.

Observation during the exposure recorded some abnormal changes to the fish in terms of its swimming pattern and breathing. Leachate collected from an active landfill recorded higher mortality than the leachate from the non operating landfill. This is so as leachate concentration used for the definitive test was 2–10% v/v for the active landfill while it was 6.4–8% v/v from the non-active landfill.

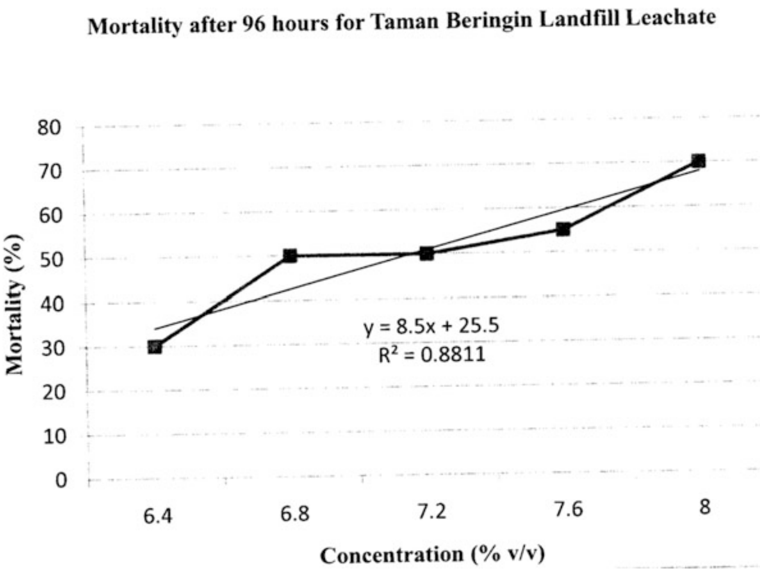

Fig. 2 Mortality of *L. hoevenii* after 96 h of exposure to leachate from non-active landfill

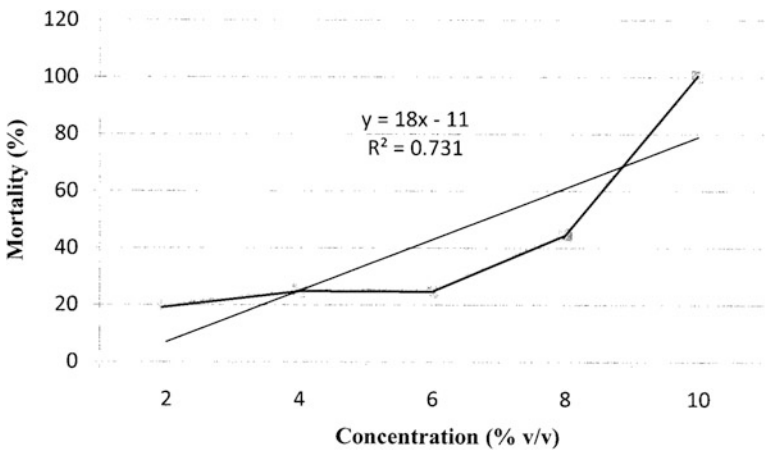

Fig. 3 Mortality of *L. hoevenii* after 96 h of exposure to leachate from active landfill

4 Conclusions

This study concluded that the toxicity of leachate from different landfills is different and highly dependent on the physico-chemical of the individual leachate. For this study, leachate from active landfill is more toxic to the fish than leachate from the non-active landfill. Thus, it is very important that leachate is treated accordingly before its released to the water bodies. This is crucial to prevent any pollution effects to the aquatic organism and the environment.

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Leachate and Septage Management of Model Regional Waste Management Centre of Six Waste Bank Municipalities of River Hooghly

Amit Dutta, Abhisek Roy and Indranil Mookherjee

Abstract The Kolkata Solid Waste Management Improvement Project (KSWMIP) proposes an integrated municipal solid waste management system for six waste bank municipalities of river Hoogly, namely Champdani, Baidyabati, Serampore, Rishra, Konnagar and Uttarpara-Kotrung, which is being executed by the Kolkata Metropolitan Development Authority (KMDA) in association with the six municipalities under funding support from the Japanese International Cooperation Agency (JICA). Segregated waste from two bin system will be transported to transfer stations of the municipalities. Recyclables will be taken out for reuse, and biodegradable portion will be composted by windrow process. Inerts and rejects (60% of the total) will be transported to Regional Waste Management Centre (RWMC) for sanitary landfilling along with 50 m^3/day of septic tank sludge (septage). Aim of this work is to manage leachate and septage in RWMC which consists of sanitary landfill (SLF) of 140,000 m^3 capacity, approximate life of 16 years; septage treatment facility of capacity 125 m^3/day with dilution water and leachate treatment facility of capacity 816 m^3/day. Septage will be treated by the single-stage anaerobic sludge digester with 40 days detention period, and digested sludge will be sent to Centrifuge for dewatering. Supernatant liquor from anaerobic sludge digester (75.37 m^3/day) and centrate from centrifuge (40.6 m^3/day) will be discharged to the leachate treatment system for further treatment. Mixture of treated septage (116 m^3/day) and leachate (700 m^3/day) will be treated first in the facultative aerated lagoon-I, then in the facultative aerated lagoon-II in series. Treated effluent from the facultative aerated lagoon II will be transferred by gravity to the facultative cum sedimentation pond for further treatment. Treated effluent will be discharged in the Dankuni Canal by gravity after meeting the discharge standards of inland surface water, and a part of it will be used as dilution water in the septage treatment system and also for other uses within the RWMC.

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Keywords Integrated municipal solid waste management
Regional waste management centre · Leachate and septage treatment
Anaerobic sludge digester · Facultative aerated lagoon
International society of waste management · Air and water

1 Introduction

Municipal solid waste management should be integrated, and after segregation, it has to be transferred to the engineered landfill site as per Municipal Solid Waste Management Rule [1]. A single landfill has been constructed to serve the six municipalities, namely Champdani, Baidyabati, Serampore, Rishra, Konnagar and Uttarpara-Kotrung which has been termed as Regional Waste Management Centre (RWMC). In addition to the primary function of waste disposal, the RWMC also includes facilities for treatment of sludge collected from septic tanks as a secondary function. In these semiurban areas, septage sludge is also transported to RWMC. It contains high BOD and COD values along with other toxic constituents. The leachate generated from the landfill also contains toxic materials. Proper management of landfill leachate and septage is of utmost necessary. The above project is under Kolkata Solid Waste Management Improvement Project (KSWMIP) which is been executed by the Kolkata Metropolitan Development Authority (KMDA) in association with the six municipalities under funding support from the Japanese International Cooperation Agency (JICA). Segregated waste from two bin system will be transported to transfer stations of the municipalities. Recyclables will be taken out for reuse, and biodegradable portion will be composted by windrow process. Inerts and rejects (60% of the total) will be transported to RWMC for sanitary landfilling along with 50 m^3/day of septic tank sludge (septage). RWMC consists of sanitary landfill (SLF) of 140,000 m^3 capacity, approximate life of 16 years; septage treatment facility of capacity 125 m^3/day with dilution water and leachate treatment facility of capacity of 816 m^3/day.

2 Methodology for Leachate and Septic Tank Sludge Treatment

In the leachate treatment system, the facultative aerated lagoon I and II have float-type aerators (8 numbers in each pond), which will supply O_2 in the upper zone for degradation of BOD and for nitrification of nitrogen in extended aeration. In the lower zone of the lagoons, facultative and anaerobic zone will be developed for further degradation of BOD and denitrification. This system will reduce the O_2 requirement; i.e., capacity of aerators and also the amount of stored digested sludge will be reduced. In the facultative aerated lagoon II, aerators will be operated according to the requirement. The facultative/sedimentation pond will store the partly treated leachate and BOD, COD degradation, denitrification, and removal of

SS will take place to meet the permissible discharge limit. Treated effluent will be discharged in the Dankuni canal after meeting the appropriate discharge standards, and a part of it will be used as dilution water in the septage treatment system. After filling up to 1 m from the bottom of the Lagoons and pond with sediments and digested sludge, it will be cleaned. During dry season, ponds will be cleaned one at a time and other two will be operational and sludge will be discharged in the active landfill site. For cleaning and maintenance operation, by-passing arrangement for the lagoons and ponds will be provided.

In the septic tank sludge treatment system, the partly digested septic tank sludge (septage) will be diluted with the treated leachate for better operational and treatment flexibility at the receiving sump. After passing through bar screen, diluted septage will be pumped to the anaerobic digestor. Gas from anaerobic digestor, primarily CH_4, will be stored to gas tank and ultimately flared. Digested sludge from the bottom of the anaerobic digestor will be pumped to centrifuge for dewatering. After dewatering, sludge cake will be transferred to nearby compost facility. Supernatant from anaerobic digestor and centrifuge will be conveyed to leachate treatment system for further treatment.

2.1 Methodology for Estimating Leachate Quantity

Design leachate quantity is estimated by the following rational formula based on the past 20 years data:

$$Q = 1/1,000 \times (C_1 \times A_1 + C_2 \times A_2) \times I\text{---rational formula [2]}$$

where Q: leachate quantity (m^3/day); C_1: coefficient for seepage into active disposal area (0.81)

C_2: coefficient for seepage into intermediate soil covered area; ($C_2 = C_1 \times 60\% = 0.486$)

A_1: waste disposal area (24,900 m^2); A_2: soil covered area (66,800 m^2)

I: rainfall (mm/day): considering past 20 years data, July is the maximum rain fall month (396.4 mm/month).

Coefficient for seepage calculation method [2]

$$C_s = (I - E_{PT})/I$$

where C_s: coefficient for monthly seepage; I: monthly rainfall; E_{PT}: evapotranspiration.

Evapotranspiration

$$E_{PT} = 25.4 \times K \times C \times t\text{---Blaney and Criddle [2]}$$

where E_{PT}: evapotranspiration; K: empirical crop and meteorological coefficient (0.7)

C: monthly fraction of annual sunshine hours (based on past 20 years data)
t: monthly average temperature (°F).
According to Table 1,

$$Q = 1/1{,}000 \times (0.81 \times 24{,}900 + 0.486 \times 66{,}800) \times 396.4\,/31 = 673.1\ \mathrm{m}^3/\mathrm{day}$$

Therefore, design leachate quantity is considered as 700 m^3/day.

2.2 Tentative Design (Capacity Estimation)

2.2.1 Septic Tank Sludge (septage) Treatment System

(A) Basic Item
Quantity of raw septage is 50 m^3/day. Dilution water (Treated leachate) is 75 m^3/day. Treatment system is anaerobic digestion method.

(B) Design Principle
Partly digested septic tank sludge (septage) from the six municipalities will be collected by cesspool machine in the morning hours and then transported by them to the RWMC. It will be reached in the noon at RWMC from six municipalities more or less at same time. In worst condition, total quantity of septage will be reached within 2 h duration, intermittently and transferred to the sump. The maximum capacity of the sump is decided, considering pump failure, one-day storage of septage along with some dilution water. 75 m^3 of dilution water (treated Leachate) will be added to the septage for better operational and treatment flexibility. After passing through bar screen, diluted septage will be pumped to the anaerobic digester. Gas from anaerobic digester, primarily CH_4, will be stored to gas tank and ultimately flared. Digested sludge (5% solids) from the bottom of the anaerobic digester will be pumped to centrifuge for dewatering. Some coagulating agents will be fed online for better dewatering. After dewatering, sludge cake (25% solids) will be transferred to nearby compost facility. Supernatant from anaerobic digester and centrate from centrifuge will preferably be conveyed by gravity to leachate treatment system for further treatment. If gravity conveyance is not possible, it (supernatant and centrate) will be transferred through the relay sump and pump.

(C) Quality
Septage quality is on the basis of average of 8 nos. of representative sample analysis from six municipalities. Design conditions dor septage treatment system from six municipalities shown in the Table 2.

(D) Design of septage treatment system

(a) Flow chart of septage treatment system on the basis of 75 m^3/day of dilution water was shown in Fig. 1.

Table 1 Coefficient for monthly seepage

Month	(1) Annual sunshine hours	(2) Monthly sunshine hours	(3) $C = (2)/(1)$	(4) K	(5) t (°C)	(6) t(°F) = (5) × 9/5 + 32	(7) E_{pt}	(8) Monthly rainfall	(9) Coefficient for monthly seepage = ((8) − (7))/(8)
Jan	2,125.2	204.9	0.096	0.7	20.0	68.0	116.6	11.7	0.00
Feb	2,125.2	200.3	0.094	0.7	23.4	74.2	124.3	23.3	0.00
Mar	2,125.2	230.9	0.109	0.7	28.0	82.4	159.3	31.7	0.00
Apr	2,125.2	239.1	0.113	0.7	30.4	86.7	173.4	53.7	0.00
May	2,125.2	223.3	0.105	0.7	30.8	87.4	163.3	137.6	0.00
Jun	2,125.2	112.1	0.053	0.7	30.2	86.4	81.0	319.5	0.74
Jul	2,125.2	103.6	0.049	0.7	29.4	85.0	73.7	**396.4**	**0.81**
Aug	2,125.2	116.9	0.055	0.7	29.3	84.8	82.9	336.2	0.75
Sep	2,125.2	121.4	0.057	0.7	29.2	84.5	85.8	302.9	0.71
Oct	2,125.2	178.2	0.084	0.7	28.2	82.8	123.4	166.9	0.26
Nov	2,125.2	196.4	0.092	0.7	25.0	77.0	126.6	40.9	0.00
Dec	2,125.2	198.1	0.093	0.7	21.1	70.0	116.1	3.4	0.00

Table 2 Design conditions for septage treatment system

Parameter		Design condition		
		Influent [septage]	Influent [leachate]	Effluent [canal]
pH	–	5.5–8.0	5.5–9.0	5.5–9.0
BOD	mg/L	10,087.5	250	30
COD	mg/L	79,740.4	1,000	250
SS	mg/L	76,200	300	100
T-N	mg/L	3,553.6	–	–
TKN	mg/L	3,383	100	100
NH_4-N	mg/L	–	50	50
Chloride	mg/L	1,329.5	500	1,000
DS	mg/L	6,425	–	2,100
VS	mg/L	53,340 (VS/SS = 70%)	–	–

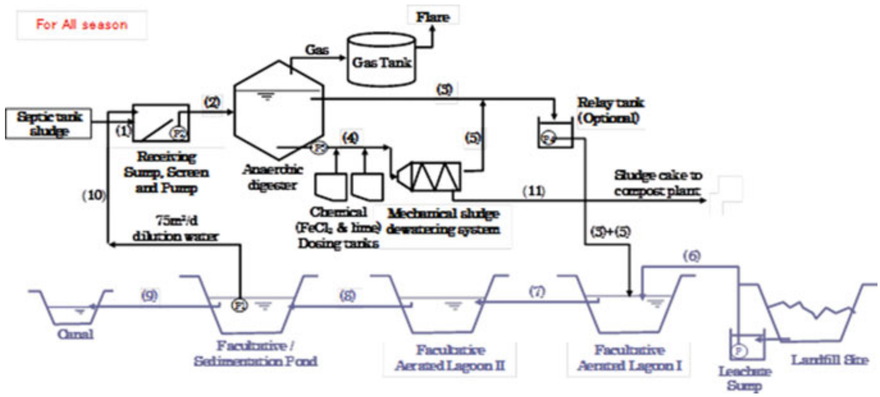

Fig. 1 Flow chart of septage treatment system (75 m^3/day of dilution water)

(b) Stream characteristics summary of septage treatment system was shown in Table 3.

(c) Tentative size of the components of septage treatment system on the basis Concept Design (CPHEEO [1]; CPHEEO [3]; USEPA [4]; Metcalf and Eddy [5])

(1) Pump for dilution water (P1): In worst condition, total quantity of septage will come within 2 h intermittently. To cope up with that quantity pump capacity is considered as 75m^3/h. So 2 no's (1 W + 1S) of capacity 75 m^3/h each are provided.

(2) Receiving sump: Retention time (RT) is considered as 1 day. So 1 no. of capacity 60 m^3 is provided.

Table 3 Stream characteristics summary of septage treatment system (tentative)

		(1) Raw septage	(10) Dilution water	(2) Influent to digester	(3) Supernatant	(4) Digested sludge	(5) Centrate	(11) Sludge cake (25% consistency)
Quantity	(m^3/day)	50	75	125	75.37	49.63	40.60	9.03
BOD	(mg/L)	10,087.5	30	4,053.0	3,000	–	3,000	–
COD	(mg/L)	79,740.4	250	32,046.2	10,000	–	10,000	–
SS	(mg/L)	76,200.0	100	30,540.0	3,000	50,000	6,111	–
TKN	(mg/L)	3,383.0	100	1,413.2	1,000	–	1,000	–
NH_4-N	(mg/L)	–	50	30.0	25	–	25	–
DS	(mg/L)	6,425.0	2,100	3,830.0	3,500	–	3,500	–
Chloride	(mg/L)	1,329.5	1,000	1,131.8	1,000	–	1,000	–

(3) Bar screen: Bar size is 10 mm × 50 mm; clear opening between bars is 25 mm to 50 mm; inclination is 45°–60°.

(4) Transfer pump (P2): In worst condition total quantity of septage will come within 2 h. Considering extra 0.5 h, total pumping hours is 2.5 h. So 2 nos. (1W + 1S) of capacity 50 m^3/h each are provided.

(5) Anaerobic digester with mixing device: RT is 40 days; percentage of volatile matter is 70%, digestion of volatile matter is 50%, solids consistency of the digested sludge is 5%. So 1 no. of capacity 2898 m^3 is provided with $D = 25$ m and $H = 7.2$ m. Schematic diagram of the anaerobic digestor was shown in Fig. 2.

(6) Gas tank and flare system: Gas production rate is at 0.9 m^3/kg of volatile matter destructed, and detention period is 2 days. So 1 no. of capacity 2405 m^3 is provided. Diameter of tank = 21 m, and height = 7 m.

(7) Chemical dozing tanks with mixing and online feeding arrangements: $FeCl_3$ tank 1 no. of 1 m^3 capacity and lime tank 1 no. of 2 m^3 capacity.

(8) Sludge dewatering machine (centrifuge): operation day = 5 days/week; operation time = 6 h/day; sludge amount to be treated at 11.6 m^3/h or 12 T/h. 3 nos. (2W + 1S) of centrifuge of capacity 6 m^3/h or 6 T/h each are provided.

(9) Sludge transfer pumps (P3): 3 nos. (2W + 1S) of sludge transfer pumps (P3) of capacity 6 m^3/h each are provided.

(10) Relay tank and transfer pumps (P4) (optional): Gravity flow of digester supernatant and centrate will be considered first. Retention time = 0.5 h. As diluted septage will be transferred within 2.5 h to the digester, so supernatant will be generated within 2.5 h. So, 1 no. of relay tank of effective volume = 24 m^3 and 2 nos. (1W + 1S) transfer pump (P4) of capacity of each pump 50 m^3/h are provided.

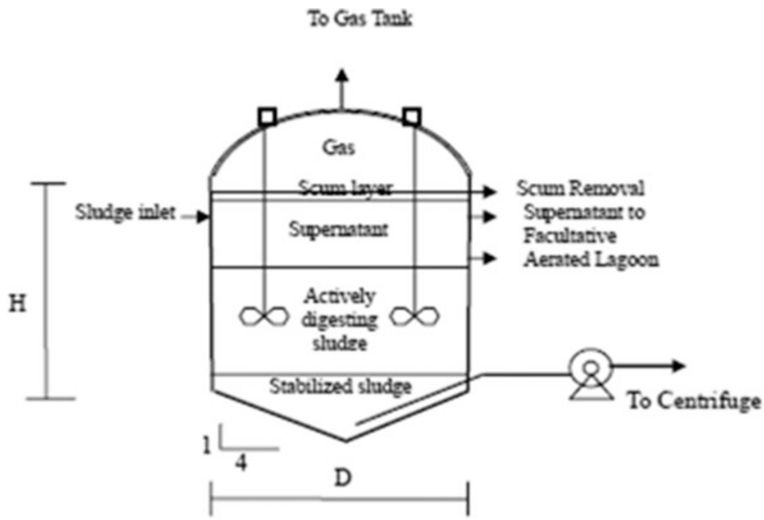

Fig. 2 Anaerobic digestor

2.2.2 Leachate Treatment System

(A) Basic item: Quantity of leachate is 700 m^3/day (In rainy season). Treated septage is 116 m^3/day. Treatment system consists of two facultative aerated lagoons and a facultative cum sedimentation pond.

(B) Design principle:

(a) Quantity of treatment: Quantity of treatment is 816 m^3/day [average amount of leachate, during July, maximum rainfall month of monsoon season, past 20 (1983–2002) years data = 700 m^3/day + treated septage = 116 m^3/day (supernatant from anaerobic digester = 75.37 m^3/day + centrate from centrifuge = 40.6 m^3/day)]. Leachate quality is considered on the basis of 700 m^3/day for safer side. If quantity is more than that [highest 10 daily leachate generation during 20 years period varies from 15,000 to 7,000 m^3/day (past 20 (1983–2002) years data)], pollutant concentration will be diluted and treated accordingly and treated effluent will be within the permissible limit. During dry season, leachate generation is very less and will get enough detention period for degradation, and treated leachate will be used for green belt development within the plant apart from its regular use as dilution water for septage treatment. So July is the most critical.

(b) Treatment system: Treated septage, i.e., Supernatant from the anaerobic digester and centrate from centrifuge will be discharge directly into the facultative aerated lagoon-I. Leachate generated from the active and intermediate soil covered landfills will be collected at leachate sump by gravity and pumped to the facultative aerated lagoon-I. Mixture of treated septage and leachate will be treated first in the facultative aerated lagoon-I, then in the facultative aerated lagoon-II in series. These facultative aerated lagoon I and II will have float-type aerators, which will supply O_2 in the upper zone for degradation of BOD and for nitrification of nitrogen in the extended aeration. In the lower zone of the Lagoons, facultative and anaerobic zone will be developed for further degradation of BOD and denitrification. This system will reduce the O_2 requirement; i.e., capacity of aerators and also the amount of stored digested sludge will be reduced. In the facultative aerated lagoon II, aerators will be operated according to the requirement. Treated effluent from the facultative aerated lagoon II will be transferred by gravity to the facultative cum sedimentation pond for further treatment. Usually, BOD, COD degradation, nitrification and part removal of SS will take place in facultative aerated lagoon I, II, and in facultative/sedimentation pond, BOD, COD degradation, denitrification and removal of SS will take place to meet the permissible discharge limit. Treated effluent will be discharged in the Dankuni canal by gravity after meeting the appropriate discharge standards, and a part of it will be used as dilution water in the septage treatment system. Leachate due to precipitation is almost negligible, except some occasional rain, in dry season. The influent will get high detention period and meet the discharge quality requirement. Evaporation will also take place from pond surfaces. Effluent generated due to occasional precipitation will be usually used for green belt development within the plant. After filling up of 1 (one) m from the bottom of the Lagoons and pond with the sediments and digested sludge, it will be cleaned. The estimated cleaning frequencies of the Lagoons are 5–6 years, and for facultative pond it is 3 years. During dry season, ponds will be cleaned one at a time and other two will be operative and sludge will be discharged in the active landfill site. For cleaning and maintenance operation, by-passing arrangement of the Lagoons and ponds will be provided.

(c) Quality: leachate quality is determined on the basis of Japanese data and other literature data in India and other. Design conditions are shown in Table 2.

(d) Design of leachate treatment system

(i) Flow chart of leachate treatment system for rainy season was shown in Fig. 3.

(ii) Stream characteristics summary of leachate treatment system on the basis leachate generation during rainy season, maximum, July (Table 4).

As 75 m^3/day dilution water will always be recirculated within the system, it will not come in the effluent.

(iii) Flow chart of leachate treatment system for dry season was shown in Fig. 4.

(iv) Stream characteristics summary of leachate treatment system on the basis leachate generation during dry season was shown in Table 5.

(e) Detailed design of different components of leachate treatment system (CPHEEO [1]; CPHEEO [3]; Mara [6]; Arceivala and Asolekar [7]; Metcalf and Eddy [5])

(i) Facultative aerated lagoon: Design leachate quantity = 700 m^3/day; waste water discharge from septage treatment system = 116 m^3/day; total design water quantity = 816 m^3/day; total design effluent discharge during monsoon = 741 m^3/day. 75 m^3/day of dilution water will be always within the system (recirculated) and will not come out from the system as effluent.

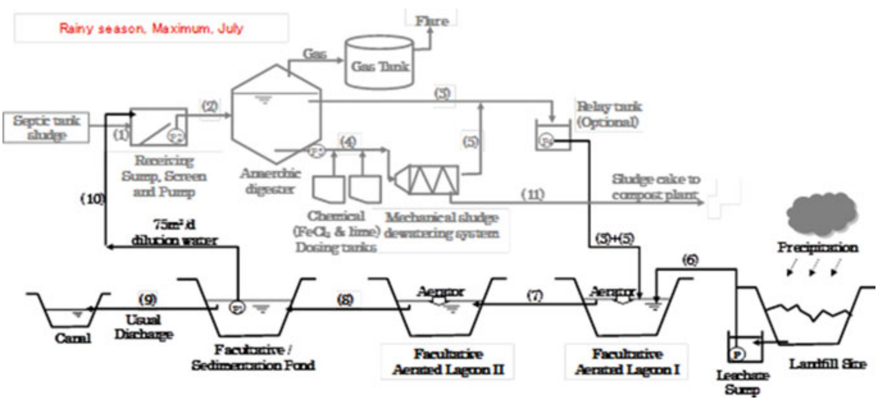

Fig. 3 Flow chart of leachate treatment system (during rainy season)

Table 4 Stream characteristics summary of leachate treatment system (during rainy season)

		(6) Leachate	(3) Supernatant from digester	(5) Centrate	(6 + 3 + 5) Influent to Lagoon I	(7) Effluent from Lagoon I (influent to Lagoon II)	(8) Effluent from Lagoon II (influent to facultative pond)	(9) Effluent from facultative pond	Standards	
									Inland surface	Land disposal
Quantity	(m^3/day)	700	75.4	40.6	816.0	816.0	816.0	741.0	–	–
BOD	(mg/L)	250	3,000	3,000	640.9	156.5	38.2	10.0	30	100
COD	(mg/L)	1,000	10,000	10,000	2,279.1	782.5	191.0	100.0	250	–
SS	(mg/L)	300	3,000	6,111	838.5	200.0	100.0	20.0	100	200
TKN	(mg/L)	100	1,000	1,000	227.9	22.8	2.3	2.3	100	–

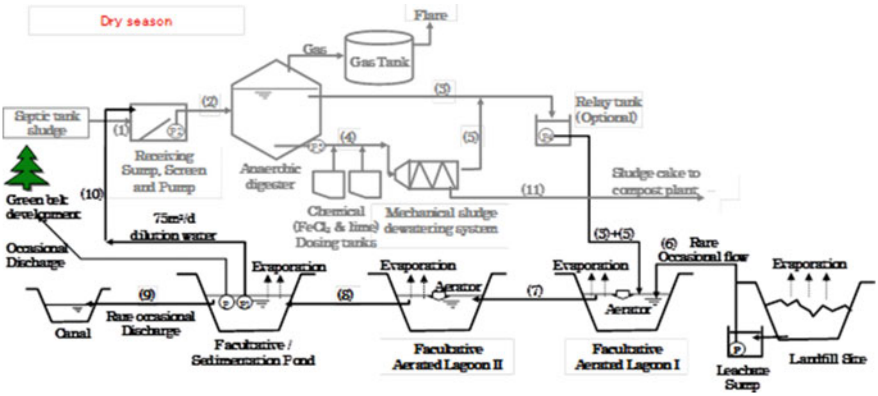

Fig. 4 Flow chart of leachate treatment system (during dry season)

As highest 10 daily leachate generation during 20 years period (past 20 (1983–2002) years data) varies from 15,000 to 7,000 m^3/day approximately considering maximum surface area of the landfill, so during monsoon some extra pumping arrangement should be provided for pumping out of the leachate to the treatment units. Effective top surface of the landfill area will be reduced time to time especially after second layer. So, rather than 15,000 m^3/day, maximum design leachate pumping capacity of 7,000 m^3/day is justified. During that period, if leachate generation is more than that, then some area in the landfill will be water logged for certain period and cleaned afterwards by continuous pumping, assuming that excessive rainfall will not continue for days.

One leachate collection sump is considered for collecting total quantity of leachate and pumping it to the facultative aerated lagoon.

Leachate transfer pump (P5) requirement: 2 (1W + 1SB) nos. of capacity 30 m^3/h + 2 (1W + 1SB) nos. of capacity 60 m^3/h + 3 (2W + 1SB) nos. of 100 m^3/h. If all the working pumps are added, capacity is 290 m^3/h; i.e., ≈7,000 m^3/day. Smaller capacity pumps are for dry season. For safe side during July, net evaporation from the pond surface is not considered.

Sizing on the basis of worst condition: Considering 2 days detention period for the worst condition, i.e. 15,000 m^3/day of leachate generation, total capacity of the three ponds is considered as 30,000 m^3.

Capacity of the facultative aerated lagoon I = 13,195 m^3. Tentative size of the facultative aerated lagoon I = 70 m × 70 m at top; total depth = 4 m; free board = 0.5 m; water depth = 3.5 m; side slope = 1:2. Size and capacity of the facultative aerated lagoon II is same as I.

Capacity of the facultative/sedimentation pond = 5,723 m^3. Tentative size of the facultative/sedimentation pond = 70 m × 35 m at top; total depth = 4 m; free board = 0.5 m; water depth = 3.5 m; side slope = 1:2. Total capacity of the 2 lagoons and 1 pond = 32,113 m^3 > 30,000 m^3.

Table 5 Stream characteristics summary of leachate treatment system (during dry season)

		(6) Leachate	(3) Supernatant from digester	(5) Centrate	(6 + 3 + 5) Influent to Lagoon I	(7) Evaporation from Lagoon and pond surfaces	(10) Dilution water	Effluent from facultative pond		Standards	
								(9) To canal	(12) To green belt	Inland surface	Land disposal
Quantity	(m^3/day)	≈0	75.4	40.6	116.0	57.5	75	≈0	Occasional	–	–
BOD	(mg/L)	250	3,000	3,000	3,000	–	<30	<30	<30	30	100
COD	(mg/L)	1,000	10,000	10,000	10,000	–	<250	<250	<250	250	–
SS	(mg/L)	300	3,000	6,111	4,089	–	<100	<100	<100	100	200
TKN	(mg/L)	100	1,000	1,000	1,000	–	<100	<100	<100	100	–

Design on the basis of maximum rainfall month, July: 20 years average temperature in July = 29.4 °C. Design temperature = 29 °C. (KL) 29 °C = 0.818. D/UL is considered as 4.0. Lagoon volume, V = 13,000 m^3. Flow, Q = 816 m^3/day. RT, t = 16 days.

Now, the dispersed flow model

$$\frac{S}{SO} = \frac{4ae^{\frac{1}{2}}d}{(1+a)^2 e^{a/2d} - (1-a)^2 e^{-a/2d}}$$

where, $a = \sqrt{1 + 4K_L td}$ with usual notations.

Soluble BOD_5 in the effluent = 64.1 mg/L. SS likely to flow out in the effluent from Lagoon I is considered 200 mg/L (for safe side as range = 60–70 mg/L). BOD_5 of VSS = 92.4 mg/L. Total BOD5 in the effluent = 64.1 + 92.4 = 156.5 mg/L [Effluent from Lagoon I or Influent to Lagoon II]. So, overall BOD5 removal efficiency = 75.6%. Total BOD5 in the Effluent from Lagoon II or Influent to facultative pond = 38.2 mg/L. BOD_5:COD = 1:3.6; for safe side consider BOD_5: COD = 1:5. So, COD in the Effluent from Lagoon I or Influent to Lagoon II = 782.5 mg/L. So, COD in the Effluent from Lagoon II or Influent to facultative pond = 191.0 mg/L. So, SS in the Effluent from Lagoon I or Influent to Lagoon II = 200 mg/L. So, SS in the Effluent from Lagoon II or Influent to facultative pond = 100 mg/L.

For removal of nitrogen, extended aeration system is adopted. So, TKN in the effluent from Lagoon I or unfluent to Lagoon II = 22.8 mg/L. So, TKN in the effluent from Lagoon II or Influent to facultative pond = 2.3 mg/L.

As first two lagoons and last pond are facultative type, sufficient amount of denitrification will also take place.

Quality check at excessive rainfall, say 15,000 m^3/day: In excessive rain fall say 15,000 m^3/day, dilution factor is 18.38 (=15,000/816). Consider 30% overall reduction for 2 days detention period (except TKN removal) for safe side. So, influent and effluent qualities for leachate treatment at excessive rainfall are as shown in Table 6.

Quality check at dry season: For dry season, leachate generation is almost zero. Considering recirculation of dilution water (75 m^3) for septage, RT, t = 317 days for facultative lagoon I, which is more than the dry season. During this period, two ponds will be operative other will be cleaned (sludge removal). Effluent from the facultative pond will be well within the permissible limit. For occasional rain, leachate will be utilized to replenish net evaporation and excess amount will be utilized for green-belt development. During dry season net evaporation rate from the pond surface is considered as 5 mm/day. Total surface area of the ponds = 11,492 m^2. Evaporation quantity = 57.46 m^3 > 41 m^3.

Air Requirement

In monsoon season,

Table 6 Influent and effluent qualities for leachate treatment system at excessive rainfall

		Influent quality in the Lagoon I	Effluent quality from facultative pond	Standards	
				Inland surface	Land disposal
Quantity	(m^3/day)	≈15,000	≈15,000	–	–
BOD	(mg/L)	34.9	24.4	30	100
COD	(mg/L)	124.0	86.8	250	–
SS	(mg/L)	45.6	31.9	100	200
TKN	(mg/L)	12.4	12.4.3	100	–

Total incoming BOD_5 in monsoon = 522.91 kg/day. Total incoming nitrogen in monsoon = 185.97 kg N/day. Nf = 0.8, and oxygenation capacity in O_2/KW h = 2 is considered. Oxygen required for BOD_5 removal = 553.31 kg/day. Oxygen required for nitrogen removal = 724.73 kg/day. Total oxygen requirement = 53.25 kg/h. Total power needed = 33.28 KW say 35 KW.

In dry season,

In dry season, consider 350 m^3/day of occasional leachate generation in worst condition. Total incoming BOD_5 in monsoon = 435.41 kg/day. Total incoming nitrogen in monsoon = 150.97 kg N/day. Oxygen required for BOD_5 removal = 548.62 kg/day. Oxygen required for nitrogen removal = 653.7 kg/day. Total oxygen requirement = 50.1 kg/h. Total power needed = 31.31 KW.

Provide eight nos. of surface aerator (A1) each having capacity = 35/8 KW = 4.375 KW say 4.5 KW.

(ii) Influent and effluent qualities for facultative/sedimentation pond are shown in Table 7.

For 29 °C, design loading λ_s = 424 kg BOD_5/ha-day, volume of the facultative or sedimentation pond = 5732 m^3. Retention period = 7 days > minimum detention period of 5 days for temp. < 20 °C; 4 days for temp. > 20 °C. Facultative pond area $A_f = 10\ L_i\ Q/\lambda_s$ = 735.36 m^2. Area of the pond provided = 2244 m^2.

Table 7 Influent and effluent qualities for leachate treatment system

		(8) Effluent from Lagoon II/influent to facultative pond	(10) Dilution water	(9) Effluent from facultative pond	Standards	
					Inland surface	Land disposal
Quantity	(m^3/day)	815.97	75	740.97		–
BOD	(mg/L)	38.21	<30	10	30	100
COD	(mg/L)	191.05	<250	100	250	–
SS	(mg/L)	100	<100	20	100	200
TKN	(mg/L)	2.28	<100	2.28	100	–

BOD_5 removal efficiency = 75%. BOD_5 in the facultative pond effluent = 9.55 mg/L ≈ 10 mg/L.

COD in the facultative pond effluent = 50 mg/L; say 100 mg/L for safe side. Surface overflow rate (as sedimentation pond) = 0.36 m^3/m^2.day < 8 m^3/m^2.day; O.K. SS removal efficiency = 80% (for safe side). SS in the facultative pond effluent = 20 mg/L.

No nitrification is considered in facultative pond, only denitrification will take place, but we are not concern about total nitrogen removal (as standards are for TKN).

(iii) Sludge generation: Amount of sludge = 475 m^3/year ≈ 500 m^3/year. The ponds will be cleaned when 1 m from the bottom is filled up with sludge. Volume of bottom 1 m of the facultative aerated lagoon I and II = 3140 m^3 each. Minimum cleaning interval of facultative aerated lagoon I and II = 6.28 say 5 years. Volume of bottom 1 m of the facultative pond = 1180 m^3. Minimum cleaning interval of facultative pond = 3 years.

3 Conclusion

Leachate and septage treatment already exists in different municipalities. But in small municipalities, waste segregation and septage disposal are a major problem. So this project is a way out for these problems. The project aimed at improving the overall municipal solid waste management system for the six municipalities. These six municipalities lie in the same geographical domain and have similar environmental settings. On one side the project involved the setting up of engineered facilities for waste storage, composting and disposal, while on the other, it improved the primary and secondary collection systems with active participation of the municipalities and the community. The project assisted the municipalities to improve their primary waste collection from the household level, increasing the efficiency of waste transportation and setting up scientific facilities that helped in recycling/reusing waste through composting and for the disposal of the rest in a sanitary landfill. The project also installed facilities for treatment of the septic tank sludge.

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Reducing Pressure on Existing Landfill: Challenges and Solutions Accompanied by a Case Study

S. Sengupta, S. Mukherjee and S. Mukherjee

Abstract This paper deals with the problem of managing and handling issues of municipal solid waste management system, considering the limited size of dumpsite or sanitary landfill in almost all Indian cities. In the next ten years, the filled up dump sites will appear as the biggest challenge to the city governments as well as the urban planners. Our objective is to suggest alternative ways to handle the issue so that lesser amount of waste gets dumped in the existing dumpsites and landfills. Use of a small mechanical composter helps to reduce dumping of average 25 tons of waste per month to the dumpsite. The first section is the review of existing literature which sets the background. The second section describes the dimension of the present problem. The third section deals with the rules and legal provisions. The forth section describes the case study on the details about the experiment. The last and final section is the conclusion.

Keywords Mechanical composter · Behavioural change · Indian SWM rule 2016

1 Background

As India is increasingly urbanized, MSW generation in its cities is becoming an acute problem. This is because of the rapid increase in population [1], tendency of the population to concentrate in the urban centres [2], as well as the growth of the per capita rate of waste generation [3, 4]. This will require a huge increase in land for disposal if the ULBs stick with the landfill method of MSW disposal [5], even if

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one assumes the present rate of growth in per capita generation of waste [6–9]. If that rate increases with economic development, the requirement would be higher [10]. Estimates of waste generation carried out in 59 cities (35 metros and 24 State Capitals) by National Environmental Engineering Research Institute (NEERI) in 2004–05 and by CIPET in 2009–10 vary by over 25% [10] which may reflect both the lack of reliable data as well as the rapid growth in MSW. Over the last decade, solid waste generation has increased nearly 2.5 times, only about 70% of which is collected and about 13% processed and treated [10].

In order to reduce the requirement of land for disposal of MSW, it is essential to segregate waste and to reutilize or recycle it [11–13]. However, very little waste in India is segregated into classes like biodegradable, non-degradable and hazardous or residential, industrial and commercial waste, and the mixed waste is sent to the landfill [5, 7, 14].

2 Present Scenario

The landfill is the ultimate site for waste disposal. Whether it is dump site or landfill, the present cities face increasing difficulty in managing these sites. Table 1 [15] explains the current status of waste handling practices in different cities.

For every city authority or municipal authority, the major challenge is either expired landfill or about to expire landfill in the absence of proper segregation and reuse of waste. The city, whose landfill has expired, hardly finds any land in the close vicinity where the transportation is viable and cost effective. As the lifecycle of the landfills is limited so the city or municipal authority has to try to enhance the duration of the life of the landfill.

The poor management of the landfill sites leads to the putrid smell of decaying wastes in addition to the release of harmful gases like carbon dioxide and methane and occasionally even to explosions and fires. This makes it difficult to convince residents in any locality to situate any landfill site in their vicinity.

Often the municipal bodies try to use compactors as a solution. These machines —of various types—typically use hydraulic mechanisms to compress the volume of residential, commercial, or industrial waste so that a greater amount of waste can be accommodated at the landfill sites. In many cities in India, municipal bodies transport unsegregated compacted waste to landfill site by compactors. This practice often leads to a more complicated situation.

When the compacted blocks reach the landfill, the rag pickers cannot segregate the recyclables easily. This results in the composting of mixed waste where recyclable MSW compost is contaminated by organic and inorganic materials, mainly heavy metals. Use of such contaminated composts in agriculture is harmful to public health and environment. Due to the absence of public awareness regarding these issues, mixed waste composting is widely practiced in India. The attempt of rag pickers to physically desegregate the waste to retrieve the recyclables also partially decompactifies the waste reducing the capacity and life of the landfills.

Table 1 Status of present waste handling techniques in India

Sl. No.	City	MSW generated (TPD)	Composting	RDF/ WTE	LFG recovery	Sanitary landfill	Earth cover	Alignment/ compaction	Uncontrolled dumping	Biomethanation
1	Greater Kolkata	12,060	**700**	NO	NO	NO	**YES**	NO	**YES**	NO
2	Greater Mumbai	11,645	**370**	**80**	**YES**	NO	**YES**	**YES**	**YES**	**YES**
3	Delhi	11,558	**825**	NO	NO	NO	NO	**YES**	**YES**	**YES**
4	Chennai	6,404	**YES**	NO	NO	NO	**YES**	NO	**YES**	NO
5	Greater Hyderabad	5,154	**40**	**700**	NO	NO	NO	**YES**	**YES**	NO
6	Greater Bengaluru	3,501	**450**	NO	NO	NO	NO	NO	**YES**	NO
7	Pune	2,724	**600**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
8	Ahmadabad	2,636	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	NO
9	Kanpur	1,839	**YES**	NO	NO	NO	**YES**	NO	**YES**	NO
10	Surat	1,815	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	NO
11	Kochi	1,431	**YES**	NO	NO	NO	NO	NO	**YES**	**20**
12	Jaipur	1,426	NO	**500**	NO	NO	**YES**	**YES**	**YES**	NO
13	Coimbatore	1,311	**YES**	NO	NO	NO	**YES**	NO	**YES**	NO
14	Greater Visakhapatnam	1,250	NO	NO	NO	NO	NO	**YES**	**YES**	NO
15	Ludhiana	1,167	NO	NO	NO	NO	NO	NO	**YES**	**NO**
16	Agra	1,069	NO	NO	**YES**	NO	NO	**YES**	**YES**	NO
17	Patna	989	**YES**	NO	NO	NO	NO	NO	**YES**	NO

(continued)

Table 1 (continued)

Sl. No.	City	MSW generated (TPD)	Composting	RDF/WTE	LFG recovery	Sanitary landfill	Earth cover	Alignment/compaction	Uncontrolled dumping	Biomethanation
18	Bhopal	919	**100**	NO	NO	NO	NO	**YES**	**YES**	NO
19	Indore	908	**YES**	NO	NO	NO	NO	**YES**	**YES**	NO
20	Allahabad	853	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**
21	Meerut	841	NO	NO	NO	NO	NO	NO	**YES**	NO

So we understand from the above discussion that compaction is not a holistic solution for enhancing the life cycle of the landfill. Rather emphasis should be given on separation at source. Unless the waste is segregated at source the effectiveness of recycling and composting are substantially reduced. The 2015 rule on MSW has made segregation at source compulsory. Moreover, to reduce the cost of waste handling, decentralized model of waste management is getting emphasized. The reduction in cost of transport to the landfill site can be highly reduced by following decentralised process of waste management.

3 Amendments of the SWM Rules

The recent Amendments of the SWM Rules 2015 unequivocally suggests (SCHEDULE II Rule 14 (1) (b), 14 (1) (e), 14 (4), 15(7) (b)) the following.

1. The waste processing facilities shall include composting as one of the technologies for processing of biodegradable waste.
2. In order to prevent pollution problems from compost plant, the following shall be complied with, namely
    (a) The incoming organic waste at site shall be maintained prior to further processing. To the extent possible, the waste storage area should be covered. If, such storage is done in an open area, it shall be provided with impermeable base with facility for collection of leachate and surface water run-off into lined drains leading to a leachate treatment and disposal facility;
    (b) Necessary precautions shall be taken to minimize nuisance of odour, flies, rodents, bird menace, and fire hazard;
    (c) In case of breakdown or maintenance of plant, waste intake shall be stopped and arrangements be worked out for diversion of waste to the temporary processing site or temporary landfill sites which will be again reprocessed when plant is in order;
    (d) Preprocess and postprocess rejects shall be removed from the processing facility on regular basis and shall not be allowed to pile at the site. Recyclables shall be routed through appropriate vendors. The non-recyclable high calorific fractions are to be segregated as a feedstock and sent for RDF production/co-processing in cement plants or to power plants. **Only rejects from all processes shall be sent for well-designed landfill site(s)**.
3. In case of breakdown or maintenance of plant, waste intake shall be stopped and arrangements be worked out for diversion of waste to the temporary processing site or temporary landfill sites which will be again reprocessed when plant is in order.

Hereby, a case study of a newly growing township has been described where the waste management is based on decentralized model and at the same time segregation at source is carried out to facilitate a good practice of waste handling.

4 Case Study at Calcutta Riverside Township, Batanagar

1. **Introduction**

Calcutta Riverside Green is an under construction township developing at Batanagar, West Bengal, India. During construction, around three to four thousand labourers are located at the site. The local municipal body is unable to accommodate the huge waste generated by the mass population. On the other hand, the waste generated by these labourers is huge.

A team of waste management was appointed to look into the matter. The first visit of the team gave them a dreadful experience. First and foremost, we need to remember that the temporary labour hutment is not comparable to the settlement that is seen in general. Often we read case studies of city or townships which have proper house, road, or drainage system. But here the labour huts are absolutely temporary type with the roads and drainage system meant for short term. However, these temporary things often need to stay for years as the construction period is long.

2. **Background Description**

The labourers stay in the provisional temporary hut, and each hut is provided with a kitchen. Average occupancy in the hut varies from 10 to 50. The kitchens are provided with big drums to discard the liquid waste during cooking. But dwellers had the habit of discarding all kind of waste in the drums (Photo 1). Cleaning of the drums was

Photo 1 Open pit that existed near labour huts

Photo 2 Open big drum near kitchen

done regularly. But it was not possible to remove the big drum and clean it thoroughly. People were appointed who decanted the liquid part from top and the settled solid part was taken out with smaller bucket and disposed in pits. The pits were situated near hutment and were not possible to maintain properly because each day high amount of waste was produced, which often exceeded the capacity of the pits (Photo 2).

3. **Improvement measures**

Keeping in view the above-mentioned scenario, certain measurements were taken to improve the system. Emphasis was given on the following steps: (a) collection (b) transportation (c) mobilization (d) processing.

(a) **Collection**

Major change was done in the collecting system. Each kitchen was provided with bins of 30 L capacity instead of the wide-mouthed bins (Photo 3). The bins were placed near to every kitchen. Every morning, the bins are transported to the processing centre. Second set of clean bins are given in place of the filled one. The bins are with handle and easy to carry. Few holes are made below the bins which prevented the dwellers from pouring water in it. The bins are often tied with some support as the ground is not even everywhere; moreover, this helps to protect the waste from stray dogs and cows. Getting clean bins gave the dweller a feeling of cleanliness. The bins also had lids tied to its handle; this helped to keep the content closed preventing it from rodents and flies (Photo 4).

Photo 3 Old bins which were difficult to clean

Photo 4 30 L bins with lids

(b) **Transportation**

Transportation is an important step of waste management. It is done daily in low-height rickshaw vans. The low-height vans were preferred to make the lifting of the bins easier by the workers. The waste collectors are also part of our mobilizing group, and they help the team to get information regarding the waste disposal system. The workers are provided with apron, mask, and gloves for their personal protection. The collector carry the set of clean bins with them, they replace the filled bins with the empty bins.

(c) **Mobilization**

Mobilization is an integrated part of waste management. There are many technologies to get value-added product from waste, but it often gets hampered due to disposal of mixed waste. So "separation at source" is the main target to be fulfilled to make the technology work.

So, sincere approach has been taken to mobilize the mass. It was a very difficult job. There are often floating population of labourers, kitchen cooks, and other waste generators. First and foremost, the kitchen mates and cooks were targeted. Interactive sessions were carried out (Photo 5). In case of waste management community, participation is a strong tool and it needs to be considered. They had issues regarding the narrow-mouthed bins in place of the wide bins. But they were told about the utility of the bins and the positive point of getting cleaned bins every morning.

Photo 5 Mobilization programme at site

An additional session was also included for the other labours during their daily prep talk, which they attend regularly for getting instruction on safety rules. So, waste management issues were also made a part of such routine programme. Supervisors were appointed to look after the daily habits of disposal and continuous interaction and request to the inhabitants helped the process of waste disposal more scientific. They started throwing the wet waste in the bins provided to them, and kept their dry wastes in bags which are collected once in a week.

(d) **Processing**

During the waste analysis, it was found that the 90% of the generated waste is the food waste or the bio-degradable waste. Thus, care was taken to process the biodegradable waste. So a mechanical composter was installed (Photo 6). The mechanical composter consists of a shredder and mixture which helps to incise the bigger waste into smaller particle. This process increases the surface area, which helps to increase the composting rate. Moreover, a bio-culture is added which acts a catalyst for the aerobic composting.

The steps of processing are as follows:

(i) Shredding: here the biodegradable waste is shredded into smaller pieces to increase the surface area thus help to increase the reaction rate
(ii) Mercerization: here mixing of the shredded waste is done with moisture absorbing agent like saw dust and the designated bio-culture

Photo 6 Newly installed mechanical composter

(iii) Curing and fogging: the processed waste is collected in crates which are lined with shed net to allow aeration. They are put into racks for curing. The racks are provided with in-built nebulizer with auto-timer to sprinkle water from time to time.

4. **Present scenario**

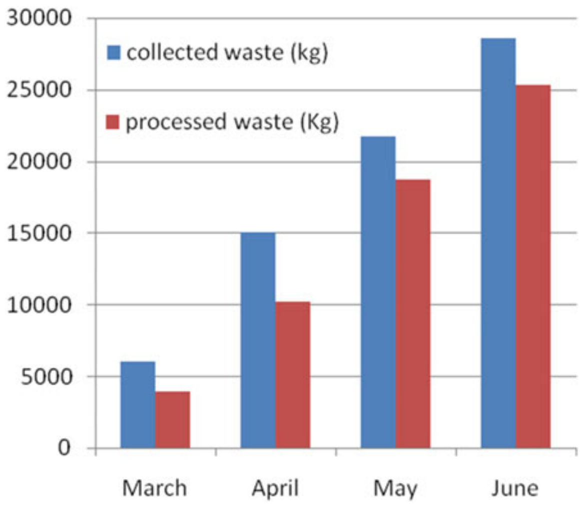
Wastes generated in the labour hutment are mainly biodegradable waste. The mechanical composter was commissioned on first week of March. Training was given in small pockets to the kitchen mates and cooks. The operators were also given training for working in the machine. After the training session, collection of wastes was carried out with care. Some time was required to change the habit. But it is evident that slowly the amount of collection increased. As we can see in Graph 1, that in the month of March, rate of processing was slow but with time we were able to increase the processing rate. Similarly, the waste collection increased from 5987 kg in March to 28596 kg in June. More than 25 tons of biodegradable waste was processed in June. Composting takes place within 12–15 days.

After the process of composting is complete, good-quality organic fertilizer is obtained. The C:N ratio found to be compatible to FCO norms, varying from 19 to 25. The potassium and phosphorus is also found to be in good proportion. The temperature of the compost is measure from time to time to determine the maturity of the compost. Moreover, the pH is also measured from time to time, and it is found that within eighth to tenth day, the pH attains a neutral range.

Best part of the waste management system is to find the behavioural change that took place with the dwellers of the labour hut. They got habituated with the cleanliness. Even a one day disruption in the system is informed to the authority. They have grown the habit of keeping their place clean. Some of the inhabitants even started doing gardening in the near-by barren lands (Photo 7).

Photo 7 Garden at labour site

Graph 1 Comparative waste collection and processes chart



5 Conclusion

At present, implementing segregation of waste at source in most of the cities is challenging for the city governments. Though awareness campaigns are gaining momentum, but segregation at source in larger context is still unachieved. We send 100% solid wastes to our dumpsites or landfill. Due to limited availability of landfills nationwide, the pile of garbage in the dumpsites keeps increasing in volume allowing leachets to contaminate the soil and groundwater. Our suggestion is to segregate the biodegradables at some points like markets or gated housing complexes to start with where a sizable supply is available. Hence, we propose the use of mechanical composter which will turn the degradable to usable compost in few days with almost no odour by using some microbes in the process. This will, as a result, enhance the sustainability of the existing landfills or dumpsites to some extent, as urban land is an extremely scarce commodity.

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Improving Stability of Overburden Dump Through Volume Minimization by Co-Deposition of Materials Based on Size and Material Type Distribution

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Abstract QueryRock fragmentation by blasting, presumedly uneconomic, for overburden (OB) removal in opencast mining is given little importance. This causes generation of an erratic particle gradation ranging from particles less than 0.1 mm OB (clay) to bigger than 1 m in diameter (large boulder). Deposition of these OB by conventional practice using of dumper or dragline generally results in uneven distribution of materials in response of size and type and so is the packing pattern in the spoil heap. Sometimes, the risk of failures increases due to the presence of excessive fines or boulders in the whole structure resulting from improper packing of the mixed spoil materials. With a view to achieve better packing density of the spoil materials, laboratory studies on compaction properties of coal mine waste dump materials were conducted. Based on the compaction properties observed in laboratory studies, a method of waste disposal by layer deposition of materials considering both material size and types is proposed here. Various aspects of the proposed method of layer deposition of waste materials have also been outlined along with those of conventional practice of waste management in Indian coal mines.

Keywords Mine waste dump · Waste management · Particle gradation
Layered deposition

1 Introduction

Generation of waste material is inevitable in mining operation. Various methods are used to extract raw materials from the earth's surface and further beneficiation to obtain the valuable minerals with the rejection of generated wastes [2, 14, 17]. Each step of mining generates some kind of wastes; their respective volumes and type

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being dependent on a number of processes. Solid waste (overburden, waste rock, tailings) and liquid waste (tailings liquid, mine and processed waters, and acid mine rock drainage) are the two commonly generated wastes during mining operation [2, 15]. In excavation of coal by open-pit method, two distinct stages of operation, namely overburden (OB) removal and coal extraction, are followed [3]. The striping nature of extraction in open-pit mining generally ends up with creation of a massive volume of waste, which is almost equal or even more than the economic material produced in the mining operation. Coal seams available at shallow depth further promote opencast operation with added advantage of bulk production at a cost of initial capital investment in overburden removal. Due to improvement in mining and mineral processing technology, opencast mines, a predominant method of coal extraction in India, gradually become deeper resulting in production of massive amount of OB spoil material. With the increasing size of spoil dumps, the risk of their becoming geo-technically unstable and economically unviable is increasing exponentially. Inadequacy of available land within leasehold area results in unplanned deposition of waste piles within and around the mines [13]. In view of various factors such as material type distribution, exposure to the alternate climatic condition, and its subsequent degradation over years that affect its stability, more careful and scientific planning of mine waste dumps needs to be done for long-term stability. Further, with the future planning of increasing coal production to 1.5 billion tons per annum by 2020 with the limited availability of land resources, the storage and disposal of waste material need special attention so that it does not affect the harmony of operation in the near future. This paper summarizes a basic method of waste disposal, in order to minimize the OB dump volume and therefore reduce the waste of land occupation, based on distribution of particle size and material type that might improve its stability. The main objective of this study is to suggest a dumping method based on layered co-deposition of material in order to take care of both the safety and environmental concern of mine waste dumps. This paper also briefly outlines an overview of current mining and related waste generation trend in India, problems associated with the present method of waste handling, particle size distribution and its impact on stability, and volume minimization by layered dumping of mine waste based on particle size and material type distribution.

2 Current Scenario of Coal Mining in India

Coal has been a source of energy production in India since independence, and today its share in electricity generation has risen to a massive 61% [6]. India is endowed with the fifth largest coal reserves in the world. In Asia-Pacific regions and worldwide, India is ranked 2nd and 3rd, respectively, in terms of coal production. To meet the energy demand, coal deposits are extracted mainly by opencast or underground operation depending on the profitability condition. Due to high productivity (output per man shift) favoured by suitable geographical distribution of coal deposits, opencast mines are adopted more as compared to an underground mining operation which involves high risk of accident and lower productivity. From the statistics given by Ministry of Coal, a massive 91.22% of coal production of India in 2013–14 was from opencast mines (516.116 MT) and the rest 49.649 MT from underground mines. It was observed that only three states, namely Chhattisgarh (22.5%), Jharkhand (20.0%), and Odisha (20.0%), together account for about 62.41% of the total coal production in the country. Though the coal production is at its highest in India, the requirement of coal in both industrial and power sector is still very high causing import of high-grade coal mostly from Indonesia, Australia, and South Africa, respectively. During the year 2013–14, total import of coal was 166.557 MT compared to 145.785 MT in 2012–13 registering an increase of 14.25%. Further demand versus production projections gives a positive indication of massive volume of overburden generation.

3 Waste Management Practice

Waste products from coal mining comprise mainly of overburden and washery rejects. This overburden is stored in the form of external or internal spoil piles or backfilled in abandoned open-pits or in underground voids. Washery rejects along with river sand have occasionally backfilled in underground mine voids caused due to mining. The coal mine overburden is generally deposited in the form of spoil heaps by using truck/dumper, dragline, or stacker–belt conveyor combinations. These spoil dump structures are constructed in layered fashion, either a descending or ascending order. Valley-fill, cross-valley, side-hill, ridge, and heaped are the common dump formation methods [33] on the basis of type of formation. Based on the nature of dumping, it can be classified into five basic methods, namely end dumping, push dumping, free dumping, plug duping and dragline dumping [12, 16, 19, 20, 22, 26]. However, end dumping method is more conveniently used due to flexibility of operation and economic concern. In India, OB wastes are generally piled up in the form of benches with a common height of 30 m in single lift with the slope angle being the angle of repose of the waste material. These structures have a maximum height of 90–120 m in multiple lifts.

Cost followed by stability is the most preferred criterion for design and construction of mine waste dumps, while environmental considerations are given last priority. Coal mining incites drastic adverse environmental impacts, including interference with groundwater, land subsidence, water pollution; impact on land uses, ecological disturbances [4]. Stability analysis of mine waste dumps possesses specially challenges due to its erratic distribution of material size and their types.

Conventional disposal of coal mine OB by truck or dumper may sometimes result in formation of excess fines or coarse contents in spoil dumps. Since most of the overburden disposals in open-pit mines are done by using trucks/dumper following end-tipping method, there is very little control over the exact size distribution of these materials due to natural gravity [21]. Similarly, the constituent materials present in overburden get disposed of randomly in the dumping process, and again, no attempt is made to segregate the OB material based on material type citing cost consideration.

4 Waste Minimization Techniques

It was observed that there remains a lot of void space in the matrix since the optimum packing pattern of all the coarse and fines materials is practically impossible to achieve. However, some form of compaction over the OB materials reduces the void resulting in increase of strength [7]. For particular set of geo-mining condition, the volume of dump materials generally depends on the bulking factor of OB material, which in turn is a function of density of material, particle size distribution, or fragmentation. If the material gradation is controlled during dumping, the void space can be minimized to some extent. Waste prevention and recycling are the most desirable methods of volume reduction, but such a move is seen to be unfeasible in mining industry. A flow diagram (Fig. 1) presented by Yilmaz [32] shows the hierarchy of waste management where the method volume reduction by selective dumping practice can be adopted for waste minimization.

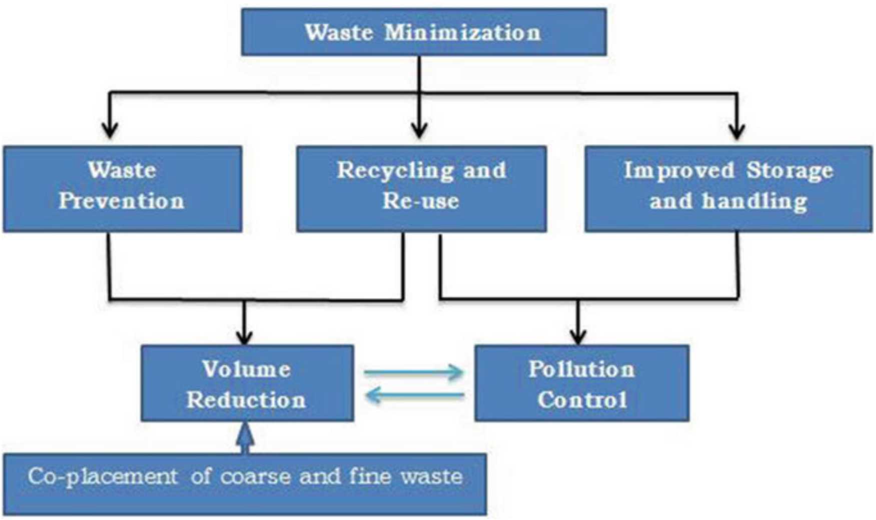

Fig. 1 Waste management for volume reduction (Modified after [32])

5 Material Distribution in Mine Waste Dumps

Complexity in estimation of mechanical characteristics of mine waste dump material arises due to irregular distribution of rock-soil aggregates which show behaviour intermediate to soil and rock [34]. Mine OB also shows a wide variation in its material properties due to uneven distribution of shale, sandstone, and other formations attributed by different geologic origin. According to Fernando and Nag [9], a coal mine waste dump predominantly consists of mixtures of inferior coal, limestone, sandy clay, silty clay, and different invariants of shale and sandstone. As these materials are excavated by blasting operation, it gets intermixed with each other during the process of hauling and dumping. But, if we can control the material distribution and get it disposed off to the spoil dump, it may be helpful in improving the stability pattern of the structure.

Although various studies were made to classify the waste dump materials, it has created problem in proper estimation of particle size distribution due to the presence of wide range of materials in it. Depending upon the presence of fines content, the spoil material is classified as rock-like or soil-like [8, 10, 24]. However, a different classification approach was suggested by Simmons and McManus [23] where the waste dump can be divided into four categories based on distribution of fines and coarse content (Fig. 2). These are (i) waste rock only content, (ii) waste rock with fines partially filled, (iii) waste rock with fines filling the void space, and (iv) a floating structure of rock in fines.

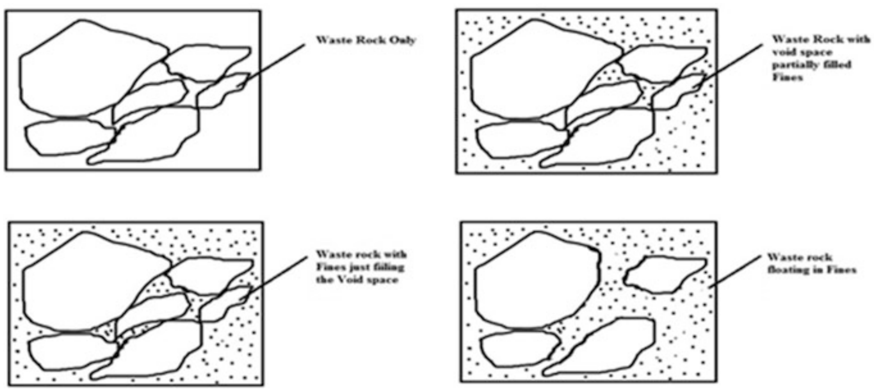

Fig. 2 Matrix structure in rock coarse–fine grain mixture

6 Mine Waste Disposal by Co-Deposition

In free dumping of spoil material containing large percentage of rock and boulders, the bulk density is mainly affected, which depends on the degree of mixing, layering, compaction, method of operation, drainage condition, etc. Typically dump built with fresh waste rock is known to have a porosity of around 30%; i.e., there is considerable amount of void space available in the waste rock [11]. The concept of dumping has been practised in various mines and mainly categorized into different terms such as co-mixing, co-mingling, and co-placement [2, 5, 29, 31]. Co-deposition of mine waste is a form of waste co-disposal where the coarse waste and fine tailings or washery rejects are dumped together. Morris and Williams [18] used concepts of particle packing theory to estimate porosity of mixed coarse and fine coal wastes. The method of waste dumping kept being fixed, the packing of irregular shaped particles/boulders, mostly found in mine waste dumps results in greater void ratio than that of a uniformly graded rock particles. But, there may be cases where the fines material is exactly equal in volumes to that of voids of the waste rock where the voids are just filled resulting in maximum density of the matrix [30]. The ideal mixture ratio however depends upon a number of factors as mentioned above and is difficult to control. The compaction effort due to movement of dumping vehicles is insignificant, and void space within the dump remains high. However, these voids can be eliminated to some extent by layered placement of fines and coarse content of the OB material (Fig. 3).

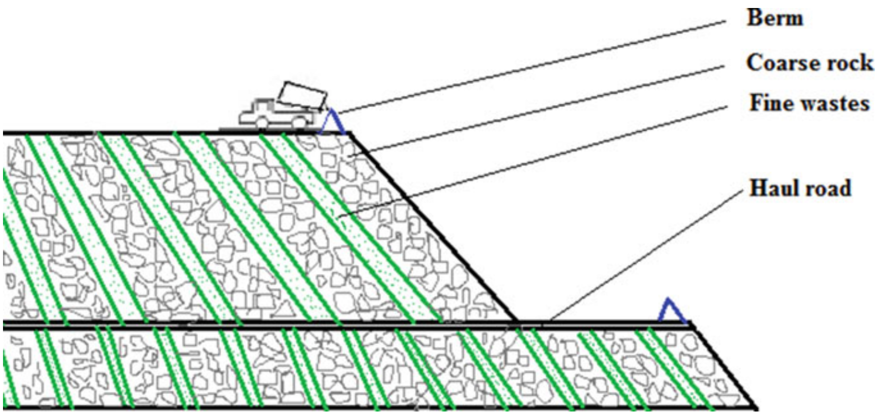

Fig. 3 Disposal of mine waste based on layered placement of coarse and fine contents

7 Experimental Study

An improved packing pattern of highly durable sandstone and fissile shale can help in improving the bulk unit weight and simultaneously help in reducing the void content. The densest and strongest mixture is attained when the volume of the mixture and fine and coarse aggregates just fills the voids. In order to know behaviour of the spoil dump, it is necessary to know the particle gradations. The actual particle size distribution of rock piles can be determined by laboratory methods [1, 27], in situ [28], or by image analysis of photographs. Conventional method of particle size analysis by sieving or by boulder count method is generally not suitable in case of waste dump materials due to the presences of oversize materials. An analysis by image processing module Fragalyst was done to generate the particle gradation curve and other size parameters from a population of 60 different photographs collected from OB dump of Alkusa-Kusunda Colliery (BCCL), Dhanbad. The detailed reports are presented below.

The mean particle size (D_{50}) versus the frequency of size of the spoil material in the Fig. 4 shows that only 13% of the mean size is in the range of gravel and fines (<64 cm), while the rest of the particles are in cobble and boulder categories, of which a significant part about 40% are boulders (>25 cm) in nature. The mean particle size (D_{50}) is the size for which 50% of material is finer than it, while the rest 50% is coarser than the mean size.

Using selective disposal of waste materials, the optimum mixture that gives maximum density, minimum void ratio, and hence maximum theoretical stability of OB dumps can be achieved. In order to study the compaction properties of mixed shale and sandstone, a study was conducted to know it significance. Laboratory

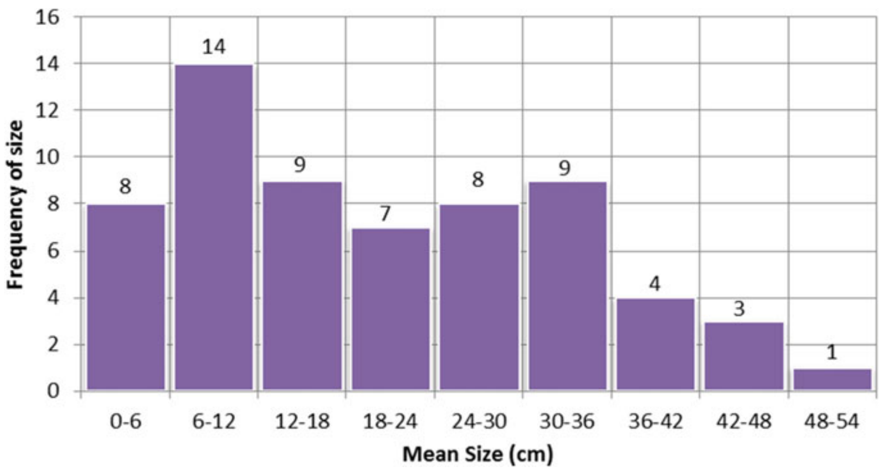

Fig. 4 Frequency distribution of mean particle size of waste dump material

study on compaction properties was made by mixing various percentages of shale and sandstone. It shows that at about 50–70% of shale in the mixture helps in achieving better result than that compared with individual properties (Fig. 5).

8 Discussion and Conclusion

Excessive presence of fines content in waste dump has resulted in failure due to weakening of shear strength in many cases. The limited availability of land along with higher dumping cost may necessitate a change in the current practice of waste dumping. With a goal of achieving 1.5 billion TPA of coal by 2020, the projected waste obtained from coal mines can be to the tune of 2–4 billion TPA, which the mining industry is unprepared to handle. Adaptation of co-deposition of waste rock, though costlier, has more advantages than other methods of waste dumping. Reduction in the void within the waste rock by way of filling with fines/tailing materials reduces the chance of acid rock formation by eliminating flow of water and air. Stewart and Atkins [25] suggested that at about 30–40% fines content, the mixture results in maximum density and minimum permeability. It was reported by various researches that on mixing fines and coarse waste material, the volume can be reduced to the extent of 30%, helping in improving shear strength of the material. Furthermore, the dimension of dump is optimized by perfect packing of the dump material which also reduces the cost associated with waste handling, mine closure, and reclamation. Layer dumping, though it is a cost-intensive programme, was found to be helpful in reducing the cost associated with reclamation, post-mining, and environment-related expenditures like elimination of acid rock drainage, spontaneous heating [32].

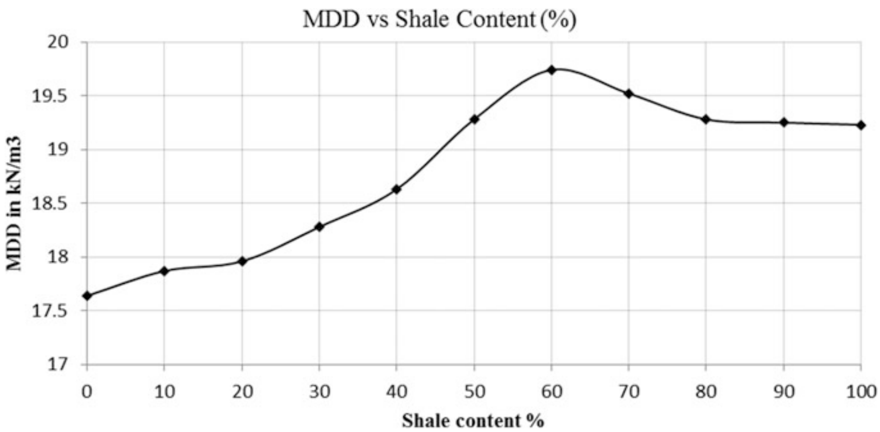

Fig. 5 Maximum dry density (MDD) vs shale content of the mixture

Disposal of mine wastes based on layer dumping of fines and coarse content by truck-dumper combination, based on coarse and fine content, has remained economically unacceptable till now due to its massive volume, but co-disposal of fine tailing/fly ash with coarse content is practised sometimes. The amount of dry solid waste material excavated by blasting is so huge that most of the aforesaid methods become uneconomic. The only viable method of handling such kind of waste is improved storage and volume reduction. A reduction of the waste volume by such practice is beneficial in many ways and deserves proper attention in further research and development in making it techno-economically more beneficial.

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Assessment of Additional Land Area Required for MSW Landfills/Dumps in Million-Plus Cities of India: Two Scenarios

Swati Rani, Amit Kumar, Manoj Datta and A. K. Nema

Abstract This paper examines the status of land being used for dumping municipal solid waste (MSW) in India. The additional land area required for disposal of municipal solid waste generated by 53 major urban cities of the country has been evaluated. Estimation of land requirement has been done considering two scenarios: one considering rapid adoption of waste processing done by municipalities leading to reduction of waste reaching landfills to 25% till end of year 2048 and other considering scenario of slow waste processing practice leading to reduction of waste reaching landfill to 50% till the end of year 2048. The analysis shows that 5685 hectares of additional land will be needed for rapid scenario and 11369 hectares will be needed for slow adopted scenario till year 2048. Thus increase in land demand by year 2048 can be reduced to half by ensuring the fast track adoption of waste processing to be done by municipalities.

Keywords Landfills · Land requirement · Municipal solid waste
MSW dumps

1 Introduction

Overall, India generates 1,43,449 tons of waste daily and out of which only 32,871 tons of waste are reported to be processed [2]. Approximately 80% of waste generated ultimately finds its way to disposal on waste dumps/landfills. Due to the rapid rate of urbanization and the tremendous increase in population, communities have proliferated in the close vicinity of these dump sites. The waste disposal facilities in various cities (both bigger and smaller) have faced opposition from nearby residents [17]. Further uncontrolled disposal of waste on MSW dump sites

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leads to a number of environmental hazards, the most significant of which are ground and surface water contamination, greenhouse gas emissions, odor emissions, and slope instability [8]. So now it is becoming a peculiar problem for the local as well as for state government to locate sites for new landfills.

The objective of the study is to briefly describe the status of land being used for landfilling/dumping MSW in India and evaluating the additional land area requirement in future years. The scope of the study is limited to dumping sites in Indian cities consisting of population more than one million (fifty-three in total).

Two scenarios are being assumed: first considering that municipalities practice a rapid transition toward increasing waste processing and second scenario assuming that transition is comparatively lower due to financial constraints, lower efficiency, and lack of technical skills. Thus, first scenario, i.e., rapid transition scenario, assumes that 66.25% of waste would be reaching dump sites by the year 2024, 52.5% by the year 2032, 38.75% by the year 2040, and ultimately 25% by end of year 2048 with corresponding rapid increase in waste processing. The second scenario assumes that by the year 2024 waste reaching dumpsites at a rate of 72.5% would be achieved. 65% by the year 2032, 57.5% by the year 2040, and 50% waste processing is assumed to be achieved by end of year 2048. Although Planning Commission [16] gives a consolidated estimate of landfill area requirement in future, there is no specific study conducted for estimation of landfill area requirement for the concerned cities till now.

2 Methodology Adopted for Study

Initial step was to review the literature regarding information on the current situation of land occupied by various waste dumps/landfills in India. Thereafter, data were collected from Web site of Swachh Bharat Mission [14] regarding waste generation and processing in selected 53 cities. In cities for which data were not available, generation values were obtained by accounting waste generation rates and population of the city as per census of 2011. Floating population was not considered in study domain.

In the present study, estimation of the landfill area requirement was done according to guidelines issued by MSW Manual 2000 [6]. As per document released by [15] present waste processing rate is taken as 18%. An annual increase in solid waste being generated is assumed to be 5% [1, 9]. For the determination of total volume of waste in designated life years of landfill, density of waste is taken as 0.85 tons/m^3. Additional volume consumed by daily cover of 15 cm on top by soil is considered as 0.1% of total volume (default value). Value for volume requirement for components of liner system and cover system is also estimated, which takes into account a factor k whose value ranges from 0.25 to 0.08 for height of landfill 10–30 m. Volume reduction observed due to settlement/biodegradation of waste is considered as 0.10 when biodegradable waste (when none to 50% of processing of waste occurs) is disposed majorly in waste dumps. A value of 0.05 is taken when more than 50% of waste is processed and majorly incinerated/inert waste reaches MSW dump sites. It has been reported that even if 100% of the waste is being processed, 25% of waste would still reach landfills that would include waste like preprocessing rejects from plants and post-processing residues after processing [11]. In this study, 75% waste processing by end of year 2048 is envisaged; i.e., 25% of waste would still reach waste dumps.

Thus, total area requirement in hectares is calculated by taking the height of the landfill to be 10 m for cities consisting population from 1 to 2 million, and above 2 million, it is taken as 20 m. With this methodology only area requirement for disposal of waste is evaluated, and an additional area of about 15% more would be still be required for the accommodation of infrastructure, support facilities, and green belt around the landfill.

3 Current Waste Generation and Disposal in Million-Plus Cities of India

Currently 377 million people reside in 7935 towns/cities, which constituting 31% of the total population. Simultaneously, cities having more than million population have risen to 53 in number [13]. Approximately 161 million people reside in these 53 million-plus cities. As per recent report (Planning Commission [16] solid waste produced from all towns/cities has reached up to 1,70,000 tons per day, i.e., 62 million per year. It is estimated to rise in future at a rate of more than 5% per annum [8]. Table 1 shows the amount of waste generated (estimated and reported) and waste processed by a total of 53 million-plus cities of India. Waste generation values of some cities are estimated by accounting MSW generation rates range between 0.17 and 0.76 kg/capita/day as per report of [5] and population of cities as per 2011 census of India. Out of 53 cities waste generation data of 38 cities have been reported. It can be inferred from Table 1 that 13% (5 out of 38) cities generate waste approximately more than 4000 TPD of waste, and about 18% (7 out of 38) generates waste between 2000 and 1000 TPD. Around 44% (17 out of 38) generates waste between 1000 and 500 TPD. Approximately 23% (9 out of 38) produces less than 500 TPD of waste, considering those cities only whose values were reported. Waste processing details of only thirty-one cities were available. It is reported that sixteen cities do not process their waste by any technique and directly dump in waste dumps/landfill. About four cities process less than 20% of waste collected by municipalities. Only three cities process 20–40% of total waste collected. Three cities process between 40 and 60%, and five cities process more than 60% of waste collected.

The average collection efficiency for MSW in major metro cities is about 70–90%, and for smaller cities, it is around 60% [10, 18]. Segregation of waste at household level is rarely practiced. Sorting is mainly by carried out at a macro-level by an unorganized sector of the country and later in municipality level. It

Table 1 Waste generation scenario for million-plus cities of India

SI	Cities	Population (million)	Waste generation			Waste being processed** (thousand tons per annum)
			Rate* (Kg/ capita/ day)	Estimated (thousand tons per annum)	Reported** (thousand tons per annum)	
1	Mumbai	18.41	0.45	3024	–	–
2	Delhi	16.79	0.57	3493	3285	–
3	Kolkata	14.04	0.58	2971	–	–
4	Chennai	8.70	0.62	1968	1825	18
5	Bangalore	8.50	0.39	1210	1460	876
6	Hyderabad	7.75	0.57	1612	1460	–
7	Ahmedabad	6.35	0.37	858	1460	456
8	Pune	5.05	0.46	848	621	–
9	Surat	4.59	0.41	686	613	18
10	Jaipur	3.07	0.39	438	444	183
11	Kanpur	2.92	0.43	458	584	–
12	Lucknow	2.90	0.22	233	506	231
13	Nagpur	2.50	0.25	228	–	–
14	Ghaziabad	2.36	0.35	301	292	0
15	Indore	2.17	0.38	301	402	183
16	Coimbatore	2.15	0.57	447	325	237
17	Kochi	2.12	0.67	518	66	0
18	Patna	2.05	0.37	276	256	0
19	Kozhikode	2.03	0.35	260	–	–
20	Bhopal	1.88	0.4	275	292	18
21	Thrissur	1.85	0.35	237	–	–
22	Vadodara	1.82	0.27	179	537	91
23	Agra	1.75	0.51	325	286	0
24	Visakhapatnam	1.73	0.59	373	336	117
25	Malappuram	1.70	0.35	217	–	–
26	Trivandrum	1.69	0.23	142	–	–
27	Kannur	1.64	0.35	210	–	–
28	Ludhiana	1.61	0.53	312	353	0
29	Nashik	1.56	0.19	108	–	–
30	Vijayawada	1.49	0.44	239	193	0
31	Madurai	1.46	0.3	160	248	248
32	Varanasi	1.44	0.39	204	219	–
33	Meerut	1.42	0.46	239	219	0
34	Faridabad	1.40	0.42	215	242	0
35	Rajkot	1.39	0.21	107	193	0
36	Jamshedpur	1.34	0.31	151	–	–
37	Srinagar	1.27	0.48	223	–	–

(continued)

Table 1 (continued)

SI	Cities	Population (million)	Waste generation			Waste being processed** (thousand tons per annum)
			Rate* (Kg/ capita/ day)	Estimated (thousand tons per annum)	Reported** (thousand tons per annum)	
38	Jabalpur	1.27	0.23	107	164	0
39	Asansol	1.24	0.44	200	182	0
40	Vasai-Virar	1.22	0.35	156	219	0
41	Allahabad	1.22	0.52	231	219	150
42	Dhanbad	1.20	0.39	170	186	–
43	Aurangabad	1.19	0.35	152	–	–
44	Amritsar	1.18	0.45	195	237	–
45	Jodhpur	1.14	0.35	145	164	0
46	Ranchi	1.13	0.25	103	183	–
47	Raipur	1.12	0.3	123	149	0
48	Kollam	1.11	0.35	142	–	–
49	Gwalior	1.10	0.35	141	–	–
50	Durg-Bhilai	1.06	0.35	136	40	0
51	Chandigarh	1.03	0.40	150	135	99
52	Tiruchirappalli	1.02	0.23	86	159	55
53	Kota	1.00	0.35	128	164	0

Note *Indicates waste generation rates as obtained from CPCB [5], estimated waste generation values based on rate

**Represents values as reported by municipalities (*Source* MoUD [14]), '–' implies value not available

occasionally results in improper handling and mixing of waste during transportation and disposal [3]. Table 2 shows the overall waste generation, processing, and disposal values of India. According to MoUD [15], only 18% of the waste collected is reported to be treated by various processing techniques, e.g., composting, waste to energy (production of RDF pallets, electricity, heat, etc.), and bio-methanation. According to CPCB [2], total waste processing of around 23% is occurring. Remaining, amount of waste finds its way in various waste dumps/landfills. As of now, area occupied by known landfills and new landfills of 59 cities of the country is more than 1900 ha. [4].

Table 2 Aggregated waste generation, processing, disposal values

Data source	MoUD [15] (Swachh Bharat urban website)	CPCB [2]
Total waste generated (TPD)	147381	143449
Total waste processed (TPD)	26484	32871
Total waste processing (%)	18	23
Total waste reaching landfill (TPD)	120897	110578

Furthermore, only a minute fraction of the disposal sites in India have engineered measures in place which makes the situation more severe [12]. Even if disposing waste in engineered landfills would be practiced, to cautiously store waste, it still demands a large wide area for disposal. According to report by Planning Commission [16], it is estimated that by the year 2031 various urban cities would generate 165 million tons of waste annually and by the year 2050 it could reach 436 million tons. If this quantum of waste is continued to be dumped without treatment, then 1240 ha of land would be required per year. Thus, total of 66 thousand hectares (taking 10 m height) of landfill area would be required for year 2031–2050.

4 Results and Discussion

Estimation of land required for dumping waste is evaluated through analysis of two scenarios of waste management. The areas required for various groups of cities have been shown in three categories, cities consisting population of more than 5 million (8 out of 53) and 1–5 million (45 out of 53).

It is visible from above analysis that reduction in land requirement is observed in future years to come if waste processing techniques are successfully implemented. Figure 1 shows total land requirement under scenario of rapid transition by end of year 2024, year 2032, year 2040, and year 2048 taking base year as 2016. Similarly, Fig. 2 shows the land requirement if slow transition scenario occurs and thus more quantum of waste reaches waste dumps. Table 3 summarizes the total additional land area demand that would be eminent in the future years to come. It is evident from table that 5685 ha of additional land area will be required by end of year 2048, even if rapid transition is practiced and 11,369 ha for the slowly adopted scenario.

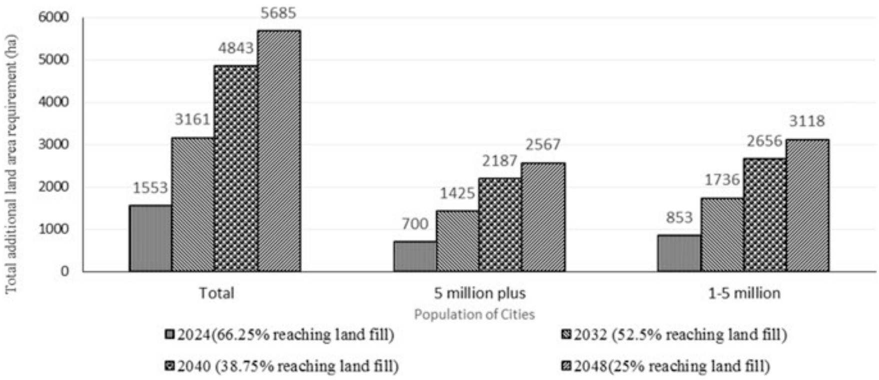

Fig. 1 Additional land area requirement for 53 cities with million-plus population in rapid transition scenario

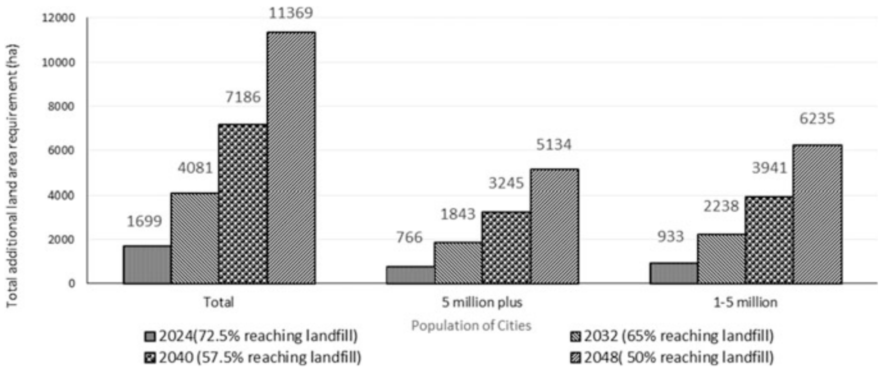

Fig. 2 Additional land area requirement for 53 cities with million-plus population in slow transition scenario

Table 3 Future estimation of land area requirement for landfilling/dumping

Category of cities	Estimation of land requirement (ha)			
	Rapid transition		Slow transition	
	2024	2048	2024	2048
5 million plus	700	2567	766	5134
1–5 million	853	3118	933	6235
Total	1553	5685	1699	11369

Figure 3 illustrates the total additional area requirement for future in addition to current occupied land by various cities as per [4]. Out of 59 cities, 31 cities were only considered in this study. Thus, the total existing land area under various metropolitan cities, consisting of a population more than 5 million (7 cities out of 31), is 943 ha, whereas projected total additional land requirement in year 2024 considering rapid transition (66.25% waste reaching waste dumps) is 1616 ha, and by a slow transition (72.5% reaching waste dumps) it is 1679 ha. For cities having a population of 1–5 million, (24 out of 31 cities) a total of 961 ha of land is presently occupied, whereas it is estimated that it will further consume a total area of 1479 ha as per rapid scenario and 1528 ha as per slow scenario.

In total 1904 ha of land is currently consumed by various metropolitan cities, whereas 3095 ha of total land would be required by end of year 2024 if considering rapid scenario and 3207 ha if considering slow scenario, respectively. Similarly, estimation of future land requirement in 2048 has been evaluated. It illustrates that total 3411 ha of land would be required by 5 million-plus populated cities if rapid processing of waste is practiced, whereas 5879 ha of land would be required in slow scenario. Cities consisting population range of 1–5 million require land of 2855 ha in rapid scenario and 4748 ha in slow scenario. Thus, in total 6266 ha of total land

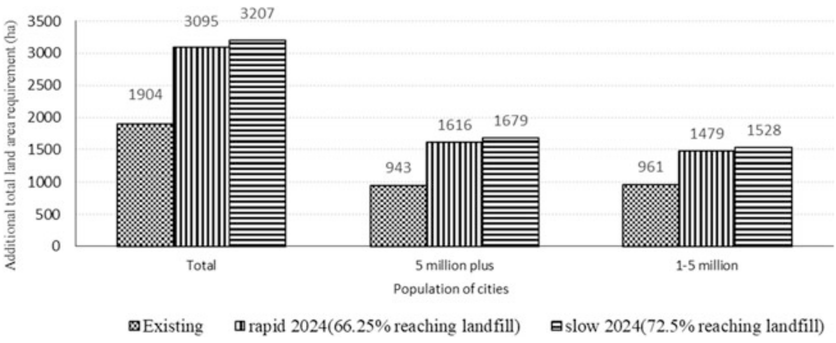

Fig. 3 Land under waste dumps in 2011 and total land requirement by 2024 for 31 cities

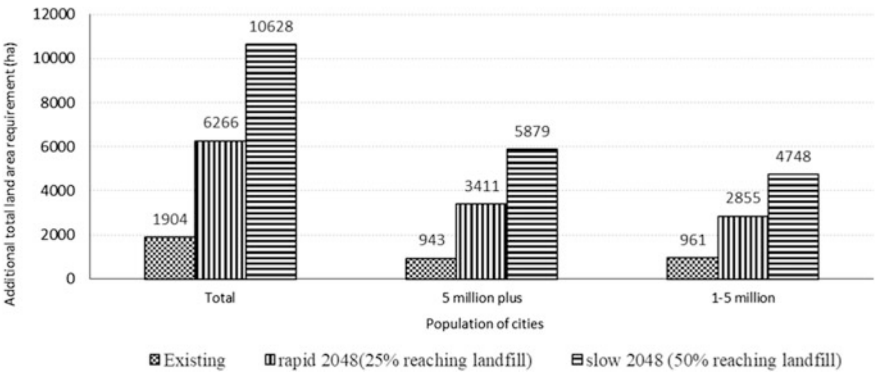

Fig. 4 Land under waste dumps in 2011 and total land requirement by 2048 for 31 cities

would be required by end of year 2024 if considering rapid scenario and 10,628 ha if considering slow scenario, respectively. Thus, requirement of total additional land for concerned 31 cities by end of year 2048 under rapid scenario would be 6266 ha which is three times current value. Similarly, for slow scenario by end of year 2048, total additional 10,628 ha of land would be a required which is approximately six times of current land occupied under waste dumps (Fig. 4).

5 Conclusions

In this paper, an attempt has been made to estimate the amount of land needed for disposal of MSW generated by 53 major urban cities in the future if waste processing continues at the current rate (18%); thus, 82% of waste reaches landfills/dumps; then, additional 22,739 ha of land area would be needed by the year 2048.

Rapid adoption of waste processing leading to only 25% of waste reaching landfills by the year 2048 would lead to 5685 ha of land being needed for landfilling. In contrast, slow adoption of waste processing would be leading to 50% of waste reaching landfills by the year 2048 and would require 11,369 ha of land area for landfilling. Thus, it is important to adopt fast-track mode waste processing projects for producing compost/RDF/energy and thus reduce quantum of waste reaching waste dumps/landfills.

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Part VIII
Composting

Performance Evaluation of In-vessel System for Co-composting of Septage

Anu Rachel Thomas, A. Praveen Rosario, Ligy Philip and Martin Kranert

Abstract The present study deals with the evaluation of in-vessel co-composting as a treatment option for septage management. Optimization of process parameters such as carbon: nitrogen (*C*/*N*) ratio, moisture content, pH, temperature and oxygen supply can accelerate the naturally occurring composting process. Since the *C*/*N* ratio of septage is <10, it needs to be composted with complementary waste having higher *C*/*N*. Hence, in this study, efforts were made to understand the compost dynamics of septage co-composting in a laboratory-scale in-vessel system. Co-composting of septage was done with mixed organic fraction which includes mainly paper waste, vegetable waste and food waste to increase the overall *C*/*N* ratio. The parameters such as pH, moisture content, temperature, carbon and nitrogen were monitored during the process. The results showed that the compost mixture has an initial *C*/*N* ratio of 20 and organic matter (OM) content of 83%. The OM content was reduced to 62% and *C*/*N* ratio to 11 after a composting operation of 20 days, which indicated the effective degradation of organic waste. Temperature above 55 °C for more than 5 days ensured significant pathogen inactivation during the composting process. Final compost quality indicated that it can be used as a fertilizer since it has enough organic and nutrient content for plants to grow.

Keywords Septage treatment · In-vessel composting · *C*/*N* ratio Temperature

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1 Introduction

The management of waste generated from onsite sanitation systems (OSS) is a looming problem in many developing nations. In India, the usage of septic tanks is 14.7% in rural area and 38.2% in urban area, which can increase in the near future [1]. As a result, large quantities of septic tank waste (septage) are generated which do not have proper management strategy at present. It has been reported that in India, the faecal sludge or septage generation from both OSS and open defecation contributes to 0.12 million tons per day (EAI estimate) [2]. Disposal of large quantity of untreated or partially treated septage to the environment will lead to significant greenhouse gases emission [3], water sources contamination [4] and serious health threats [5, 6]. Though septage is harmful, it has got significant nutrient value. The usage of septage as manure was justified by the study conducted by Jönsson et al. [7], where it was reported that excreta contain valuable nutrients. The estimated nutrient content from excreta was 4.5, 0.6 and 1.2 kg/person/year for nitrogen, phosphorus and potassium, respectively.

Vincent et al. [8] conducted feasibility studies to treat septage in sludge drying reed bed and were succeeded in removing >80% of chemical oxygen demand (COD), suspended solids (SS) and ammonia-nitrogen (NH_4^+-N). Lin et al. [9] investigated the anaerobic co-digestion of septage and landfill leachate in an upflow anaerobic sludge blanket (UASB) reactor and found significant removal of organic matter and nutrients. Similarly, other treatment options like aerobic digestion [10], waste stabilization ponds [11], vertical flow constructed wetlands [12] and combination of both waste stabilization ponds and vertical flow constructed wetlands [13] were also investigated for septage treatment. Lime treatment, activated sludge process and anaerobic digestion are also widely used technologies for treating septage [14]. But seldom studies were conducted to recover nutrients from septage. Cofie et al. [15] reported that co-composting of organic solid waste and faecal sludge helps in the recycling of nutrients. As septage is a highly variable kind of waste [16–19], a complementary waste needs to be mixed with septage in order to provide lacking components to use as a fertilizer. They carried out studies to co-compost septage with municipal solid waste, household waste and market waste. In India, proper septage treatment is rarely practiced due to the lack of knowledge on sustainable management options. Even though co-composting can be considered as a sustainable treatment technology for septage management, only very few research studies have been carried out to understand the efficiency of co-composting of septage. This study aims at understanding the composting dynamics during septage co-composting using mixed organic waste by closely monitoring the in-vessel system. Additionally, the correlation between different operational parameters and organic matter decomposition was also investigated.

2 Materials and Methods

2.1 Sample Collection

Septage, obtained from different parts of Chennai city, was then pooled together to get a representative septage. Septage dewatering was achieved using drying beds and alum coagulation. The dewatered septage solids thus obtained were subjected to co-composting. Green vegetable waste and food waste were collected from Himalaya mess, IIT Madras campus, Chennai, India. Cow dung and wood chips were procured from the nearby shops of IIT Madras campus. Coir pith waste was obtained from Kancheepuram district. The particle size in the mixed waste was limited to 2–5 cm in order to ensure moisture control aeration by using a mechanical shredder with 2.2 kW motor. About 50 g of each grab sample was collected from different locations without disturbing the neighbouring materials. The grab samples thus obtained were mixed together to produce homogenized sample.

2.2 Analytical Procedure

The homogenized samples were collected in triplicate and analysed for electrical conductivity and pH (1:10 waste: water extract). The moisture content of the compost was determined after drying to a constant weight at 105 °C in a hot-air oven [20]. Sub-samples were air dried, grounded to pass through a 0.2 mm sieve and were analysed for the following parameters: ammonia nitrogen (NH_4^+-N) using potassium chloride (KCl) extraction [21], organic matter content (550 °C for 2 h), total phosphorus (TP) (acid digest) using the stannous chloride method [20] and total organic carbon (TOC) determined by a Shimadzu (TOC-VCSN*)* solid sample module (SSM-5000A). The total carbon (TC) and total nitrogen (TN) contents of the solids from septage were determined using CHNS analyzer (Elementar, Germany).

2.3 Experimental Set-Up

The composting experiment was carried out in a vertical drum having a diameter of 320 mm and height of 600 mm. Aeration was achieved by providing 50 mm diameter holes along the perimeter at the bottom side of the drum. The compost matrix was supported by a perforated metal mesh. The mesh not only supported the matrix but also provided a pathway for air exchange. A leachate collection system was provided at the bottom of the drum. The entire set-up was insulated using glass wool for the prevention of heat loss during the process. Temperature probes were inserted at the top and bottom of compost matrix, and the data was stored using a temperature data logger. Figure 1 shows the experimental set-up of in-vessel system.

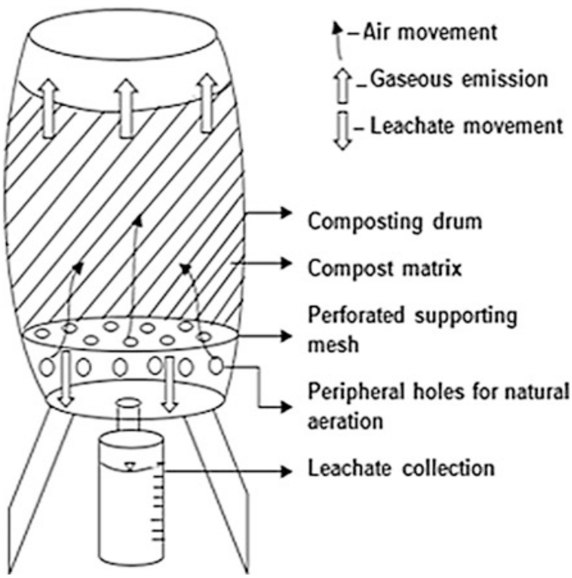


Fig. 1 In-vessel co-composting set-up

2.4 Statistical Analysis

All the results reported are the mean of three replicates except the temperature data in order to ensure reproducibility and representativeness of the samples. Pearson's correlation test (*p test*) was conducted using IBM SPSS 22.0 in order to understand the correlation of organic matter reduction with various composting parameters.

3 Results and Discussion

Composting is the most sustainable treatment option for managing organic wastes. Septage is a waste which is rich in nitrogen content. Composting septage with the acceptable organic wastes in a proper compost system will turn waste into value-added products such as compost. It can be used as fertilizer that enhances soil condition and aids the plant growth. Co-composting of complementary wastes could reduce the GHG emissions of the subsequent composting process and could even enrich the nutrient content significantly [22]. Moreover, the quality of final compost is influenced by initial feedstock materials and process conditions. In this study, the feasibility of in-vessel system for septage co-composting with mixed organic waste was investigated.

3.1 Feedstock Material Composition

The dewatered septage solids having an average moisture content of 74% were co-composted with mixed organic waste. The mixed organic fraction includes vegetable waste, cooked waste and paper waste which provide readily available carbon and nitrogen for the composting microbes [23]. The feedstock composition and initial characteristics of the waste mixture for co-composting are given in Tables 1 and 2, respectively. In addition to the organic wastes, coir pith and wood chips were added as bulking material and structural material, respectively. Malińska and Zabochnicka-Świątek [24] suggested the need of adding bulking material for wastes which are high in moisture content, low *C*/*N* ratio and with high susceptibility to compaction. Wood chips act as a structural support and resist compaction during composting which results in maintaining air filled porosity throughout the composting pile (Haug 1993). Since the water holding capacity and *C*/*N* ratio of coir pith is high, the addition of coir pith to the compost matrix absorbed excess moisture and increased the *C*/*N* ratio [25, 26]. Cow dung (3.3% of total waste on wet basis) was also added to dewatered septage along with organic waste as it as a booster which can result in faster degradation of organic wastes. The mixing is done based on water content and *C*/*N* ratio [27]. Proper mixing of the wastes was ensured by using a rotary drum mixer. The total weight of waste treated in each system was 30 kg. The initial waste mixture is having an optimum *C*/*N* ratio of 23.4 [28]. The initial water content of waste is 77% where the optimum range is of 55–70% [29].

Table 1 Waste composition

Waste material components	% wet ratio	Total mass (kg)	H_2O in total mass	Total solids (TS) (kg)	Volatile solids (VS) (kg)
Dewatered septage	23.30	7.0	5.20	1.80	1.20
Vegetable waste	36.70	11.0	10.50	0.50	0.41
Food waste	23.30	7.0	5.70	1.30	1.28
Paper waste	3.30	1.0	0.10	0.90	0.87
Cow dung	3.30	1.0	0.95	0.05	0.04
Coir pith	3.30	1.0	0.45	0.55	0.47
Wood chips	6.60	2.0	0.20	1.80	1.46
Waste mixture		30.0	23.10	6.90	5.73

Moisture content in waste mixture = 77%
Volatile solids (VS) content in waste mixture = 83% of TS

Table 2 Waste mixture characteristics

Parameter	Concentration
pH	3.9 ± 0.3
Electrical conductivity (dS/m)	1.9 ± 0.3
Moisture content (%)	77 ± 1.3
Organic matter content (% dry weight)	83 ± 0.5
Total organic carbon (g/kg)	38.7 ± 1.4
Total nitrogen (g/kg)	19.2 ± 0.2
Total phosphorous (g/kg)	2.3 ± 0.1
C/*N* ratio	23.4 ± 0.5

3.2 Temperature Profile

The temperature plays a significant role in the establishment of various microbial communities in the compost pile [23]. The rate of raw material decomposition is dependent on the growth of composting microbes which is in turn influenced by ambient air temperature. Therefore, it is important to monitor both the ambient and compost pile temperature during the process. The temperature of composting pile and ambient air are shown in Fig. 2. The temperature rise from 35 to 45 °C observed within 24–36 h clearly shows the quick establishment of mesophilic micro-organisms. The initial increase in temperature was due to the high microbial activity in composting pile. The composting matrix was dominated by mesophilic micro-organisms during the first 4 days and later occupied by thermophilic micro-organisms. The major organic matter transformations happen during thermophilic temperature. The higher temperature rise indicated that the feedstock composition is adequate especially in terms of *C*/*N* ratio as it supported aerobic

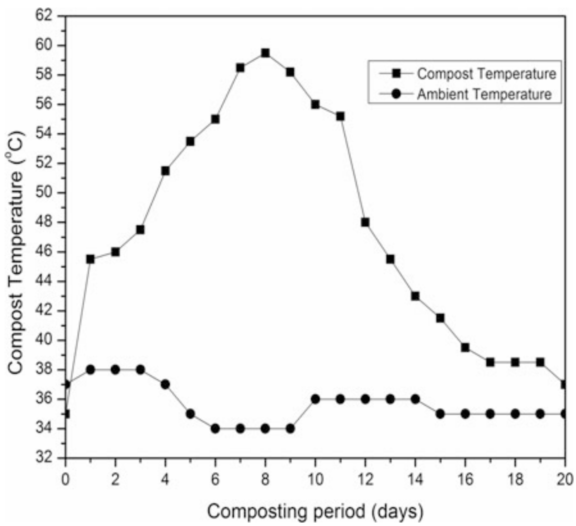


Fig. 2 Temperature profile during composting

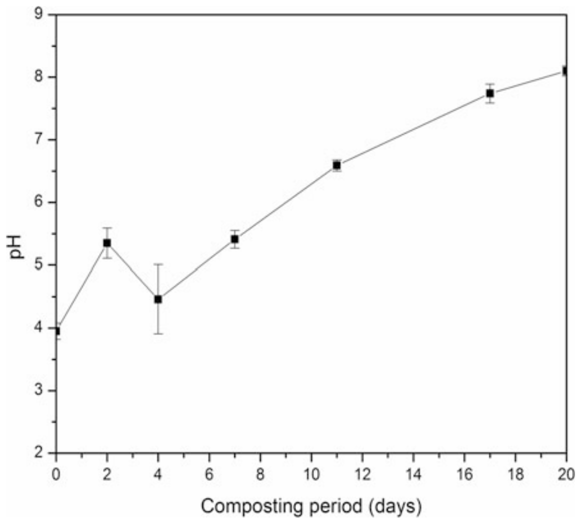
microbial degradation. This further resulted in the prolonged thermophilic stage during the composting process [30, 31]. Temperature above 55 °C for more than 5 days ensured significant pathogen inactivation during composting [32]. The composting pile reached the ambient temperature after 20 days of composting and indicated a good degree of stability.

3.3 Patterns of pH and Electrical Conductivity

The pH is considered as one of the crucial parameters controlling the biodegradation process in composting. In the current study, the initial pH of the compost mixture was found to be in the range of 3.8–4.0 which is less when compared to most of the compost systems [33]. Though the initial pH is low, an increasing trend in pH (Fig. 3) was observed during the composting period. Even though composting started at an extreme end, the process continued without a lag due to the establishment of a diverse group of microbes [34]. The increasing pattern of pH level observed during composting was due to the net release of CO_2 from the system and also due to release of ammonia by protein degradation [35]. The change in pH is found to be highly negatively correlated with loss in organic matter with a *P* value of 0.956 ($p < 0.05$).

The electrical conductivity (EC) directly indicates the salinity in the composting matrix. Higher salinity in the compost can cause phytotoxic effects. The trend of electrical conductivity observed in this study is in agreement with Huang et al. [36]. The early high EC is attributed to the release of ammonium ions and mineral salts

Fig. 3 Change in pH during composting



during the mineralization process, whereas the decrease in EC at the later phase of composting was due to the precipitation of mineral salts and volatilization of ammonia. The final compost has an EC value of 1.6 mS/cm which is not toxic for plant growth [37].

3.4 Moisture Content

Loss in moisture content is an index of organic matter decomposition rate. Heat evolution occurred during microbial decomposition of organic matter resulted in moisture loss [33]. Moisture content decreased from an initial value of 77–68% during 20 days of composting. Figure 4 clearly depicts the change in moisture content during in-vessel composting. The loss in moisture content is proportional to the leachate production. The change in moisture content is found to be highly positively correlated with loss in organic matter with a *P* value of 0.966 ($p < 0.05$). Thus, the organic matter degradation will be more with higher moisture content.

3.5 Carbon Decomposition and Organic Matter Content

The loss of organic matter occurred due to the decomposition of organic compounds such as sugars, lipids and proteins in the composting mass into CO_2 water vapour and heat. The total mass of the compost will be gradually decreased with higher degree of degradation, and the loss can be directly noticed by the decrease in

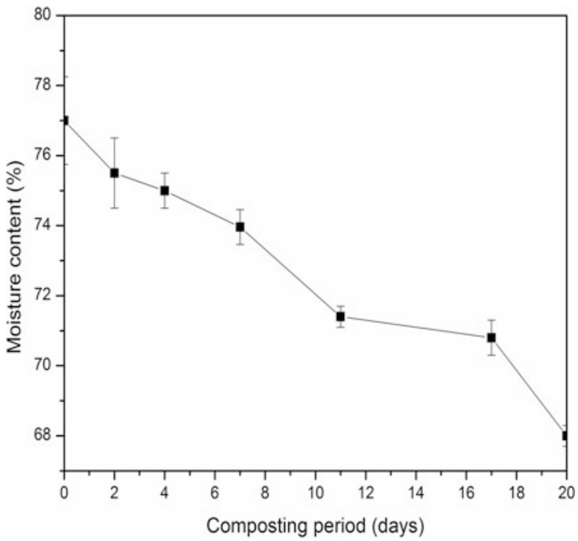


Fig. 4 Moisture content during composting

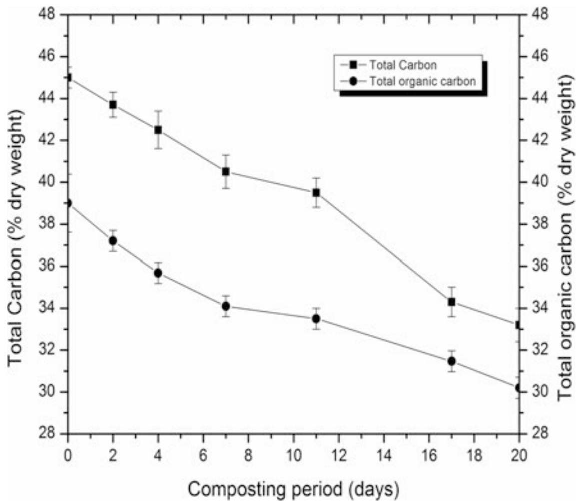


Fig. 5 Carbon decomposition during composting

TOC content [38]. The carbon decomposition during composting period is presented in Fig. 5. Initially, the TC and TOC content were 45 and 39%, respectively. The TC and TOC content were reduced to 33.2 and 30.2% after 20 days of the composting operation, respectively. Around 22.5% of the available carbon is utilized by micro-organisms as source of energy. The change in TOC content was found to be highly positively correlated with loss in organic matter with a *P* value of 0.886 ($p < 0.05$). The OM content was decreased from 83 to 62.5% within 20 days. Loss in OM is due to the rise in temperature during composting. The OM loss during composting is shown in Fig. 6. Similar trend was observed by

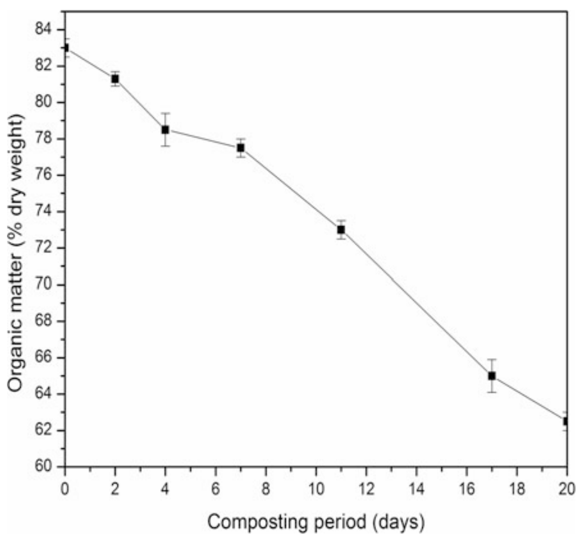


Fig. 6 Organic matter degradation during composting

Kalamdhad and Kazmi [30]. The results showed effective organic matter degradation during the process.

3.6 Nitrogen and Phosphorous Dynamics

The change in TN and ammonia during composting is clearly depicted in Fig. 7. TN (% dry weight) increased from 1.9 to 2.9% within 20 days of composting. This is attributed to net loss of dry mass as CO_2, loss of water by evaporation and significant organic matter oxidation [36]. As a result, the change in TN content showed a highly negative correlation with loss in organic matter with a *P* value of 0.924 ($p < 0.05$). Ammoniacal nitrogen showed an increasing trend till 17th day of composting and decreased at the later days of composting. The breakdown of organic nitrogen during composting and the availability of H^+ ions (pH < 7) resulted in the initial increase in NH_4-N concentration [39]. Hirai et al. [40] suggested that the decrease in NH_4-N is an indicator of a high-quality composting process. In the present study, the NH_4-N content <0.4% indicated the stabilization of final compost [41].

Phosphorus present in the organic material is released by the mineralization process which involves micro-organisms. During the process, the negatively charged inorganic phosphorus reacts with positively charged ions like calcium (Ca), aluminium (Al) and iron (Fe) to form comparatively insoluble substances. As a result, the phosphorus is considered to be fixed up [42]. The fractional value of total phosphorus (TP) depends on the dry mass in the system. In this study, TP (g/kg) showed an increasing pattern due to the net dry mass loss. Figure 8 clearly shows the increase in phosphorous during composting. As a result, the change in TP content showed a highly negative correlation with loss in organic matter with a *P* value of 0.959 ($p < 0.05$).

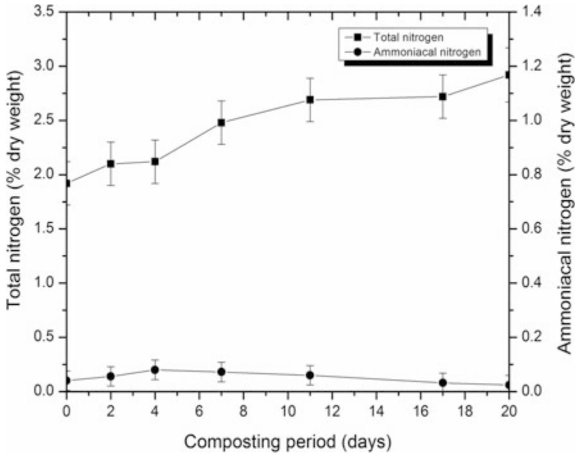


Fig. 7 Nitrogen dynamics during composting

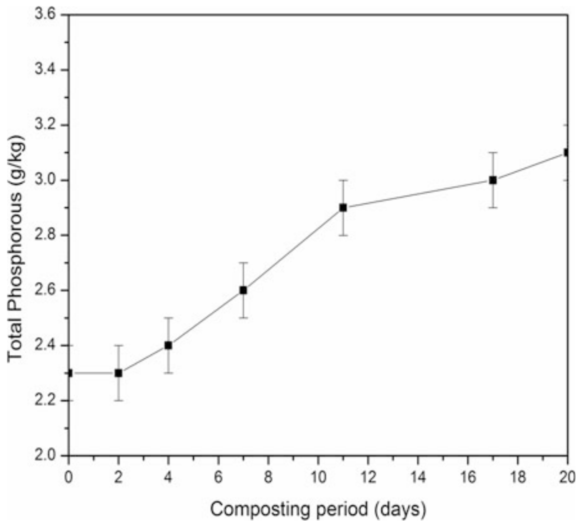


Fig. 8 Total phosphorous during composting

3.7 Carbon to Nitrogen Ratio

The change in *C*/*N* ratio is a sign of degree of stabilization and degree of organic matter decomposition attained during composting [43]. Figure 9 shows the change in *C*/*N* ratio with respect to time. The ideal *C*/*N* ratio to enable composting is 25:1–30:1. Composting micro-organisms decompose organic matter by utilizing nitrogen as the source for cell build-up and carbon as source of energy which results in the reduction of *C*/*N* ratio [35]. The compost mixture with *C*/*N* ratio > 30 may

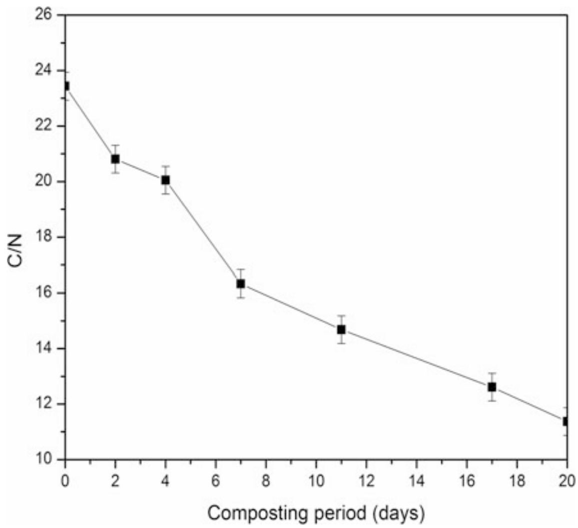


Fig. 9 Change in *C*/*N* during composting

hinder microbial growth due to insufficient *N* [44], while too much *N* results in higher losses of *N* as ammonia and nitrogen oxides [39]. In this study, the initial *C*/*N* ratio of the compost mixture was found to be 23.4. The *C*/*N* ratio gradually decreased to 11.4 after 20 days of composting process which indicates that the bioavailability of carbon was high [45]. A similar trend in *C*/*N* ratio was noticed with in-vessel composting of different organic waste mixtures [23, 35]. Van Heerden et al. [46] suggested that a $C/N < 20$ ensures proper compost maturity, where with a ratio of ≤ 15 is also preferred. In the present study, the final compost has a *C*/*N* ratio of 11.4 which indicates that it is stabilized. The change in *C*/*N* content showed a highly positive correlation with loss in organic matter with a *P* value of 0.945 ($p < 0.05$).

4 Conclusion

The feasibility of septage co-composting using in-vessel system was investigated. A suitable feedstock composition was formulated for the effective co-composting of septage. The close monitoring of in-vessel system helped in the detailed understanding of compost dynamics during septage co-composting. Moreover, proper feedstock materials' mixing resulted in obtaining the matured compost within 20 days of composting process. The ripened compost has a TOC content of $30.2 \pm 0.5\%$, TN value of $2.92 \pm 0.3\%$ and a TP value of $0.31 \pm 0.01\%$. The compost stability was assured by a low temperature (37 °C) and low *C*/*N* ratio (11.4 ± 0.5) of final compost. Therefore, the present study revealed that in-vessel co-composting is a better decentralized sustainable treatment option for converting septic tank waste into a valuable resource.

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Assessment of Phytotoxicity in the Compost Derived Through Different Techniques from Municipal Solid Waste and Industrial Solids

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Abstract Co-composting of municipal solid waste with that of industrial solids is gaining importance nowadays due to the possibility of the disposal of both the waste simultaneously in an eco-friendly manner as soil-enhancer for nutrient hungry soils. This study focuses on the suitability of co-composting organic part of municipal solid waste (OPMSW) generated from Coimbatore city with industrial solids from pulp and paper (P), sugar (S) and dairy (D) industries in three different proportions, i.e. 3:1, 6:1 and 9:1 designated as 1, 2 and 3, respectively, and subjecting to three different composting techniques like windrow composting (W), vermicomposting (V) and twin process (Windrow + Vermicomposting, WV). The phytotoxicity of the finished compost in each case, i.e. from nine different combinations for each industrial solid, has been analysed in terms of germination index (GI) and vigour index (VI using Lycopersicum esculentum (Tomato plant—test species recommended by USEPA/FD). In the group P–P3, WV showed highest GI (62) and VI (764); in group S–S3, WV showed highest GI (55) and VI (703); and in group D–D2, WV showed highest GI (57) and VI (743) than their corresponding counterparts. This shows that the twin process (WV) to be an ideal method for treatment of OPMSW with the sludge from various industries due to its short duration of processing (40 days) and better quality of the final compost than their counterparts with respect to phytotoxicity.

Keywords Composting · Vermicomposting · Phytotoxicity · Germination index Vigour index

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1 Introduction

Solid waste management (SWM) is a vital part of any urban environment and planning of the urban infrastructure to ensure a safe and healthy human environment with parallel planning for sustainable economic growth. The rapid economic growth due to industrialization of the developing countries like Asia has created serious problems in the sphere of solid waste management. The solid waste management is the segment which lacks any trained human resources in the area of collection, transportation, processing and final disposal. These aspects greatly determine the quality of the management and treatment strategies in any treatment facility in India. The concern over the environmental problems has raised the need for adopting measures to tackle the inadequate waste management, as well as global warming, which promotes action towards a sustainable management of the organic part of the waste coming out from the MSW disposal sites and from the industrial activities. Landfills end up as the most common means of disposal sites for the municipal solid waste (MSW) in most of the cases, thereby leading to the conversion of the organic waste to biogas, containing about 50% methane, a very active greenhouse gas (GHG). Similarly, industrial solids are also dumped as heaps without any economical use and posing a threat to environment in terms of soil contamination and groundwater contamination. The present study focuses on the analysis of the feasibility of composting followed by analysis of phytotoxicity of the end product derived from the organic part of MSW generated from Coimbatore city with the industrial solids from various industries like pulp and paper industry, sugar industry and dairy industry.

Coimbatore happens to be the second largest city in Tamil Nadu (India) after Chennai located in the time zone of latitude of 11° 00′N and longitude 77° 00′E, popularly known as Manchester of South India, and is situated in the western part of the state of Tamil Nadu. It is located on the banks of the Noyal River in western Tamil Nadu; Coimbatore (Kovanputhur, meaning the new town of Kovan) is believed to have been named after a local chieftain called Kovan. As per the provisional reports of Census India, population of Coimbatore in 2011 was 10.6 lakhs covering an extent of 105.6 km^2. The city's growth can also be accredited to the escalation of industries owing to copious water and power accessibility. Industrialization has created livelihoods attracting to urban migration from nearby villages increasing the daily floating population (1.5–2 lakhs). In terms of solid waste generation, 1200 TPD is generated in the city accounting for about 800 g per capita per day. The problem of waste disposal confronting myriad industries is well perceivable the world over. Some of the measures that have been adopted to solve these problems have resulted in more serious problems.

The Indian paper industry happens to be the 15th largest in the world and is indeed a very water-intensive industry and ranks third in the world in terms of freshwater withdrawal. In general, wastewater treatment sludge constitutes the largest residual waste stream generated by the pulp and paper mills in terms of volume [11]. The sugar mills also fall in the same line consuming around 1,500–2,000 L of water and generate about 1,000 L of wastewater per tonne of the cane crushed. The sugar mill effluent has a Biochemical Oxygen Demand (BOD) of 1,000–1,500 mg/L. The solid wastes generated by sugar mills include bagasse, molasses, lime sludge and press mud of which lime sludge and press mud are of great concern. The purification of the sugarcane juice from organic matter, dirt and other impurities involves the addition of milk of lime which produces lime sludge. The impurities from the sugarcane juice are vacuum filtered and removed as press mud. Dairy industry is no exception in pollution perception. The major contaminants in dairy processing wastewater are milk solids that contain milk fat, protein, lactose and lactic acid. The dairy industry solids are mostly utilized in one or other form but the apprehensible major waste is the sludge from the wastewater treatment plant.

Industrial waste also contains hazardous waste, thereby aggravating the difficulties of disposal. Earlier, landfills were considered to be the least expensive and most widely used waste management option for both municipal and industrial waste. In many cases, leachate from the dump yard haunts the later generation in the form of groundwater and subsoil water contamination. Though incineration of hazardous waste is advocated nowadays, it proves to be a sophisticated expensive process, where high degree of technological expertise is essential for satisfactory operation. The capital cost of incinerator is high, especially, if it is intended for hazardous wastes and gas scrubbing equipment is required. Therefore, an eco-friendly disposal strategy always proves to be an issue for the disposal of both the domestic and industrial waste.

The sludge from the pulp and paper industry, sugar industry and dairy industry waste forms a good source of organic matter which can be utilized for recycling of nutrients in the soil. The best method for the recycling of nutrients from the waste into the soil is composting. Though this process is age-old and nature's own method of recycling nutrients, it has been followed at present using several improvements in the techniques.

Composting, nature's own method usually considered as the most common method for recycling the organic part of municipal solid waste (OPMSW), since it provides an agricultural amendment capable of compensating the serious deficit of organic matter in agricultural soils [17]. A great economic and environmental significance is that production of compost from 'organic wastes' [4, 5, 14] can divert huge amount of MSW from ending up in the landfills, ultimately saving the cost on waste disposal and considerably reducing discharge of toxic leachate and gases and emission of GHG which emanates from waste landfills. Moreover, the stabilized end product is safe to apply to crops as fertilizer or soil conditioner or land reclamation purposes [9, 19]. The chemical and physical technologies for soil remediation are either proved to be incompetent or too costly. Compost addition has an added advantage of increasing soil organic matter content and soil fertility besides bioremediating the toxin contents in the raw materials, and thus, it is believed to be one of the most cost-effective methods for soil remediation [7]. The present work throws an insight into the features of phytotoxicity of the composted end products from different composting techniques with both OPMSW and secondary solids from the pulp and paper, sugar and dairy industry worked with different proportions. Plant growth bioassays like germination index and vigour index show phytotoxicity of immature compost with slight difference in phytotoxic period in their growth duration. Although phytotoxicity of immature compost is a well-presented phenomena [6, 18], its detailed mechanism of action and duration of activity is rather poorly understood, which can be explained by the complexity of the process due to the heterogeneity of stock material, differences in composting technology and management of the process. Nevertheless, understanding of the phenomena of phytotoxicity is very important for the assessment of compost quality in terms of stability and maturity, particularly if the material is used as soil conditioner.

2 Methods and Materials

The present research was carried out at the MSW dump yard in Coimbatore, Tamil Nadu, which is about 15 km away from the city. The municipal solid waste reaches the dump yard near the Vellalore area. About 860 tons of waste is generated per day in Coimbatore city alone. The waste is segregated and organic part of municipal solid waste is (OPMSW) diverted for composting. The raw OPMSW with large-sized materials was shredded initially, followed by pre-composting for a period of 20 days to remove excess water. The wastes were then sieved through a rotary drum sieve to retain contents sized smaller than 50 mm. After these pre-treatments, a uniform and compact OPMSW is obtained.

The sawdust (sd) used for the present study was collected from a sawmill located in Eachanari, Coimbatore, which is used as a bulking agent. The paper industry sludge (PS) was obtained from Amaravathy paper and pulp industry, Udumalpet. The sugar industry press mud (SS) was obtained from Amaravathy sugar factory, Udumalpet. The dairy effluent sludge (DS) from was collected from Aavin Milk Depot, Perur, Coimbatore. The samples were collected in plastic bags and transported to the laboratory for analysis.

The cow dung (cd) was collected from the local dairy farm in Vellalore area, Coimbatore district. Microbial inoculum used in this investigation was obtained from Ramky Energy and Environment Limited at Vellalore, Coimbatore. This commercial preparation of microorganisms (designated as EM hereafter) was used in the composting process as an inoculum to accelerate the processes. The precise composition of the preparation is consisting of *Phosphobacteria, Azospirillum lipoferum, Acetobacter aerogens and Trichoderma viridi* microorganisms. *Eisenia foetida* (Savigny) an African variety of earthworm was used in this study for vermicomposting. It was obtained from Tamil Nadu Agricultural University, Coimbatore. The breeding stock was maintained on urine-free dried cattle manure at a temperature of 25 °C. Only mature and clitellate worms were used in this investigation. The main characteristics of the above have been tabulated in Table 1.

Table 1 Physico-chemical characteristics of the raw materials

Parameters	OPMSW	PS	SS	DS	sd	cd
pH	5.9	6.8	7.82	8.1	5.8	7.23
EC (μmhos/cm)	2.3	3.5	0.9	0.21	0.32	0.80
TOC (%)	31.86	22.38	33.54	46.5	52.4	26.53
TKN (%)	1.24	0.95	1.8	1.6	0.21	0.89
C:*N* ratio	25.69	23.56	18.63	29.06	249.52	29.80
K (%)	2	0.75	0.8	1.9	0.38	0.38
P (%)	0.36	0.24	0.28	0.40	0.50	0.48
VS (%)	59	40.30	32	56	78	31
COD mg g^{-1}	286	423	235	302	1243	554
Moisture content (%)	30	55	24	86	41.2	35

2.1 Composting Experiments

Composting studies were carried out with OPMSW and industrial solids (PS, SS, DS) in different proportions, i.e., 3:1, 6:1 and 9:1 designated as 1, 2 and 3, respectively. The sawdust was used (in proportion of 200 g/kg for PS, 100 g/kg for SS and 250 g/kg for DS) as a bulking agent for maintaining moisture content of the mixture. The mixture was blended with effective microorganisms in all the combinations in order to enhance the rate of the composting process as prescribed by the manufacturer, i.e. 4 mL/kg of the compost. They were grouped under P, S and D groups with different proportions designated as follows: group P with mixing ratios 3:1 corresponds to P1, 6:1 to P2 and 9:1 to P3. Similar mixing patterns were followed for group S and group D which were designated as S1, S2, S3 and D1, D2, D3 for Sugar and dairy industry composting processes. Each set of ratio in the individual group, i.e. groups P, S and D, tried with three different composting techniques. They are as follows:

- Windrow composting method (for 90 days), i.e. designated as 'W',
- Vermicomposting for about 45 days designated as 'V' and
- Windrow composting (for 15 days) + Vermicomposting,
- (25 days), i.e. designated as 'WV'.

2.1.1 Pilot-Scale Design of the Composting and Vermicomposting Systems

The windrows (W) were prepared in heaps of 2 m × 2 m × 1 m size in an aerobic environment and left for composting for a period of 90 days, amending OPMSW and industrial solids in the above-said combinations with sawdust with the inoculum effective microorganisms. A pilot-scale set-up of vermicomposting (V) tanks was used for this investigation. The tank measured about 2 m in length, 1 m in width and 1 m height. The tank was covered with thatched roof to protect the earthworms from direct sunlight, heat, predators and to maintain the favourable temperature for the growth of the earthworms. The moisture content was maintained in the tank at around 40–50% [2]. The whole set-up was left to work out by the earthworms for a period of 45 days under the ambient temperature conditions of around 33–35 °C. The tank is designed with the three layers—first layer of broken bricks (15 cm), coir waste (10 cm) as second layer and the OPMSW and industrials solids with different mixing ratios for about a height of 25 cm third layer. The earthworms were transferred into each tank approximately 500 numbers. The whole set-up is covered with cow dung and silage straw for the growth and protection of the earthworms, respectively. The half of the compost from the windrows was diverted to carry out the twin process of windrow and vermicomposting (WV). This diversion of OPMSW and the industrial sludge was done at the end of 14th day of windrow composting for each group. The composts from windrows were allowed to reach the normal temperature by spreading out overnight on the 14th day. The cooled compost from windrows was transferred to the vermicomposting bins designed as explained above and the vermicomposting was allowed to carry out from the 15th day onwards till the 40th day.

2.1.2 Sampling

The sampling was made using a drill of about 250 mL capacity introduced manually. The samples were collected at three points at different depths (0–25 cm, 25–30 cm and 50–80 cm). The optimum numbers of sampling points were taken as 10, and each sample consisted of a mixture of materials extracted from 10 randomized points thus forming composite sample. Each such sample was oven dried at 105 °C and then passed through a 1.0 mm sieve and used for physico-chemical analysis. All the samples were analysed on dry weight basis in triplicates and results were averaged. The final mature end products from various treatments were analysed for phytotoxicity by means of germination index (GI) and vigour index (VI) using tomato seeds. The best treatments from each group falling under each different treatment technology were identified based on the least phytotoxicity in terms of GI and VI using *Lycopersicum esculentum* (Tomato plant—test species recommended by USEPA/FD).

2.1.3 Phytotoxicity Analysis

Plant growth bioassays like germination index and vigour index show phytotoxicity of immature compost with slight difference in duration of phytotoxic period. The phytotoxicity bioassay indeed was determined by preparing water extracts (1:5) with the compost and vermicompost [12]. Fifteen seeds of tomato (Lycopersicum esculentum*)* were placed, by triplicate, in petri dishes (7 cm diameter) lined with filter paper containing 1 mL of each extract. The control was prepared with distilled water. The percentage of germination was measured after incubating the covered petri dishes in the dark at 28 °C for 4 days [13, 15]. Germinated seeds were counted in both the control (G_o—measured in the distilled water) and the sample (G) and radical growth (L) measured.

The germination index (GI) was calculated, according to the formula:

$$\text{Germination Index (GI)} = \{(G/G_o) \cdot 100\} \cdot (L/L_o) \quad (1)$$

where G and G_o are the number of seeds germinated in compost/vermicompost extracts, respectively, while L and L_o are the radical/root lengths observed in the sample and control, respectively.

The vigour index (VI) of the seedlings was estimated as suggested by Abdul-Baki and Anderson [1]:

$$\text{VI} = L + \text{SL} \times G\%, \quad (2)$$

where L is root length (cm), SL is shoot length (cm), and $G\%$ is germination percentage.

The statistical analyses of the data were done using DUNCAN's Multiple Range Test (DMRT).

3 Results and Discussion

The treatment P3WV in the group P showed a significant ($P < 0.05$) increase in the GI (62) and VI (764) values when compared to other processes, whereas P2 W and P3 V treatments showed highest GI and VI values of 53,571 and 52,600, respectively. The germination percentage showed a significant increase in all the treatments of P group. The order of highest GI within P group is P3WV > P2 W > P3 V, whereas the order of highest VI within P group is P3WV > P3 V > P2 W (Table 2).

The S3WV treatment in the group S showed a significant ($P < 0.05$) increase in the GI (55) and VI (703) values when compared to other processes, whereas S2 W and S2 V treatments showed highest GI and VI values of 51,652 and 52,633, respectively. The germination percentage showed a significant increase in all the treatments of S group. The order of highest GI within S group is S3WV > S2 V > S2 W, whereas the order of highest VI within S group is S3 WV > S3W > S2 V (Table 2).

The D2WV treatment in the group D also showed a significant ($P < 0.05$) increase in the GI (57) and VI (743) values when compared to other processes, whereas D1 W and D2 V treatments showed highest GI and VI values of 51,575 and 53,628, respectively. The germination percentage showed a significant increase in all the treatments of P group. The order of highest GI within D group is

Table 2 Germination index and vigour index values for various treatments

	Treatments	Seeds germinated in (out of 15 seeds)		Germination %	Shoot length SL (cm)	Root length-RL (cm)		Germination index (GI)	Vigour index (VI)
		Control (G_o)	Sample (G)			Control (L_o)	Sample (L)		
P group	P1 W	12	6.3 + 1.8	52.5 + 2.5b	6.2	8	5 + 1.3	33 + 3.5a	331 + 84b
	P2 W	12	8.7 + 1.2	72.5 + 3.1c	7.8	8	5.9 + 1.5	53 + 4.1c	571 + 102
	P3 W	12	5.7 + 1.3	47.5 + 2.5a	5.8	8	5.3 + 1.3	31 + 5.1a	281 + 92a
	P1 V	12	5 + 1.0	41.7 + 3.2a	5.2	8	4.8 + 2.1	25 + 2.3a	221 + 74a
	P2 V	12	5 + 1.0	41.7 + 2.6a	5	8	4.9 + 1.2	26 + 3.5a	213 + 65a
	P3 V	12	8.7 + 1.5	72.5 + 3.5	8.2	8	5.7 + 1.4	52 + 2.6	600 + 153c
	P1 WV	12	6.7 + 1.2	55.8 + 3.4b	5.4	8	4.6 + 1.3	32 + 3.1a	306 + 52b
	P2 WV	12	8 + 1.3	66.7 + 3.2bc	5.3	8	4.9 + 0.9	41 + 2.1b	358 + 56b
	P3 WV	12	10.7 + 1.5	89.2 + 4.3d	8.5	8	5.6 + 0.8	62 + 3.6d	764 + 141d
S group	S1W	12	6.3 + 1.3	52.5 + 3.5ab	5.2	8	5.1 + 1.3	33 + 1.0a	278 + 121a
	S2W	12	9.7 + 0.9	80.8 + 5.5c	8	8	5 + 1.2	51 + 3.2b	652 + 234c
	S3W	12	5 + 1.0	41.7 + 2.1a	5.5	8	5.1 + 0.5	27 + 2.1a	234 + 124a
	S1 V	12	5.7 + 0.5	47.5 + 2.6a	5.4	8	5 + 1.5	30 + 3.2a	262 + 98a
	S2 V	12	8 + 1.2	66.7 + 3.5b	9.4	8	6.2 + 2.0	52 + 2.3b	633 + 214c
	S3 V	12	7.3 + 1.3	60.8 + 3.1b	4.8	8	4.1 + 1.7	31 + 1.3a	296 + 87a
	S1 WV	12	7.3 + 1.2	60.8 + 3.4b	4.9	8	4.6 + 1.6	35 + 2.1a	303 + 120b
	S2 WV	12	7 + 1	58.3 + 2.3b	4.9	8	4.5 + 0.7	33 + 2.1a	290 + 75a
	S3 WV	12	9.3 + 1.4	77.5 + 5.2c	9	8	5.7 + 0.8	55 + 3.2b	703 + 321d
D group	D1W	12	9 + 0.9	75.0 + 4.3c	7.6	8	5.4 + 1.3	51 + 4.4c	575 + 211d
	D2W	12	3.7 + 0.5	30.8 + 2.1a	5.8	8	5.1 + 1.2	20 + 0.4a	184 + 57a
	D3W	12	4.7 + 0.6	39.2 + 2.1a	5.3	8	5 + 1.3	25 + 1.2a	213 + 112b

(continued)

Table 2 (continued)

	D1 V	12	7 + 0.9	58.3 + 3.2b	5.3	8	4.7 + 1.2	34 + 2.1b	314 + 102c
	D2 V	12	9 + 0.8	75.0 + 5.1c	8.3	8	5.6 + 1.4	53 + 3.6c	628 + 101d
	D3 V	12	7.7 + 1.2	64.2 + 4.1b	5	8	4.5 + 1.2	36 + 1.3b	325 + 112c
	D1WV	12	8 + 1.2	66.7 + 5.7b	4.5	8	3.9 + 1.3	33 + 1.4b	304 + 98c
	D2WV	12	10.3 + 1.1	85.8 + 4.2d	8.6	8	5.3 + 1.5	57 + 4.8c	743 + 102e
	D3WV	12	8.3 + 0.9	69.2 + 3.4b	5.5	8	4.3 + 0.9	37 + 5.2b	385 + 112c

D2WV > D2 V > D1 W, whereas the order of highest VI within D group is D2WV > D2 V > D1 W (Table 2).

Maturity and stability are important indicators of high-quality compost. The extent of completion of the composting process can be evaluated by measuring various changes in the chemical, physical and biological properties of the substrate subjected to composting. The problem associated with immature compost is that it can induce anaerobic conditions, as the microbial biomass utilizes oxygen present in soil pores, depriving the plant roots of oxygen, generating of H_2S and NO^{-2} [13]. Moreover, overturning or moisturizing the windrows after a given period did not result in any temperature rise, instead, remained at the ambient level indicating the depletion of degradable materials and subsequently maturation [16]. Though the *C/N* ratio gives the status of the compost in terms of maturity, the prevalence of phytotoxins is not clearly outlined by these values. Hence, germination index and vigour index were considered to be ideal and more sensitive parameters for analysing the potential phytotoxins in the final composts derived from various sources. The germination index is a factor of relative seed germination and relative root elongation, whereas the vigour index is the factor of germination potential of the seedling with respect to maturity of the compost substrate. The data pertaining to vigour index was very negligible in literature review. In general, the decrease of phytotoxicity during composting is attributed to the action of microorganisms [3]. Phytotoxicity, a parameter related to stability, was calculated as the germination index (GI) using the test species recommended by USEPA and FDA [10].

GI values above 50 were considered to be ideal [8, 20] indicating that the compost is mature and ready for land application. It has been proposed that if the value of GI is between 66 and 100 then the substrate is characterized as non-phytotoxic; stable and can be used in agricultural purpose, and if GI > 101 the substrate is characterized to be phytonutrient–phytostimulant, it can be used in agricultural purposes as fertilizer. The final end products produced by composting satisfied to be phytotoxin-free, which resulted from treatments P2 W, P3 V, P3WV, S2 W, S2 V, S3WV, D1 W, D2 V and D2WV with all GI values of above 50, which indicates that these composts are ideal for land application. Similar results were concluded by Lakshmi Priya et al. [12] in vermicomposts obtained from pulp and paper industry; secondary sludge in three different treatment mixtures showed least phytotoxicity in terms of germination index and vigour index in tomato plants indicating that this technique can reduce the phytotoxins in the industrial waste leading to sustainable utilization of the waste. The corresponding increase in the GI values in the present study may also be attributed to the corresponding decrease in the concentrations of the NH^{+}-N, heavy metals like Cu and Zn and electrical conductivity values which are the major components inhibiting the germination and root growth [18].

4 Conclusion

The co-composting OPMSW and industrial solids of different proportions have proved to be fruitful. Especially, the twin process (windrow and vermicomposting) processes showed better results in terms of stability in compost like GI and VI indicating phytotoxin-free end product formation. The study further needs in-depth analysis of the facts responsible for the decrease in phytotoxins with the different industrial solids and their effects on the final compost.

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Production of High-Quality Compost from Feather Waste: A Novel, Cost-Effective and Sustainable Approach for Feather Waste Management and Organic Soil Management

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Abstract Chicken feathers, generated as waste by commercial poultry processing industry and local chicken slaughterhouses, are currently being processed and disposed by methods that require high energy input and cause pollution problems. Thus, efficient, sustainable and cost-effective management of feather waste is the need of the hour. The present study describes a cost-effective and sustainable approach for feather waste management using a novel composting method employing a consortium of three keratinolytic micro-organisms, viz. *Stenotrophomonas maltophilia* K279a, *Bacillus cereus* strain JF70 *and Acinetobacter sp*. PD 12 and three cellulolytic micro-organisms viz. *Bacillus licheniformis, Bacillus subtilis* and *Cellulomonas* sp. The compost obtained was analysed for its quality as per Indian Standards. Results of the analysis showed that the compost had a pH of 7.48, C:N ratio of 5.32:1, total organic carbon—35.07%, total nitrogen (N)—6.58%, total phosphates as P_2O_5—1.5% and total potash as K_2O—1.189%. The feather compost had a C:N ratio of 5.32:1 indicating that it will act as a very good nitrogen fertilizer. All the heavy metals were found to be within the permissible limits. The above results indicate that the compost is a good source of nitrogen, phosphorus and potassium, containing a full spectrum of essential nutrients for plant growth. Such compost can be used for organic soil management to reduce dependence on chemical fertilizers as well as to reverse the cycle of soil deterioration. The process is scalable and can be used effectively for efficient feather waste management.

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Keywords Feather waste management · Compost · Keratinolytic micro-organisms Organic soil management

1 Introduction

Across the world poultry market, India ranks sixth (FAOSTAT Rankings) [1]. Broiler meat production in India is estimated at about 4.8 million tons annually. India's poultry industry, which includes broilers and eggs, is worth $12.96 billion annually [2]. Thus, large amount of waste products are produced by poultry processing plants reaching millions of tons annually. Huge amount of poultry wastes are also generated by small poultry farms as well as by local poultry shops.

Feathers constitute a sizable portion of the poultry waste. Industries dispose feather waste mainly by incineration. Small poultry farms dump these wastes on open lands, whereas local poultry shops dump these wastes at local municipal waste dumping sites, which ultimately land on dumping grounds. All these methods of feather waste disposal cause environmental pollution. Management of this feather waste is the need of the hour.

Feathers are made up of 90% keratin. Keratin is an insoluble, hard-to-degrade protein which has high degree of cross-linking and disulphide bonds. Due to its structural stability, normal proteolytic enzymes like pepsin and trypsin cannot break down keratin. Thus, keratinaceous waste persists in nature for a longer period. Keratinolytic micro-organisms can be exploited as a possible alternative to convert this abundant low-cost organic waste into value-added products such as animal feed, fertilizer, or for production of keratinase enzymes [3, 4]. "Composting" means controlled decomposition. Solid waste can be converted into a valuable resource by composting. Compost is a good source of macronutrients like nitrogen, phosphates, potash and micronutrients such as Cu, Fe, Zn. Due to the presence of organic matter, compost acts as a soil conditioner. It increases soil porosity, thus causing increased aeration, and increases water holding capacity of the soil [5]. Good-quality compost can be used for organic soil management, which is considered to be an effective approach for restoring soil fertility and reversing the cycle of soil deterioration [6].

The present study was aimed at the use of a consortium of keratinolytic and cellulolytic micro-organisms for the production of high-quality compost from feather waste using an effective, economical and easy approach.

2 Materials and Methods

Keratinolytic and cellulolytic micro-organisms: Keratinolytic isolates employed in this study have been isolated from feather waste dumping sites. Three keratinolytic isolates used in this study have been identified by 16s rDNA sequencing as *Stenotrophomonas maltophilia K279a, Bacillus cereus strain JF70* and *Acinetobacter sp. PD 12.* All these isolates show good keratinolytic activity under submerged condition. Three cellulolytic isolates used in this study have been identified by 16s rDNA sequencing as *Bacillus licheniformis, Bacillus subtilis* and *Cellulomonas* sp. were isolated from mangrove soil.

Chicken feathers: Whole chicken feathers with and without skin were obtained from a local poultry shop. They were used in the study without any processing.

Feather degradation in submerged cultivation: Feather degradation in submerged cultivation was performed to confirm keratinolytic potential of each isolate. For this, 1 mL of culture suspension (0.1 abs. at 530 nm) of each isolate was added to 100 mL sterile feather basal media having the following composition in gms/L: NaCl, 0.5; K_2HPO_4, 0.3; KH_2PO_4, 0.4; Na_2SO_3, 0.5 and feathers (cut into 1–2 cm), 10; pH 7.5; D/W, 1000 mL. The medium was sterilized by autoclaving. Flasks for *Stenotrophomonas maltophilia K279a* and *Acinetobacter sp. PD 12* were incubated in incubator shaker at 37 °C for 6 days and those of *Bacillus cereus strain JF70* K3 at 32 °C for 6 days. Feather degradation was determined by the following formula:

$$\text{Percentage feather degradation} = \frac{\text{Dry weight of feathers from control flask} - \text{Dry weight of residual feathers from test flask}}{\text{Dry weight of feathers from control flask}} \times 100$$

Preparation of compost from feather waste using consortia: A composting metal cage lined with mosquito net from inside was used in the study. 12 kg of chicken feathers (wet weight) plus approximately 6 kg of leaves (crushed with hand and soaked in water for 30 min) and 1 kg of wheat flour (waste flour was procured from flour mill) were mixed and added to the cage. Three keratinolytic bacteria were grown separately in 100 mL FMM medium for 6 days. After incubation, the media were filtered and used was inocula. Three cellulolytic bacteria viz. *Bacillus licheniformis, Bacillus subtilis* and *Cellulomonas* sp. were grown separately in 100 mL nutrient broth, incubated for 24 h. The broth after 24 h of incubation was used as inoculum (Figs. 1 and 2). Consortia suspension (600 mL) was sprayed on the mixture once at the start and again on the tenth day. The mixture was turned regularly, and sprayed with small amounts of water to maintain moisture. The process was carried out for a period of 10 weeks after which the compost was dried and pulverized using hammer mill pulverizer to obtain compost particles of uniform size. The pulverized compost was once again sprayed with consortia and kept for ageing for 2 weeks with intermittent mixing.

Fig. 1 Requirements of composting: **a** composting metal cage with mosquito net, **b** composting basket used in preliminary studies, **c** soaked crushed garden waste, **d** chicken feather waste and **e** keratinolytic and cellulolytic isolates

Fig. 2 **a** Mixing of feather waste, garden waste and spraying with consortia, **b** mixture transferred to composting cage

Analysis of compost: The compost was analysed for various physical and chemical parameters such as smell, pH, moisture content, colour, density, particle size, total organic carbon, total nitrogen, total potash, total phosphates, *C*:*N* ratio and various heavy metals. The testing was carried out as per Indian Standards of compost testing at Sheetal Analytical Laboratory, Sadashiv Peth, Pune, India.

3 Results and Discussion

1. **Keratinolytic activity in submerged cultivation**: All the three keratinolytic isolates employed in the study showed good keratinolytic activity when grown in submerged cultivation under aerobic conditions. Because of their potent keratinolytic activity, these isolates were employed for composting of feather waste (Table 1).
2. **Cellulolytic organisms**: The cellulolytic organisms employed in the study showed good cellulolytic activity on CMC Congo red medium. These organisms were added to the consortium for the degradation of cellulolytic waste (garden waste).
3. **Feather waste composting using consortia**: "Composting" is a process of controlled decomposition of organic material under aerobic conditions. It helps in the conversion of unusable solid waste into useful product, i.e. "compost". Composting is rapid and effective if the conditions encourage the growth of the micro-organisms. These conditions include balanced supply of carbon and nitrogen (*C*:*N* ratio), oxygen, appropriate levels of moisture to permit biological activity, etc. Thus, in the present study, the feather waste was mixed with garden waste for effective degradation of feather waste, since garden waste is cellulosic and rich source of carbohydrates. Degradation of cellulolytic waste by cellulolytic micro-organisms resulted in release of simple sugars, which could be utilized by keratinolytic organisms as a source of carbohydrates for their growth and metabolism. Addition of flour waste increased the rate of composting. This may be due to increased growth of composting microorganisms as flour is a rich source of carbohydrates.

The composting cage was kept in a ventilated room. Foul smell of chicken feathers was felt in the composting room for initial two days, which gradually reduced and was eliminated by the end of the third day of composting. Foul smell is

Table 1 Feather degradation by keratinolytic isolates

Isolates	Residual dry weight (mg)	% Degradation
Acinetobacter sp. PD 12	258	73.72%
Stenotrophomonas maltophilia K279a	216	78%
Bacillus cereus JF70	295	70%
Control	982	0%

produced during anaerobic decomposition of any organic waste. In this case, since the compost was turned regularly, it helped in preventing anaerobic conditions in the composting cage. Composting cage (a metal mesh) itself was very well ventilated. Mosquito net allowed entry of air but prevented entry of flies and other insects which get attracted towards these waste.

The compost was sprayed with sufficient amounts of water to maintain the much needed moisture required for microbial activity. Turning of compost facilitated distribution of moisture. Excess spraying of water results in water logging, reducing aeration efficiency and creating anaerobic conditions. All this in turn affects microbial growth and in turn composting rate.

This study indicated that feathers along with garden waste can be effectively converted to compost by use of mixture of potent keratinolytic and cellulolytic isolates. Keratin-degrading bacteria have been used in the preparation of compost by using poultry litter and wheat husk in polythene bags [7].

As shown in Fig. 3, at eighth week of composting, the compost turned brown black in colour. The compost pile had reduced in its size. No intact feathers were seen. Feather rachis, which had not got completely degraded, had turned brittle. The compost had a fresh pleasant smell typical of rich fertile soil. The dark brown compost was dried and pulverized to particles of uniform size (Fig. 4) using hammer mill pulverizer.

Fig. 3 Compost at tenth week

Fig. 4 Ready-to-use pulverized compost after ageing

4. **Results of Compost Analysis**: Application of good-quality compost increases soil productivity by providing nutrients and by improving drainage and moisture absorption. On the contrary, application of bad-quality compost can lead to heavy metal toxicity and immobilization of nitrogen in soil. Hence, it is important to test for compost quality before soil application. Results of compost analysis as well as the Fertilizer Control Order (FCO) standards [8] prescribed by Ministry of Agriculture, Government of India, are presented in Table 2.

Physicochemical properties of the compost:

The colour of the compost was light brown, and the odour was pleasant, typical of fertile soil. 98.76% of the particles passed through a 4 mm sieve which compared favourably with the FCO standard of minimum 90%. The moisture content of compost was 28%. Very high moisture content is undesirable as it reduces air pockets in the compost [5]. The compost has a bulk density of 0.21 g/cm^3. Long-term application of the low bulk density compost helps in increasing water holding capacity of the soil. The pH of the feather compost was 7.48. Based on the quantity of compost applied to soil, its addition can influence pH of the soil. Electrical conductivity of the feather compost was 2.99 dsm-1 indicating normal levels of soluble salts. Excess of soluble salts can cause phytotoxicity to the plants [9–11].

Nutrient content in the compost:

Nitrogen, phosphorus and potassium are the three important nutrients utilized by plants in maximum quantities. Commercial fertilizers most often contain these

Table 2 Results of physicochemical analysis of chicken feather compost

S. No.	Parameter	Results	FCO standards
1	Colour	Light brown	Dark brown to black
2	Odour	Foul odour absent	Absence of foul odour
3	Particle size	98.76%	Minimum 90% of materials should pass through the 4.0 mm IS sieve
4	Moisture percentage	28%	15–25%
5	Bulk density	0.21 g/cm^3	<1 g/cm^3
6	pH (5% solution)	7.48	6.5–7.5
7	Electrical conductivity (5% solution)	2.99 dsm^{-1}	Conductivity (as dsm^{-1}), not more than 4
8	Total organic carbon	35.07%	Not less than 12.0%
9	Total nitrogen (as N)	6.58%	Not less than 0.8%
10	Total phosphates (as P_2O5)	1.50%	Not less than 0.4%
11	Total potash (as K_2O)	1.189%	Not less than 0.4%
12	*C*:*N* ratio	5.32:1	<20
14	Heavy metals		Maximum ppm
	Zinc (as Zn)	246.33	1000.00
	Copper (as Cu)	32.05	300.00
	Nickel (as Ni)	13.36	50.00
	Lead (as Pb)	5.315	100.00
	Chromium (as Cr)	6.35	50.00
	Cadmium (as Cd)	1.41	5.00
	Arsenic as (As2O3)	<0.1	10.00
	Mercury (as Hg)	<0.1	0.15

chemicals. Carbon, nitrogen, phosphorus and potash in the compost sample were estimated to determine its fertility value. Total organic carbon of the compost was 35.07%, total nitrogen (as N) was 6.58%, total phosphates (as P_2O_5) were 1.5% and total potash (as K_2O) was found to be 1.189%. These values indicate that the compost is rich in its major nutrient contents, much above the values specified by FCO. This indicates an intense biodegradation process in the feather compost with minimum loss of inherent nutrients. The total level of various elements does not guarantee that these elements are available for plant growth. However, gradual decomposition of the compost will release most of these nutrients making them available for plant growth [12]. A water-extractable test can be employed to estimate the quantity of these available nutrients.

High nitrogen content of the compost can be attributed to the feathers, which are 90% protein. *C*:*N* ratio of the compost can help in predicting the amount of nitrogen that will be available for plant growth. Nitrogen neutral soils have *C*:*N* ratio of about 30:1. In general, compost having *C*:*N* ratio of <30:1 will release nitrogen in the soils and act as nitrogen fertilizers while those having *C*:*N* ratios >30:1 will immobilize the nitrogen in soil making it unavailable for plant growth [12–14]. The feather compost had a *C*:*N* ratio of 5.32:1 indicating that it will act as a very good nitrogen fertilizer.

Heavy metal in the compost:

All the heavy metals examined in the feather compost were found to be well within the FCO standards. High concentration of certain heavy metals and trace elements like copper, cadmium, chromium, arsenic, mercury, lead, nickel, molybdenum, zinc and selenium is known to have phytotoxic effects in plants. The current trend of organic farming in agriculture and horticulture production requires compost with low concentrations of heavy metals. The heavy metal profile of any compost is determined by the source of raw materials used for composting. For example, composts obtained from sawdust may contain high levels of copper, chromium and arsenic [13].

4 Conclusion

This study indicates that compost can be prepared from chicken feather waste and garden wastes by using a simple, low-cost, convenient and sustainable method. The method can be easily scaled up to handle large volumes of waste, provided mixing during composting process is managed efficiently. Further, consortium of keratinolytic and cellulolytic bacteria has efficiently degraded the feather waste and garden waste to brown compost within 10 weeks. Analysis of compost for compost quality indicated that it contains a full spectrum of nutrients and can be used as nitrogenous fertilizer due to its low *C*:*N* ratio. Thus, such compost can be suitable not only for organic farming, but can also help in improving the fertility of agriculture soils.

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Assessment of Maturity and Quality of Compost Through Evolution of Aerobic and Anaerobic Composting of Flower Waste

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Abstract Easily segregable flower waste as mixed with municipal solid waste increases the waste handling issues. Flower waste has rich nutrient content and could produce good quality of compost. Present study is focused on flower waste composting in aerobic and anaerobic conditions. Agitated pile composting method was used for aerobic composting, and closed air-tight containers of height 0.60 m and diameter 0.30 m were used as the reactor for the anaerobic decomposition of flower waste. Flower waste is mixed with cow dung and dry leaves into two combinations for aerobic and anaerobic composting. Temperature, pH, electrical conductivity (EC), total organic carbon, total nitrogen, *C*/*N* ratio, potassium, sodium, phosphorous were analyzed and studied for the effects on both methods during composting period. At the end of composting pH, EC (ms cm^{-1}), total organic carbon (%), *C*/*N* ratio, sodium (g kg^{-1}), potassium (g kg^{-1}) were 8.32, 1.08, 39.14, 14, 3.11, and 15.21 for aerobic and 8.43, 1.1, 39.14, 17, 3.32, and 15.32 for anaerobic composting, respectively. The result shows that aerobic composting was efficient than anaerobic composting.

Keywords Composting · Agitated pile · *C*/*N* ratio · Nutrients
Anaerobic composting

1 Introduction

Increased world population, urbanization, and industrialization have led the world to the increased accumulation of waste materials in nature. Because of these reasons, the researches on waste minimization and modern waste treatments have great scope. It is estimated that in India, nearly 700 million ton organic wastes are generated annually [1]. In which, the floral waste is the one of the major organic waste generating from various sources like temples, marriages, gardens, churches,

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mosques, and various other cultural and religious functions. Among all these sources, temples are the major source of flower waste. Because of our religious customs, many people avoid to dump this flower waste along with other waste materials. Instead, put them in the waste bins or plastic bags and throw them directly into the water bodies or dump at the available open places. This unscientific way of disposal of flower waste from the sources will create serious environmental problems like pollution of water bodies by reducing the oxygen level, silting in rivers, worm development, offensive odor, and other severe health problems to all the organisms. On comparison with kitchen waste, the rate of degradation of the flower waste is a very slow process [1]. Mishra [2] reported that on each day, floral waste weighing 3.5–4 tones is left behind in the city of temples, Ujjain. Because of these reasons, a special attention has to be given in case of disposal of floral waste. In a country like India, eco-friendly treatment of flower waste has great scope to convert organic waste into valuable resources like bio-fertilizers and flower extracts. The bio-fertilizers contain all kind of plant nutrients and organic matter which are necessary for improving the soil fertility. Composting is one of the best organic wasting disposal techniques, and end products of composting can be used as soil conditioners and amendments for horticulture, agriculture, etc. [3]. Being organic waste, the study on flower waste disposal has a great scope to the convert it into valuable products. Finding and implementing an effective technology for the flower waste will reduce all kind of environmental problems generated by the unscientific dumping of flower waste.

The composting methods widely used are aerobic and anaerobic composting. Aerobic composting is famous for easy to practice and less economical cost and no energy consumption during the process. Aerobic composting is the controlled aerobic biological decomposition of organic matter and transformation into stable and nutrient-enriched products called compost. Aerobic composting method helps to reduce the odors and fly problem during the composting process. Anaerobic composting is the degradation of organic waste in the absence of oxygen. Commonly, air-tight containers are used for the anaerobic decomposition of organic waste.

The aim of the present study was to compare both aerobic and anaerobic methods for the composting of flower waste. Agitated pile composting technology was used for the aerobic decomposition, and closed air-tight containers are used for the anaerobic decomposition of flower waste.

2 Materials and Methods

2.1 Materials

Flower waste, cow dung, and crushed dry leaves were the main materials used throughout the study period. Initial physico-chemical characteristics of waste mixtures are shown in Table 1.

Table 1 Initial physico-chemical characteristics of waste mixture used during the composting process

Parameter	Flower waste	Cow dung	Dry leaves
pH	6.26 ± 0.1	7.11 ± 0.1	6.8 ± 0.2
EC (mS cm^{-1})	5.34 ± 0.2	4.5 ± 0.2	0.5 ± 0.1
MC (%)	78.75 ± 2	74.47 ± 2	2.5 ± 0.5
Na (g kg^{-1})	1.8 ± 0.07	1.05 ± 0.2	1.2 ± 0.1
K (g kg^{-1})	10.3 ± 0.3	1.96 ± 0.2	1.05 ± 0.1
Ca (g kg^{-1})	7.01 ± 0.3	2.72 ± 0.2	0.85 ± 0.1
Total organic carbon (%)	44.47 ± 1.54	32.11 ± 1.23	88 ± 2.21
Total nitrogen (%)	1.51 ± 0.2	1.20 ± 0.1	2.75 ± 0.2
C/N	29.45 ± 1	26.75 ± 1	32 ± 1

2.1.1 Flower Waste

Flower waste is the main material used for the study in which Marigold, Roses, Tansy, Lotus, Jasmine, and Columbine were the major types of flowers collected from the temple. Flower waste was collected from nearby temples in Surat, Gujarat. The unwanted materials were removed from the flower waste before using for the study.

2.1.2 Cow Dung

The cow dung was collected from the cattle farm near the SVNIT campus. Cow dung is very rich in microbial population and used as the inoculums to enrich the microbial biomass in the flower waste.

2.1.3 Crushed Dry Leaves

Dried leaves were collected from SVNIT college campus in summer season and then crushed into smaller sizes of 2–4 cm. Dried leaves were used as bulking agent for providing the porosity and to control the leachate problem.

2.2 Methodology

The main aim of the study is the comparison of aerobic and anaerobic technologies for the degradation of flower waste. Agitated pile was used to the aerobic system, and closed container was used for the anaerobic system. The following two combinations were used to the study the role of each material in aerobic and anaerobic composting (Table 2).

Table 2 Composition of waste mixtures into agitated pile and anaerobic reactor

Composition of waste	Proportion in %	Quantity of fresh materials (Kg)
Aerobic composting		
FW:CD (AP1)	90:10	22.5 + 2.5
FW:CD:BA (AP2)	70:15:15	17.5 + 3.75 + 3.75
Anaerobic composting		
FW:CD (ANR1)	90:10	22.5 + 2.5
FW:CD:BA (ANR2)	70:15:15	17.5 + 3.75 + 3.75

2.2.1 Agitated Pile Composting

Duplicate piles were prepared with 25 kg mixture of materials (flower waste, cow dung, and bulking agent) in different proportions. Initially, all the piles were covered with polythene for one week, and further, all piles were turned manually in each day of the composting period after the measurement of pile temperature. The proper and periodic turning was done to ensure the proper porosity throughout the pile and to provide proper aeration inside the pile. The size of the pile constructed was limited to a size of 1.2 m length and 0.45 m height to allow adequate air circulation through the pile; otherwise, it will lead to the formation of anaerobic zones inside the pile.

2.2.2 Anaerobic Composting

Duplicate reactors were prepared with 25 kg mixture of materials in different proportion. Closed air-tight containers (reactor) of height 0.6 m and diameter 0.30 m were used for the anaerobic decomposition of flower waste. Those waste mixes were filled in corresponding labeled air-tight containers. The mixing and rotation of waste materials inside the reactor were done every day after the measurement of temperature from three different locations.

2.2.3 Monitoring of Parameters

Temperature was the daily monitored parameter, and the moisture content was the parameter that was monitored in every sampling time throughout the study period. Temperature is the key indicator to maintain the degradation of the materials. The daily monitoring of temperature was done in three different locations of pile as well as the anaerobic reactor by using a digital thermometer. A moisture content of 55–65% was maintained in agitated piles throughout the study period. If the moisture content is less than 50% in any case, it was maintained by the sprinkling of water. In case of anaerobic composting, the addition of moisture content was not required throughout the study period.

2.2.4 Collection of Samples

Samples were collected after the proper mixing of materials in piles as well as in reactors, and the total composting period was 90 days for both agitated pile and anaerobic composting. The sampling interval was 7 days for the first month, and then, the interval was reduced to 3 days for next two months. All the samples were collected from thoroughly mixed piles and reactors.

2.2.5 Analysis of Physico-Chemical Parameters

The important physico-chemical parameters analyzed for the study are pH, electrical conductivity, total nitrogen, total organic carbon, *C*/*N* ratio, volatile solids, Na^+, K^+, phosphorus, and carbon dioxide evolution rate. The fresh sample was used for the analysis of carbon dioxide evolution rate, pH, and electrical conductivity determination. After monitoring the moisture content, the oven-dried sample was grinded and sieved through 0.1 mm sieve size. This sieved sample was used for the analysis of total nitrogen, total organic carbon, volatile solids Na^+, K^+, phosphorus, and calculation of *C*/*N* ratio.

3 Result and Discussion

3.1 Temperature

Temperature is the key parameters for the composting process. During the composting period, temperature was observed in three phases in AP1 and AP2 that is mesophilic phase, thermophilic phase, and cooling phase. In AP1, initial day temperature was observed as 40.2 °C and it gradually increased to 44.3, 47.9, 50.21 °C, etc., in day 3, 4, and 5, respectively. After this period, there was no further increment in the temperature observed and it was fluctuating between 31.1 and 32 °C. In AP2, the temperature of pile was 40.7 °C in the initial day and then it reached up to a peak temperature of 56.32 °C and then it reduced gradually to reach at the ambient temperature in 17–19 days interval (Fig. 1).

The presence of thermophilic phase was more in AP2 as compared to AP1 due to the presence of dry leaves as bulking material. It absorbs the moisture content and helps to maintain the favorable condition for the growth of microbes. The bulking agents will increase the porosity of the compost; hence, the aeration will be more efficient in the case of pile mixed with the bulking agent [4]. It also resists the compost from the formation of the lumps so that the microbes get more surface area to attack the organic matter, and then more fast will be the degradation rate; therefore, the pile having bulking agent (AP2) shows very high peak temperature range than the other pile (AP1). Temperature more than 50 °C for three days shows

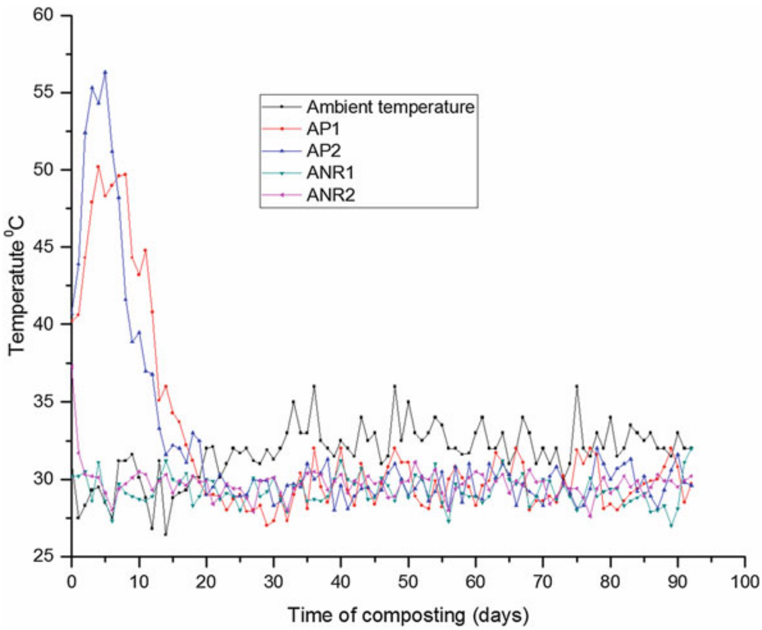

Fig. 1 Variation of temperature during the composting periods

the sanitization of compost [5]. The increment of the temperature of agitated pile indicates that the fast degradation of the flower waste. As the aeration provided to the compost by agitation, the microbial biomass will be very active to degrade the organic matter.

In the anaerobic reactors, there was no increment of temperature observed because of the slow biodegradation of the waste materials inside the reactors. All the time, the produced leachate was contained inside the reactor.

3.2 *Electrical Conductivity (EC) and PH*

Electrical conductivity was used for maturity of compost which shows the presence of salinity in the compost [6]. Initially, electrical conductivity in agitated pile AP1 and AP2 was 0.6 and 0.62 mS cm^{-1}, and it was increased to 2.1 and 1.7, 1.42 and 1.66, 1.32 and 1.27, and 1.08 and 0.93, respectively, during 14th, 28th, 65th, and 92nd day of composting, respectively. Similar increasing trends of electrical conductivity were observed during the agitated pile composting of municipal solid waste by Awasthi et al. [7]. The degradation of organic matter in thermophilic phase releases the mineral salts such as ammonium, phosphate and thus increases in EC.

In the anaerobic composting, the electrical conductivity in ANR1 and ANR2 was 0.69 and 0.65 during the initial day of composting periods. The rate of electrical conductivity was 1 and 1.1 mS cm^{-1} at the end of composting periods. In anaerobic reactor, fluctuation of EC was observed due to formation of leachate during the composting periods.

pH is a very important parameter which influences the composting process. The variation in the pH of the system affects the microbial activity on the organic waste. There should be a good control and maintenance of pH in optimum range necessary for the effective composting process. The observed values of pH for the piles AP1 and AP2, were 4.4 and 4.2, respectively, determined on the initial day of composting. For the pile AP1, the pH was increased gradually to 7.18 and 7.89 on 7th and 14th day of sampling and then observed 8.34 and 8.43 at the end of composting period. In AP2, the pH was increased to 8.32 on the 60th day. The reasons for increase in pH was due to turning of piles aerobic condition developed and organic *N* is transformed into NH_3 or NH_4^+ during ammonification which was responsible for increasing the pH of the compost [8, 9]. The stabilization pH during composting is due to the buffering capacity of humus, which is synthesized during the maturation phase of composting (Fig. 2).

In case of anaerobic reactors, both the reactors ANR1 and ANR2 showed similar trend in the variation of pH on entire composting period. In all the anaerobic reactors, initial pH was very low and almost same values were observed for the initial day. In case of AR1, the values of pH were fluctuated as 4.55, 4.62, 6.08, and 6.1 on 7th, 14th, 21st, and 28th day, respectively. The values fluctuated in a range 4.55–6.08. In case of ANR2, the initial value of pH were 4.7 and showed an irregular variation as 5.56, 5.66, 6.55, 7.93 on 35th, 38th, 41st, and 60th day of composting, and irregular variation of pH was continued up to the last day of composting period. On the last day (92nd day), observed value for ANR2 was 8.43. For the reactors ANR1 and ANR2, there was no considerable increment or decrement on the pH values; only irregular fluctuations were observed throughout the composting period.

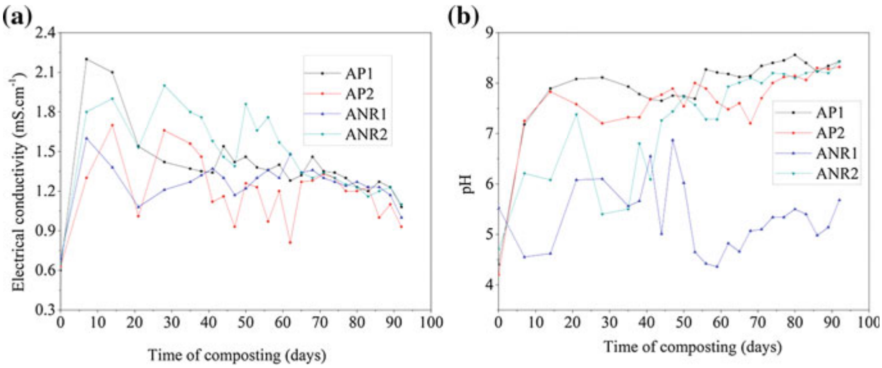

Fig. 2 Variation of electrical conductivity and pH during the composting periods

3.3 Total Organic Carbon (TOC) and Total Nitrogen (TN)

Total organic carbon is the important parameters for the metabolism of the microbes. The microbes utilize the carbon as the source of energy, and some part of carbon was lost as CO_2 during the composting process. Initially, the presence of total organic into AP1 was 46.12% and it was reduced to 44.15, 44.81, 44.26, and 40.12% during 14th, 28th, 65th, and 92nd days of composting periods. Similarly, initial 48.96% reduction in TOC was observed for AP2 which was decreased to 46.66, 41.53, 38.94, and 36.45% during 14th, 28th, 65th, and 92nd day of composting periods. The rate of reduction of TOC was higher as compared to AP1 due to thermophilic phase and development of aerobic condition which helps in degradation of organic matter [10]. The presence of bulking agents helps to increase the temperature and maintain the moisture content during the composting period [11] (Fig. 3).

In anaerobic reactor, the reduction of TOC was less as compared to agitated pile. Initially, the presence of TOC in ANR1 and ANR2 was 47.10 and 45.03%, respectively, and it was reduced to 44.45 and 39.14% at 92 days of composting period. The reasons for less reduction were low temperature and the absence of thermophilic conditions during the composting periods.

The nitrogen content is a very important parameter and shows the maturity of compost in the composting practices. The nitrogen content is utilized by the microorganisms for building the cell structure and for the synthesis of cellular matter, amino acids, and proteins. The observed %TN for the piles AP1 and AP2 on the initial days of the composting was 3.08 and 2.38. Then, the pile showed an increment on %TN value on the 7th day of composting and was noted as 4.34 and 4.2% for the piles AP1 and AP2. In the plots of agitated piles AP1 and AP2, it was observed that an increment of %TN on the initial periods of composting and this is because of the presence of nitrogen components such as amino acids, proteins in the cellular material of the microbes present in the piles [12, 13]. Ammonia was lost after 30 days of composting periods. As the pH of the system increases to 8–8.5, the excess nitrogen will be converted to ammonia gas.

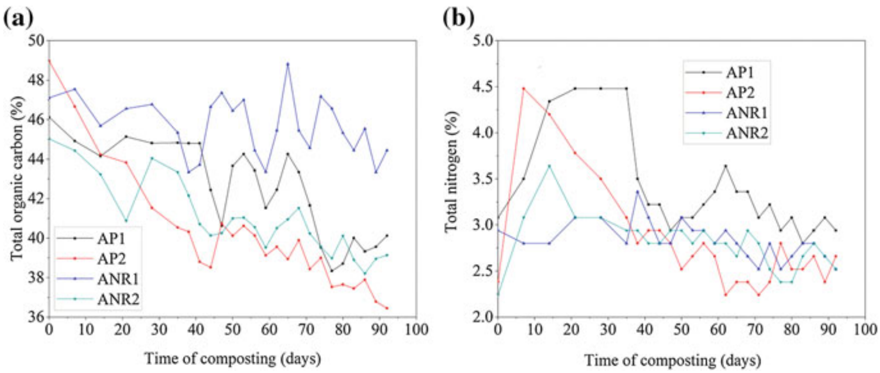

Fig. 3 Variation of total organic carbon (%) and total nitrogen (%) during the composting periods

For anaerobic reactors ANR1 and ANR2 in initial day, an observation of %TKN was 2.94 and 2.24 and slight changes 2.52 and 2.52% were observed at 92 days of composting periods. Production of leachate also reduces the amount of nitrogen from the system (nitrogen loss as leachate). The leachate production was higher in case of anaerobic degradation; hence, it was observed from the plot that the nitrogen content of anaerobic system is lesser than the agitated piles. In the anaerobic reactor, the growth and multiplication of microbes were very slow because of the acidic conditions inside the system and a little increment was observed on the initial days because of the addition of cow dung in the waste mix.

3.4 Macro- and Micro-nutrients

The presence of nutrients into the compost shows the compost quality because macro- and micro-nutrients are essential for the growth of the plants. Table 3 shows the presence of initial and final concentration of nutrients into the compost. The concentration of potassium content was high in both aerobic and anaerobic condition. It shows the high inherent content in flower waste, suggesting that compost might be good source of potassium fertilizers. The concentration of sodium and calcium gradually increased which also indicates the net loss in dry mass due to

Table 3 Presence of macro- (P, K, Na, Ca, and Mg) and micro-nutrients (Fe, Mn, Zn, and Cu) at initial and final day in compost

Parameter	Day	AP1	AP2	ANR1	ANR2
P (g kg^{-1})	0	6.32 ± 0.08	7.19 ± 0.04	6.35 ± 0.04	6.32 ± 0.03
	30	12.21 ± 0.04	11.24 ± 0.06	10.05 ± 0.02	9.15 ± 0.08
K (g kg^{-1})	0	8.23 ± 0.05	10.87 ± 0.04	8.23 ± 0.02	10.54 ± 0.03
	30	13.06 ± 0.08	15.21 ± 0.06	10.20 ± 0.04	15.32 ± 0.03
Na (g kg^{-1})	0	2.32 ± 0.05	2.44 ± 0.05	2.30 ± 0.02	2.47 ± 0.04
	30	3.42 ± 0.07	3.11 ± 0.04	3.11 ± 0.05	3.32 ± 0.05
Ca (g kg^{-1})	0	6.66 ± 0.09	7.10 ± 1.28	6.95 ± 0.93	7.23 ± 1.02
	30	11.62 ± 1.21	12.50 ± 1.25	10.66 ± 0.91	9.35 ± 1.81
Mg (g kg^{-1})	0	2.46 ± 0.04	2.16 ± 0.05	2.49 ± 0.05	2.18 ± 0.05
	30	6.12 ± 0.7	5.24 ± 0.08	3.25 ± 0.05	5.03 ± 0.07
Fe (g kg^{-1})	0	1.02 ± 0.47	1.84 ± 0.48	1.06 ± 0.18	1.21 ± 0.37
	30	3.10 ± 0.59	3.62 ± 0.35	3.02 ± 0.46	3.68 ± 0.39
Mn (mg kg^{-1})	0	83.09 ± 61	97.37 ± 51.5	83.13 ± 48.26	75.78 ± 41.09
	30	168.45 ± 21	166.54 ± 59	160.31 ± 0.93	158.76 ± 0.89
Zn (mg kg^{-1})	0	142.33 ± 0.8	158.27 ± 0.16	149.51 ± 0.61	159.44 ± 0.8
	30	166.66 ± 1.3	187.41 ± 0.83	180.25 ± 1.4	168.2 ± 1.02
Cu (mg kg^{-1})	0	31.41 ± 0.28	36.73 ± 0.25	31.7 ± 0.27	35.61 ± 0.28
	30	38.39 ± 0.25	42.4 ± 0.31	40.51 ± 0.25	40.29 ± 0.24

degradation of organic matter, release of CO_2 mineralization during composting period. Calcium and sodium are useful nutrients for the plant growth. When compost mixed with soil, it increases soil acidification and makes nutrient more available to plant. The order of concentration of macro- and micro-nutrients into the flower waste composting is K > Ca > Mg > Na and Fe > Mn > Zn > Cu, and this concentrations of nutrients is suitable for the use of agriculture. Similarly, it was observed in literature that quantity of nutrients increases in compost due to degradation of organic matter [7, 14].

3.5 C/N Ratio

C/N ratio is the very important parameter which influences the microbial activity. Proper ratio of carbon to nitrogen should be maintained for the active microbial degradation process. For the piles AP1 and AP2, the initial *C/N* ratios were recorded as 15 and 21 which were reduced to 14 and 14 at the end of composting periods. Figure 4 shows that the *C/N* ratio decreased initially and after 30 days it increased due to variation in nitrogen contents.

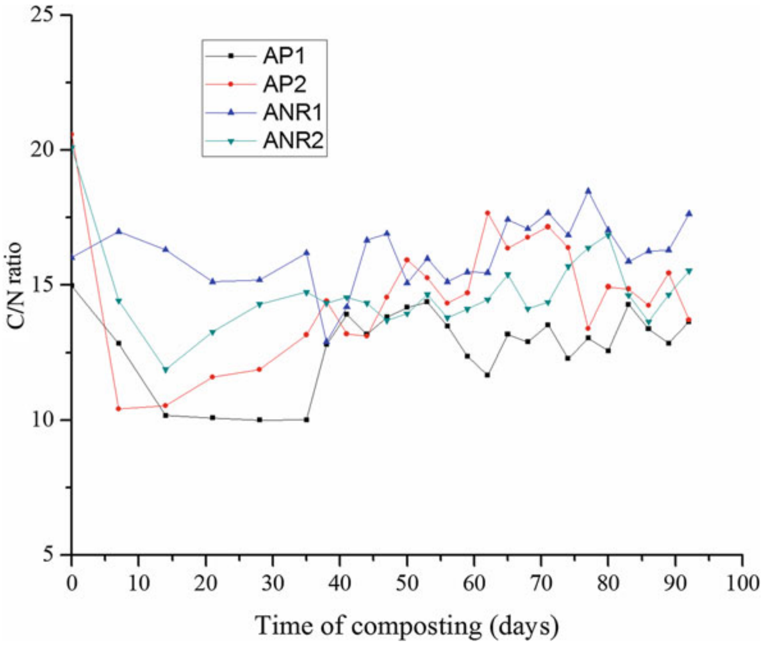

Fig. 4 Variation of *C/N* ratio during the composting periods

The optimum *C/N* ratio required for the active degradation of organic waste is 25:1 [15, 16]. The *C/N* ratios of the piles were reduced because of the reduction of total carbon content in the composting pile [17, 18].

In the anaerobic reactor ANR1 and ANR2, the initial *C/N* ratio was 17 and 21 which was reduced to 18 and 16 at 92 days of composting periods. During the composting periods, the formation of leachate was observed into the anaerobic reactor which was responsible for increase or decrease of total nitrogen and responsible for variation of *C/N* ratio during the composting periods.

4 Conclusions

Agitated pile composting method and anaerobic composting methods were performed for the comparison of aerobic and anaerobic decomposition of flower waste. The agitated piles and the anaerobic reactors were fed with different proportion of flower waste, cow dung, and bulking agent, and all the physico-chemical parameters were monitored in the entire composting period of 92 days. The following conclusions were made from the detailed study.

- The increment of temperature was observed in all the agitated piles which indicate the active microbial activity in the system. There was no increment of temperature inside the anaerobic reactors because of the slow microbial activity.
- For the degradation of flower waste, the aerobic composting method is more fast and efficient method than the anaerobic decomposition method. The proper turning, control of moisture content, adjustment of pH, and C/N ratio are essential for the active composting practice.
- The optimum mixes found from the study are 70 flower wastes: 15 cow dung: 15 dry leaves for the agitated pile composting.
- Lump formation was one of the major problems in both the anaerobic reactor and the agitated piles without bulking agents. The lump formation and algal growth were observed in the anaerobic reactors and lasted for the entire composting period. The lump formation was not observed in the pile AP2.

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Aerobic Composting of Household Biodegradable Waste—An Experimental Study

V. S. Vairagade and S. A. Vairagade

Abstract Composting is one of the methods for better management of the solid waste which results in a profitable product. The main objective of the work was to carry out composting of the biodegradable waste generated at home. The work was a laboratory test conducted on the household waste generated daily which normally consists of the vegetables, fruits and food waste. Various parameters were tested on the compost produced on weekly basis. This includes pH, temperature, moisture content, carbon content, total phosphorus and germination index. The results obtained were compared with the parameters required for the ideal compost, and the results were in the proximity of what required for ideal compost. The compost at near maturity shows an average temperature of 35 °C, pH close to neutral, moisture content of 69%, carbon content of 45%, total phosphorus of 1.1% and germination index of 80%. Being the size of the reactor small, it can be installed at home.

Keywords Solid waste · Household waste · Composting · Solid waste management

1 Introduction

Solid wastes are those materials other than liquids or gases that are considered by their owner to no longer possess value and are discarded as useless or unwanted. Solid waste is very heterogeneous in nature and its composition varies with place and time. Based on the source, origin and type of waste, a comprehensive classification of solid waste is available and defined accordingly. Terminologies as domestic/residential waste, municipal waste, commercial waste, institutional waste, garbage, rubbish, ashes, bulky wastes, street sweeping, dead animals, construction

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and demolition wastes, industrial wastes, hazardous wastes and sewage wastes include the solid waste. The quantity of waste produced is normally observed to vary between 0.2 and 0.6 kg/capita/day. Values up to 0.6 kg/capita/day are observed in metropolitan cities [1].

Migration and population upsurge, due to rapid industrialisation in Indian cities, have led to the generation of thousands of tonnes of municipal solid waste (MSW) daily that are disposed in low-lying areas, without taking any precautions or operational controls. In many cities, nearly half of solid waste generated remains unattended, giving rise to insanitary conditions especially in densely populated slums which in turn results in an increase in morbidity especially due to microbial and parasitic infections and infestations in all segments of population, with the urban slum dwellers and the waste handlers being the worst affected. When solid waste is disposed off on land in open dumps or in improperly designed landfills (e.g. in low-lying areas), it causes the following impact on the environment such as groundwater contamination by the leachate generated by the waste dump, surface water contamination by the runoff from the waste dump, bad odour, pests, rodents and wind-blown litter in and around the waste dump, generation of inflammable gas (e.g. methane) within the waste dump, bird menace above the waste dump which affects flight of aircraft, fires within the waste dump, erosion and stability problems relating to slopes of the waste dump, epidemics through stray animals, acidity to surrounding soil and release of green house gas. Therefore, municipal solid waste management (MSWM) has become one of the major environmental problems for all Indian cities that manage the activities associated with generation, storage, collection, transport, processing and disposal of solid wastes [1].

Effective solid waste management systems are needed to ensure better human health and safety. An economically and environmentally sustainable solid waste management system is effective if it follows an integrated approach; i.e. it deals with all types of solid waste materials and all sources of solid waste. The hierarchy usually adopted is (a) waste minimisation/reduction at source, (b) recycling, (c) waste processing (with recovery of resources, i.e. materials (products) and energy), (d) waste transformation (without recovery of resources) and (e) disposal on land (landfilling) [1]. Waste processing through biological or thermal treatment of waste is generally adopted. Biological treatment involves micro-organisms to decompose the biodegradable components of waste. Two types of processes are used as aerobic and anaerobic processes. In the aerobic process, the utilisable product is compost. In the anaerobic process, the utilisable product is methane gas. The organic content of municipal solid waste (MSW) tends to decompose leading to various smell and odour problems. It also leads to pollution of the environment. To ensure a safe disposal of the MSW, it is desirable to reduce its pollution potential and several processing methods are proposed for this purpose. Composting process is quite commonly used and results in production of a stable product—compost which depending upon its quality can be used as a low-grade manure and soil conditioner.

Composting is defined as the biological decomposition and stabilization of organic substrates under conditions which allow development of thermophilic temperature as a result of biologically produced heat, with a final product sufficiently stable for storage and application to land without adverse environmental effects. Another definition, agreed in Europe, refers composting to a controlled aerobic process carried out by successive microbial populations combining both mesophilic and thermophilic activities, leading to the production of carbon dioxide, water, minerals and stabilized organic matter. Generally, composting is applied to solid and semi-solid organic wastes, such as night soil, sludge, animal manures, agricultural residues and municipal refuse. Composting of organic waste can be done using various techniques as mentioned in the literature such as Vermicomposting, Bangalore method of composting, Indore method of composting, Chinese rural composting—pit method, aerated static pile composting, heap and windrow composting, box, bin and barrel composting, Takakura home method, and in-vessel—forced aeration compost bin method [2, 3, 4, 5, 6].

Developing countries like India generate more food waste compared to developed countries. The putrefying nature of food waste makes it less viable for storage and transportation. It also hinders the recovery of recyclable materials. Limited land resource available for dumping of waste which is ever increasing with increase in population has led India to think over techniques of reducing waste at the source itself. Composting is one such and the most viable technique to serve the purpose. The use of small-scale in-vessel composting systems at household level is a better way to dispose the kitchen waste and turn it into compost on site in a relatively short time. It is envisaged that a fully developed and highly efficient in-vessel composting system will provide one of the practical solutions to deal with the tremendous amount of food waste generated and related problems faced by housing societies, community halls, shopping centres, hotels and restaurants, institutions like universities, colleges and schools. The concept of in-vessel composting has a great scope in India because it is simple to use at the backyard, saves lot of space, easy to operate in all weather conditions and easy handling of waste. The whole process is clean and economical, when compared to conventional methods of composting like windrow composting, static pile composting. Presently, simple to highly sophisticated in-vessel composting systems are widely used in western countries [3].

The following paper deals with the food waste (garbage) which includes the waste from preparation, cooking and serving of food. Also, market refuse and waste from handling, storage and sale of vegetables are included in this type of waste. The paper proposed designing and testing of actively aerated (forced aeration) compost reactor, production of compost from organic fraction of household waste, analysing the different parameters of the mulch at various stages, assessing the final product from the reactor in terms of quality and time of maturation and checking the efficiency of the bio-reactor and recommending the changes to improve the same.

2 Materials and Methodology

2.1 Materials for Composting

The materials required for composting include food waste, vegetable waste and fruit waste. The food waste was collected from the D-mess, V.J.T.I. hostel campus. The vegetable waste and fruit waste were collected from the Matunga market, Mumbai. The materials were shredded to a size of 2–5 cm. The materials required for composting are proportioned in such a way so as to match up with household kitchen conditions.

2.2 Methodology

2.2.1 Composting Reactor

A specially designed composting reactor was used for food waste composting in this study. The reactor was a bin having 42 cm at the top and 35.31 cm at the bottom (Fig. 1). The height of reactor was 47 cm. A 6-mm-thick and 35.0-cm-diameter acrylic circular plate was placed at the bottom of the reactor, and a plate of 8 mm thickness and 15 cm diameter was placed above it at the centre. Acrylic cover of 5 mm thickness was placed above the reactor. In the top cover of acrylic material, six holes of 1.4 cm diameter were made, through which aeration pipes were passed for providing aeration. The pipes from top were arranged in such a way that the bottom of alternate pipes was maintained at the level of 10 and 20 cm with respect to the bottom, for providing uniform aeration at different levels. Also, a rectangular opening was kept in the cover. A central acrylic rod of 3.5 cm diameter was placed with curved blades for efficient mixing process. A handle was provided for rotating the rod. A circular pattern of 4-mm-diameter holes was provided at the bottom around the central rod for collecting leachate sample from the reactor. A tray was provided to collect the leachate sample coming from the reactor. For providing forced aeration, nebulizer with an air flow rate of 8 L/min and an air compressor having the flow rate 2.4 m^3/h were used.

The reactor was loaded with 1.2 kg of the food waste four times a week. Fruit waste and vegetable waste (1.2 kg) were loaded into the reactor once every week. Pre- and post-loading mixing was done 2–3 times a day. Air was supplied from the nebulizer having a flow rate of 24 hour/day, whereas the air compressor supplied air with a flow rate of 4 hour/day.

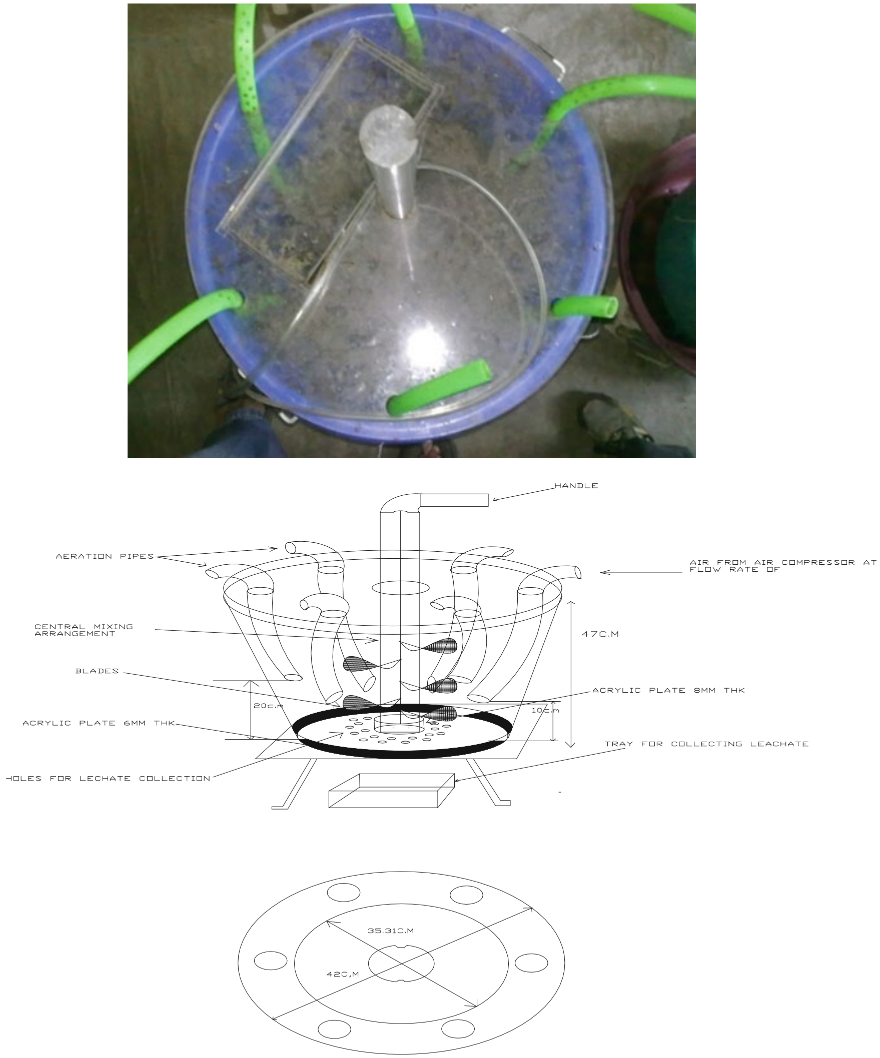

Fig. 1 Experimental setup for composting reactor

3 Observations and Results

3.1 Physical and Chemical Parameters of Compost

Effects of loading on different parameter with respect to time were observed and are shown in Table 1 [1, 5, 7].

Table 1 Tabular presentation of physical and chemical parameters

Parameters	Loading period (days)								Maturation period (days)	
	7	14	21	28	35	42	49	56	63	70
Temperature (°C)	30.10	30	30	29.23	31.13	31.7	32.8	33.25	33.5	35
pH	4.30	4.70	4.80	5.30	5.32	5.25	5.10	5.41	4.35	5.17
Moisture content (%)	83.91	85.53	85.57	81.52	78.43	75.46	74.40	76.77	72.86	69.63
Carbon content (%)	54.23	54.40	39.70	45.35	44.61	47.61	46.69	44.76	42.91	43.98

Table 2 Tabular presentation of maturation parameters reading

Parameters	Time after the loading started (maturation period in days)					
	31	45	58	60	65	69
Total phosphorus (%)				0.735	0.730	1.070
Germination index (%)	0	58.82	96.55			

3.2 Maturation Parameters Reading

Effects of loading on different maturation parameter with respect to time are shown in Table 2 [8, 9, 10].

3.3 Effect of Rise of Temperature

Effect of rise of temperature on compost is shown in Fig. 2. The gradual rise of the temperature shows the growth in the microbial activity and the maturation of the compost. The study carried out shows that the optimum temperature for a composting process is in the range 30–50 °C.

As the graph shows, during the initial composting period of about 21 days, the temperature almost remained constant. However, due to collection of leachate in the reactor itself, the temperature considerably dipped during 21st–28th day and continued to be less till the 35th day. Clinical arrangements for leachate removal were done, and then again, there was a rise in the temperature. This increased temperature results in increased rate of biological activity and hence results in faster stabilization of the material.

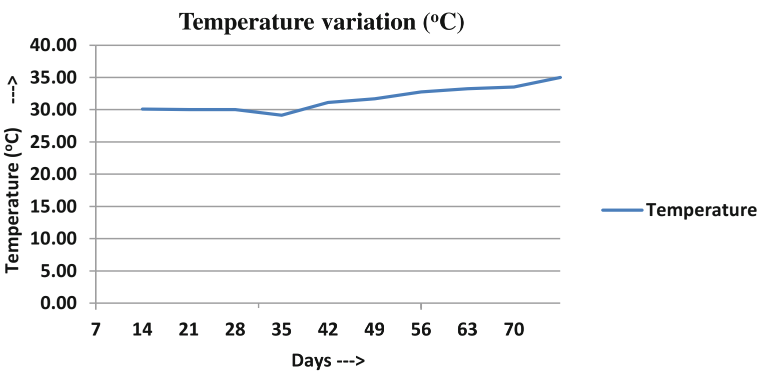

Fig. 2 Temperature effect on compost

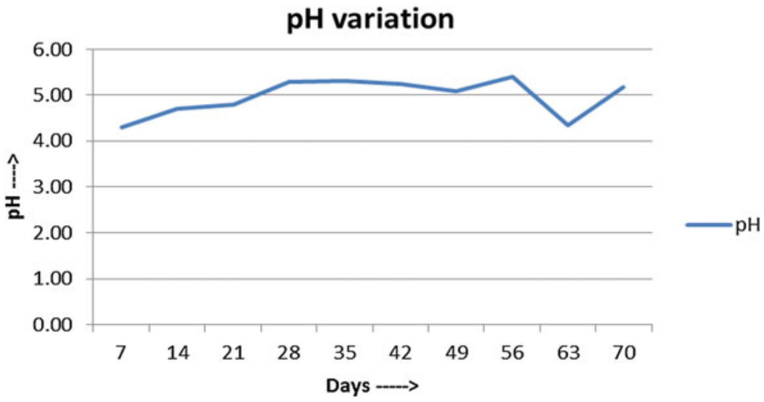

Fig. 3 pH effect on compost

3.4 pH

pH is one of the important physical parameters in the process of composting and also in the plant growth. Figure 3 shows the pH variation during the loading and initial maturation period.

The variation in pH is due to heterogeneous nature of food waste. The loading included rice, noodles, wheat bread and raw vegetables. Thus, due to variety of loaded wastes, the pH varied. On the 60th day, mixing and aeration were not done deliberately to observe the variation of pH in their absence.

3.5 Moisture Content

Water is essential for all microbial activity and should be present in appropriate amounts throughout the composting cycle. Optimal moisture content in the starting material varies and essentially depends on the physical state and size of the particles and on the composting system used. The effect of moisture content on compost is shown in Fig. 4.

Due to increase in the temperature and proper aeration, the moisture content is gradually decreasing. The reduction in the moisture content shows proper aerobic composting process in progress. It is observed that the active composting period occurs when moisture ranges from 45 to 55%. The nature of the graph indicates that optimum moisture content required for the active composting will be achieved in the days to come.

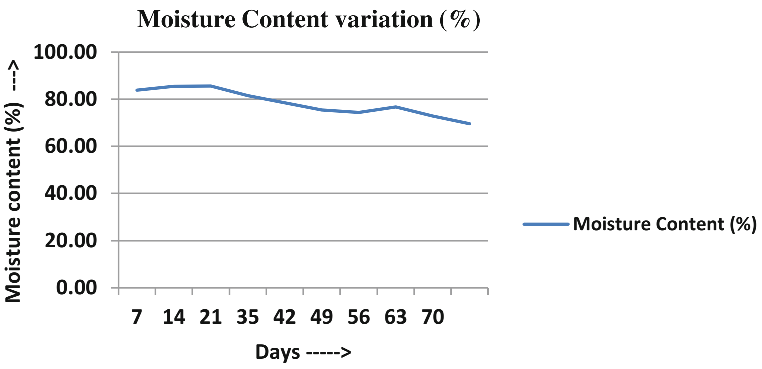

Fig. 4 Effect of moisture content on compost

3.6 Carbon Content

Carbon content of compost with respect to time is shown in Fig. 5:

The above graph trend is decreasing in nature. The loading waste material was rich in carbohydrates. Slowly, due to the degradation of the carbohydrates, the carbon content went on decreasing.

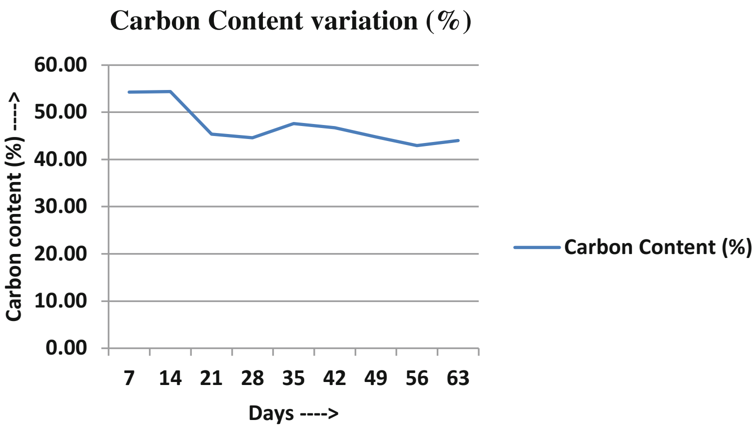

Fig. 5 Effect on carbon content on Compost

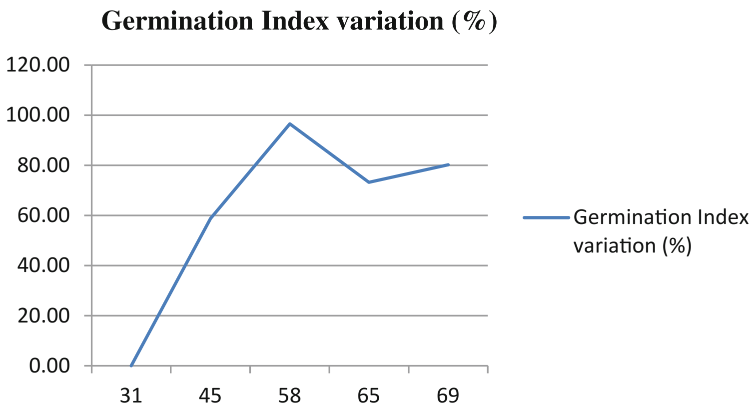

Fig. 6 Variation in germination index

3.7 Germination Index (G.I.)

Nature of germination index for compost is shown in Fig. 6:

As the graph indicates, there has been a continuous increase in the germination index. Higher the germination index, better is the compost. This indicates that the process of compost maturation is progressing in the right direction. Thus, at complete maturation, the compost so formed will be suitable to be used as manure (Fig. 7).

3.8 Total Phosphorous

As phosphorus produces vigorous seed and root system development, it is very important to have it available during early stages of plant development. Compost itself applied to a garden over time, makes it easier for plants to extract phosphorus from the soil. Homemade compost contains 0.5–4% phosphorus and as the graph shows continuous increase in the phosphorous level from 0.7 to 1.1 (Fig. 8).

It can be concluded that the phosphorous content in the final compost after maturation period will be as per standard requirement and the compost will be it as manure for the plants.

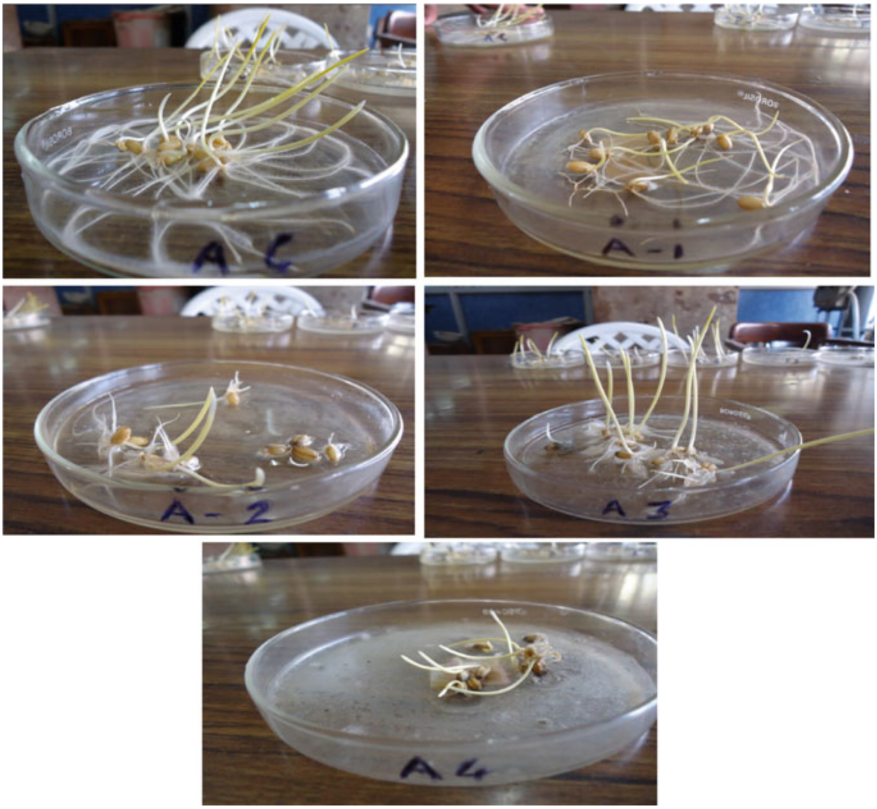

Fig. 7 Germination index test results

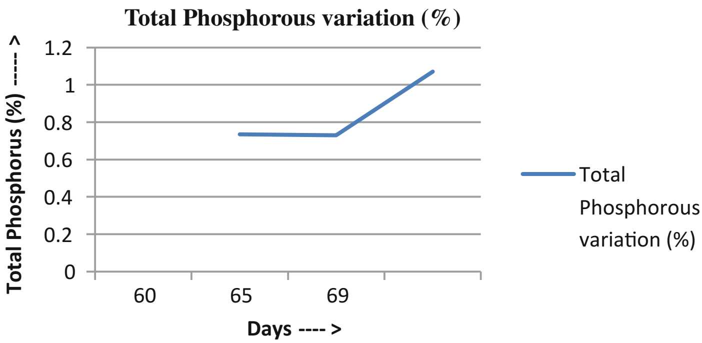

Fig. 8 Variation of total phosphorous

4 Discussion and Conclusion

Actively aerated reactor should be looked as one of the options for processing household waste. In this reactor, all sort of household waste which is organic in nature can be used efficiently for composting.

The following points regarding the process can be inferred:

- Good quality compost can be prepared from the household organic waste.
- The reactor produces the compost more rapidly than the other conventional methods.
- Installing this reactor will reduce the load on the municipal waste processing authorities.
- Compost which is produced from the reactor can be used for gardening purpose. This compost can be used as substitution for chemical fertilizers.
- Processing of household waste at household level will reduce the load on municipal dumping grounds.
- This process of composting converts complex form of organic waste into the stable, simpler and inorganic form which has little pollution effect.
- Treating household waste in this reactor will reduce the health hazards caused due to pathogens which get formed due to unstable dumping of waste.
- Production of compost at household level from the household waste can be seen as the source of secondary income.

The current project work has shown that a good quality of compost can be prepared by using this reactor at household level also. Still there is scope for further study in this work which includes:

- Comparative study for rate of composting, quality of compost, and cost of processing between the conventional methods of composting and present methodology.
- Cost estimation for implementing and processing this reactor at household level can be done.
- Work efficiency of this reactor at different environmental and temperature conditions can be studied.
- Further modification and improvement in the design and working of this reactor can be done in order to reduce the duration and to improve the quality of compost.
- Analysis of leachate can be included in the further study. This will help in getting a clear idea of the nature of the leachate.
- Spreading awareness among the people about such composting processes and approaching them to install such reactors will ultimately produce benefits for the society.

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Part IX
Industrial Waste Treatment and Management

Studies on Paper and Pulp Industry Waste for Leather Making: An Insight in Converting Waste to Wealth

P. Balasubramanian, M. Vedhanayagam, G. C. Jayakumar, K. J. Sreeram, J. Raghava Rao and B. U. Nair

Abstract The present work describes the preparation of leather dye using paper and pulp industry wastes. In this work, black liquor was modified to pH 7 by using sulfuric acid and was used as a retanning agent for leather processing. The characteristic features of modified products were thoroughly investigated by Fourier transform infrared spectroscopy (FT-IR), Zetasizer, and energy dispersive spectrometer (EDS). The purity of the modified black liquor is ascertained through UV-visible spectroscopy. The modified black liquor treated leather shows good softness, filling, and high strength, with uniform dyeing. This process divulges to increase the accessibility to value-added products using black liquor as a starting material. This study paves a way in providing some basic understanding on the degradation of paper and pulp industry waste and its chemical constituents like phenolic hydroxyl groups involved in leather dyeing cum retanning effect. Additionally, this research works emphasis on the reduction of conventional synthetic chemicals used in leather manufacture by utilizing the waste product leads to reduce the environmental pollution loads.

Keywords Black liquor · Acidification · Lignin · Retanning agent Leather

1 Introduction

Reuse and recycle of various industrial waste lead to decrease in environmental pollution [1, 2]. The paper and pulp industry waste contains larger amount of highly toxic and intensely colored effluents, and these wastes are called as black liquors [3, 4]. These waste liquors contribute high pollution load to the environment owing to

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high level of chemical oxygen demand (COD) [5]. Black liquor is a major waste from paper and pulp which is used as a raw material for many applications like preparation of carbon filter, concrete, dispersants, and antioxidant. Black liquor mainly composed of lignin (60%) and other derivatives along with inorganic salts (40%). This waste has the potential to be used as a raw material for manufacturing and energy production in a sustainable environment [6]. One of the major impediments to use these feedstocks is the presence of lignin [7]. Lignin is one of the most abundant natural polymers and present in the higher plants [8]. Black liquors are highly concentrated in organic materials with lignin being the main component of the total dry mass. Lignin has a highly branched three-dimensional phenolic structure including three main phenylpropane units such as p-coumaryl, coniferyl, and sinapyl alcohol [9–11]. Leather industries have been using phenolic compounds which are structurally related to the natural plant polyphenol tannins for synthetic tanning agent preparation because they contain phenolic hydroxyl groups and has the ability to react with collagen to produce leather [12]. These commercial phenolic derivatives are expensive, and hence, there is a scope to develop tanning agents based on phenolic compounds from alternate source. Oxidation of phenolic derivatives results in very dark colored products [13]. Hence, phenolic lignin degradation products have potential to be used in synthesis of colored products for dyeing and in syntan production after condensation for retanning of leather [14, 15]. In fact, these degraded lignin compounds were polymerized with formaldehyde and used for leather tanning process as reported by Suparno et al. [15]. To the best of our knowledge, there is no report on understanding the mechanism of dyeing and retanning effect of black liquor in leather manufacture. In this work, black liquor was modified using sulfuric acid and the same was used as a retanning cum dyeing agent for leather processing. This study enables to explore the basic science involved in the acidification of black liquor and better utilization of paper and pulp industry waste (black liquor) for value addition in leather making as leather auxiliary with multiple properties.

2 Materials and Methods

2.1 Materials

Black liquors were procured from a commercial paper and pulp industry in Erode, Tamil Nadu. Sulfuric acid (98%), sodium acetate, and sodium chloride were purchased from HiMedia Laboratories Pvt. Ltd and potassium dichromate and silver sulfate from Sigma-Aldrich. Deionized water was used for the analytical experiments. Commercial grade chemicals were used for leather processing.

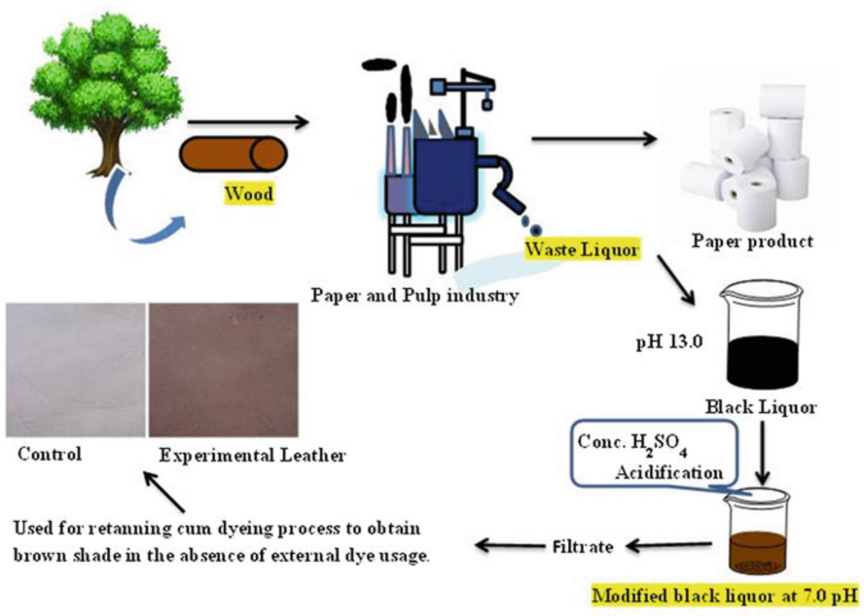

Fig. 1 Modification of black liquor

2.2 *Percentage Organic Content of Modified Black Liquor*

The black liquor was analyzed for total dissolved solids, % organics, % inorganics, and pH using standard methods [16]. The pH of black liquor was adjusted with sulfuric acid to 7 with continuous stirring. The black liquor solution at 7 pH was filtered using normal filter paper and collected the filtrate for further studies.

2.3 *Methodology*

See Fig. 1

3 Characterization Techniques

3.1 *Modification of Black Liquor*

The black liquor was modified by adjusting the pH 7 using of sulfuric acid. The modified black liquor was filtered and analyzed for soluble organics by standard methods [16]. The filtrate at pH 7.0 was kept stirring using magnetic stirrer for 3 h at ambient temperature. 10 mL of the modified black liquor was transferred to crucible and kept in the hot air oven at 110 °C for 12 h. The percentage soluble organics in the modified black liquor was calculated by using weight loss method after heating the total solids at 1100 °C in muffle furnace.

3.2 Characterization of Black Liquor Using UV–Visible Spectroscopy

The black liquor as well as modified black liquor was subjected to UV-visible spectroscopy. The absorbance of the solution was recorded in the wavelength range of 240–370 nm using a Lambda 35 UV/VIS spectrophotometer (PerkinElmer, UK).

3.3 Characterization of Black Liquor Using FT-IR Spectroscopy

FT-IR spectrum was obtained using an ABB MB 3000 spectrometer at room temperature. All spectra were taken at 4 cm^{-1} resolution, averaged over 31 scans in the range of 500–4000 cm^{-1}. Dried black liquor and dried modified black liquor were mixed with potassium bromide in the ratio of 2:100 (IR grade KBr was used as scanning matrix) to make nearly transparent and homogeneous pellets and then taken for FT-IR measurement. The final spectra were recorded after subtracting the background spectra of KBr.

3.4 Zeta Potential Evaluation

Zeta potential of the black liquor and modified black liquors were determined by using dynamic light scattering (Zetasizer Nano, Malvern instruments UK) at 25 °C. Initially, the modified black liquor of 7 pH was dissolved in Milli-Q water and then sonicated for 10 min before the analysis. All the experiments were performed in triplicate, and average was taken.

3.5 Energy Dispersive X-ray (EDS) Analysis

Modified black liquor was oven dried at 90 °C for 1 h. The samples were rinsed with methanol and sputter-coated with gold to avoid possible contamination. Scanning electron microscope (SEM) characterization of the modified black liquor was performed using Quanta 200 FEI micrograph analyzer. The substance on the cell wall of modified black liquor was analyzed through EDAX. EDAX provides the elemental composition of the surface of the sample.

3.6 Application of Modified Black Liquor in Leather Making

3.6.1 Retanning Process

The pH of the chrome tanned leathers was adjusted to 4.8–5.0 using 200% water, 1% neutralizing syntan, 0.5% sodium formate, and 0.5% sodium bicarbonate and subsequently washed, and the float was drained. Retanning process was carried out on the neutralized leather with 10% each of the prepared modified black liquor added to 50% water, and 8% fatliquor (oil emulsion) and preservative 0.1% for 2 h [17]. Finally, the pH was adjusted to 4.0 with acetic acid for fixing the chemicals to the leather matrix. The retanned leathers were washed with water and left to dry in fresh air by hanging at room temperature [18].

3.6.2 Determination of Color Difference of Final Leather

The conventional (control) and experimental crust leather obtained using modified black liquor was subjected to reflectance measurements using a premier color scan SS5100A instrument. Color measurement (L, a*, b*, h, and c*) has been recorded, where L represents lightness, a* represents the red and green axis and b* represents the yellow and blue axis, h represents hue, c* represents chromaticity [19].

3.6.3 Physical Testing of Leather Samples

The samples for physical testing were obtained as per IULTCS methods [20].The samples were conditioned at 26 °C and 65% relative humidity for 48 h. Physical properties such as tensile strength, % elongation, tear strength, and grain crack strength were investigated as per standard procedures [21–23] for all the leathers made in this study. Each value reported is an average of four (2 along and 2 across the backbone) measurements. Young's modulus was also calculated.

4 Results and Discussion

4.1 *Modification of Black Liquor for Retanning Cum Dyeing*

The black liquor comprises of 60% total solids of which 60% is organics and 40% inorganics. The pH of the black liquor is 13.0. Although reports exist [24] on the extraction of organic components from black liquor using different solvents and further condensation with formaldehyde, the yield of the extracted organics is low and the presence of formaldehyde is a cause for concern. In order to take advantage of the presence of higher soluble organics, it has been planned to use the black liquor directly for leather processing as a retanning agent, as the degraded lignin present contains phenolic derivatives similar to vegetable tanning molecules.

However, the higher pH of the black liquor is determental to its use as a retanning agent due to practical difficulty in employing it for post tanning process. Hence, it has been attempted to modify the black liquor by acidification with sulfuric acid to pH 7, which falls in the operational pH of the leather auxiliaries. The change in the pH of the black liquor results in the variation in the composition of the soluble organics. The percentage soluble organics in the modified black liquor at pH 7 is 66%, which indicates the organics extraction as the pH of the black liquor shifts to acidic range. Finally, the pH 7 has better strength to compare standards. This trend is in accordance with the earlier observations of higher insoluble lignins at lower pH [25].

4.2 *UV–Visible Spectroscopy*

Modified black liquor has the ability to absorb in the UV–visible region due to its chromophoric groups. The purity of precipitated degraded lignin was verified from UV–visible spectrum of the sample at 210–350 nm [26]. Degraded lignins absorb UV light with high molar extinction coefficients because of the several methoxylated phenylpropane units [27]. The absorption peaks observed around in the range of 269–280 nm. This result clearly reveals that black liquors are degraded, and most of modified black liquor product contains unconjugated phenolic hydroxyl groups and the aromatic moiety of the lignin molecule [28].

4.3 *FT-IR Spectroscopy*

The FT-IR spectrum of dried black liquor and dried modified black liquor at pH 7 is shown in Fig. 1. The black liquor exhibits seven main asymmetric absorption bands, which are typical for high molecular weight compounds with irregular structure. The broad peak at 3422 cm^{-1} corresponds to stretching frequency of –OH groups. Peaks observed at 2939 cm^{-1} and 2845 cm^{-1} are predominantly arising from $–CH_2$ symmetric and asymmetric stretching frequency of methyl or methylene groups of side chains. The broad peak observed at 1588 cm^{-1} corresponds to the –C=C– stretching frequency of aromatic rings. Peaks observed at 1445 cm^{-1} and 1125 cm^{-1} are due to –C–C– aromatic rings and syringyl stretching frequency, respectively. The peak observed at 835 cm^{-1} is due to –C–H deformation. On the other hand, the modified black liquor exhibits similar peaks along with some new peaks. The narrow peak observed at 1615 cm^{-1} is attributed to the –C=C– stretching frequency of aromatic rings, whereas the pure black liquor shows broad peak for C=C– stretching. In addition, one sharp and intense new peak at 1511 cm^{-1} corresponding to stretching frequency of aromatic –C=C groups was observed. The narrowness of peaks along with appearance of a new peak clearly indicates that the black liquor was effectively modified. The peak at 1445 cm^{-1} is split into two peaks positioned at 1453 cm^{-1} and 1424 cm^{-1} attributable to stretching frequency of aromatic ring –C–C– stretching [29]. The bands at 1212 cm^{-1} and 614 cm^{-1} present in the spectrum of modified black liquor are due to –C–S stretching. The above results clearly confirm the modification of black liquor (Fig. 2).

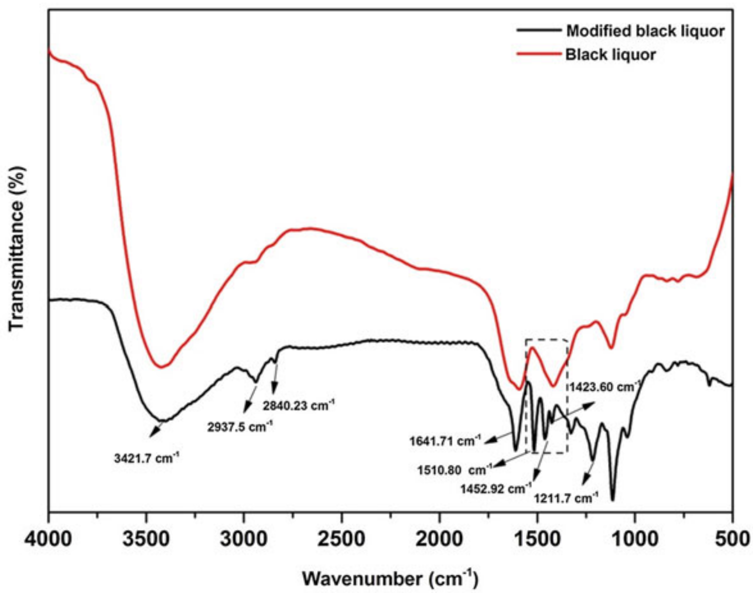

Fig. 2 FT-IR spectra of black liquor and modified black liquor at pH 7

4.4 Zeta Potential Evaluation

The zeta potential of black liquor is −58 mV, which decreases on acidification to −39 mV indicating degradation of black liquor. The black liquor at pH 13.0 has a large number of carboxylate anion leading to higher negative charge on the surface. The modified black liquor exhibits lower zeta potential when compared to the black liquor due to lower number of negatively charged ion present in the solution. The result suggests that both the samples have a higher stability in colloidal form.

4.5 Energy Dispersive X-ray (EDS) Analysis

EDAX micrographs of the waste black liquor after modification at pH 7 are shown (Table 1) that modified black liquor has 49.21% content of carbon, 25.745 content of oxygen, 13.20% content of sodium, 08.91% content of sulfur, that may help to improve the inner lubrications of the leather, 00.88% content of chlorine, and 02.06% content of potassium, respectively.

4.6 Application of Modified Black Liquor for Leather Manufacture

4.6.1 Color Measurements

The modified black liquor at pH 7 was applied as a retanning cum dyeing agent for leather processing in post-tanning operation. The *L*, *a*, *b* values of these leathers along with those of conventionally treated leathers (Control leather) are presented in Table 2. It is observed that the control leather has *L* value of 81 indicating lightness in shade as compared to modified black liquor treated leathers. The color changes from brown hue of leather at pH 7 with a value of 68° to lighter brownish gray as compared to control of lighter shade at 138°. The lightness in color with decreases in pH for the modified black liquor indicates the removal of darker lignin components from the black liquor. The quality of the leather is good in terms of grain

Table 1 Elemental measurements of modified black liquor at pH 7

Elements	wt%
C	34.60
O	33.35
Na	20.24
S	08.98
Cl	00.86
K	01.97

smoothness, fullness, and feels for the modified black liquor at pH 7 indicating the optimum pH for the modification of black liquor for leather application. Although leather prepared with the modified black liquor with lower pH exhibits lighter shades, the usage for post tanning needs slight modification in the application. It is important to assess the final quality of the leather when a new chemical formulation is employed for leather processing. In order to look at the performance of the modified black liquor, the physical strength properties of the final leathers made from modified black liquor as well as conventional process were measured. The tensile, tear, and grain crack strength were measured for the control and modified black liquor retanned leather both along and across backbone line in identical areas. The corresponding mean values of each experiment were averaged, and the values are given in Table 3.

It is observed that the results from physical strength of retanned leathers are comparable in terms of tear and grain crack strength with that of control leather except that of tensile strength. The decrease in tensile strength for modified black liquor with decrease in pH may be due to acidity of the system.

Table 3 shows Young's modulus of control and modified black liquor retanned leather. Young's modulus of the modified black liquor retanned leather increased linearly when compared to the control leather. Particularly, for modified black liquor at pH 7, Young's modulus of retanned leather exhibit higher values due to better distribution and optimum filling of the leather. In addition to this, the load at grain crack values is gradually increased, and at the same time, the distention at grain crack values is decreased compared to the control leather. This result clearly demonstrates that the retanned leather has higher load capacity and softness than control leather. The modified black liquor at pH 7 showed improved mechanical properties compared to the conventional control leather.

Table 2 Color measurements of modified black liquor

Sl. No.	Name	L	a*	b*	c*	H
1	Control white crust	81.46	−2.28	2.07	3.08	137.73
2	pH = 7	52.97	5.10	12.74	13.72	68.17

https://en.wikipedia.org/wiki/CIELAB_color_space

Table 3 Physical strength characteristics of the leathers obtained from modified black liquor at various pH

pH of extract	Tensile strength (N/mm^2)	Tear strength (N)	Young's Modulus (MPA)	Lastometer	
				Load at grain crack (kg)	Distention at grain crack (mm)
Control	29.00 ± 0.20	26.00 ± 0.12	33.72 ± 0.30	21	8.00
pH 7	30.58 ± 0.13	72.53 ± 0.15	47.90 ± 0.24	37	8.28

4.6.2 Bio-Resource Utilization for Value Addition in Leather Making

The black liquor has been directly applied for leather making with addition of minimum chemicals. The waste effluent from leather making contains very low COD values (2400 mg/kg) for 10% solution. These results suggested that the modified black liquor from black liquor can be used effectively for leather making application.

5 Conclusions

The present work involves modification of the black liquor through acidification to pH 7 for removing the degraded lignin of higher molecular weight. The modified black liquor was characterized through different spectral techniques and used for leather processing as a retanning cum dyeing agent. The modified black liquor was stable and when used for leather processing it resulted in producing leather of brown shades. The quality of the final leather made from modified black liquor is comparable with that of control leather and exhibited better physical properties. The leathers made from modified black liquor are fuller in substance with softness and flat grain. The main advantages of the work lie in (1) cost-effective process of using by-product as value-added product, (2) better utilization of industrial waste, (3) the product act as better replacement for additives like dye enhancer, filler in an efficient way. This work provides an ample opportunity to effectively utilize the black liquor from paper and pulp industry to prepare a value-added product for application in leather processing.

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Production of Construction Bricks Using Iron Ore Tailings and Clay

K. Behera, B. P. Bose and M. K. Mondal

Abstract Mixing iron ore tailings with clay for manufacturing bricks was investigated with the objective of converting the hazardous solid waste into useful products. Blocks were prepared using different compositions of iron ore tailings and clay in 70.6 mm cubic moulds. They were sundried and then placed in a furnace at 110 °C for 24 h to remove water. The dry blocks were fired at temperatures ranging from 900 to 1050 °C for 3 h. Characterization of tailings, clay, and sintered blocks was done. Mechanical properties such as compressive strength, water absorption rates, loss on ignition, and bulk density were measured. The maximum compressive strength of 25.40 MPa was recorded for tailing and clay ratio of 40:60 sintered at 950 °C. This compares very well with the best quality bricks in India. The results also indicate that the percentage of tailings in the blocks influences their mechanical properties. The water absorption rates of the sample blocks are low compared to clay and fly ash bricks, and the same varies with process parameters. The low porosity may deter the formation of efflorescence. The process, with standardized parameters, may be commercially adapted, and large quantities of iron ore tailings may be put to use in making bricks. Thus, the process technology delineated in this paper can potentially convert the huge amount of environmentally harmful useless waste into wealth. Iron ore tailing may emerge as a sustainable supplement to clay, use of which in brick making is increasingly being restricted. The work also paves the way for a new strand of research.

Keywords Iron ore tailings · Waste management · Recycling waste
Bricks · Clay · Waste to wealth · Sustainable construction materials

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1 Introduction

The world produced an estimated 3.32 billion tonnes of iron ore during 2015 ([1]US Geological Survey, Mineral Commodity Summaries, January 2016). The fact that generation of tailing is about 10–15% of ore [4] indicates that more than 0.3 billion tonnes of tailings are generated annually leading to increasing amount of waste. Tailings are known for leaching toxic substances—particularly heavy metals—leading to acid mine drainage in water bodies resulting contamination of water, soil, and vegetation, affecting human health and forest degradation [12, 15, 17]. Payne et al. [13] provide evidence that iron ore effluents are actually toxic with deleterious effect on the freshwater aquatic life. Besides being a concern for water, air, and soil pollution, the tailings occupy huge land area. It is, therefore, imperative to find the application of iron ore tailing for productive use. On the other hand, the use of clay for making bricks leads to irreversible depletion of the limited fertile topsoil. Many nations such as India and China are increasingly restricting the use of clay for making bricks. Finding alternative sources of raw materials is essential for sustainability of supply of construction materials, and engineers are increasingly striving to use wastes as a sustainable supplement for conventional building materials [11, 18].

Appreciating the enormity of the environmental problem associated with iron ore, many researchers have been advocating various processes to utilize this waste material in construction industry for quantitative reduction as also to supplement the scarce traditional resources. Notable among the alternatives are to use iron ore tailing to manufacture bricks, ceramic tiles [4], as fine aggregate in mortar, and coarse aggregate in concrete [8, 20], and to produce geopolymer bricks [9]. Giri et al. [6] and Sakthivel et al. [14] synthesized magnetite powder out of iron and silica that is recovered from iron ore tailings, whereas Li et al. [10] demonstrated possibility of preparing cementitious materials out of the similar residue.

Besides the fact that tailing and clay predominantly contain oxides of iron and silica, respectively, both contain common constituents, though in different proportions, such as silica, iron, alumina, calcium, manganese, sulphur, phosphorous, and a few heavy metals of different percentages. Thus, an argument is gaining currency that iron ore tailing can be a suitable substitute of clay for making bricks [3]. However, tailings lack pozzolanic characteristic and require a binding agent or may be vitrified through incineration. A strand of the literature reports encouraging results from studies that combine different materials with tailings. As an instance, Yang et al. [18] produce bricks using tailings and fly ash of different proportions. They fire them at temperature ranging from 900 to 1000 °C and report comparable mechanical properties that of clay bricks in China. Even though water absorption rates for such bricks are more than the benchmark and the physical properties tend

[1]http://minerals.usgs.gov/minerals/pubs/mcs/2016/mcs2016.pdf, accessed 15 July 2016.

to deteriorate with increasing content of fly ash, the overall performance promises large-scale use of tailings in producing bricks. Ceramic tiles made of iron ore tailings mixed with clay and feldspar fired at 1150 °C possess high cold crushing strength [4]. Furthermore, mortars produced by replacing natural aggregate with tailings showed improved mechanical properties compared with conventional materials [5]. Velasco et al. [16] provide interesting commentary on the major researches that explore various applications of tailings and the outcomes thereof. Primary objectives in these researches are to determine feasibility of using tailings —at least partially—in construction materials, optimize process parameters for large-scale consumption of this waste, and create social and economic values [19]. Few studies, if any, have been carried out to explore feasibility of producing brick using mixture of iron ore tailing and clay. The present study starts with the characterization of tailings from Indian mine and clay used in conventional brick and produces blocks of tailing and clay in different compositions and sinter at different temperatures. Some of the possible applications of tailings being proffered in the literature are shown schematically in Fig. 1.

Even though the elemental constituents of tailings from different mines and in different countries vary significantly, reports on the physical properties of bricks made by different authors across geographies are quite similar in that they meet the international standards [16]. In this light, the chances of error in generalizing the findings in any particular study are limited.

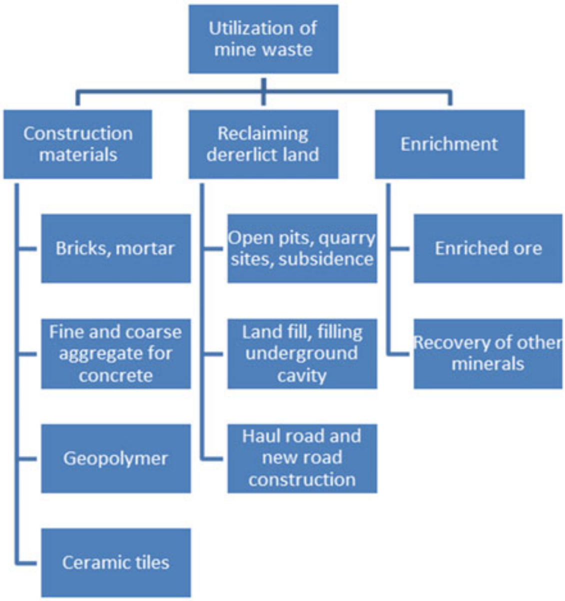

Fig. 1 Schematic explaining possible use of tailings

2 Materials and Methods

2.1 Preparation of Materials

The iron ore tailings used in the study were sourced from tailing dam (Fig. 2b) of beneficiation plant at Barbil iron ore mine of Odisha state, India. Processed clay was procured from a local established fired clay brick manufacturing company, particularly to take advantage of the traditional knowledge of the kiln workers in selecting and preparing good-quality clay for making brick. The clay and tailings were pulverized and sieved helping to prepare consistent mix. The elemental compositions of the tailings and clay obtained in SEM tests are presented in Table 1, and the morphologies are presented in Fig. 3a, b respectively. The dry tailings were sieved, and the size distribution was noted (Fig. 2a). We used the portion of the tailings with particle size of 0.6 mm and less.

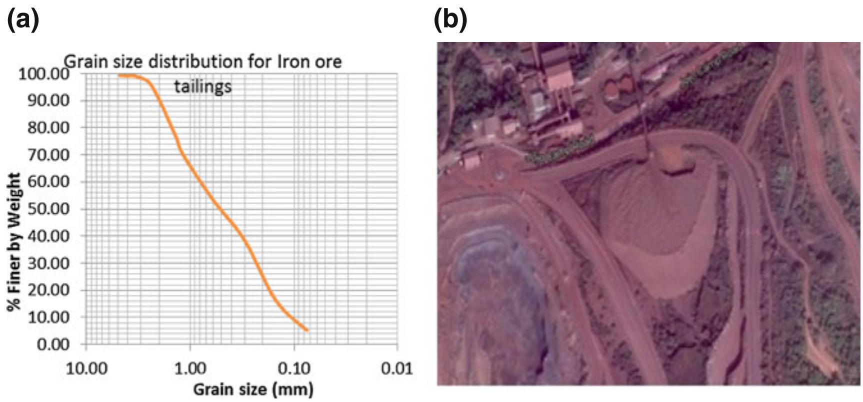

Fig. 2 **a** Grain size distribution of tailings, **b** screenshot of the Barbil tailing dam

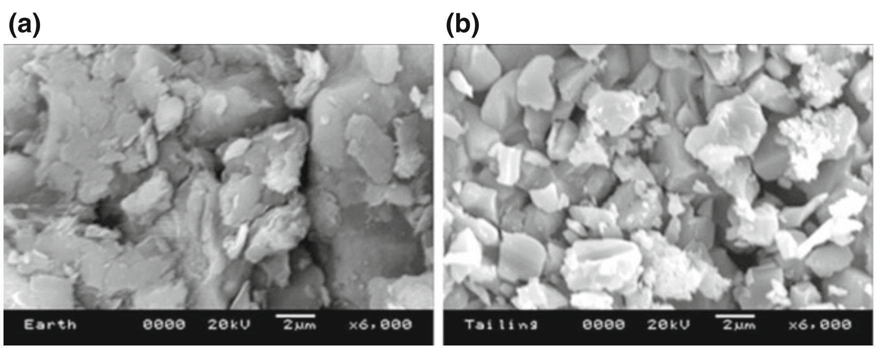

Fig. 3 **a** Morphology of clay, **b** morphology of tailing

Table 1 Elemental analysis of tailing and clay using SEM

Iron ore tailing					Clay				
Symbol	Weight %	Atomic %	Compound	wt%	Symbol	Weight %	Atomic %	Compound	wt%
C	11.62	20.33	CO_2	42.59	C	6.46	10.39	CO_2	23.67
Na	0.13	0.12	Na_2O	0.18	Na	0.11	0.09	Na_2O	0.15
Mg	0.05	0.04	MgO	0.08	Mg	0.62	0.49	MgO	1.02
Al	2.82	2.20	Al_2O_3	5.33	Al	6.83	4.89	Al_2O_3	12.90
Si	2.92	2.19	SiO_2	6.25	Si	23.70	16.30	SiO_2	50.70
K	0.12	0.06	K_2O	0.14	K	2.07	1.02	K_2O	2.49
Ca	0.12	0.06	CaO	0.17	Ca	0.0	0.00	CaO	0.0
Ti	0.0	0.0	TiO_2	0.0	Ti	0.64	0.26	TiO_2	1.06
Fe	35.18	13.24	FeO	45.26	Fe	6.21	2.15	FeO	7.99
O	47.03	61.76			O	53.36	64.41		

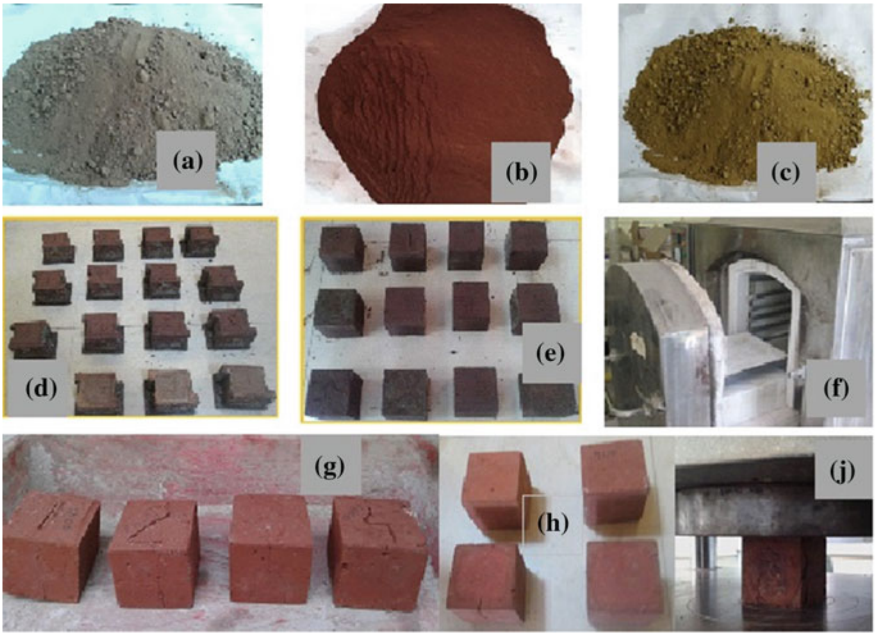

Fig. 4 **a** Pulverized clay, **b** pulverized tailing, **c** mix of tailing and clay, **d** moulds with mix poured in, **e** stripped blocks **f** furnace used for firing, **g** sample blocks fired at 1000 °C, **h** blocks fired at 900 °C, **i** measuring CS

2.2 *Preparation of Samples*

Compositions of tailings and clay were prepared by mixing 20, 40, 60, and 80% dry tailing with remaining amount of dry clay, respectively, using blender. Water was added to ensure workability and to prepare homogenous mixture. Blocks were prepared in 70.6 mm^3 moulds compacting by tamping rod as specified in IS code IS: 516—1959, and they were allowed to dry for 24 h under ambient conditions (Fig. 4d) before being stripped out of the moulds (Fig. 4e). Control samples were prepared using only clay. The blocks were then placed into a furnace at 110 °C for 24 h for removing moisture, and their weight was recorded. They were then placed into furnace, the temperature in which were raised gradually from room temperature (30 °C) in steps of 200 °C with gap of 2 h allowing the block to soak the heat uniformly, and crack formation due to sudden rise of temperature may be avoided (Fig. 9). The interior of the furnace contained air at the beginning and no air was supplied during firing; neither the firing was done in nitrogen atmosphere practiced by others such as Yang et al. [18]. Based on the literature [3, 18] it was presumed that the possible temperature for firing of bricks to obtain the best mechanical properties lies between 900 and 1100 °C. Therefore, the blocks were kept in the

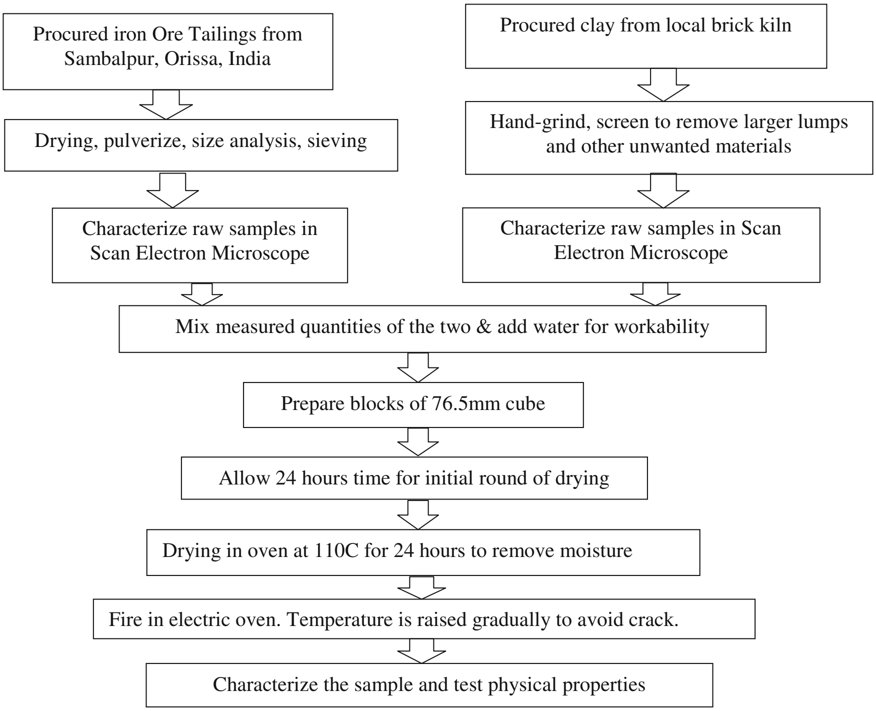

Fig. 5 Schematic representation of the process flow for making clay–tailing

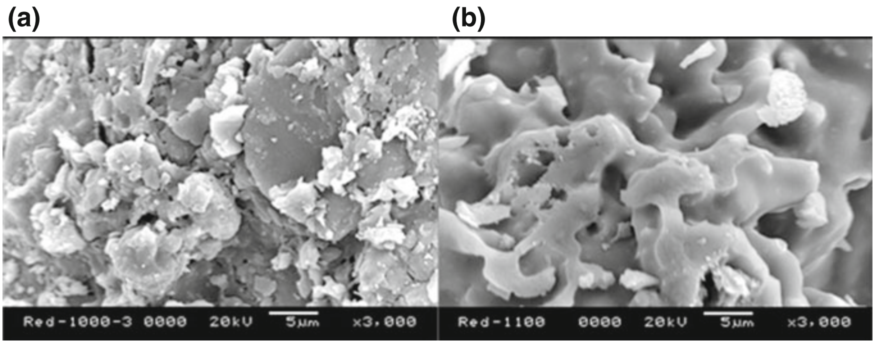

Fig. 6 **a** Morphology of brick fired at 1000 °C, **b** morphology of brick fired at 1100 °C

furnace for 3 h at 900, 950, 1000, and 1050 °C. The blocks were allowed to cool within the furnace naturally through convection.

Various tests were conducted on the cooled samples. The mineralogical composition of clay, tailings, and fired blocks was determined using the XRD and SEM

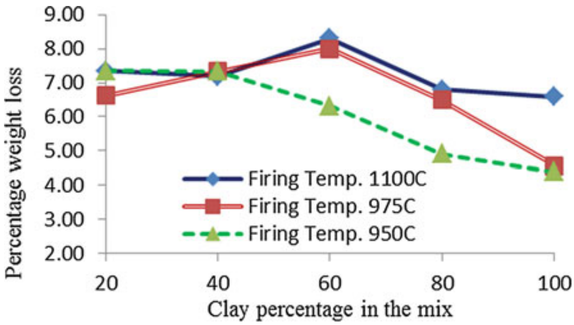

Fig. 7 Graphical representation of weight loss of blocks on ignition at different firing temperatures

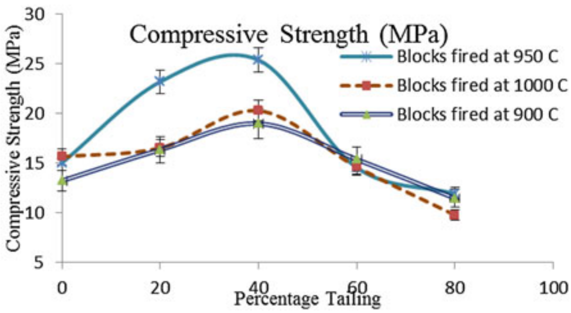

Fig. 8 Compressive strength of blocks of tailings and clay at different temperatures

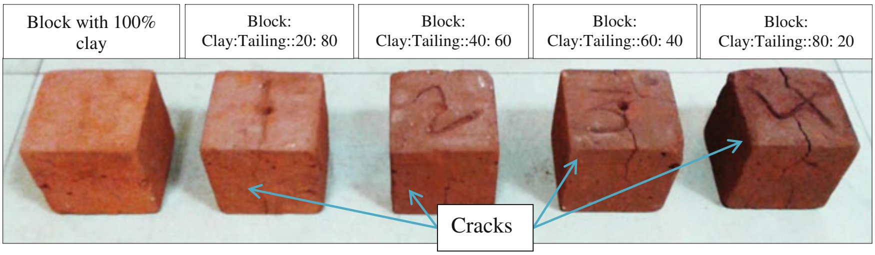

Fig. 9 Demonstration of the cracks formed on the blocks fired at 975 °C

test. The above sample preparation process was repeated three times to gain stability in data. Images of materials and sample blocks as also the furnace and the machine for measuring CS are presented in Fig. 4a through 4i. A flow chart depicting step-by-step process is presented in Fig. 5.

One of the important observations in the SEM results is that the major compounds present in the tailings are also present in clay, though in different proportions, making the former a good candidate to replace the later in making bricks. Determining the exact compositions of iron in different forms such as haematite, magnetite, goethite, siderite, or limonite is not within the scope of this study, and the results of elemental compositions contain only the bulk of iron content. Notably, the iron content in the tailing in oxide form is at about 45%. Some authors such as Zhao et al. [20] used tailing containing less than 10% iron (Fig. 6).

2.3 Characterization

2.3.1 Characterization of Fired Brick Samples

Table 2 shows the elemental compositions of the fired blocks as determined using SEM tests, and Fig. 6a, b contains the morphologies. Notably, the tailing sample used in the study contains high carbon, and on firing, the carbon content is substantially reduced, leading to higher percentage of iron in the fired blocks. We test the mechanical properties of the fired samples such as compressive strength, water absorption, loss on ignition, sintering shrinkage, and bulk density to compare them with the regular clay bricks and to understand the suitability of these blocks in civil construction work.

Weight loss on ignition is the loss of the blocks during the sintering process and is determined by recording weights before and after firing. Water absorption rates were determined following IS:3495-Part 2-1992. The specimens were dried in a ventilated oven at 110 °C for 24 h to ensure that all moisture is removed. They were then cooled at room temperature, and their weights were recorded ($W1$). The dried blocks were then immersed completely in clean water at ambient temperature (roughly 30 °C) for 24 h. After removing from water, the samples were wiped with damp cloth to remove free water on the surface. The blocks were then quickly weighed ($W2$). The rates of water absorption (WA) were determined by the formula $\mathrm{WA} = \frac{(W2-W1)\times 100}{W1}$ and are presented in Table 6. Volumes (V) of the blocks are measured to estimate the bulk density (BD) as $\mathrm{BD} = \frac{W1}{V}$ (Table 3). The $W1$ and the weight of the blocks after firing ($W3$) are used to measure loss on ignition (LI) as $\mathrm{LI} = \frac{(W3-W1)\times 100}{W3}$ and are presented in Fig. 7 and Table 4. The CS (Fig. 8) of the fired blocks was determined using a computer controlled automatic machine (Fig. 4i) following IS:516-1959. The machine with ultrasound thickness measurement facility estimates the compressive strength automatically. The data indicate that higher concentration of tailing in block increases loss on ignition.

Table 2 Elemental compositions of blocks fired at 950 °C using SEM test

Clay: tailing::40:60					Clay: tailing::20:80				
Symbol	Weight %	Atomic %	Compound	wt%	Symbol	Weight %	Atomic %	Compound	wt%
C	0.48	1.04	CO_2	1.78	C	3.23	7.22	CO_2	11.84
Na	0.0	0.0	Na_2O	0.0	Na	0.34	0.40	Na_2O	0.46
Mg	0.22	0.24	MgO	0.37	Mg	0.08	0.09	MgO	0.13
Al	7.74	7.40	Al_2O_3	14.63	Al	6.25	6.22	Al_2O_3	11.80
Si	14.68	13.47	SiO_2	31.40	Si	3.92	3.75	SiO_2	8.38
K	1.37	0.91	K_2O	1.66	K	0.13	0.09	K2O	0.16
Ca	0.55	0.36	CaO	0.78	Ca	0.0	0.0	CaO	0.0
Ti	0.0	0.0	TiO_2	0.0	Ti	0.83	0.47	TiO_2	1.39
Fe	38.39	17.72	FeO	49.39	Fe	51.19	24.62	FeO	65.85
O	36.55	58.88			O	34.04	57.15		

Table 3 Bulk density of sample blocks after firing at 950 °C

Firing temperature	Tailing percentage	Bulk density (gm/cm^3)
950	0	1.65
950	20	1.75
950	40	1.82
950	60	1.84
950	80	1.87

Table 4 Data on weight loss of blocks on ignition at different firing

	Percentage loss on ignition		
Clay %	Firing temp. 1100 °C	Firing temp. 975 °C	Firing temp. 950 °C
100	6.59	4.56	4.39
80	6.80	6.49	4.91
60	8.31	8.00	6.31
40	7.18	7.33	7.33
20	7.35	6.63	7.35

3 Results and Discussion

3.1 Results

The plots of compressive strength (CS) versus tailing percentages (TP) in the mix used in making the blocks presented in Fig. 8 indicate that the CS consistently increases with increase in TP peaking at about 40% after which it declines (data provided in Table 5). Notably, the bricks containing 40% tailing fired at 950 °C are quite superior to premium quality clay bricks in India in terms of CS. Notably, blocks with tailing content as high as 80% are found to perform well and meet requirements for applications in civil constructions where low-grade clay bricks are used. Bricks of iron ore tailings and clay made in this study without applying any forming pressure demonstrate slightly better compressive strength compared to those made using combinations of tailing, clay, and fly ash applying forming pressure of 20–25 MPa as reported by Chen et al. [3]. It is critically important to note that cracks (Fig. 9) in the blocks, though significantly reduced through slowing the heating process, could not be totally prevented. The final blocks, test results of which are reported here, have considerable cracks on all the surfaces. We are of the opinion that the CS will further improve if the cracks can be fully avoided (Fig. 9).

Water absorption (WA) of the block increases with increase in tailing percentage in the mix and reduces with increasing firing temperature for particular composition (Table 6), perhaps due to increasing vitrification that begins at temperature above 800 °C. However, the WA rate is lower than that of the standard clay bricks.

Table 5 Compressive strength of blocks of different compositions and fired at different temperatures

Mix (tailing: clay)	Compressive strength (in MPa) of blocks sintered at		
	900 °C	950 °C	1000 °C
00:100	13.25	15.04	15.67
20:80	16.37	23.20	16.55
40:60	19.00	25.40	20.30
60:40	15.40	14.58	14.64
80:20	11.50	11.95	9.80

Table 6 Data on water absorption of blocks after firing at different temperatures

Clay percentage	Tailing percentage	Water absorption rates % at firing temperature		
		950 °C	975 °C	1000 °C
100	0	10.899	10.27	8.27
80	20	12.495	10.15	7.15
60	40	14.196	11.54	8.13
40	60	16.632	13.69	9.64
20	80	16.905	14.87	10.47

3.2 Some Major Issues Requiring Mention

The blocks developed substantial cracks on firing giving an impression that the surface contracted more than the core during either firing or cooling. Several batches of samples were fired by raising the temperature in steps in order to observe the cracking behaviour with respect to firing cycles. It finally revealed that if the temperature rose very slowly and continuously the cracks would be substantially reduced. The process of cooling could be controlled only to the extent possible by keeping the furnace door shut for a long time after firing. Once the desired firing temperature is reached, the blocks are sintered at this temperature for 3 h. Another significant observation is that when blocks were fired at temperature above 1000 °C, a 'black core' was formed at the centre of the block. The phenomena have been reported earlier as black glassy spots formed due to incomplete oxidation of ferrous compounds that combine with silica and basic oxides [2]. Such black or grey core is frequently observed in fired clay bricks and floor tiles and believed to be caused by reduced magnetite Fe_3O_4 in the centre of the brick body, though 'no large scale iron gradient from Fe_3O_4 magnetite core to the Fe_2O_3 haematite outer region was detectable' [7], p. 4485). Barba et al. [1] attribute this phenomenon to the thermal decomposition of the organic material and to oxidation–reduction reactions of the inorganic components. The explanation in this regard appears inconclusive, and further study seems to be necessary to explain it. From experimental data, it appears that the CS of the blocks fired at 1000 °C is substantially less than that of the blocks of same composition fired at 950 °C (Fig. 8; Table 6). The lowering of CS is due to either the black core formation at the centre of the blocks or larger cracks resulting in firing at higher temperature.

The furnace could accommodate only four blocks at a time. Therefore, some variation may be plausible across samples of different batches.

4 Conclusion

This study provides evidence that iron ore tailings can be used to make bricks by mixing it with traditional clay used in making fired clay bricks. The percentage of tailing can be as high as 80% in the mix with the remainder being clay, though the best performance is obtained for a composition with 40% tailing and 60% clay. The compressive strength of the blocks of different compositions prepared in the present study meets that of the standard fired clay bricks and is superior at some specific conditions. One of the significant desirable properties of the tailing–clay bricks is that the water absorption rate is fairly less compared to traditional clay bricks and fly ash bricks. Therefore, the tailing–clay bricks will find the application in areas where water absorption is undesirable.

Use of tailings with clay for producing bricks can lead to consumption of large quantities of the waste materials and manage it in an environmentally friendly way. On the other hand, it can reduce consumption of topsoil for making bricks and improve construction materials availability. The low porosity as demonstrated by low water absorption rate may also be a deterrent to formation of efflorescence.

5 Further Work

Though crack could be reduced considerably by slowing the process of temperature rise in the furnace, it could not be completely eliminated. Further research is necessary in this regard. Addition of other additives such as silica fume, fly ash, cement, lime may be explored. Besides, the reasons for the formation of the 'black core' and its implication on long-term mechanical properties of bricks need further study.

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Environmental Sound Management of Asbestos-Containing Wastes Generated from Industries in India

R. Singh, M. Sontakke, J. M. Vivek, B. Rao and S. R. Asolekar

Abstract "Asbestos" has been used since the historical period for the manufacture of around 3000 products; the reasons are attributed to its characteristic properties such as high tensile strength, lightweight, heat resistance capacity and most importantly its usability as an insulating material. But, due to its unambiguous links with diseases such as 'Mesothelioma' and 'Lung-fibrosis', many of the developed nations have already imposed a ban on its usage. However, it is still extensively used in other nations including India, China, Nepal, Pakistan, Iran, Malaysia, Philippines, Indonesia, Thailand, Burma and Vietnam. These countries persistently produce and consume asbestos and other associated asbestos-containing products. In a developing economy like India, the occupational exposure of asbestos is usually encountered during mining of asbestos, manufacturing asbestos-containing construction products, in asbestos processing industries as well as in asbestos-containing product (ACP) (insulation material) manufacturing industries. A major quantum of asbestos wastes (AW) is generated during refurbishment activities such as demotion of old buildings (corrugated cement sheets) and dismantling of end-of-life ships. There are a large number of asbestos products manufacturing and utilizing industries in India, both in large- and medium-scale sectors. But a huge significant amount of small-scale and unorganised sectors is located around the major rural and urban centres. This study articulates the current trend of production of asbestos and consumption in India as well as the generation of asbestos wastes (AW) and asbestos-containing wastes (ACW) in various industries in India. As asbestos is known for its resistance to fire and being lightweight, it has been widely used in chemical plant machinery, infrastructural framework of industrial plants and manufacture of fire and chemical-resistant protective clothing for chemical plant workers. Therefore, it is imperative to estimate various asbestos-

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containing materials (ACM) and generation of AW and ACW in industries for adopting the precautionary measures while handling such materials. To address the asbestos problem, effective government policies and regulations are imperatively associated with technical interventions. Self-regulation by the concerned industries, including the adoption of cleaner production and management strategies during planning, design and operations, will significantly help to ensure proper asbestos wastes management and minimization of exposure to the workforce. The strategies for preventive environmental management of AW and ACW have been discussed in this work.

Keywords Asbestos · Asbestos-containing wastes (ACW) · Asbestos wastes (AW) · Asbestos-related diseases (ARD) · Personal protective equipment (PPE) Treatment, storage and disposal facility (TSDF)

1 Introduction

Asbestos is commonly referred to a group of naturally occurring six types of silicate minerals which are thin, flexible and elongated. These groups of minerals can be woven and spun into fabrics with high resistance to heat and chemicals and are non-biodegradable [1–3]. It is basically a poly-silicate fibre, formed due to the Si–O–Si bond formation. It consists of six minerals, namely chrysotile, amosite, crocidolite, anthophyllite, tremolite and actinolite [4]. All the minerals, except chrysotile, come under the category of amphibole. Chrysotile is classified as serpentine asbestos, which is a hydrated magnesium silicate with stoichiometric chemical formula as $Mg_3Si_2O_5(OH)_4$. It forms a sheet-like structure of silicate crystals. Chrysotile fibre is very thin with a diameter of approximately, 25 nm. The fibre length ranges from fraction of millimetres to a few centimetres [5, 6]. Most of the industrial asbestos used nowadays is chrysotile [7–9]. Amphiboles are widely found in earth's crust. They form polymeric structure, but are linear and longer and not sheet-like as that of serpentine.

Asbestos has high tensile strength, good heat-resistant capacity, chemically inert and is inflammable, non-biodegradable. The tensile strength of chrysotile is about 1.1–4.4 GPa [5, 6]. Due to a polymeric sheet-like structure of chrysotile, it has high friability. However, the negative effects of asbestos were recognized in 1899, thereafter, it is considered as a carcinogenic material [10]. Its prolonged exposure can cause "Asbestosis", "Mesothelioma" and "Lung Fibrosis" [11, 12]. They have small diameter, which helps it to get into the respiratory tract despite the presence of ciliated airways. Also, it has long length; due to which, it cannot be enclosed by macrophages, thereby producing incomplete phagocytosis. The asbestos fibre is also characterized by biological persistence, which helps in its long-term persistence in the lungs [13]. The biological persistence of chrysotile is comparatively less than that of amphiboles. Chrysotile can leach out, while amphiboles remain for a longer time in the lungs [14]. However, each type of asbestos is carcinogenic.

Many of the developed nations have already imposed ban on usage of ACP. However, it is still extensively used in other nations including India, China, Nepal, Pakistan, Iran, Malaysia, Philippines, Indonesia, Thailand, Burma and Vietnam [15]. India not only mines chrysotile, but also imports a major portion from other countries. In India, the latency period, i.e. the duration between the exposure to hazardous asbestos fibres and occurrence or developing symptoms of disease for "Mesothelioma", is approximately 20–37 yr [16]. This might be a potential reason for vague records of mesothelioma and lung fibrosis cases in India, as the major chunk of labourers work on contract basis due to which it becomes difficult to monitor their health in a long run. In India, it is observed that asbestos-related diseases (ARDs) occur at comparatively younger ages as compared to other countries in the world, since these workers are employed at very early stages of their life in the asbestos-related industries. Moreover, due to more involvement of Indian women workers, female workforce becomes more vulnerable to ARDs [17]. Industrial application of asbestos has created a huge demand for environmental sound management of AW and ACW in order to minimize the adverse environmental and health impacts.

2 Production and Consumption of Asbestos in India

In India, there is rapid increase in the consumption of asbestos from the period 1930–2013. Though in the last few years, there is not a definite pattern seen in the consumption rate. The consumption is fluctuating in the range of 3,00,000–4,70,000 MT/annum [18]. Besides a huge number of industries manufacturing and processing asbestos products, there are a large number of unorganized sectors for asbestos processing. Ninety per cent of the total asbestos produced in the country originates from Rajasthan wherein 60% of this production is centred upon unorganized industrial units which include asbestos milling units as well as industries manufacturing asbestos-containing products [14]. Milling of asbestos-containing rocks and the production of ACP constitute a major fraction of the unorganized small-scale industries, particularly in Beawer and Deogarh districts of Rajasthan.

As the developing world is phasing out the use of asbestos, India is trying to come forward as the primary manufacturer and consumer of asbestos after China. It is estimated that more than 25 asbestos mines actively operate in India having a monthly production rate of nearly 3,000 tonnes. Beside this, greater than 70% of the quantity of white asbestos is being imported from other asbestos producing nations [16]. Asbestos imports are around 3,00,000 metric tonnes/annum as per US Geological Survey report. As discussed earlier, Rajasthan constitutes 90% in production of asbestos. Other major producers and consumers include Andhra Pradesh, Bihar, Karnataka, Manipur and Tamil Nadu (Fig. 1).

There are over 3000 commercial products which constitute asbestos. These ACPs are in various forms and concentrations depending on the end use. In developing nations, it is found that various construction materials like corrugated

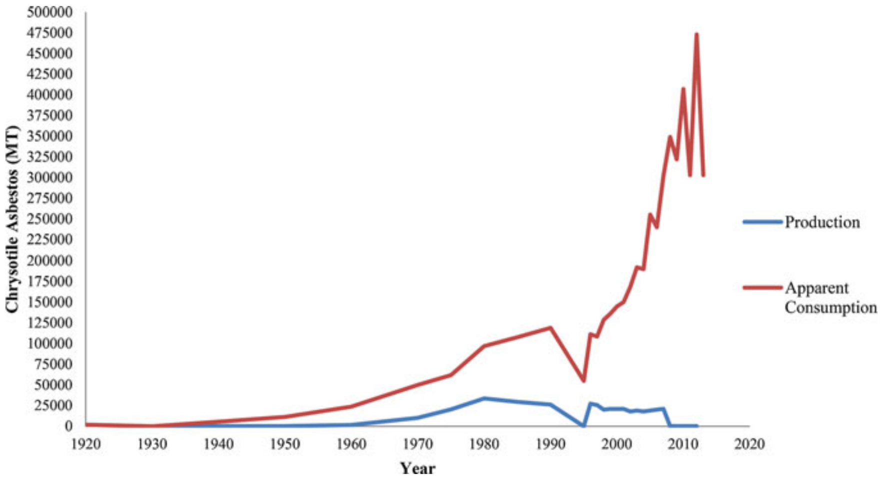

Fig. 1 Production versus apparent consumption of asbestos in India [19–39]

asbestos cement sheets, cement pipes, floor tiles, vinyl carpets, cooking appliances like stoves, pipes all contain asbestos. Asbestos is commonly used in sound proofing (like in lecture halls or theatres), fireproofing (e.g. hospitals, bank vaults), insulating pipelines (like pipes carrying hot water or steam), filler material, brake pads and insulation lining of clutch, textile products particularly for industrial applications and floor or roof tiles [40]. Owing to the growing public awareness about the health risks associated with asbestos, asbestos consumption declined by 36% from 2010 to 2011 in India. But this is not sufficient enough to save us from the unacknowledged imminent public health crisis. As per Indian bureau of mines, the apparent demand of white asbestos in India was assessed to be 393,000 MT in 2011–12 and is projected to touch around 6,05,000 MT by 2016–17 with a growth rate of 9% as per the report of the working group for 12th Plan [18]

3 Use of Asbestos in Industries

Among the class of six silicate minerals of asbestos, the white asbestos variant, namely chrysotile asbestos, is the widely used (approximately 95%) one for all the major ACPs produced and consumed. It is used in the manufacture of a broad range of industrial products and applications due to its peculiar properties such as ability to easily wove, blend with a wide range of inorganic as well as polymeric additives to derive composite products [1, 3]. The huge quantum of asbestos consumption and thereby production of various asbestos-containing goods produce a considerable amount of wastes residues which is termed as asbestos-containing wastes (ACW). Asbestos wastes from industries are generated from either from industries which require mined asbestos for manufacture of asbestos products such as building materials, protective clothing, textiles or other insulation material or in the form of end-of-life insulation material (ACM) from other type of industries (such as textile industries, dye industries and other chemical industries). In chemical industries, asbestos is widely used in following installations:

- As an insulation material for boilers, gaskets, pipes
- In protective clothing for the workers
- In building material.

A huge quantum of asbestos is released from industries where mined asbestos is used for manufacture of various ACMs. The production and processing in an asbestos industry are organized in the following manner. First, the mining of asbestos ore is carried out followed by milling to attain a homogeneous material which is shipped to the primary asbestos industries. During mining and milling activities, a huge quantum of AW is generated in the form of mine tailings and wastes residue. Further, the primary industries process and convert the raw asbestos into an intermediate product. Secondary industries are then employed for the final processing and conversion of the intermediate product into finished goods. The finished ACP is further sold to consumer industries which then utilize or install or consume the product in their industrial structural components and installations. All of these activities have great potential to generate enormous amount hazardous asbestos fibres in the atmosphere as well as to contribute potentially in generation of AW and ACW. Figure 2 illustrates movement within the asbestos industry.

Being an excellent insulating material, it is widely used in chemical plant machinery, where insulation is required, such as gaskets, pipelines, valves, pumps, boiler units, exhaust ducts, furnaces, ovens and drying units, burner pads, radiator stop-leak materials, blenders, crushers and grinders. It is extensively used in the infrastructural framework of chemical plants particularly in the form of cement corrugated sheets, cement block primer sand elastomers, adhesives and moulded flexible parts. Also, a major use is in the manufacture of fire and chemical-resistant personal protective equipment (PPE) which covers a wide range of products like fire-resistant suits for workers engaged in chemical industries. It is installed majorly in pipes, furnaces, boilers, heat exchangers, ovens, driers and extruders.

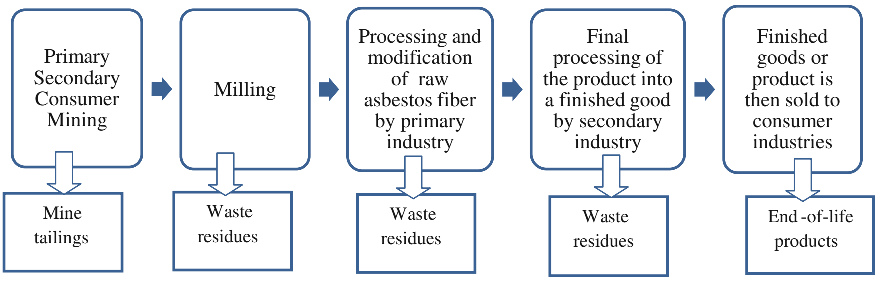

Fig. 2 Use of asbestos products in primary, secondary and consumer industries

4 Potential Health Impacts Due to Chrysotile Asbestos

As per the statutory norms in India, the Factories Act [41] notifies about asbestos and Schedule 3 lists out asbestosis under the section of notifiable diseases. The Air and Water Act of the country also regulates asbestos and is listed in Schedule I of Hazardous and Other Wastes (Management and Transboundary Movement) Rules, [42] under aegis of Environment Protection Act (1986). Furthermore, there are few of the national standards and guidelines for controlling and regulating the hazards due to asbestos mining, manufacturing of ACP and asbestos handling under Indian Standards Institution (ISI). Reportedly, India has very relaxed standards for air-borne asbestos and no guidelines for AWs and ACWs management in comparison to the European countries and USA.

There are a number of studies which claims that industrial hygiene conditions of unorganized sectors dealing with asbestos processing are very poor [43]. Ansari et al. [14] studies stated that the fibre concentration at workplaces in Beawer and Deogarh districts of Rajasthan is multiple times higher than Indian as well as worldwide standards. The mine workers were found not using any PPE, and the milling industries were lacking any pollution control devices for controlling and mitigating the pollution caused by asbestos.

In a similar study done on health hazard at ship dismantling yards, an elevated trend of asbestos exposure with cases of cancer (oesophagus cancer, trachea, bronchus and lung cancer) among the ship-breaking workers was observed [44]. It has been observed that cases of mesothelioma and the accurate measurement of their numbers in a systematic manner at the national level are often found insufficient. As reported by World Health Organization, the latency period (time between exposure to asbestos fibres and developing conditions of mesothelioma) may stretch as far as 40 years or much more; thus, the systems of monitoring need to be far stretched and long sighted [45]. Numerous countries have acted at their nationwide level to control and restrict of asbestos in most of its usage to minimize the exposure, thereby preventing and ultimately eradicating the diseases associated with asbestos. As per the WHO reports, at least 107,000 people die globally due to asbestos-related diseases (ARDs). However, there are still a number of countries that have yet to restrict and act in a similar way. India is one among them due to lack of epidemiological studies done on ARD. Very nominal efforts have taken to protect workers who are potentially exposed to asbestos, and no efforts have been done to compensate those who are suffering due to the hazardous exposure of asbestos fibres. There is no inventorization of ARD (mesothelioma/asbestos cancer) patients in India, and no data collection is available on occupational diseases in India.

5 Asbestos Wastes Management in Industries

There are typically two ways in which asbestos could be a matter of concern for the industries. First, if the industry is engaged in manufacture of any asbestos-containing products and second if there is installations where asbestos-containing materials are used inside the industrial plant. In both the cases, the operator has to ensure proper handling and disposal of the waste asbestos. The International Labour Organization (ILO) convened the Asbestos Convention in [46] to control the global use of asbestos. As per this convention, Article 10, a need for a systemic approach for replacing the asbestos materials is explained keeping workers' health at high priority. The Article 11 sternly prohibits the consumption and use of the crocidolite and other products containing this class of fibre. The end-of-life ACMs need to be managed and disposed of in accordance with Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016, as per the Indian legal framework.

5.1 Strategies for AW Management at Industry Level

There is enough literature available that validates the ill effects of airborne AW in the form of asbestos fibres. In order to avoid the deleterious health impacts to the workforce potentially exposed to fibres, there is a stern need to use PPEs or application of some in situ technology to reduce the friability of the asbestos or combination of both of these.

In indoor working areas, while performing dust-related work, the secondary release of the collected dust can adversely impact the work activity as well as the surrounding environment. This secondary release needs to be controlled and mitigated as these dust particulates may induce issues of serious concern to health of the workers. Adequate precautionary measures need to be geared up before the operations which may include installing a high-efficiency particulate air (HEPA) filter behind the dust-collecting equipment. Thus, clean-up is essential to suppress and control the secondary emanation of the fibres of asbestos. Removal of asbestos at ship recycling industry is performed by licenced contractors. These skilled asbestos professionals first designate the locations, label them and performs the dismantling operations in controlled conditions (Fig. 3).

In case of management of end-of-life ACM which is called asbestos-containing wastes (ACW), sometimes it is recommendable to treat the wastes before its final disposal. There are various methods for converting hazardous AW and ACW into non-hazardous material, which can be further utilized or recycled for various purposes. There are different methods for removing asbestos-containing materials such as asbestos coatings and/or plastering materials from the structural and building materials upon which such asbestos-containing materials have been incorporated. The simplest method is wet stripping of the ACW [47]. To control the emanation of the dust containing asbestos fibres, wetting using a suitable liquid carrier is an

Fig. 3 Labelling of asbestos-containing material found in ship recycling industries. Before dismantling the ship, proper identification and labelling of asbestos-containing areas are done and disposal activity is further done by the licensed asbestos contractors

effective method. In this method, water is showered or sprayed. This technique employs devices like shower, sprinkler or atomizer wherein fine water droplets are sprinkled in the air which will capture the airborne dust by the sedimentation. By this method, the dust dispersal can be controlled by pre-moisturizing the raw materials which can be the potential sources of the dust fibres.

Out of other different methods proposed and studied by different authors for altering hazardous nature of chrysotile asbestos, the major ones were treating the ACM with acids [48, 49] and thermal treatment [50–52]. This method includes wetting the asbestos fibres with an aqueous solution containing about 1–10% by weight acid solution [53]. The crystal structure of the chrysotile asbestos is attacked by the acid solution which hydrolyzes the brucite layer (magnesium oxide) of the crystal, which ultimately destroys the crystal lattice and thus the fibrous nature of the asbestos. In addition, this mode of treatment can be used in situ by spraying chrysotile-containing insulation material installed in various machinery structures. Up to 90% conversion of asbestos can be achieved depending on the type of acid used. When 90% or more of chrysotile asbestos is converted, the remaining unconverted asbestos is not sufficient to impart a fibrous nature to the product. AW and ACW produced are ultimately bagged and transported to the hazardous wastes TSDF for final disposal in secured landfills. The schematic representation of ACW management is given in Fig. 4.

5.2 *PPE for Asbestos Handling and Collection*

ACMs may pose a serious risk to human health if they are disturbed from their dormant state that can eventually lead to the release of the microscopic fibres to the surrounding working environment. Environmentally safe and sound handling as well as final disposal of the end-of-life ACMs in industrial premises, therefore, demands systematic sequential actions to be undertaken so that potential exposure to the workforce is minimized. Workers engaged in AW handling should be

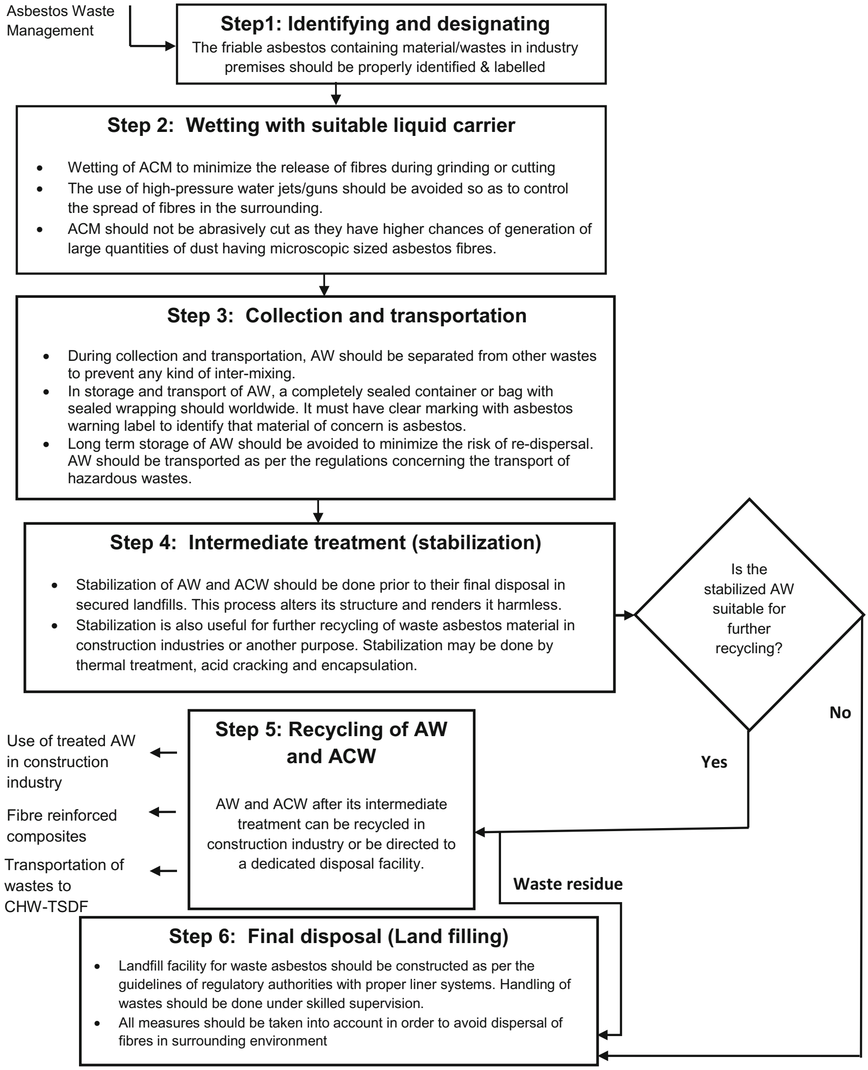

Fig. 4 Steps involved in ACW management

provided with required personal protective gears, ancillary machinery, appropriate training and information for safe handling and disposal of AW and ACW [47].

While handling asbestos fibres, the workers are mandated to use a half-face filter respirator which may encompass a class P1 or P2 filter cartridge. Class P1 or P2 disposable respirator is also considered appropriate for handling asbestos fibres [45]. During the dismantling activity, the workers should wear other adequate protective devices like coveralls, safety boots, hat and gloves which all must be

Fig. 5 PPEs used by the allocated trained and licensed asbestos removers and sealed ACM before dismantling

disposable in nature. At the closure of each day work, the used PPEs must be sprinkled with water, then sealed, double bagged and properly labelled for disposal. During these operations, the respirator must be worn so as to prevent the exposure to fibres while removing and disposing of the coveralls worn during the dismantling activity. After the completion of work, onsite washing facilities must be made available to the workers so as to decontaminate them before doing their routine works like eating, drinking and returning home (Fig. 5).

6 Disposal of AW and ACWs

The process of dismantling and removal of ACM from industries generates friable AWs which when airborne causes carcinogenic impacts. Hence, for workers, a decontamination area is very much essential to handle this class of work. The enclosure is kept at negative pressure to handle the friable asbestos components.

After proper dismantling of industrial components in a separate enclosure, three possible options for the final disposal of AWs and ACWs can be adopted, and these include:

- Recycle and reuse
- Secure/engineered landfilling
- High-temperature transformation.

6.1 Recycling and Reuse

Recycling waste asbestos has become one of the emerging fields of research especially in developing nations, where it is still in massive application. Development of a secondary raw material (SRM) as a replacement for cement in concrete will help to recycle asbestos as well as suffice the concept of green concrete. It has been reported that the thermal transformation product of cement asbestos has the potential to be used as an SRM, which has chemical characteristics much similar to a magnesium-rich clinker [51]. The pozzolanic property of treated asbestos-containing wastes (roof sheets) was studied, and it was found suitable to be used as construction material [54]. Xiaoming and Linrong [55] had studied the asbestos tailing and claims to have no heavy metals in the matrix and hence lower toxicity, which implies to their prospect of being used as an aggregate material. A wide range of products including composite materials, glass-ceramics, ceramic pigments, plastic materials and bricks can be produced by using the asbestos cement conversion product.

6.2 Secure Landfilling

Land disposal of properly packed AW is practised all over the world [56–58]. In the disposal of asbestos in secure landfills, due care has to be taken to avoid the dispersal of fibres during handling. These landfills should have installed all the infrastructural requirements such as liner systems and leachate collection systems. Burning of asbestos-contaminated wastes is not a suitable disposal strategy. The occupier (waste generator) should send the wastes to the dedicated hazardous wastes TSDF (treatment, storage disposal facility) authorized by the pollution control authorities. The collected asbestos wastes are usually double bagged and are sent for disposal in specially reserved cells along with other kinds of wastes. During disposal of large items like asbestos sheets, pipelines, tiles or boards, the material has to be wrapped and well sealed in polyethylene bags. Adequate precautions must be taken to prevent the sharp edges of these wrapped up waste contents to cause any scratches/dents/cuts to these polythene bags. While disposing of these wastes, a comprehensive record of location of waste must be made available which includes the precise geographical coordinates also which will aid proper mitigation and management of these wastes.

6.3 High-Temperature Transformation

It has been reported that at high temperatures the crystal structure of asbestos gets altered which ultimately leads to formation of non-hazardous constituents [59].

Considering the risk of asbestos emission from landfill sites, some researchers developed thermal transformation of needle-shaped crystalline of asbestos into harmless form usually under 1200–1500 °C [60]. In a study conducted on microwave inertization treated ACW, the treated products were recycled to produce good-quality porcelain stoneware tiles, ceramic materials as well as porous single-fired wall and roof tiles [61]. The high-energy milling product of asbestos cement is asbestos-free and can be gainfully recycled in the manufacturing of construction products [54]. It is imperative to note that making the AWs inert by chemical–physical techniques and transformations (vitrification, hydrothermal, re-crystallization, mechano-chemical) and then recycling the products of transformation as an SRM will indeed assure a lower environmental footprint as well as reduce the usage of the primary raw materials. These processes are appropriate for small-scale disposal of waste asbestos.

7 Summary and Discussion

The management of fibrous hazardous wastes such as asbestos is very challenging in the present era of industrialization. India consumes around 4–5 MT of asbestos per annum for its industrial requirements. A considerable amount of chrysotile is mined in various parts of the country, and a major portion of quantity consumed is being imported from other nations.

Due to lack of identification technology, the AW and ACW are dumped along with all kinds of other wastes like garbage and construction wastes. This may lead to public health hazards. Eventually, workers engaged in ship-breaking yards, construction labourers, electricians, mechanics and other workforce employed in various industries that are potentially exposed to asbestos are forced to breathe-in hundreds and thousands of fibres. This may lead to "Asbestosis" and "Mesothelioma". Industries must take precautionary measures in order to avoid the potential exposure to the workforce due to asbestos, whether it occurs in the form of raw material or is present in products. If the utilization of asbestos substitute materials is not possible for the industries, scientific and systematic waste minimization strategies and environmental sound handling of AW should be implemented to reduce the environmental and health impacts. Disposal must be done only at a site authorized by pollution control boards to accept waste asbestos.

An attempt is required to be made for assessment of various technologies available for the pre-treatment and recycling of asbestos-containing wastes and strategies for minimization of exposure to the workforce, who is potentially exposed to asbestos fibres due to their occupation. Various techniques such as solidification, stabilization, chemical fixation, thermal treatment, encapsulation can serve for the purpose of immobilizing various kinds of contaminants in hazardous wastes into physically and chemically stable form which could have a better environmental acceptance. Affordability, acceptability and sustainability should be the approach road of effective AWs and ACWs management.

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Analysis of Erosion Properties of Polymer Composite Filled with Granite Dust for Hydraulic Turbine Blade Material

J. Joy Mathavan, Sugandha Shrestha, Rehan Kaifi and Amar Patnaik

Abstract The main objective of this research work is to introduce a new material for hydraulic turbine blade for efficient usage of hydraulic energy. Instead of the usual alloys used for hydraulic turbine blades, composite material has been tested in this paper. Polyamide needle fibre (aramid fibre) has been used here; due to its high resistivity to erosion by water, it is cheap among other fibres while polyester resin was used as the matrix. The samples were prepared by hand lay-up process. As a new trend and considering waste matter utilization, granite dust was added to the above composite as a filler material, because it is considered as an industrial waste. It belongs to the igneous rock family and is found to have good mechanical properties. In different percentages, granite dust was added to the composite to test the improvement in the erosion resistance and other mechanical properties. The velocity of jet, the feed rate of erodent (silica sand), the size of erodent, and the angle of impingement were changed, and the tests were done in Taguchi standard L25 table with five variables and five factors. The results are analysed and plotted in graphs. Hardness number was calculated in Rockwell hardness tester. Theoretical and experimental densities were also calculated.

Keywords Polyamide needle fibre · Slurry jet erosion · Granite dust

1 Introduction

Sediment erosion in hydraulic turbine blade is being as the main hindrance in the advancement of projects based on hydraulic power. Solid abrasive particles found in waterfall, or river water is the source for fast wear down of turbine blades and other parts, which causes reduction in the performance of turbines. It leads to the drop-off in reliability and efficiency of turbine and also operating life of turbine blades. M. Pandhy and P. Senapati stated in their studies that silt erosion in hydro

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turbines cannot be avoided totally, but excellent materials and surface coating can be used to raise the life of the runner. So they worked and found that NiCrFeSiB alloys are resistant to abrasive wear [1]. From this, it can be noticed that there is requirement for new materials to be developed for the purpose of turbine blades, and they should be able to stand firm in erosion situation due to excess sediment. The primary action on the way to such progress is to explore different possibilities in material selection in laboratory. It should be noticed that a standard methodology has to be followed to perform sediment erosion experiments in controlled atmosphere.

Wear on the blade of the turbine due to erosion is a complex occurrence which is caused by (i) the hardness, size and shape of the erodent particles, and their concentration (ii) elastic properties, substrates, surface hardness, chemistry and surface morphology and (iii) operating conditions such as impingement angle and velocity. 13Cr–4Ni steels are the usual material for the application of water pumps and hydro-turbines. They are preferred because they have outstanding mechanical properties. Though these alloys have noticeably poor resistance to erosive wear and scratched-off because of high content of silt in water, B. Rajkarnikar et al. numerically obtained erosion pattern for Francis turbine components. Their information may serve as an input for turbine design method to recognize the regions where distinct surface treatment is needed in order to enhance the durability of the components which are exposed to sediment erosion [2].

Composites are made from two or more constituent materials which have significantly dissimilar physical/chemical properties which when combined produce a material having properties altered from its individual components where the individual components remain separate as well as distinct within the finished structure. Composite material structure possesses two components: the fibre and the matrix. The fibres which generally possesses a high modulus of elasticity and ultimate strength are the part of the composite material which contributes to the strength. Examples of commonly used fibres are carbon, glass and aramid fibres. The matrix in a composite is to bind the fibres together as well as protect the fibres from damage by the transfer of stresses to the fibres. Examples of common structural resin systems are vinylester, polyester and epoxy. This paper includes our findings of a composite material of polyamide fibre and epoxy resin with various percentage addition of granite dust.

Granite dust has been mixed in different percentages to test the improvement in required properties. The density of the granite is between 2.65 and 2.75 g/cm^3 (but for granite dust/powder, it decreases to 1.65 g/cm^3) and its compressive strength is greater than 200 MPa. The reason behind the selection of granite dust to be added is that it contains SiO_2 (Silica)—72.04% and Al_2O_3 (Alumina)—14.42%. So it is expected that the erosion resistance and hardness values will satisfy the requirements.

2 Methodology

There are a lot of methods for fabrication of composite materials. Some of the methods developed which meet specific manufacturing or design challenges are injection moulding, hand lay-up process, etc. Selection of a method for a particular part depends on the materials used, the design of the part and application of that particular model or end-use of it. Composite production procedure engages some kind of casting to strengthen the resin/fibre mixture and its shape. A casting apparatus is essential to provide the shapeless fibre/resin arrangement its shape prior to and all through its cure.

2.1 *Specimen Preparation*

The most popular type of open moulding process is hand lay-up process. The hand lay-up is done manually and is a slow and labour consuming method. In this process, polyamide fibre gets added layer by layer and polyester resin mixed with granite dust used as the matrix to adjoin and strengthen the composite. Different percentage of granite dust mixed to form the composite is given in Table 1.

2.2 *Slurry Jet Erosion Test*

Slurry Jet Erosion Testers facilitate the detection of excellent material in particular working environment. The wear rates found by experiments may be referred to calculate the service life and cost of life cycle. In this experiment, the test variables considered are velocity of water jet (8, 16, 24, 32 and 40 m/s), angle of impingement (30°, 45°, 60°, 75° and 90°), erodent size (150, 200, 250, 300 and 355 μm) and erodent feed rate (160, 195, 230, 265 and 300 g/min). The slurry jet erosion tester required the test material to be of the exact size of the die of the tester (25 mm × 25 mm) and silica sand of less than 400 μm to act because an abrasive sand particles or impurities larger than 400 μm would get stuck in the nozzle of slurry jet erosion tester through which the jet water with erodent impinges on the test material. Average reading of five tests of

Table 1 Percentage addition of individual materials to form the composite

S. no.	Sample	Polyamide fibre (%)	Polyester resin (%)	Granite dust (%)
1	Sample 1	10	90	0
2	Sample 2	10	85	5
3	Sample 3	10	80	10
4	Sample 4	10	75	15
5	Sample 5	10	70	20

each having a test duration of 10 min has been taken to finalize the erosion loss. The weight before and after the tests was measured with a balance of least count 100 μg. The obtained results are analysed and compared by Taguchi L25 table (five factors and five variables), and the optimum results have been identified.

2.3 Rockwell Hardness Test

The Rockwell hardness test method, as defined in ASTM E-18, is the most commonly used hardness test method. Unlike Brinell hardness test, it can also be performed to the specimens which do not have a reflective surface. The Rockwell test is generally very easier to perform, and more accurate than other types of hardness testing methods. In Rockwell hardness tester, variety of indenters may be used. In this study, conical hard steel with a round tip for composite materials with indenter size 1/16″ was used. The load applied is 100 kgf according to machine standards. Average of 5 readings for each sample has been taken to conclude the hardness of the sample.

2.4 Tensile Test

Tensile test has been done through dynamic mechanical analysis. The graphs drawn for modulus vs temperature and tan delta vs temperature are compared for different percentage addition of granite dust. For this purpose, sample has been cut in a size of 2 mm × 3 mm × 12 mm. The highest temperature assigned as 120 °C and increment per minute fixed at 3 °C per minute.

3 Results and Discussion

3.1 Results of Taguchi Analysis

Figure 1 shows the graph obtained by Taguchi analysis after obtaining the average of five set of experiments for each. It can be noticed that the velocity of the water jet plays a vital role than all the other factors. With increment in velocity of water jet, the erosion rate also increasing. It can be observed that 75° angle emerged as the best angle with least erosion, and it is followed by 90° angle. 10% addition of granite dust gives minimum erosion. 200 μm size erodent particles give less amount of erosion and minimum feed rate of 160 g/min causes least erosion.

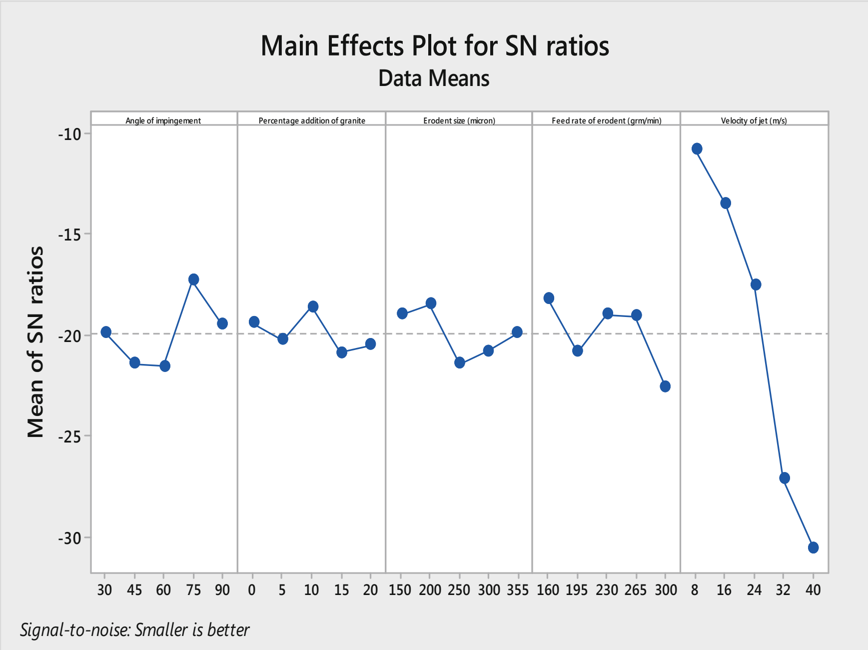

Fig. 1 Graphical representation of results of Taguchi table

3.2 Density Comparison of the Samples

In composite materials, the theoretical density in terms of weight fraction can simply be found by using the formula [3, 4, 5]

$$\rho_{ct} = 1/\left[(w_f/\rho_f) + (w_m/\rho_m) + \left(w_g/\rho_g\right)\right] \quad (1)$$

This formula has already been used by Agarwal and Broutman [3] in their work, where w represent the weight fraction and ρ represent the density. The suffix g stands for granite, m stands for matrix, f stands for fibre and ct stands for composite material (Table 2).

The prepared composites in this study contain three elements namely fibre, matrix and particulate filler. The actual density (ρ_{cm}) of the composite can be found out experimentally by usual water immersion method. The volume fraction of voids (V_v) in the composites is calculated using the following equation [3, 4, 5]:

$$\mathrm{Vv} = (\rho_{ct} - \rho_{cm})/\rho_{ct} \quad (2)$$

Table 2 Density comparison of the samples

Sample	Percentage addition of granite dust	Experimental density (kg/m^3)	Theoretical density (Kg/m^3)	Volume fraction of voids (%)
Sample 1	0	1108	1286	13.8
Sample 2	5	1223	1302	6.0
Sample 3	10	1248	1307	4.5
Sample 4	15	1275	1320	3.4
Sample 5	20	1321	1332	0.8

3.3 Rockwell Hardness B Test Results

See Table 3.

3.4 Variation of Modulus with Temperature

Loss modulus means being proportional to the energy dissipated during one loading cycle. For example, it can be said that energy lost as heat and is a degree of vibration energy that has been converted during vibration. It cannot be recovered. Figure 2 represents the variation of storage modulus with temperature. We can see that there are three significant regions in this graph. A high modulus zone from 20 ° C to 50 °C is the first region. A transition region, where a significant reduction in the storage modulus values occur with rise of temperature (50 °C – 80 °C) is the second region. An elastic region where a severe deterioration in the modulus occur with rise of temperature (80 °C –120 °C) is the third region. It can also be noticed from the graph that 10 and 15% granite dust added samples have a high modulus of 900 Mpa and pure polyamide fibre–resin combination have minimum of 500 MPa. All the samples show above 800 MPa for which the granite dust has been added.

Table 3 Rockwell hardness B Test results

Sample	Percentage addition of granite	RHB value
Sample 1	0	108.5
Sample 2	5	110.5
Sample 3	10	115.6
Sample 4	15	117.4
Sample 5	20	119.6

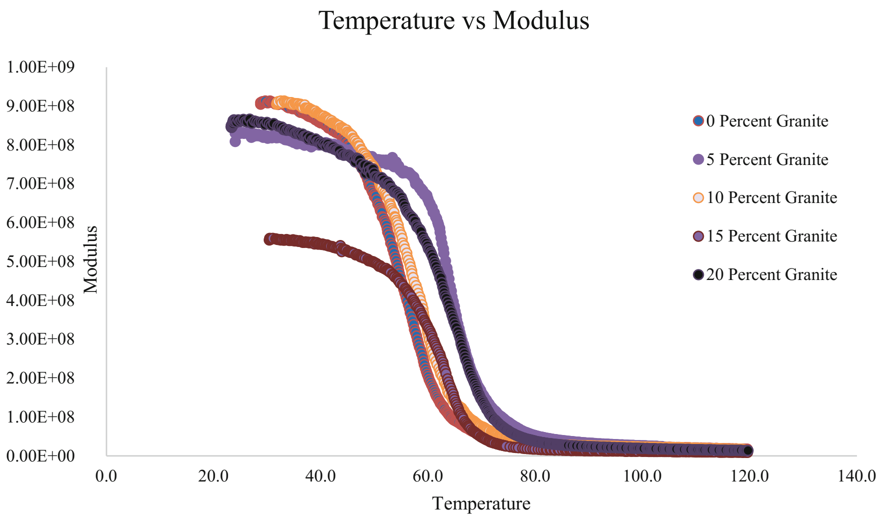

Fig. 2 Variation of modulus with temperature

3.5 Variation of Damping Factor (Tan Delta) with Temperature

Figure 3 displays the variation of damping factor (tan delta) with temperature. The loss factor tan delta considered as the ratio of loss modulus to storage modulus. It is the amount of the energy lost, which can be recovered, and characterizes internal

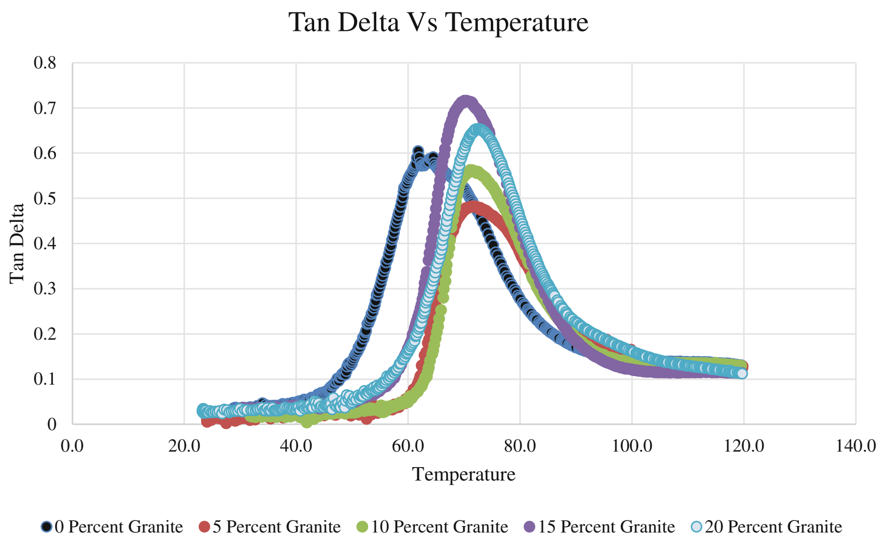

Fig. 3 Variation of damping factor (tan delta) with temperature

friction or mechanical damping in a viscoelastic system. The loss factor tan delta is a dimensionless number. A high tan delta value suggests that the material has a high, nonelastic strain component, whereas a low value shows that the material is more elastic.

4 Discussion

It can be observed that the overall erosion rate decreases with reduction in particle size, reduction in velocity and reduction in feed rate, whereas when using optimum angle of impingement and optimum filler material addition. It has been observed a slight deviation between the experimental and theoretical densities. It may be concluded due to the absorption of water particles by the sample when we immersed the material for experimental density calculation. If we consider the DMA analysis, significant reduction in storage modulus occurs in the range of 50–80 °C and a total decline beyond 80 °C. Almost the same pattern of results obtained in the study of thermo-mechanical characters for fibres by Amar Patnaik and SachinTejyan [4].

5 Conclusion

The velocity of water jet has great impact in the erosion. With the increase of velocity from 8 to 40 m/s, the rate of erosion also increases. Erosion rate is minimum when the velocity was 8 m/s and maximum when it was 40 m/s. In the same way, the highest erosion occurred when the feed rate was maximum and lowest erosion occurred when the feed rate was minimum; even though it is not showing a linear pattern, the size of erodent does not show a significant effect on erosion rate. But it showed that the minimum erosion occurred when the erodent size was 200 μm. While considering the angles of impingement, it showed highest erosion in the angles of 45° and 60° and showed lowest erosion in the angle of 75°. When considering the percentage addition of granite dust, lowest erosion observed on 10% addition of granite dust and highest erosion observed on 15% addition of it. So we can assume that 10% addition would be optimum.

Both hardness and density (theoretical and experimental) values are increasing with increment in addition of granite dust. If we pay attention on storage modulus, 10 and 15% granite dust added polyamide fibre samples have a high storage modulus of 900 MPa and pure polyamide fibre–resin added sample have minimum of 500 Mpa.

6 Future Scope

This paper has provided various conclusions and has brought into light various aspects that we can take into considerations about the material selection for hydraulic turbine blade. A waste product (granite dust) has been utilized as a constituent of our composite which is a prevalent by-product of stone cutting industries which are prevalent in Rajasthan. The analysis shows that 10% addition of granite dust to be optimum and a range of optimum results have been given. But in future, through further testing and analysis, an even more optimum addition percentage for granite dust can be obtained. Furthermore, in the future more advanced fibres may come for the purpose of turbine blades.

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Part X
Sludge Management

Sustainable Management of Arsenic-Bearing Sludge

Indranil Mookherjee, Abhisek Roy, Amit Dutta, Anupam Debsarkar and Pritam Aitch

Abstract Electrochemical Arsenic Remediation (ECAR) technology has been developed to efficiently reduce high levels of arsenic in groundwater below the WHO MCL at extremely low cost. This process produces arsenic-bearing sludge which being a hazardous waste has to be disposed by a cost-effective robust stabilization process. This study is focused on the embedment of ECAR sludge in concrete in variable proportion (% by weight of cement) up to the point of substantial deterioration in strength in an environmentally sound manner. This sludge differs reasonably from that of silt and sand in terms of parameters, viz. specific gravity, optimum moisture content, void ratio, and porosity. Grain size is similar to filler materials used in concrete, which suggests that there is potential for the sludge to be embedded in concrete, thus emphasizing its immobilization. The sludge was added by replacing equivalent amount of sand and extra water equivalent to the OMC of the sludge in the concrete mix. Seven cubes (three cubes each for determining strength on 7 days and 28 days and one cube for determining long-term leachability) of dimension 100 mm × 100 mm × 100 mm were cast for each of the percentages. In each case, the slump height and compacting factor had been determined to signify its workability. These cubes were crushed to three size ranges, viz. <9.5, <1.0, and 5–50 mm, and TCLP was performed to determine the arsenic concentration in the leachate. The arsenic-bearing ECAR sludge was immobilized in M20 grade of concrete, and the maximum percentage of sludge that can be mixed safely in terms of compressive strength was observed as 30% by weight of cement. The arsenic concentration in the leachate produced from the concrete cubes was found well below the prescribed safe limit, indicating a good stabilization option both in terms of economy and simplicity.

Keywords ECAR · Sludge · Stabilization · Immobilization · Concrete

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1 Introduction

In Electrochemical Arsenic Remediation (ECAR), a blend of corrosion products such as oxyhydroxides, ferric hydroxides, and oxides (i.e., rust) is formed by continuously dissolving iron with the help of electricity. These products are collectively known as electrochemically generated adsorbent, or EGA, and EGA has a very high affinity toward arsenic. Advantage of EGA is that it eliminates the requirement of a costly supply chain as it is produced at the time of use. Moreover, in comparison to chemical addition of ferric salts or metallic iron, electrochemical processes increase the arsenic-removal capacity (i.e., arsenic removed per unit iron input) of ECAR. This increase in high arsenic-removal capacity is primarily due to (i) the increase in the rust production rate, and (ii) the formation of the oxidized state of As (III), i.e., As (V), whose bonding with iron-based adsorbents is much stronger. So here in this process, the efficiency is increased, the operating cost is lowered, and the production of arsenic-bearing waste is also lowered only by employing a small amount of electricity. Also, if the current is altered, the electrodes are self-cleansing, thereby reducing the maintenance cost and eliminating the need of corrosive acids and strong alkalis for regeneration [1].

ECAR is already a proven technology for arsenic removal and will be commercialized by Luminous Water Technologies Pvt Ltd. (LWT). As a part of commercialization, LWT has already installed a 10,000 L ECAR plant at Dhapdhapi High School, Baruipur, 24 Parganas (S), West Bengal, India. Figures 1 and 2 represents the working principle of ECAR process.

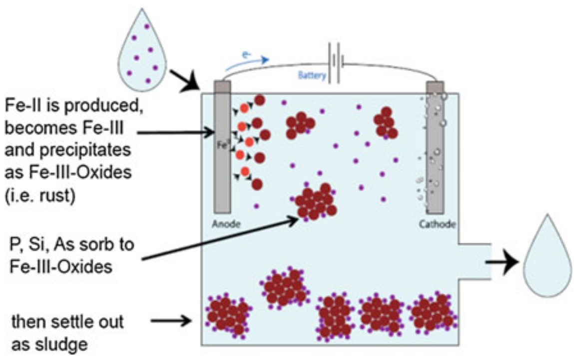


Fig. 1 Working of ECAR

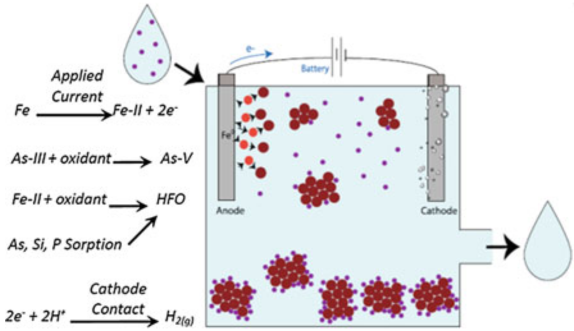


Fig. 2 Processes involved in ECAR

2 Literature Review

Banerjee and Chakraborty [2] studied that the sludge was generated as a by-product in arsenic-removal water plants where arsenic is co-precipitated with iron hydroxide-contained arsenic in alarmingly high levels (an average of 6.1 kg As/m^3 of sludge). In an attempt to propose safe means of disposal of this sludge, it had been stabilized in processes such as briquette production, cement mortar, and concrete making. For preparation of briquette, cement–sand mortar, and concrete, 10, 18, and 40% of arsenic-bearing sludge by volume was mixed, respectively, and it had been studied that TCLP leachate produced was well within the Ministry of Environment and Forest, Government of India, with prescribed standard of 0.2 g/m^3. It had been also studied that 25% (by volume) of cement could be replaced by fly ash to stabilize arsenic-laden sludge to the tune of 11% by volume of cement–sand (1:3) mortar [2].

3 Research Interest

Sustainable development is concerned with ensuring that design is made with the intention of avoiding unnecessary social, economic, or environmental loss that will have consequences for future generations. In this respect, methods of arsenic waste disposal must be effective and reliable. Disposal of any hazardous waste requires effective management, so wherever arsenic waste is generated, there is a need to establish a well-defined method for the disposal of the arsenic sludge [3]. If not done so and arsenic is disposed, then through rainwater, arsenic may come in contact with surface water and also may percolate into groundwater. Thus, without proper management of arsenic-bearing sludge, the sole purpose of arsenic remediation becomes impractical.

A common method for hazardous waste disposal is encapsulation but that will require trained labor and a proper transfer facility from plant to hazardous waste disposal site. All this require a huge capital investment which can be minimized by exploring some in situ disposal options.

The main objective of performing this study is to provide a cost-effective robust stabilization option to get rid of the issues of arsenic-bearing water plant waste management. The high arsenic-bearing sludge coming from ECAR can be stabilized in concrete which can be a removal option. This study will try to find out the maximum limit of arsenic-bearing sludge that can be mixed safely in concrete with satisfying leachability and strength criteria.

4 Work Done

Detailed characterization of arsenic-bearing sludge from ECAR in terms of pertinent physical parameters and chemical parameters had been done. ECAR sludge in variable proportions (till the point of substantial deterioration of mechanical strength) in concrete had been embedded, and the strength and workability of the concrete had been measured. Also, the arsenic concentration in the leachate generated from the ECAR sludge embedded concrete had been determined.

5 Raw Materials

a) **Sludge**: The arsenic-bearing sludge was collected from the 600L prototype ECAR installed at Environmental Engineering Division of Department of Civil Engineering, Jadavpur University. This prototype ECAR is designed to operate at a highest Columbic dose of 450 C/L, and it produces 245 mg/L of dried sludge. This dose was sufficient to consistently produce product water with below 5 μg/L arsenic.
b) **Cement**: Portland Pozzolana Cement (PPC) (fly ash-based) conforming to IS: 1489(Part I):1991 [4] manufactured by Ambuja Cement was used in this study. The cement was tested to contain no arsenic.
c) **Sand**: Sand conforming to Zone II of IS: 383:1970 [5] was used in this study.
d) **Coarse Aggregate**: 20 mm nominal size coarse aggregates were used in this study.
e) **Water**: Ordinary tap water was used in the preparation as well as curing of concrete. The general composition of water was: pH = 7.8; Acidity = 18 mg/L as $CaCO_3$; Alkalinity = 55 mg/L as $CaCO_3$; Chloride = 46 mg/L as Cl^-; Sulfate = 10 mg/L as $SO^{4=}$; Volatile Dissolved Solids = 24 mg/L; Fixed Dissolved Solids = 96 mg/L; Suspended Matter = 0 mg/L; Arsenic = BDL.

6 Characterization of ECAR Sludge

The specific gravity of the sludge sample is found to be more than that of sand and silt which is in the range of 2.65–2.7. This may be due to the different mineral composition of the sludge sample. Generally, heavier the minerals composing the soil, the greater is its specific gravity. As this sludge sample contains iron, its specific gravity is high [11].

The OMC value of ECAR sludge is higher than most soil types. Higher OMC means a higher capability of holding the moisture. High OMC value will create a higher water demand in concrete if used as filler material. Additional water has to be added to compensate that demand, which should be brought into consideration during the water–cement ratio computation in mix design of concrete. Result of physical characterization shown in Table 1.

Void ratio and porosity of the sludge sample are quite higher than those of sand [11].

The magnitude of plasticity index signifies that the sludge sample is of medium plasticity as it is in between 7 and 17 [11].

The particle size range falls mainly in the silt size range [11]. As per IS 383:1970 [5], percent passing through 0.6 mm sieve for Grade IV fine aggregate (sand) is 80–100 and that through 0.3 mm is 15–50. For the sludge sample, percent passing through 0.5 mm sieve is 100, so the sludge sample is finer than Grade IV sand.

At OMC, the permeability of the sludge ample is like clay [11]. Normally, the permeability of the cement paste system is reduced when aggregate of low permeability is introduced into it as the aggregate particles will intercept the flow channels making the water to take a circuitous route [12]. Result of chemical characterization shown in Table 2.

Table 1 Results of physical characterization

S. no.	Parameters	Values	Reference
1	Specific gravity	2.897	IS: 2720(Part III/Sec i):1980 [6]
2	Maximum dry density	0.883 gm/cc	IS: 2720(Part VII):1980 [7]
3	Optimum moisture content	72%	IS: 2720(Part VII):1980 [7]
4	Void ratio at OMC	2.281	IS: 2720(Part VII):1980 [7]
5	Porosity at OMC	69.5%	IS: 2720(Part VII):1980 [7]
6	Liquid limit	76.27%	IS: 2720(Part V):1985 [8]
7	Plastic limit	63.57%	IS: 2720(Part V):1985 [8]
8	Plasticity index	12.696	IS: 2720(Part V):1985 [8]
9	Grain size analysis	i. Around 5% is less than 0.002 mm diameter ii. 57.5% lies between 0.002 and 0.075 mm iii. 37.5% lies between 0.075 and 0.425 mm	IS: 2720(Part IV):1985 [9]
10	Permeability	3.22×10^{-7} cm/sec	IS: 2720(Part XVII):1986 [10]

Table 2 Results of chemical characterization

S. no.	Parameters	No. of samples	Conc. range (in %)	Mean conc. (in %)	S. D.
1	Arsenic	5	0.12–0.13	0.122	0.004
2	Iron	6	19.05–22.84	20.63	1.424
3	Aluminum	3	8.07–9.92	9.24	1.018
4	Silica	3	16–19.02	17.51	1.424
5	Calcium	3	5.84–6.7728	6.3243	0.467
6	Magnesium	3	0.7430–0.7500	0.7542	0.014
7	Chloride	3	0.8–1.038	0.919	0.073
8	Sulfate	2	0.92–1.06	0.99	0.097

When 1 gm sludge sample is diluted in 20 ml, pH of the aqueous solution was found to be 7.97.

Mean arsenic concentration in the sludge sample is 1220 mg/Kg, which is much higher than 50 mg/Kg {as per Indian Standard, i.e., Hazardous Material (Management, Handling and Transboundary Movement) Rules, 2008}. Hence, it comes under Class A type of Hazardous Waste.

7 Immobilization in Concrete

The arsenic-bearing sludge had been embedded in the M20 grade concrete in varying proportions, viz. 0, 5, 10, 12.5, 15, 20, 25, 30, 32.5, 35, 37.5, 40, 60, 80, and 100% by weight of cement. This amount of sludge had been added by replacing equivalent amount of sand. And water equivalent to the OMC of this sludge had also been added to the concrete mix. Seven cubes of dimension 100 mm × 100 mm × 100 mm had been cast for each of the percentages from 0 to 40%. In each case, the slump height and compacting factor had been determined to signify its workability. Also, three cubes each for 7 days and 28 days had been cured separately (using 25L of water) in two different crates, and their strengths had been determined at the end of respective curing periods. This had been done for determination of the leached arsenic concentration in the curing water both after 7 days and 28 days of curing. Among these three cubes (for 7 days and 28 days), one cube had been crushed to three size ranges, viz. <9.5, <1, and 5–50 mm and TCLP as per the method outlined in USEPA Method 1311 [13] had been performed to determine the arsenic concentration in the leachate. For 60, 80, and 100% sludge-mixed concrete cubes, only three cubes had been cast in each case. Only their strength after 28 days of curing had been determined, and the TCLP had been performed on them. These three percentage sludge-mixed concrete had been cast for the purpose to see whether any arsenic is leaching out of the concrete even when such a high percentage like 100% by weight of cement of sludge be mixed. All the data collected for each percentage of sludge-mixed concrete are given below in Tables 3 and 4.

Table 3 Strength and other parameters for M20 grade of concrete

Percentage sludge mixed	Average 7 days compressive strength (N/mm^2)	Average 28 days compressive strength (N/mm^2)	Workability (mm)	Compacting factor	Average weight of concrete cubes (Kg)
0.00	31.67	45.67	35	0.85	2.49
5.00	29.67	42.33	25	0.83	2.47
10.0	28.33	38.33	15	0.79	2.45
12.5	27.67	34.67	15	0.79	2.44
15.0	25.67	34.67	15	0.78	2.44
20.0	24.00	33.67	15	0.77	2.42
25.0	22.00	31.50	10	0.76	2.41
30.0	20.00	26.67	10	0.75	2.39
32.5	19.00	22.00	05	0.74	2.37
35.0	17.00	20.17	05	0.74	2.36
37.5	18.50	19.83	05	0.74	2.34
40.0	17.00	18.50	05	0.73	2.35
60.0	–	21.00	00	–	2.21
80.0	–	15.50	00	–	2.11
100	–	16.00	00	–	2.12

Change of 7 day compressive strength of the concrete cubes as a function of percentage sludge mixed shown in Fig. 3. From Fig. 3, it is seen that the compressive strength of concrete cubes after 7 days of curing had been decreasing with increase in amount of sludge mixed. As per IS 456:2000 [14], generally the strength at end of 7 days is two-thirds of the target mean strength.

For M20 grade of concrete, the strength to be achieved at the end of 7 days is 17.8 N/mm^2. Up to 32.5% (by weight of cement) sludge-mixed concrete cube had achieved this strength. But on the next increment of sludge-mixed concrete, i.e., 35% (by weight of cement), it had failed to achieve this strength. This 35% sludge-mixed concrete cube had achieved 64% of the target mean strength after 7 days of curing. Change of 28 day compressive strength of the concrete cubes as a function of percentage sludge mixed shown in Fig. 4.

From Fig. 4, it is seen that the compressive strength of concrete cubes after 28 days of curing had been decreasing with increase in amount of sludge mixed.

For M20 grade of concrete, the strength to be achieved at the end of 28 days is 26.6 N/mm^2. Up to 25% (by weight of cement) sludge-mixed concrete cube had achieved this strength. But on the next increment of sludge-mixed concrete, i.e., 30% (by weight of cement), it had just achieved this strength. So, this point signifies the maximum amount of sludge that can be mixed by weight of cement in M20 grade of concrete. But from practical point of view keeping a margin for safety, a factor of safety of minimum 1.5 had been prescribed. So, the recommended maximum percentage of sludge (by weight of cement) that can be safely mixed with M20 grade concrete is 20%.

Table 4 Arsenic concentration in curing water and leachate for M20 grade of concrete

% sludge mixed	Arsenic conc. in curing water after 7 days (ppb)	Arsenic conc. in leachate after 7 days for size range <1 mm (ppb)	Arsenic conc. in leachate after 7 days for size range <9.5 mm (ppb)	Arsenic conc. in leachate after 7 days for size range 5–50 mm (ppb)	Arsenic conc. in curing water after 28 days (ppb)	Arsenic conc. in leachate after 28 days for size range<1 mm (ppb)	Arsenic conc. in leachate after 28 days for size range <9.5 mm (ppb)	Arsenic conc. in leachate after 28 days for size range 5–50 mm (ppb)
0.00	0.213	0.693	0.201	0.136	0.335	0.369	0.334	0.990
5.00	0.481	1.149	1.894	0.599	0.611	0.093	0.509	1.663
10.0	0.642	1.746	1.895	0.919	0.634	1.772	1.699	1.415
12.5	0.511	3.758	3.937	3.176	0.605	4.138	5.339	3.170
15.0	0.784	2.159	2.378	1.105	0.842	3.216	3.736	2.492
20.0	0.623	4.574	4.441	3.926	0.793	6.285	9.476	6.335
25.0	0.781	7.188	9.870	5.074	0.918	9.219	9.940	7.048
30.0	1.123	2.022	3.152	1.746	1.612	2.820	7.369	1.762
32.5	1.016	5.296	8.133	3.000	1.584	7.569	6.289	9.804
35.0	1.027	2.654	3.122	1.742	1.295	4.624	3.418	3.767
37.5	1.153	3.401	7.885	2.096	1.458	2.558	8.961	7.094
40.0	1.129	3.624	7.926	2.164	1.222	4.175	4.827	2.387
60.0	–	–	–	–	2.527	4.866	5.110	2.778
80.0	–	–	–	–	2.711	4.858	5.376	3.456
100	–	–	–	–	2.733	5.413	5.712	2.255

Fig. 3 Percentage sludge mixed vs 7 days compressive strength graph for M20

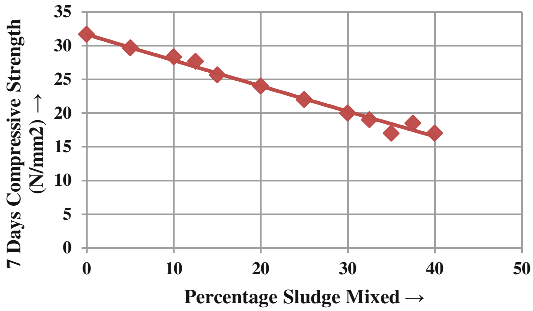
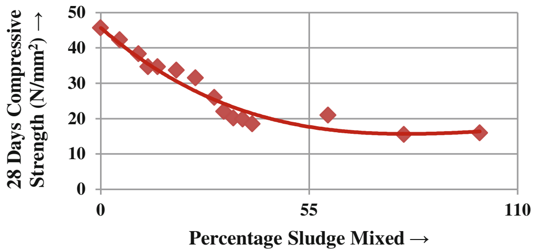


Fig. 4 Percentage sludge mixed vs 28 days compressive strength graph for M20



Change of workability of the concrete mix as a function of percentage sludge mixed shown in Fig. 5. From Fig. 5, it is seen that the workability determined by slump height is decreasing with increase in amount of sludge mixed. This sludge sample mixed has an exceptionally high OMC value (72%), so its moisture-holding capacity is high. And although in this study extra water equivalent to the OMC of the sludge have been added, still the increase in sludge amount showed a gradual drying up of the freshly prepared concrete mix. So, the workability has been decreasing significantly with addition of sludge.

For M20 grade concrete, the slump height was 35 mm for 0% sludge (by weight of cement)-mixed cubes. It signifies a low workability (within 25–75 mm as per IS 456:2000). The slump height has decreased to 10 mm for 30% sludge (by weight of cement)-mixed cubes in which the maximum percentage of sludge can be mixed to achieve the target mean strength of M20. So, there had been a 71.4% decrease in workability.

Change of compacting factor of the concrete mix as a function of percentage sludge mixed shown in Fig. 6. From Fig. 6, it is seen that with increase in sludge percentage, the compacting factor is decreasing. Compacting factor is another measure for workability, and it is decreasing because of the same reason why the slump height is decreasing.

For M20 grade concrete, the compacting factor was 0.85 for 0% sludge (by weight of cement)-mixed cubes. It signifies a low workability (within 0.80–0.85 as per Table No. 22 of SP23:1982 [15]). The compacting factor has decreased to 0.75 for 30% sludge (by weight of cement)-mixed cubes in which the maximum percentage of sludge can be mixed to achieve the target mean strength of M20. It

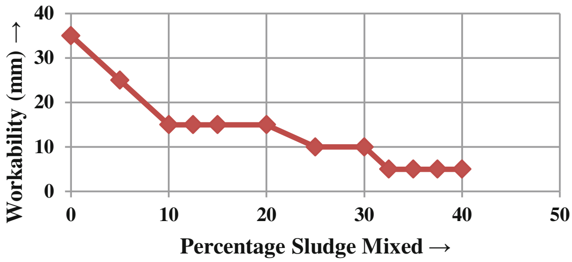


Fig. 5 Percentage sludge mixed vs workability of concrete mix graph for M20

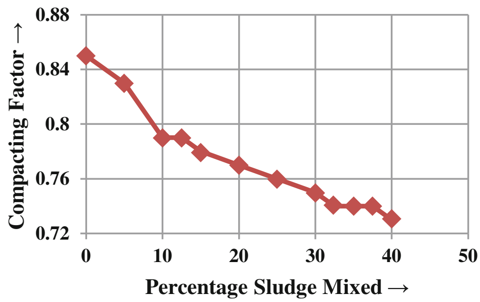


Fig. 6 Percentage sludge mixed vs compacting factor of concrete mix graph for M20

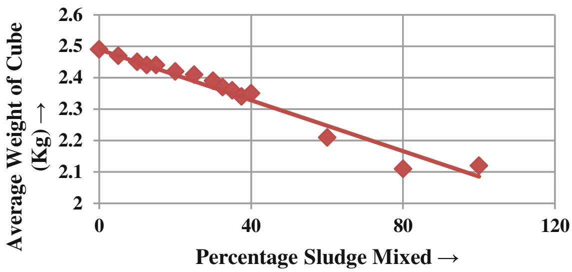


Fig. 7 Percentage sludge mixed vs average weight of concrete cubes after 28 days of curing graph for M20

signifies a very low workability (within 0.75–0.80 as per Table No. 22 of SP23:1982 [15]). So, there had been an 11.8% decrease in compacting factor (Fig. 6). Figure 7 shows the variation of average weight of concrete cubes as a function of percentage sludge mixed.

From the above graph, it is seen that with the increase in percentage of sludge mixed, the average weight of the concrete cubes is decreasing. This may be due to the fact that the maximum dry density (0.883 gm/cc) of this sludge is less than the other constituents of concrete like cement, sand, and stone chips. This low density owes to the fact that the void ratio (2.281) of the sludge sample is higher than the other constituents of concrete. So, the amount of voids is much higher in the sludge sample. But the design mix weight of concrete cube is fixed, and with this low density, it is taking up more volume. So, the overall weight of the concrete cube is becoming less as we are increasing the amount of sludge mixed.

For M20 grade concrete, the average weight of the concrete cubes is 2.49 kg for 0% sludge (by weight of cement)-mixed cubes. It has decreased to 2.39 for 30% sludge (by weight of cement)-mixed cubes in which the maximum percentage of sludge can be mixed to achieve the target mean strength of M20. So, there had been a 4% decrease in average weight of concrete cubes.

The sludge-mixed concrete cubes have been checked for leachability of arsenic by TCLP. For this, it had been pulverized into three size zones: (i) <1 mm, (ii) <9.5 mm, and (iii) 5–50 mm.

Figures 8 and 9 show that for M20 grade concrete, the leached arsenic concentration in the leachate tested for the cubes after both 7 days and 28 days of curing shows an increasing trend; i.e., with increase in percentage of sludge mixed, the arsenic concentration in the leachate increases. But still all the arsenic concentrations are well below 200 ppb (the limit of arsenic for safe disposal of leachates as stipulated by the Ministry of Environment and Forest, Government of India) and also below 10 ppb (the drinking water acceptable limit of arsenic as per

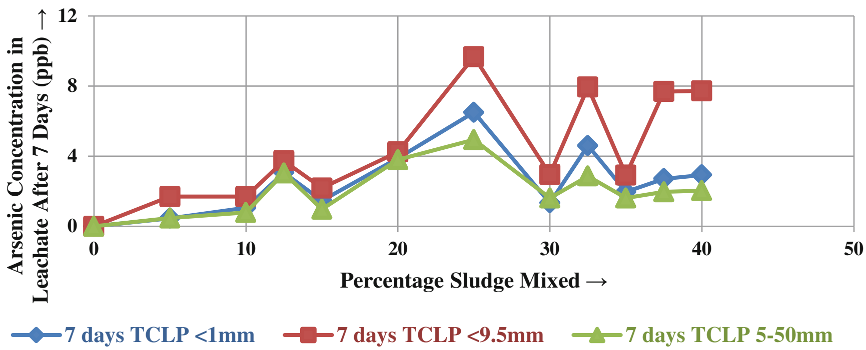


Fig. 8 As concentration in leachate by TCLP from 7 day cured concrete cubes as a function of percentage sludge mixed

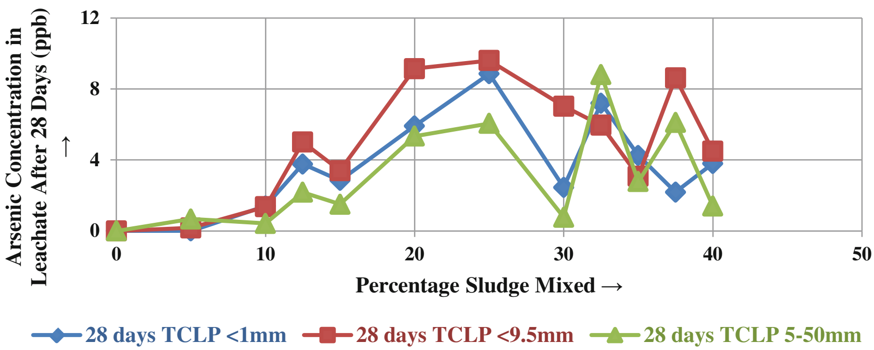


Fig. 9 As concentration in leachate by TCLP from 28 day cured concrete cubes as a function of percentage sludge mixed

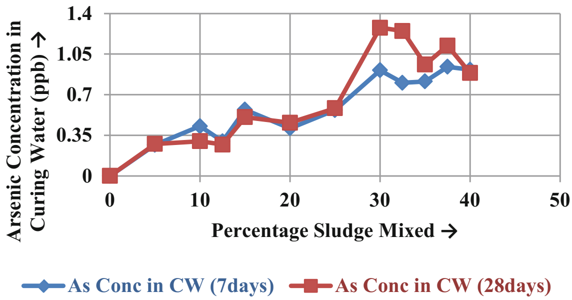


Fig. 10 As concentration in curing water for M20 concrete after 7 days and 28 days of curing as a function of percentage sludge mixed

IS10500:2012 [16]). The size zone <9.5 mm shows the worst case scenario in terms of leached arsenic concentration, and the results of this size zone can be taken as the representative one. USEPA has also recommended this size zone of <9.5 mm for the determination using TCLP.

Figure 10 shows the arsenic concentration in curing water tested after both 7 days and 28 days of curing as a function of percentage sludge mixed.

For M20 grade of concrete, it shows an increasing trend; i.e., for increase in percentage of sludge mixed, the arsenic concentration in curing increases. But still all the arsenic concentrations tested after both 7 days and 28 days of curing are well below 10 ppb (the drinking water acceptable limit of arsenic as per IS10500:2012 [16]). The arsenic content in the curing water after 28 days of curing is slightly higher than that after 7 days of curing.

8 Conclusion

The arsenic-bearing ECAR sludge was immobilized in M20 grade of concrete, and it was observed that the maximum percentage of sludge that can be mixed safely in terms of compressive strength is 30%. The arsenic concentration in the leachate produced from the concrete cubes was well below the prescribed safe limit. Thus, this sludge being a Class A Hazardous Waste can be immobilized in concrete which is a good stabilization option both in terms of economy and simplicity.

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Effect of Sulphate on Fermentative Sludge Hydrolysis Cum Biodegradation of Waste Activated Sludge

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Abstract The waste activated sludge (WAS) from the activated sludge process needs an appropriate sustainable sludge treatment and management. The sludge treatment and the management cost around 60% of the capital cost and 50–60% of the operating cost of a wastewater treatment plant. Anaerobic digestion is the dominant process for the sludge reduction and/or stabilization of WAS. Though many physico-chemical techniques are developed as a pre-treatment to enhance the hydrolysis of sludge prior to biomethanation, most of the techniques are very expensive and therefore not practical to apply in the field scale. This work shows the effect of fermentative sludge hydrolysis cum biodegradation of WAS in the presence and in the absence of sulphate. Sequencing batch reactor (SBR) operation at room temperature (31–33 °C) in an orbital shaker at 120 ± 2 rpm with cycle time of 7 days was adopted to compare the performance of fermentation in the presence and in the absence of sulphate. The fermentation in the absence of sulphate was conducted in the presence of externally added COD (sucrose) varied as 500, 1000, 1500 and 2000 (in mg/L). The sulphidogenesis reactors were maintained at a COD/SO_4^{2-} ratio of 1.0 and varied the concentration of both sulphate and COD as 500, 1000, 1500 and 2000 (in mg/L). An abiotic control was also maintained to evaluate the processes. The percentage sludge reduction varied between 27 and 98%, where the maximum reduction of about 96% was observed in the fermentative reactor in the presence of 500 mg/L of COD, whereas 98% solid reduction was observed in the sulphidogenesis reactor at 2000 mg/L of COD and sulphate. The other parameters such as pH, oxidation–reduction potential (ORP), VFA, alkalinity, soluble and total COD, and turbidity were analysed, and the results are discussed in the paper.

Keywords Waste activated sludge · Fermentation · Sequencing batch reactor Sulphidogenesis · Sludge treatment

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1 Introduction

The increase in population, industries and the related wastewater treatment operation in India is increasing the production of sludge in the wastewater treatment plants. The widely used technology for the treatment of wastewater is the conventional activated sludge process which generates large quantity of waste activated sludge (WAS). The WAS is highly putrescible and contains pathogens and therefore poses a serious threat to the environment and affects the ecological system [14]. It is estimated that the sludge treatment (stabilization) and disposal cost accounts for 50% of the total operational and maintenance cost of the wastewater treatment plants [16].

Anaerobic digestion is a widely used method for energy (biogas) production and stabilisation of WAS [7]. The steps involved in the anaerobic digestion are hydrolysis, acidogenesis, acetogenesis and methanogenesis. The hydrolysis step involves the conversion of insoluble organic material (lipids, polysaccharides, protein and nucleic acids) to soluble organic substances (amino acids and fatty acid) [3]. The long retention time required for the anaerobic digestion of WAS is due to the presence of microbial cells. The microbial cells act as barrier for hydrolysis and resist the biodegradation of cell components. Hence, hydrolysis is the rate-limiting step in anaerobic digestion of WAS [22].

A pre-treatment is required for enhancing the sludge hydrolysis [5]. There are different pre-treatment methods which include physical (mechanical, thermal, microwave, ultrasonic), chemical (alkaline, ozone oxidation) and biological (enzyme) or a combination of methods [8, 11]. These pre-treatments have limitations due to high energy requirement, high maintenance cost and high chemical cost. The physical treatment such as microwave and ultrasonication requires high energy, and it is not favourable for field-scale application in terms of economy [4]. The chemical treatment such as alkaline treatment affects the anaerobic bacteria and requires the addition of acid for maintaining the pH and thus increases the chemical cost [9]. The biological treatments are eco-friendly and cause less pollution to the environment [24]. But, the treatment with the commercial enzyme increases the cost of the treatment. Due to the limitation of high energy requirement and high chemical cost in physical and chemical methods, recently the combination of the physico-chemical treatment was approached [6].

The intermediate product in the anaerobic digestion is volatile fatty acids (VFAs) that are being produced by fermentative reactions and consumed by methanogenesis. Anaerobic fermentation is a promising technology for the production of VFA. This work deals with the fermentation of waste activated sludge in the presence and in the absence of sulphate in a sequencing batch reactor (SBR) in four cycles. The sulphates are sometimes present in wastewater as a result of industrial effluent discharge to municipal sewers. The VFA acts as the electron acceptor for sulphate reduction, and therefore, it is required to study the effect of sulphate on fermentative sludge hydrolysis cum biodegradation of WAS.

2 Materials and Methods

2.1 *Waste Activated Sludge*

The flocculent waste activated sludge was collected from the settling tank of an SBR (secondary treatment) in wastewater treatment plant of VIT, Chennai. The plant treats the wastewater from the campus. The sludge collected was allowed to settle for 2 h, and the settled sludge (2.9 g MLSS/l) was taken for the experimental study.

2.2 *Nutrient Media*

The nutrient media used was composed of $NaHCO_3$, 0.7 g; NH_4Cl, 0.04786 g/g sucrose; K_2HPO_4, 0.014 g/g sucrose; $MgCl_2$, 0.08 g/g sucrose; dissolved in 1 L of distilled water. The composition of trace element solution was (in g/L): H_3BO_4, 0.0005; $ZnCl_2$, 0.0005; $(NH_4)_6MO_7O_{24}{\cdot}4H_2O$, 0.0005; $NiCl_2{\cdot}6H_2O$, 0.0005; $AlCl_3{\cdot}6H_2O$, 0.0005; $MnCl_2{\cdot}4H_2O$, 0.0005; $CoCl_2{\cdot}4H_2O$, 0.0005; $NaSeO_3{\cdot}5H_2O$, 0.001; $CuSO_4{\cdot}5H_2O$, 0.0005; $CaCl_2$, 0.0003; $FeCl_2$, 0.000015; and EDTA, 0.000015.

2.3 *Seed Sludge for Sulphidogenesis*

The activated sludge taken from the treatment plant was enriched for sulphidogenesis with COD/SO_4^{2-} ratio as 1 in a SBR with cycle time of 2 days. The nutrient media used for enrichment was same as described in Sect. 2.2. The removal efficiency of sulphate in the reactor was 87%. This enriched sludge of 5 mL each was used for seeding batch sulphidogenesis reactor.

2.4 *SBR Operation for Anaerobic Fermentation*

The batch anaerobic fermentation was carried in the conical flasks having working volume of 250 mL. Each 100 mL settled WAS was taken in a series of nine reactors, where four were sulphidogenesis reactors and another four were fermentation reactors, and the last one was biotic control. In the sulphidogenesis reactors, COD/SO_4^{2-} ratio was maintained as 1 [13] with both COD and SO_4^{2-} concentration varied as 500, 1000, 1500 and 2000 (in mg/L). In the case of fermentation reactors in the absence of sulphate, the COD concentration varied as 500, 1000, 1500 and 2000 (in mg/L). A biotic control was kept with COD and sulphate concentration as 0 mg/L. The sucrose (Thomas baker, India) and sodium sulphate (Na_2SO_4) (Merck, India) were used as sources of COD and sulphate, respectively. Each 100 mL of nutrient media was added to all the reactors, and a headspace was maintained in each reactor for the escape of the gas produced. Gas escape mechanism was arranged as shown in Fig. 1, where the gas collection PVC tube (8 mm diameter) was immersed in 50 mm water depth. This ensures an escape of gas without affecting anaerobic condition inside the reactor. All the reactors were covered with black polyethylene sheets to avoid photosynthetic activity in the reactors. The anaerobic fermentation was done in complete mixing by keeping the reactors in the shaker (Scigenics biotech, orbitech, India) at 120 ± 2 rpm. All the reactors were maintained in the room temperature varied from 31 to 33 °C. SBR cycles were repeated for four cycles with cycle time of 7 days. In the start of repeating a cycle, 10 mL of thickened sludge was added to the residual sludge in each reactor along with fresh nutrient media. The time for feeding, settling and decanting was 2 h, which is negligible compared to the reaction time (7 days) in the SBR.

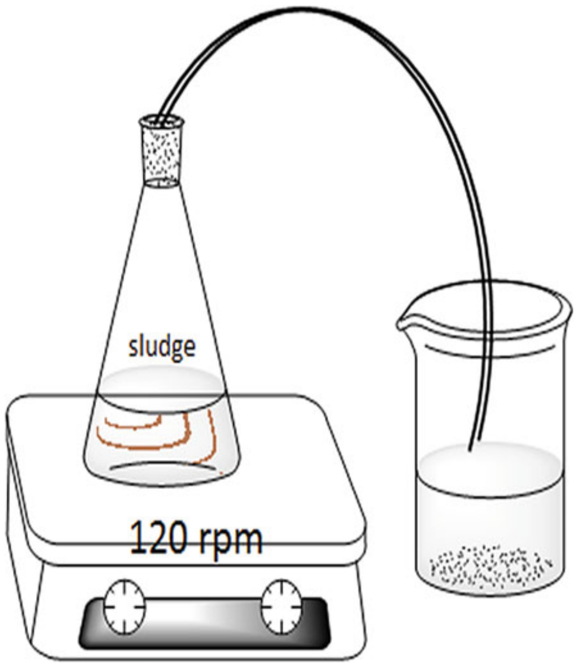

Fig. 1 Schematic set-up of a typical batch reactor

2.5 Analytical Methods

The pH and oxidation–reduction potential (ORP) were measured using the digital pH meter (Mettler Toledo, Switzerland) and ORP digital meter (WTW inoLab, Germany), respectively. The ORP was measured using double junction platinum ORP electrode connected to a calibrated WTW inoLab pH (720) meter in mV mode. ORP electrode (Pt–Ag/AgCl) was calibrated using RH 28 supplied by WTW, Germany. The suspended solids, turbidity, TCOD and SCOD were measured according to the standard methods [2]. Volatile fatty acid (VFA) and alkalinity were determined by the titration method [17]. The sludge sample from the reactors were centrifuged and filtered in the Whatman filter paper of 0.42 µm, and the clear supernatant was analysed for soluble COD, VFA and alkalinity.

2.6 Calculations

The disintegration degree (DD) was calculated to know the efficiency of the sludge disintegration by Eq. (1) [7].

$$\mathrm{DDCOD}(\%) = (\mathrm{SCOD} - \mathrm{SCOD_o})/(\mathrm{TCOD} - \mathrm{SCOD_o}) * 100 \tag{1}$$

where $SCOD_o$ is the SCOD of the sludge before treatment; SCOD is the final soluble COD after treatment; and TCOD is the initial total COD.

The solid reduction can be calculated using Eq. (2)

$$\mathrm{SS}(\%) = \frac{\mathrm{SS_{in}} - \mathrm{SS_{out}}}{\mathrm{SS_{in}}} * 100 \tag{2}$$

where SS_{in} and SS_{out} are the suspended solids before and after treatment.

3 Results and Discussion

3.1 Variation of PH in SBR Cycles

Figure 1 shows the variation of pH in the fermentation and the sulphidogenic reactors. The initial pH was around 7.2 at the start-up. The average final pH of four cycles showed a decrease in pH corresponds to the increase in concentration of substrates. This could be due to the fermentation of organic matter and due to the production of VFA and its dissociation. Yuan et al. [25] reported similar drop in pH when there is a production of VFA as a result of fermentation of WAS. There was an increase in pH in the last cycle compared to the previous cycles, but maintains in the acidic range. This could be due to the decreased sludge fermentation and increased utilisation of VFA in the last cycle compared to the previous cycles. The pH varied from 3.6 to 7.0 in all the cycles. The acidic range favours the hydrolysis of the WAS. The acid-producing fermentative microorganism can survive in the pH ranged between 5 and 8.5 [7]. The three types of fermentation normally occur are butyric fermentation, propionic fermentation and ethanol fermentation. The ethanol fermentation occurs when the pH < 4.5 [12].

In the case of sulphidogenic reactor too, pH dropped as a result of fermentation and similar condition was observed by Wang et al. [20]. However, there were no aqueous sulphides present during the analysis. This could be due to escape of the entire sulphides as H_2S in acidic pH. The percentage of H_2S can be calculated from Eq. (3) [18].

$$H_2S(\%) = 100/\left(1 + \frac{K_{a1}}{[H+]}\right) \tag{3}$$

K_{a1} is the dissociation constant for hydrogen sulphide. It indicates that when pH value is 7 at 30 °C, 60% of H_2S is present as gaseous form. It is evident that when pH decreases, the gaseous form of H_2S increases to 100%. In this study, acidic condition prevails for sludge disintegration and further degradation in both fermentation and sulphidogenic reactors. Normally under alkaline condition, the presence of higher concentrations of sulphides enhances the sludge hydrolysis and degradation of organic substance [23]. Since sulphides were not present in the sulphidogenic reactor, the contribution of sulphides in sludge hydrolysis is insignificant. The main advantage is that the residual management of sulphides is not required since the gaseous H_2S escapes to the atmosphere. But release of H_2S in higher concentrations into the environment gives unpleasant odour and will be toxic to the humans. Therefore, one needs to take care of this environmental hazard when the process is applied in field scale.

3.2 Variation of ORP in SBR Cycles

The variation of ORP is shown in Fig. 2. The ORP values indicate that all the reactors were maintained in the reduced conditions for a favourable fermentation process to occur. The ORP values indicate higher microbial activities happened during second and third cycles. The relative lesser microbial activities in first cycle could be due to lag phase as the microbes need time to produce the required enzymes. The maximum sulphate reduction occurs when the reduction potential is too negative [10]. In the study, the ORP was negative in both the sulphidogenic and fermentation reactor. The ORP varied from −374 to −49 during the cycles. The ORP would fluctuate if the concentration of glucose completely depletes during the fermentation process [15]. This indicates the degradation of organic matter in the presence of glucose or sucrose. The relative lesser values of ORP in the last cycles could be due to the enhanced degradation of organic matter.

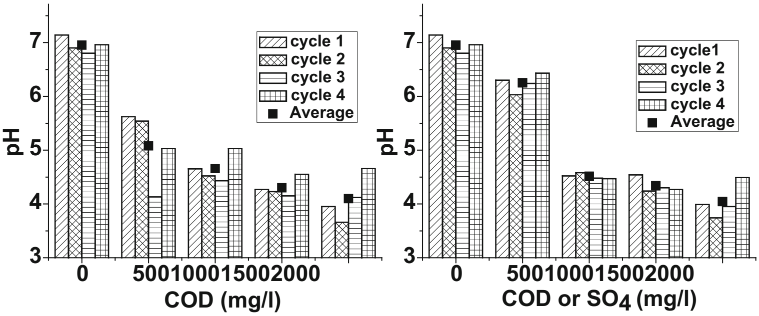

Fig. 2 Variation of pH in fermentation and sulphidogenesis

3.3 *Solid Reduction in the SBR Cycles*

The control reactors gave maximum solid reduction in the second cycle, and later cycles' solid removal got affected. This could be due to more resistance to sludge hydrolysis as difficult to hydrolyse cell components increases as the cycle progresses. It was observed that solid reduction in the fermentation reactor (absence of sulphate) showed a highest reduction of 96% in the presence of 500 mg/L of COD. This could be due to sucrose which might have triggered the fermentation reactions, and since the substrate is limiting, the cells need to work hard to hydrolyse the sludge for their survival. However, when the COD increases, cells get easily degradable substrates for their survival. There is a relative decrease in the solid reduction in the last three cycles when the COD varied as 1000, 1500, 2000 (in mg/L) which indicates that disintegration efficiency decreases. Also, there may be a possibility of growth of cells in correspondence with increase in COD. The overall results also show that as the COD increases, the net solid reduction decreases. In short, from this limited study, to enhance solid reduction, 500 mg/L of external supply of COD is optimal.

In contrary to fermentation reactor, the solid reduction in the sulphidogenic reactor showed a greater reduction at increased substrate concentrations. Also, it is observed that the last cycles gave more solid reduction when the substrate concentration exceeds 1000 mg/L. It reveals that solid reduction increases when the substrate concentration increases. When compared with fermentation reactor, the sulphidogenic reactor proved to be higher in solid reduction at increased substrate concentrations. The reason behind this is that the fermentation product is being used by the sulphate-reducing bacteria as carbon source [19].

3.4 Disintegration Degree in the SBR Cycles

The important indicating parameter for sludge disintegration is the generation of soluble COD [21]. The disintegration degree was highest in the first cycle in the control reactors (Fig. 4), and when the cycle progressed in control reactors, there was no accumulation of soluble COD in correspondence with solid reduction (Fig. 3). This indicates that control reactors could biodegrade the generated COD when the cycle progressed. Also, the performance of fermentation reactors shows that biodegradation was an effective process as there was no accumulation of soluble COD in correspondence with the solid reduction (Fig. 3). In contrary, in the sulphidogenic reactors at higher concentrations, there was a limitation in biodegradation in the initial cycles compared to the last cycles. Increase in the disintegration degree increases the solubilisation of organic matter [1]. The reason for the results obtained in the disintegration degree (Fig. 4) in fermentation and sulphidogenic reactors in contrast to solid reduction (Fig. 3) is due to the simultaneous solid disintegration cum biodegradation in the SBR operation.

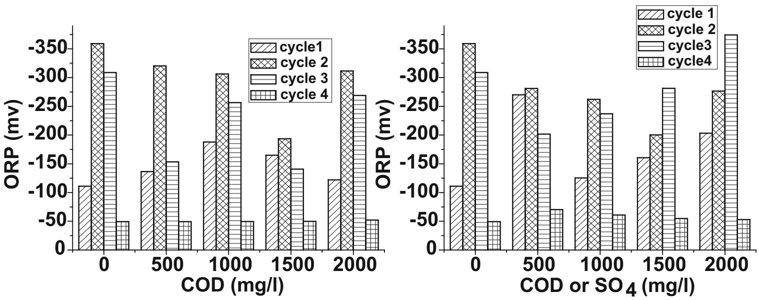

Fig. 3 Variation of ORP in fermentation and sulphidogenesis

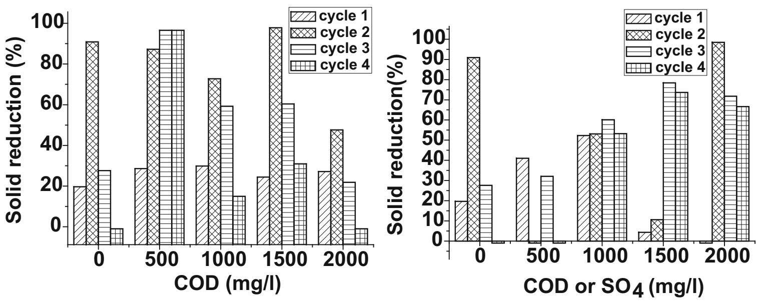

Fig. 4 Solid reduction in fermentation and sulphidogenesis

3.5 Variation of VFA and Alkalinity

Sludge acidification results in fermentation (Fig. 5) of soluble organics having low molecular weight by associative acidogenic bacteria [21]. The VFA varied from 6 to 105 meq/L in both the SBR systems (Fig. 6). The generic trend is that as the substrate concentration increases, the average VFA increases, and it is expected in a fermentation reactor.

Figure 7 shows the variation of alkalinity in the reactors. The alkalinity could have formed as a result of fermentation end products dissolved in the water. The trend of average alkalinity shows an increase in line with the average increase of VFA. This is in contrast to the general understanding that when VFA increases, the alkalinity decreases. Therefore, the results of this investigation indicate that SBR operation is beneficial in the sludge disintegration cum biodegradation process of WAS. However, the alkalinity produced is not sufficient enough to buffer the system.

The variation of turbidity is represented in Fig. 8. The results show that the turbidity increased in the first two cycles and further decreased in the last two

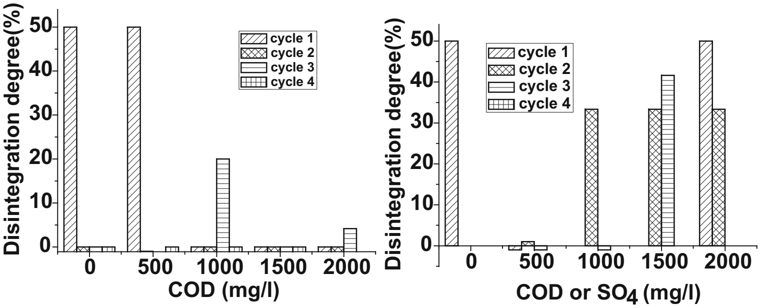

Fig. 5 Disintegration degree in fermentation and sulphidogenesis

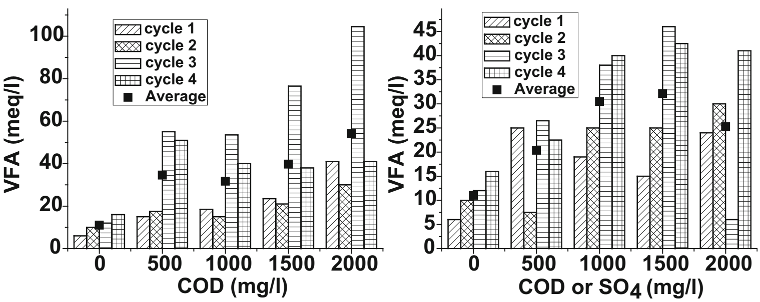

Fig. 6 Variation of VFA in fermentation and sulphidogenesis

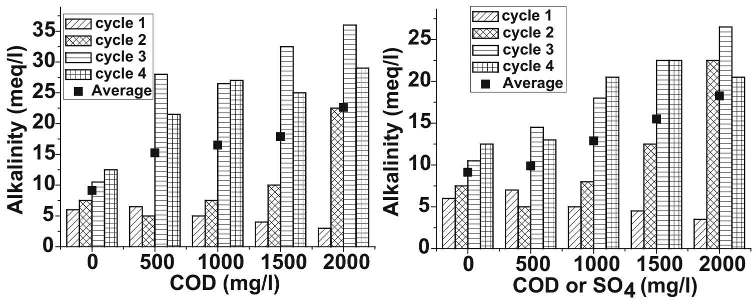

Fig. 7 Variation of alkalinity in fermentation and sulphidogenesis

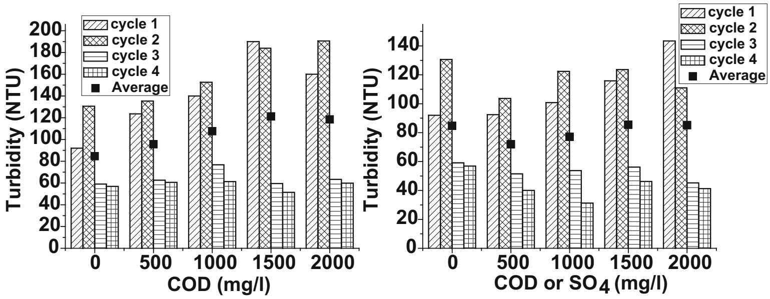

Fig. 8 Variation of turbidity in fermentation and sulphidogenesis

cycles. The turbidity is caused by the presence of suspended solids and/or colloids. Here also, the results show that SBR operation is beneficial in getting a more clarified treated effluent.

3.6 Variation of Turbidity

See Fig. 8.

4 Conclusions

The simultaneous occurrence of sludge disintegration and degradation occurs in the SBR operation of both fermentation without sulphate and fermentation in the presence of sulphate. The fermentation reactor was effective in the presence of 500 mg/L of COD to get 96% of solid reduction. On contrary, the higher solid reduction to the extent of 98% in the sulphidogenic reactor was obtained at

2000 mg/L of COD and SO_4^{2-}. The presence of sulphate helps in increased solids disintegration in higher concentrations of externally added COD. The other process parameters monitored support the simultaneous occurrence of sludge disintegration and degradation in the SBR.

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Impact of Varied Ratio of Duckweed (*Spirodela polyrhiza*) and Waste-Activated Sludge on Anaerobic Digestion

Rubia Zahid Gaur and Surendra S. Suthar

Abstract In this study, duckweed (*Spirodela polyrhiza*) and waste-activated sludge (WAS) were co-digested in different proportions with acclimatized anaerobic granular sludge (AAGS) in mesophilic conditions. The aim was to evaluate if the co-digestion could lead to an increased efficiency of methane production compared to digestion of waste-activated sludge alone. Results indicate that co-digestion with both duckweed and WAS, in certain proportions, i.e., T4, increased the methane generation compared with digestion at other proportions. The methane generation yield in treatment setup T4 was significantly higher than the calculated in many of the proportion. The Gompertz model fits well on the experimental data of the treatment setup T4. The values of correlation coefficient were achieved relatively higher ($R^2 \geq 0.99$). The trend of methane generation was not obsevred similar for the co-digestion of duckweed with WAS in the without pretreated samples.

Keywords Biogas · Aquatic weed · Biomass · Waste-activated sludge Gompertz equation

1 Introduction

Anaerobic digestion is considered as one of the prospective alternatives to recover energy and other valuable resources from organic biomass, but it has few operational constraints such as slow hydrolysis and lower biogas yield. These process limitations can be overcome by pre-treating the feedstock before anaerobic digestion and or anaerobic co-digestion. The pre-treatment could accelerate the hydrolysis; thus, results in enhanced biogas generation [9, 13, 19] while co-digestion improve the process stability, digestibility, enhanced biogas yield. Results reported in the literature have shown that co-digestion of multiple substrates like banana and

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plantain peels, spent grains and rice husk, pig waste and cassava peels, sewage and brewery sludge, among many others, have resulted in improved methane yield [1, 4, 15, 16].

Aquatic weeds are ubiquitous and grow in different environmental and climatic conditions and act as a reservoir of both energy and nutrients [17, 22]. For last couple of decades, duckweed has attracted the attention of researchers to use it as a potential biomass since it is rich in nutrients and has the high organic matter content. This could lead to enhanced biogas generation, and the produced sludge contains almost all of the nutrients and can be used as a good fertilizer with no detrimental effects on the environment. Duckweed plant forms the special class of aquatic plant that signifies peculiar characteristics of the short life cycle, easy availability, cost-supportive, easily harvestable and processed into energy form [23]. Several species of duckweeds offers great potential for the polishing and valorization of wastewater nutrients and helps to improve water quality and minimize nutrient load by accumulating nutrients [8, 21]. However, massive growth rate of plant poses issues related to regular biomass harvesting, disposal, and possible utilization [20].

Previous studies reported that the biochemical composition of duckweed ensures the generation of adequate biomass highly rich in essential metabolites such as carbohydrate, starch, protein, and lipids and advocates its role as bio-energy feedstock [7, 20, 23].

Although co-digestion of different substrate has been studied significantly, still, the process lacks in co-digestion of duckweed with a waste-activated sludge and required more exploration under specific species with a variety of sewage sludge.

The present study was designed to investigate the potential of indigenous duckweed species *Spirodela polyrhiza* as a co-substrate in anaerobic digestion with waste-activated sludge (WAS) in various proportions to investigate the methane generation potential. Therefore, the primary aim of this study was to investigate the feasibility of addition of duckweed with waste-activated sludge (WAS) as a co-substrate for anaerobic co-digestion and its subsequent effect on bio-methane generation.

2 Materials and Methods

2.1 Substrate Collection

Two different substrates, duckweed *S. polyrhiza* and WAS, were used for the anaerobic co-digestion study. The duckweed (whole plants) was freshly harvested from a pond situated near Doon University campus (30° 16′N, 78° 02′E), in Dehradun, India. The plant was brought to the laboratory in a sampling bucket and rinsed with tap water followed by distilled water. The cleaned plant was spread over bloating papers to absorb excess water droplets. The plant was shredded in a mixer to reduce its particle size to easily available for microbes. Waste-activated sludge was brought from the excess sludge line of the sequencing batch reactor (SBR) ~27 MLD capacity from a sewage treatment plant (STP) situated at Haridwar (India). Acclimatized anaerobic granular sludge (AAGS) was used as inoculum in the present study which was obtained from anaerobic digester of an activated sludge process (ASP) capacity ~18 MLD, STP, Haridwar, India.

2.2 Reactor Configuration and Experimental Protocol

The present study was investigated in batch reactors of 500 mL capacity reagent bottles. All experiments were carried out in triplicates. Batch experiments were performed in water bath shaker at 30 °C. The duckweed biomass was thermally pre-treated using autoclave to get solubilized form of organic matter to accelerate the hydrolysis process. Batch studies of varied combination of pre-treated duckweed plant biomass with constant volume of anaerobic inoculum (AAGS—100 mL) and waste-activated sludge (WAS—22.5 mL) were carried out. The final volume of the reactors was kept 450 mL by using distilled water. Typical five different compositions with varied ratios of substrate, inoculum, and waste-activated sludge were as follows:

T1—22.5 mL pre-treated *S. polyrhiza* (5% total volume) + 100 mL AAGS + 22.5 mL WAS
T2—45.0 mL pre-treated *S. polyrhiza* (10% total volume) + 100 mL AAGS + 22.5 mL WAS
T3—67.5 mL pre-treated *S. polyrhiza* (15% total volume) + 100 mL AAGS + 22.5 mL WAS
T4—90.0 mL pre-treated *S. polyrhiza* (20% total volume) + 100 mL AAGS + 22.5 mL WAS
T5—90.0 mL without pre-treatment *S. polyrhiza* (20% total volume) + 100 mL AAGS +
22.5 mL WAS

After mixing substrate and inoculum, the nitrogen gas was purged into each reactor to create anaerobic condition. All reactors were connected to inverted plastic bottles filled with 1.5 N NaOH [14], and a needle was punched into the bottom of the bottle to collect the displace NaOH. The displaced volume of NaOH was collected in a beaker placed below the inverted bottle. The volume of NaOH collected in beaker was considered an equivalent amount of methane gas generation [14]. The methane gas generation was recorded daily, while total solids (TS), volatile solids (VS), soluble chemical oxygen demand (SCOD), and volatile fatty acid (VFA) were analyzed at fixed time interval of five days and lasts till 35th day.

2.3 Analytical Method

Both substrates (duckweed + WAS) and inoculums were oven dried at 105 °C for 24 h and grind in the mixer. Grinded power was passed through 0.2 mm sieve and then used for further analysis. The pH of substrate and inoculums was measured using digital pH meter (Metrohm, Swiss made). The total solids (TS), volatile solids (VS) and soluble chemical oxygen demand (SCOD) of all materials (*S. polyrhiza*, WAS and AAGS) were determined using standard protocols as described in [3]. Total nitrogen (TN) was measured through Kjeldahl digestion unit with digestion mixture of H_2SO_4, K_2SO_4, and $CuSO_4$ [5]. VFA was measured according to pH titration method presented by DiLalo and Albertson [12].

3 Results and Discussion

3.1 Performance Evaluation Under Different Treatment Setup

Table 1 summarizes the various physico-chemical parameters obtained from different batch studies. As it is shown, there is a significant variation in the composition of feed mixtures, which is due to the variability in the composition of the samples of the different substrates taken over the experimental period. The initial content of TS and VS of treatment T1 to T5 ranged between 167.10 ± 0.85 to 290.46 ± 1.19 g/kg and 98.83 ± 0.60 to 138.53 ± 0.60 g/kg reduced to 8.77 ± 0.05 to 22.83 ± 0.25 g/kg and 0.14 ± 0.01 to 5.60 ± 0.07 g/kg. Results revealed that the overall reduction occurs in TS and VS concentration ranged 94–98% in all treatment setups. A similar trend for the removal of SCOD was observed in all treatment setups; however, SCOD

Table 1 Performance evaluation in terms of physico-chemical parameters under different treatment setup

Treatment	Duration (day)	TS (g/kg)	VS (g/kg)	SCOD (g/kg)	VFA (mg/L)
1	At start	250.8 ± 2.52	126.3 ± 1.15	188.01 ± 21.63	501.3 ± 0.57
	At end	9.93 ± 0.20	3.66 ± 0.15	3.66 ± 3.51	396.00 ± 4.00
2	At start	260.43 ± 0.94	130.10 ± 0.40	194.50 ± 1.81	512.00 ± 2.00
	At end	22.83 ± 0.25	1.23 ± 0.11	1.94 ± 0.01	388.33 ± 1.12
3	At start	279.20 ± 1.47	133.79 ± 1.11	209.95 ± 0.95	546.33 ± 3.05
	At end	6.23 ± 0.05	0.48 ± 0.04	0.71 ± 0.03	498.33 ± 1.52
4	At start	290.46 ± 1.19	138.53 ± 0.60	208.18 ± 0.41	566.33 ± 2.08
	At end	8.77 ± 0.05	0.14 ± 0.01	0.22 ± 0.00	559.67 ± 1.25
5	At start	167.10 ± 0.85	98.83 ± 0.60	148.48 ± 0.45	245.80 ± 1.62
	At end	14.23 ± 0.32	5.60 ± 0.07	8.42 ± 0.08	284.66 ± 4.21

removal was more in treatment setup T4. The VFA concentration was observed in sufficient range as reported in previous studies. No adverse affect on lowering of alkalinity observed. The C/N ratio varied between values of 16 and 18. Although most researchers recommend operating within a C/N ratio range of 20–30 for anaerobic bacterial growth in anaerobic digestion systems [18], the optimal C/N ratio varies with the type of feedstock to be digested. For example, Romano and Zhang (2008) recommended maintaining the C/N ratio at 15 for the co-digestion of onion juice and digested sludge.

3.2 Variation in VSS, VFA, SCOD, and Methane Production

Figure 1 shows temporal variation in SCOD, VSS, VFA, and methane production from different experimental setups supplemented with variable duckweed biomass. It was found that the SCOD and VSS decrease exponentially with time in all cases. In case of VFA, after initial accumulation from 5th to 10th day, a continuous reduction in VFA was observed. The maximum value of VFA of 1800 mg/L in treatment setup T4 was found and remains 600 mg/L at the end of the test run. The methane gas generation during maximum VFA in this treatment setup was less but

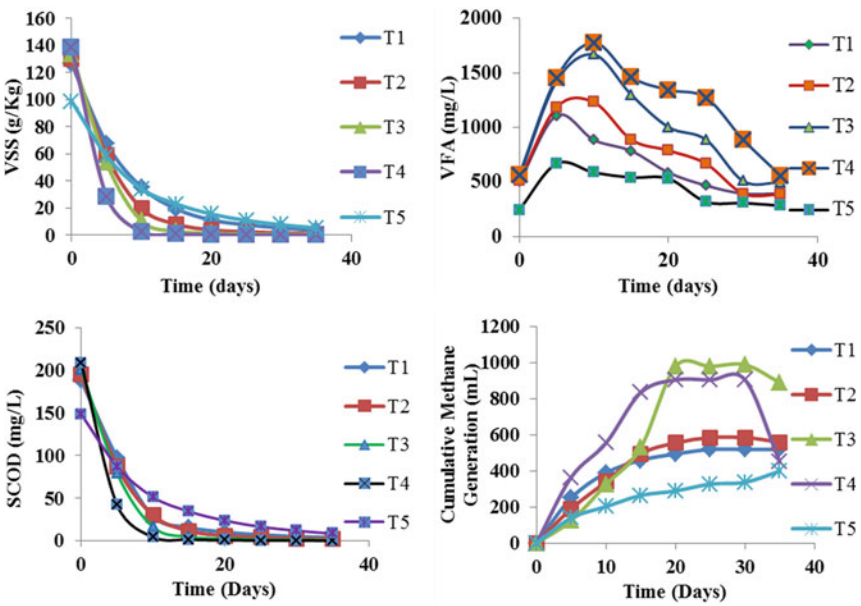

Fig. 1 Temporal variation of VSS, VFA, SCOD, and methane production in different duckweed inoculum reactor

continues to rise until the experiment ends (Fig. 1). The initial low production of the methane might be due to acclimatization of the methanogens to the environment. A similar pattern of VFA and methane gas generation was observed in other treatment setups.

Methane generation in the anaerobic digestion is closely related to the typical composition of the feed. Results indicate one-day lag phase in all experimental setups; then, a progressive trend was witnessed for methane generation. The maximum methane yield was observed in experimental setup T3 followed by T2 > T1 > T4 > T5. The methane production was observed 12–123% in pre-treated duckweed that indicates clearly the solubility of organic matter is higher compared to methane production; however, contradictory results were reported in the literature. Chen and Oswald [6] observed increased algal methane fermentation up to 33% at 100 °C for 8 h, while De Schamphelaire and Verstraete [10] did not detect any effect when pre-treating a mixture of microalgae at 80 °C for 2.5 h. Thus, the methane production greatly varies with factors such as inoculum, VS, VFA, and temperature. The methane production was a result of acidogenic/acetogenic activity of associated microbial communities. It was mainly depend on the inoculum activity and adoptability of the inoculum toward substrate [11]. Loss in volatile solid was related to transition process (hydrolysis and fermentation) of biomass to biogas. The transitional process also pre-dominates the formation of volatile fatty acids (acetic acid, propionic acid, butyric acid). The VFA and SCOD production/degradation was closely related to changes in pH, alkalinity, and the activity of methanogens. The relative degradation of solids and release of volatile fatty acids help to maintain relevant pH range for methanogenic microorganisms and acid-forming bacteria activity [2]. Results inferred that the pre-treatment mechanism along with different substrate to inoculum ratio will help to optimize the methane production.

4 Conclusions

Duckweed as an aquatic weed was abundantly available. The applicability of duckweed biomass in anaerobic co-digestion process revealed its suitability as a substrate. The maximum value of methane yield (140.5 mL/d) was achieved for the co-digestion of 20% duckweed biomass, 5% of WAS, and 10% of AAS for treatment setup T4. The variation of duckweed substrate in different treatment setups interlinked to the methane yield. Also, pre-treatment significantly influences the biodegradability of biomass and governs methane production. The experimental results validate that increase in methane yield was correlated with biochemical processes of anaerobic fermentation step and composition of the substrate. The employed kinetic model (Gompertz equation) predicts the pattern of methane production with time. The experimental methane production and predicted methane production showcase a linear correlation. This model was able to establish that duckweed is a promising substrate which offers short-term biodegradability.

Altogether, further research on optimization of processes condition such as temperature, methods of pre-treatments for duckweed biomass to use it as co-substrate in anaerobic digestion was need to be explored. It can be concluded that co-digestion of duckweed with WAS and AAS should be a better approach in order to get higher gas yield.

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An Effective Dewatering Method for Eco-friendly Disposal of Faecal Sludge

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Abstract The safe treatment of sewage is crucial for the health of any community. When the influent is rich in organic loading, the disposal of excess sludge is a major environmental challenge. This project aims to characterize the domestic sludge from the secondary treatment of an overloaded sewage treatment plant in a residential campus in order to test its suitability for effective dewatering. The influent is highly septic due to its mixing with partially digested sludge from anaerobic digestion tanks used for biogas production. Due to this reason, the range of various physic-chemical parameters such as bulk density, pH, total solids, MLSS and COD were observed to be on the high end compared to any domestic faecal sludge. A series of experiments were conducted to evaluate the solid-liquid separation potential of the sludge by employing different pre-treatments for settling. A unique combination of pre-treatment conditions such as heat drying, physical and chemical conditioning was designed for an eco-friendly disposal of sludge. In heat drying, the temperature of the sludge has been varied from 50 to 80 °C. The physical conditioning was done by slow mixing with a measured amount of bentonite clay to the sludge to improve its settling efficiency. The dewatering technique has resulted in quick drying of the sludge to a moisture content of 25% in less than 2 hours. This has resulted in about 70% removal of COD and 80% removal of solids to make the stabilized sludge for safe disposal. The resultant characteristics of stabilized sludge were suitable for co-composting.

Keywords Faecal sludge · Dewatering · Sludge stabilization · Moisture content Pre-treatment

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1 Introduction

The rapid pace of urbanization and deteriorating freshwater resources has accelerated the search for safe water supply system as well as hygienic sanitation for the public health in developing countries. In India, sanitation is one of the biggest management challenges faced by urban and rural governing bodies. It is reported that 53.1% of the households do not have a toilet, and for the 38% of the urban households in India who use toilet, there is no provision for safe disposal of faecal sludge [9]. Even though there are a lot of initiatives for creating sanitation facilities in the state, there is little attention going to the proper management of the faecal sludge for the safety of people and environment. Therefore, it is essential to ensure that proper faecal sludge management is implemented by considering its impacts on the current and future ecosystem.

Generally, the wastewater discharged from domestic premises comprises of 99.9% water and 0.1% solids and is considered as "organic" due to the presence of carbon compounds like human waste, paper, vegetable matter. Due to the extensive network of sewerage lines adopted in the urban and peri-urban regions for the centralized treatment system, there exist huge challenges in safe handling and disposal of sewage sludge containing large amount of faecal matter [4].

The term faecal sludge management (FSM) refers to the timely removal, treatment and disposal of faecal sludge from the septic tank through a network of sewerage pipes. Essentially, it leads to the necessity of a centralized facility at each nodal station, thereby targeting huge requirements for sludge handling and treatment. The high rate of average faeces generation for low-income countries (250 g/capita/day) than high-income countries (126 g/capita/day) is believed to be due to the high intake of fibrous food [6]. Based on the conventional proximity analysis, fertilizing equivalent of human excreta is identified to provide the essential macro-nutrients to the plant [2]. The specific advantages of designing a co-composting facility has been perceived as complementing the nutrients into the soil while achieving natural inactivation of pathogens [1, 8]. The typical nutrient values of human waste make it suitable to supplement fertilization (Table 1).

There are a few studies about co-composting of solid waste with various admixtures and industrial sludge. In India, fresh faecal sludge collected from bucket latrines and frequently emptied latrine vaults were informally co-composted in olden days [5]. Most of these composting initiatives were successful and used for

Table 1 Equivalent fertilization capacity of human excreta (adopted from [2])

Elements	Faecal sludge			Municipal solid waste
	In urine (500 L/year)	In faeces (50 L/year)	Total	(kg/capita/year)
Carbon (as C)	2.9	8.8	11.7	16–22
Nitrogen (as N)	4.0	0.5	4.5	0.55–1.1
Phosphorous (as P)	0.4	0.2	0.6	0.2–0.4
Potassium (as K)	0.9	0.3	1.2	0.55

producing compost at a regular rate. Results of the pilot study conducted [3] in the low-, middle- and high-income areas of Jabalpur city with a population over 5 lakh showed that windrow composting of the source-separated organic matter of municipal solid waste has resulted in crumbly earthy smelling materials with pH about 8, organic matter as 45%, moisture content as 36% and have acceptable amount of plant nutrients carbon 35%, nitrogen (0.05%), phosphorous (0.002), sodium (4.8%) and potassium (0.35%).

The main objective of the study is to characterize the sewage sludge collected from the secondary clarifier of an activated sludge-based treatment plant, which is receiving partially undigested sludge from a biogas plant. The solid–liquid separation potential of the sludge is compared between two conventional methods, viz. settling and filtration, in order to select the suitable pre-treatment. It is also aimed to evaluate a unique combination of pre-treatment conditions such as heat drying, physical and chemical conditioning in order to design an eco-friendly disposal of sludge.

2 Materials and Methods

The sewage treatment plant at Bannari Amman Institute of Technology (BIT), Sathyamangalam, Tamil Nadu, India, has been functioning over 15 years and undergone periodic development in the infrastructure of the treatment components. Recently, the treatment plant has been modified to uptake the increased organic loading due to the increased students' uptake and related developments. It is witnessed that the exiting process flow of human waste between biogas plant and STP has been disturbed seriously, resulting in accumulation of partially undigested sludge in the aeration tank of STP (Fig. 1). The sludge drying beds of STP also experienced deficiency in dewatering due to the insufficient time for open-drying. It is, therefore, decided to study the dewatering properties of faecal-rich sludge considering the overall treatment process available at the site. For this purpose, the sludge samples were collected from different locations on the treatment line and various physical and chemical properties of the sewage sludge have been determined periodically in the laboratory (Fig. 2).

2.1 Physico-chemical Characterization of Sewage Sludge

The pH and electrical conductivity (EC) were measured directly by employing the in-line type electrode instruments. The organic strength of the effluent was estimated in terms of biochemical oxygen demand (BOD) by measuring the depletion of dissolved oxygen in the diluted sample by modified Winkler's method and chemical oxygen demand (COD) by employing COD analyzer (Hanna make). The suspended and dissolved solids of the sludge samples were estimated by gravimetric method. The

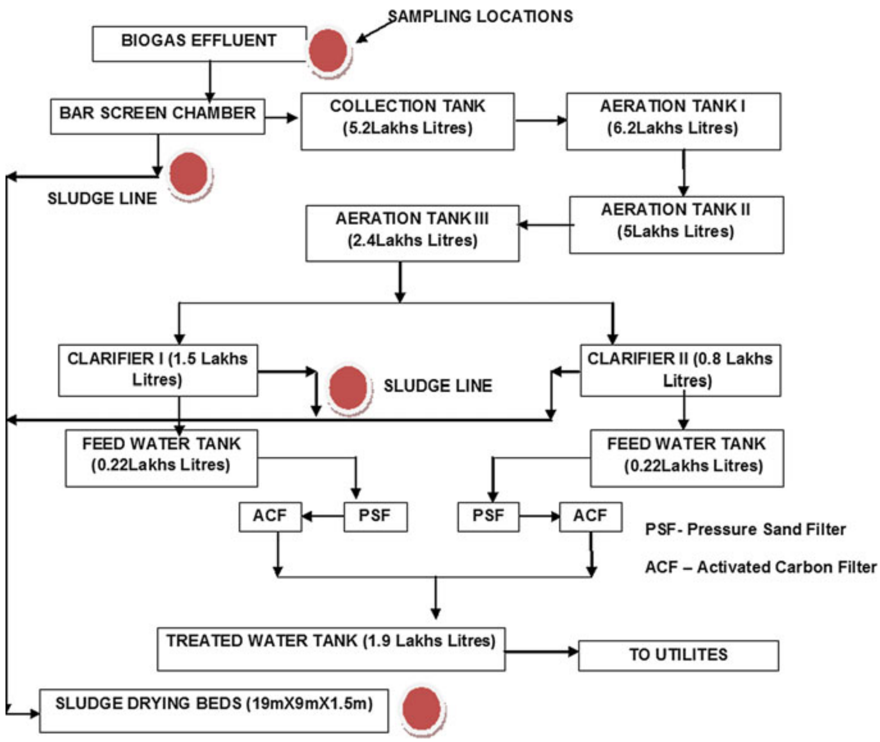


Fig. 1 Layout of the existing sewage treatment plant at BIT Sathyamangalam with a capacity of 700 m^3/day

Fig. 2 Wastewater samples collected at different locations of treatment process

concentration of the settleable micro-organisms was measured by in terms of mean liquor suspended solids (MLSS) by employing Imhoff cone of 1 L capacity and by measuring the settled volume after a period of 1 h.

2.2 Settling Column Experiment

The sludge samples were diluted with tap water for different concentration ratio of mixing. A glass cylinder of capacity 1 L was filled with the diluted sample and allowed to settle freely (Fig. 3). It is presumed that selection of dilution factor will allow the solids to settle without undergoing considerable inter-particle collaboration leading to compression settling and deep zone settling. The settling rate was measured by closely observing the depreciation of settling level through the glass cylinder.

Some alterations were incorporated to the normal settling of sludge to aid enhanced settling. The effect of temperature in the settling of the flocculent sludge was evaluated by varying the temperature of the diluted water between 30 and 90 °C. The experiment was repeated for different temperature of the sludge, resembling the possible heat treatment available for sludge dewatering in the field. The effect of guided flocculent settling was studied with the help of subsequent addition of bentonite clay to the sludge and mixing the solution before allowing for settling. The dosage of bentonite clay was optimized to get maximum settling efficiency with minimum dosage.

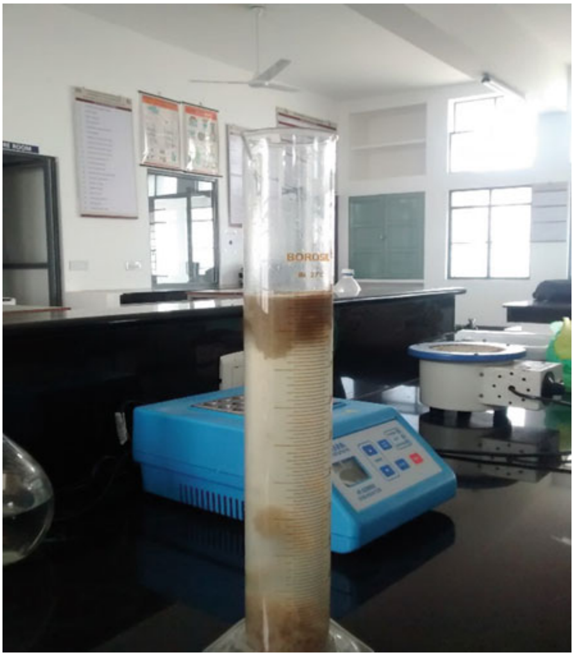


Fig. 3 Settling column experiment

3 Results and Discussion

3.1 Basic Sludge Characteristics

Physico-chemical analysis of the sewage sludge revealed the predominant nature of the sludge towards improving its dewatering capacity. Given the conditions tested by different sampling locations, it was observed that the variation of pH and EC is directly indicating the treatment efficiency of the existing process plants (Table 2). It was observed that most of the samples were in the alkaline range, indicating the mixing effect of faecal sludge with washing water. However, while considering the presence of a large number of dissolved organic compounds, the solids concentrations were very high at the STP inlet as well as in the aeration tank (Table 3). These characteristics of the sewage were directly correlating the physic-chemical properties of the sludge, which is generated at the secondary clarifier tank.

As observed that the organic loading rate varied even diurnally, the samples were collected periodically at an interval of 6 h and the average is represented for a day. Due to the peak loading during the morning and evening hours, the average values of BOD and COD were incremented to much higher than the average for the non-peak hours. It was observed that STP is getting an average input BOD of 1000 mg/L which could treat only for getting a removal efficiency of 65% (Table 4). Even though COD for the sewage is not much higher than BOD as usual in organic wastes, it is presumed that most of the undigested and weathered solids which are aerobic in nature could not exert relative oxygen demand in the aerobic treatment process. This particular treatment process indicated that combination of aerobic–anaerobic systems can in fact influence reaction efficiency, if not loaded according to the mean cell residence time. As a check for the activity of aerobic micro-organisms in the treatment plant, we have determined the mean liquor suspended solids concentration for different samples (Table 5). The MLSS in aeration

Table 2 Physico-chemical properties of the collected sewage sludge samples (pH and electrical conductivity)

S. No.	Sample	pH	EC (μmho/cm)
1	Boys biogas inlet	7.84	6.29
2	Boys biogas outlet	5.64	1.23
3	Ladies biogas inlet	6.13	0.94
4	Ladies biogas outlet	6.78	2.21
5	STP inlet	6.85	0.89
6	Aeration tank-I	8.06	0.83
7	Aeration tank-II	8.08	0.75
8	Aeration tank-III	7.98	0.88
9	Aeration tank-IV	8.01	0.89
10	Aeration tank-V	8.13	0.88
11	STP outlet	8.22	0.86

Table 3 Physico-chemical properties of the collected sewage sludge samples (total dissolved solids and total suspended solids)

S. No.	Sample	TDS (mg/L)	TSS (mg/L)
1	STP inlet	2780	1850
2	Aeration tank	2400	1240
3	STP outlet	750	270

Table 4 Physico-chemical properties of the collected sewage sludge samples (biochemical oxygen demand and chemical oxygen demand)

S. No.	Sample	BOD (mg/L)	COD (mg/L)
1	Boys biogas inlet	1170	3746
2	Boys biogas outlet	995	4386
3	Ladies biogas inlet	1200	3150
4	Ladies biogas outlet	1285	3910
5	STP inlet	1018	3468
6	Aeration tank-I	1833	2992
7	Aeration tank-II	1918	2550
8	Aeration tank-III	2580	2142
9	Aeration tank-IV	1672	1700
10	Aeration tank-V	1168	748
11	STP outlet	324	306

Table 5 Determination of MLSS by using Imhoff cone

S. No.	Sample	Dilution factor	Duration	MLSS (mg/L)
1	STP inlet	50	45 min	2400
2	Aeration tank-I	33	45 min	1600
3	Aeration tank-V	25	1 h	800

tank at peak hours is found to be less than the normal value found when biogas plant input is higher. This can be due to the difference in hydraulic retention time the sludge materials experience in the collection tank and aeration tank.

3.2 *Settling Properties of Sludge*

Settling properties of sludge were studied to decide on a proper dewatering mechanism for the excess sewage sludge from the STP. Since gravity is the most commonly employed method of liquid–solid separation, it can achieve the separation of suspended particles and unbound water since particles that are heavier than water can settle out under quiescent conditions at rates based on the size of particles, suspended solids concentration and flocculation [7].

It can be observed from Fig. 4 that within a period of 10 h, sewage sludge samples from aeration tanks 1 and 5 were able to settle for about 50% irrespective of their difference in initial volume. However, the sludge from the collection tank was more flocculent-type and could not settle more than 20.7% within the same time period. This informs us about the relative surveillance aerobic and anaerobic organisms entering STP and experiencing different hydraulic retention periods in various unit processes. It is postulated that the settling properties of sludge have to be improved before employing any effective dewatering mechanisms in the existing process chain.

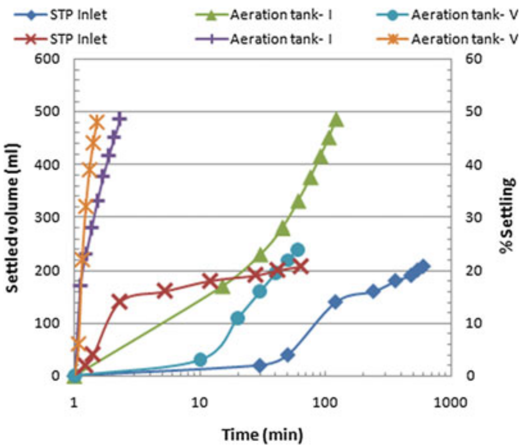


Fig. 4 Settling properties of sewage sludge from different sampling locations

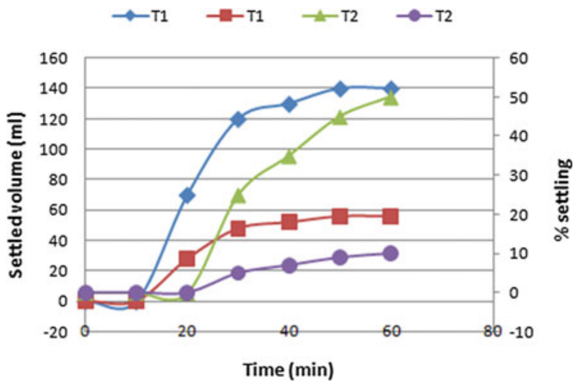


Fig. 5 Effect of temperature of sludge settling (T1 corresponds to 50 °C and T2 corresponds to 80 °C respectively)

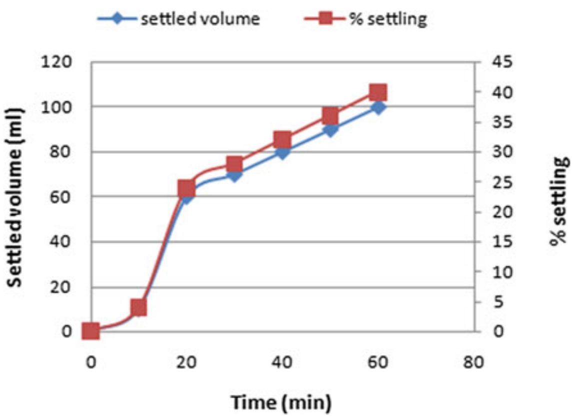
3.3 *Effect of Pre-treatment on Sludge Settling*

Sludge drying can be applied to achieve both weight and volume reduction, and water will be lost as vapour. The thermal settling is employed by constantly heating the diluted sludge mass at 50 and 80 °C and thereafter allowed for free settling in the same apparatus as mentioned above. It was observed that maximum settling efficiency obtained at 80 °C is much low compared to when the temperature was 50 °C (Fig. 5). It is clear that the mass settling of flocculent sludge has not improved at higher temperature; rather, sludge destabilization was predominant due to the low specific gravity of the collected aerobic bio-solids.

When the sludge was pre-treated with bentonite clay as described in the materials and methods section, the settling is assumed to be quicker due to the presence of a large number of tiny interception sites for the destabilized sludge particles to settle. However, as observed in Fig. 6, the sludge settling was not much improved by clay addition (only 40%) compared to temperature rise. Even though there is every possibility that by adding more clay particles, accumulation and aided-sedimentation will happen, this cannot be advised as an efficient treatment system because of the increased addition of suspended solids to the system, thereby increasing the specific gravity of sludge as well as altering the biological activity due to increased mineral components.

In order to optimize these two pre-treatments, a combination of clay addition and temperature variation has been attempted further. To the best of accountability, the settling rate of sludge has increased drastically (67%) by this combination as compared to the normal settling (Fig. 7). The high temperature provided sufficient energy to the bio-solids to form agglomerates and combine with the tiny clay particle, resulting in increased specific gravity for quick settling. During further heating, the sludge particles tend to separate out and start to move from top to bottom and from bottom to top. Therefore, the addition of bentonite clay has improved the settling characteristics of the sewage sludge.

Fig. 6 Effect of addition of bentonite clay on flocculent settling of sewage sludge



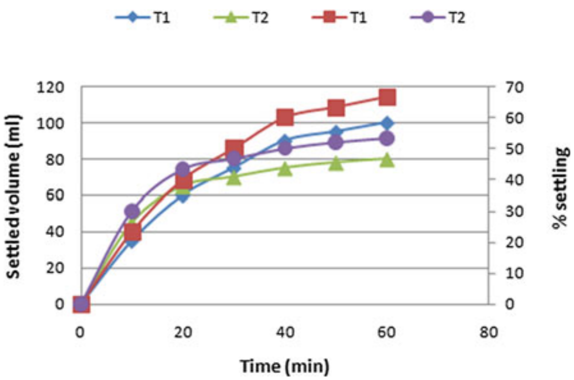


Fig. 7 Effect of temperature and clay addition on sludge settling

This study has limited scope in trying out the best combination of thermal and physical pre-treatment of the sewage sludge, but it can be well ascertained that an optimized combination of these two pre-treatments is necessary for improving the settling characteristics of the sewage sludge in a solid–liquid separating system.

4 Conclusions

Faecal sludge generated as a by-product from municipal sewage treatment plant in India requires special attention for its safe and economic disposal in the environment. Since the bio-solids in sludge are highly gelatinous colloids in nature, they need special pre-treatment techniques in order to improve the dewatering and drying characteristics. From this study, it was observed that a unique combination of heating and flocculating after adding bentonite clay to the sludge has resulted in significant settling efficiency. The settling nature of faecal sludge follows flocculent-(type-2) settling, thereby necessitating the coagulant-aided settling with natural materials. Since there is no chemical alteration to the thickened sludge, it can be effectively used for co-composting with regular municipal solid waste.

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Part XI
Waste to Energy

Waste-to-Energy Trends and Prospects: A Review

S. T. El Sheltawy, Eslam G. Al-Sakkari and M. M. K. Fouad

Abstract The production of wastes with huge amounts represents a big problem for many countries. Also, transportation and disposal of these amounts are land and resources consumers, so managing these wastes became an urgent issue recently. Waste management includes recycling, safe disposal of hazardous waste materials, and using materials which have reasonable calorific value to be converted into energy. Waste-to-energy concept provides economical and environmental benefits and introduces a renewable energy source as well. Utilization of wastes as a renewable source of energy can achieve environmental sustainability and compensate the shortage of other energy sources. Energy demand and consumption increased dramatically over the previous few years, for example the world daily consumption of natural gas and oil from 261 billion cubic feet and 85.4 million barrels in 2009 to reach about 335 billion cubic feet and 91.2 million barrels in 2013 by an increase of about 28 and 7% of natural gas and oil consumption, respectively. By the end of 2015, the daily oil consumption increased by about 4.17% from that of 2013 to reach 95 million barrels, so it is a must to utilize wastes for producing energy to satisfy the increasing demand. The scope of this study is to introduce and discuss the efforts done in Egypt to manage wastes for the aim of energy production as well as comparing these efforts with those of other different countries such as USA, Germany, India, and China.

Keywords Waste problems · Energy demand · Waste to energy
Environmental sustainability

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1 Introduction

1.1 Waste Problem

World countries suffer from the big problem of waste production in huge amounts every year. These wastes have serious impacts on the environment and surrounding landscapes. They include municipal solid waste MSW, industrial wastes, agricultural wastes. On the basis of their state, they could be classified into different types such as solid or semisolids including organic, plastic, papers, and many other useful or hazardous waste. Agricultural wastes could be leaves, tree cuts, crop residues, husks, or roots. Domestic and industrial wastewater are the two main sources of semisolid wastes. Proposed management alternatives for such waste must be considered.

1.2 Waste Management Overview

Solid waste management normally begins with its collection and ending by safe disposal, passing through transportation, segregation, and processing. According to the type of the waste, processing is planned. MSW processing is conducted after segregation to organic, which may be composted [1], recyclables as glass or plastics which may be recycled [2], and non recyclables having high calorific value are directed to profitable products known as refused derived fuel RDF used as alternative fuels for energy consuming industries as cement [3]. Processing and uses of agricultural waste vary between animal feed, fertilizers, or energy sources [4]. Semisolids and used oil are physically and chemically treated for reuse [5] or being used as renewable energy source through biodiesel production [6].

Hazardous and non-recyclable wastes are normally incinerated or landfilled. Examples of these wastes are radioactive waste materials, medical wastes, wastes from leather tanning industry, etc. Medical wastes are first incinerated; then, the remaining ashes are disposed [7].

1.3 Energy Problem and the Need for New Resources

Energy demand increases steadily due to the yearly increase of population as well as rise of living standard that lead to increase the demand of new energy sources. Over the previous few years, the world daily consumption of natural gas and oil increased from 261 billion cubic feet and 85.4 million barrels in 2009 to reach about 335 billion cubic feet and 91.2 million barrels in 2013 by an increase of about 28 and 7% of natural gas and oil consumption, respectively [8]. By the end of 2015, the daily oil consumption increased by about 4.2% from that of 2013. Based on the above estimation, new and renewable energy resources should be developed to overcome the problem of fossil fuels shortage over the upcoming decades.

2 Waste-to-Energy WTE Concept

The simple definition of waste-to-energy concept is using different wastes for energy production as alternative energy sources instead of conventional sources. Waste materials with a reasonable calorific value can be used for energy generation directly after simple processing as sorting and shredding or through more complicated processes such as thermo-chemical processes like transesterification and pyrolysis. It may be observed that products from thermo-chemical processes have higher calorific values due to the elimination of non-combustible content from the waste materials. These products should be upgraded to match the international standards.

3 Examples of WTE Processes

As mentioned before, WTE processes may be classified as direct and indirect ones. Direct processes may be conducted by combustion of RDF, activated sludge, used tires, or agro-waste, while indirect processes deal with the production of fuel alternatives through other thermo-chemical processes such as transesterification, pyrolysis, gasification, digestion, fermentation.

3.1 Direct WTE Processes

One of the good examples of direct WTE processes is the use of RDF for energy production in cement plants. As mentioned before, RDF is the remaining non-recyclable part of MSW, and it should be further processed to be used for energy production. RDF should be shredded, screened, and dried; the energy content per unit mass of RDF is about one-third that of natural gas which makes it a promising alternative for fossil fuels [9]. Activated sludge, used tires, and agro-wastes can be used directly to generate energy, but using these materials may have some drawbacks such as the emission of SO_x and NO_x gases when combusted [10], and in the case of using activated sludge, it may be harmful because of the presence of heavy metals [11]. Agricultural and farm wastes are demanded in other industries, e.g., pulp industry and production of animal feed [12], but this problem can be solved through the optimization between different uses of these valuable wastes.

3.2 Indirect WTE Processes

3.2.1 Waste Oil (WO) Transesterification

WO can be converted into biodiesel through transesterification where WO reacts with an alcohol in presence of a catalyst to produce fatty acid alkyl ester, i.e., biodiesel, and glycerol, as a valuable by-product [13]. The most applied method is the homogeneous base-catalyzed transesterification where alkaline base catalyst such as potassium hydroxide KOH is used [14]. If the free fatty acid content is higher than 2% of WO weight, an esterification step should be performed using an alcohol in high excess in presence of mineral acid as a catalyst to decrease the free fatty acids content to make WO suitable for the transesterification step [15]. After reaction, different phases are separated and further upgraded to match with the ASTM and EN standards [16].

3.2.2 Pyrolysis and Gasification of Wastes

Pyrolysis is an endothermic reaction that takes place at high temperatures in an inert atmosphere in which tree cuts or materials containing cellulose are converted into more valuable products having higher calorific value, such as char, bio-oil, and flammable gases [17]. According to the reaction temperature, residence time, and heating rate, the reaction produces different products [18]. At relatively low temperature, $T \leq 450$ °C, and low heating rate, 2–5 °C/min, the product is mainly solid char, while relatively medium temperature, $500-700\,^{\circ}\mathrm{C}$, fast heating rate $450\,^{\circ}\mathrm{C/min}$, and short residence time the product are mainly liquid bio-oil; if the desired product is flammable gases, then the operating conditions are high operating temperature, $T \geq 700\,^{\circ}\mathrm{C}$, fast heating rate $450\,^{\circ}\mathrm{C/min}$, and long-residence time [19]. On the other hand, gasification takes place at higher temperatures than that of pyrolysis and in presence of air. Partial oxidation occurs, and the final product of this process is *syngas*, carbon monoxide, and water vapor; then, this gas mixture can be used for the synthesis of higher hydrocarbons through the well-known *Fischer–Tropsch* process [20].

3.2.3 Biological Processes for Biofuels Production

Biogas is the product obtained from anaerobic fermentation and digestion of organic materials by micro-organisms under controlled conditions, temperature, moisture, pH, etc. [21]. Biogas is a mixture of gases mainly methane and carbon dioxide that results from anaerobic fermentation of organic matter by bacteria [22]. The possible wastes that can be used as a source for biogas production are agricultural wastes, animal manures, food wastes, industrial wastes, and wastewater [23].

Cellulosic wastes can be used for production of bio-ethanol, which can replace fossil gasoline, through fermentation process [24]. After conversion, the residues can be burnt for energy production. If the produced bio-ethanol will be used in vehicles engines, then it should be further purified to remove solid particles, water content, and associated sour gases such as carbon dioxide [25]. Wastes are pre-treated and conditioned before fermentation process to make the waste ready for conversion to the desired bio-ethanol product. Pre-treatment and conditioning steps include physical and chemical processes such as size reduction, screening and chemical or enzymatic hydrolysis [26].

4 Waste to Energy in Different Countries

WTE concept is a dual benefit solution for waste problem since it will solve the fossil fuel shortage problem and decrease the environmental impacts associated with waste accumulation. According to Grand View Research, the global WTE market is expected to increase by nearly half, from \$25.3 billion in 2013 to \$37.6 billion in 2020 [27]. So the WTE alternative must take a priority in solid waste management consideration for different countries.

4.1 Waste to Energy in Egypt

Using waste for energy production is ranked low in priority of Egyptian energy policy, and there is no estimate of the share of wastes of the total energy sources potential. Huge amounts of organic waste such as agriculture waste, sludge from municipal treatment plants, and organic waste from garbage as well as animal manure and animal carcasses are generated in Egypt. The total Egyptian MSW production is about 20.5 million tons per year [28]. Table 1 shows a sample of types and quantities of organic wastes generated in Egypt [29], while Table 2 illustrates the composition of Egyptian MSW [30]. These wastes can be considered as organic carbon-based materials and energy sources as char, bio-oil, biogas, bio-ethanol, etc. [31].

Table 1 Waste type and quantities in Egypt [29]

Waste	Quantity million tons/year
Agricultural waste	25 of dry material
Municipal solid waste (MSW)	6.6 of dry organic waste
	11 of wet organic waste
Sewage treatment plants	4.3 of dry sludge

Table 2 Egyptian MSW compositions [30]

Component	Paper	Organic	Plastic	Metals	Glass	Others
Percentage	8	54	13	14	6	5

4.1.1 Biogas Production

Biogas activities in Egypt focused mainly on small-scale plants with digester volume of 5–50 m^3 except the Gabal Al-Asfar plant. The total energy potential of centralized biogas plants with 50–500 tons per day input was estimated to be about 1 million tons of energy. If the total technical potentials were exploited, it was estimated that Egypt could produce 40% of its present electricity consumption from biogas and save a substantial amount of chemical fertilizer [32]. A realistic potential was that 4% of the present electricity consumption could be covered by biogas applications. The potential sites for large biogas plants were identified as being large cattle and dairy farms, communities in old and new villages, food processing industries, sewage treatment plants, waste treatment companies processing solid organic municipal waste, new industrial cities, and tourist villages [33].

4.1.2 RDF Production

Suez Cement Group of Companies (SCGC), Egyptian cement producer, has opened a waste processing facility at its Kattameya cement plant to produce wastederived fuel from pre-sorted waste. This project, which is worth 5 million euros, is part of SCGC strategy to boost the amount of energy generated from refuse-derived fuels (RDF) [34]. It will process an estimated 35000 tons of waste to provide the cement plant with about 20% of its energy requirements [35]. Also, Egyptian Company for Solid waste Management (Ecaru) is now supplying cement plants with RDF to be used instead of fossil fuels. The beneficiaries of the produced RDF are Messebo cement plant in Ethiopia with capacity of 80,000 tons/year, Arabian Cement Company in Egypt with capacity of 30,000 tons/year, and Helwan Cement Company in Egypt with capacity of 85,000 tons/year [36].

4.1.3 Biodiesel Production

Few plants are implemented in Egypt for transesterification of WO into biodiesel. The first plant in Egypt was *Tagaddod* having relatively small production capacity which is exported to European countries [37].

4.1.4 Pyrolysis

The most popular WTE technology in Egypt is pyrolysis. There are more than 5000 local old pyrolysis systems in Egypt to produce bio-char at a rate of 30,000 tons per year which are almost exported [38]. The main disadvantage of these systems is that they are uncontrolled have a negative impact on environment and human health [39]. The Egyptian government now tries to regulate these systems by rehabilitation of the old plants to other controlled and environmentally friend systems to avoid the drawbacks of old technology [40].

4.2 Waste to Energy in India

India generates MSW at a rate of about 55 million tons per year and about 38 million cubic meters per year of sewage water [41]. The average composition of Indian MSW is tabulated in Table 3.

The potential of using these wastes was discussed in many studies [43, 44]. The expected potential of power generation from sewage water or liquid municipal waste is about 226 MW, while on using solid wastes, the value increases to reach about 1457 MW; this means that the total potential of power production from wastes is about 1700 MW [43]. According to the Ministry of New and Renewable Energy, there is a potential to recover 1,300 MW of power from industrial wastes, which is projected to increase to 2,000 MW by 2017 [44]. WTE installed capacity in India in 2011 reported by MNRE is illustrated in Table 4 [45]. Projects of over 135 MW have been installed so far in distilleries, pulp and paper mills, and food processing and starch industries [46]. Two waste-to-energy plants producing 11 MW each were announced to be implemented in 2015 in Jabalpur and

Table 3 Composition of Indian MSW [42]

Component	Paper	Textile	Leather	Plastic	Metals	Glass	Combustibles	Others
Percentage	5.7	3.5	0.8	3.9	1.9	2.1	41.8	40.3

Table 4 WTE installed capacity in India in 2011 [45]

Area	Capacity MW	Contribution %
Grid-interactive power		
Urban	20.20	27.4
Industrial	53.46	72.6
Total	73.66	
Off-grid/captive power		
Urban	3.50	4.6
Industrial	72.30	95.4
Total	75.8	

Table 5 Selected waste types and the corresponding WTE process(s) [48]

Waste type	Process
Liquids	Biomethanation
Solids	Gasification/pyrolysis and incineration/combustion
Semisolids	Biomethanation, gasification/pyrolysis and incineration/combustion

Hyderabad, besides a 12.6 MW plant at Nalgonda in Telangana, and 3 MW plant in Chennai and these plants will be commissioned by the end of 2016 [47].

The most applied technologies in India for converting waste to energy are biomethanation, gasification/pyrolysis, and incineration/combustion. Each type of waste needs a specific WTE process as mentioned in Table 5.

4.3 *Waste to Energy in USA*

USA produces 387 million tons of MSW per year [49] from which 8% is utilized in WTE plants and 25% is recycled or composted, while the remaining 64% is directed to sanitary landfills [50]. Table 6 displays the average composition of produced MSW in USA [51]. It should be noticed that these percentages are average values over USA as the percentages vary significantly from state to another; in some states like the case of Maine and Connecticut, only 10–15% of the produced MSW is landfilled, while over 50% of waste is utilized for energy production [52].

The most common WTE process used is the moving grate technology, as well as a new technology called two-stage gasification process [53]. This new process consists of two steps; the first one is the gasification of waste materials to produce syngas; then, the produced syngas is combusted for energy generation. The two-stage process offers better control on the emission of harmful gases such as nitrogen oxides [54].

4.4 *Waste to Energy in Germany*

The yearly MSW production in Germany is about 48 million tons [55]. As one of the high-income countries, the average composition of German MSW is presented

Table 6 Average MSW compositions in USA [51]

Component	Paper	Textile, leather and rubber	Wood	Plastic	Metals	Glass	Yard trimmings	Food	Others
Percentage	27	9	6.2	12.8	9.1	4.5	13.5	14.6	3.3

Table 7 German average MSW composition [56]

Component	Paper	Organic	Plastic	Metals	Glass	Others
Percentage	31	28	11	6	7	17

in Table 7 [56]. About 37.8% of the produced MSW are incinerated, 44.5% are recycled and 17.3% are composted, while the remaining 0.4% goes to landfills [57].

There are many WTE technologies applied in Germany such as mono-incineration, co-incineration, RDF production, and biomethanation for biogas production [58]. The average number of existing WTE plants in Germany is about 900 fermentation plants, 62 mechanical-biological waste treatment plants, 67 waste incineration plants, one pyrolysis plant, and about 36 RDF power plants [57].

4.5 Waste to Energy in China

It is reported that the total yearly production of MSW in China is about 154 million tons [59]. The average composition of produced MSW by three Chinese cities is illustrated in Table 8. An average composition of Chinese MSW can be estimated using the information of these three cities, and it is mentioned in the highlighted row in Table 8.

Twenty-three million tons (about 15% of the produced amount of MSW) are used in energy production. They are processed in over 100 WTE plants [61]. The most applied WTE technologies inside these plants are moving grate combustion of as-received MSW and circulating fluidized bed (CFB) [62].

Although China is making a great effort in WTE technology development and application, the majority of its MSW are still being landfilled. So, more efforts are needed to be done to increase the percentage of recycled wastes as well as processed wastes in WTE plants.

Table 8 Chinese MSW composition [60]

City	Food	Paper	Plastic	Textile	Wood	Glass	Metal	Others
Beijing	64.48	6.71	8.12	1.22	0.05	2.02	0.31	17.09
Shanghai	62.83	8.57	10.83	4.17	0.96	2.17	0.00	10.47
Hangzhou	67.1	7.81	9.61	1.05	3.45	0.97	0.33	9.68
Average	64.80	7.70	9.52	2.15	1.49	1.70	0.24	12.40

5 Conclusion

From the above study, it may be concluded that on planning for municipal solid waste management MSWM decision makers must take into account waste-to-energy alternatives according to economic, technical, legislative,. and environmental aspects. This research proposes a multi-objective WTE recovery systems performed through a variety of processes such as combustion, pyrolysis, and gasification to achieve optimum performance. The results show that WTE can generate a better solution, for MSWM, than that of the national practices compared to international trends.

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Carbon Footprint Assessment of Recycling Fluorspar from Waste Calcium Fluoride (CaF_2) Sludge

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Abstract Waste has been identified as one of the main sources of greenhouse gas (GHG) emissions resulting from global population growth. Climate change and resource scarcity have emerged as pressing environmental issues in recent years. Resource recycling and recovery have been proven effective ways of implementing circular economy and GHG reduction to maintain sustainable resource use. Calcium fluoride sludge and hydrofluoric acid are the primary wastes generated from the electronics industry, such as from semiconductors, liquid crystal displays, light-emitting diodes, solar cells and other optoelectronic sectors. The accumulation of such waste has become a major problem of Taiwan's electronics industry. If not properly treated or managed, electronic waste would cause serious health and environmental problems; however, if recycled, they can be recovered and transformed into artificial fluorite (CaF_2) and sodium fluorosilicate ($NaSiF_6$), which have economic and environmental benefits. For example, CaF_2 can be applied as fluxing agent to replace raw fluorite in the steel industry. Moreover, both materials can be used as substitutes for cement in construction. The main objective of this study is to evaluate carbon footprint of renewable material from calcium fluoride sludge to understand the carbon emission of waste reuse method from a life cycle perspective. The scope and system boundary of the assessment will be determined on the basis of literature review and expert consultation. Data for calculating carbon footprints will be collected by in situ inventory and from the literature. The commercial software SimaPro 8.2.0 will be used for calculations. The results of carbon footprint may be used to develop strategies for life cycle management of waste reuse to realize sustainable usage.

Keywords Calcium fluoride sludge · Artificial fluorspar · Life cycle assessment Carbon footprint

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1 Introduction

In recent years, climate change and resource scarcity have been the critical environmental issues all over the world. In order to mitigate the resource depletion and protect the environment, closed material loop and resources recovery techniques have played important role to achieve zero waste [11]. While treated by incineration and landfill, recycling and so on, those kinds of treatment would cause more greenhouse gas emission and damage impact for human society. At the global level, landfilling of waste is the most common waste utilization type. Landfilling of waste causes great impact on the environment: soil and ground, groundwater and air as well as landscape pollution [6]. Therefore, the waste reuse and remanufacture has been identified as an important approach to achieve environment friendly. The waste resource recycling has proven to be an important way to implement "Cradle to Cradle" and GHG reduction from several studies. Hence, the sustainable materials management (SMM) has been identified as one of the main strategy to embed resource or material value in products and waste streams [2]. In Taiwan, there are four main industries including metal machinery industry, electronic information industry, chemical industry and livelihood industry to support the economy system. The calcium fluoride sludge and hydrofluoric acid are wastes mainly produced by semiconductors, liquid crystal displays, light-emitting diodes, solar cells and other optoelectronic industry [7]. If all waste calcium fluoride sludge could adopt reuse method to replace raw material, it would reduce the environmental impact and human damage form waste emission. For sustainable material and waste recycling, artificial fluorite is main product remanufactured by recycling waste hydrofluoric acid and calcium fluoride sludge. Artificial fluorite can be applied as fluxing agent to replace raw fluorite in steel industry. It can not only improve the waste to resource efficiency, but also reduce the raw material extraction. Hence, in this study, life cycle assessment will be applied to evaluate carbon footprint of artificial fluorite from waste calcium fluoride sludge to figure out the hot spot of carbon emission. The main objectives of this study are as follows: (1) to evaluate the carbon footprints of calcium fluoride sludge reuse method; (2) to investigate the in situ industry of reuse process and inventory data; and (3) to identify critical aspects for carbon emissions and give some comments for the waste reuse method.

2 Disposal and Utilization of Calcium Fluoride Sludge

The hydrofluoric acid is the raw material to etch for IC, TFT-LCD panel and solar wafers, which produced by semiconductors, liquid crystal displays, light-emitting diodes, solar cells and other optoelectronic industry [1]. The end of pip would produce a large amount of fluoride-containing wastewater. The fluoride-containing wastewater is normally precipitated using calcium hydroxide and calcium chloride coagulant to generate calcium fluoride sludge [17]. In shortly, the source of calcium fluoride sludge is waste hydrofluoric acid. Fluorine is a common element in nature, which is quite active chemical elements, rarely existing in ion or elemental state, and also among essential trace elements required in minute quantities for the human body to maintain proper physical functioning [12], but fluoride would cause damage to organs. In China, calcium fluoride sludge is directly landfilled which not only causes an increase of unavailable landfill sites, but also produces secondary environmental pollution owing to the release of fluoride ions from calcium fluoride sludge dissolution [16]. Hence, how to treat the calcium fluoride sludge becomes a big environmental problem in the future research. Recent calcium fluoride sludge research has suggested that disposal and utilization may indeed facilitate processes beneficial to resource recycle and reduce environment pollution. This section is talking about a review concerning the existing approaches to treat, recycle and utilize calcium fluoride sludge in Taiwan, including recycling as additive in cement, concrete industries, and acting as artificial fluorite in steel industries. All these methods are feasible in theory and practice, providing a reference to the treatment and proposal of calcium fluoride sludge.

2.1 Reused in Cement and Concrete Production

The calcium fluoride sludge can replace the raw material of cement because the calcium fluoride sludge consists of calcium. The calcium fluoride sludge was added to cement ovens as a flux material, which emitted harmful, volatile hydrogen fluoride and used to partly replace cement in cement mortar to safely solidify and immobilize the nanoparticles for safe disposal [9, 10, 13]. This way not only achieves the target of waste to resource, but also reduces the hazardous and toxicant characteristic of calcium fluoride sludge in cement, mitigating the environmental impact. Japan Taiheiyo Cement Company has indicated that adoption of calcium fluoride sludge to produce cement has the best economic and resource use efficiency [8]. The calcium fluoride sludge reused in cement industry can improve the product ecofriendly, enhance the competitiveness and become the green industry. On the other hand, the calcium fluoride sludge also can replace the raw material of concrete production. This disposal method can protect natural resources, reduce the environmental damage and make solid waste material be reasonably reused.

2.2 Reused in Steel-Making

Fluorite consists of calcium fluoride, which has the low melting point feature and can be a good fluxing agent to break the structure of silica in steel-making process [14]. Hence, the fluorite can improve the fluidity of the slag, easy to separate slag and metal, enhance the dephosphorization effect, effectively reduce the temperature smelting and saving the energy consume in steel industry. Iron and steel smelting industry has lower requirements of calcium fluoride content in fluorite than the chemical production; therefore, the artificial fluorite can be remanufactured by recycling waste calcium fluoride sludge, which can replace nature fluorite used in steel-making [15]. The artificial fluorite contains the stable of calcium fluoride and lower silica content, also have some benefit in the steel-making process included reduce the loss of the furnace wall, and extend steelmaking furnace life. In addition, the artificial fluorite can reduce natural fluorite import in Taiwan to achieve the goal of resource recycling and sustainable materials management.

3 Methodology

3.1 System Boundary and Scope Definition

The main goal of this study was to estimate the carbon footprint of the calcium fluoride sludge reuse methods by life cycle assessment. The system boundary is a remanufacture process from waste calcium fluoride sludge, which includes raw material, manufacturing and pollution control stages, and all raw material, energy, and resource use are quantified over the whole life cycle from "gate to gate" (B2B). In this study, the LCA of the resource consumption includes waste calcium fluoride sludge, space bag, adhesive and electricity. The equipment maintenance is not included in this study. The output of the remanufacture process was included artificial fluorite and waste emission. The waste emission was included dust and air pollutant. The instrument of pollution control was included cyclone, wet scrubber and vortex bag filter, collecting the dust. The system boundary and scope of the remanufacturing process is shown in Fig. 1.

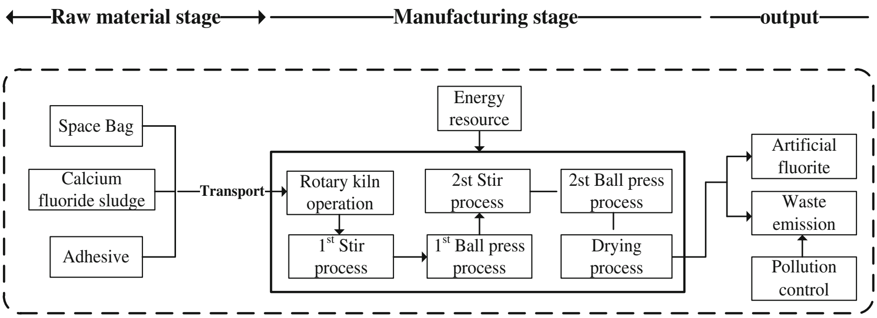

Fig. 1 System boundary and scope of reuse method

3.2 Functional Unit

The functional unit was defined based on reuse waste calcium fluoride sludge. To indicate the results of carbon footprint assessment, this study selected the amounts of artificial fluorite output mass as the functional units within the LCA model: one ton of artificial fluorite.

3.3 Inventory Data Collection

Inventory data of the waste to resource method were collected to survey the in situ industry; the inventory data were collected from January 2015 to December 2015; primary data were collected through remanufacturing process. In the raw material stage, we investigated the information of supplier background and the input weight of remanufacturing process, and then locations were searched and the transport distance was estimated using Google Maps; the concept of ton–kilometre was used. Material transport was assumed to be a 35-ton truck. In the manufacturing stage, the industry supervisor provided the energy resources input data and the operating power for the equipment. The inventory data of energy and resources inputs were included space bag, electricity, natural gas and diesel calcium fluoride sludge, adhesive. The results of inventory data of the reuse method are shown in Table 1.

3.4 Life Cycle Assessment and Carbon Footprint

Life cycle assessment (LCA) is a method used for evaluating consumption of resources and estimating the cumulative environmental impacts associated with the entire life cycle of a product [3]. The methodological framework of all LCA techniques is based on the ISO standards 14040 [5]. The evaluation of the structure and processes has four parts, including goal and scope definition, inventory analysis, impact assessment and interpretation. The carbon footprint calculation in this study is based on the ISO standard 14067-1, which is the accumulated activity date of the entire LCA multiplied by carbon emission factor (f) (Eq. 1). The carbon footprint denotes the total carbon emission for the entire life cycle.

Table 1 Inventory data of the waste reuse method

The product	Transport distance (T-km)	Electricity consumption (kWh)	Water consumption (kg)	Natural gas consumption (m^3)	Other resource depletion (kg)
Artificial fluorite	769,066.5	348,741	1760	242,375	3470

$$\text{Carbon footprint activities} = \Sigma(\text{Activity data}\, i \times \text{Emission factor}\, f) \quad (1)$$

The activity data *i* denotes the intensity of the activity, which is expressed by volume or mass. The carbon emission factors are constants, which depend on the linear relation between the activity intensity and carbon emission. The calculation methodology of 2007 GWP 100a is based on the Intergovernmental Panel on Climate Change (IPCC) factors and used SimaPro software to calculate. Carbon Emission Coefficients data related to materials consumption and emissions were obtained from the Taiwan EPA database. These electricity data were adapted from the 103 annual electricity carbon emission factor (i.e., 0.66 kg CO_2e/kWh) of the Taiwan Bureau of Energy, Ministry of Economic Affairs [4].

4 Results and Discussion

4.1 The Mass Balance of Calcium Fluoride Sludge

In this study, the amounts of calcium fluoride could be calculated from calcium fluoride sludge via removing moisture and drying, about 2939.86 tons. The output of artificial fluorite was accounted for 2781.71 tons calcium fluoride from waste to resource process. The input and output have a difference of 158 tons of calcium fluoride, about 5.3%. The mass balance can track the material flow in system, increase the calculation correctness, and check the mass would not miss in all life cycle assessment. Figure 2 shows the results of mass balance of calcium fluoride.

4.2 Results of Reuse Methods

Carbon footprint was estimated using SimaPro 8.2.0, and the IPCC 2007 GWP 100a methodology was applied. The calcium fluoride sludge reuse method was employed in the raw material, manufacturing and pollution control stages. The

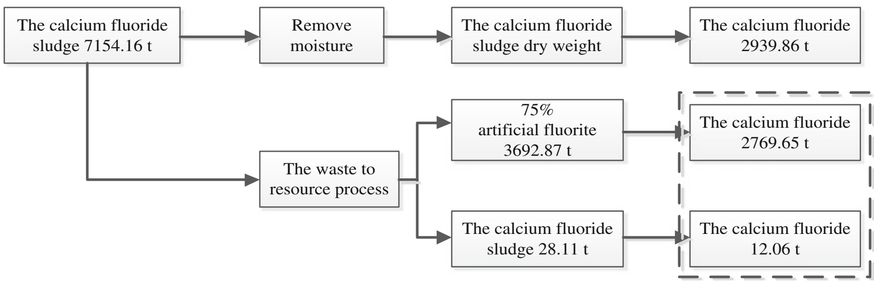

Fig. 2 Mass balance of the calcium fluoride

Table 2 Results of carbon footprint of the reuse method

Output (ton)	Stage			
	Raw material stage (kg CO_2eq)	Manufacturing stage (kg CO_2eq)	Pollution control stage (kg CO_2eq)	Total emission (kg CO_2eq)
3692.87	2.43E+05	8.01E+05	5.91E+04	1.10E+06
1	65.8 (22%)	216.9 (73%)	16 (5%)	297.87 (100%)

calcium fluoride sludge reuse of carbon footprint is 1.10E+06 kg CO_2eq in all life cycle assessment. The carbon footprint is 2.43E+05 kg CO_2eq in raw material stage, 8.01E+05 kg CO_2eq in manufacturing stage and 5.91E+04 kg CO_2eq in pollution control. The amount of artificial fluorite output is 3692.87 ton; hence, the results of carbon footprint should be based on the functional unit, one tone of artificial fluorite output mass. Therefore, the carbon footprint of artificial fluorite is 297.87 kg CO_2eq in reuse method. The raw material, manufacturing and pollution control stage are 65.8, 216.9 and 16 kg CO_2eq, respectively. The results of carbon footprint of the reuse method are shown in Table 2.

4.3 Discussion

The carbon footprint of artificial fluorite was estimated in this study. The results of carbon footprint were divided into three stages, including raw material, manufacturing and pollution control stage. The main contributors to the carbon footprint emission in the manufacturing stage include the rotary kiln process (26%) and drying process (36%), with approximately 77.44 and 107.2 kg CO_2eq emissions in all life cycle assessment, respectively. In addition, the diesel is also one of the main

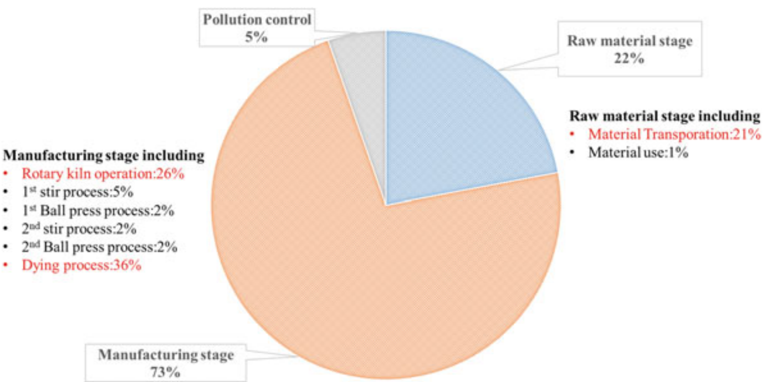

Fig. 3 Hot spot of the carbon footprint assessment

carbon emission factors in manufacturing stage. The contributor in the raw material stage is the material transportation (21%), which exhibited a close relationship with the calcium fluoride sludge weight and distance of transportation. The more weight and distance for material transportation, the more carbon emission will be generated. The pollution control stage consumed extra electricity via air pollution control equipment to collect dust and air pollution, and the dust was being return to manufacturing process again. Figure 3 shows the hot spot of the reuse method.

5 Conclusion and Future Research

Results showed that the main contributor to reuse method was manufacturing stage. Electricity and natural gas consumption had the highest carbon footprint in the manufacturing stage, which exhibited a close relationship with the operating wattage, operating time of instruments and heating. The main contributor to electricity and natural gas consumption was the drying process, which consume for approximately 149,060 m^3, 39,663 kWh and with a total emission of approximately 401,808.78 kg CO_2eq, accounting for about 36% of carbon emission in all life cycle assessment.

In this study, the main contributor to carbon emission of calcium fluoride sludge reuse method is electricity and natural gas consumption of equipment operated in the manufacturing stage. Low-power equipment may be used to achieve an environmentally friendly technology with low carbon emission and introduce the energy management standard to improve the energy efficiency. In addition, future studies on calcium fluoride sludge reuse should focus on the economic benefit and their environmental impacts, such as ecological damage, human toxicity and resource depletion, which could be used to enhance our understanding of the life cycle of calcium fluoride sludge and achieve the sustainable materials development. In addition, the carbon reduction with raw material and renewable is an important research distance for sustainable material management; hence, the future research will extend the raw fluorite of mining and transportation to compare the carbon reduction benefit with artificial fluorite.

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Accident Cases and Safety Issues in Gasification Plants

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Abstract Institute for Advance Engineering in Korea has developed and tested the pilot-scale gasifiers since 1994 and has experienced several accidents and has solved safety issues during the last two decades. Actual accident cases are discussed with the inherent safety issues related to syngas facilities, specifically on the safety/toxicity issues related to syngas and syngas-related explosion. In addition, suggestions for the safe operation in gasification plants are summarized.

Keywords Gasification · Syngas · Accident · Safety · CO · Nickel tetracarbonyl

1 Introduction

Gasification is a process of producing the syngas that mainly consists of CO and hydrogen at high temperatures in an oxygen-deficient environment. Gasification sometimes involves the pure oxygen with the feeds like coal powder, coal slurry, biomass, or wastes. Under the normal operating conditions, reactants are moving to the lower pressure region, and the reaction occurs while passing through the gasifier, yielding syngas. The pressure at the feeding vessel of reactants should remain at a higher pressure than the pressure of the gasifier. Then, the hot syngas is flowing forward, which will guarantee the safety in feeding lines. Otherwise, hot syngas has a chance to meet the oxygen and fuels, which might initiate explosion accident. At all times, the pressure difference through the gasification process must be maintained.

Inherently, CO and hydrogen are gases that need special care in dealing during the process due to their explosion possibility and toxicity. But the CO and hydrogen are key starting materials in many chemical and petroleum industry. Since the main elemental composition in organic materials consists of C, H, O, N, S, final gas products eventually end up to CO, CO_2, H_2, H_2O, SO_x, NO_x, COS, H_2S, NH_3,

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HCN, depending on the processing conditions. When enough oxygen is supplied, all organic components change to CO_2, H_2O, SO_x, and NO_x, whereas a limited oxygen supply(gasification) condition yields a product gas of CO, H_2, H_2S, COS, NH_3. This product gas is syngas and can be a starting material for the clean energy and value-added applications.

In principle, all organic materials can be converted into syngas, including coal, petroleum end-products like asphalts and petroleum coke, biomass, municipal/industrial wastes. Major syngas industry exists in the field of coal, pet coke in China, South Africa, USA, Japan, with a capacity of 1,000–3,000 ton-feed/day scale. Biomass gasification is being developed and utilized in many EU countries in several hundred tons of feed amount per day scale, mainly as a part of reducing CO_2 in energy field. Waste gasification has been in the market (50–150 ton/day one unit scale) in Germany, Japan, and Korea, but receded due to high costs in construction and in operation. Recent rebirth of interest in waste gasification emerges by the startling increase in electricity demand in developing countries.

Conventional electricity generation has used coal or nuclear in a scale of over 500 MW, and nowadays of 1,000–1,200 MW size, which definitely requires a major investment and operation skills. In contrast, waste and biomass gasification has a typical size of 1–20 MW in electricity generation, mainly because of the limitation in available amounts of feedstock in one area. In addition, most developing countries possess a significant volume in biomass and wastes that wait to be utilized, instead of simple reclamation. Distributed power is in great demand, and renewable energy sources like solar and wind can be a good part of it, but they have an inherent problem of uneven daily electricity generation. Biomass and wastes are far cheaper source for distributed electricity generation that is suitable for developing countries. And Gasification is a key solution for the proper utilization of biomass and wastes.

The problem arises when the small-scale gasification plant is in operation without a proper safety equipment and without highly trained personnel. Economies of scale prevail in gasification plants by the sheer requirements in safety-related investment. Understanding the safety issues in gasification plants and training operation personnel will be even more critical when the gasification system cannot afford the fully implementing the known safety equipment and protocols. In principle, gasification plants that deal with syngas should operate in remote control basis with no personnel nearby at the gasifier and at other key high-pressure/-temperature equipment during the operation, which definitely necessitates a significant capital investment. Unfortunately, small-scale gasification plants in developing countries where most of the electricity demand arises cannot afford the investment. Thus, understanding the key area and critical components that have a high probability of accidents is important to utilize the limited amount of capital expenditure to the core safety instrumentation.

2 Experimental

Institute for Advanced Engineering (IAE) has developed the gasification technology from 1994, starting with a 3 ton/day coal gasification system as illustrated in Fig. 1. The entrained-bed side-feeding system was first tried in 1994 and operated till 2011. From 2009, several different types of entrained-bed gasifiers were tested in order to acquire the best performing version.

Since low-rank coals become a major available feedstock that needs a cheaper version of gasifier, IAE has developed the partial/non-slagging coal gasifier that has a specialized to high-reactive low-rank coals. In 2011, a prototype of 3 ton/day (TPD) scale coal gasifier system was installed at Suwon, Korea (see Fig. 2, Left). With successful operations of three years with the prototype facility, the 20 TPD facility as shown in Fig. 2 (Right) has constructed in Taean, Korea, where the commercial coal-fired power plant complex is in operation of more than 4,000 MW electricity capacity. The Taean site in Korea suits to obtain several different types of importing subbituminous coals for the 20 TPD gasification plant since it is located just beside of the coal-fired power plants.

Accidents related to gasification plants all occur at the 1–3 TPD research facilities, mainly due to the frequent dissembling of equipment for sample gathering and inner observation after the tests. The 20 TPD gasification facility is regulated to the Korean authorities as a semi-commercial plant that requires satisfying all the expensive safety regulations and permit conditions, so that till now no accidents have yet experienced.

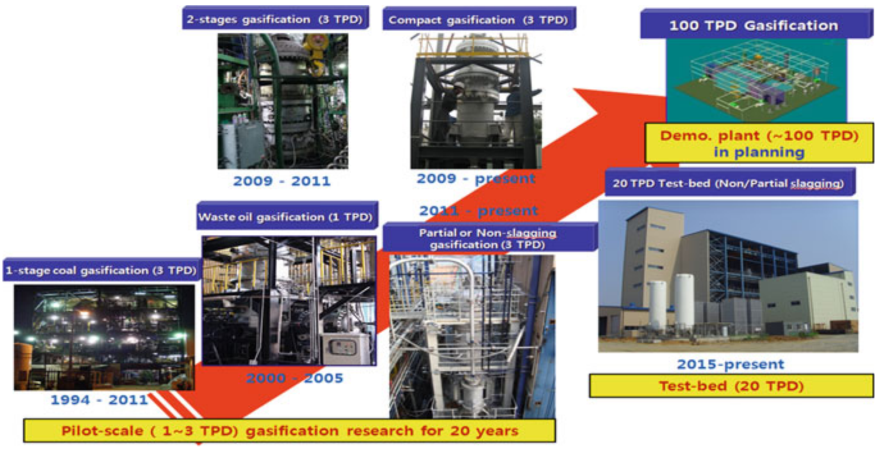

Fig. 1 Scale-up history of coal gasifiers at Institute for Advanced Engineering (IAE) in Korea

Fig. 2 Coal gasification pilot (left, 3 ton/day) and demo test-bed (right, 20 ton/day) plants at Institute for Advanced Engineering in Korea

3 Results and Discussion

3.1 Safety/Toxicity Issues Related to Syngas

Syngas from the pilot coal gasifiers possesses typically 20–60% carbon monoxide (CO). Examples in coal gasification pilot tests can be seen in Fig. 3. As shown in Table 1, the allowed CO concentration is only 50 ppm and any exposure of CO above the lethal dose can lead to fatality. The 20–60%, which means 20,000–60,000 ppm, can lead to extremely dangerous safety hazards. One short inhaling of syngas would be enough to cause a person to serious dizziness and vomiting. In gasification plants, it was advised that CO detectors should be installed with the setting of CO detection level of 25 ppm and CO alarm level of 50 ppm.

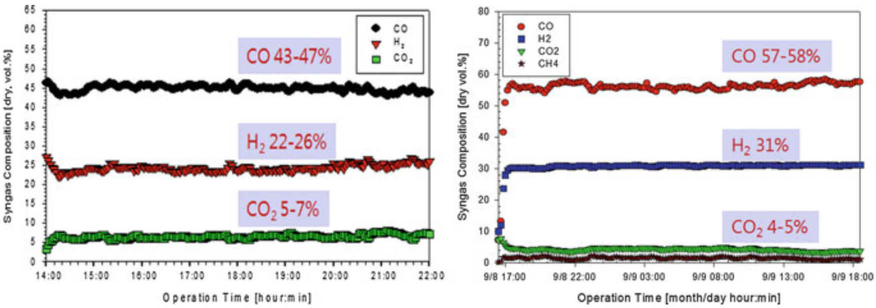

Fig. 3 Typical syngas composition profiles during the gasifier operation. (Left) 3 ton/day pilot plant, Indonesian KPU subbituminous coal, (right) 20 ton/day test-bed plant, Indonesian KCH subbituminous coal

Table 1 Toxicity and explosive limit data of main syngas components

Item	Threshold limit value (ppm)[a]	TLV (8-h TWA)[b] (ppm)	OSHA permissible exposure level[a]	Lethal dose (low)	Explosive limits (%)
CO	50		35	4000 ppm (human, 30 min) 5000 ppm (human, 5 min)	12.5–74.2
H_2S	10	1	10	600 ppm (human, 30 min) 800 ppm (human, 5 min)	4.3–46
HCN	10 (skin)		10 (skin)	107 ppm (human, 10 min) 357 ppm (human, 2 min)	5.6–40
COS		5			12–29

[a]Chemical Process Safety Fundamentals with Applications, Prentice Hall, 1990
[b]https://www.atsdr.cdc.gov/toxprofiles/tp114-c8.pdf

H_2S gas is dangerous as much as CO and produces toxicity through the similar way as CO such that the gas forms complex bonds with iron in the mitochondrial cytochrome enzymes which will prevent cellular respiration [1]. In coal gasification pilot plants at IAE, H_2S concentration in syngas ranged from 100–1,500 ppm, and COS concentrations showed the 20–400 ppm range for subbituminous coals. Hydrogen cyanide (HCN) is also a dangerous compound and is soluble in water. Gasification reaction produces HCN under oxygen-deficient environment, and HCN ends up at the slag cooling water and other water streams that contact with syngas.

Syngas is widely employed in manufacturing chemicals or synthetic fuels, which involves reactions with catalysts in many cases. Extreme caution is advised when nickel-containing catalysts are used in syngas conversion reactions. Although the probability is very low and even when a small amount is used just as a test, any possibility inducing the formation of nickel tetracarbonyl ($Ni(CO)_4$) should be checked and even slightest inhaling by personnel should be avoided [7]. Nickel tetracarbonyl should be treated as one of the most fatal compounds and is known as more hazardous than CO gas itself.

4 Accident Cases

4.1 Syngas Leakage and Explosion

During the testing of the two-stage coal gasification at IAE in 2009–2011 period, one part of ferrules connecting coal feeding nozzle tubes had become loose due to the impulse action by high-pressure nitrogen in eliminating the powder plugging, resulting in a leakage of syngas. Gasification condition at the core part of the gasifier at that time was 8 bar and around 1,450 °C. Remaining coal powder (80% passing 200 mesh) gushed out with syngas and showed the torch-like flame until the syngas inside the gasifier consumed all (see Fig. 4). When the leakage developed, the gasifier outlet value opened and guided the syngas to the flare stack for complete combustion before venting outside to the atmosphere. But, this venting to the flare stack takes time, and some portion of syngas would come out as shown in Fig. 4. The venting syngas flame in Fig. 4 by appearance looks similar to the flame of welding torch.

Pilot plants use many Swagelok-type tube connections which are accident-prone locations and should be dealt with caution. In principle, the welded connection should be preferred over flanges, particularly for hot pipes of above 500 °C. In pilot plants that need assembling and dissembling for checking and sampling with different dimensions of tubes, however, welded connections could be inconvenient. When the nozzle design has finalized with certain dimension, then the welded version can be installed for more safety.

During the testing of top-feeding partial slagging coal gasification from 2011, several types of coal powder feeding nozzles were tested. One nozzle design that can provide the plug flow type of syngas inside the gasifier was fabricated and tested in April 2011. The design required many intricate welding points inside the nozzle block that included the coal feeding tubes, pure oxygen supply tubes, and cooling water jacket. Initial gasifier operation was very stable, but after about five

Fig. 4 Syngas flame caused by leakage at the feed nozzle area of the coal gasification pilot plant. (Left) flame at the side-feeding nozzle, (right) enlarged picture on the nozzle area

hours of operation, a major explosion in the coal/oxygen feeding nozzle area happened. Figures 5 and 6 illustrate the accident sequence. Left picture in Fig. 5 shows the upper section of the gasifier during the normal steady-state operation. The right picture in Fig. 5 shows the black plume of coal powder leaked through the cracks in feed nozzle. Then, a fire ball explosion (left picture) and the ensuing a short burst of flames through the cracks (right picture) occurred as shown in Fig. 6.

After the explosion accident, the coal/oxygen feeding nozzle section was disassembled and scrutinized. It revealed that the vertical welding part on the water cooling zone was an initial starting point of explosion and the syngas of high temperature in the coal gasifier passed through the cooling water section. By the hot syngas, the feeding nozzle was damaged and the hot syngas met pure oxygen in the feeding nozzle, which eventually resulted in explosion. In the commercial gasification facilities, the water cooling system operates at a higher pressure than the gasifier pressure, which will ensure in preventing any backward flow of syngas. If the cooling water section is utilizing water at the higher pressure than the gasifier, syngas will not flow to the outside of gasifier even when the leak occurs in the cooling water area. But in the pilot system that is not using the high-pressure water facility due to a high instrumentation cost, the nozzle area should be monitored carefully and should make a way to prevent the possibility of syngas leakage through the cooling zone [7].

During the last 20 years or so experience on the pilot coal gasifiers, several explosion accidents had occurred in our facilities, and all the explosion accidents had happened in the coal/oxygen feeding nozzle area. Explosion is very short of few seconds, and most danger resides in high-speed flying small pieces of metal debris during the explosion. Thereby extreme caution should be exercised in such a way that any personnel should not allow nearby the nozzle area during the high-pressure

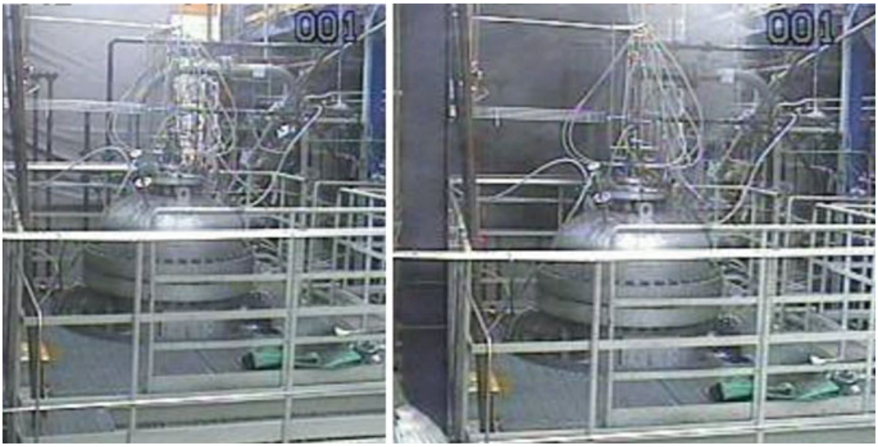

Fig. 5 (Left) upper section of gasifier (normal operation) and (right) coal powder leaks from the nozzle area at the upper section of the gasifier

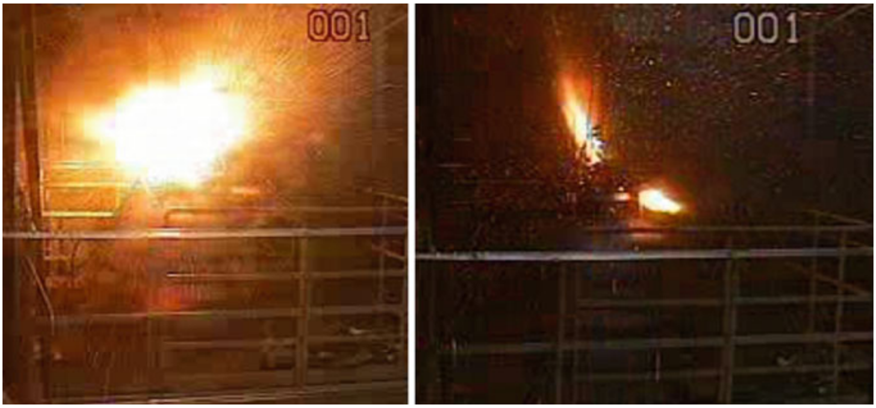

Fig. 6 Explosion moments at the coal feeding nozzle area during the pilot gasifier operation at IAE (20 bar, 1,400 °C). Left: explosion at the nozzle area, (right) remaining explosion gas leaks out after a short explosion as in the left picture

gasification operation. This area should be monitored with CCTV or by simple laptop camera. Cheap PC camera can do the monitoring.

4.2 Accident by Inhaling Syngas

There had been four accident cases of inhaling syngas during the last two decades at IAE. All were related to syngas leakage during the operation of gas analyzers to measure the syngas compositions at the plant site. Leakage happened through the loose Tygon tube connections and also at the syngas pre-treatment system. At those times, the CO concentrations were at least 30%. Even the inhaling amount was limited probably to a few breath, an operator's face became pale in few minutes with dizziness and went to the emergency room at the nearby big hospital. Blood test at the hospital after just about two hours showed a clear CO signal and had to hospitalize for two days.

4.3 Experience at Foreign Commercial Gasification Plants

There should have been many accidents in gasification plants, but not many were reported openly in details. One of the tragic accidents in coal gasification happened in Wabash River 260 MW IGCC plant in USA on April 28, 2008. According to the local newspaper reporting the accident which is available through Internet source of legalelectric.org, loud explosion noise lasted a minute and a half or two minutes.

Two men from Sterling Boiler Local 374 were working on an opening of one of the gasification units, and they were tightening bolts on the flanged opening of the gasifier from nearly 150 ft in the air. The flange opening did fail and come off, resulting in two casualties. Fire from the explosion was out before fire crews arrived. This kind of accident can happen anytime in high-pressure gasification plants. If there is a weak leakage and appeared, it could be blocked with a simple tightening; operators were tempted to do the repair during the operation. Otherwise, whole or a portion of the system has to be stopped and lower the pressure until the repair work initiated, which costs a lot in general due to the loss in syngas production.

Another accident happened at the ISAB Refinery 532 MW IGCC plant in Italy on October 13, 2008. According to the news reporting the accident which is available through Internet source of modern power systems in 2009, explosion and fire happened at one of the 532 MW plant's two trains. Total damages by accident were reported as about Euro 280 million. At the time of accident, one gasification train was shut down as a planned outage, while the other train was in operation. Syngas produced from the operating train slipped into the non-operating train and flowed through the gas turbine and resulted in exploding or igniting when the syngas mixed with air in HRSG which has a big volume in size. Fire from the HRSG then moved into the gas turbine section. Incomplete nitrogen purging of the non-operating train has been identified as a possible cause for the accident. Fluor has been awarded a $150 million EPC contract for reconstruction of the severely damaged combined cycle power train.

5 Considerations for Safe Operation in Gasification Plants [7]

For the safe operation in gasification plants, the following considerations among others were identified based upon the accident experience through the pilot tests at IAE:

- Maintain the enough higher pressure difference all the time at the coal feeding equipment over the gasifier.
- Make sure that connected lines would not leak. Leakage of syngas can lead to critical accidents. Most possible leakage points that need a careful supervision include heat exchangers (inner tubes), and tubes that are not welded (Swagelok-type connection parts) in the feeding nozzle area.
- Welded area that would be exposed to hot syngas should be minimized. Need adequate cooling system (at least should spray water to the hot wall as a cheapest way).
- Weakest and most dangerous area is the coal/oxygen feeding nozzle lines that are the most concerned explosion-prone location and should be off-limit to personnel during the operation.

- Be prepared for dealing with toxicity of CO with proper emergency oxygen cans, etc.
- Be careful when even a slightest possibility of contacting CO- and Ni-based catalysts exist, which might produce nickel tetracarbonyl ($Ni(CO)_4$) that is one of the most fatal compound, more hazardous than CO.

6 Conclusions

Gasification all the time deals with the toxic and explosive syngas and should be dealt with extreme caution. Preventive early gas detectors and every safety instrumentation cannot guarantee all the safety without proper training of operating personnel, and the basic understanding on the causes and process on the syngas-related accidents should be fully explained to the operators.

Experience obtained from the pilot-scale coal gasification systems provides key items that need a due deliberation as follows: (1) Pressure-involved gasification should all the time maintain the positive pressure from the feeding section to the gas outlet place, (2) Swagelok-type tube connections should be checked any leakage before every high-pressure gasification tests, especially in the pilot test facilities, (3) welded pipe connection area that is exposed to hot syngas should be minimized since the welded part is the most weakest point of gas leakage, (4) the feeding line nozzle that includes oxygen and fuels is the most dangerous component with a high probability of explosion accident, and thus, this area should be monitored with the assumption that there can be an explosion any time, (5) CO in syngas is a very toxic gas, and the CO gas detector should be installed, and (6) when Ni-based catalysts are involved with syngas operation, extreme caution should be exercised for the nickel tetracarbonyl ($Ni(CO)_4$) which is classified as one of the most fatal components and is known as more hazardous than CO gas.

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Energy Content of Egyptian MSW as a Supporting Tool for Waste-to-Energy (WTE) Approach

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Abstract To help achieve Energy Sustainability goal, Egypt requested to prepare a waste-to-energy plan (WTEP) that would focus on assessment of MSW as energy resource through characterization of generated waste. Recovery of energy from MSW may be performed through a variety of processes such as combustion, pyrolysis and gasification. To achieve optimum system performance, waste energy content must be well estimated. This paper sets out a proposed waste strategy for energy content determination using different theoretical and experimental techniques as well as multiple regression analysis, taking into account the MSW generation ratios and characteristics. The study was conducted during the summer of 2015 in four representative Egyptian Governorates to obtain the most reliable calorific value results necessary for a national WTE programme. The total number of samples studied was 160. Waste streams were shown to consist of entirely different proportions of waste components with an average percentage composition of 54.4% food waste, 8.8% paper and cardboard, 3.9% glass, 2.9% metals and 11.6% plastic. The target percent error was 15%. Energy content was found to be strongly influenced by demographic features as well as meteorological conditions and most estimation techniques are comparable and will be helpful to WTE planners and as a baseline design data.

Keywords Calorific value · Energy content · Waste to energy
MSWM · Energy resource

1 Introduction

Approximately 54.4% of municipal solid waste MSW produced in Egypt consists of organic waste and 27.2% recyclables. More than 80% of the MSW is open dumped, 15% composted and 5% recycled [1].

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The Egyptian government is facing numerous issues concerning waste management especially minimization, treatment and disposal stages. It fails to provide efficient waste management system (WMS). Most of the allocated budget is spent on the initial management step, collection and transportation. Over the years, different WM approaches need to be adopted among which is the shifting to waste-to-energy (WTE) technologies [2]. The calorific value of the MSW is its energy content which may be released when the waste is burned.

A basic knowledge of MSW characteristics is important for several reasons. First, it provides solid waste management with essential information; second, it is necessary for waste-to-energy knowledge and understanding of MSW characteristics, specially the calorific value, is essential for waste-to-energy planning to enable setting up an effective sustainable waste-to-energy (WTE) management programmes.

As the WTE approach has been established as management alternative for MSW [3], it is important to develop techniques for calorific value estimation. In the present work, both experimental and mathematical techniques are presented and used to calculate the calorific value of the final mixed stream of MSW going to disposal of the residual waste as a function of its initial fraction, composition, socio-economic features and demographic characteristics. Estimated calorific values in different regions are compared aiming at the quantification of the waste to energy probabilities. Different mathematical models estimating the calorific value CV of MSW generated from different Egyptian Governorates were described. The models include physical, chemical and proximate characteristics of collected MSW samples.

2 Materials and Methods

2.1 Materials

Since MSW is a heterogeneous material and its characteristics vary from place to place as it is a function of socio-economic level and climatic conditions, the energy content will differ from one region to another. As a result of the difference in demographic features, different MSW samples were considered. Waste from three different regions in Qena Governorate in Egypt was collected and compared to other governorates.

2.2 MSW Site Selection

The first step in solid waste characterization is the selection of sampling area which was confirmed based on several socio-economic and demographic parameters such as ethnic groups and income level. Three subdivisions of Qena Governorate from

Egypt were selected; El Biaa as high income level (HIL), Sidi Omar as medium income level (MIL) and El Sheoon as low income level (LIL) and compared to other three governorates; El Gharbeya, Kafr El Sheikh and Asyout.

2.3 Preparation of Raw Materials

One month was covered for sample collection processing and analysing in order to estimate MSW calorific value. From the above three Qena districts, 300 households were selected. Generated waste were collected once a day at a fixed time (8 am) all over the week and transferred to a prearranged treatment plant for further sorting and characterization.

2.4 Parameters Measured

The generation rate, bulk density, moisture content and MSW composition were determined and recorded in situ as illustrated in Table 1.

The calorific values of the samples were determined either by analysing the previous parameters or experimentally.

2.5 Methodology

Many techniques are used for characterization of selected MSW samples, and calorific value CV was determined using either experimental or empirical models approaches.

2.5.1 Experimental Approach

Municipal solid waste samples were collected from different households in plastic bags, coded and weighed. All samples were transferred to a suitable dumping site

Table 1 Analytical parameters and methods

Analytical parameters	Method/instrument
Moisture content	ASTM method D3137
Volatile matter	ASTM method D3172
Density	ASTM method D792
Calorific value	Bomb calorimeter ASTM E-711

where the area was covered with a non-permeable plastic cover to prevent dust contamination. In the dumping site, the waste was first screened using a 10 mesh screen and then was carefully mixed and divided into 4 humps. Two diagonal humps were excluded, and the other two were remixed and divided into three-thirds; one for moisture content measurement and two-thirds for manual classification and calorific value determination. Figure 1 illustrates the followed steps in MSW collection and characterization.

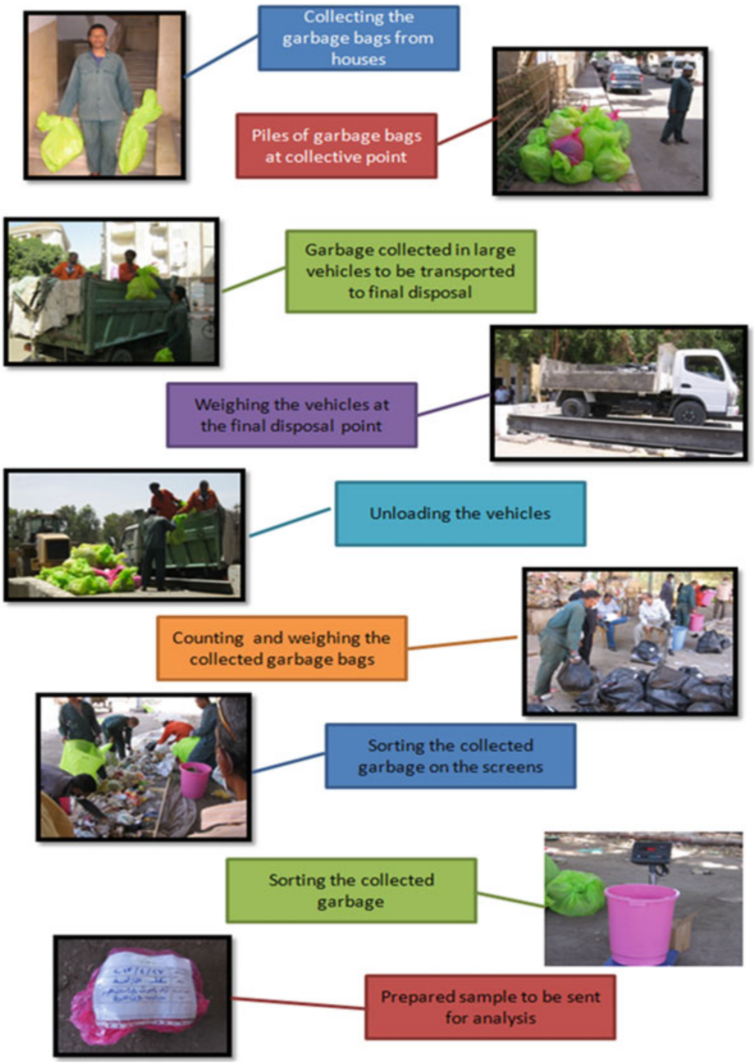

Fig. 1 A schematic diagram showing the steps followed in MSW collection and characterization

2.5.2 Empirical Models Approaches

Calorific value is a property which depends on both physical and chemical characteristics. A pretest of collected samples is performed to determine MSW characteristics (moisture content, composition, ultimate and proximate analysis,…) in order to apply them in different models.

2.6 Calorific Values Determination

2.6.1 Experimental Techniques for CV Determination

The calorific values of 160 remixed samples were measured using a CAL 2k Bomb calorimetric according to ASTME-711. Each day samples from selected districts were milled, pelletized and sent to a certified laboratory. The samples were then ignited in excess oxygen at 30 bars using electric arc where the temperature rise is measured and CV recorded.

2.6.2 Empirical Models for CV Determination

In order to evaluate the calorific value of processed MSW theoretically, different parameters were measured; generation rate, moisture content, density, proximate analysis, ultimate analysis (C, H, N, S) using experimental results, field data as well as typical published data.

Predictive models for the heating values, HHV and LHV, of the MSW have been developed by several authors; although many current models currently exist, the most commonly used models are Abu-Qudais and Abu Qudais [4], Channiwala and Parikh [5, 6], Koufodimos and Samaras [7], Mastro and Mistretta [8], Magrinho and Semiao [9], Komilis and Tziouvaras [10], Komilis et al [11] as illustrated in Table 2.

Some of these models are based on the waste physical composition, whereas others are based on the proximate chemical analysis or ultimate analysis. Therefore, it is necessary to convert the MSW physical composition into its chemical composition [9, 12].

Table 3 exhibits an example of such conversion. The dry chemical composition of each waste material was obtained from the works of Meraz et al. [13]. With such dry chemical composition (C, H, O, N, S and ashes) for each waste component, the mass weighed average of the waste dry chemical composition can be evaluated as shown in Table 3.

The evaluated moisture content may be also introduced for each waste component and the wet chemical composition shown in Table 4.

Table 2 Summary of empirical models used for predicting the energy content of MSW

Physical composition analysis	Ultimate analysis	Proximate analysis
Conventional model $C_v = 88.2R + 40.5(G + P) - 6W$	*Dulong's model* $C_v = 337(C) + 1428(H - O/28) + 955$	*Traditional model* $C_v = 45B - 6W$
Khan and Abu Ghrarah $C_v^* = 23[F + 3.6(P)] + 160(PL)$	*Steuer's model* $C_v = 81(C - 3O/8) + 57(3O/8) + 345(H - O/16) + 25S - 6(9H + W)$	*Bento's model* $C_v = 44.75B - 5.85W + 21.2$
	Scheurer-Kestner's model $C_v = 81(C - 3O/4) + 342.5H + 22.5S + 57(3O/4) - 6(9H + W)$	
	Walter model $C_v = 396(C - O/2) + 287(H/28)$	

Where: C_v net calorific value kcal/kg, C_v^* energy content BTU/lb, *C* carbon weight percent, *H* hydrogen weight percent, *O* oxygen weight percent, *S* sulphur weight percent, *W* water (% dry basis), *B* combustible volatile matter, *R* plastic percent weight on dry basis, *G* garbage percent weight on dry basis, *P* paper percent weight on dry basis, *PL* plastic weight percent, *F* food weight percent

Table 3 Ultimate analysis of MSW based on dry basis (% by mass dry basis)-typical values

Component	Property					
	C	H	O	N	S	Ash
Food wastes	50	6	38	3	0.4	2.6
Paper	44	6	44	0.3	0.2	5.5
Cardboard	44	6	44	0.3	0.2	5.5
Wood	50	6	43	0.2	0.1	0.7
Plastics	60	7	23	–	–	10
Textiles	56	7	30	5	02	1.8
Misc. organics	49	6	38	2	0.3	4.7
Dirt, ash, etc.	25	3	1	0.5	0.2	70.3

Moisture content is on either dry basis P_D or wet basis P_w.

$$P_w = \frac{W}{S_w} \times 100$$

$$P_D = \frac{W}{S_d} \times 100$$

Table 4 Computation of the chemical composition of El Biaa waste sample (25 April 2013)

Component	Wet mass, kg	Moisture % (typical)	Dry mass, kg	Composition, kg					
				C	H	O	N	S	Ash
Food wastes	76.5	60	30.6	15.3	1.84	11.63	0.92	0.12	0.79
Paper	7.45	5	7.08	3.54	0.42	2.69	0.21	0.03	0.19
Cardboard	1.55	5	1.47	0.74	0.09	0.56	0.04	0.01	0.03
Wood	0	25	0	0	0	0	0	0	0
Plastics	12.1	2	11.86	5.93	0.71	4.51	0.36	0.05	0.3
Textiles	0.75	10	0.68	0.34	0.04	0.26	0.02	0	0.02
Misc. organics	31.35	25	23.51	11.76	1.41	8.93	0.71	0.09	0.61
Glass	1.5	0.5	1.49	0.75	0.09	0.57	0.04	0.01	0.03
Tin cans	0	0.5	0	0	0	0	0	0	0
Metals	1.3	0.5	1.29	0.65	0.08	0.49	0.04	0.01	0.02
Dirt, ash, etc.	6.5	8	5.98	2.99	0.36	2.27	0.18	0.02	0.16
Total	139	55.04	83.96	42	5.04	31.91	2.52	0.34	2.15

where:

P_w wet moisture content
P_D dry moisture content
S_w mass of wet solid, kg
S_D mass of dry solid, kg
W $S_w - S_D$, kg

3 Results and Discussion

As previously mentioned, the main objective of this study is the estimation of CV necessary for WTE plant design since it is feasible to recover energy from MSW through incineration.

MSW is a heterogeneous material, and its characteristics vary depending upon the location, season as well as socio-economic level.

The knowledge of MSW composition is a key issue of waste management decisions. Tables 3 and 4 and Figs. 2, 3 and 4 show the waste characteristics data for selected Egyptian regions and the mass fraction of each component for theoretical considerations, taking into account that all of the rejected waste at the sorting process is reintroduced into the mixed MSW stream going to the WTE process and subjected to experimental estimation of calorific value.

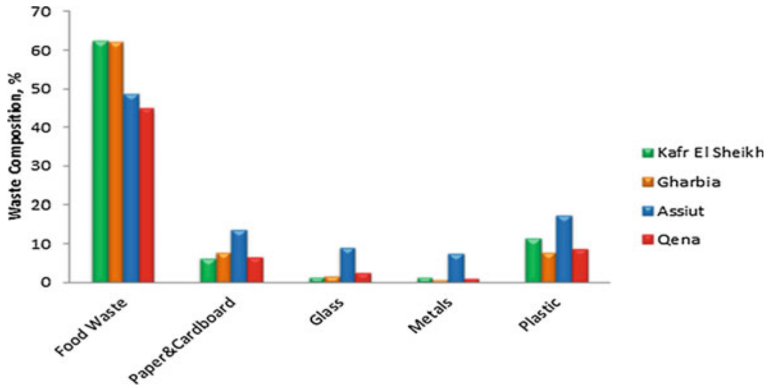

Fig. 2 Comparison of the waste composition of selected governorates in Egypt

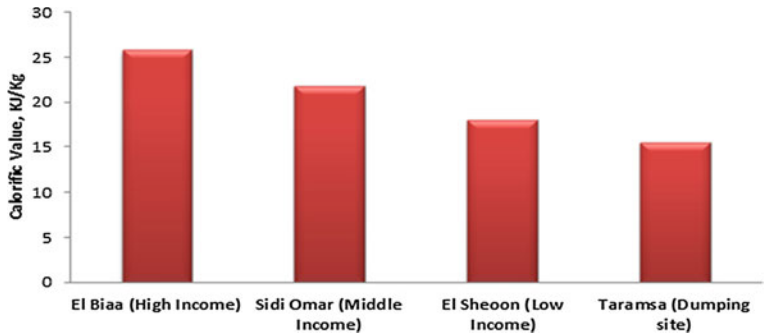

Fig. 3 Average calorific value of waste generated from different income levels

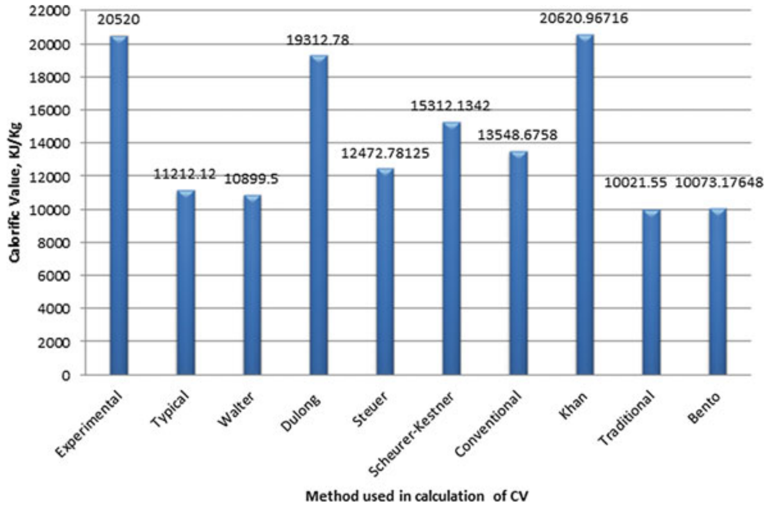

Fig. 4 Calorific value of MSW in Qena Governorate

Table 5 Experimental characteristics of MSW generated from different districts in Qena Governorate

Parameter	Area			
	El Biaa	Sidi Omar	El Sheoon	Dumping Site El Taramsa
Population	46,162	29,936	80,663	NA
Income level	HIL	MIL	LIL	NA
Generation rate (per capita)	0.84	0.51	0.55	NA
Density (kg/m^3)	225.35	199.01	175.58	183.37
% Moisture content	40.68	22.05	52.22	22.47
% Composition				
• Food waste	47.55	45.97	41.54	56.16
• Paper	4.84	4.11	4	6.05
• Cardboard	2.57	3.18	1.89	0
• Wood	0	0.43	0	2.38
• Plastics	8.61	9.75	8.79	3.46
• Textiles	1.65	2.72	2.67	11.9
• Miscellaneous organics	26.76	17.77	30.28	12.5
• Glass	2.64	2.91	2.67	0
• Metals	0.96	1.66	1.61	0.65
• Dirt, ash, etc.	4.42	11.5	6.55	8.66
Average actual calorific value, MJ/kg	25.83	21.79	17.95	15.53
Ultimate analysis, mass %				
• C	32.02	32.61	33.33	
• H	7.84	7.79	7.71	
• O	56.32	55.7	54.99	–
• N	1.92	1.96	1.99	
• S	0.25	0.25	0.26	
• Ash	1.64	1.66	1.71	

Results of field investigation of MSW from the three selected districts are illustrated in Table 5, and selected comparisons are shown in Fig. 1.

From the Table 5, it may be illustrated that all MSW characteristic parameters varied with income level since this is directly related to the socio-economic level and culture, influencing the consumption pattern and MSW composition.

The maximum CV belonged to El Biaa district, and the lowest was that of El Sheoon. On the other hand, the dumping site, El Taramsa, has the lowest CV which may be attributed to the fact that MSW disposed at the dumping area subjected to scavengers' activities in the absence of regulations and many components with high calorific values. Paper, plastics, wood,… are selected before and after dumping as well as during transportation.

Although according to the typical values, paper content is 33%, the actual percentage of paper in all selected districts was found to be very low and was usually found contaminated with food and miscellaneous organic materials. This could be attributed to the fact that it is a habit in most Egyptian households to sort paper and reuse or sell it (newspaper, writing paper, notebooks…).

3.1 Calorific Values Using Different Models

As previously mentioned, selected models illustrated in Table 2 were used to estimate the calorific value of several Egyptian districts. The purpose of using the models is to allow the experts to readily decide the best options for Egyptian MSWM and to access the knowledge base for WTE decision-making purposes.

Applying the modelling concept to Qena solid waste characteristics, the corresponding CV was calculated.

Figure 4 shows the calorific values for the MSW of Qena Governorate using different models compared to the results obtained experimentally and typical values.

Figure 4 shows that results obtained using Dulong's and Khan's methods were in accordance with those obtained experimentally and both were quite higher than the typical value which was very close to the results obtained using Walter, Traditional and Bento's methods.

4 Conclusions

Modelling is a tool designed to help plan a best available waste management technique. It relies on local data, but is automated to output the key tasks in the estimation of difficult parameter. It incorporates the capability for data analysis to obtain CV once results have been obtained from basic properties estimation. The research suggests that experimental investigation for CV is too costly and inconvenient for most waste producers to perform. A modelling method with predictive capabilities minimizes this need.

Results of the study show that calorific value of MSW in selected Governorates can be routed via three distinctly different stream type: the high income and low density population, middle income-middle density population and low income-high density population.

The calorific value of MSW ranges from 9300 to 12,800 kJ/kg and that obtained from our study was in the range of 19,037–20,620 kJ/kg which reveals the sustainability of Egyptian MSW for WTE application.

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Energy Analysis of Water Hyacinth–Cow Dung–Sawdust Mixture Briquettes—An Indian Perspective

Rahul Baidya, Tapobrata Bhattacharya, Gunjan Kumar and Sadhan Kumar Ghosh

Abstract Water hyacinth poses a major problem for Indian water bodies due to its aggressive growth property: engulfing the local flora and fauna and destroying water bodies. The removal of water hyacinth by mechanical means has not been sustainable but when considered as a biomass source, the removal process can become sustainable. The plant has a high growth rate and contains high level of cellulose, thus having high potential for energy generation. The study involves experimental analysis of briquettes, prepared from water hyacinth, cow dung and saw dust. The three compositions were varied in different percentages by mass. The samples were prepared by developing a homogeneous mixture, and analysis was carried out to evaluate the calorific value of the briquettes. The study revealed high calorific value of the briquettes with likelihood of high economic gains. The findings, if commercialized, can lead to utilization of biomass, which would otherwise have been wasted, and furthermore, the briquettes have potential to be utilized in commercial setup like captive power plant, cement plant and bricks manufacturing plant as source of alternative fuel. A number of literature exists, but study emphasising a combination of three compositions is scarce in the literature.

Keywords Water hyacinth · Briquettes · India · Calorific value
Residence time

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1 Introduction

India is one of the fastest developing economies with exponential industrial growth. Likewise, its commercial energy consumption is also growing with the same pace. The major sources which meet the energy requirement of India are coal and oil. The primary energy consumption during 2015 is reported to be: coal 407.2 million tonnes oil equivalent with increase of 4.8%; oil 4159 thousands barrel daily with increase of 8.1%; natural gas 50.6 billion m^3 with decrease of 0.1%; hydroelectricity 28.1 million tonnes oil equivalent with decrease of 4.9%; and nuclear energy 8.6 million tonnes oil equivalent with increase of 9.5% from 2014 [1]. The major renewable sources of energy available alternatively are solar energy, wind energy, small hydropower and biomass. India is a country which is very rich in natural resources. Many of these resources have a great potential for exploitation in India [2]. The need for harvesting alternative energy sources as substitute for fossil fuels has been a vital area of concern for environmental scientists and engineers. In the context of developing countries, significant challenges lie in identification of alternative energy sources as lack of access to cheap and sustainable energy affects majority of the population in such countries [3].

The causal relationship between energy consumption, pricing and income is a determining factor in choosing an energy source for utilization by the people [4]. There is increased emphasis on accessibility and cost in recent times which has resulted in shifting of attention on renewable energy from the fringe to the mainstream [5]. A vital strategy in achieving energy sufficiency in a sustainable way is to identify potential renewable resources that are endemic to a region. Water hyacinth (*Eichhornia crassipes*), an aquatic plant found in Asia, Africa, North America and Australia, is noted for its ability to proliferate aggressively. Though these plants are responsible for negative effect on the flora and fauna of water bodies and cause serious problems in navigation and in captive power generation, recent research point to the possibility of utilization of the plant as a beneficial resource. Water hyacinth acts as agents for removal of heavy metals, thereby improving water quality and has been studied in the role of pollution monitors for arsenic, cadmium, lead and mercury [6, 7].

The plant has also been examined as a source of biomass for alternative fuel [8]. The methodologies range from briquetting biomass material in different ratios in gasifier [9] to direct biogas production [10]. The energy recovery from dried water hyacinth is unsustainable due low energy content, although it can be sustainable if the plant is processed into briquettes. The water hyacinth due to its high water contained and long drying time is best suited for being dried in the summer season and then stored for being used in other season. The drying process becomes lengthy in other seasons due to low intensity of the sun rays. The storage of dried biomass or briquettes is more feasible solution [11]. The material resulting after briquetting water hyacinth has an energy density of 8.3 GJ/m^3, which is comparable to charcoal that, has 9.6 GJ/m^3 [8]. Hu et al. [12] performed catalytic and non-catalytic pyrolysis of water hyacinth in a quartz reactor at different temperature and with different particles size and showed the optimal condition for the reaction and syngas production. Xia et al. [13] proposed a microwave-assisted dilute acid pre-treatment of water hyacinth in order to enhance the enzymatic saccharification for better energy utilization. Gao et al. [14] studied the effect of pre-treatment of water hyacinth with ionic liquid and co-solvent on the lignocellulosic composition, structural change and biogas production. Gao et al. [15] conducted experimental studies on hydrothermal carbonization of water hyacinth at 513 K and maximum pressure of 40 Mpa time ranging from 30 min to 24 h. They also investigated chemical and structural properties of the hydrochar product. Cheng et al. [16] proposed a novel reaction mechanism of hydrogen and methane co-generation from water hyacinth that increases the energy conversion efficiency. Singh et al. [17] investigated thermal and catalytic hydrothermal liquefaction of water hyacinth at different temperature under different water hyacinth: water ratio to obtained high aliphatic carbon content bio-oil. Kunatsa and Mufundirwa [18] presented a review of biogas production from water Hyacinth in Zimbabwe. They found that this approach of energy retrieval from water Hyacinth is a sustainable route. Kunatsa [19] studied the feasibility of biogas production from water hyacinth considering Lake Space Chivero (Harare, Zimbabwe) as a case study. They found dry water hyacinth annually yields 573248.28 m^3 of biogas per year with electricity generation potential 87.57 kW per day. The stability of water hyacinth–cow dung briquettes for different mixing ratios has been studied [20].

The scope of current research involves evaluating water hyacinth–cow dung–sawdust briquette as potential source of fuel in terms of its calorific value. The effect of varying proportions of cow dung and water hyacinth on residence time of combustion is investigated as well. The organization of the paper is as follows: Sect. 2 elaborates the methodology used for the study and discusses the experimental process in detail. Section 3 presents a discussion on the experimental outcome. Section 4 concludes the paper.

2 Materials and Methods

Firstly, a literature review was carried out to gauge the present status and practices in utilization of water hyacinth as a biomass source across the world and specifically in India. Secondly, sampling and characterization of the plant, cow dung and sawdust was carried out, a mixture of the three components was prepared and briquettes were produced by varying the proportion of the three components, four samples were produced. Thirdly, the calorific value of each of the sample was calculated experimentally by a bomb calorimeter and the residence time of each sample was also measured.

2.1 Experiment

The experiments were carried out in three phases—(a) preparation of the samples with different proposition of the three components (b) preparation of the briquettes (c) drying of the briquettes and (d) calorific value and residence time analysis of the briquettes. The drying of water hyacinth was carried out in two different ways, that is, by shredding the plants and without shredding the plants. The specimen plant was dried openly under the sun. The period of the year when it was dried was summer season with scorching heat across the region: the temperature reached up to 311 K. The time period for drying and temperature of each was noted. It was found that shredded ones took less time to completely dry, whereas the un-shredded ones took not only longer time but also due to some sort of shielding effect of the plant outer layer the inner part of the vegetation remained green, laden with moisture. The temperature of the each day was measured for both un-shredded and shredded plant and tabulated in Table 1.

The dried water hyacinth was then further shredded and powdered then added to fresh cow dung and sawdust in the ratios of water hyacinth: cow dung: sawdust as given below in Table 2. A briquette mixture of each sample was prepared. The samples were then dried in direct sun for six days in the month of January; the peak temperature was approximately in the range of 297–300 K; the samples were openly dried in a two stage process. In the initial stage the samples dried were in the open for 4 days. The dried samples were then made into briquettes using a manual screw-type compactor, which were subsequently dried in the open for a day. Followed by drying process the sample were analysed for their calorific value and residence time. The calorific values and approximate residence time were obtained using a bomb calorimeter. A separate analysis of each component was also carried out for finding calorific value so as to develop the correlation of the sample with each of the sample separately.

Table 1 Temperature measurement (in Kelvin)

Sample	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Shredded	303	306	306	306	306	306	306
Un-shredded	307	305	301	303	303	304	–

Table 2 Experimental result of each component

Components of the mixture	Calorific value (kcal/kg)	Residence time in min
Water hyacinth	3209.5	46
Cow dung	4160	16
Saw Dust	4181.25	10

3 Results and Discussion

The calorific value test and residence time of the components of the briquettes were separately measured. The analysis revealed that water hyacinth has the lowest calorific value, followed by cow dung and sawdust (Table 2). The calorific value of the cow dung usually differs based on the source of collection. The residence time of the water hyacinth is the highest with value of 46 min approximately depending on the plant portion used. The sample had a mixture of the roots, stem and leaves in equal proportion. The least residence time was of the sawdust followed by the cow dung (Table 2).

The experimental analysis of each briquettes samples with different proportion of water hyacinth, cow dung and sawdust was carried out. The analysis revealed the most effective sample by balancing both the residence time and calorific value considering the three components in different proportion. The most effective proportion is with the ratio of 10:80:10 of water hyacinth: cow dung: sawdust and followed by 20:70:10 water hyacinth: cow dung: saw dust. The calorific value gets reduced to 3997.5 and 3875, respectively, for two proportions, respectively. Further, the residence time changes from 21 to 38 min depending upon the proportion of the components (Table 3).

The general trend as revealed is that with increase of water hyacinth the residence time was increasing, with downside of simultaneous reduction of calorific value of the briquettes. Although the calorific value got reduced, compared to the calorific value of the cow dung or saw dust, but the mixture with the varying compositions, still has the calorific value comparable to the low-quality coal. The composition of the sawdust in the briquettes has been kept fixed; this is due to the fact that other two components are waste raw materials and hardly have any economical value compare to the saw dust, which has economical value with the cost ranging from USD 44–55 per ton depending upon the area and demand. The increase in residence time can be a boon for utilization of the briquettes in the brick manufacturing plants and other similar type of plants. The result shows a huge potential in term of environmental sustainability and economic gain via substitution of the virgin raw materials with the water hyacinth as a commercial energy resource. The study also shows that even though water hyacinth is a problem in term of it nature as a pest plants and lacks economical benefit in term of physical

Table 3 Experimental result of the mixture in various proportions

Sl. No.	Water hyacinth (% by weight)	Cow dung (% by weight)	Sawdust (% by weight)	Calorific value (kcal/kg)	Residence time in min
1	40	50	10	3654.5	38
2	30	60	10	3693.25	32
3	20	70	10	3875	23
4	10	80	10	3997.5	21

removal process, but when the same plant is used as a biomass resource, it can be an effective source of energy; further, combining the same material with other waste material like cow dung and sawdust in different proportion led to the development of a commercialized energy resource in the form of briquettes. Thus, the study shows the briquettes developed with the combination of the different waste components and water hyacinth in varying proportion can be used commercially in place of coal in bricks manufacturing plants and captive power plant.

4 Conclusion

The experimental analysis reveals that water hyacinth can be economically harvested and utilized in briquette making by using cow dung as binder and sawdust as compressive strength enhancer. Cow dung and sawdust addition further improve calorific value of briquettes developed from water hyacinth. The trade-off between residence time and calorific value of the samples can be attributed to the fact that water hyacinth promotes residence time whereas cow dung and sawdust improves the calorific value. The sawdust further decreases the drying time of the briquettes mixture. The experimental findings support the premise that water hyacinth can be a sustainable biomass for energy generation in conjunction with other locally available renewable resource. The briquettes can meet the energy needs of bricks manufacturing units, local agro-industries, domestic users and low capacity captive power plants partially or in full measures.

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Evaluation of Use of SRF as AFR in Cement Kiln

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Abstract In India, large quantum of non-hazardous waste gets collected as Municipal Solid Waste (MSW) from households and commercial and industrial establishments. This waste, being a non-homogenous mix of various wet and dry fractions, does not provide viable opportunity to recover the material and energy value present in the same. Solid Recovered Fuel (SRF) is a material prepared by processing non-hazardous dry waste collected from commercial and industrial establishments, produced and utilized as Alternative Fuel and raw material (AFR) in cement kilns in many countries around the world. In India, also this material offers a vast potential for utilizing as an AFR in cement kilns. Considering vast availability of the dry material from commercial and industrial establishments in India, it was considered relevant to evaluate the feasibility of its collection and transportation separately and then processing it into SRF for use as AFR in cement plants in India. This necessitated evaluating the feasibility for use of SRF as AFR in cement kiln. The co-processing feasibility of SRF in cement process was evaluated by implementing co-processing trial of SRF imported from SUEZ, UK in Wadi Cement plant of ACC Limited as per the protocol prescribed by CPCB. This study report provides the detailed assessment of the results of the co-processing trial conducted on SRF. These results indicate that SRF is an excellent material for use

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as AFR in cement kilns and its use in cement kiln does not impact emissions or the quality of cement. It is therefore desired that municipalities start collection and transportation dry waste from commercial and industrial institutions separately and implement their processing into SRF for use as substitute material to fossil fuels in resource-intensive industries such as cement. This study will definitely help developing collaboration between municipalities and cement industries to curb the municipal waste management problem.

Keywords Co-processing · SRF · Wastes · Cement kiln · AFR
MSW

1 Introduction

In India, large quantum of Municipal Solid Waste (MSW) is generated annually which gets collected from households together with commercial and industrial establishments. This waste, being a non-homogenous mix of various wet and dry fractions, does not provide viable opportunity to recover the material and energy value present in the same.

Solid Recovered Fuel (SRF) is a material prepared by processing non-hazardous dry waste collected from commercial and industrial establishments separately. This dry waste consists mainly of paper, plastics, wood, cardboards and textiles. Collection of this kind of wastes from commercial and industrial establishments separately without allowing it to get mixed up with household wastes allows it to get converted into a fuel grade material having excellent quality. It is produced and utilized as Alternative Fuels in cement kilns in many countries around the world. In India, also this material offers a vast potential for utilizing as an Alternative Fuel in cement kilns.

Given vast availability of such material in India, it was considered relevant to evaluate the feasibility of collection, transportation and processing of such waste into SRF and then also evaluate its use in cement plants as an Alternative Fuel by studying the impact on kiln emissions and the quality of cement.

Geocycle India is a shared business division of ACC Limited and Ambuja Cement Ltd for management of wastes as Alternative Fuels and Raw materials (AFR) in cement kilns. Geocycle is a brand of LafargeHolcim under which ACC and ACL implement waste management services through co-processing in India. SUEZ is a nearly 200-year-old environment business primarily in waste and water sectors having a global presence. This includes operations in India, in the form of SUEZ India (former Degremont), a prominent water and liquid waste water company based in Gurgaon. SUEZ through its waste business (formerly SITA) is a world's leading producer of SRF having dedicated SRF production and waste treatment facilities in many different countries.

SRF is an Alternative Fuel prepared from non-hazardous waste meeting the specification requirements of CEN TS 15359. The SRF is a consistent fuel produced from non-hazardous residual material collected from commercial industrial materials including paper, card, plastics, wood and textiles.

Use of waste-derived fuels as a source of energy has been a popular waste management option in many countries around the world. Many waste factions having calorific value and are non-recyclable can be used as a fuel for energy recovery where such markets/end-users are available.

This use of SRF would require waste management companies to produce consistent quality Alternative Fuels that comply with the requirements of the customers. Generally, a material generated from constituents having reasonable calorific wastes is referred to as refuse-derived fuel (RDF). But this creates a lot of confusion in understanding different types of RDF as the content and quality of the fuel may vary. Often the environmental parameters and compositional quality are not described. So while an RDF (usually collected from municipal–household waste) might have a good calorific value and low chlorine content, it does not give end clients the clarity on its composition as it is not tested and described in a standard format. Hence, it is more appropriate to call it as Segregated Combustible Fraction (SCF) and overcome the problems faced by defining it as RDF. The typical features of SCF and SRF therefore are illustrated in Table 1.

For achieving ease in operation, a common language has devised by European standards of CEN/TC 343 for 'solid recovered fuel' (SRF) [1].

SRF is an Alternative Fuel prepared by pre-processing non-hazardous waste in compliance with the European standard EN 15359. The main requirement under this definition is that a producer specifies and classifies its SRF by detailing its net calorific value (NCV), chlorine and mercury content. Other specification includes (as mandatory) the content of all heavy metals mentioned in the Industrial Emissions Directive [1]. Thus, SRF producer can produce and guarantee product of a defined specification as required by the customer.

The evaluation on use of SRF as AFR consisted of implementing co-processing trial of SRF imported from SUEZ (UK), in Wadi Cement plant of ACC Limited as per the protocol prescribed by CPCB and by obtaining necessary clearances from MoEFCC and DGFT. The monitoring of emission and other parameters was carried out by SGS Limited which is a CPCB approved laboratory agency.

Table 1 Difference between SCF and SRF

Parameter	SCF	SRF
Particle size	0–400 mm	<35 mm
Calorific value	8–15 MJ/kg	>16 MJ/kg
Moisture	25–40%	<15%
Chloride	Not defined	<0.8%
Sulphur	Not defined	<0.5%

2 Use of Waste-Derived Fuel Globally in Cement Production—Literature Review

Large quantity of SRF is utilized globally in the cement plants, and several studies have been carried out by researchers in this area. John R. Fyffe et al. have evaluated the use of SRF in the cement kilns and concluded that SRF gets utilized as an Alternative Fuel [2]. Roland Pomberger and Renato Sarc have evaluated the various quality aspects of SRF on the co-processing performance [3]. Nicola Dondur et al. evaluated the economical and environmental implications of utilizing SRF in cement kilns [4]. Juan Conesa et al. have studied the pollutant formation and emissions from cement kilns while utilizing SRF [5]. Juliet Curry has compiled information on the typical characteristics of SRF desired while utilizing them as AFR in main burner and calciners of the cement kilns [6]. Vaishali Nandan et al. have studied the co-processing of segregated combustible fraction from MSW in cement kiln [7]. The use of MSW, in mass burning WTE facilities, or in the form of RDF in dedicated combustion facilities or as RDF in lignite-fired power will result in significant energy-reduction and environmental benefits. Considering the volume and energy content of MSW generated, and the National Plan for Solid Waste Management in Greece indicate that the potential for electricity production from it is quite high [8]. The conclusions from past studies indicate that it may be possible to use RDF in existing power plants of Macedonia and Peloponnese, while Athens, Thessaloniki, Thessaly and Western Greece require mass burn waste-to-energy facilities in combination with/RDF facilities. In Crete, an RDF utilization in dedicated power plant is foreseen. Apart from the environmental benefits that would be derived, other benefits foreseen in this exercise are reduced need for fossil fuels, reduction of import fuels, mitigation of the climate change impact from the Power Generation Sector, and avoidance of land-filling. Therefore, it is imperative that the National Waste Management Plan takes into full consideration the ramifications of using MSW as a fuel, either in mass burn WTE facilities or in the form of RDF combusted in dedicated facilities or co-combusted in lignite thermoelectric power plants [9].

Based on the above studies, it is concluded that it may be feasible to use the RDF produced by the Western Macedonia and Peloponnese facilities in the nearby power plants as an Alternative Fuel. The results of these studies indicate that it is feasible to achieve a 1:1 substitution of lignite by RDF and, also, reduce equal quantum of CO_2 generation that would take place from use of Lignite. Use of RDF in lignite power plants may reduce use of lignite by 20,000 TPA and equal quantum of CO_2 in Western Macedonia and will reduce CO_2 76,000 TPA of lignite and equal quantum of CO_2 in Peloponnese [10–14]. While utilizing RDF as an Alternative Fuel in these applications, it must be stressed it should not lead to higher emissions of polluting substances in the stack gas compared to those permitted for dedicated incineration plants. Hence, these facilities must be equipped with adequate Air Pollution Control (APC) systems [15]. A dedicated RDF-combustion plant is foreseen in the National Plan of Crete for MSW management that would combust

105,000 TPA of RDF. Based on the international experience, such a plant would generate about 70 GWh of electricity annually [9–14, 16–21].

A debate is open on the issues of waste-to-energy methodologies aiming to answer to questions of particular relevance, such as whether the concept of SRF/RDF production can be applied directly to MSW through the Mechanical–Biological Treatment (MBT) process, when selective collection acts as a virtual pre-treatment of the same, or if the use of pre-processed combustible fraction of MSW into SRF in cement kilns is the most sustainable solution. Analysis of the (a) use of SRF in a new dedicated thermal plant for electricity production and (b) use of SRF as a resource in an existing cement plant were carried out is the study for the comparative assessment based on principles of Sustainable Waste Management embracing technical and cost issues, environmental protection, industrial ecology and symbiosis [15]. SRF, which is prepared by pre-processing combustible fraction of MSW obtained by conventional separation systems, can be utilized as a resource in cement kilns in order to obtain a useful energy recovery. It is always useful to evaluate this possibility within the general framework of waste-to-energy solutions. Based on the study of different experiences of this issue throughout Europe and some applications within Italy, it is reviewed that the use of SRF in cement kilns instead of coal or coke offers environmental benefits in terms of greenhouse gases, while the formation of conventional gaseous pollutants is not a critical aspect. It is also observed that the generation of nitrogen oxides can probably be lower because of lower flame temperatures or lower air excess. The presence of chlorinated micro-pollutants is not influenced by the presence of SRF in fuel, whereas depending on the quality of the SRF, some problems could arise compared to the substituted fuel as far as heavy metals are concerned, chiefly the more volatile ones [22].

Though waste-derived fuels in form of SRF and RDF are very popular for replacing fossil fuel in cement kilns, the terms are used interchangeably and create confusion. Therefore, it is very important to understand the difference between SRF and RDF.

3 Supply Chain Including Collection, Transportation and Production of SUEZ UK SRF

SRF is a solid fuel prepared from non-hazardous waste meeting the classification and specification requirements of CEN TS15359. The SRF is processed homogenized and can be produced to a range of specifications to meet the customer requirements. The typical specification parameters of SRF are illustrated in Table 2.

The SRF produced by SUEZ is a uniform quality Alternative Fuel material produced from non-hazardous dry material collected from commercial and industrial sources. This includes mainly combustibles such as paper, card, plastics, wood, textiles. This material does not contain any waste from domestic or household

Table 2 Typical specification of key parameters of SRF

Parameter	Limit
Particle size	<35 mm
Calorific value	>16 MJ/kg
Moisture	<15%
Chloride	<0.8%
Sulphur	<0.5%

sources. The typical specification of the key parameters of SRF is provided in Table 1. The separate collection, transportation and management system MSW from commercial and industrial establishments is shown in Fig. 1.

Before the waste goes through a high-tech processing line, it gets pre-sorted manually and with machine. Then it is evaluated to check that its quality surpasses the best in class standard. This pre-sorted material then is shredded, and the metallic materials from the same are removed using magnetic separators. After the inert, magnetic and metallic contents from this material are removed, the shredded material is left with a mix of paper, wood, textiles, card and plastic, etc.

This material, which has a moisture content of less than 15%, is shredded to between 0 and 30 mm in size. The material is shipped or stored after getting it baled. The production process of SRF from source separated collections is depicted in Fig. 2.

Fig. 1 Separate collections of commercial and industrial wastes

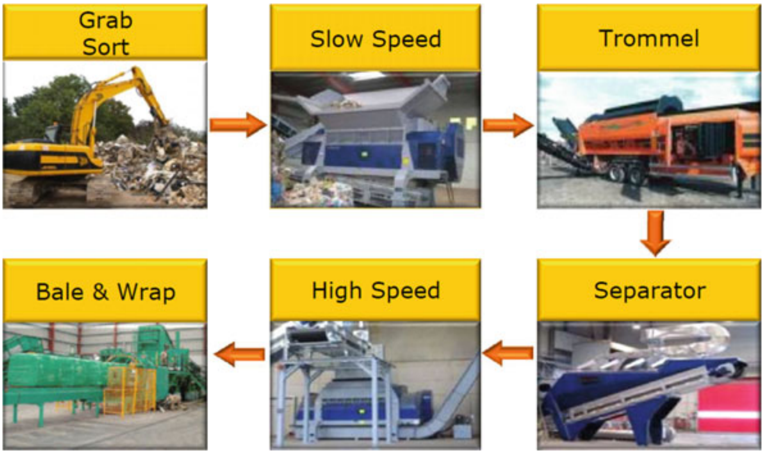

Fig. 2 Production process of SRF from source separated industrial and commercial collections

4 Production and Utilization of SUEZ UK's SRF in Cement Plants Globally

SRF is produced by SUEZ from segregated Dry fractions of source segregated waste from industrial and commercial customers and is consumed in large quantities as Alternative Fuels in cement kilns. SUEZ Group has capacity of producing 1.1 Mio TPA of SRF which is produced from the dry fractions collected from commercial and industrial establishments. The advantage of producing SRF from the non-recyclable dry fractions is that the contamination of organic biodegradable fraction and the heavy metals gets completely avoided. This provides an SRF having high calorific value, low moisture and ash contents. The SRF produced from these input source tends to have calorific value in the range of 16–22 MJ/kg and moisture content <15% which is highly desired.

5 Trial of Utilizing SRF in Cement Plant in India—ACC Wadi Case Study

Considering the potential available to produce and use good quality SRF from the segregated material collected from commercial and industrial establishments separately, ACC and SUEZ, UK considered it appropriate to undertake a process trial of such material in the cement plant in India. Wadi Cement Works of ACC was selected to undertake this trial. Since the SRF of this kind is not produced in India

Fig. 3 Baled SRF receipt, movement and storage

currently, it was decided to import this material from SUEZ, UK. For this, the permission was granted by MoEFCC and DGFT. To ensure desired quality SRF is received, proper monitoring system was put in place through third-party inspection.

The imported SRF was received in bales of about 1 ton each. Figure 3 provides the photograph of the truck in which the bales were received and later stacked in the AFR storage shed of the Wadi cement Works.

The material was then removed from the bales and then stacked as loose material into heaps. The loose SRF was then fed into the AFR feeding system of the plant using tipper trucks. The same is shown in Fig. 4.

Fig. 4 De-baled SRF being fed into AFR feeding system

Table 3 Chemical characteristics of SRF

Chemical analysis of SRF		
Parameter	Unit	Result
Calorific value (gross)	kcal/kg	4356
Calorific value (net)	kcal/kg	3789
Chloride	mg/kg	282.6
Fluoride	mg/kg	1.4
Carbon	%	45.08
Hydrogen	%	6.89
Sulphur	%	0.8
Nitrogen	%	1.41
Oxygen	%	29.44
Moisture	%	4.6
Ash	%	16.4
Volatile matter	%	73.7
Fixed carbon	%	5.3

6 Quality of SRF

The SRF received at the plant was evaluated during the trial for its chemical characteristics, and the same is provided in Table 3. It can be observed that because it is produced from a commercial and industrial establishment, it has less contamination of undesired elements such as moisture and hence its calorific value is very good. Further, due to the defined nature of the input material and proper processing of the SRF material, it was observed that it has highly consistent quality in terms of calorific value, moisture, ash and chloride contents.

7 Co-processing Trial of SRF

As part of the CPCB protocol [23], the trial was conducted without any AFR material for one day (pre), with feeding of SRF for 3 days (during) and without any AFR material for one day (post). The trial was conducted for 5 days from 26 June 2016 to 30 June 2016. SRF was fed in the inline calciner of the kiln at a feed rate of 3.5 TPH which was at a Thermal Substitution Rate (TSR) of 3.9%.

8 Impact of Feeding SRF on the Process Operation of the Kiln

There was no specific impact observed on the kiln operating parameters during the co-processing trial of SRF.

Table 4 Emission monitoring results of SRF co-processing trial

Parameter	Unit	Pre-coprocessing	During co-processing	Post-coprocessing
PM	mg/Nm^3	1.71	1.5	1.73
SO_2	mg/Nm^3	12.43	12.34	11.44
NO_x	mg/Nm^3	1133	926.7	1190.7
CO	mg/Nm^3	137.2	95.5	165.8
HCL	mg/Nm^3	2.27	<1.5	<1.5
HF	mg/Nm^3	<0.5	<0.5	<0.5
TOC	mg C/Nm^3	6.68	5.57	5.43
Hg	µg/Nm^3	<0.5	<0.5	<0.5
Cd and Th	µg/Nm^3	<1	<1	<1
DIOXIN and FURAN	ng TEQ/ Nm^3	0.003	0.002	0.003

9 Impact on Emissions from the Cement Kiln

The measurements of all specified parameters as per the CPCB protocol were carried out in the pre, during and post phases of the trial.

The cement produced during the co-processing period was tested for its product quality considerations including leach ability. All the product quality parameters were observed to be within the specifications and the leach ability test was negative.

Various emission parameters as specified in the CPCB protocol were measured during each phase of the SRF co-processing trial, and the results of the same are provided in Table 4.

It may be observed from Table 1 that there is no untoward impact on the emissions from the kiln during co-processing of SRF.

10 Conclusions

Following was concluded from the results of the co-processing trial of SRF.

(a) Properly processed SRF prepared from the dry waste collected and transported separately from commercial and industrial establishments has no odour concerns
(b) Processed SRF has uniform thermal, chemical and physical properties
(c) Processed SRF has high calorific value and acts as a good quality fuel in cement kilns, reducing the use of fossil fuels.
(d) SRF co-processing does not impact the product quality or emissions from the cement kilns

11 Recommendations

Considering large quantity of dry waste generated by the commercial and industrial establishments and its co-process ability after converting it into SRF, it is desired that separate collection and transportation of this dry waste from commercial and industrial establishments needs to be encouraged and incorporated in the tenders of the SWM processing. As this waste can be gainfully converted into SRF and used as a good quality fuel in the cement plants, it is desired that dedicated production facilities be developed to ensure consistent supply of SRF. This could be facilitated by wider industry acceptance of SRF and long-term contracts/PPPs to encourage this conversion of waste to fuel by experienced players and provide them to the cement plants. This action will help conserve the precious natural resources (coal) and also contribute to the GHG mitigation action. It is also a very effective way to put to good use large amounts of non-hazardous industrial and commercial waste material, which would otherwise end up in landfill. Furthermore, the widespread adoption of SRF as a fossil fuel replacement can significantly help India towards its COP21 commitment of reducing CO_2 emissions by 33–35% and generation of 40% of energy requirements from non-fossil fuel sources.

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Part XII
W2E Pyrolysis and Gasification

Updraft Gasification of Waste and Produced Syngas Treatment

Murat Dogru, Michael R. Beltran, Swapan Mitra, Ahmet Erdem and Eon Sang Park

Abstract The EU is expected to become one of the world's strongest markets for gasification. This is driven by both the impact of the EU landfill directive and government recognition of the need to generate energy from domestic and industrial waste, particularly from advanced new technologies. The cost of landfill is increasing globally, in particular special industrial waste which has a higher disposal cost. The introduction of the climate change levy has also hastened the need to generate renewable sources of tax-exempt energy. During the recent decade, Beltran Technologies Inc (New York, US) in conjunction with Gasification Consultancy Ltd (Newcastle, UK) and Gebze Technical University (Istanbul, TR) has devoted considerable research and development into biomass and RDF updraft fixed-bed gasification systems. These systems are suitable for CHP technology. Beltran can competitively offer gasification plants for a fuel input up to 2000 kg/h (8 MWt) with power efficiencies in excess of 30% and simultaneous delivery of steam for industrial use or hot water for district heating. Beltran has designed, fabricated, installed, and commissioned a single stream 1 MWh power plus 1.25 MWh thermal energy output from refuse-derived fuel (RDF) derived from municipal solid waste (MSW) gasification plant close-coupled with the internal combustion gas engines. This plant has been commissioned recently and in operation since May 2015. A significant part of the work has been related to testing a new gasifier design to handle high plastic content RDF fuel and the conditioning of the gasifier syngas for use in gas engines. For the fine filtration of the gas and produced water, a reliable solution based on wet electrostatic precipitation and a novel cleanup technology has

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been demonstrated. Furthermore, the complete gasification system has been fully automated for operating remotely. Beltran's small-scale single or large-scale modular gasification technology is now considered as state of the art, highly competitive, and an alternative to other existing technologies.

Keywords MSW · RDF · Updraft · Gasification · Gasifier · Syngas
Gas treatment · Power energy generation

1 Introduction

The most important and urgent global issue is the establishment of a sustainable energy technology to stop global warming. Therefore, alternatives for fossil fuel-based energy and raw materials for chemicals industry must be established urgently while improving the efficiency of energy conversion and preservation processes. The energy equivalent of global biomass production is about 8 times the world energy requirement every year. Currently, only a small fraction of this vast resource is utilized globally. Unlike the other energy sources, biomass can be harmful to the environment if it is not utilized as renewable source of energy and raw material. On the other hand, control of combustion conditions, use of catalysts, gas, and process water cleanup reduces pollutant emission by two orders of magnitude and generate heat and power. When biomass is used for ethanol production, some 70–80% of the feedstock remains as residue which can be further utilized through gasification. Transport fuels and hydrogen can be obtained through the chemical conversion of the producer gas.

Due to the logistics of biomass feedstock (often as biomass waste), biomass-based energy technology has to be locally supported and utilized. Therefore, such a technology will not have the scales of economy enjoyed by fossil fuel-based energy technologies, but it will have the desired environmental and societal acceptance as well as economic competitiveness based on process integration, reduced transport and delivery costs, reduced capital cost through process intensification and miniaturization and being locally utilized. Operated in relatively small scale (0.1–10 MWe) with locally available feedstock, it will provide security of raw material and energy supply. In order to achieve this economic competitiveness, types of biomass, which can be easily integrated, which have the potential for further development, and which reduce environmental impact of energy production, need to be examined. In this respect, the most important raw materials are lignocellulosic feedstock (from agriculture, forests, energy crops), municipal solid waste, sewage sludge, and industry-specific wastes such as animal and oil/food waste.

In order to achieve sustainable gasification technology, it is necessary to examine the unit operations of a gasification plant, including feedstock handling, fixed-bed gasifier, syngas conditioning (dust cyclones, gas cooler heat exchanger, water scrubbers, demister, and wet electrostatic precipitator), process water cleanup, and the final destination of the product syngas from the gasification system to the prime mover. Usually, the final destination of treated syngas is either an internal combustion gas engines for power/heat generation, gas turbines, gas separation units for hydrogen generation or high-temperature fuel cells.

There are a number of unit operations which can be intensified thus making the entire plant cost effective. These unit operations are: gasifier, gas and process water cleanup, and gas separation. In order to achieve these intensified processes, several novel systems have been developed, including intensified wet electrostatic precipitators (WESP) for particulate and tar removal, and process water cleanup technologies.

2 Gasifier Development

Gasification is the thermal decomposition of solid fuel to a combustible gas, or synthesis gas (syngas) rich in carbon monoxide and hydrogen. By using limited amount of oxidant (pure oxygen, air or steam), a partial oxidation (gasification) will take place. There are several types of gasifiers available; while fixed-bed gasifiers have electrical energy output of up to a few MW; fluidized-bed gasifiers are suitable for multi-MW operations. Locations of the biomass, air supply, and syngas outlet are also important in the gasifier performance [1–8].

An experimental pilot plant multi-mode 50 kWh gasifier system has been developed at Newcastle University (UK) in late 1990s and early 2000 [2–8], and this system has been scaled up from 50 to 250 kWh (for Anglian Water plc, UK) and scaled up to 1 MWh (for Beltran Technologies, Inc., US) in Korea. Although at each stage of development, the experience from the operation of the previous scale-up was utilized, and the most radical changes were made in the Beltran gasifier system [8]. Nevertheless, basic scale-up rules developed so far were validated in the subsequent gasifier designs and gas cleaning/water removal systems [9]. The operational results reported in this study are based on the 1 MWh gasifier development plant which was recently designed, supplied, and commissioned in South Korea by Beltran in conjunction with Korean Environmental Cooperation (Keco). The 1MWh output Beltran gasification plant is a fixed-bed updraft gasifier capable of handling different types of feedstock including but not limited to RDF.

In a typical gasification experiment gas compositions, gas flow rate, gasifier system temperature profile, fuel input, and char output rates are evaluated as a function of gasifier parameters. Several different feedstocks were used, including wood chips, sugar cane bagasse, leather waste, refuse-derived fuel obtained from sorted municipal solid waste, sewage sludge which represents the mainstream biomass waste. Some of these materials were also used in the 1MWe gasifier in order to test the validity of the scale-up criteria.

2.1 50 kWh Gasifier System

The down-updraft gasifier consists of a cylindrical reaction vessel, with a constriction near the base. Biomass waste fuel is admitted from the top, and it proceeds by gravity down through the unit. Four process stages can be identified as: drying, pyrolysis, oxidation, and reduction zones from top to bottom. Figure 1 is a diagrammatic illustration of the gasifier showing the reaction zones and the temperature profile. The experimental setup and the procedure are discussed in detail [2–7].

2.2 Gasifier

In the drying zone, heat passes by convection and conduction within the gasifier upward to the fresh fuel charge. The temperature of the charge rises and the moisture content lowers. The temperature range and, the height of the drying zone are 70–200 °C and 0.10 m, respectively. In the pyrolysis zone, the temperature of the fuel rises to the point where the volatile constituents are driven off. This takes place using the thermal energy released by the partial oxidation of the pyrolysis products at the zone below. The temperature range and the height of the pyrolysis zone are 350–500 °C and 0.17 m.

In the oxidation zone, air is admitted via nozzles to the pyrolysed biomass (char). The heat absorbed in all other stages is supplied by the exothermic reactions in this zone. Tar molecules are degraded in the gas phase to form CO_2 and H_2O at above

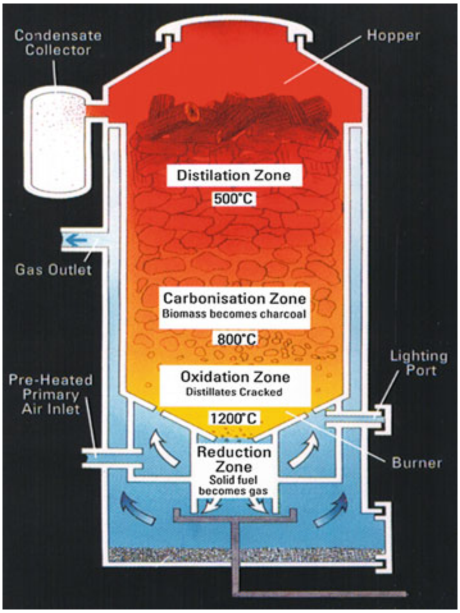

Fig. 1 Simulated picture of downdraft-throated gasifier

1000 °C. The temperature and the height of the oxidation zone are approximately 1000–1200 °C and 0.12 m. In the reduction zone often called gasification zone, endothermic reactions occur between the char and the gases (including water) yielding mainly CO and H_2, with some CH_4.

2.3 Gas Cleanup

The produced gas leaves the gasifier at a temperature range of 300–550 °C. The produced gas needs to be cleaned as it is loaded with particulates and pyrolytic products, so-called tars and water mist. The cleanup unit should be designed according to the end use of the produced gas. Depending on the use of the gas, product gas may have to be cooled and condensate is removed (see Fig. 2). It is also important to remove heavy metals to achieve final emission standards and prevent metal deposition in the proceeding process units.

The product gas was cleaned by a V-tex vortex scrubber [10]. In the scrubber, the soluble inorganic compounds and some organic compounds in the gas are removed as the gas passes through a thin water film produced by the impingement of two water jets. Furthermore, the rapid cooling causes the deposition of high-temperature boiling tars from the gas. A gas booster fan is used to provide gas suction at the outlet to water scrubber before it is flared after ignition by a pilot burner.

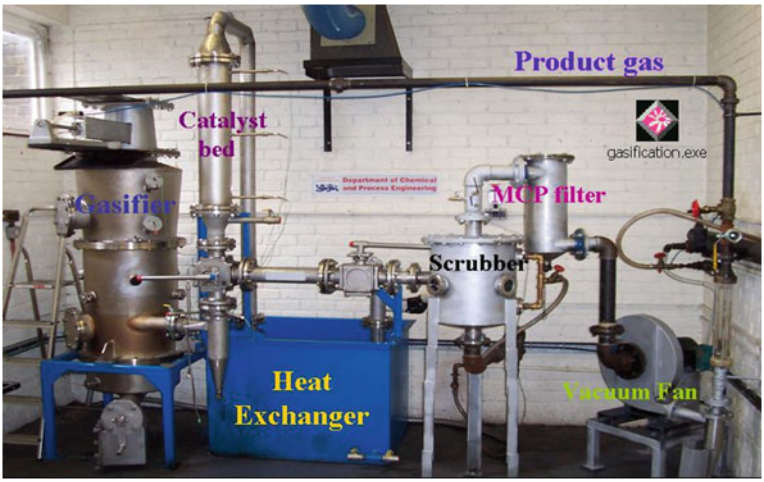

Fig. 2 Gasifier and gas cleanup system developed at Newcastle University

2.4 Experimental Procedure

Biomass waste fuel consistency is important in gasification in order to achieve continuous flow through the reactor and to provide reliable product gas composition and calorific value for the downstream energy conversion processes. Furthermore, densification of the biomass fuel reduces the reactor size, while shape and size of the dense fuel reduce fluctuations in gas and fuel flow rates as well as the subsequent product quality. For biomass fuels such as wood chips which are already dense, further densification is not crucial but desirable. However, for fuels with large variations in its content and low bulk density, such as municipal solid waste, densification is absolutely inevitable for standard downdraft gasifier. Therefore, municipal solid waste, after the removal of metals and glass, is either heat treated to obtain cellulose-rich powder, or it is shredded and subsequently briquetted to densify the fuel for downdraft applications.

The data acquired in the gasification experiments are: fuel and gas flow rates, gas composition, tar and particulate concentration in the gas, temperatures and pressures along the process line. Temperatures were recorded with an analogue to digital converter every 15 s for inlet air, drying zone, pyrolysis zone, throat, and scrubber outlets. The pressure drops were measured at the gasifier and water scrubber outlet. The product gas flow rate was measured after the suction fan. The amounts of tar and condensate in the product gas were determined from gas samples taken at the gasifier and water scrubber outlets (Fig. 2). Clean and dry wood chips and charcoal used as filters are placed in the respective trays in the box filter (not shown in the diagram) between the scrubber outlet and gas booster fan. The gas flow meter is regulated to the required flow rate.

Two Pyrex U-tubes in series were used to collect tar and condensate and to clean the gas samples for gas analysis. The first U-tube trap contained small spherical glass beads, while the second trap contains silica. Produced gas passed through the U-tubes using a vacuum pump via a rotameter to measure gas flow rate from which tar content was evaluated. After each gasification experiment, gasifier was cleaned and amounts of ash, char, and unused biomass were determined and the biomass flow rate was evaluated.

Gas chromatography (GC) was used to analyze the gas samples using helium as a carrier gas using a dual column system (chromosorb 101 and molecular sieve) with a thermal conductivity detector. Table 1 summarizes the GC column operating conditions and gas concentrations that are evaluated. Air and producer gas humidity were also measured in order to carry out accurate energy and mass balances.

Table 1 GC operating conditions

	Column 1	Column 2
Pressure (kPa)	130	95
Carrier gas vel.	40 ml/min	35 ml/min
Packing material	Mol. Sieve	Chromosorb
Peaks for gases	H_2; O_2; CH_4; CO; N_2	CO_2; C_2H_6; C_2H_2

2.5 Biomass Characterization

Based on the ultimate analysis, the high heating value (HHV) was calculated using the IGT method [2] in which HHV is calculated from:

$$HHV = 341C + 1323H \times 68S - 15.3A - 120\,(O + N)$$

In designing thermochemical conversion systems, it is more realistic to use the low heating value (LHV) of the gas which excludes the latent heat of steam in the fuel as it does not contribute to the actual heating value of the fuel. LHV is calculated from [2–4]:

$$LHV(\text{dry basis}) = HHV(\text{dry basis}) - 2.44(9H)$$

where HHV and LHV are in kJ/kg; C, H, S, A, O, and N are the weight percentages of carbon, hydrogen, sulfur, ash, oxygen, and nitrogen. Alternatively, the calorific value of the gas can be calculated from:

$$LHV(\text{dry basis}) = HHV(\text{dry basis}) - 2.44(9H)$$

where X_{H2}, $X_{CO,}$ and X_{CH4} are the mole fractions of the main combustible gases, hydrogen, carbon monoxide, and methane, respectively.

3 Gasification of Municipal Solid Waste

3.1 Background to Municipal Solid Waste Gasification

Estimates in 2011 indicate that, in Europe, some 62.6% of the total waste is landfilled, 21.9% is incinerated, 4.5% is composted, and 11.0% is recycled [11]. In 2001, it was reported that the total municipal solid waste (MSW) production is about 32 million tons per year in the UK [12]. After the removal of metals and glass, some of the municipal waste is composted, but it is mainly landfilled which is being severely curtailed due to the unavailability of land and environmental concerns. The UK Landfill Directive on waste management strategies [12] forecasts that by 2015, 33% of household waste should be recycled, and therefore, very small (if any) growth in MSW generation is predicted as shown in Table 2.

MSW is generally defined as "household waste plus other waste of a similar composition collected by (or on behalf of) the local authority." In practice, this means that if the waste generated by a particular commercial business is collected along the household waste, the material is classed as MSW [13]. The combustion of

Table 2 Strategies to meet the landfill directive and waste strategy targets [12]

	UK diversion required by 2020	
Route	Total mass (Mt per year)	No of new plants required
Recycling	6.9–12.5	100–210
Organic waste composting	3.0–5.6	130–260
Incineration with energy recovery	10.9–30.1	35–110
Total diversion	20.8–48.2	–

MSW for energy production is an effective use of waste products that significantly reduce problems of waste disposal. It has been claimed that lower air emissions and more efficient energy recovery can be achieved with gasification than with conventional mass burn technologies at similar cost [14]. The potential and the economical analysis of the clean fuels from MSW based on metropolitan areas are available [15].

3.2 Characteristics of Municipal Solid Waste (MSW)

Black-bag bin waste as collected in refuse collection vehicle (RCV) was obtained from Slain Environmental Limited, UK. This material does not contain any metals or glass. It was shredded prior to the gasification. Results of proximate and ultimate analysis of MSW are given in Table 3, where they are compared with those of wood [2]. Bulk and absolute densities of both MSW and wood chips are also given in Table 3 for comparison. Although metals and glass were removed from MSW at the pre-gasification treatment process, samples still contained metal traces.

Table 3 Physical and chemical properties (proximate, ultimate, and calorific analyses) of MSW and wood

	MSW	Wood chips
Abs. density, kg/m^3	926	837
Bulk density, kg/m^3	110	250
C (%)	45.60	42.70
H (%)	6.18	6.58
O (%)	24.70	47.77
N (%)	1.66	0.45
S (%)	0.46	0.37
Ash (%)	21.80	2.20
Moisture (%, wet)	8.65	21.10
Volatile matter (%)	53.70	70.20
Fixed carbon (%)	15.40	7.72
GCV (MJ/kg)	20.12	16.89

3.3 Gasification Characteristics of MSW

Gasification characteristics of shredded MSW are summarized in Table 4 and compared with those of wood. Table 4 shows that percentage of carbon monoxide for MSW in the product gas is highest when gas flow is low and it decreases as the gas flow rate is increased. However, for wood chips, CO content of the product gas first increases with the increase in gas flow and then slightly decreases whilst the flow rate of the gas continue to increase which these changes were found to be not significant. These analyses results are obtained from 50 kWh pilot gasifier system.

Tar and particulate contents of the product gas from the gasifier exit were found to be between 4.55 and 5.75 g/m^3 for MSW. While for wood chips, tar content of the product gas was between 1.44 and 1.92 g/m^3. Net energy output varied from 0.62 to 0.76 kWe per kg of MSW and from 0.45 to 0.56 kWe per kg of wood chips. Both hot gas and cold gas efficiencies were in the range of 45 and 75%.

4 Large-Scale (1MWh) RDF Gasification Trials

The scaled-up version of the gasifier system (1 MWh) has been built by Beltran Technologies, Inc., in South Korea under the under a collaboration with Korean Environmental Cooperation (Keco).

The gasifier plant is commissioned in May 2015 and will be fully operational from December 2015 (see Fig. 3). Due to commercially confidentiality agreement, the design details will not be given in this article, but the commissioning results will be presented in this study.

The gasifier system is designed for any type of solid biomass and in particular shredded RDF. The commissioning of the plant is performed utilizing locally available RDF in Korea in a remote location. The analysis of Korean RDF is given in Table 5. As clearly seen from Tables 3 and 5, characteristics of the utilized

Table 4 Product dry gas composition at different feed flow rates for MSW and wood chips

	MSW	MSW	MSW	Wood	Wood	Wood
% ↓/flow rate (Nm^3/h) →	7.38	10.44	13.41	7.38	10.44	13.41
H_2	15.60	16.28	14.00	17.46	17.24	16.75
N_2	51.60	52.12	53.57	50.40	50.22	51.01
CH_4	1.98	1.93	1.80	2.04	2.21	2.13
CO	15.30	14.17	13.82	16.30	17.09	16.38
CO_2	14.90	15.03	16.17	13.20	12.54	13.09
C_2H_4	0.52	0.36	0.45	0.47	0.53	0.48
C_3H_4	0.10	0.11	0.19	0.13	0.17	0.16
CV (MJ/m^3)	5.02	4.82	4.60	5.37	5.60	5.37

Fig. 3 1 MWh RDF Beltran gasifier system in Korea showing the color of the flame at the flare stack during the commissioning operation

Table 5 Physical and chemical properties (proximate, ultimate, and calorific analyses) of Korean RDF

	RDF
Abs. density (kg/m^3)	1099.00
Bulk density (kg/m^3)	37.50
C (%)	50.01
H (%)	6.17
O (%)	23.54
N (%)	1.73
S (%)	0.45
Ash (%)	18.10
Moisture (%, wet)	4.00
Volatile matter (%)	67.90
Fixed Carbon (%)	10.00
GCV (MJ/kg)	21.05

MSW are found to be similar although MSW is known as very heterogeneous waste and high plastic in Korea.

Therefore, it is evident that utilized feedstock in both cases is similar, but the differences are the design and the scale which experimental gasifier design in Newcastle University was a downdraft and scale was 50 kWh output, whereas Beltran gasifier system is updraft and the scale was 1000 kWe output. This represents 20 times scale-up in terms of output power.

During the large-scale updraft gasifier operation, gas analysis is taken and analyzed independently. The analyses results are given in Table 6. The cleaned and cooled gasifier-produced gas is then utilized in internal combustion gas engines. The three engines designed for total 1500 kWh (1 MWh) output rated for natural gas (see Fig. 3). Due to low calorific value of the gasifier syngas (GCV = 7.54 MJ/m^3),

Table 6 Produced syngas composition for large-scale RDF gasification

	MSW
% ↓/flow rate (Nm^3/h) →	2250
H_2	9.20
N_2	63.23
CH_4	8.75
CO	8.50
CO_2	7.50
C_2H_4	1.57
C_3H_4	1.25
CV (MJ/m^3)	7.54

engines were down-rated by about 40% and produced approximately 1000 kWe output using 2250 Nm^3/h product gas at 40 °C.

It is obvious that the produced gasifier gas characteristics and calorific value of the gas are shown in Tables 4 and 6, and results are the evidence of the correct modeling of design scale-up of the gasifier system from 50 to 1000 kWe. Slightly higher calorific value obtained from Korean RDF large-scale gasifier than from the pilot MSW gasifier in Newcastle (UK) is the result of high plastic content of RDF in Korea.

5 Conclusion

(1) So far from the commissioning trials, it is concluded that gasification of MSW derived RDF for power production is feasible using small to large-scale (50 to 1000 kWe) specially designed fixed-bed gasifier with a well-designed char removal system and a good air distribution in the reactor bed for achieving high temperatures.
(2) Both experiments in small and large gasifiers showed that the heating value of the product gas is around 5–7 MJ/m^3.
(3) The product gas quality is found to be suitable for internal combustion gas engine for power and heat production.
(4) Gas conditioning system has been proved to be successful in order to obtain clean syngas for stable engine operation.
(5) It is proved that the correct scale-up modeling for gasifier and gas treatment design is achieved.

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Intensification of Bio-oil Yield from Waste Banana Pseudo-Stems—Experimental Studies on Catalytic Pyrolysis

S. Das, S. Ghosh and Ranjana Chowdhury

Abstract Regular generation of huge amount of solid wastes from various origin and the difficulties in obtaining a feasible management measure is a persisting problem faced by the societies of all countries. Thermochemical conversion, particularly through pyrolysis, of the abundant solid wastes to renewable energy resources and other value-added products is a sensible solution of this problem which can be adapted globally. In the present research work, non-edible parts of waste pseudo-stems of banana (Musa sp.) have been selected as the lignocellulosic feedstock for pyrolysis and its conversion to bio-oil, pyro-char and pyro-gas has been studied using temperature as a parameter. Initially, pyrolysis of raw and untreated banana pseudo-stems (BPS) has been conducted in a 50-mm-diameter and 164-mm-long semi-batch pyrolyzer under non-isothermal conditions in the temperature range of 673–1173 K. Five metal-based catalysts namely alumina, zinc oxide, sodium chloride, potassium chloride, and sodium aluminosilicate have been used to comparatively assess the enhancing effect of the catalysts on the product yields, particularly on the bio-oil yield. Pattern of the yields of bio-oil from non-catalytic and catalytic pyrolysis under same temperature range has been compared. Among the five catalysts, maximum bio-oil yield of 50 wt% at 873 K was obtained using potassium chloride (KCl). Hence, KCl is the best performing catalyst among all the other catalysts for bio-oil production using BPS. The lumped kinetic parameters for both non-catalytic and catalytic pyrolysis of BPS have been determined in the temperature range of 673–1173 K. The kinetics indicated that the weight loss increases with the increase in pyrolysis temperature due to the increased rate of pyrolysis for all experimental runs. Based on the current experimental findings, it has been recommended that lignocellulosic solid wastes can serve as excellent feedstocks for enhanced production of bio-oil through catalytic pyrolysis.

Keywords Lignocellulosic solid waste · Banana pseudo-stem · Catalytic pyrolysis
Bio-oil yield

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1 Introduction

Generation of huge amounts of lignocellulosic biomass waste from the agro, agro-food and municipal sectors is a regular activity of all countries worldwide and constitutes the major fraction of global solid waste [1, 2]. Many of these wastes create environmental pollution upon their generation either directly or indirectly and needs proper handling to keep the pollution from crossing permissible limits. Thermochemical conversion namely gasification and pyrolysis of the abundant lignocellulosic wastes to renewable energy resources (syngas, bio-oil) and other valuable by products is practiced globally as convenient methods of solid waste management [1, 3].

In India, several types of lignocellulosic wastes including grain husks, straws, press cakes, vegetable residues, fruit peel and shells are generated in copious amounts from the agro and agro-food processing industries and often face proper disposal problems. Many of these wastes can serve as excellent local feedstocks for gasification and pyrolysis and successfully used in several studies for generation of syngas, bio-oil and bio-char [4–11]. Recently, strategies like co-pyrolysis of mixed lignocellulosic feedstocks and use of catalysts in the pyrolysis process are being investigated for enhancement of the better conversion, product yields and energy saving [12, 13].

Under the present research study, non-edible fraction of waste banana pseudo-stems (BPS) has been selected as lignocellulosic feedstock for the production of bio-oil through pyrolysis. The catalytic effects of five metal-based catalysts namely alumina, zinc oxide, sodium chloride, potassium chloride, and sodium aluminosilicate on pyrolysis of BPS under non-isothermal conditions in the temperature range of 673–1173 K have been investigated. The catalysts have been chosen on the basis of their catalytic activity on pyrolysis of different biomass investigated by previous researchers [14–16]. Although BPS has been used as a feedstock for pyrolysis by some researchers [17, 18], to the best of our knowledge, this is the first research study conducted on the catalytic pyrolysis of BPS to investigate its effect on the bio-oil production. Particular attention has been given to the enhancement of bio-oil yield from BPS in the catalytic pyrolysis than that obtained from the non-catalytic pyrolysis. Lumped kinetic parameters have been determined for all catalysts used and compared with those of non-catalytic pyrolysis in the temperature range of 673–1173 K. Each catalyst resulted in different trends of bio-oil, bio-char and pyro-gas yield for all temperatures. The best performing catalyst with respect to bio-oil yield has been found to be KCl, which yielded 50 wt % bio-oil at 873 K. The kinetics indicated a direct correlation between the weight loss and pyrolysis temperature. Due to the increased rate of pyrolysis, the weight loss increased with the increase in pyrolysis temperature for all experimental runs.

2 Materials and Methods

2.1 Feedstock

The BPS used for the catalytic and non-catalytic pyrolysis has been collected from the local market near Jadavpur University. The BPS has been sun dried first and then oven-dried at 60 °C to remove the moisture. Size of the BPS has been adjusted to 10–20 mm by milling before being charged to the pyrolyzer. The results of proximate and elemental analyses of BPS are shown along with higher heating value in Table 1.

2.2 Catalysts

Five metal-based catalysts have been chosen based on our previous study [13] and used in catalytic pyrolysis of BPS. The catalysts used were aluminium oxide [Al_2O_3], zinc oxide [ZnO], sodium chloride [NaCl], potassium chloride [KCl] and sodium aluminosilicate [$NaAl(SiO_3)_2$]. All catalysts have been procured from Merck, India. The particle diameter of all catalysts was approximately 0.087 mm and all the catalysts were calcined for 2 h at 120 °C prior to their use in the pyrolysis process [13].

Table 1 Calculated activation energies and frequency factors as per Arrhenius Law

Type of feedstock	Reaction rate constant	Activation energy (kJ/mol)	Frequency factor (1/min)
Non-catalytically pyrolysed BPS	k k_v k_c	0.10499 0.113223 0.017573	3.502023 6.541871 0.594858
BPS + Al_2O_3	k k_v k_c	0.22135 0.18506 0.04791	8.30801392 10.1505626 4.83633694
BPS + KCl	k k_v k_c	0.125281 0.105981 0.032726	4.205055 6.190022 1.949966
BPS + NaCl	k k_v k_c	0.182501 0.117796 0.035668	7.583116 7.722542 2.79683
BPS + ZnO	k k_v k_c	0.255738 0.21797 0.246424	8.683973 10.86058 15.44907
BPS + NaAl $(SiO_3)_2$	k k_v k_c	0.082695 0.072093 0.026772	0.654553 2.651168 0.515135

2.3 Pyrolysis

The pyrolysis experiments have been conducted in a 50-mm-diameter and 640-mm-long semi-batch fixed-bed pyrolyzer isothermally, as described in our previous research reports [12]. Both catalytic and non-catalytic pyrolysis experiments have been conducted isothermally in an inert atmosphere created by N_2 purging. All experiments have been performed in the temperature range of 673–1173 K for 1 h. The bio-oil has been collected by passing the volatiles coming out of the pyrolyzer through a series of condensation units. The change in weight loss of solid residue in the pyrolyzer was recorded continuously using the electronic balance attached with the pyrolyzer set-up and collected as bio-char after completion of the process. The non-condensable fraction was collected as the pyro-gas in a sampling bottle.

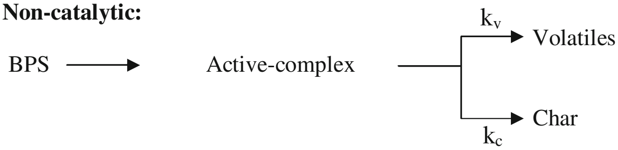
2.4 Theoretical Analysis

During pyrolysis, the lignocellulosic BPS proceeds through a series of complex reactions, either in series, parallel or combination of both. Various intermediates have been formed during the complex reactions forming bio-oil as the main liquid product and solid pyro-char and the pyro-gas as the by-products. A simple model proposed by Bandyopadhay et al. [7] considering occurrence of two parallel reactions producing two lumped products namely condensable volatile and solid char has been used here. The rate of active complex formation has been assumed to be instantaneous [16].

2.4.1 Lumped Kinetics of Primary Pyrolysis

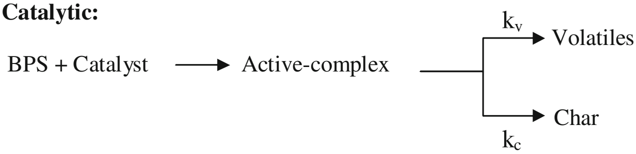
According to the model proposed by Bandyopadhay et al. [7], the reaction scheme for non-catalytic and catalytic pyrolysis of BPS may be described as following:

Non-catalytic:



(1)

Catalytic:



(2)

The weight loss profile of the solid reactant W with time is given by:

$$-\frac{\mathrm{d}W}{\mathrm{d}t} = (k_v + k_c)W \tag{3}$$

Let $k_v + k_c = k$
Therefore,

$$-\frac{\mathrm{d}W}{\mathrm{d}t} = kW \tag{4}$$

The profile of increase of weight of volatiles with time is given by the expression below:

$$\frac{\mathrm{d}Wv}{\mathrm{d}t} = k_v W = k_v W_0 \exp(-kt) \tag{5}$$

The profile of increase of weight of char with time is given by the expression below:

$$\frac{\mathrm{d}W_c}{\mathrm{d}t} = k_c W = k_c W_0 \exp(-kt) \tag{6}$$

Equations (3)–(5) have been solved analytically with the following initial conditions:

$$W(t \to 0) = W_0, W_v(t \to 0) = W_{v0}, W_c(t \to 0) = W_{c0} \tag{7}$$

The solutions under isothermal conditions are as follows:

$$W(t) = W_0 \exp(-kt) \tag{8}$$

$$W_v(t) - W_{v0} = \left(\frac{k_v}{k}\right) W_0 \left[1 - \exp(-kt)\right] \tag{9}$$

$$W_c(t) - W_{c0} = \left(\frac{k_c}{k}\right) W_0 [1 - \exp(-kt)] \tag{10}$$

Under isothermal condition:

$$\frac{W_c(t) - W_{c0}}{W_v(t) - W_{v0}} = \frac{k_c W}{k_v W} = \frac{k_c}{k_v} = \frac{W_c(t \to \infty) - W_{c0}}{W_v(t \to \infty) - W_{v0}} \tag{11}$$

Assuming that at any temperature above 633 K the ultimate residue $(t \to \infty)$ is entirely constituted of char, we can write,

$$W_c(t \to \infty) = W_R(t \to \infty), W_v(t \to \infty) = W_0 - W_R(t \to \infty) \quad (12)$$

Therefore:

$$\frac{W_c(t) - W_{c0}}{W_v(t) - W_{v0}} = \frac{W_R(t \to \infty) - W_{c0}}{W_0 - W_R(t \to \infty)} \text{ Or, } W_c(t) - W_{c0} = \frac{W_R(t \to \infty) - W_{c0}}{W_0 - W_R(t \to \infty)} * (W_v(t) - W_{v0}) \quad (13)$$

At any time t, the weight of the unreacted reactant is given by:

$$W(t) = W_0 - (W_v(t) - W_{v0}) * \left[1 + \frac{W_R(t \to \infty) - W_{c0}}{W_0 - W_R(t \to \infty)}\right] \quad (14)$$

Regression analysis of Eqs. (8)–(10) gives the values of the rate constants k, k_v, k_c, respectively, at different temperatures. Kinetic parameters have been determined for the catalytic and non-catalytic pyrolysis of BPS.

3 Results and Discussion

3.1 Weight Loss Characteristics of BPS in Non-catalytic and Catalytic Pyrolysis

The weight of the unreacted reactant at any time and at any temperature has been calculated by weighing the condensable part of the volatile obtained from the experiment. The amount of residue has been calculated using Eq. (14). For non-catalytic pyrolysis of BPS, the percentage (%) of weight residue had been plotted against time (Fig. 1) in the temperature range of 673–1173 K.

From Fig. 1, it is observed that there is a gradual weight loss of the BPS as it is pyrolysed to produce volatiles and char with the increase in temperature over a time

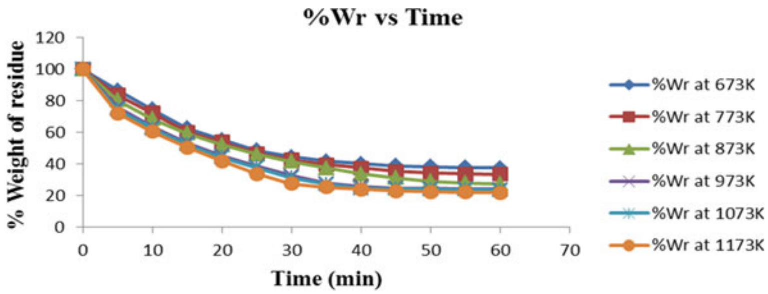


Fig. 1 Comparative curve of % Wt residue versus time in non-catalytic pyrolysis of BPS

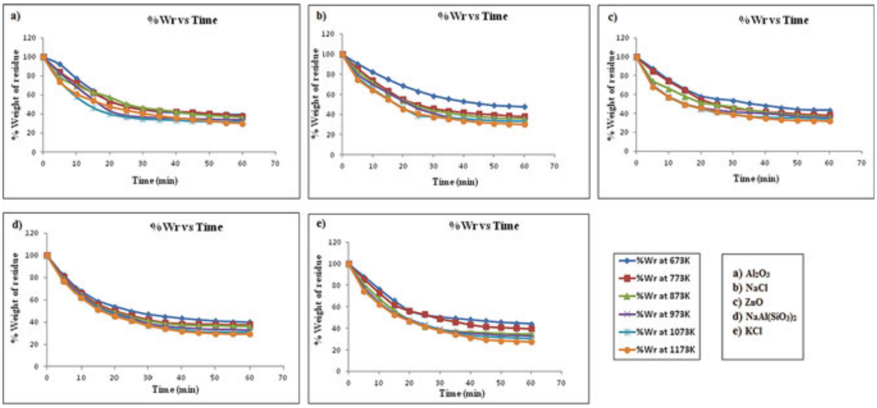


Fig. 2 Comparative curves of % Wt residue versus time in catalytic pyrolysis of BPS

period of 1 h. In each run, the weight loss is increasing with the increase in pyrolysis temperature due to the increased rate of pyrolysis.

BPS is pyrolysed with five different catalysts namely potassium chloride [KCl], zinc oxide [ZnO], sodium chloride [NaCl], alumina [Al_2O_3] and sodium aluminosilicate [$NaAl(SiO_3)_2$], and the amount of residue is calculated again using Eq. (14).

The percentage (%) of weight residue is plotted against time (Fig. 2) in the temperature range of 673–1173 K for all the different catalysts, respectively. From Fig. 2a–e, it can be observed that there is a gradual weight loss of the catalytically treated BPS as it is pyrolysed to produce volatiles and char with the increase in temperature over a time period of 1 h. At each time, the weight loss is increasing with the increase in pyrolysis temperature due to the increase of rate of pyrolysis. Among all catalytically treated BPS, it is observed that the greatest weight loss took place for the BPS treated with catalyst KCl. Hence, it is evident that KCl is more effective than the other catalysts, increasing the rate of pyrolysis the most.

3.2 Lumped Kinetics for Pyrolysis of Untreated and Catalytically Treated BPS

The primary kinetics for the non-catalytically and catalytically treated BPS is calculated. For calculating the values, the rate constants k, k_v and k_c are plotted in the logarithmic scale against reciprocal of temperature as per the Arrhenius Law using the activation energies and frequency factors reported in Table 1. All the rate constants are calculated from the experimental results in the temperature range of 673–1173 K and are superimposed with the predicted rate constants (data not shown).

From Table 1, a comparative analysis of the kinetic parameter, activation energy for the different pyrolysis reactions for untreated and catalytically treated BPS is done. It is observed that the activation energy is the greatest for the pyrolysis reaction of BPS treated with ZnO. On the other hand, the activation energies are less for the pyrolysis reactions for both KCl and $NaAl(SiO_3)_2$-treated BPS. KCl also acts as the most effective catalyst for the pyrolysis of BPS under the presently studied temperature range.

3.3 *Bio-oil Yields from Pyrolysis of BPS Using Different Catalysts*

The various bio-oil yields from catalytically pyrolysed BPS are plotted against varying temperatures from 673–1173 K. The five different catalysts used for the experiments resulted in different trends of bio-oil yield. The bio-oil yield obtained from non-catalytic pyrolysis of BPS at same temperature range has been plotted along with the yields of catalytic pyrolysis for comparative assessment of the enhancement.

Figure 3 shows the trends of bio-oil yield obtained from BPS using potassium chloride [KCl], zinc oxide [ZnO], sodium chloride [NaCl], alumina [Al_2O_3] and sodium aluminosilicate [$NaAl(SiO_3)_2$]. Most of the catalysts enhanced bio-oil yields in comparison to the yields obtained from non-catalytic pyrolysis of BPS, especially at elevated temperatures. From Fig. 3, the trends of bio-oil yield from pyrolysis of BPS treated with five different catalysts are compared at different pyrolysis temperature. From the figure, it is also observed that the maximum bio-oil yield is obtained from the pyrolysis of BPS treated with catalyst potassium chloride (KCl), its bio-oil yield being 50 wt% at 873 K.

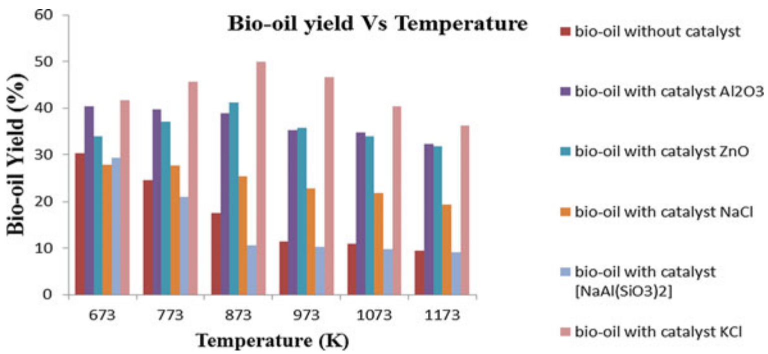


Fig. 3 Bio-oil yields (%) obtained from catalytically pyrolysed BPS at different temperatures (K)

4 Conclusion

From the findings of the experimental studies, it can be inferred that BPS can serve as an excellent low cost and abundantly available lignocellulosic feedstock for production of bio-oil through pyrolysis. Using suitable catalysts in the pyrolysis of BPS was found to be enhancing regarding the bio-oil yield. Comparison of the catalytic effects of five metal-based catalysts namely aluminium oxide [Al_2O_3], zinc oxide [ZnO], sodium chloride [NaCl], potassium chloride [KCl] and sodium aluminosilicate [$NaAl(SiO_3)_2$] on pyrolysis of BPS under non-isothermal conditions in the temperature range of 673–1173 K has been assessed. From the comparison of bio-oil yields obtained, it was observed that the best performing catalyst with respect to bio-oil yield is KCl, which resulted in production of 50 wt% bio-oil at 873 K. Hence, KCl is recommended as the most suitable catalyst for bio-oil production when BPS is used as the lignocellulosic feedstock. The use of catalysts in pyrolysis may also have enhancing effect on the biochemical composition of the bio-oil, particularly on the lowering of the high oxygen content, which is a lingering problem. Systematic studies on this aspect are currently underway in our laboratory.

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Part XIII
C&D Waste Management

Recycling of Ceramic Dust Waste in Ceramic Tiles Manufacture

Sh. K. Amin, S. A. El Sherbiny, D. A. Nagi, H. A. Sibak and M. F. Abadir

Abstract This research aims to accomplish improvements in the technical process of the ceramic manufacture of wall and floor tiles, by using the ceramic powder waste produces from the cyclone which follows the spray drier in the manufacturing process of ceramic tiles, so it is the same composition of the manufactured ceramic floor and wall tiles powder, but a finer grade, which results in saving an amount of the raw materials that are used in wall and floor tiles manufacture, and will lower in energy needs, since in the firing process the tiles will be fired at lower firing temperatures than used industrial which are 1050 °C for wall tiles and 1150 °C for floor tiles. Mixtures were prepared by substituting manufacturing powder with the powder waste as 0, 10, 20, 30, 40, 50 wt%; powder is uniaxially pressed at almost 25 MPa yielding in a rectangular-shaped tile with average dimensions of $110 \times 55 \times 6.8$ mm^3. The pressed tiles entered a dryer of 70 °C temperature. Tiles are fired at three temperatures, and wall tiles samples are fired at temperatures of 1000, 1050, and 1100 °C, while floor tiles samples are fired at temperatures of 1050, 1100, 1150 °C. After the experimental tests on powders, green and fired tiles, results show that the optimum percentages of wall and floor wastes' replacement with its firing temperatures of the formed tiles, that could be recycled and satisfied to the international quality standards, are 25% wall powder waste replacement in wall mix with firing temperature of 1000 °C for tiles water absorption ($E > 10\%$), 20% floor powder waste replacement in floor mix with firing temperature of 1050 °C for tiles water absorption ($E > 10\%$), and 40% floor tiles waste replacement in floor mix with firing temperature of 1100 °C for tiles water absorption ($6\% < E < 10\%$).

Keywords Ceramic dust waste · Ceramic tiles industry · Ceramic tiles standards

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1 Introduction

The ceramic tiles industry is a dynamic sector whose market is growing worldwide, and it is impacted by the need for the availability of the raw materials and the high energy costs; a great quantity of fuel is consumed in the manufacturing process mainly in the firing stage [11]. The main raw materials for the ceramic tile industry are clay, quartz, and feldspar, but recently due to the flexibility of the manufacture cycle, a range of wastes are incorporated in the manufacture of ceramic wall and floor tiles. Blast furnace slag, by-product of steel production, can be used for ceramic wall tile [14]. The sugarcane bagasse ash, generated from sugarcane industry, is used for ceramic floor tile [16], and the glass powder waste, collected from waste broken bottles, is used in ceramic wall and floor tiles [13].

This research aims to accomplish improvements in the technical process of the ceramic manufacture of wall and floor tiles, by using the ceramic powder waste produced from the cyclone which follows the spray drier in the manufacturing process of ceramic tiles, so it is the same composition of the manufactured ceramic floor and wall tiles powder, but a finer grade, which results in savings in the raw materials used in wall and floor tiles manufacture, and will lower in energy needs.

2 Materials and Methods

2.1 Raw Materials' Characterization

These consisted two components: First, the raw mix used to manufacture ceramic wall and floor tile bodies, which was prepared from Egyptian raw materials (kindly supplied by Ceramica Royal Company located in a Cairo suburb). Its composition is displayed in Table 1, as stated by the supplying company. The second is the ceramic powder waste produced from the cyclone which follows the spray drier in the manufacturing process of ceramic tiles.

The chemical composition of both materials was determined using X-ray fluorescence technique type Axios, panalytical 2005, wavelength dispersive (WD-XRF) sequential spectrometer.

Table 1 Raw mix tiles body composition

Percent	Kaolin	Ball clay	Bentonite	Feldspar	Sand	Limestone	Talc
Wall tile mix	25	35	2	14	15	9	–
Floor tile mix	25	35	–	28	10	–	2

On the other hand, the mineralogical composition was assessed using X-ray diffraction Brukur D_8 Advanced Computerized X-ray Diffractometer apparatus with mono-chromatized Cu K_α radiation, operated at 40 kV and 40 mA.

Thermal analysis (DTA-TGA) was performed on both materials using Netzsch STA 409 C/CD apparatus at a heating rate of 10 °C/min. Runs were performed in air.

The particle size distribution (PSD) of a granular material (wall and floor mixes) was determined according to the standard sieving procedure described by ASTM D 422 [3]. Alternatively, the waste fineness was investigated through BT–2001 Laser Particle Size Analyzer, which is conforming to ISO 13320 [8].

Finally, the powder densities of basic mixture of wall and floor tiles (raw mixes) and ceramic powder waste were measured using the standard pycnometer method (density flask). This method is a very precise procedure for determining the density of powders, granules, and dispersions that have poor flowability characteristics [5].

2.2 Samples Preparation

The ceramic powder waste was blended in different proportions (from 0 up to 50% by weight) with basic mixture powder of wall and floor tiles in a laboratory horizontal tumbler for two hours. The plasticity of the different blends was determined using the Pfefferkorn method [4].

Rectangular tile specimens of approximate dimensions 110.4 × 55.4 × 8 mm^3 were then molded using the blend by dry pressing using the automatically laboratory hydraulic press under uniaxial pressure of 25 MPa and 5–7% water. Tile specimens were then dried on a laboratory dryer for 24 h at 110 ± 5 °C.

The following properties of green dried samples were determined: Linear drying shrinkage [1], green breaking strength, and green modulus of rupture [6]. Each sample consisted of three specimens and the average value was taken.

The dried samples were then fired in a laboratory muffle furnace at three different temperatures, following a programmed schedule that takes into account the evolution water from the dehydroxylation of kaolinite by fixing the temperature at 750 °C for 30 min. The maximum temperatures attained varied from 1000, 1050, and 1100 °C for wall tiles, while at 1050, 1100, and 1150 °C for floor tiles, with a soaking time of 15 min to simulate fast firing conditions.

The following tests were performed to determine the characteristics of fired samples: percent linear firing shrinkage [1], percent water absorption and apparent porosity [2], breaking strength and modulus of rupture [6]. SEM was also used to provide micrographs of some chosen sections. The used SEM apparatus was of type JEOL-JSM 6510 apparatus with maximum zoom magnification power = 300,000x.

3 Results and Discussion

3.1 Raw Materials' Characterization

3.1.1 Chemical Analysis of Raw Materials

Table 2 shows the chemical analysis of raw materials. It can be noted that the loss on ignition is mainly due to loss of the chemical water of clays, carbon dioxide from limestone, and organic matter content. It is also higher in case of wall tile mix than floor tile since the former contains limestone while most of the L.O.I of the latter is due to loss of water of hydration in clays.

Table 2 Chemical analysis of raw materials

Constituents, wt. (%)	Wall mix	Wall dust	Floor mix	Floor dust
SiO_2	55.18	61.29	58.53	61.13
Al_2O_3	19.24	14.67	22.97	20.82
$Fe_2O_3^{tot.}$	3.03	2.80	3.68	3.66
TiO_2	0.92	0.74	1.06	0.98
MgO	0.41	0.32	1.40	1.37
CaO	7.88	8.26	1.34	1.40
Na_2O	1.41	1.60	2.59	2.96
K_2O	1.81	2.14	1.37	1.52
P_2O_5	0.16	0.14	0.21	0.20
SO_3	0.43	0.44	0.41	0.40
Cr_2O_3	0.014	0.016	0.023	0.023
MnO	0.019	0.023	0.027	0.031
ZrO_2	0.072	0.044	0.056	0.048
ZnO	0.018	0.025	0.018	0.050
NiO	0.007	0.007	0.012	0.016
CuO	0.007	0.007	0.009	0.009
Ga_2O_3	0.005	0.004	0.007	0.005
Nb_2O_5	0.002	0.003	0.004	0.003
Rb_2O	0.009	0.010	0.007	0.007
SrO	0.021	0.017	0.022	0.020
Y_2O_3	0.003	0.003	–	–
Cl	0.06	0.07	0.07	0.08
L.O.I	9.29	7.37	6.18	5.26
Total	99.997	99.999	99.995	99.992

3.1.2 Mineralogical Analysis of Raw Materials

Figure 1 shows the mineralogical analyses of all four raw materials (wall mix, wall dust waste, floor mix, and floor dust waste), whereas wall mix and dust main phase presence is quartz, while floor mix and dust main phases noticed are quartz and albite.

3.1.3 Thermal Analysis of Raw Materials

Combined TGA-DTA charts of all four raw materials (wall mix, wall dust waste, floor mix, and floor dust waste) are shown in Fig. 2. It appears from the charts that there is a slight early decrease in weight due to elimination of physical water followed by a small exothermic peak at about 425 °C due to oxidation of organic impurities. An endothermic peak follows at about 485 °C that extends to some extent in case of floor tiles. This is presumably due to loss of lattice water of clays present in the mixes that is practically completed at about 650 °C. In case of wall tiles and owing to the presence of limestone, a supplementary peak can be observed at about 720 °C.

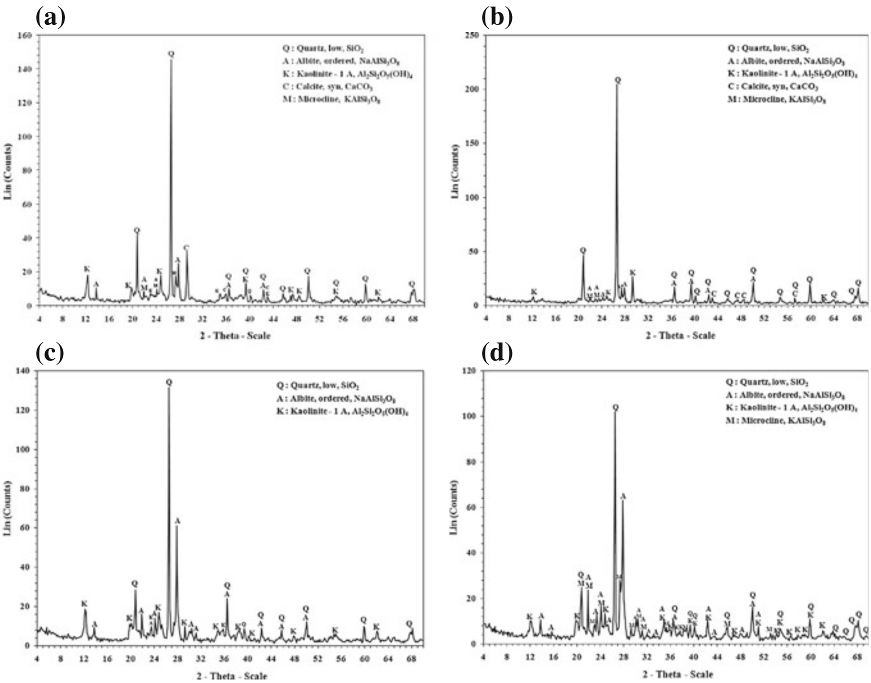


Fig. 1 XRD pattern of raw materials, **a** wall mix, **b** wall dust waste, **c** floor mix, and **d** floor dust waste

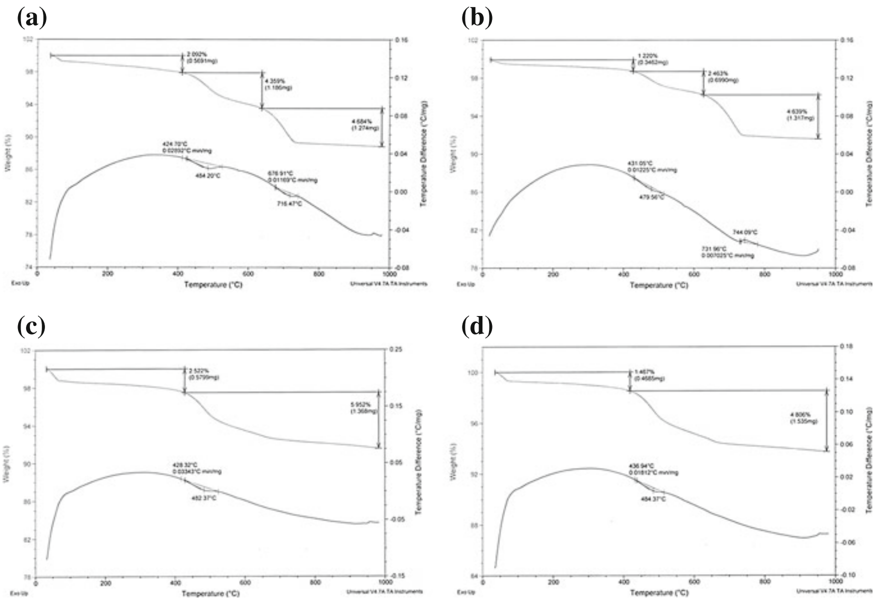


Fig. 2 DTA and TGA pattern of raw materials, **a** wall mix, **b** wall dust waste, **c** floor mix, and **d** floor dust waste

3.1.4 Screen Analysis of Raw Materials

Figure 3a shows the cumulative screen analysis of wall and floor mixes, which determined using several sieves according to ASTM D 422 [3]. On the other hand, Fig. 3b shows the cumulative screen analysis of wall and floor dust wastes, which determined using BT–2001 Laser Particle Size Analyzer, which is conforming to

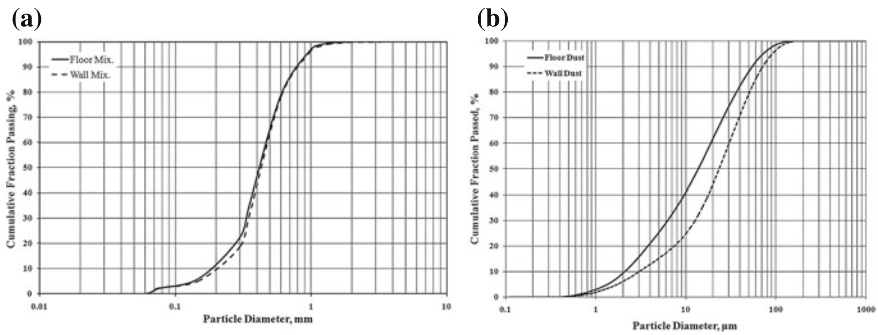


Fig. 3 Cumulative particle size distribution of raw materials, **a** wall and floor mixes, and **b** wall and floor dust wastes

ISO 13320 [8]. The vertical axis represents the fraction retained on each particular screen diameter. This figure shows that the two wastes are very fine.

Sauter mean diameter (SMD) is an average particle size for a mixture of particles. It was originally developed by German scientist J. Sauter in the late 1920s. It is defined as the diameter of a sphere that has the same volume–surface area ratio as a particle of interest. Several methods have been devised to obtain a good estimate of the SMD. Probably, the most used is the volume–surface mean diameter $(\overline{D_s})$, which is related to the specific surface area (A_w). It is defined by the following equation [10]:

$$\overline{D_s} = \frac{1}{\sum_{i=1}^{n} \frac{X_i}{\overline{D_{Pi}}}} \tag{1}$$

where

X_i is the differential fraction retained between two sieves (i) and ($i - 1$),

$\overline{D_{Pi}}$ is the average particle diameter, or the mean nominal screen opening between these two sieves (i) and ($i - 1$).

Table 3 shows both of the volume–surface mean diameter $(\overline{D_s})$ and D_{50} values for all four powders.

3.1.5 Powder Density of Raw Materials

Table 4 displays the powder density of the materials used in this work. It appears that wall and floor raw mix densities are lower than the wall and floor dust waste, so it is expected adding the waste to the raw mix will increase the densities.

Table 3 Volume–surface mean diameter $(\overline{D_s})$ and (D_{50}) values of raw materials

Powder	Wall mix	Floor mix	Wall dust	Floor dust
D_{50} µm	420	410	23.35	13.72
$\overline{D_s}$ µm	355	338	7.91	5.392

Table 4 Powder density of raw materials

Raw material	Powder density (gm/cm^3)
Wall mix	2.28
Wall dust waste	2.57
Floor mix	2.23
Floor dust waste	2.37

3.2 *Unfired Mixes' Characteristics*

3.2.1 Effect of Waste Replacement on Plasticity of Mixes

The plasticity of the mixed powders of the tiles, which are prepared by substituting the raw mix with different waste proportions from 0 to 50 wt%, was determined using the Pfefferkorn apparatus [4]. The final results illustrating the effect of waste replacement on plasticity are shown in Fig. 4a. The results show that plasticity of wall tiles mixes generally increases while increasing waste replacement, while plasticity of floor tiles mixes shows practically no change on waste replacement.

3.2.2 Effect of Waste Replacement on Drying Shrinkage

The linear drying shrinkage for dry samples was determined according to ASTM C 326 [1]. The effect of waste replacement on the linear drying shrinkage of both wall and floor raw mix is shown in Fig. 4b. Since the percent water used is limited (5%), it is much lower than the critical moisture content of ceramic–water mixtures which

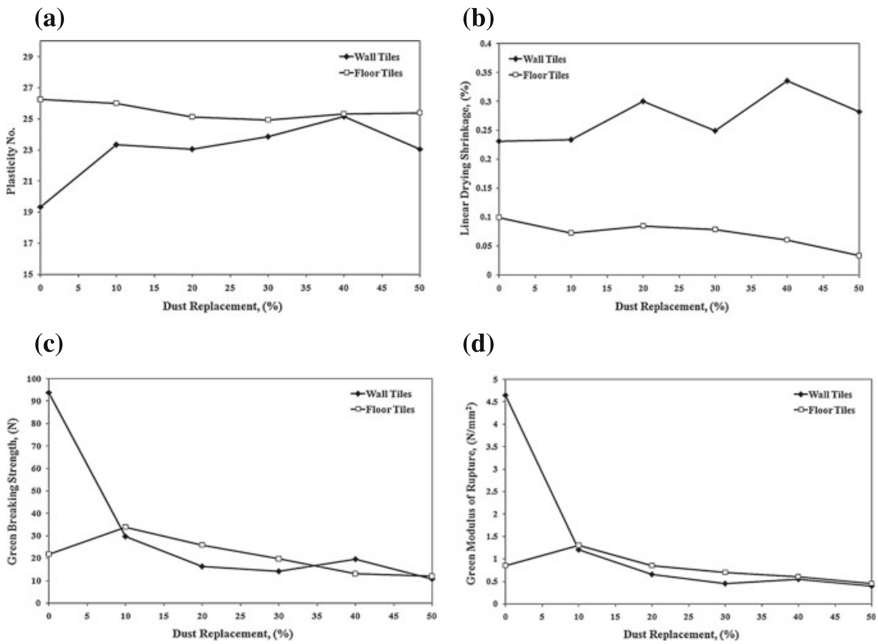


Fig. 4 Effect of percent dust replacement on unfired mixes' characteristics, **a** effect of percent dust replacement on plasticity number, **b** effect of percent dust replacement on linear drying shrinkage, **c** effect of percent dust replacement on green breaking strength, **d** effect of percent dust replacement on green modulus of rupture

usually ranges from 10 to 20%. That is why the measured values of linear drying shrinkage were insignificant for as much as 50% dust replacement [12].

3.2.3 Effect of Waste Replacement on Green Strength

The breaking strength and modulus of rupture of the resulting green bodies were determined according to ISO 10545–4 [6], in order to assess the possibility of proper handling of the green bodies prior to firing. The results in Fig. 4c, d show that wall dust waste replacement causes the breaking strength and modulus of rupture for green tiles to drop till 20% waste replacement then values stabilize, while adding floor dust shows slight increase in both properties till 10% waste replacement then a linear decrease until reaching 50%.

3.3 Fired Tile Samples Characteristics

3.3.1 Effect of Waste Replacement on Percent Linear Firing Shrinkage

Figure 5a displays the effect of waste replacement on linear firing shrinkage. While increasing the firing temperature had a predictable effect of increasing shrinkage, the effect of dust replacement was insignificant at all firing temperatures for floor tiles, while the waste replacement tends to reduce the firing shrinkage for wall tiles.

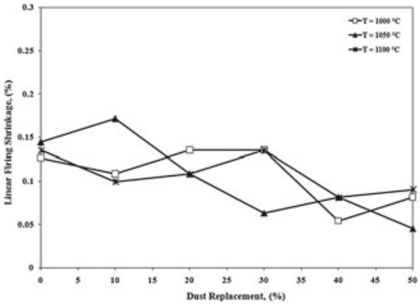
The main reason for shrinkage is the elevated amount of feldspar in the original mix which by lowering vitrification temperature enhances liquid-phase sintering [9]. As the percent dust replacement is increased, there is a subsequent decrease in raw mix meaningless feldspar. This could explain the decrease in shrinkage observed in all curves of wall tiles. It is to be noted that all samples resulted in fired tiles of thickness slightly lower than 7.5 mm.

3.3.2 Effect of Waste Replacement on Percent Water Absorption

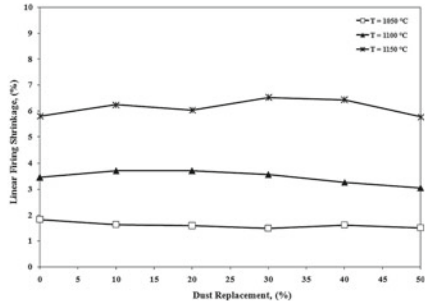
Water absorption is a main property to be reckoned with when characterizing ceramic tiles of any type. Its percent reveals the open porosity of the tile that reflects the degree of vitrification. According to the International Standard [7], ceramic tiles are classified as either having percent water absorption lying between 6 and 10% ($6\% < E \leq 10\%$), or higher than 10% ($E > 10\%$). Wall tiles usually lie in the latter category, but floor tiles can lie in either category.

As can be seen from Fig. 5b, it is clear that, for wall tiles, water absorption is affected by the presence of waste, and its values increase with increasing percent waste replacement. In this case, the main reason is the decomposition of limestone present in waste that opens up new pores in the fired bodies. For floor tiles, water

(a)

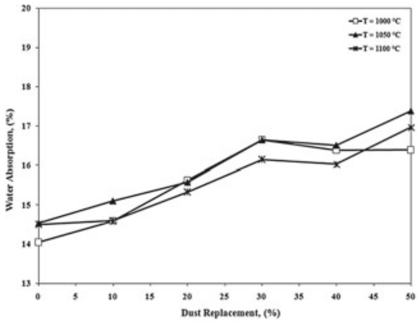


(a–1): Wall Tiles

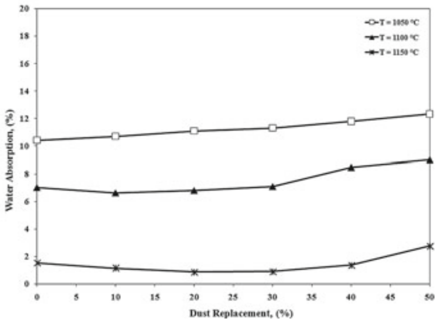


(a–2): Floor Tiles

(b)

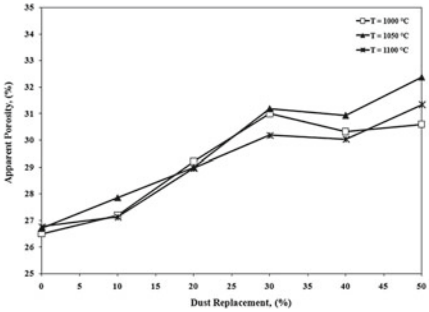


(b–1): Wall Tiles

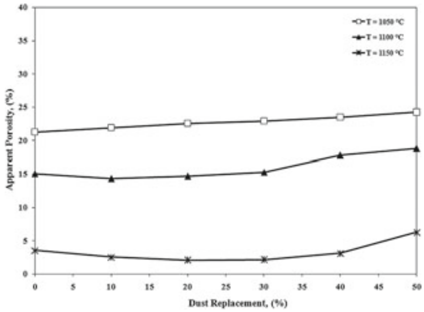


(b–2): Floor Tiles

(c)



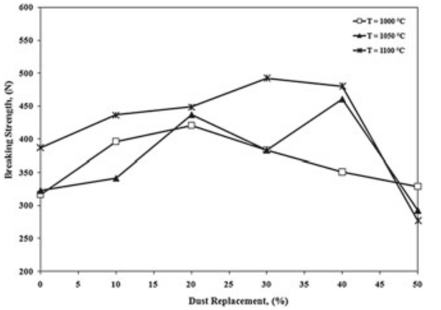
(c–1): Wall Tiles



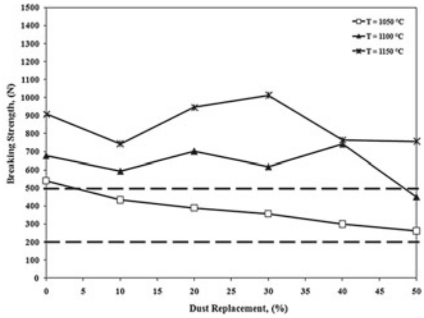
(c–2): Floor Tiles

Fig. 5 **a** Effect of percent dust replacement on linear firing shrinkage, **b** effect of percent dust replacement on percent water absorption, **c** effect of percent dust replacement on percent apparent porosity, **d** effect of percent dust replacement on breaking strength, **e** effect of percent dust replacement on modulus of rupture

(d)

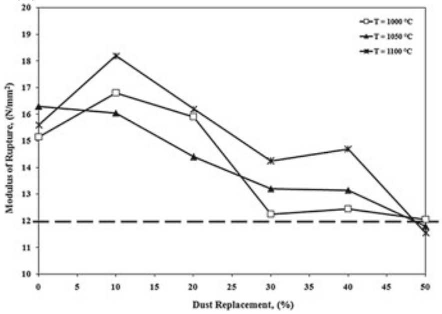


(d–1): Wall Tiles

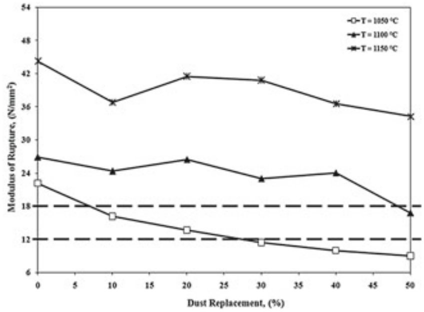


(d–2): Floor Tiles

(e)



(e–1): Wall Tiles



(e–2): Floor Tiles

Fig. 5 (continued)

absorption shows no significant change by the presence of waste, but increasing the firing temperature results in decreasing of the water absorption of the tiles.

To abide by ISO standard, for floor tiles, for water absorption <10%, it is necessary to fire at 1100 and 1150 °C with 50% waste replacement. And if the floor tiles are categorized as having water absorption >10%, then more waste can be replaced (up to 50%), and lower firing temperatures can be used (fired at 1050 °C). For wall tiles, all test samples are having water absorption more than 10%. So, more waste can be replaced (up to 50%) and lower firing temperatures can be used (fired at 1000 °C).

3.3.3 Effect of Waste Replacement on Percent Apparent Porosity

This property is not a standard requirement although it is indicative of the percent open pores and hence extent of vitrification in more direct way than water absorption, to which it is strongly related. The apparent porosity was followed as function of two parameters: percent waste replacement, and the firing temperature. Figure 5c shows the results obtained at 15-min soaking time.

This figure shows the same general trend observed in water absorption. That is, an increase in porosity with increased waste replacement and a decrease in porosity following an increase in firing temperature.

3.3.4 Effect of Waste Replacement on Mechanical Strength

According to the International Standard [7], the mechanical strength of ceramic tiles has to be formulated as two values: the breaking strength and the modulus of rupture (MOR). The minimum values of breaking strengths and MOR are related to the tile thickness as shown in Table 5.

The effect of waste replacement in wall and floor tiles mixes on mechanical properties was established as being one of the most important properties governing the viability of using the tiles. In this respect, the breaking strength and the modulus of rupture serve to assess the mechanical strength of the tile body. Other properties such as abrasion resistance and skid resistance are concerned with the finished glazed surface rather than the body are were not consequently considered in this work. Figure 5d, e illustrates the effect of firing temperature and percent waste replacement on both breaking strength and modulus of rupture, respectively.

Values of breaking strength and MOR displayed in the aforementioned figures show that:

- For wall tiles of thickness <7.5 mm and water absorption >10%, the minimum breaking strength of 200 N was achieved in all cases. Values of modulus of rupture are higher than the minimum standard values (12 MPa) in all cases containing less than 50% waste.
- For floor tiles of thickness <7.5 mm and water absorption >10%, the minimum breaking strength of 200 N was achieved in tiles firing at 1050 °C and containing up to 50% waste. Values of modulus of rupture are higher than the minimum standard values (12 MPa) in all tiles firing at 1050 °C and containing up to 20% waste.
- For floor tiles of thickness <7.5 mm and water absorption <10%, the minimum breaking strength of 500 N and minimum MOR of 18 MPa were achieved in tiles firing at 1100 and 1150 °C and containing less than 50% waste.

Table 5 Minimum permissible values for breaking strength and MOR

	Thickness < 7.5 mm		Thickness ≥ 7.5 mm	
	$6\% < E \leq 10\%$	$E > 10\%$	$6\% < E \leq 10\%$	$E > 10\%$
Breaking strength (N)	≥ 500	≥ 200	≥ 800	≥ 600
MOR, N/mm^2 (MPa)	Minimum 18	Minimum 12	Minimum 18	Minimum 15

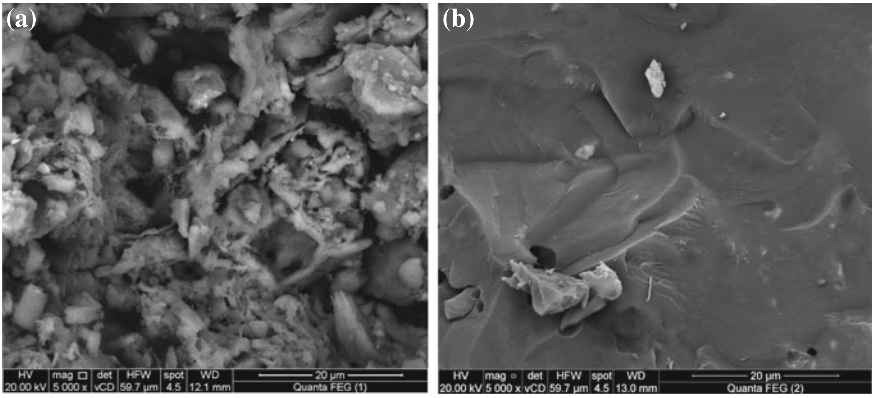


Fig. 6 SEM micrograph of firing samples (5000×), **a** wall Tiles containing 50% dust fired at 1050 °C, **b** floor tiles containing 20 % dust fired at 1150 °C

3.4 SEM Results for Fired Samples

In order to assess the previously obtained results, specimens were examined under the scanning electron microscope (SEM). The SEM micrographs at magnifying 5000× of the surface of a transversal section in a wall tile containing 50% dust fired at 1050 °C, and in a floor tile containing 20% dust fired at 1150 °C, are shown in Fig. 6. It indicates a clear reduction in porosity owing to the apparent glassy phase that has formed [15].

4 Conclusions

The ceramic dust waste produced from the cyclone which follows the spray drier in the manufacturing process of ceramic tiles was mixed with a standard mix of ceramic wall and floor tiles at different percentages reaching 50%, molded and pressed uniaxially at 25 MPa. Firing was performed for a soaking period of 15 min to simulate fast firing conditions. It was possible to obtain tiles of thickness less than 7.5 mm that abided by standards for 25% wall powder waste replacement in wall mix with firing temperature of 1000 °C for tiles water absorption ($E > 10\%$), 20% floor powder waste replacement in floor mix with firing temperature of 1050 °C for tiles water absorption ($E > 10\%$), and 40% floor tiles waste replacement in floor mix with firing temperature of 1100 °C for tiles water absorption ($6\% < E < 10\%$).

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An Assessment of C&D Waste Quality and Its Recycling Potential—An Indian Perspective

Vidyadhar V. Gedam, Pawan Labhasetwar and Christian J. Engelsen

Abstract The present research work evaluates physico-chemical, mineralogical and mechanical characterizations of Construction–Demolition (C&D) waste so that basic and relevant information about nature of C&D waste can be determined. The comprehensive characterization of C&D waste collected from two waste generation sites in India were carried out. The material analysed has different compositions and was selected with a view to determine their suitability for concrete industry as Recycled Aggregates (RA) and for further research studies. It was observed that different physico-chemical, mineralogical and mechanical characteristics of C&D wastes were variable parameters. The basic mechanical properties of RA were within the limit of Indian Standard IS:383 and IS:6579. During compressive strengths test of C&D for M-20 grade cubes as per IS:516, it was observed that the target cube strength was achieved at 7 and 28 days and was higher for 90 days. The study shows the potential of C&D waste as RA and can be reliable alternatives to Natural Aggregates (NA) during concrete making.

Keywords C&D waste · Characterization · Carbonation · Recycled aggregates Natural aggregates

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1 Introduction

1.1 Construction and Demolition (C&D) Waste—An Indian Scenario

Preservation of the environment and conservation of the rapidly diminishing natural resources are the essence of sustainable development. Sustainable development exerted the pressure for demanding adoption of proper methods to protect the environment and proper management of all kind of waste [21, 28]. Presently in India, about 960 MT of solid waste is being generated annually as by-products during industrial, mining, municipal, agricultural and other processes [22]. Construction and demolition (C&D) waste represents an important fraction of the total amount of inorganic waste generated. Annual generation of C&D waste which is considered as a part of municipal solid waste is nearly 50 MT [24]. However, this waste stream will increase significantly in near future due to rapidly growing construction industry in India.

Generation of C&D waste is increasing tremendously due to new constructions as a part of economic growth. Considering the present and future prospective, quantum of C&D waste is ever increasing and needs urgent attention. Currently in India, some components of C&D waste, like bricks, tiles, wood, metal, are reused and recycled; whereas concrete rubble and masonry constituting about 50–60% of C&D waste are not yet recycled [1]. On the other hand, there is a critical shortage of Natural Aggregates (NA) for production of concrete. Furthermore, continuous excavation of these limited natural resources for NA creates severe ecological and environmental imbalance [5]. Thus, C&D waste can be reliable alternatives of Recycled Aggregates (RA) in construction industry, and its usage will reduce the burden on natural resources and thereby on surrounding environment [20].

The main objective of present work was to study in detail the physico-chemical, mineralogical and mechanical characteristics of C&D waste; so as to provide typical Indian C&D waste qualities. The present study also assess the effect of C&D waste as a RA during concrete making for M-20 grade concrete cubes.

2 Materials and Methods

2.1 Sample Collection and Material Used

The field visit was done at Chhatrapati Shivaji International Airport (CSIA), Mumbai, and Bhandewadi municipal waste disposal site, Nagpur. The C&D waste samples were collected during demolition of bridge near CSIA and from municipal waste disposal site near Bhandewadi, Nagpur. The collected C&D wastes were stored in airtight polyethylene bags/drums prior to analysis [2]. Figure 1 shows collection of C&D waste samples. During present study OPC-43 grade Associated

Fig. 1 Collection of C&D waste from construction and demolition sites

Cement Companies (ACC) cement was used and IS:383 [16] specifications was used for aggregates. Normal tap water available in concrete laboratory conforming requirements of water for concrete making and curing conditions was used as per IS:456 [12].

2.2 *Methods and Parameters for Characterization of Mineral Wastes*

2.2.1 Sample Preparation

Sieve analysis of collected C&D waste samples was undertaken directly after receiving sample from sampling location, without crushing or further processing. But during the demolition of international airport bridge of Mumbai, local workers were hired by demolisher to recover the useful materials from big debris of C&D waste. They hammered the C&D waste samples, and thus, the size of C&D waste was reduced at site. Similarly, the C&D waste collected from Bhandewadi municipal waste disposal site, Nagpur has reduced size at source. After sieve analysis of C&D waste samples, it was observed that collected C&D waste fractions were varying from sizes of 10–40 mm and more than 90% aggregates are of 40 mm size. C&D waste was then directly incorporated for concrete making and for further physico-chemical, mineralogical and mechanical characteristics.

2.2.2 Characterization of Mineral Wastes Samples

Various techniques/methods were used for characterization and analysis of C&D waste samples.

The physico-chemical characteristics of C&D waste such as Loss on Ignition (LOI), moisture content and acid-insoluble residue were determined according to the Indian Standard IS:4032 [18]. The pH of C&D waste samples was determined by Indian Standard method IS:2720-Part 26 [15]. Chloride concentration was measured according to British Standard BS:812-117 [4]. Concentration of sulphate ions in collected samples was determined spectrometrically (UV-VIS Spectrophotometer 118). Depth of carbonation was determined by phenolphthalein indicator test. Trace metal concentrations in C&D waste samples were determined by ICP-OES after acid digestion procedure of United States Environmental Protection Agency (USEPA, SW-846, Method-3050B) [7]. Major and minor element analysis (chemical composition) was conducted using X-ray fluorescence (XRF-PANalytical PW-2403). The mineralogical characteristics were determined by X-ray diffraction using CuKα (Rigaku Miniflex II) radiation.

Mechanical characteristics such as aggregate crushing, impact, abrasion value and water absorption were determined as per IS:2386-Part IV [19]. The workability of concrete mix was determined by slump cone test. The compressive strength at 7, 28 and 90 days of concrete block were done as per IS:10262 [13] and IS:456 [12] at 0.5 water to cement ratio (w/c) and the compressive strength test was done as per IS:516 [14].

3 Results and Discussions

3.1 Physico-chemical Characteristics of C&D Waste

The physico-chemical properties of C&D waste are influenced by sampling location, amount of sampling and nature of waste [30, 31]. The properties of collected samples are shown in Table 1. Solution pH is a master variable that controls leaching and mobility of the potential groundwater contaminant which may be present in material [30–32]. The pH of C&D wastes was also alkaline in nature, due to adhering cement and concrete paste which were varied from 9.9 to 11.4 for Nagpur and Mumbai, respectively. The variation in pH is also due to different carbonation level, and the results are in agreement with earlier findings [8, 9].

The C&D waste samples were collected in dry form directly from sampling locations with moisture content 1.2 and 1.7% for Nagpur and Mumbai C&D waste, respectively. Acid-insoluble residues varied in the range of 60–62%. The major source of insoluble residue is silicates and aluminosilicates. The crystalline part in the mineral waste samples was dominated by quartz and mullite which are not

Table 1 Physico-chemical characteristics of mineral wastes

Sampling locations	pH	Moisture content (%)	Acid-insoluble residue (% by mass)	Chloride (%)	Sulphate (mg/L)	LOI (%)
C&D, Nagpur	9.9	1.2	62	0.09	91	1.2
C&D, Mumbai	11.4	1.7	60	0.04	110	1.1

C&D—construction and demolition

reactive towards $Ca(OH)_2$ at high pH. The chloride in C&D waste may present in different forms such as $CaCl_2$, NaCl and KCl [3, 10]; low chloride contents were found in all samples ($\leq 0.04\%$), and the soluble sulphate which can be leached out from C&D was found as 91–110 mg/L for Nagpur and Mumbai C&D waste, respectively. The Loss on Ignition (LOI) of the C&D includes mass loss from oxidation of carbon, decomposition of carbonates and loss of water; LOI in collected samples was 1.2 and 1.1%.

3.2 Carbonation of C&D Waste

The phenolphthalein indicator solution was applied to a fresh fractured surface of Nagpur and Mumbai C&D waste having irregular size 10 * 8 * 5 and 12 * 6 * 4, respectively. It was observed that the carbonation depth of Nagpur C&D waste was varying from 10 to 11 mm, whereas for Mumbai it was varying from 30 to 40 mm. Figure 2 shows the depth of carbonation.

The results obtained in the present study showed that concrete was partly carbonated; see Fig. 2. This implies that upon crushing, carbonation free pastes were mixed with carbonated paste and the pH will appear in the high alkaline region (11, 12). This is important for mechanical properties as well as for environmental properties [9].

3.3 Major, Minor and Trace Analysis of Mineral Wastes

It was also observed that major constituents in C&D waste were SiO_2, Fe_2O_3, CaO and Al_2O_3 along with trace amount of P_2O_5, SO_3, TiO_2, Na_2O, K_2O, MgO. From Table 2, it can be observed that the presence of SiO_2 in C&D wastes was higher which is due to the presence of more quartz in the former sample.

Mumbai Nagpur

Fig. 2 Determination of depth of carbonation by phenolphthalein indicator

Table 2 Chemical composition % of mineral wastes

Minerals/oxides	C&D-N (%)	C&D-M (%)
SiO_2	50	57
Al_2O_3	6.8	8.4
Fe_2O_3	3.3	3.4
CaO	23	15
MgO	1.9	0.88
K_2O	2.5	2.3
Na_2O	1.3	1.4
TiO_2	0.5	0.5
SO_3	0.9	0.42
P_2O_5	0.2	0.1

C&D-N—construction–demolition waste, Nagpur; *C&D-M*—construction–demolition waste, Mumbai

Table 3 Trace element concentration (mg/kg) of mineral waste sample

Mineral	C&D-N	C&D-M
As	N.D.	N.D.
Zn	66	240
Co	N.D.	12.72
Mn	300.5	500
Cr	160.2	240
Mo	40.2	N.D.
Pb	64.2	44
V	N.D.	49.44
Cu	19.7	40
Hg	0.0012	0.0015

N.D.—not detected; *C&D-N*—construction–demolition waste, Nagpur; *C&D-M*—construction–demolition waste, Mumbai

The heavy metal analysis of collected C&D waste samples is shown in Table 3. From Table 3, it was observed that in C&D waste the most abundant were Mn, Cr, Pb, Cu, Zn. The contents of As were not detected. Difference between the trace metal concentrations in C&D waste can mainly be attributed due to the presence of different material in these mineral wastes, sampling location and the amount of sampling. The results are in agreement with the literature related to the trace metal concentrations of C&D waste and other mineral waste studies [11, 30–32].

3.4 Mineralogical Properties of C&D Waste

X-ray diffraction (XRD) of collected mineral waste samples showed well-identified peaks at $2\theta°$ of 20, 25 and 35. The mineralogical analyses of collected samples are

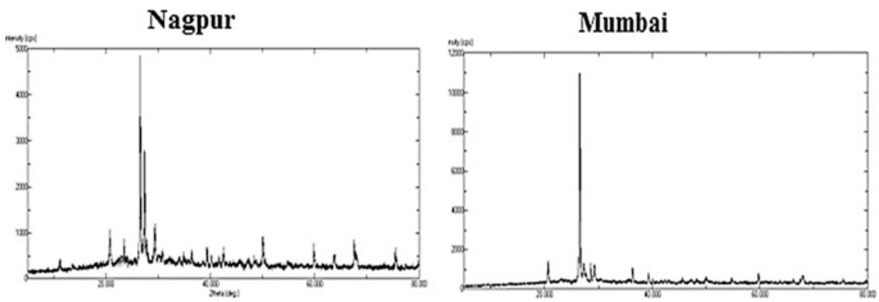

Fig. 3 X-ray Diffractogram of C&D samples

shown in Fig. 3. Mineralogical analysis indicates that the major crystalline phases in C&D waste samples were quartz and mullite, wollastonite, belite and alite, and quartz and feldspar. The result is in agreement with previous studies [6, 11, 27, 29–31].

3.5 Mechanical Characteristics of C&D Wastes

The C&D waste samples collected from two different locations were mixed in nature. Comparative mechanical characteristics of C&D waste are shown in Table 4. It can be observed that the impact value of C&D waste was in the range of 38–44% satisfying Indian Standard IS:383 [16]. The obtained crushing value of C&D waste was 37–45% and complies with the Indian Standard. The abrasion

Table 4 Comparative mechanical properties of natural aggregates and C&D

Type of aggregates	Sampling locations	Characteristics of aggregates			
		Impact value (%)	Crushing value (%)	Abrasion value (%)	Water absorption (%)
Recycled aggregates	C&D, Mumbai	38	37	30	10
	C&D, Nagpur	44	45	44	11
Natural aggregates	Uncrushed gravel/stone[a]	15	25	13	–
	Crushed gravel/stone[a]	20.4	23.5	–	0.5
	Crushed gravel/stone[b]	8.88	14.04	15.58	0.89
	Crushed gravel/stone[c]	17.65	18.4	–	0.29–0.3
BIS:383, specifications	Crushed and uncrushed gravels	45	45	50	–

[a]Sahay and Saini [25]
[b]Parekh and Modhera [23]
[c]Sonawane and Pimplikar [26]

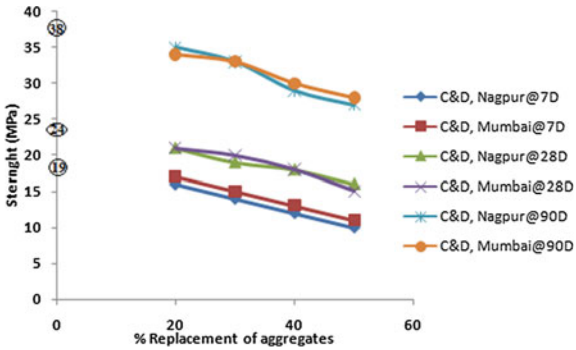

Fig. 4 Variation in compressive strength with % replacement of RA @7, 28 and 90 days

value of C&D waste was found to be in the range of 30–44%, which also complies to IS:383 [16]. From Table 4, it was also observed the collected C&D waste samples cannot be used for wearing surfaces as they do not comply the standards limits as prescribed by IS:383 [16]. The water absorption for C&D waste varied between 10 and 11% and was higher due to porous nature. Also, the workability of concrete in terms of height of subsidence (slump) was in the range of 90–120 mm.

3.6 Compressive Strength at 7, 28 and 90 Days

The average compressive strengths for M-20 grade casted cubes were determined as per IS:456 [12] and IS:10262 [13]. C&D waste was used as RA for 20, 30, 40 and 50% replacement at 7, 28 and 90 days. Figure 4 shows that the target cube strength was nearly achieved at 28 days for M-20 grade of concrete and was higher for 90 days. Figure 4 shows generalized trends of reduction of compressive strength with increased ratio of RA. The reduction in strength of RA compared to NA was in the order of 5–38, 8–29 and 5–23% for 7, 28 and 90 days of M-20 concretes, respectively. The amount of reduction in strength depends on parameters such as grade of demolished concrete, replacement ratio, *w*/*c* ratio, processing of recycled aggregate etc.

4 Conclusion

During the analysis of C&D waste for different physico-chemical, mineralogical and mechanical characteristics; it was observed that all these characteristics were variable parameters which were influenced by sampling location, amount of sampling and nature of waste. It was also observed that the basic mechanical properties such as water absorption, abrasion value, crushing value and impact value are within the limit of Indian Standard IS:383 [16] and IS:6579 [17] and also the concrete was partly carbonated. During compressive strength test of C&D waste for M-20 grade cubes as per IS:516 [14], it was observed that the target cube strength was achieved at 28 days and was higher for 90 days. Hence, C&D waste can be used as an RA replacing NA during concrete making.

The study highlights possible use of C&D wastes as per Indian Standards. On the basis of present research work, it can be concluded that C&D waste can be a viable alternative as RA for concrete industry and can easily merge the gap of NA. The study suggests and recommends the use of C&D waste as RA for low-grade concrete (M-20) up to replacement level of 30–50%.

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Technical and Economic Parameters Affecting Reuse of Construction and Demolition Waste in India: Case Studies from Bengaluru and Ahmedabad

A. Banerjee, R. Arora, U. Becker and T. Fernandes

Abstract The construction sector in India requires enormous amounts of natural resources such as sand, soil, stones, and the demand is expected to increase manifold in coming decades. Serious environmental impacts of extraction of these resources have often led to bans and restrictions, leading to price spikes and supply disruptions. Construction and demolition (C&D) waste can be used as a substitute for construction materials with proper management and processing, but such practice is still at a nascent stage in India. Under the new Construction and Demolition Waste Management Rules 2016, all cities will have to institute C&D waste management within a specified timeframe, and there is a dire need of capacity development to make this happen. The GIZ Resource Efficiency project is working to promote sound management and utilisation of C&D waste in Ahmedabad and Bengaluru. The main challenge was found to be the lack of a solid business case for processing in the absence of a reliable market for C&D waste-based products due to negative perception among buyers. Paving blocks made with C&D waste from Ahmedabad exceeded BIS standards for strength and were cost competitive with conventional blocks; therefore, a recognised certification scheme would help their market uptake. In addition, the processing facility being located in the south, a decentralized option for waste generated in the northern part of the city was found to be optimal. In Bengaluru, preliminary analysis showed that C&D waste processing enterprises located close to designated C&D waste disposal sites as well as to product markets are likely to be commercially viable under high-capacity utilisation scenarios. Attractive payback periods of 5 years or less were found for existing stone crushing units with idle capacity. Lessons from these cases can benefit C&D waste management planning in other cities in India.

Keywords Construction and demolition waste · India · Ahmedabad Bengaluru

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1 Introduction

The booming construction sector in India has put tremendous pressure on natural resources such as sand, soil, stones. Extraction of these resources has created serious environmental impacts in many parts of the country, often leading to restrictions, and therefore price spikes and supply disruptions [1]. These trends are expected to worsen with increasing demand, absent steps to promote resource efficiency, substitution and recycling [2]. Construction and demolition (C&D) waste offers a partial solution since it can be processed into fine and coarse aggregates suitable for the construction industry. However, at present, management and utilisation of C&D waste is extremely poor in most parts of India, with widespread unauthorised dumping creating serious nuisance and environmental problems. Only Delhi and Ahmedabad currently have C&D waste management and processing systems, but the new Construction and Demolition Waste Management Rules 2016 notified by the Ministry of Environment, Forest and Climate Change (MoEF&CC), will make it mandatory for all cities [3]. In this scenario, a thorough analysis of the C&D waste challenge is essential to develop appropriate and viable management plans in different cities.

2 Context and Methodology of the Study

The Resource Efficiency project, an Indo-German bilateral cooperation project, is being implemented in India by Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ) GmbH. C&D waste reuse is one of the areas of focus in this project, and Development Alternatives (DA) is the project partner of GIZ on this sector. As a first step, the project completed a survey of the C&D waste situation in 10 cities across India—a mix of metros and smaller cities geographically spread out all over the country. During the survey, interviews were conducted with government officials and building industry stakeholders to understand the current C&D waste management scenario, and field visits and sampling were also conducted to understand the trends in C&D waste generation, utilisation and disposal. Based on the outcome of this initial survey, two cities—Ahmedabad and Bengaluru—were shortlisted for further detailed analysis and possible pilot interventions. These two cities were chosen because either a pilot C&D waste management system was already in place (Ahmedabad), or ULB and private sector interest were strong in setting up a C&D waste management and utilisation system (Bengaluru). Detailed studies were conducted in these two cities, and the findings for each are presented in this paper.

3 Case Study of Ahmedabad

3.1 Background of C&D Waste Management in Ahmedabad

Ahmedabad was the second city in India, after Delhi, to successfully implement a C&D waste management and utilisation system. The process was initiated by the Ahmedabad Municipal Corporation (AMC) in 2012 and the processing plant started operating in 2014. A public–private partnership (PPP) model was followed, with Amdavad Enviro Projects Pvt. Ltd. (AEP) as the private sector partner establishing and operating the processing plant. The initially approved processing capacity of the plant is 300 tonnes per day (TPD), which was agreed on a pilot basis with scope for further expansion in future [4].

AMC has designated 16 intermediate collection points for C&D waste across the city to which construction contractors are supposed to bring their C&D waste free of cost. From these points, AEP picks up the waste and transports it to their processing plant for which they are paid by AMC Rs. 200/tonne. AMC collects C&D waste dumped in unauthorised locations and brings it to these designated collection points. AEP is also authorised to charge private parties for collection of waste from their respective sites at a pre-determined rate approved by AMC (exact charge depends on tonnage and distance). The collection and transportation of waste by AEP is tracked electronically, and the data are submitted to AEP on a real-time basis for accurate and efficient monitoring.

AEP processes the collected waste at their plant initially into coarse and fine aggregates. These aggregates are then used for the manufacturing of building materials like paver blocks, kerbstones and other pre-cast structures which are sold under the brand name of Nu-Earth materials [4]. However, the market uptake of these products has not met expectations so far.

3.2 Study Scope and Methodology

GIZ and DA collaborated with AMC and AEP with the objective of improving C&D waste management and utilisation in Ahmedabad through analysis of gaps and challenges and providing recommendations. As part of the market analysis, to visualise current management practice of C&D waste in the city, dumping sites were visited and mapped using Global Positioning System (GPS) coordinates. Paver block manufacturers were identified as potential users of C&D waste-based aggregates, and the paver block manufacturing units in two clusters, namely Gota and Naroda-Dehgam region, were mapped. In addition to obtaining relevant data from AMC and AEP, field surveys with a range of stakeholders were conducted to gather data on prices of raw materials, prices of finished products, prices of equipment and operating costs, knowledge, interest and concern about C&D

waste-based products, etc., for analysing financial viability scenarios. Stakeholders surveyed included builders/construction contractors, demolition contractors and C&D waste handlers, and building/construction material manufacturers including stone crushers and paving block manufacturers. Surveys were conducted in different parts of the city to gain reliable and comprehensive data.

3.3 Findings from Survey and Mapping

Currently, only some of the collection points for C&D waste designated by AMC are active. In many others, insufficient amount of C&D waste is collected to justify transportation effort by AEP. As shown in Fig. 1, the designated dumping sites in the northern parts of the city are quite far from the AEP facility. Currently, the AEP facility is only processing 300 TPD and has capacity for significant expansion. However, under the current model, this would involve transporting of waste to the facility from farther and farther away.

However, the collection sites in the north are quite close to two paver block manufacturing clusters—Gota and Naroda. This location synergy can potentially be utilised beneficially if C&D waste is processed at or near these sites; this would significantly minimise transportation distances.

In terms of raw materials, river sand mining is banned inside the city but is easily available from the outskirts of the city; aggregates are transported from

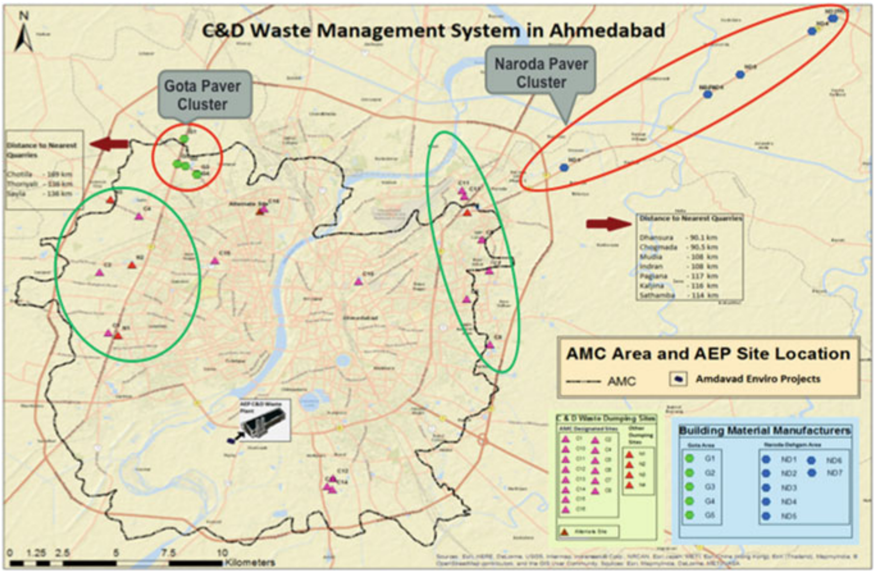

Fig. 1 C&D waste management sites in Ahmedabad and proximity to paver clusters

neighbouring towns like Baroda, Surat, Sevali and Moda. Hence, an additional cost is paid for the transport. There is shortage of river sand during monsoon season. Cost of sand was found to be uniform across the city at Rs. 450/tonne, while cost of aggregates varied between Rs. 300–550/tonne based on distance from stone quarries and crushing units.

A major problem identified was that building material manufacturers (paver block makers) were not very enthusiastic about using recycled aggregates from C&D waste citing concerns over cost, quality and reliable supply. Builders were also not very enthusiastic about using building products like paving blocks and bricks made from C&D waste, again citing similar concerns. Although AEP tests their product quality and their products are cost competitive, lack of an independent certification system is hampering market development of such products.

3.4 Results of Financial Viability Analysis

Based on data collected on market conditions through the survey, business cases were modelled for different cases with the goal of promoting decentralised C&D waste management for optimal utilisation. The different cases analysed and key results are summarised in Table 1.

From the analysis, Case 1 appears to be the most viable, while cases 5 and 6 may be quite attractive under conditions where decentralised C&D waste processing becomes widespread.

3.5 Key Recommendations

(1) A testing and certification system (such as GRIHA,[1] which is recognised by the Government of India) will help to create market acceptance of products made from processing C&D waste.
(2) Preferential procurement of such recycled products in contracts of government agencies will create a broad market for these products.
(3) Decentralised C&D waste processing and utilisation should be promoted by AMC in light of the spatial analysis for optimal and efficient utilisation of C&D waste.
(4) Education of all stakeholders in the construction, demolition and building material manufacture industry is essential through workshops, etc., to promote better adherence to AMC's management plan (proper disposal in designated areas, etc.), as well as to inform and convince entrepreneurs of the viability and profitability of decentralised C&D waste utilisation.

[1]Green Rating for Integrated Habitat Assessment (http://grihaindia.org/).

Table 1 Summary of business case modelling

Case	Key results
Case 1: Existing stone crushing entrepreneur processes C&D waste into secondary aggregates and an existing paver block manufacturer utilises the secondary aggregates into finished products	Since only minor modifications will be required for stone crushers to utilise C&D waste, there is little additional investment required. Input cost savings are significant if C&D waste is obtained within short distance. For paving block manufacturers, no additional investment is required for using recycled aggregates. Profit margin and/or cost competitiveness is increased significantly
Case 2: Existing stone crushing entrepreneur processes C&D waste into secondary aggregates and also starts a new paver block manufacturing unit that utilises the secondary aggregates	Since only minor modifications will be required for stone crushers to utilise C&D waste, there is little additional investment required. Input cost savings are significant if C&D waste is obtained within short distance. However, significant investment is required for setting up a new paving block manufacturing unit, which will be profitable after a cost recovery period
Case 3: Existing paver block manufacturing unit utilises the secondary aggregates with additional investment for mini-crushing unit	Major investment will be required for the mini-crushing unit, and the cost recovery period may be quite long
Case 4: New enterprise for C&D waste crushing and processing and new enterprise for paver block manufacturing utilising the secondary aggregates	Major investments will be needed for both the crushing unit as well as the new paving block making unit. A long cost recovery period may not be justified if high capacity utilisation cannot be guaranteed (if the large AEP facility expands, then supply of C&D waste for another large facility may be uncertain)
Case 5: New enterprise renting out mini-mobile crusher to waste generators/ demolition sites	The mini-mobile crusher is expensive and the investment is justified if decentralised waste processing and utilisation becomes widespread, necessitating high utilisation of the crusher
Case 6: Existing crushing unit enterprise using mini-mobile crusher	A crushing unit invests in a mobile crusher to go to waste generation sites and the crushed aggregate is transported back to the entrepreneur for marketing. The additional investment in the mobile crusher will only be justified if decentralised waste processing and utilisation becomes widespread, necessitating high utilisation of the crusher

4 Case Study of Bengaluru

4.1 Background of C&D Waste Management in Bengaluru

Bengaluru is a fast-growing metropolis with a booming construction sector. Proper management of municipal waste, including C&D waste, has been an ongoing challenge. The Greater Bengaluru Municipal Corporation (BBMP) has recently concluded a feasibility analysis for setting up a C&D waste management system in 2015. According to the BBMP analysis, the amount of C&D waste generation in Bengaluru is 2,500 TPD [5]. Other estimates have put the figure above 3,000 TPD. Currently, there is no comprehensive management system for C&D waste in place; BBMP is in the process of developing a management plan. BBMP has designated eight sites for disposal of C&D waste but they remain underutilised; unauthorised dumping is common elsewhere [5]. Due to shortage of natural (river) sand, the manufactured sand (m-sand) industry is well established, with entrepreneurs in the stone crushing industry making m-sand from virgin rock. One SME[2] entrepreneur, Rock Crystals Pvt. Ltd., has also started crushing small amounts of C&D waste into coarse and fine aggregates on a pilot basis, and selling these aggregates directly in the market.

4.2 Study Scope and Methodology

GIZ and DA, in collaboration with Bengaluru-based Centre for Study of Science, Technology and Policy (CSTEP), conducted a detailed study to analyse factors that may influence the viability of a future C&D waste management system in Bengaluru and identify the most promising models suited to the local context. First, existing C&D waste disposal sites and practices were surveyed. Second, locations of existing stone crushing units (SCUs) and paver block manufacturers (PBMs) were mapped vis-à-vis their proximity to designated C&D waste disposal sites using Geographic Information Systems (GIS) tools. Third, a wide range of stakeholders in the construction/demolition industry as well as building product manufacturers were interviewed to obtain data on market trends for conducting a financial viability analysis. Finally, financial viability modelling analysis was conducted for a range of scenarios including greenfield projects for processing and utilising C&D waste, as well as for existing SCUs and PBMs to start utilising C&D waste.

[2]Small and/or Medium Enterprise.

4.3 Findings from Survey and Mapping

None of the eight sites designated for C&D waste disposal by BBMP are properly demarcated and there is no monitoring of these sites. Only three of the designated sites are actively receiving C&D waste. Interviews with construction industry and independent experts revealed that only about 10% of the C&D waste generated in the city is disposed in the designated sites. About 30% is re-used in construction sites for land levelling and low-lying areas reclamation, while the other 60% ends up being disposed illegally in unauthorised places.

For the mapping exercise, a buffer of 30 km was generated from the center of the city and only stakeholders falling within the buffer zone were mapped. A total of 118 SCUs and 26 PBMs were mapped, in addition to the seven designated C&D waste dumping sites. The mapping results are shown in Fig. 2.

Further, individual SCUs and PBMs were grouped into clusters based on proximity and a distance analysis was conducted between the clusters as well as from the city center. The results of the cluster mapping and distance analysis are depicted in Fig. 3 and Table 2.

From the analysis, some clear trends are noticeable. For example, PBM cluster 1 is close to SCU clusters 1 and 2 and both are close to one active C&D waste dumping site in north Bengaluru. Therefore, such analyses could be used to plan a

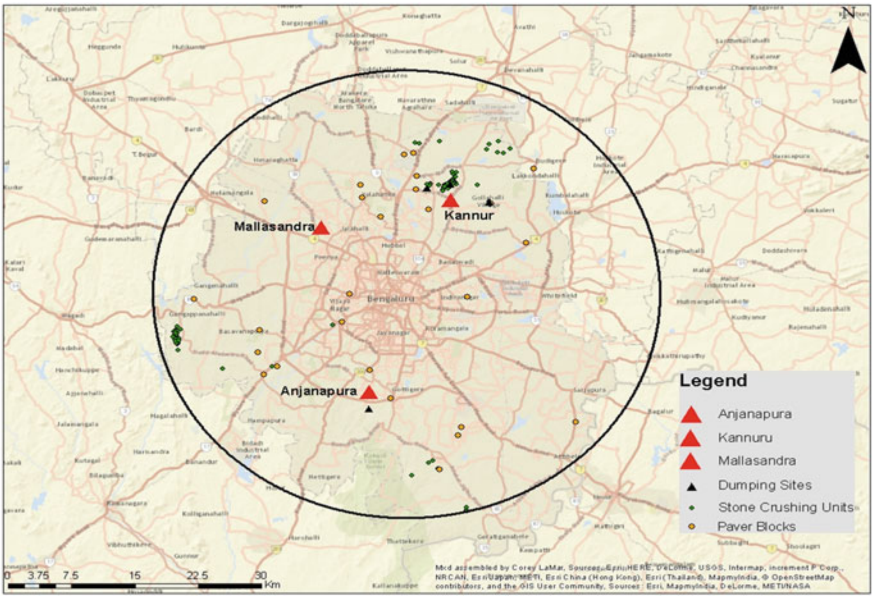

Fig. 2 Location of SCUs, PBMs, and designated C&D waste dumping sites within a 30 km buffer of Bengaluru (active dumping sites depicted in red)

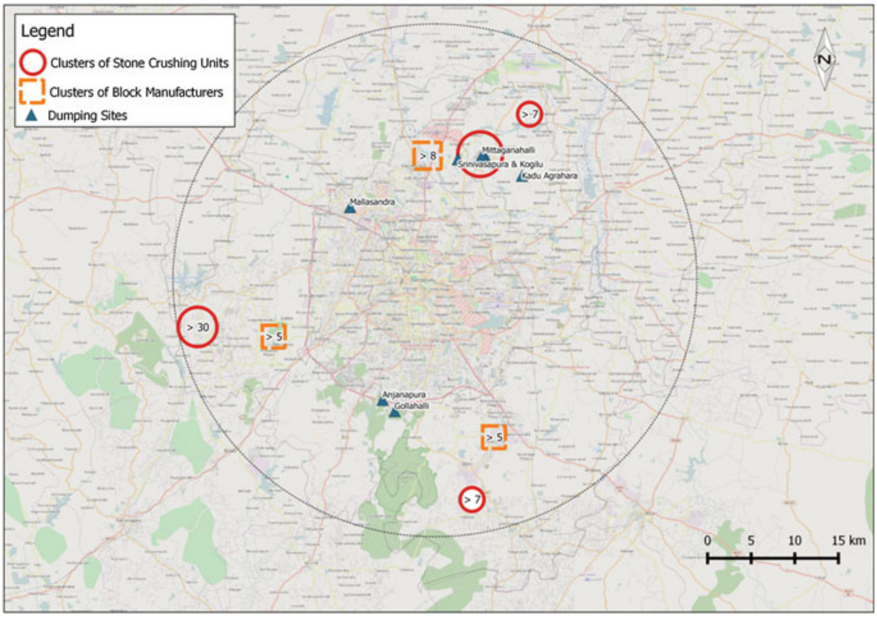

Fig. 3 SCU and PBM clusters in Bengaluru vis-à-vis C&D waste dumping sites

decentralised C&D waste collection and utilisation system that maximises the chance of financial viability by reducing transportation distances along the value chain.

Table 2 Distance analysis between SCU and PBM clusters in Bengaluru

Distance matrix (in km)		Number of units	City centre (km)	Clusters of paving block manufacturers		
				Cluster 1 (North Bengaluru)	Cluster 2 (West Bengaluru)	Cluster 3 (South Bengaluru)
				>8	>5	>5
Clusters of stone crushing units	Cluster 1 (North Bengaluru)	>60	22.6	8.6	42.0	46.5
	Cluster 2 (North Bengaluru)	>7	33.4	15.4	52.6	57.1
	Cluster 3 (West Bengaluru)	>30	37.5	51.6	12.0	49.6
	Cluster 4 (South Bengaluru)	>7	34	51.9	38.8	10.3
City centre				19.4	25.5	24.4

4.4 Results of Financial Viability Analysis

Since no functioning C&D waste processing plant exists in Bengaluru, proxy figures from SCUs, PBMs, and equipment suppliers, as well as the C&D waste processing plant in Ahmedabad were used to estimate investment costs for setting up C&D waste processing units. Figure 4 shows these costs for SCUs and integrated PBMs producing aggregates and paver blocks, respectively.

From Fig. 4, although it appears that economies of scale are more attractive for larger plants, in practice, larger plants may not be able to perform efficiently with high capacity utilisation due to the dispersed nature of C&D waste generation, collection and disposal. A key advantage of C&D waste-based products is that they turn out to be cheaper than products made from natural raw materials (NRM). The cheaper cost is an important factor for C&D waste-based products to gain market penetration.

Financial viability modelling was first conducted for hypothetical new "greenfield" units—for both SCUs and integrated PBMs. For each kind of unit, different sizes (from 100–1,000 TPD), different product configurations, and different capacity utilisation (CU) levels were examined. Outcomes with internal rates of return (IRR) above 10% were considered financially attractive.

100 TPD SCUs become viable only if they operate at 90% CU throughout, whereas 250 TPD SCUs offer moderate returns from 80% CU onwards. Larger units offer moderate-to-good returns at 70% or higher CU, which can be considered a threshold for the SCUs. At 60% or lower CU, it becomes difficult to justify the investment. Therefore, market assurance and organisation will play a critical role for a profitable C&D waste reprocessing business. For IPBMs, the story is very similar to that of the SCUs, except the returns are much better at higher capacities and utilisation factors. Conversely, the returns at smaller capacities (e.g., 100 TPD) are worse than those of the SCUs.

Financial viability modelling was then conducted for existing SCU units, assuming that they add C&D waste processing to their operations. For plants with idle crushing capacity, an analysis of the marginal cost and benefits of adding a unit

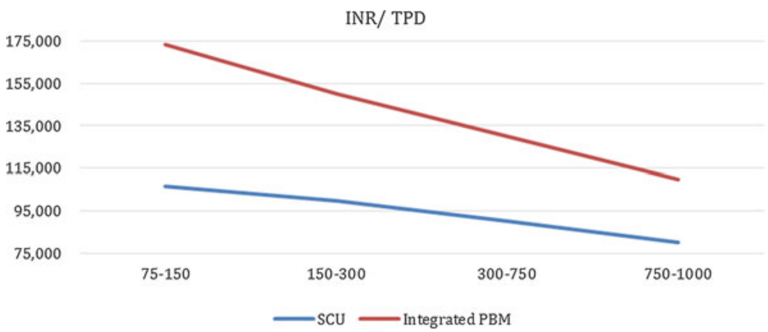

Fig. 4 Investment costs versus size for C&D waste processing units

of C&D waste processing capacity was conducted. C&D waste can be used to blend with virgin material to improve the CU of existing units and offer cheaper recycled products. The additional investment cost for C&D waste handling and processing (pre-crushing) was estimated to be INR 6,400/TPD based on stakeholder surveys. The C&D waste handling costs (operational expenses) are variable according to the planned CU. The average annual revenues are adjusted to account for the value addition from the marginal C&D waste processing capacity. Five cases of capacity utilisation are examined—30, 40, 50, 60, and 70%; Fig. 5 shows the payback period in each case.

C&D waste-based investments in existing SCUs have attractive payback periods at 50% or higher CU. This is because the additional investment is small relative to net surplus generated annually, and operating expenses can be managed more effectively in existing SCUs. Decision on such expansion must therefore carefully consider the health of existing operations and the anticipated market growth for building materials.

4.5 Key Recommendations

(1) Better demarcation and road access of designated C&D waste disposal sites, along with publicising their location to the construction industry, will help achieve better utilisation of these sites and reduce unauthorised dumping. Better regulation of demolition contractors through registration and tracking will also be necessary.

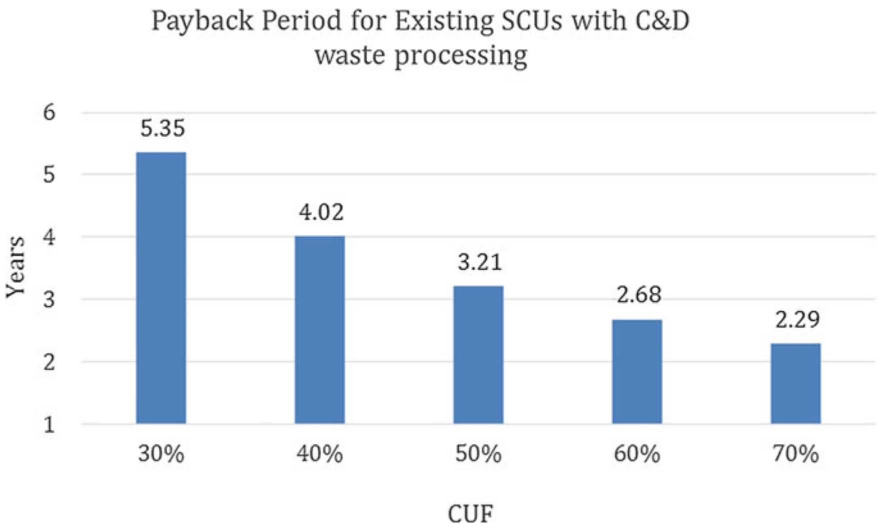

Fig. 5 Payback period for existing SCUs with C&D waste processing added

(2) BBMP should plan to establish (with private sector partner) C&D waste processing units near geographically optimal points in close proximity to C&D waste dumping sites and building material manufacturing clusters, as demonstrated through the mapping analysis.
(3) Although large capacity plants are more cost-effective in theory, the initial C&D waste plant should not be more than 500 TPD capacity to ensure high-capacity utilisation for financial viability. Collection and transportation-related logistical challenges may take time to sort out in the beginning and there may be unexpected surprises.
(4) BBMP should encourage existing SCUs with idle capacity to take up C&D waste processing and existing PBMs to utilise aggregates produced thereof. Targeted outreach to geographically proximate clusters can help generate interest of these entrepreneurs. The participation of such entrepreneurs will gradually help to create a market for C&D waste-based products.
(5) Other measures to build up market demand for C&D waste-based products should also be initiated such as: facilitation of testing and certification of such products, adoption of preferential procurement policies, and targeted awareness campaigns for the construction industry.

5 Overall Conclusion

It is clear from the study that simply being interested in adopting a C&D waste management system is not enough for a city. Careful planning and involvement of multiple stakeholders is essential for a successful outcome. Even in cities where pilot programs have started, there remains scope for improvement. It is essential for MoEF&CC/CPCB, with relevant partners, to conduct capacity development workshops for ULBs to enable them to plan and initiate a C&D waste management system. At the same time, it is equally important for the ULBs to pay attention to the business case of C&D waste utilisation by the private sector. The business case is context specific and is likely to vary from city to city, but is crucial for the long-term success of the venture. In parallel, market development through standards, certification and public procurement will help to establish C&D waste-based products as a viable commercial enterprise.

Acknowledgements The study was made possible due to the Indo-German Bilateral Resource Efficiency project. The authors would like to thank study partners Development Alternatives and CSTEP, as well as acknowledge help in data collection from BBMP, AMC, AEP, and other stakeholders.

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Part XIV
WEEE Management

E-waste Management and Resource Recovery in Vietnam

Nguyen Trung Thang and Duong Thi Phuong Anh

Abstract E-waste has become an emerging issue in Vietnam due to the rapid increase of generated volume and its harmful effects. It has been estimated that there are 61,000–113,000 tons of e-waste generated in 2010, mainly from households. Resource recovery of e-waste has brought high profits of valuable metals; however, recycling practices are mainly dismantling for refurbishment or recovery of valuable parts, which is implemented by informal sector in craft villages and caused negative impacts on the environment and human health. E-waste has been treated as hazardous waste and is included in the starting extended producers' responsibility (EPR) system; however, there are still many challenges for a successful implementation. Recommendations have been provided for a better management of e-waste in Vietnam.

Keywords E-waste · Recycling · Resource recovery · E-waste management

1 Introduction

Like in many developing countries, e-waste has become an emerging issue in Vietnam due to the rapid growth of generated volume of waste from electronic and electric products. The reasons are the increase in population, economic growth, increasing middle-income class, and also fast development of technologies in the last two decades. E-waste has been considered as a resource in Vietnam and almost all e-waste are recycled; however, recycling and treatment are still far from sustainable.

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2 E-waste Generation in Vietnam

E-waste comes from four main sources: households, offices, industry, and imported from abroad as used equipments. A survey by JICA and URENCO in 2007 showed the increase of all types of e-waste, of which mobile phone has the highest rate of growth, almost six times from 2002 to 2006 (Table 1) [5].

H. T. Hai et al. in their research have estimated the amount of e-waste from household as electronic home appliances in Vietnam from 1.8 million units (approximately 61,100 tonnes) to 3.8 million units (113,500 tons) in 2010, and e-waste amount from industry was much smaller than from household [1]. According to the State of Environment Report 2011, Vietnam has 52 electronic and electric producers, which produce printed circuit boards, cathode ray tubes, and assembly electronic devices such as TV, refrigerators, air conditioners, and washing machines, generating wastes such as broken pieces, packages [3]. With regard to e-waste generated from office and import, there have not been any data reported so far.

In general, the amount of e-waste is increasing due to the development of the electronic industry as well as increasing demand for new electronic devices. Prices of electronic products continue to decrease, also designs change constantly making them become more suited to many different people including low-income people, and making the life of electronic devices increasingly shortened. In projection, URENCO has estimated that there will be about 10.6 million pieces of electronic and electric good in 2020 (including 4.85 million TVs, 2.27 million refrigerators, 2.6 million washing machines, and 873 thousand air conditioners) [5]. Similarly, N. D. Quang et al. has also estimated 12.1 million pieces (including 6.5 million TVs, 3.4 million refrigerators, 1.9 million washing machines and 284 thousand air conditioners) in 2020 [4].

Composition of e-waste is very diverse and may contain more than 1,000 different substances. It consists of ferrous and non-ferrous metals, plastics, glass, wood and plywood, printed circuit boards, concrete and ceramics, rubber and other items. Potential for resource recovery from e-waste is high because iron and steel constitute about 50% of the e-waste, followed by 21% of plastic, 13% of non-ferrous metals, and others [5].

Table 1 Electronic wastes in Vietnam in 2002–2006 (unit: tons/year)

Year	TV	PC	Mobile phone	Refrigerator	Air conditioner	Washing machine
2002	190.445	62.771	80.912	112.402	17.778	184.140
2003	222.977	77.845	86.467	140.916	24.706	214.271
2004	261.542	90.447	103.414	162.262	29.853	249.094
2005	308.076	110.123	472.707	194.570	39.157	287.910
2006	364.684	131.536	505.268	230.856	49.782	327.649

Source URENCO, JICA, 2007

3 E-waste Separation, Collection, and Recycling

It has been observed that e-waste has not been controlled in Vietnam; there is no any official e-waste collection and treatment system so far. Most of the e-waste is collected by waste brokers, then transferred to dismantling/refurbishing workshops, which focus mainly on dismantling or refurbishing discarded appliances rather than recycling them (Fig. 1) [2]. E-waste recycling system has been fragmented, uses backward technology, and mainly recovers some metals (Cu, Fe, Al) and plastics [1].

In Vietnam, e-waste has not been sorted at source, but usually sold to and separated by private collectors into several categories: (i) devices that can be reused; (ii) devices that can be dismantled and refurbished; and (iii) devices that can be recycled. Devices or their parts/components that cannot be sold will be discarded with municipal wastes.

The private collectors collect the discarded products from users and other sources, check, and classify them into above categories. Then collectors sell

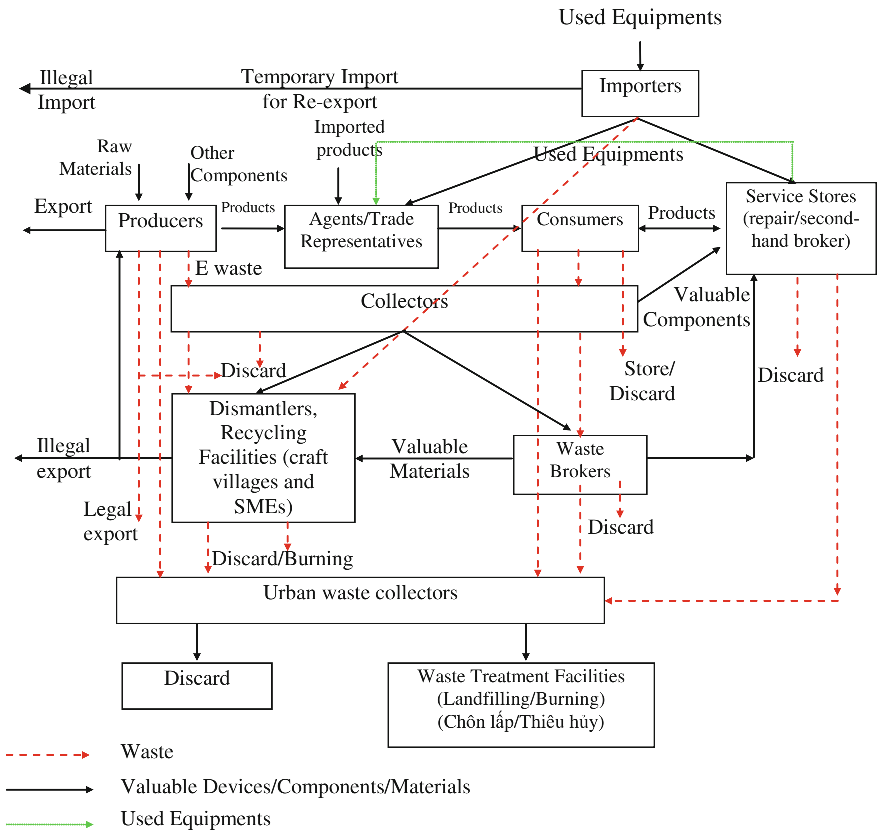

Fig. 1 Flow of household electronic equipments and e-waste in Vietnam. *Source* Institute of Environment Science and Technology, 2013 [3]

category (i) and (ii) for the maintenance/refurbishing shops and sell category (iii) for the dismantling facilities. This is a private collection system which is very dynamic and successful. The system has extracted almost valuable parts and materials from e-waste collected directly from the final users and the landfill. Valuable parts are sold to private maintenance system and will be used to repair other damaged appliances to become new goods with poor quality for sale to low-income households. Most valuable materials are manually recycled in the craft villages and the recycling facilities. In these facilities, only some common materials such as iron, copper, aluminum, and plastic can be recycled with outdated technology, rudimentary equipment, and causing serious environmental pollution [3].

4 Current Legislations Related to E-waste Management

E-waste has been considered as hazardous waste in Vietnam but not yet managed by a special policy as in other countries. Vietnam has ratified the Basel Convention on March 13, 1995. The *Law on Environment Protection 2014* (LEP 2014) has provisions on retrieval, treatment of discarded products along with regulations on hazardous waste management. Article 87 under LEP 2014 regulated that owners of production, business, service facilities must retrieve and treat discarded products, while consumers have responsibility for bringing the discarded products to the specified disposal point.

Decree 38/2015/ND-CP dated April 24, 2015, on waste management and scraps stipulates detailed regulations of hazardous waste management, and the *Circular 36/2015/TT-BTNMT dated June 30, 2015, of Ministry of Natural Resources and Environment* has regulated that discarded electronic equipments and parts belong to the list of hazardous waste.

However, the most important document is the *Decision 16/2015/QD-TTg dated January 22, 2015, on retrieval, treatment of discarded products*, which is the EPR system in Vietnam. The decision provides a list of discarded products that must be taken back and treated by producers and importers. In this list, discarded electrical and electronic appliances, such as computers (desktop, laptop); computer screens; CPU (microprocessor of the computer); printers; fax machines; scanners; camera; mobiles; tablets; DVD players; VCD; CD and tape reader types, other disks; photocopiers; televisions; fridges; air conditioners; washing machines, must be applied from July 1, 2016. Manufacturers can directly take back and recycle products by themselves or they can authorize the waste transport, treatment companies to do this. For easier implementation, collection, storage, and transportation of electronic and electrical discarded products do not need to be licensed for hazardous waste management functions but they must meet national technical regulations of collecting, storing, transporting discarded products.

5 Challenges for E-waste Management

After the Decision 16/2015/QD-TTg had been issued, a number of businesses have developed plans to implement the take-back system for discarded products. For example, Dien Quang Lamp Production Company has actively developed a network for take back of compact, fluorescent bulbs based on its distribution system, with an initial focus on major cities such as Hanoi and Ho Chi Minh City. Other information technology companies including Apple, Canon, HP, and Sony also together developed a pilot program on retrieval systems of electrical and electronic waste in Vietnam. However, it is observed that until now, the EPR system is still not operated as required. For the time being, the Ministry of Natural Resources and Environment is developing the guiding document of implementing the Decision No. 16/2015/QD-TTg, which is expected to be issued at the end of 2016.

There are number of challenges and issues for implementation of e-waste management in Vietnam. *Firstly, there is a lack of special legislation of e-waste management.* The EPR regulation has been adopted, however, a guidance circular still needs to be issued for this policy implementation. There are lacks of standards and technical specifications of recycled products and safe recycling technologies to be applied. *Secondly, the recycling capacity is still very weak.* Recycling in Vietnam has been implemented by informal sector not only for e-waste but for all material recovery. Formalization of the informal recycling facilities is one of the urgent tasks that need to be implemented. E-waste contains high number of toxic metals such as lead, mercury, cadimi, arsenic and so formal recycling with safe technologies is very important. *Thirdly, awareness and sense of responsibility of consumers, producers, retailers are still very low* not only on EPR implementation but also on environmental protection in general. *Finally, monitoring and reporting mechanism have not been set up* and so is difficult to promote implementation nationwide.

6 Conclusions/Recommendations

Vietnam is a developing country that still faces many issues in environmental protection. E-waste management has not been effectively implemented; the waste is not managed by a formal system; treatment/recycling is still implemented by informal sector, causing pollution, and health impacts.

To improve e-waste management, several recommendations of appropriate solutions have been proposed as follows:

Firstly, to raise awareness of people about the harm caused by improper waste management, enhancing separation of solid waste at source, increasing the reuse of waste including e-waste. Raising awareness of authorities the about importance of public participation in solid waste management work, ensuring authorities are qualified enough in coordinating the activities, planning, implementation, and to mobilize the participation of all parties. Raising awareness and responsibility of manufacturers, particularly in taking back and treatment of discarded products as well as in environment protection in general.

Secondly, to complete policy and legislation on e-waste management including the policy on EPR, specifically to promulgate the circular guiding implementation of the Decision 16/2015/QD-TTg. Develop also the monitoring and reporting system for EPR implementation as well as the standards of recycled products and materials.

Thirdly, step by step to establish a formal recycling industry for e-waste through constructing modern recycling facilities and infrastructure for collecting discarded products. Private recycling facilities should be enhanced, which can be contractor of producers/importers.

Finally, to promote R&D, international cooperation and transfer of technology on e-waste recycling to improve the recovery of valuable materials, reducing environmental pollution and enhancing the recycling industry development in the country.

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E-waste Recycling in Taiwan

Hsiao-Kang Ma

Abstract In the year of 1998, the "Recycling Management Fund" was founded by Taiwan Environmental Protection Agency (EPA) to be in charge of all the recycling and treatment items in accordance with WDA due to the extended producer responsibility (EPR) from the importers and manufactures. Manufacturers, importers, and sellers must pay a recycling fee as the resource Recycling Management Fund based on the sales or import amount and the rate approved by EPA. Taiwan is a key player in the global information and communications technology (ICT) industry including notebook computers, wafer contract foundries, IC encapsulation testing, and IC design. Yet, Taiwan is not only a leader in the IC technologies; it has also seen successes in reducing waste. The average volume of e-waste recycling amount increased from 30,087 ton/year in 2005 to 54,248 ton/year in 2014. Although EU legislation restricting the use of hazardous substances on waste electrical and electric equipment (WEEE) and promoting the collection and recycling of such equipment since 2003, a high percentage of e-waste collected in the west for recycling is still continuous exported to the developing countries in Asia. At the same time, a "Zero Waste" Policy for establishing a Sound Material-Cycle Society (SMC) had been proposed by Taiwan government in 2008. The recycling scheme has clearly defined the roles among the government, producers, retails, and customers. This paper described the Taiwan model to recycle the e-waste, the recycling fee, subsides, and the related recycling system. The "Green Differential Fee Rate" was proposed in 2014, in order to encourage the environment-friendly product development, which might reduce the rate for recycling for the producers of green products. Obviously, "Green Differential Fee Rate" may form the driving force among stakeholders toward establishing a Sound Material-Cycle Society (SMC) in the future.

Keywords E-waste · EPR · Subsidy · Recycling fee · Green differential fee rate SMC

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1 Introduction—Zero Waste Policy in Taiwan

Taiwan is a small island with averaged US.$17,000/person/year in a near closed surrounding. Since the establishment of the "Solid Waste Disposal Act" in 1974 in Taiwan, for nearly four decades the country has been developing the waste management system. In 1984, the "Municipal Solid Waste (MSW) Disposal Plan" in 1984 established landfill to be the initial goal and incineration to be the long-term policy. In 1991, the "MSW Disposal Plan" was promulgated which empowered the government to commission 24 MSW incineration plants in the country. Then, several comprehensive reforms in MSW policies shown in Table 1 were done including the "Charge of Clean-Up and Treatment Charge for MSW" on the concept of the polluter pays principle in 1997, the establishment of "Recycling Management Fund (RMF)" to recycle and treat Due Recycled Waste items including WEEE. At the same time, Taipei city also proposed the "Keep Trash off the Ground policy" in 1996, "Four-in-One Recycling Plan" to combine the community, recyclers, local government cleaning units, and recycling foundations in 1997, and "Pay-by-Bag Collection Fee System" in 2000. In 2002, the relevant laws such as the "Resource Reuse and Recycling Act" and "Restrictions of Product Over-packaging" were gradually formulated to improve the rate of resource recycling.

In 2003, the "Zero Waste Policy" was first initiated by the Taipei city government. From 2005, "Mandatory Garbage Sorting" plan was carried out step by step, and by 2006 it was implemented in all cities and municipals in order to achieve the goal of "zero waste." Recently, the emphasis of solid waste treatment was focused on the management to reduce and recycle the source waste. In addition, the government began to advocate green production, green consumption, source reduction, resource recycling, reuse, and reutilization to effectively recycle resources and achieve the goals of total garbage recycling and zero waste [1]. According to the Environmental Protection Administration (EPA), the volume of municipal solid waste in Taiwan reduced from 8.729 million tons in 1999 to 3.352 million tons in 2015, while the volume of garbage generated per capita per day reduced from 1.10 kg in 1999 to 0.38 kg. In terms of garbage recycling, the percentage of recycling increased from 6.80% in 1999 to 45.92% in 2015. Figure 1 shows the amount for the incineration/recycling/landfill in Taiwan during 2000–2012. Although the de-coupling of waste generation and population growth/economic growth come true in Taiwan, there are still several issues and challenges listed in Table 2 needed to solve for the goal of zero waste [2–8].

Table 1 Major regulations related to MSW management in Taiwan

Law	Supplemental regulation	Effective date	Brief description
Waste Disposal Act (WDA)		26/07/1974	First law for solid waste (SW) management. Definition classification of solid waste. Obligations and responsibilities of SW management were also clarified
WDA	Charge of Clean-Up and Treatment Charge for MSW	31/07/1991	Using the concept polluter pays principle, the charge for MSW treatment was there
WDA	Recycle, clean-up, and treatment of MSW	23/04/1997	Classification of collection mechanism, treatment technologies, and disposal facilities for MSW recycling
WDA	Recycling Management Fund (RMF)	01/07/1998	Recycling and treatment of Due Recycled Waste items including WEEE
WDA	Recycling general waste items by implementation agency	17/04/2006	Designates items with further resource to be collected by the local government
WDA	Management criteria for public landfill facilities	01/01/2007	MSW with good calorific value should not be dumped in landfill sites except the treated SW
Environmental Fundamental Law		11/12/2002	Sustainable development law. Green consumption, proper recycling, reusing, life-cycle assessment of finished products, and cleaner production in waste management systems
Resource Reuse and Recycling Act		03/07/2002	Definitions of recyclable goods and fundamental principles. Obligation and responsibilities of goods recycling
Resource Reuse and Recycling Act		2003	Zero Waste Policy
Resource Reuse and Recycling Act	Restrictions of Product Over-packaging	01/07/2006	Restricts the size and weight of specific commodities including: cookies, cosmetic products, liquor, refined foods, packaged items, and gift boxes

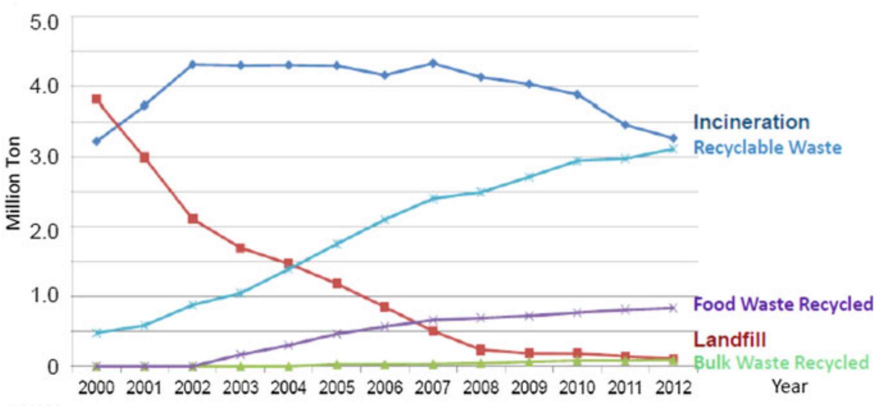


Fig. 1 Amount for the incineration/recycling/landfill in Taiwan during 2000–2012

Table 2 Challenges and opportunities of MSW in Taiwan

Country and City	Collection system	Transportation system	Segregation	Issues and challenges	Possible solution
Taiwan	1. Four-in-One Resource Recycling Plan 2. Mandatory Garbage Sorting 3. **Pay-by-Water** Collection Fee System for MSW (the polluter pays principle) 4. Free for resource recycling items	Public or private collecting team	1. Combustible MSW with high CV not be dumped in landfill sites except the treated SW 2. Resource recycling items including bottom ash, organic waste 3. Incinerator: waste to energy	1. Fly ash 2. Organic waste as fertilizer 3. Shortage of landfill site	1. New resource recycling technologies 2. Recycling SW from the old landfill site
Taipei and New Taipei City	1. Four-in-One Resource Recycling Plan 2. Mandatory garbage sorting 3. **Pay-by-Bag** Collection Fee System for MSW (the polluter pays principle) 4. Free for resource recycling items	Public or private collecting team	1. Combustible MSW with high CV not be dumped in landfill sites except the treated SW 2. Resource recycling items including bottom ash, organic waste. 3. Incinerator: Waste to Energy 4. Recycling SW from the old landfill site	1. Fly ash 2. Remodel the existed incinerators to increase the efficiency 3. Shortage of landfill site	1. New resource recycling technologies

2 Present WEEE Recycling in Taiwan

E-waste is defined as "*electrical or electronic equipment which is waste, including all components, sub-assemblies and consumables which are part of the product at the time of discarding*." It includes televisions, mobile phones, computers, and entertainment electronics which consist of valuable as well as harmful, toxic materials. The Directive 2002/96/EC on waste electrical and electronic equipment (WEEE) is a key guideline of EU's environmental policy on waste. It addresses a particularly complex waste flow in terms of certain parameters—variety of products, association of different materials and components, contents in hazardous substances, and pattern of growth. The objectives of WEEE include:

- Channelization of WEEE from landfills and incinerators to environmentally sound treatment and resource recovery.
- Preservation of resources—materials and energy.
- Extended producer responsibility (EPR).
- Harmonize national measures on the management of WEEE.
- Common minimum standards of treatment.

In the year of 1998, the "Recycling Management Fund" shown in Fig. 2 was founded by Taiwan Environmental Protection Agency (EPA) to be in charge of all the recycling and treatment items in accordance with WDA due to the extended producer responsibility (EPR) from the importers and manufactures. Manufacturers, importers, and sellers must pay a recycle/disposal/treatment fee as the resource recovery management fund based on the sales or import amount and the rate approved by EPA. Taiwan is a key player in the global information and

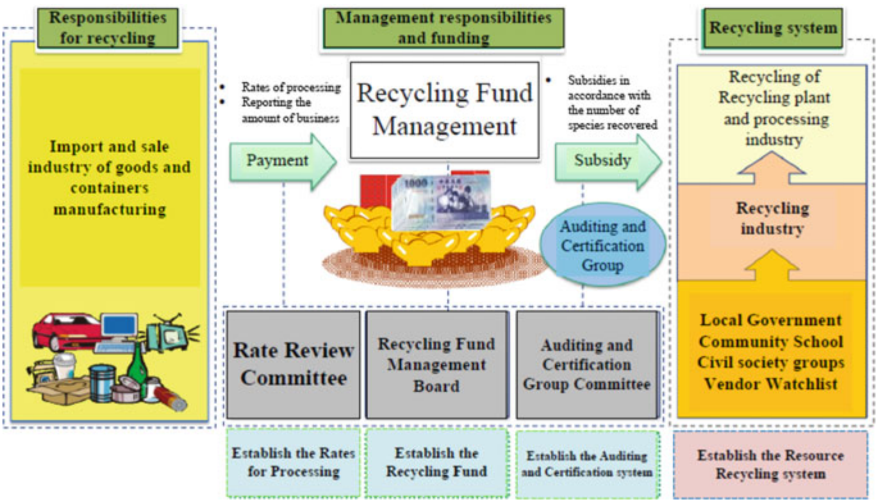


Fig. 2 Recycling fund management system in Taiwan

communications technology (ICT) industry and remains as the world's top producer of notebook computers, producing a monthly average of over 14 million units. Yet, Taiwan is not only a leader in the technology industry. It has also seen successes in reducing waste. Waste household appliance recycling volume increased 6.3 times in 2013 as compared to 1998 (Fig. 3), and waste recycling volume increased 22.6 times in 2013, as compared to 1998 (in Fig. 4). Table 3 shows the average volume of e-waste recycling amount increased from 30,087 ton/year in 2005 to 54,248 ton/year in 2014. At the same time, the year of Recycling Due Recycled Waste items was enforced to fulfill the "Zero Waste" Policy for establishing a Sound Material-Cycle Society (SMC) shown in Fig. 5.

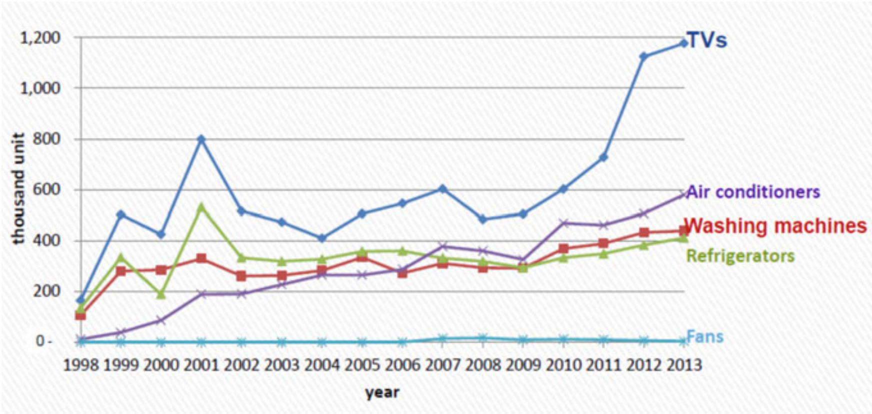


Fig. 3 Waste household appliance recycling volume increased 6.3 times in 2013 as compared to 1998

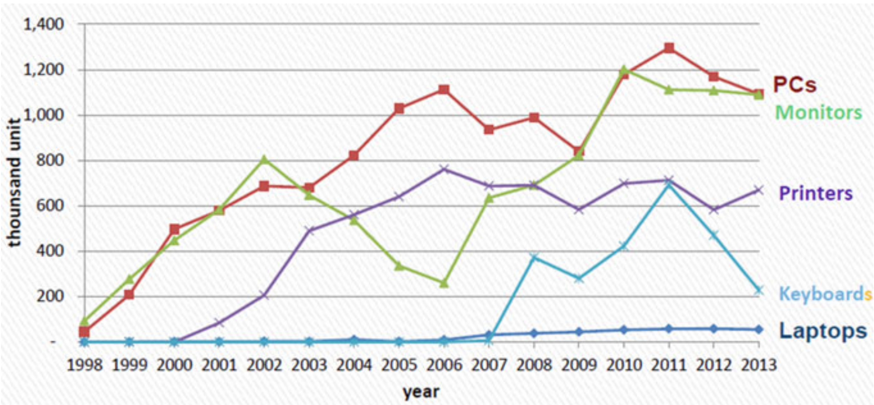


Fig. 4 Waste IT recycling volume increased 22.6 times in 2013 as compared to 1998

Table 3 E-waste recycling amount on 2005–2014 in Taiwan

Year	Home appliances	Computer	Total (ton)
2005	20,889	9,198	30,087
2006	24,597	11,527	36,424
2007	27,764	12,859	40,623
2008	29,600	11,931	41,531
2009	31,821	12,597	44,418
2010	30,987	13,474	44,461
2011	30,313	12,831	43,144
2012	36,187	13,457	49,644
2013	39,853	11,864	51,717
2014	41,673	12,575	54,248

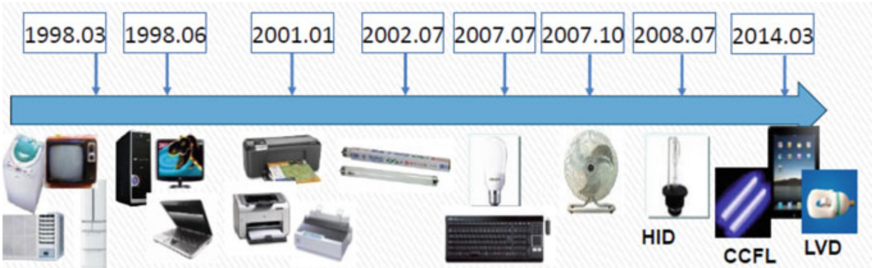


Fig. 5 Year of recycling Due Recycled Waste items was enforced

3 The Extended Producer Responsibility—Taiwan Model

The European Union's WEEE Directive that was enforced in August 2004 makes it compulsory for manufacturers and importers in EU states to take back their products from consumers and ensure environmentally sound disposal. E-waste has triggered significant interest among policymakers due to their unique combination of characteristics. Firstly, generation of e-waste is increasing and is expected to continue so. Secondly, e-waste contains toxic materials—lead, mercury, and cadmium—which have led to increased environmental concern about casual treatment and disposal. Thirdly, there are valuable metals in e-waste and recovery of these materials can alleviate mining of virgin metals. There is a patchwork of different implementations of e-waste take-back systems in many countries and regions. There are more than 250 producer responsibility organizations (PROs) being established to meet EPR obligations in Europe.

Taiwan is a small island in a near closed surrounding. The recycling scheme has clearly defined the roles among the government, producers, retails, and customers. The recycling fees charged to manufacturers and importers of new regulated recyclable waste (RRW) products are fed in the recycling fund. This fund is used to subsidize licensed collectors and recyclers who meet the EPAT standards for better operation of the collection chain. In the Taiwan model shown in Fig. 6, manufacturers, importers, and sellers must pay recycling fees as the resource recovery management fund to fulfill the extended producer responsibility. Thus, Recycling Management Fund takes the major responsibility to recycle the regulated recycled waste. Other than recycling funds, special income funds are mobilized to education, research and development, auditing and certification, grants for municipalities and citizen groups, and administration of the Four-in-One Recycling Program. The results show that recyclers and treatment plants can have subsidies from the recycling fund to have the moderate profits. Figures 7, 8, and 9 show the subsidies from the Recycling Management Fund paid to the recycling plants. Now too many recyclers and treatment plants were built with vigor competition for recycling e-waste in Taiwan. The average utilization rates of e-waste treatment plant are lower than 20%. In Taiwan, government and producer share the responsibilities for recycling e-waste. Producers may have less responsibility for further recycling once they have paid the recycling fee. Obviously, the mechanism of EPR is different from the European Union and other countries. Some international companies complained that they have paid the recycling fee, but they still have to run their own recycling scheme and treatment system to fulfill the EPR requested by their mother company.

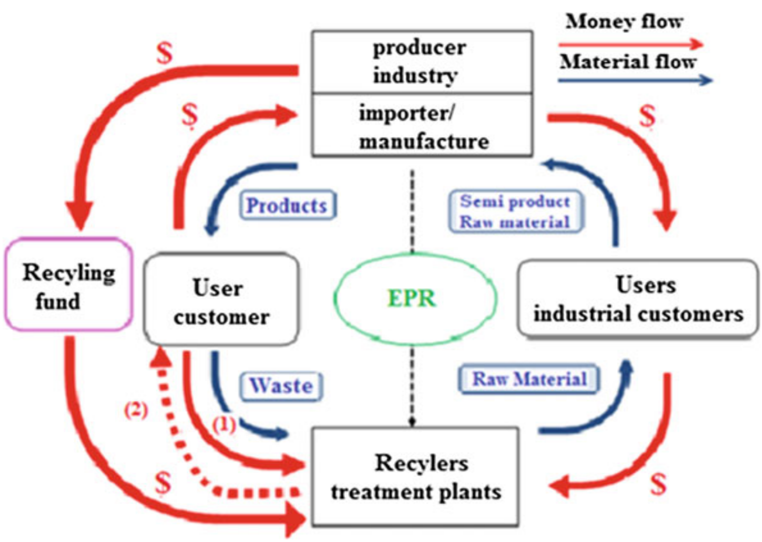


Fig. 6 Material and money flows in the Taiwan model

Fig. 7 Subsidies from the recycling fund paid to the recycling plant (WEEE)

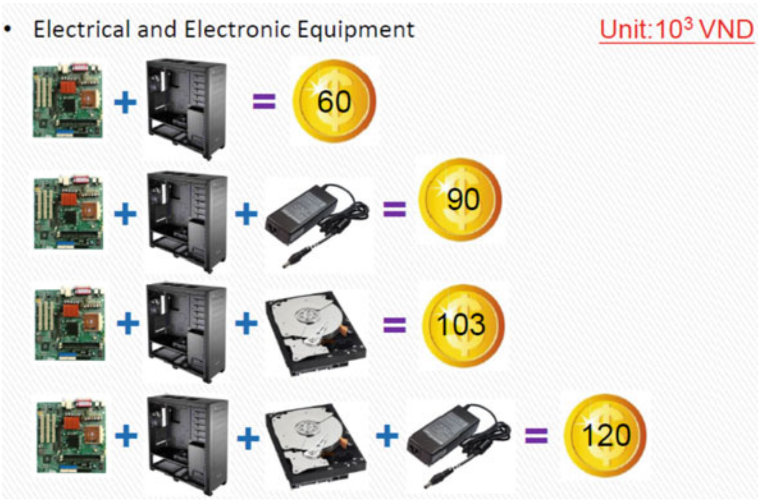


Fig. 8 Subsidies from the recycling fund paid to the recycling plant (WEEE)

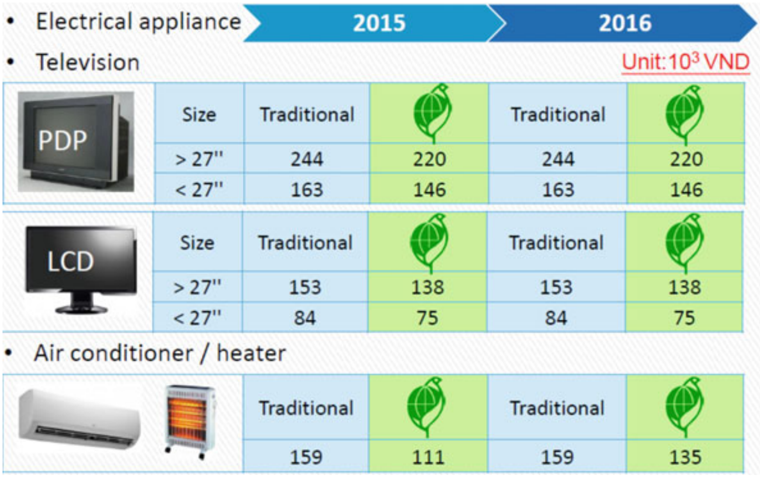
Fig. 9 Subsidies from the recycling fund paid to the recycling plant (WEEE)

4 Differential Fee—The Driving Force for a Sound Material-Cycle Society (SMC)

In order to increase the recycling amount, "Four-in-One Program" was proposed to bring municipalities, Recycling Management Fund, communities, and recycling industries together for sharing the EPR in e-waste recycling system. All the recycled waste electrical or electronic equipment should have identification number before sending to the recycling plants. The "Green Differential Fee Rate" was proposed in 2014, in order to encourage the environment-friendly product development,

Fig. 10 Differential Fee Rate with multiple environmental characteristics of the Green Mark

which might reduce the rate for recycling for the producers of green products or increase the recycling fee rate to hinder less environmental-friendly product production. Figure 10 shows the differential fee, which is 30% discount of traditional fee with multiple environmental characteristics of the "Green Mark" at the initial stage. Then, the EPA dropped the discount to about 15% of traditional fee for the green products with multiple environmental characteristics of the "Green Mark," which was in effect from January 1, 2015, and shown in Figs. 11, 12, 13, and 14.



- Electrical appliance
- Television

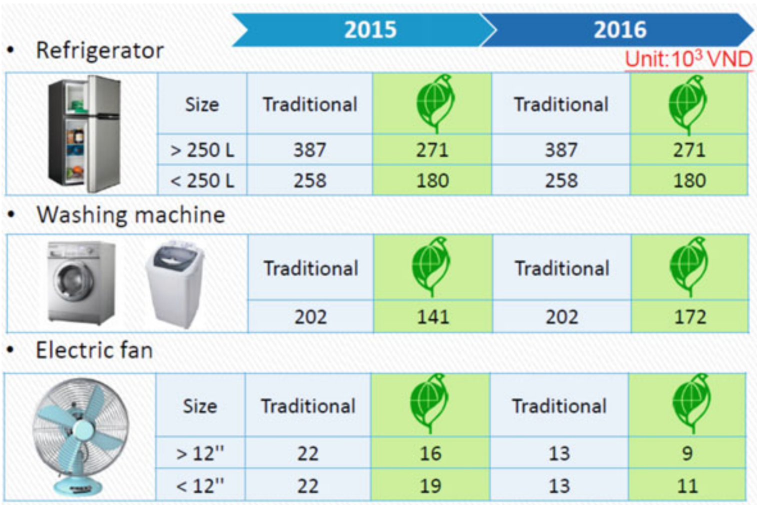
Unit: 10^3 VND

	Size	2015 Traditional	2015	2016 Traditional	2016
PDP	> 27"	244	220	244	220
PDP	< 27"	163	146	163	146
LCD	> 27"	153	138	153	138
LCD	< 27"	84	75	84	75

- Air conditioner / heater

2015 Traditional	2015	2016 Traditional	2016
159	111	159	135

Fig. 11 Differential Fee Rate for the fund from the manufacturers, importers, and sellers



- Refrigerator

Unit: 10^3 VND

Size	2015 Traditional	2015	2016 Traditional	2016
> 250 L	387	271	387	271
< 250 L	258	180	258	180

- Washing machine

2015 Traditional	2015	2016 Traditional	2016
202	141	202	172

- Electric fan

Size	2015 Traditional	2015	2016 Traditional	2016
> 12"	22	16	13	9
< 12"	22	19	13	11

Fig. 12 Differential Fee Rate for the fund from the manufacturers, importers, and sellers

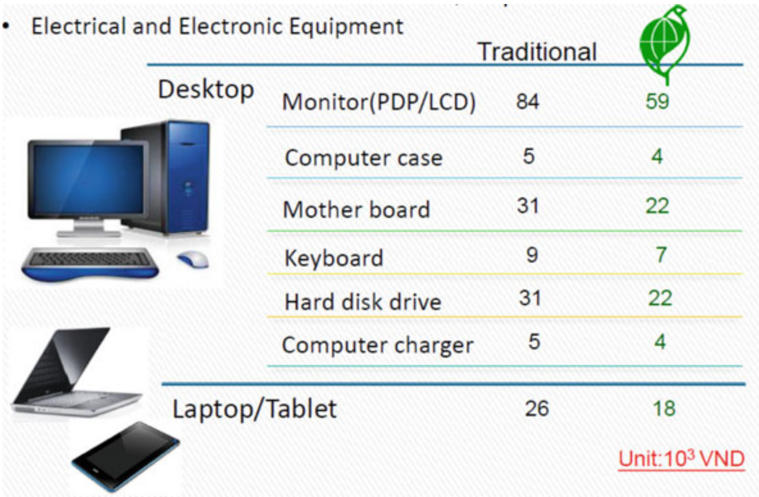


Fig. 13 Differential Fee Rate for the fund from the manufacturers, importers, and sellers

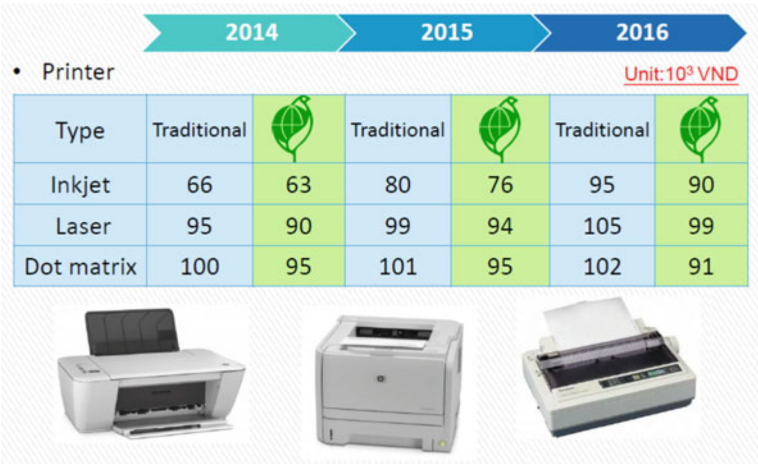


Fig. 14 Differential Fee Rate for the fund from the manufacturers, importers, and sellers

Obviously "Green Differential Fee Rate" may form the driving force among stakeholders toward establishing a Sound Material-Cycle Society (SMC) in the future.

5 Conclusions

The mechanism of WEEE recycling and treatment in Taiwan includes the EPR, subsidy, and Green Differential Fee Rate. The major findings and suggestions are as follows;

To achieve the goal of "zero waste," the emphasis of solid waste treatment was focused on the management to reduce and recycle the source waste.

Although the de-coupling of waste generation and population growth/economic growth come true in Taiwan, there are still several issues and challenges (i.e., fly ash, organic waste, e-waste) needed to solve for the goal of zero waste.

The mechanism of EPR in Taiwan is different from the European Union and other countries. Manufacturers, importers, and sellers must pay recycling fees to the Recycling Management Fund operating by Taiwan EPA to fulfill the extended producer responsibility. Thus, Recycling Management Fund takes the major responsibility to recycle the regulated recycled waste.

In order to improve the recycling system, the "Green Differential Fee Rate" was proposed in 2014, which might decrease the rate of recycling fee for the producers of green products. Obviously "Green Differential Fee Rate" may form the driving force among stakeholders toward establishing a Sound Material-Cycle Society (SMC) in the future.

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Estimation of E-waste Generation—A Lifecycle-Based Approach

Reshma Roychoudhuri, Biswajit Debnath, Debasree De, Pavel Albores, Chandrima Banerjee and Sadhan Kumar Ghosh

Abstract The problem of e-waste disposal is a very well-known fact, and its generation is increasing exponentially every year. In 2015, 54 million tons of e-waste was generated, whereas it has been predicted that around 50 million tons of e-waste will be generated worldwide by 2018, by the UN report. Another source predicts that e-waste generation will be 72 million tons by 2017. This anomaly exists due to the different methodologies adopted in prediction of e-waste. The most common method used so far to calculate the amount of e-waste generated is as follows. The amount of EEE sold by manufacturers is collected first. The average lifespan of an EEE is known. Thus, applying the average lifespan of the EEE on the amount sold per year, the amount of e-waste is calculated. However, this method is not free from flaws since a sizable portion of the EEE, once the average lifespan is over, does not directly become e-waste. They land in the second-hand market and are resold, and are again used for more number of years. Hence, the process of becoming e-waste for these recycled products is delayed. Once an EEE leaves the

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Original Equipment Manufacturer (OEM), the lifecycle of an EEE begins. After a certain time of use, the user may discard it for several reasons, which then becomes Used EEE (UEEE). One can exchange this UEEE for a newer and upgraded models (or cash) via authorized or unauthorized resellers, in which case also the UEEE lands up in the second-hand market. The original user can also discard the product completely so that it lands up as e-waste. From the e-waste, precious metals are recovered through recycling process and the discarded parts mostly end up as landfill. In this paper, a model has been proposed based on the lifecycle of EEE. Based on this model, an attempt has been made to predict the amount of e-waste generation in India. Standard data available from the data bank of EU has been used for this purpose. The work has been carried out using Vensim software. The results have been compared with the real-life data.

Keywords E-waste generation · E-waste estimation · EEE lifecycle Vensim

1 Introduction

E-waste refers to waste electrical and electronic equipment, whole or in part, or rejects from their manufacturing and repair process, which are intended to be discarded. Developing countries, suffering with rapidly growing problems of e-waste, need to have an efficient solution in order to build a sound e-waste management system [1]. E-waste contaminates the environment and threatens human health. In developed countries, the tools used to manage e-waste are life-cycle Assessment (LCA), Material Flow Analysis (MFA), Multi-Criteria Analysis (MCA) and Extended Producer Responsibility (EPR). In 2015, 54 million tons of e-waste was generated, whereas it has been predicted, by the UN report, that around 50 million tons of E-waste will be generated worldwide by 2018. Another source predicts that e-waste generation will be 72 million tons by 2017. This anomaly exists due to the different methodologies adopted in prediction of e-waste. The amount of EEE sold by manufacturers is collected first. The average lifespan of an EEE is known. Thus, applying the average lifespan of the EEE on the amount sold per year, the amount of e-waste is calculated. However, this method is not free from flaws since a sizable portion of the EEE, once the average lifespan is over, does not directly become e-waste. They land in the second-hand market and are resold, and are again used for more number of years. Hence, the process of becoming e-waste for these recycled products is delayed. Once an EEE leaves the Original Equipment Manufacturer (OEM), the lifecycle of an EEE begins. After a certain time of use, the user may discard it for several reasons and it then becomes Used EEE (UEEE). One can exchange this UEEE for a newer and upgraded model (or cash) via authorized or unauthorized reseller, in which case also the UEEE lands up in the second-hand market. The original user can also discard the product completely so that it lands up as e-waste. From the e-waste, precious metals are recovered through recycling process and the discarded parts end up mostly as landfill. In this paper, a model has been proposed based on the lifecycle of EEE.

There is an urgent need to handle this huge waste generated and hence forecast the actual amount of waste which will be generated. The amount of waste generated has been forecasted in the past by the ITU data released in June 2012 and UNEP [2]. Rajya Sabha Secretariat [3] estimates the amount of e-waste generated in India. The amount of e-waste generated depends on the lifespan of the different mobile phones [4]. MFA, which is based on the principle of material conservation [5], has been applied to estimate the generation of obsolete computers and mobile phones. There is a significant impact of collection rate on amount of mobile phones in e-waste due to the presence of user in second-hand market. The lifespan of EEE, assessment of e-waste volumes and their corresponding impact and management status globally are measured from harmonized modelling steps and data sources by using internationally adopted measuring framework. And it is desirable to have a clear view of second-hand market and regional details of e-waste quantities and management [4]. The prediction of the exact amount of waste generated will help the second-hand market to utilize their capacity efficiently and effectively. There have been efforts to put forward an estimation technique to calculate the growth of e-waste [6]; the steps of those are: (1) estimating the quantity of end-of-life product generated, that is, recycled versus disposed. (2) Estimating the portion of end-of-life electronics recycled. (3) Estimating the portion of end-of-life electronics disposal. The paper aims to predict the amount of e-waste generated based upon the system dynamics software in Vensim PLE software.

2 Objective

The main objective of the paper is to develop a new method for estimation of e-waste generation which takes the said gaps into account for a realistic result.

3 Methodology

The methodology adopted in this paper spans published literature including journals, books, conference proceedings and information obtained from electronic media. Several databases such as Science Direct, Google Scholar, Emerald Insight, Springer has been explored for the purpose of literature search. Different keywords such as ‘E-waste estimation’, ‘EEE lifecycle simulation’ and ‘EEE sales data’ were used for this purpose. The publications were found in the areas of EEE lifecycle simulation and e-waste estimation. Vensim PLE has been used to sketch and simulate the model. Papers and other materials illustrating the usage of Vensim were also referred for this purpose. The references cited in each relevant literature were examined to find out additional sources of information. All the literature have been studied and referred properly.

4 Existing E-waste Estimation Framework

Widmar et al. [7] summarize aptly the different methods to estimate possible global quantities of WEEE. The first and most common used model is the 'consumption and use method', which takes the average lifespan of an EEE as the basis for a prediction of the potential amount of WEEE. The second method is the 'market supply method', which uses data about production and sales figures in a given geographical region. The Global E-waste Monitor published in 2014 has used a method which is a combination of the above two methods to predict that the amount of e-waste is expected to grow to 49.8 Mt in 2018, with an annual growth rate of 4–5%. A third method is used by the Swiss Environmental Agency which estimates based on the assumption that private households are already saturated and for each end-of-life old EEE, a new appliance is bought.

The missing link in the above methods is the acknowledgement of the existence of the second-hand market. After the lapse of the lifespan while some UEEE becomes WEEE, a significant portion of UEEE is introduced into the second-hand market. Hence, the process of becoming e-waste of that particular UEEE is delayed. A model similar to this was mentioned in the paper proposed by Matthews et al. [8]. The paper devised a model, only for the US market, which acknowledges the fact that some UEEE do not become WEEE immediately but enter the second-hand market. Our model is on the same line but a more generic one. Our objective is if the sales data is provided to the model, then it should be able to estimate e-waste, taking into consideration both lifespan and the second-hand market.

5 Proposed Model

The model proposed in this study is based on the lifecycle of EEE. Debnath et al. [9] discussed a framework of lifecycle of EEE. Based on that framework of life-cycle of EEE, the following model has been proposed in this study. The proposed model (Fig. 1) depicts the possible flow of EEE from OEM's warehouse to landfill. The following are the assumptions taken for this model:

(a) There is no defective product manufactured by the OEM's.
(b) The users do not buy same electronic equipment over the period of whole lifespan.
(c) No new equipments enter the inflow of the chain over the lifespan.
(d) Only the non-recyclable fraction lands up in the landfill.
(e) The end-of-life equipment from second-hand users is not being repaired or refurbished.

In this proposed model, OEMs are the manufacturers of the electronic and electrical equipments (EEEs) which are being used by the users. Within the life-cycle period, some users may discard the EEE and that goes to the second-hand user

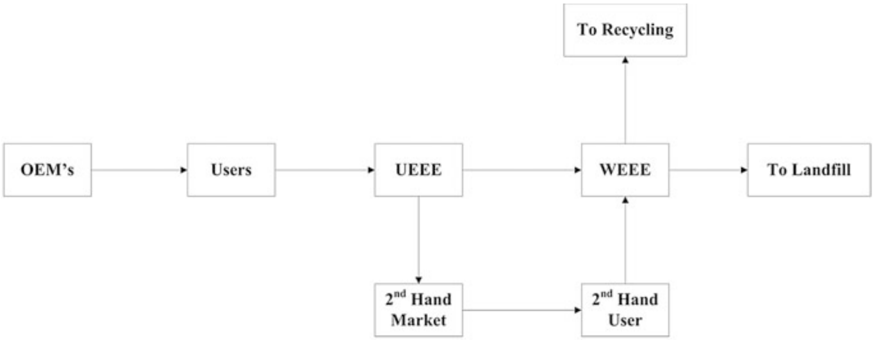

Fig. 1 E-waste generation estimation model based on the lifecycle of EEE

with or without repairing via the second-hand market. After being used by the second-hand user, it becomes waste electronic and electrical equipments (WEEEs) or e-waste. The non-recyclable fraction ends up in e-waste, and the rest is recycled.

6 Results and Discussion

The simulation has been carried out using the Vensim PLE software. Under the present study, two cases have been explored—(a) case of personal computers and (b) case of mobile phones. The study has been carried out on the Indian perspective.

6.1 Case 1: Personal Computers (PC)

The personal computers are one of the major sources of e-waste. In general, standard lifespan of a PC is considered as five years [8]. Simulations were carried out over the whole lifespan of five years, and the percentage of e-waste generated per year was estimated by the model (Fig. 2).

It was found that at the end of the lifespan, nearly 67% of the total PCs acquired by the users were e-waste. The amount of landfill was found to be nearly 27% of the manufactured EEE. This indicated nearly 73% material in e-waste is recyclable and materials can be recovered.

6.2 Case 2: Mobile Phones

Rate of obsolescence of mobile phones is higher than any other EEE. Standard lifespan of mobile phones is considered as two years. However, in case of

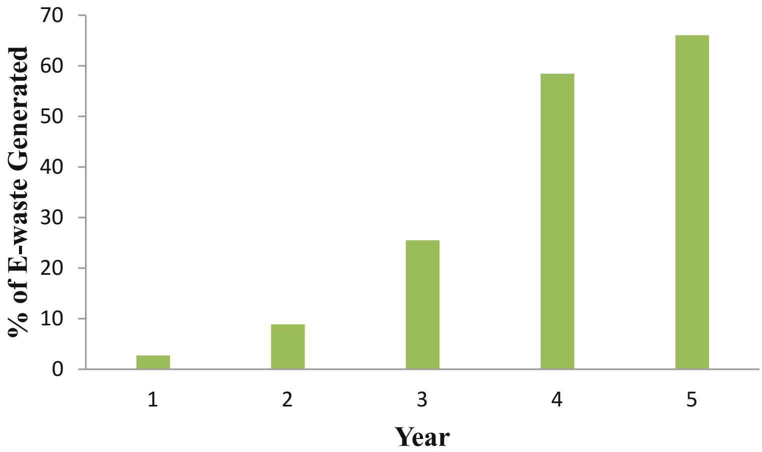

Fig. 2 E-waste generated per year by personal computers (in %)

developing countries, it may be extended to three years. Studies were carried out over the lifespan of three years, and the percentage of e-waste generated per year was estimated by the model (Fig. 3).

The result found in this case is really interesting. The model predicts that the maximum percentage of e-waste is generated in the second year of the lifecycle which is nearly 46% and it decreases during the last year of lifespan, which is in compliance with the practical scenario; i.e. the average lifespan of mobiles are considered to be two years. Nearly 9% of the manufactured EEE goes to landfill during the second year.

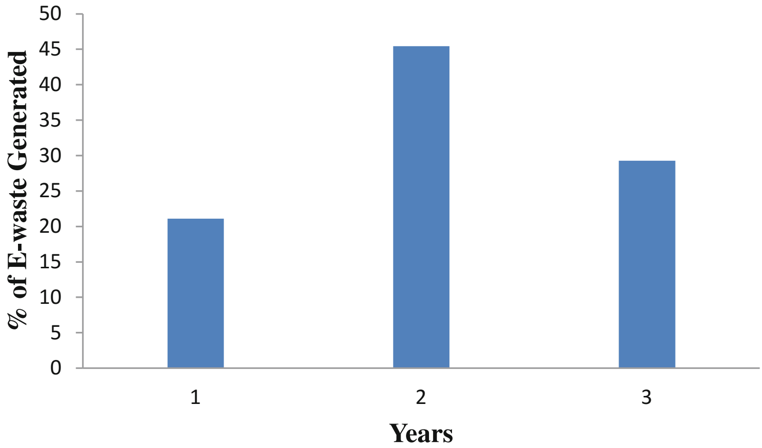

Fig. 3 E-waste generated per year by mobile phones (in %)

According to the Solution to E-waste Problem (StEP) world map, 52% of the total EEE put into the market turned into e-waste over the span of two years. Our model predicted individually for PC and mobile phone which are well in the vicinity of the data provided by StEP. The discrepancies are possibly due to the stochastic nature of the problem and the dynamics of the e-waste market. A physical interpretation is that component-wise, the values may fluctuate.

7 Conclusion and Future Recommendation

Under the present study, a model has been proposed which predicts the amount of e-waste generated over the lifespan of an EEE. The model has certain limitations; the predicted data is well within the range of the other predicted secondary data. There are certain challenges faced in during the course of the study. The primary problem faced is the absence of data indicating the amount of UEEE that enters the second-hand market. An informal industry has fostered in developing countries like India that is specialized in refurbishment and upgrade of UEEE [10]. There are some electricians who take away the waste CFL lamps and refurbish them for their personal use. UEEE which enters the second-hand market is refurbished and upgraded. CFL lamps are also sometimes sold at low cost after repairing in the rural areas. This informal industry constitutes about 90% of the total market in India and does not have any formal record keeping. While records are available for the USA and the EU, formal records are not present for most of the remaining parts of the world. There is also hardly any documented evidence available of the amount of e-waste generated for any region. Reason being, a considerable amount of this waste is handled by informal sector to extract precious metals using methods which are not green compliant. A significant portion of the e-waste is also exported illegally to developing nations which use them in a variety of ways, the primary usage being that of landfill. In such a scenario, verification of model becomes a challenge in the absence of data.

8 Future Scope

The paper presents a new approach towards estimation of e-waste generation. There are several factors which are associated with these. A practical model with more complexity is not desired. Despite the stochastic nature of the problem, it may be useful to carry out such an analysis for better understanding of the response of the problem and the output predicted may be close to reality.

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Toxicity Characterization of Heavy Metals from Waste Printed Circuit Boards

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Abstract Toxicity characterization (TC) tests for solid waste have proven to be indispensable characterization tools for estimation of environmental threat. These tests mimic the fate of solid waste in environmental conditions and provide relevant information about the leaching behaviour of metals in natural conditions based on which they are categorized as toxic. In view of this, the aim of this paper is to identify the leaching assessment on six heavy metals, namely As, Ba, Cd, Ni, Pb and Se from waste printed circuit boards (PCBs) of obsolete electrical and electronic equipment (EEE) that are computer, laptop, washing machine (WM), television (TV) and air conditioner (AC) adopting two TC tests, namely toxicity characteristic leaching procedure (TCLP) and synthetic precipitation leaching procedure (SPLP) which simulate solid waste leaching in several dumping scenarios and metal mobility potential of solid waste dumped in situ, in or on the ground, exposed to acid rain, respectively. TC results indicated that Pb was the predominant metal species with concentration of 10.50 ± 0.73 mg/L in SPLP to 856.71 ± 2.30 mg/L in TCLP leachates and exceeded the toxicity characteristic (TC) limit in all the five PCBs investigated for TCLP and SPLP tests. All other metals analysed were below permissible limit while some metals such as Ba was absent in the leachates of all the five waste PCBs in TCLP as well as SPLP analysis. Cd was absent in TCLP leachates of laptop, WM and AC, while As was not present in AC TCLP as well as SPLP leachates. Cd, Ni and Se were found to be in superior concentrations in SPLP leachates than TCLP. These results proved that leaching from waste PCBs was a significant source of Pb in landfills and electronic waste (e-waste) dump-yards leading to environmental toxicity.

Keywords Waste printed circuit board · Metals · Leaching · Toxicity characterization

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1 Introduction

The rapid growth of electric and electronic equipment (EEE) coupled with accelerated product obsolescence has led to build up of electronic waste (e-waste). The quantity of e-waste generated constitutes about 8% of municipal solid waste (MSW) and is the fastest growing waste stream in the world [1]. United Nations University (UNU) reports that around 41.8 Mt of e-waste were generated worldwide in the year 2014 out of which 11.7 Mt originated from America while Europe contributed to a total of 11.6 Mt e-waste generations. In Asia, total e-waste generation in 2014 was 16.0 Mt. India ranks third in the list of Asian countries contributing to 1.7 Mt e-waste generations. China tops among the Asian countries with the highest e-waste generation of 6.0 Mt followed by Japan with 2.2 Mt. The worldwide e-waste generation is predicted to increase at growth rate of 4–5% per annum reaching to 49.8 Mt by 2018 [2]. The problem of e-waste generation is, however, more intense in emerging economies like Africa, India and China where it is compounded by the transboundary export of e-waste in considerable quantities (about 50–80%) from the developed and industrialized countries, despite of prohibition through the Basel Convention (1992) law [3, 4]. According to a report by UNU 2015, from total of 41.8 Mt of e-waste generated worldwide in year 2014, only around 6.5 Mt of e-waste were collected formally by the takeback systems, while the rest were disposed to waste bins. However, there is great disparity and wide gap between e-waste generation, their formal collection-recycling and those entering the waste bins [2]. The composition of e-waste is heterogeneous, diverse and complex. Electronic equipment such as monitors, telecommunication devices and other large electrical appliances which are rich in metallic resources with significant amount of precious, toxic elements is usually subjected to recycling while rest, up to 90% of world's e-waste is illegally dumped [5].

Discarded e-wastes have toxic, health-threatening metals such as Hg, Cd, Cr, As, Pb, Ag in abundance. End-of-life EEE are disposed off by the consumers to normal dustbins together with the other type of household waste making up MSW stream which depending on the treatment method opted are sent either to incinerators, landfills or are dumped over the ground in the dump-yard. The discarded obsolete e-waste not only leads to resource loss but also have destructive impact on environment. E-waste in incinerators leads to emission of harmful compounds causing air pollution, whereas e-waste in landfills and open dump-yards leads to generation of toxic leachates which enter into the environment and become available to humans and biota. Printed circuit board (PCB) is core component of e-waste and constitute 3–6% of the total weight of e-waste [6, 7]. The dramatic increase in the amount of waste PCBs with the increase in e-waste generation is indispensable [1]. A variety of inorganic and organic components including metals such as heavy metals, precious metals, toxic metals; brominated flame retardants like polybrominated diphenyl ethers (PBDEs), polybrominated biphenyls (PBBs) present in PCBs makes them hazardous and also a potential reservoir of recyclable materials. Pb is the most common toxic constituents of PCBs which is abundantly present as

Sn–Pb solders (with 60:40 ratio of Sn to Pb) which have found to leach at higher concentrations in landfills and dump yards [8]. Several toxicity characteristic (TC) tests have been prescribed by the international organisations for determination of toxicity of solid waste to be classified as hazardous waste and restrict their land disposal. Resource Conservation and Recovery Act of 1976 (RCRA) promulgated criteria to differentiate hazardous and non-hazardous wastes and administers control and management of solid and hazardous waste. One of the most significant dangers posed by hazardous wastes stems from the leaching of toxic metals into soil and groundwater. Based on this concern, RCRA sets limit for eight elements, As, Ba, Cd, Cr, Pb, Hg, Se and Ag.

The United States Environmental Protection Agency (USEPA) Extraction Procedure Toxicity Characteristic (EP) test was the earliest to be designed to simulate the leaching of a solid hazardous waste co-disposed with municipal waste in a sanitary landfill and to assess the potential impact of the leachates on groundwater contamination [9]. The Toxicity Characteristic Leaching Procedure (TCLP EPA Method 1311) was second-generation extraction procedure developed by USEPA as a method addressing the shortcomings of EP [10]. TCLP promulgated for use in determination of mobility of primarily organic and inorganic constituents present in waste that may pose a threat to the environment. Both the tests, EP and TCLP, simulate solid waste leaching in landfill condition. However, EP addressed only a few toxic semi-volatile and heavy metals leachates, while TCLP waste characterization is based on additional toxic constituents of hazardous waste including extensive list of volatile and semi-volatile analytes and thus has replaced EP. In addition to the TCLP test simulating waste disposed inside MSW landfills, USEPA also designed test such as the Synthetic Precipitation Leaching Procedure (SPLP) (EPA Method 1312) for assessment of mobility of both organic and inorganic analytes of waste dumped in situ, in or on the ground surface exposed to rainfall, with an assumption that rainfall is slightly acidic [11].

Prior researches have demonstrated TC and mobility potential of various solid wastes [12–15]; however, there is very limited study on TC of e-wastes encompassing waste PCBs of various EEEs exploiting standard TCLP and SPLP, mimicking the environmental conditions for the leachability of metals in various dumping scenarios. Several studies have examined TCLP and SPLP assessment for metals leaching from PCBs [8, 16]; Zhou et al. [17] but the studies conducted are not comprehensive and have not taken into consideration leaching behaviour of toxic metals from PCBs of different type of obsolete electronic products.

This paper therefore aims at development of a detailed interpretation of leaching behaviour of six toxic metals As, Ba, Cd, Ni, Pb and Se from waste PCBs of five different end-of-life electronic equipment, viz. computer, laptop, washing machine (WM), television (TV) and air conditioner (AC) using TCLP and SPLP simulating landfill and open dump-yards conditions. The objective of this paper is to provide quantitative data for leaching potential of metals from waste PCBs of different EEEs and a comparative assessment of TCLP and SPLP for their ability to extract metals from e-wastes in environment under simulated conditions of landfills and acid rain.

2 Methods and Materials

2.1 *Sample Collection and Processing*

PCBs of different discarded electronic equipment, viz. computer, laptop, television (TV) washing machine (WM) and air conditioner (AC) were collected from electronics repair shops of Patna, India. The collected waste PCBs samples were then dismantled manually to remove mounted electronic components like capacitors, resistors, semiconductor chips and were mechanically crushed using cutting mill (SM200, Retsch) to particle size <9.5 mm. Three replicate of shredded samples were taken from each of the PCBs and were subjected to subsequent leaching tests.

2.2 *Extraction Tests*

TCLP and SPLP tests are designed to meet the intent of metal leaching in landfills and acidic rainfall conditions. To analyse the potential leachabilities and leaching trends of waste PCBs, extraction tests TCLP and SPLP were performed. Shredded PCBs of particle size <9.5 mm were subjected to each of the above-mentioned tests in polytetrafluoroethylene (PTFE) bottles at specified test conditions for determination of TC of e-waste. The extractions of metals were performed according to the prescribed standard methods of TCLP, SPLP for six toxic metals and five waste PCBs. A test blank was also included for each of the leachability test. The extraction test conditions for the metals from PCB samples are summarized in Table 1. The leaching tests were performed in triplicates to ensure the reproducibility, reliability and accuracy of the test. The extracts obtained at the end of the extraction tests were measured for their metal contents. All the analyses were conducted in triplicates.

Table 1 Leaching test conditions for TCLP and SPLP of waste PCBs

Leaching tests	Solid–liquid ratio	Extraction medium (per litre)	Extraction time (h)	pH	Agitation speed (rpm)	Temperature (°C)
TCLP	1:20	5.7 mL glacial acetic acid + 64.3 ml 1 N NaOH	18 ± 2	4.93 ± 0.05	30 ± 2	22 ± 2
SPLP	1:20	60/40 weight per cent mixture of H_2SO_4/HNO_3	18 ± 2	4.2 ± 0.05	30 ± 2	23 ± 2

2.3 Metal Content Analysis and Determination of TC

For the quantification of metals in TCLP and SPLP extracts, the leachates produced by each of the leaching tests were filtered by 0.7 μm glass fibre filters using pressure filtration. Microwave-assisted digestion (Milestone, Ethos easy) of the filtered extracts was then performed according to USEPA Method 3015A (USEPA, [18]. After digestion, the extracts were again filtered by 0.22 μm millipore filters and analysed by flame atomic absorption spectrophotometer (AAS) (iCE3500, Thermo Scientific). All analyses were done in triplicates following the standard methods.

3 Results and Discussion

3.1 Leaching Potential of Metals from Waste PCBs

Acetic acid used as leaching solution in TCLP represents the organic acids produced during biological degradation of wastes, especially MSWs in landfill. TCLP thus simulates the fate of metals present in PCBs which are indiscriminately dumped into landfills along with MSWs. Similarly, acid mixture of sulphuric and nitric acids represents the acidic constituents of acid rain. However, the concentrations of acids as prescribed by the two methods represent worst-case acidic conditions. The metals leaching potential from waste PCBs of obsolete EEEs by TCLP and SPLP are presented in Table 2. Results indicate that the concentration of majority of toxic metals leached from waste PCBs is within the threshold limit for toxicity. However, the concentration of Pb has exceeded the maximum concentration for characteristic toxicity in both TCLP and SPLP. Pb concentrations in all the five PCBs investigated by TCLP are in the range of 856.71 ± 2.30 mg/L to 251.65 ± 3.56 mg/L which is far beyond the USEPA set limit for toxicity. Conversely, metals such as Ba were not at all detected in the TCLP leachates of waste PCBs of five different obsolete EEEs. As was not found in AC TCLP leachates, while Cd was found missing in TCLP leachates of laptop, WM and AC. Pb concentrations in SPLP leachates also exceeded the 5 mg/L TC limit and are in the range of 10.50 ± 0.73 mg/L to 16.03 ± 1.11 mg/L. The concentration of Ba in SPLP leachates of all the waste PCBs of five different end-of-life EEEs was also not detected. Like TCLP, As was also absent in SPLP leachates of waste PCBs of AC.

Pb has highest ability and sensitivity to be released from PCB substrate in TCLP and SPLP conditions. Several studies have documented that PCBs often exceed the Pb toxicity limit of 5 mg/L [8]; this might be because of extensive use of Pb in PCBs as solders. Moreover, Pb is higher in hierarchy of metals in reactivity series because of which Pb reacts more vigorously with dilute acids used in TCLP as well as SPLP to form soluble salts like lead acetate and lead nitrate. Ba was not detected in any of the TCLP and SPLP leachates of PCBs; this might be because Ba is not a

Table 2 Metal concentrations in TCLP and SPLP leachates of waste PCBs (n = 3)

PCBs	Metals (mg/L)												Reference
	As		Ba		Cd		Ni		Pb		Se		
	TCLP	SPLP	TCLP	SPLP	TCLP	SPLP	TCLP	SPLP	TCLP	SPLP	TCLP	SPLP	
Computer	0.08 ± 0.42	0.24 ± 0.21	ND	ND	0.1 ± 0.01	0.116 ± 0.009	0.19 ± 0.68	0.56 ± 0.09	360.97 ± 3.71	11.68 ± 2.25	0.78 ± 0.01	0.89 ± 0.11	Present study
Laptop	0.40 ± 0.16	0.09 ± 0.05	ND	ND	ND	0.04 ± 0.02	0.03 ± 1.61	0.44 ± 0.31	856.71 ± 2.30	13.73 ± 1.21	0.39 ± 1.12	0.55 ± 0.26	
WM	0.90 ± 0.03	0.16 ± 0.11	ND	ND	ND	0.02 ± 0.01	0.42 ± 0.22	0.70 ± 0.62	251.65 ± 3.56	16.03 ± 1.11	0.76 ± 0.64	0.84 ± 0.88	
TV	0.02 ± 0.01	0.05 ± 0.02	ND	ND	0.02 ± 0.01	0.09 ± 0.001	0.49 ± 0.02	0.52 ± 0.35	308.59 ± 4.16	10.50 ± 0.73	0.151 ± 0.009	0.48 ± 0.27	
AC	ND	ND	ND	ND	ND	0.007 ± 0.0004	0.23 ± 0.001	0.81 ± 0.03	511.56 ± 2.87	16.60 ± 0.10	0.84 ± 0.32	0.95 ± 0.33	
Maximum concentration for characteristic toxicity	5		100		1		0.2*		5		1		US Federal Register [9] and *DTSC [19]

Values represent arithmetic mean ± standard deviation from three replicates major component of PCBs and is usually not extensively used in PCBs. The absence of As in both TCLP and SPLP leachates of AC can be correlated either to its nonexistence in AC PCB or inefficiency of acids in its leaching. Additionally, the mobility and stability of metals in waste PCBs depend on their binding to the PCB laminate. The fibreglass/silica laminate locks up the metals which upon physical and chemical action get liberated. Except for computer PCBs, As concentration in leachates of TCLP are higher than in SPLP which indicate its susceptibility to the acidic condition inside landfill and propensity to leach easily as compared to acid rain conditions. Concentrations of Cd Ni and Se in SPLP leachates demonstrate higher leaching potential of H_2SO_4–HNO_3 to acetic acid and NaOH. Thus, because of the dominance of Pb in the leachates beyond permissible limit of toxicity waste PCBs used in this study could be categorized as hazardous waste and require strict regulation and control.

4 Conclusions

The determination of toxicity level of metals is significant factor that indicates extent of risk of metal to environment. The presence of Pb in PCBs leachates upon disposal of the discarded EEEs raises several ecological concerns, such as the fate of the Pb in environment leading to contamination of soil, groundwater and ultimately its uptake by flora and fauna. Leachability testing of the PCBs and subsequent quantification of toxic metals concentration in all the leachates generated signify that the e-waste evaluated here exceed 5 mg/L TC limit for Pb. Cd, Ni and Se showed relatively high mobility potential compared to other metals in case of SPLP. However, all other metals except Pb were in concentrations below the recommended threshold level of toxicity.

Although majority of metals under investigation were below the toxic limit, tremendous amount of Pb leached from e-waste, in form of PCBs, can pose deplorable risk to environment if inappropriately managed and therefore should be handled as a hazardous waste. Therefore, the focus on safe disposal, management and recovery of metals from e-waste is necessary in the present scenario.

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Toxic Pollutants Survey in Soils of Electronic Waste-Contaminated Sites in Delhi NCR

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Abstract Over the years, with the advancement in technology, a rise in the usage of electronic items has been developed and along with that there has been an increase in the generation of electronic waste. This is of great concern, especially in developing countries, as it has been gradually polluting the environment, causing bioaccumulation and ultimately affecting the ecosystem function. The present study is on the pollutant-level determination of soils in the electronic waste (e-waste) dumping sites with special reference to Delhi NCR, India, and to study the effect of electronic waste contamination on soil microbial activities. Heavy metals like lead, cadmium, chromium, nickel and arsenic were studied for their contamination levels in the soil samples collected from different sites of the electronic waste dumping area. The concentrations of heavy metals were compared with a control uncontaminated sample. In India, presently there are no permissible limits set for the contamination of heavy metal pollutants in the soil. Among the heavy metals, arsenic, nickel and chromium (measured by ICP-MS), with the values of 3.15, 89.4 and 35.5 mg/kg, respectively, were found to be at high levels and are of concern. Contamination of soil with polybrominated diphenyl ether (PBDE), which is a persistent brominated hydrocarbon and which tends to bioaccumulate in the environment, was also detected by GC-MS. This shows that e-waste dumping and recycling sites are some major sources for the contamination of the environment with toxic pollutants. The effect of these toxic pollutants on soil enzyme activities was studied, and it was found that soil dehydrogenase, β-glucosidase and arylsulphatase activities were significantly reduced in the e-waste-contaminated soil samples indicating that the microbial activities are greatly affected by the toxic pollutants generated by the e-waste in the soil. Further work on the microbial community analysis of the contaminated soil samples through molecular fingerprinting is under progress.

Keywords Electronic waste · Heavy metals · Polybrominated diphenyl ether
Microbial activities

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1 Introduction

Electronic waste (e-waste) has become an increasing type of waste in many countries especially the developing countries where a number of dumping sites and illegal recycling units are present. Formally termed as waste electrical and electronic equipment (WEEE), these waste materials over a period of time accumulate and because of the toxic components present in the e-waste, the surrounding environment (soil and water) gets contaminated and further affects the ecosystem function. On the other hand, the harsh environmental conditions also give rise to the establishment of beneficial micro-organisms which can remediate the toxic pollutants in the contaminated sites. Therefore, intensive research on the soil microbial diversity, its function and its relationship to soil components and plants is very much necessary in order to maintain the ecosystem function and to utilize the beneficial effects of the bioremediating micro-organisms.

The chief pollutants of e-waste-contaminated sites are heavy metals like cadmium, lead, hexavalent chromium, mercury, arsenic, nickel, selenium, and brominated flame retardants (BFRs) like polychlorinated biphenyl (PCB), tetrabromo-bisphenol A (TBBA), polybrominated biphenyl (PBB), polybrominated diphenyl ether (PBDE). Heavy metal contamination may result in various harmful effects to human beings such as damage to kidney and liver, brain disorders, skin cancer and respiratory ailments [1]. BFRs are known to cause hormonal disorders and also neurobehavioural toxicity [2, 3]. The heavy metals and organic pollutants also have a harmful effect on the ecosystem function [4]. At low concentrations, some of the heavy metals are essential micronutrients both for the micro-organisms as well as the plants, but at higher concentrations, they may have negative influence on the microbial diversity and directly or indirectly on the growth of plants [4, 5]. Brominated flame retardants are considered toxic and persistent group of pollutants. These pollutants are known to cause bioaccumulation and entry into the food chain. The lower congeners formed after abiotic (e.g. photodegradation and decomposition at high temperature) and biotic degradation (e.g. bioaccumulation and biotransformation) are known to be more persistent and toxic [6].

Globally, more than 40 million tons of e-waste generation is estimated every year [7, 8]. India is one of the top countries affected by e-waste pollution among the developing countries because of many informal recycling units, lack of regulations and improper management of e-waste [7]. The toxic pollutants penetrate into the soil and seep into groundwater. Toxic pollutants like BFRs are recalcitrant, cause bioaccumulation and have a long-term polluting effect on the soil [3]. There have been a number of reports on the toxic effect of heavy metal contamination on soil microbial activities [9, 10]. It has been found that a number of soil enzyme activities which are important in the bio-geochemical cycles are greatly affected by toxic pollutants present in the soil. Keeping this in mind, the present study focusses on the impact of toxic pollutants (toxic heavy metals and PBDE) on soil enzyme activities. This study gives an important insight into the response of microbial community to e-waste pollutants and will further be useful in soil management studies and bioremediation.

2 Materials and Methods

2.1 Selection of E-waste Contamination and Soil Sampling

In Delhi NCR (India), Loni and Mandoli are well-known places for informal e-waste recycling and dumping. For the present study, e-waste-contaminated soil samples were collected from Loni Dehat Village and Mandoli Tila Shahbazpur village (Gaddha Colony) by the random sampling method. Five sites were chosen for each location, and four subsamples were taken under each site. The subsamples were mixed for each site to get a homogenous mixture and thereafter analyses were carried out. Samples were collected from 0 to 15 cm depth in aseptic conditions and transported to the laboratory in 4 °C conditions. The samples were sieved through a 2-mm sieve and kept at −20 °C for analysis of soil microbial activities. Samples for analysis of heavy metals and polybrominated diphenyl ether (PBDE) are air-dried and kept at room temperature.

2.2 Soil Analysis for Pollutants

2.2.1 Heavy Metal Contamination

Heavy metals like lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg) and nickel (Ni) were tested through ICP-MS at Division of Soil Sciences, Indian Agricultural Research Institute (IARI), Pusa, New Delhi.

2.2.2 Polybrominated Diphenyl Ether (PBDE) Contamination

Contamination of samples with PBDE was analysed by GC-MS using standard solutions of brominated diphenyl ethers (BDE) at the Environment Protection Services at Shriram Institute of Industrial Research, New Delhi (India).

2.3 Soil Enzyme Activities

Soil enzyme activities for dehydrogenase, β-glucosidase, alkaline phosphatase, acid phosphatase and arylsulphatase were determined for the different soil samples. The determinations were carried out in triplicates.

2.3.1 Dehydrogenase Activity

Dehydrogenase activity was determined by the method developed by Casida et al. [11]. Soil samples were mixed with $CaCO_3$ at a ratio of 0.1 g $CaCO_3$ per 10 g (moist weight) of soil and preincubated for 2 days. Six grams of preincubated soil was mixed with 1 ml of 1% (w/v) dextrose and 1 ml triphenyltetrazolium chloride (TTC). For the soil blank, 1 mL of water was taken instead of TTC. The solution was mixed with a glass rod and incubated at 37 °C for 24 h. Soil samples were transferred to a funnel containing Whatman no. 5 filter paper with the help of methanol and collected in a graduated cylinder. Filtrate was collected till red colour disappeared which indicates that formazan had been extracted. The collected filtrate was read at 485 nm using Shimadzu UV 1800 spectrophotometer. The dehydrogenase activity was determined using a formazan standard curve and expressed as milligrams of formazan per gram dry soil.

2.3.2 β-Glucosidase Activity

For the determination of β-glucosidase activity, 1 g soil was mixed with 4 mL 0.05 M McIlvaine's buffer (pH 6) and 1 ml 25 mM *p*-nitrophenyl-β-D-glucoside (pNPG) and kept at 37 °C water bath for 1 h. After that 1 mL 0.5 M $CaCl_2$ and 4 mL 0.2 M Tris-hydroxy methyl aminomethane (pH 12) were added and centrifuged for 10 min at 1500 × g. The absorbance was taken at 410 nm, and β-glucosidase activity was determined using a *p*-nitrophenol (pNP) standard curve and expressed as microgram pNP per gram dry soil.

2.3.3 Arylsulphatase Activity

Soil was preincubated for 1 h at 20 °C with 0.2 ml toluene to inhibit microbial enzyme activity due to proliferation. Arylsulphatase activity was determined by the method as described in Whalen and Warman [12]. Preincubated soil (2 g) together with 4 mL of 0.5 M acetate buffer and 1 mL of 0.02 M potassium 4-nitrophenyl sulphate was incubated at 37 °C for 1 h. The reaction was stopped by cooling at 0 °C and centrifuged at 11,000 g for 10 min. Supernatant (3 mL) was mixed with 2 mL of 0.5 M sodium hydroxide solution. The absorbance of *p*-nitrophenol released was measured at 410 nm using Shimadzu UV-VIS spectrophotometer.

The arylsulphatase activity was determined using a standard curve of *p*-nitrophenol and expressed in microgram pNP per gram dry soil per hour.

2.3.4 Acid Phosphatase Activity

Soil acid phosphatase activity was determined by the method of Tabatabai and Bremner [13]. One gram of air-dried soil together with 4 mL of Sorensen's phosphate buffer (pH 6.5), 0.25 mL of toluene, and 1 mL of 0.115 M disodium *p*-nitrophenyl phosphate tetrahydrate were mixed in a 50 mL Erlenmeyer flask. The flasks were stoppered and placed in a 37 °C water bath for 1 h. One millilitre of 0.5 M calcium chloride and 4 mL of 0.5 M sodium hydroxide were added to each flask and mixed well. Finally, the soil suspension was filtered through Whatman no. 1 filter paper, and the absorbance of the filtrate was read at 420 nm. The amount of *p*-nitrophenol was determined using a standard curve of *p*-nitrophenol and expressed in microgram pNP per gram dry soil per hour.

2.3.5 Alkaline Phosphatase Activity

Alkaline phosphatase activity was determined by the method of Tabatabai [14] and Schinner et al. [15] with a buffered disodium *p*-nitrophenyl phosphate tetrahydrate solution. Two grams of air-dried soil was mixed with 5 mL 0.5 M $CaCl_2$ and 1 mL *p*-nitrophenyl phosphate tetrahydrate solution prepared in 0.1 M phosphate buffer (pH 10). The solution was incubated at 37 °C for 1 h and 4 mL was transferred to a fresh tube. It was centrifuged at 2500 rpm for 5 min, and 3 mL supernatant was transferred to fresh tubes. The absorbance was read at 440 nm, and the amount of *p*-nitrophenol released was determined using a standard curve of *p*-nitrophenol. Results were calculated in microgram pNP released per gram dry soil per hour.

3 Results and Discussion

3.1 Sample Collection

Samples were collected from sites where e-waste contamination takes place through different activities. Control sample MC is from a place about 1 km away where no e-waste activities take place. Table 1 shows description about the different samples collected.

Table 1 Description of the soil samples

S. No.	Sample No.	Site
1	MC	Control (no e-waste)
2	M0	Disposal area
3	M2	Contaminated grassland
4	M3	Area near the open burning site
5	M5	At the open burning site
6	L1	Area near open burning site
7	L2	Contaminated grassland

3.2 Heavy Metal Contamination

Samples of Mandoli had higher levels of heavy metal contamination as compared to those of Loni (Table 2). The pH of all the soil samples ranged between 5.5 and 6.5. Lead levels in the soil samples tested varied from 5.48 to 94.1 ppm. Cadmium levels were found to be very low ranging at 0.05–0.91 ppm. However, sample M3 which had the highest Cd level was nine times higher than the control sample. Hexavalent chromium levels ranged from 5.03 to 35.5 ppm. The highest levels of chromium were found in M0 and M3 with levels about seven times higher than the control. Arsenic levels varied from 0.95 to 7.93 showing relatively high levels of contamination in samples M0 and M5. The contamination levels were about seven times higher than that of the control. Contamination with nickel was also found to be very high in samples M0 and M3 with 63.2 and 89.4 ppm, respectively (Fig. 2). In India, at present, there are no permissible limits set for the heavy metal contamination in soils. However, results of the analysis showed that lead, cadmium, chromium, arsenic and nickel levels were within the permissible limits of USA, UK and Europe [16]. It has also been observed that arsenic and nickel contamination in the Mandoli soil samples were alarmingly high (Fig. 1).

Table 2 Soil heavy metal and PBDE analysis

S. No.	Soil sample	Metals					PBDE
		Cr	Cd	Pb	As	Ni	(ng g^{-1} dry weight)
		(ppm)					
1	L1	13.9	0.05	17.2	1.43	7.40	0
2	L2	16.5	ND	5.48	1.62	7.41	0
3	M0	34.8	0.78	58.6	7.22	63.2	48.8
4	M5	22.1	0.13	14.5	7.93	22.1	45.5
5	M2	32.8	0.09	6.52	3.15	15.5	6.5
6	M3	35.5	0.91	94.1	2.47	89.4	57.5
7	MC	5.03	0.1	5.8	0.95	6.25	0

ND Not detected

Fig. 1 E-waste dumping sites, **a** disposal site Mandoli. **b**, **c** Areas near open burning site in Mandoli. **d** Open burning site in Loni

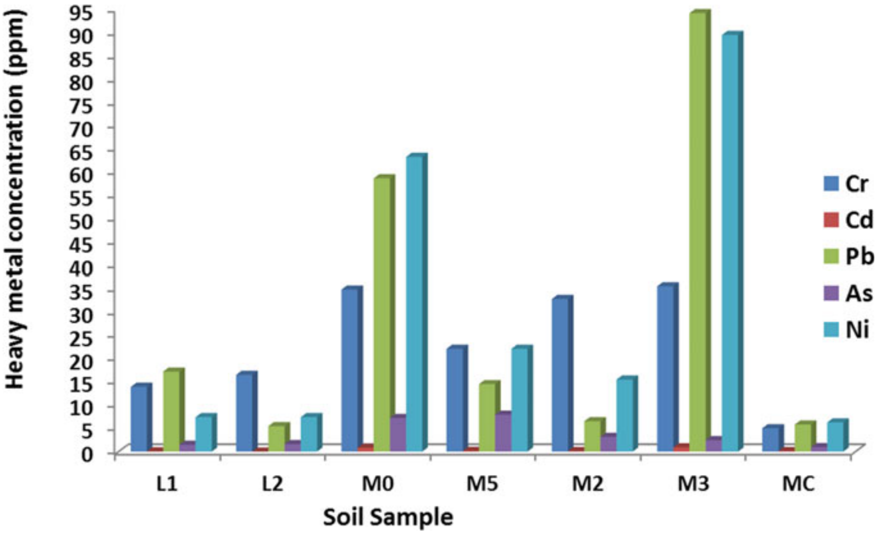

Fig. 2 Heavy metal levels in soil samples

3.3 PBDE Contamination

PBDE was detected in the Mandoli samples M0, M5, M2 and M3 and not detected in the Loni samples L1 and L2 as well as in the control sample MC. It was observed that in all the four samples collected from Mandoli, there was presence of BDE-7, BDE-28 and BDE-100 which are lower brominated congeners of PBDE and are known to be more harmful. The results show that the area contaminated with toxic heavy metals and BFRs is posing a risk to the environment and may cause health hazard to the human population [7, 17].

3.4 Effect of Heavy Metal Contamination on Soil Enzyme Activities

The effect of heavy metal contamination on soil enzyme activities has been depicted in Table 3. Heavy metal contamination greatly affected the dehydrogenase activity showing a reduced activity with increasing level of contamination. It was observed that dehydrogenase activity was 467.47 mg g^{-1} dry soil for the control sample MC whereas for sample M3, with the highest level of Pb, Cr and Ni contamination, it was 6.61 mg g^{-1} dry soil. β-glucosidase was not affected by the increasing level of contamination. Arylsulphatase and acid phosphatase activities were also reduced with increasing level of heavy metal contamination. Alkaline phosphatase was not altered much with contamination by heavy metals. There have been a number of studies on the effect of soil toxic pollutants on the soil enzyme activities. It has been reported that most of the soil enzyme activities are reduced greatly by heavy metal contamination [18]. However, microbial communities are known to vary depending on the soil types and on their resistance properties to heavy metals and toxic pollutants [4]. For example, fungi are known to secrete different substances which can absorb or precipitate the heavy metals. Therefore, the effect of toxic pollutants on different soil enzyme activities also varies greatly.

4 Conclusion

The present study is an initial investigation of the pollution level of e-waste dumping and recycling sites in an around Delhi, India. The effect of heavy metals and PBDE contamination on soil enzyme activities is also studied. It has been found that most of the heavy metals are under the permissible limits but are quite higher than that of the control. PBDE contamination has also been detected in all the soil samples collected from Mandoli region and is significantly high in the areas near the open burning sites. The soil enzyme activities were mostly found to be reduced in the contaminated samples as compared to the control indicating that the activities

Table 3 Comparison of heavy metal levels and soil enzyme activities

Sample	Heavy metals (ppm)		Dehydrogenase (mg g^{-1} dry soil)	β-glucosidase (μg pNP g^{-1} dry soil h^{-1})	Arylsulphatase (μg pNP g^{-1} dry soil h^{-1})	Acid phosphatase (μg pNP g^{-1} dry soil h^{-1})	Alkaline phosphatase (μg pNP g^{-1} dry soil h^{-1})
MC	Cr	5.03	467.47	13.37	38.64	17.83	14.56
	Cd	0.1					
	Pb	5.8					
	As	0.95					
	Ni	6.25					
M0	Cr	34.8	50.75	47.01	24.89	4.97	10.1
	Cd	0.78					
	Pb	58.6					
	As	7.22					
	Ni	63.2					
M2	Cr	32.8	96.67	25.84	7.17	5.16	14.93
	Cd	0.09					
	Pb	6.52					
	As	3.15					
	Ni	15.5					
M3	Cr	35.5	6.61	62.52	15.63	5.6	11.25
	Cd	0.91					
	Pb	94.1					
	As	2.47					
	Ni	89.4					
M5	Cr	22.1	80.14	17.76	11.84	3.5	10.65
	Cd	0.13					
	Pb	14.5					
	As	7.93					
	Ni	22.1					
L1	Cr	13.9	34.66	4.12	14.68	5.35	10.37
	Cd	0.05					
	Pb	17.2					
	As	1.43					
	Ni	7.40					
L2	Cr	16.5	71.51	7.09	13.4	3.1	12.77
	Cd	ND					
	Pb	5.48					
	As	1.62					
	Ni	7.41					

of enzymes are related to the contamination by toxic pollutants. Further work on the microbial community analysis of these e-waste-contaminated samples is underway. This will help in understanding how micro-organisms respond to toxic pollutants and influence transformation of these substances.

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Security Threat Analysis and Prevention Techniques in Electronic Waste

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Abstract With the rapid growth of information and communication technology (ICT), an increasing number of electronic gadgets like computers, cell phones, entertainment electronics gadgets, and others are being sold to consumers, and when these gadgets stop functioning or become obsolete or unwanted by a user, they get converted to e-waste, also known as waste electrical and electronic equipment (WEEE). This e-waste is either disposed of in landfills or recycled by burning and dissolution in strong acids. But all of these processes can cause hazards to the environment and human health. So, new approaches to manage e-waste effectively have been proposed and implemented to deal with the environment and human health hazards, which include reusing electronic components (EC) which are still functional within waste electronic gadgets via secondary markets. The parts of waste electronic gadgets that cannot be reused are recycled to recover the materials from them. In this paper, the security concerns arising due to reusing and recycling process through reverse engineering of waste electronic gadgets that can lead to piracy and cloning have been explored and possible existing solutions have been reviewed against the security concerns. On the other hand, since reusable ECs are entering the semiconductor industry supply chain through a secondary market, the

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supply chain security concerns that can arise due to mixing of a brand-new EC with old reusable ones are considered and possible existing solutions have been stated to address the problem. Also, the possibility of leakage of information from waste storage devices like hard drives has been considered and technique to prevent that has been inspected.

Keywords E-waste · Security threat · Reverse engineering · Data security
Electronic circuit

1 Introduction

Growth in population, urbanization, and the increase of living standard are the three major factors that drive the increase of waste generation worldwide. The 2013 world population was about 7.2 billion and is projected to increase by an average growth rate of 1% per year over the coming decade while urban population is expected to grow roughly 1.5% per year in the same period [1–3]. E-waste, a more generalized term for WEEE, may be defined as any electronic item that has reached to the end of its lifecycle. According to Basel Action Network, 'E-waste encompasses a broad and growing range of electronic devices ranging from large household devices such as refrigerators, air conditioners, cell phones, personal stereos, and consumer electronics to computers which have been discarded by their users' [4]. There are certain reasons for which e-waste is now a mini-catastrophe, the major one being the rate of product obsolesce. The rapid innovation in the electrical, commercial purposes of the electronic equipment division is continuing to shorten product lives and accelerate the replacement process, and most of these devices convert to waste within a couple of years following the manufacturing date.

It was estimated that about 20 million PCs became waste in 1994, and the figure had increased to 150 million PCs in 2010. In the USA more that 152 million communication devices were sold in 2008, whereas in European Union (EU), the total units of electronic devices placed on the market in 2009 were more than 3.8 billion. The figure is also huge for the developing countries, for example, in China approximately 40 million PCs were sold in 2009 [5]. Apple sells more than 300,000 new phones every day in the world market and in the same time frame, more than 150,000 new Blackberries are also sold, and 700,000 new Android phones are being activated. All the phones that are replaced by these new devices end up in municipal landfills, and most of the new devices will end up also in the landfills within a couple of year [5, 6]. In 2014, nearly 41.8 million tons of e-waste was generated globally [7]. The Solution to E-waste Problem (StEP) initiative forecasts that by 2017, the world will produce about 33% more WEEE or 72 million tons of WEEE [8].

E-waste has many toxic substances that may endanger the human and natural environment upon their release. The high toxicity of e-waste and its potential to cause severe environmental hazard has forced developed countries to establish strong regulations for e-waste handling and disposal in late 1980. The e-waste regulations aim to protect human life and environment and ensure safe disposal of e-waste. The new regulations have encouraged the illegal trafficking of e-waste from developed countries to developing countries (mainly to Africa and Asia). This situation coupled with the illegal trans-boundary movement of other hazardous materials, resulted in the development of international treaty on the Control of Trans-boundary Movements of Hazardous Wastes and their disposal called Basel Convention. Basel Convention aims to reduce the movements of hazardous waste between nations including e-waste and most importantly to prevent dumping of hazardous waste from developed to developing countries [9–11]. Unfortunately, the hazardous waste (including e-waste) illegal trafficking and trans-boundary movements remain major worldwide concerns to date, given the weak regulatory framework and high corruption level in developing countries. Ghosh et al. [12] presented a comparative study of e-waste management systems in the Brazil, Russia, India, China, and South Africa (BRICS) nations focusing on the compliance of these countries to Basel Convention and the trans-boundary movement of e-waste from developed countries to developing countries. The study also provided a generic framework based on learning from matured e-waste management system, visiting e-waste recycling units, and interviewing stakeholders in the supply chain to establish better e-waste management system in the BRICS nations. Debnath et al. presented a comparative analysis of sustainability of e-waste management in developed and developing countries using analytical hierarchical process (AHP) considering India, China, UK, USA, Bangladesh, Switzerland, and Nigeria [13]. The study showed that Switzerland has the most sustainable e-waste management system followed by India and China. The basic reason behind this was found to be very strong collection systems thrived by the informal collectors. Another comparative study between India, UK, and Switzerland also indicated that a strong supply chain is necessary for establishing a good e-waste management system [14]. While the collection of e-waste is at focus of the researchers, there is a hidden threat in the e-waste itself. The electronic components (EC) in the e-waste has some security concerns as techniques such as reverse engineering can be implemented to dig out information which can pose threats in different ways. Hence, proper disposal of the electronic components is imperative. Reuse and recycling option of ECs and its impact on the electronics industries has been explored by the researchers [15], but there is hardly any study that concerns the security threats from the ECs. The questions that arise now are—what are the possible security threats arising due to the reuse and recycling of electronic components? What are the possible solutions to these threats? This paper presents a study on the security analysis of electronic components reuse and addresses the questions bridge the gap.

2 Collection of Reusable ECs from E-Waste

To reuse ECs inside e-waste, Debnath et al. [15] have proposed a model by case study approach in which waste electronic gadgets are at first opened and then PCBs are taken out from the waste. While a few ECs are mounted independently inside a gadget, most of them which are mounted on PCBs are separated in a two-step method and then after testing some criteria for a specific group of an electronic component it belongs to, decision is taken regarding its reusability. A type of industry called 'Electronics Component Testing Industry' has been proposed in their model whose function is to collect e-waste from consumers and then testing electronic components inside them to check their state of reusability and selling the reusable Electronic Components to Semiconductor Manufacturing Industry.

In semiconductor industry, there is a work flow which includes steps like specification, design, manufacture, test, and ship. In the beginning, companies like IBM, Intel, Samsung, and Texas Instruments kept performing all the tasks as they possess all the facilities. Later, with advancement of technology, semiconductor manufacturing equipment becomes much more expensive and the cost of establishing and maintaining in-house manufacturing or fabrication facility commonly called 'fab' act as a hindrance in their way to make larger profit and revenue for a semiconductor company. This gave rise to companies without own fabs which send design to an external facility known as foundry for manufacturing which can be accessed on contract basis. Qualcomm founded in 1985 and Broadcom founded in 1991 were built using this model. Today, this concept companies include also giants like AMD, Nvidia, and hundreds of smaller companies with only few dozen employees. Thus, gradually from 1990s, the semiconductor manufacturing began to move offshore. In early 2000s, fabless American semiconductor companies kept doing design operations in-house and outsource the manufacturing offshore to a foundry in Asia. Today, American companies do the design offshore increasingly partly because of outsourcing. In some other cases, these companies establish an overseas office or acquire an overseas company in China, India, South Korea, and Eastern Europe where they hire high skilled workers but their salaries are much lower than their counterparts in USA which lead to spending less US dollars and increasing revenue and economic growth and prosperity in perspective of global economic terms [16].

Because of this pattern of operation of semiconductor industry, it creates an ironic situation that e-waste will be transported to these offshore countries where Electronics Component Testing Industry will accumulate reusable ECs from e-waste and supply it to neighbor semiconductor manufacturing facilities. This will be the right approach of work flow considering economic and ease of work benefits of the semiconductor industry in spite of existence of Basel Convention adopted by the EU and other OECD members [17].

But the problem is these offshore countries where e-waste will be transported are out of the jurisdiction control of organizations and governments of the country from which this has been supplied [18]. So, whether some kinds of threats exist in this process and if there are any existing solutions to these threats are explored in the upcoming sections.

3 Methodology

This paper is a combination of literature review and case studies. Nearly 50 papers were reviewed and to identify the problem. Different search engines were explored with keywords such as 'e-waste recycling,' 'threat from e-waste,' 'data security of e-waste,' 'reverse engineering' to find the literature in the focused area. The relevant literature was screened and information obtained from them was analyzed. Based on the analysis, some solutions were suggested. For further validation of the present scenario in practice, interviews with the informal collectors were carried out (as the threat is more from the informal management value chain). Based on these findings, conclusion was drawn.

4 Discussions and Analysis

4.1 Security Threat from Reverse Engineering

A waste electronic gadget is called waste but the gadget may not be totally non-functional. It can happen that the gadget is working but a few functions of it are out of service or its model is no longer wanted by a consumer and hence discarded. Chances are also there that the model is still prevailing in the market to be sold to consumers or an upgraded model of a gadget is now in demand by consumers in the market which has a number of similar features and integrated circuits and printed circuit boards used by the model in the waste gadget.

Since collection of reusable ECs from waste electronic gadgets requires opening of the gadgets systematically [15], it can pose a security threat in the form of reverse engineering (RE) of the gadget. Various advanced specialized equipments are used to perform the RE process. Examples of some of this equipment [19] are optical high-resolution digital microscope, scanning electron and transmission electron microscope (TEM), probe stations, and logic analyzers.

RE of an electronic gadget can occur in system level, PCB level and at chip level [19] which is explored in details in the upcoming subsections.

4.1.1 System Level RE

A system contains operation codes and control instructions called firmware that makes the system fully functional. By system level RE, the target is to extract the firmware in MCUs and nonvolatile memory (NVM) devices like read-only memory (ROM) and electrically erasable programmable read-only memory (EEPROM) or flash memory of DSPs with the help of modern optical and electron microscopy. For FPGA-based systems, the hardware functionality and interconnection called netlist is enclosed in binary configuration files called bitstream. FPGA RE involves accessing the bitstream file from the flash memory, decrypt the bitstream if it is encrypted, and finally making a mapping relationship between bitstream file and netlist [19].

4.1.2 PCB Level RE

The first aim of the PCB level RE is to identify all the components like active and passive ones, ICs and memory components on the board known as bill of materials (BOM) and the connections between them [19]. Other than that there can be silk-screen markings, JTAGs, DVIs, HDMIs, SATAs, PCIs, Ethernet ports, serial ports, parallel ports, debug ports, and display ports [20, 21] on PCBs. While some components mounted on the PCB can be easily identified through the use of IC markings, full custom and semi-custom ICs are identified through silk-screen markings on PCBs. After identification of an IC, its detailed functionality can be obtained from the data sheet available from the manufacturers' Web site [19].

After identification of the components of PCB, the next purpose of PCB reverse engineering is to find out how components are interconnected. The first step to do that is to access and image each layer of target circuit board. After all the layers have been placed together, a complete circuit layout can be identified which can reveal the design of PCB, locate specific connections, and find out how a product works by creating a schematic diagram. For that, the PCB deconstruction process is carried out which consists of steps like solder mask removal to expose the copper traces on PCB layers, delayering to access the inner copper layer of PCB and nondestructive imaging like 2D X-ray imaging and computerized tomography (3D X-ray) to obtain even individual image of layers of a multilayered PCB [20].

4.1.3 Chip-Level RE

The goal of the chip-level RE of an integrated circuit is to find package materials, wire bonding, different metal layers, contacts, vias and active layers and interconnection between metal layers. The steps are involved in RE process of a chip are decapsulation to access internal components of a chip, delayering, and imaging to obtain cross-sectional images of each layer of a chip and post-processing for analysis of images to identify the chip [19].

4.2 Anti-Reverse Engineering Solutions

Since the reverse engineering threats which exist in a waste electronic gadget is same as an operating electronic equipment, the anti-reverse engineering solutions that exist for operating electronic equipment will be same in case of their waste counterparts. These solutions exist in the three levels of reverse engineering (RE) which are as follows.

4.2.1 System Level Anti-RE

The system level anti-RE solutions act as the defense against firmware extraction and netlist. The system level anti-RE techniques can be categorized into three different groups:

(a) Anti-reverse engineering for ROMs: The most effective solution for increasing the complexity and difficulty of RE against ROM is by camouflaging contacts [22], transistors [23], and nanowires [24]. It increases the costs of manufacture but will force the attacker to spend considerably more time, money, and effort to get access to the ROM contents. Practically all the types of camouflaging techniques need to be implemented only on a part of the whole ROM. They provide limited protection against destructive and invasive RE at the cost of much more complicated design and fabrication process. So, now ROM replacements like anti-fuse one-time programming (AF-OTP) memory devices [25] are gaining popularity which is very highly resistant against RE.

(b) Anti-reverse engineering for EEPROMs/flash: To reverse engineer the EEPROM/flash memory, attackers prefer to delayer from the backside to avoid disturbing the floating charges. Thus, the most effective countermeasure is to prevent backside attacks. Some preventive countermeasures which are used are circuit parameter sensing and light sensing [19] in which once the detection signal generated from the sensing method is activated, the memory will automatically erase all or part of its contents. However, this technique cannot always be foolproof against the RE attackers as they can deactivate the sensing methods. Additionally, even if the memory successfully erases all the contents, the attackers can still determine the logic states according to the residual electrons on the floating gate due to data remanence [26]. To overcome that, ferroelectric RAM (FeRAM) can be used as it stores data by the polarization states of molecules. Also, it is economically very challenging to reveal data inside a FeRAM which makes it almost fully secure against RE [19].

(c) Anti-reverse engineering for FPGAs: The encrypted SRAM FPGA is resistant enough against reverse engineering (RE) which encourages less research and development of anti-RE techniques compared with the ASIC design. The existing FPGA anti-RE techniques can be categorized to three groups: bitstream hiding, side-channel resistance, and bitstream anti-reversal [19].

Another protection approach is the partial configuration by which the critical configuration bits in the bitstream file like the IP core are stored in the flash memory within the FPGA while other non-critical parts are still loaded from the external memory [19].

4.2.2 PCB Level Anti-RE

Since the complete protection against PCB Level RE is very difficult job, the goal of PCB level anti-RE techniques is to make RE expensive and time-consuming that in turn will make the RE techniques difficult to perform [19]. Physical structural analysis can be made difficult using tamperproof fittings for enclosures like torx and custom screws shapes. Protection level can be increased by fully potting the space around a PCB [19]. Removing silk-screen and component identifiers make the bill of materials (BOM) [27] RE of PCB very difficult and expensive process. Using BGA package [28], removing JTAG and other debug ports from semi-custom silicon, not labeling the pins, routing on inner layers only, routing through ASIC and FPGA, using buried vias and jumbled buses also enhance the anti-RE protection mechanism [29].

4.2.3 Chip-Level Anti-RE

The methods which are used in chip level anti-RE protection mechanisms are camouflaging different logic gates by real and dummy contacts [19] and obfuscation to make the design much more complicated as a protection mechanism against RE keeping functionality same [30, 31]. Several other techniques have also been proposed for protection against piracy of IC with each technique has own advantages and disadvantages in perspective of parameters like power consumption, area overhead, and capability of the purpose of protection [19].

4.3 New and Reusable EC Mixing Problem

After reusable ECs are sorted out of the e-waste in Electronics Component Testing Industry, they enter the semiconductor industry supply chain through a secondary market of secondhand components and gadgets. Adversaries can be present in middle of this supply chain where these reusable ECs can be mixed with brand-new ECs for making profit economically. A brand-new EC is more expensive than its reusable counterparts. Adversaries can sell reusable ECs to industries by demanding them as brand-new ECs which may not be detected by just looking from exterior and by taking the price of brand-new EC instead of reusable one; they can deceive the manufacturing industries and make profit economically. Then these reusable ECs will be used for manufacturing of new gadgets unknowingly. Although these new gadgets can operate correctly after manufacturing, their operating speed and energy efficiency will be degraded because these reusable ECs are functionally correct but they are aged [32]. The consumers and the manufacturing companies themselves will be then victimized. Hence, this can pose semiconductor industry supply chain security threat.

Based on interviews of kabadiwalas [33] in Kolkata, India, information is obtained from their practical experiences about which components of e-waste have the highest possibility to be made recognizable from exterior like their brand-new counterparts which cannot even be detected just by looking. This gives vital information to find out which of the new and reusable ECs can be mixed by adversaries. The information which is obtained is summarized into some subgroups which are as follows:

(a) ***Chip-level threat***: FPGAs are easy to reprogram and install and are very easily targeted for reuse in the secondary market. Similarly, embedded chips specially the peripheral integrated circuits like audio chips find a host of application in electronic appliances and are often used for repair work and refurbishing of damaged products. The threat is also extended to the highly compatible land grid array (LGA) processors, which find their way into the developing and emerging economy markets. The circuits remain protected by the metallic integrated heat spreader (IHS) and do not experience damages due to weathering or show any significant degradation in performance. The IHS is cleaned using alcohol-based solvents, and the processors are then sent back to the product stream for sale which can enter the primary brand-new product market.
(b) ***I/O ports and expansion slots Reuse threat***: Expansion slots, RAM slots, USB, SATA headers, audio ports, display ports, comports, etc., are susceptible to rusting and corrosion and are usually recognizable to the common eye. These products are cheap and easy to find in the primary market and are thus restricted for repair and refurbishing work in the secondary market only.
(c) ***SMD, Active components, and Passive components reuse threat***: Active components like electrolytic capacitors and passive components like chokes and toroid rings are extremely prone to weathering and lose their efficiency at the end of life. SMD's are often hard to remove and require heating to remove the solder which often damages these components in the process. However, malpractitioners after successful removal of these components can test them and send them back into the primary market if they are devoid of physical damage. These components will be hard to differentiate as they are sold in bulk quantities and are mostly mixed with the incoming product stream.

4.3.1 Detection of Reused ECs Among New ECs

To prevent any mix of reusable EC with new counterparts, manufacturing industries can test the components which are prone to mixing threat before using. These components involve many kinds of chips, PCBs, SMD, active and passive components. The testing criteria should involve finding out age of that component as many other kinds of characteristics of a reusable, and new one can remain same and hard to differentiate. Recycling sensors have to be developed and deployed which can find out age of various kinds of ECs like ICs [32, 34], PCBs, SMDs, active and passive components in precision of hours, minutes, and seconds at once.

4.4 Data Privacy in Storage Devices

There are different kinds of storage devices like hard drive, volatile memory, and solid-state drive when addressing e-waste in general. Data privacy and Data Privacy Acts exist in most of the countries worldwide. Sweden's Data Act of 1973 was the first data privacy act and a comprehensive one at that time [35]. Since then many countries have developed privacy acts. Data privacy is of utmost importance to individual consumers as well as big corporations in all industries (industrial, business, and medical, etc.) [35, 36]. Data privacy covers all aspects of data in general which then applies to digital data. When data is converted to digital format it becomes vulnerable to being accessed by unauthorized persons through different techniques that have been developed over the years to recover deleted data, decrypt encrypted data, and other techniques.

4.4.1 Data Protection Technique in Storage Devices

The definition of data protection includes safeguarding stored data from loss/damage and securing the data from being accessed by unauthorized personnel both in its stored format and through communication lines. Encryption has always been a vital factor of data privacy and security in memory devices. Initially, it was used in the US Department of Defense and national agencies; then it was publicly used in 1977 for first time [37]. The encryption techniques kept evolving, and there now exists a wide variety of encryption techniques and methods that integrate both hardware and software to increase data security. Among the survey conducted by Henson and Taylor [37] for different memory encryption techniques, a full disk encryption (FDE) is explored in details. Because of the vulnerability of the encryption techniques due to the dependency on the encryption key, many other techniques are being proposed to increase data protection in storage devices. Controlled functional encryption is proposed by Naveed et al. [38], which allows users (clients) to learn only certain functions of encrypted data with key requests continuously being requested from client on each transfer. Incremental encryption is proposed to secure data in nonvolatile main memory systems [39]. The motivation for this kind of protection is that data stays in this type of nonvolatile memory for long period of time even after power shut down which enable unauthorized persons with physical access to the system to extract sensitive data from the memory.

Even with the best protection techniques for securing personal digital data, there will always be methods to infiltrate these layers of security and gain access to unauthorized data. The attackers of systems are always trying to gain access to digital data either through network communication with the targeted machine or through brief physical access to the machine. With e-waste, the problem becomes more complicated as the attackers have unlimited physical access and time to try different methods and techniques to retrieve data (deleted data) or navigate through un-deleted data to search for personal and private data in the waste gadgets.

Many organization, firms, government agencies, business, and entities have internal organization policies and procedures to dispose of and delete data, especially if the data held contains countless records of citizens and their personal data, for example hospital medical records. However, home users of electronic equipment are not so keen about making sure that their personal data is permanently deleted before it enters the e-waste cycle. For example, many individual users think that deleting the hard drive or formatting it permanently deletes the data and protects their personal information, and of course this is not true because deleted data can be recovered.

4.4.2 Data Deletion and Destruction

Organizations (government and private), large firms, business, and medical entities all have internal policies and procedures that govern the way they dispose of digital data to protect it from falling into the hand of unauthorized personnel who might use this information in a harmful way. Many techniques exist to recover deleted data such as magnetic force microscopy (MFM), magnetic force scanning tunneling microscopy (STM), and other techniques. There are also methods to permanently delete data so that it is deemed unrecoverable. One such method is an overwriting scheme which requires no special equipment [40]. Other methods that require special equipment include degaussing (returning media to its initial state) and physical destruction (destroying the drive with specialized equipment to make it impossible for data recovery) [40].

The magnetic memory is not the only memory potentially to be read by unauthorized personnel to access personal data, the volatile memory such as DRAM and SRAM are also susceptible to attacks to retrieve personal data [40]. This problem also applies to solid-state drives (SSD) memory [41]; however, they propose a method to reliably delete data from SSDs. Every government agency in different countries has guidelines to ensure the destruction and disposal of sensitive personal data who is responsible for making sure that these policies are followed by safely deleting, destroying, and making unrecoverable the personal information of its citizens [42, 43].

5 Conclusion

In this paper, the overall reverse engineering and data security threats of electronic waste gadgets are explored in general and have been proved that these threats are the same as their operating counterparts. Also, possible threats that can arise due to reusing electronic components inside them have been explored. The possible existing countermeasures and protection mechanisms against these threats have been discussed. Also, some more advanced protection mechanisms against some form of threats need to be developed in future which have been pointed out in this paper. Before implementing the model of reusing the electronic components in mass scale in a secondhand market, all associated threats should be considered and possible countermeasures should have to be taken beforehand.

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Analysis of E-Waste Supply Chain Framework in India Using the Analytic Hierarchy Process

Rahul Baidya, Biswajit Debnath and Sadhan Kumar Ghosh

Abstract E-waste in general termed as "Waste Electronic and Electrical Equipments (WEEE)" is the fastest growing waste stream in the world. Rapid product obsolescence and short life cycles are key driving forces for this environmental problem. WEEE contains a high quantity of toxic and hazardous materials. E-waste management is a difficult task and requires environmentally safe and economical methods. Establishing a proper supply chain network for collection and segregation of e-waste is the most important step. The study develops as holistic supply chain framework to improve the sustainability of the e-waste management system in India considering the requirement of the e-waste processing plant. Specifically this paper addresses the following three questions—What are the issues and challenges in the supply chain framework considering the environmental criteria, legislative criteria and other stakeholder's requirements? What are the areas needed to be improved considering the WEEE producer requirements? Which supply chain characteristics of a WEEE processing plant are needed to be strengthened? The study follows a case study approach. Firstly, a questionnaire was developed based on the primary research and a survey was followed. Secondly, the answers obtained from the field study were used to analyse using the analytic hierarchy process (AHP), and thirdly, the drawbacks were interpreted from the results of the AHP analysis. Finally, using the results, a sustainable supply chain framework was proposed. A number of researches are available in this field but works considering the requirements of different stakeholders are scant. Further few studies are available considering the supply chain of India. This research will be helpful for researchers and the stakeholders of e-waste management.

Keywords WEEE · Supply chain · E-waste management · Sustainability AHP

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1 Introduction

Waste Electronic and Electrical Equipments (WEEE) is stacking up around the world. Rapid growth with rapid product obsolescence via short innovation cycles is turning e-waste as the fastest growing waste stream. According to Associated Chambers of Commerce of India (ASSOCHAM), in 2015, India generated 1.5 million tonnes of e-waste [1]. Mumbai produces 96,000 tons of electronic waste per followed by Delhi NCR (55,000 tons/year) and Bangalore (52,000 tons/year). Cities like Chennai, Kolkata, Ahmadabad, Hyderabad and Pune also produce a staggering quantity, with Chennai producing 47,000, Kolkata 35,000, Ahmadabad 26,000, Hyderabad 25,000 and Pune 19,000. Around 2% of India's electronic waste (e-waste) is only recycled; this is due to hurdle in implementation of infrastructure, legislation and framework [2]. Organization of Economic Cooperation and Development (OECD) defines, any equipment that uses electric power as their driving force that has reached its end of life, will fall into the category of WEEE [3, 4]. Basel Action Network [5] and Greenpeace International [6] gave the red alert about the informal processing of e-waste in different parts of Asia and Africa. Thus, it is high time to re-evaluate the e-waste problem.

WEEE or e-waste, e.g., computer, TV, mobiles phones, washing machines, refrigerators and other industrial equipment contain several types of toxic metals like lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg) and other harmful materials such as polybrominated diphenyl ethers, which pose danger for environment and human health. It also contains a plenty of precious noble metals such as gold (Au), silver (Ag), copper (Cu) [7–10]. In informal sector of WEEE reuse and recycling, toxic emission, disposal of untreated sludge and effluent due to acid cleaning and treatment, etc., are critical environmental issues. Effective and efficient e-waste management is a difficult task that requires both environmental and economical issues to be addressed effectively. A robust supply chain is an absolute necessity for collection and segregation of e-waste. Effective and appropriate technology is required for dismantling, shredding, processing/treatment/recycling and disposal of e-waste that prevents hazardous materials to infiltrate into the environment.

The supply chain management of the e-waste is very critical. However, in India, due to lack of awareness and improper implementation of legislation, the formal e-waste collection is overruled by the informal sector [11]. In India, the e-waste (Management and Handling) rules 2016 the concept of extended producer responsibility (EPR) has been explained and implementation of the rule have been given utmost priority. Although the functionality remains limited even though, EPR concept was floated in e-waste (Management and Handling) rules 2011. Trans-boundary shipment is a major problem in India as it is boosting the informal sector in spite of the presence of national and international legislation [12, 13]. However, there persist an illicit trade of e-waste. The Used Electronic and Electrical Equipments (UEEE) which are repaired or at their end of life are sent to India, China, Bangladesh and other developing countries in the name of charity which turns into e-waste when it reaches its end of life. The research questions as identified considering the literature gap are—What are the issues in the supply chain considering the environmental criteria, legislative criteria and other stakeholder's requirements? What is the area needed to be improved considering the WEEE generator's requirement? Which supply chain characteristics of a WEEE plant are needed to be strengthened?

The organizations of the paper are as follows: Sect. 2 presents the methodology of the study. Section 3 discusses the current status of the e-waste supply chain framework of e-waste processing plant. Section 4 discusses the AHP and its application methodology for the study. Section 5 discusses the results obtained from the AHP analysis, and further it discusses the proposed supply chain framework. Section 6 concludes the paper.

2 Methodology

The methodology adopted in the study involves the following step: firstly, a through literature review was carried out followed by the field study, and the challenges and issues of the present supply chain were also identified. Secondly, the important ratings for the AHP analysis were obtained through a field survey for the criteria/constructs. The ratings obtained were collected by developing a consensus among the experts. Thirdly, the ratings obtained were used for prioritizing the constructs using the AHP analysis. Fourthly, the AHP result obtained was utilized to find the most effective and optimized supply chain framework considering the four sustainable parameters.

3 Present Supply Chain Framework in India

Informal sectors are characterized by their small-scale business, intensive labour inputs, highly unorganized and unregistered processing and low-grade technology implementation [14]. They are unauthorized, do not pay taxes and are not benefitted by any social welfare and government-aided insurance schemes. E-waste collection is generally done by door-to-door collectors, popularly known as the "Kabbadiwala". They purchase e-waste along with other dry waste like newspapers, old books, scrap plastic, CFL bulbs, glassware from various consumers. The collected waste is sold to some small traders, who partially segregates the waste and sell them to the big traders [15]. The big traders are known as wholesalers, who sort out the reusable ones and the unusable ones. The reusable items end up in the second-hand market after proper repairing. The unusable e-waste is dismantled and segregated generating the following streams—metals, polymer, glass, printed circuit boards (PCB), electronic components and wires. These streams are often processed in a crude manner which leaves serious environmental footprint as well as occupational hazard to the workers.

The term “backyard recycling” was coined in accordance to the characteristics of the operation of the informal sector, as it is so naive like garage workshops repairing broken stuff. Precious metals like gold, silver, copper are recovered from the printed circuit boards by means of acid leaching, open burning, etc. [16]. The recovered metals are sold to third-party customers at a high price, from which they generate revenue. The electronic components are tested, and reusable ones are mixed with virgin ones with bulk [17]. The remaining is treated as garbage and disposed off in landfills. In India, there are some hot spots where such activities are carried out—Chandni Chowk in Kolkata [15], Nayandahally, Mysore Road in Bangalore, Chandni Chowk in Delhi, Meerut, Firozabad, Mumbai and Chennai [1, 4].

Formal sector ensures environmentally friendly dismantling, processing and recycling of e-waste. International Standards such as ISO 9001, ISO 14001 and OHSAS 18001 are followed by the operating units [18]. India has modified and updated the e-waste management rules in March 2016. The new rules have made extended producer responsibility (EPR) compulsory for the bigger OEMs except the small- and micro-scale companies [19]. The earlier version of the e-waste rules didn’t cover this. The implementation of the rules was also very poor; as a result, the dynasty of informal sector prevails. However, the momentum of the proper implementation of the rules has begun. Trans-boundary e-waste smuggling also boosts the informal sector. The new Hazardous waste and Other Wastes (Management and Transboundary Movement) Rules 2016 takes care of the e-waste smuggling [20]. Still, some loopholes exist which make this a rampant business. The formal e-waste facilities in India collects e-waste from corporate sectors and via auctions [21]. They are in contractual practices with different government and private institutions for periodical collection of e-waste [22]. The unwillingness of individual consumers to pay for e-waste disposal is due to the good amount of money offered by the Kabbadiwalas to buy the e-waste. The good news is that formal recycling is accelerating in India and awareness is spreading among the people [18]. Now in India, there are total 178 e-waste recyclers in 2017 compared to 138 in 2015 [23, 24]. However, only 25% of the authorized e-waste recyclers are functioning properly in India right now. Endeavour by both central and state government is being made to promote formal e-waste recycling by spreading awareness, setting up e-waste recycling facilities including collection centres. The central pollution control board has made the registration process for making business out of e-waste recycling easier. They are planning to give out licence to a number of collectors and refurbishers who are working well meeting the standards and the requirements.

4 AHP and Its Application in Supply Chain

The analytic hierarchy process (AHP) is a decision framework and a systematic procedure for representing the elements of any problem [25]. AHP is based on the following three principles: decomposition, comparative judgements and the priority synthesis [26]. There are numerous applications of AHP in the supply chain management. Korpela et al. [27] demonstrated the potential of AHP in supply chain development and analysed the business process re-engineering. Sharma et al. [28] developed an AHP multi-criteria decision-making methodology for optimizing supply chain delivery network which accounts both qualitative and quantitative factors. Yukshel [29] used AHP decision model to select an e-waste collection centre location. They provided a framework for analysing various e-waste collection centre locations with illustrative case study. Lin et al. [30] used AHP to analyse different criteria of notebook PC supply chain management (SCM) and proposed a Sensitivity Model for effective deployment of SCM strategies. Ciocoiu et al. [31] presented AHP as a potential decision-making method for the implementation of WEEE management systems considering political, economical, social, technical and environmental issues. Rakheja et al. [32] analysed the risk issues in the supply chain management using AHP. Sharma and Pratap [33] presented a case study on risk optimization using the AHP. Baidya et al. [34] analysed the issues affecting proper implementation of WEEE recycling as a green computing approach and utilized the AHP to identify the most important parameters which if addressed can minimize the environmental impacts of e-waste.

5 Discussion and Analysis

5.1 Generic Supply Chain Framework in India

A generic supply chain framework has been shown in Fig. 1. Usually when EEE reaches its end of life, it becomes e-waste. In India, two sectors exist for e-waste management—(a) informal sector or "backyard recycling" sector and (b) formal sector. Collection is done by the Kabbadiwalas informally by door-to-door collection, whereas formal collection is done by collection bins and collection centres located across the cities and towns. Collected waste is generally mixed in nature, hence sorting is carried out. After sorting, checking is done whether the components or the equipment itself can be reused after repairing or not. Those which can be reused are sent to workshops for refurbishment and the rest enters the processing waste stream. The usable products are refurbished and sent to second-hand market. The rest are then dismantled, sorted and again a few of them are sent for refurbishment. Remaining is treated to recover different materials. Glass, plastics and other things which are results of dismantling and processing are sold to different customers. The inert stream goes to landfill site.

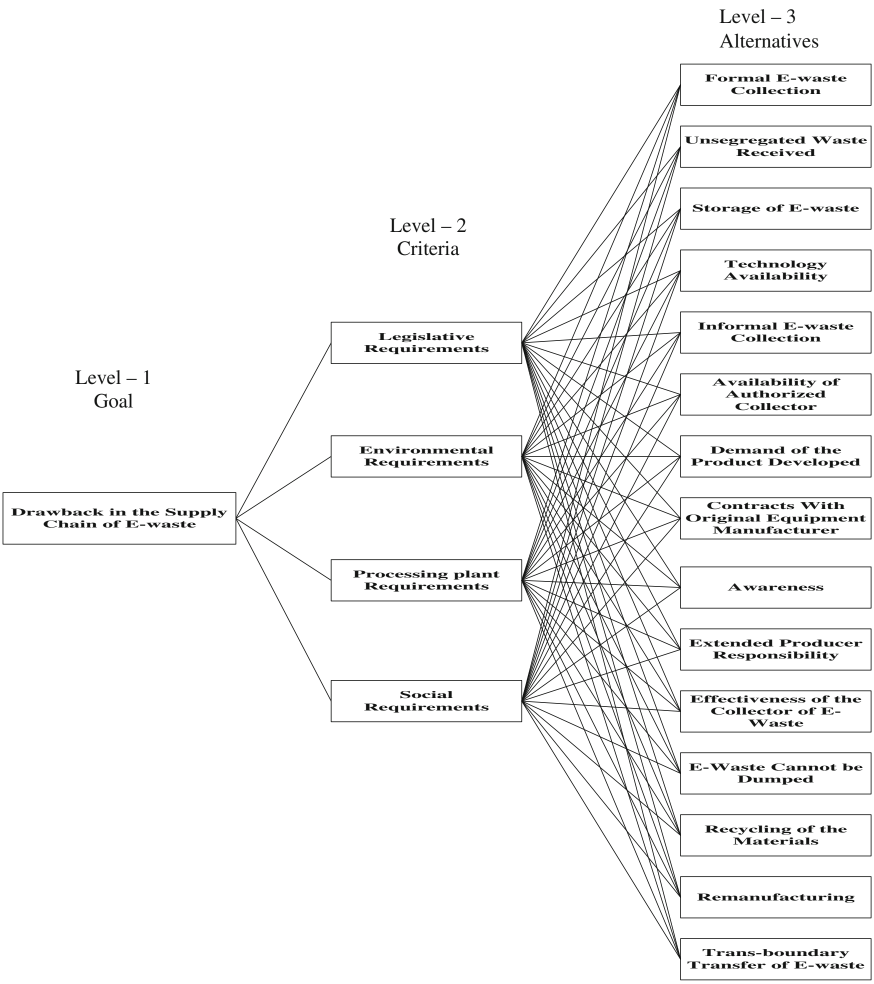

Fig. 1 AHP structure

5.2 AHP Analysis

In this study, a three-level structure has been used consisting of the goal cluster and criteria cluster and alternatives cluster. The goal cluster comprises a single node indicating the drawback in the supply chain of e-waste. The next level that is the criteria level has four nodes comprising the four parameters, namely (a) legislative requirements (C_1), (b) environmental requirements (C_2), (c) processing plant requirements (C_3) and (d) social requirements (C_4). The last level in the structure that is the alternative cluster consists of fifteen nodes which are the challenging issues as revealed by the primary research and field study. These issues are

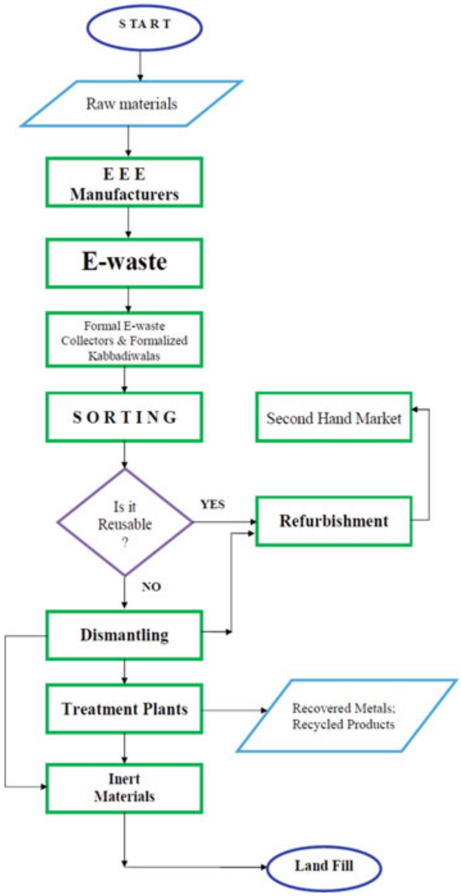

Fig. 2 Generic supply chain framework for e-waste management

(a) formal e-waste collection (A_1), (b) unsegregated waste received (A_2), (c) storage of e-waste (A_3), (d) technology availability (A_4), (e) informal e-waste collection (A_5), (f) availability of authorized collector (A_6), (g) demand of the product developed (A_7), (h) contracts with original equipment manufacturer (OEM) (A_8), (i) awareness (A_9), (j) extended producer responsibility (EPR) (A_{10}), (k) effectiveness of the collector of e-waste (A_{11}), (l) e-waste cannot be dumped (A_{12}), (m) recycling of the materials (A_{13}), (n) re-manufacturing (A_{14}), (o) trans-boundary transfer of e-waste (A_{15}). These issues and challenges do not have predefined boundary and fall under multiple parameters/criteria (Fig. 1).

The AHP analysis was done by collecting the view in term of a predefined Saaty scale from each of the stakeholders, and there ratings obtained were standardized by developing consensus among the experts. The analysis with its pair-wise rating and eigenvector that is the importance for each of the issues and challenges are identified and a rank table was developed (Table 1). The AHP analysis was done using the commercially available Super Decisions software. The analysis revealed a

Table 1 Prioritized value and rank of each of the issues

Sl. No.	Issues and challenges	Eigenvector	Rank
1	Formal e-waste collection	0.079395	5
2	Unsegregated waste received	0.033228	15
3	Storage of e-waste	0.056691	11
4	Technology availability	0.036966	13
5	Informal e-waste collection	0.081461	4
6	Availability of authorized collector	0.072824	7
7	Demand of the product developed	0.034518	14
8	Contracts with OEM	0.076163	6
9	Awareness	0.083273	3
10	EPR	0.102000	1
11	Effectiveness of the collector of e-waste	0.068047	8
12	E-waste cannot be dumped	0.067443	9
13	Recycling of the materials	0.057949	10
14	Re-manufacturing	0.055754	12
15	Trans-boundary transfer of e-waste	0.094288	2

number of issues which are needed to be improved for an effective e-waste management system, so that it can address the issues affecting the sustainability of the WEEE processing plant. The AHP analysis revealed that in the criteria level of the AHP structure “environmental requirement” is the most important criteria with eigenvector value of 0.345078 followed by “legislative requirement” (0.326915) and the least important is “operational requirement” (0.084553). The most important issue in terms of the legislative requirement is “EPR” (0.131349) followed by “formal e-waste collection” (0.104519) and “trans-boundary transfer of e-waste” (0.09154). In terms of the environmental requirement, “EPR” is the most important with eigenvector value of 0.106640467 followed by “trans-boundary transfer of e-waste” (0.105294914) and “awareness” (0.096026797). The overlapping of the important constructs between the two different parameters/criteria is due to the importance with both of the parameters. On considering the operational requirements “contract with OEM” (0.121891383) is the most important followed by “demand of the product developed” (0.110858547) and “formal e-waste collection” (0.095099913). And in terms of the social requirements, “informal e-waste collection” (0.119743509) is the most important constructs followed by “awareness” (0.103769465) and “e-waste cannot be dumped” (0.077653126). The overall analysis of the model revealed that “EPR” is the most important issue faced by a WEEE processing plant with eigenvector value of 0.102000 followed by the “trans-boundary transfer of e-waste” (0.094288) and “awareness” (0.083273), the least important issue was “unsegregated waste received” (0.033228) (Table 1). The analysis reveals the importance of each drawback in considering the requirement of the processing plant and WEEE producer, through the social requirements criteria in the AHP analysis. The analysis provides an inside understanding to the area which are needed to be addressed by both legislation and the waste producer for implementing an effective e-waste management system.

5.3 Proposed Supply Chain Network (SCN)

The AHP analysis gives important criteria for legislative requirement, environmental requirement, operating plant requirement and social requirement which should be considered for increasing the efficiency of the SCN of e-waste. The criteria are—(a) extended producer responsibility (EPR), (b) trans-boundary transfer of e-waste, (c) awareness, (d) informal e-waste collection, (e) formal e-waste collection (f) contract with OEM, (g) availability of authorized collector. Based on the results, a supply chain framework has been proposed based on the existing supply chain framework of e-waste management system with special emphasizing on the processing plant requirement. The proposed framework has been shown in Fig. 3. A comparative analysis has also been done between the proposed framework and the existing framework (Fig. 2). The proposed framework is a modification or advancement on the existing supply chain framework, which tries to address the issues as revealed by the AHP analysis so as to develop a sustainable supply chain framework.

The blocks in proposed supply chain framework have been marked with “star” and “lightning” symbols in different places. The star symbol suggests that awareness is essential in those cases and the stakeholders associated with it whereas the lightning symbol suggests legislation to be stronger in those activities. Specifically, in the second-hand market, the infiltration of UEEE and WEEE from developed countries should be controlled. The stakeholders although exist in the loop of EPR as per the guidelines but they are not acting responsibly thus the effecting the formal e-waste collection. Both awareness and legislative action are required to enforce EPR strictly. Formal collection of e-waste should be officially implemented via circulating awareness and implementing legislation effectively. The Kabbadiwalas are very efficient in door-to-door collection. Instead of removing them from the formal collection system, they should be authorized and a consortium of these groups may be formed supported by the government or the formal sector, giving the appropriate training and other required facilities, tools so as to help the formal sector in collection and thus decreasing the informal processing. The OEM’s should make proper contracts with the registered recyclers for proper treatment and vice versa for sustainability of the e-waste management system. This framework, if comes into practice properly, will lead to an efficient and effective reverse logistics system and a sustainable business model.

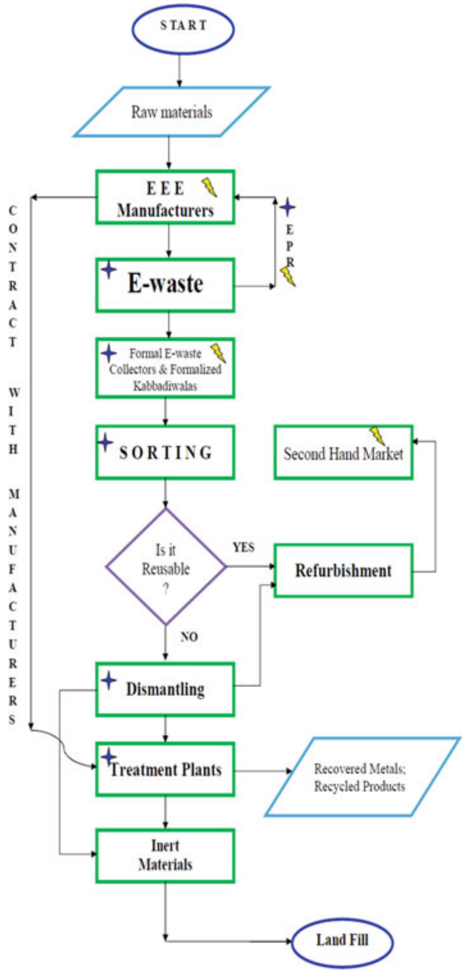

Fig. 3 Proposed supply chain framework of e-waste management

6 Conclusion

The study presented a sustainable framework on the basis of the four parameters for an effective e-waste management in India, and the important criteria were obtained from the primary research and field study. The cases studies provided the importance of each of the fifteen criteria for the AHP analysis for prioritization of the issues and challenges in the supply chain framework. The AHP analysis provided the most important constructs which were affecting the supply chain framework. The study also provided the area on which the legislative and all other stakeholders may look into for an effective and sustainable supply chain framework for e-waste management system specifically for e-waste processing plant.

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An Analysis of E-Waste Recycling Technologies from the Chemical Engineering Perspective

Biswajit Debnath, Ranjana Chowdhury and Sadhan Kumar Ghosh

Abstract Technological advancements and changes in lifestyle have led to the generation of a behemoth amount of e-waste worldwide. The demand of new Electrical and Electronic Equipment (EEE) is also increasing which is leading to rapid depletion of primary resources. Resource recovery and recycling of e-waste is the only option to keep things in balance. There are many technologies for e-waste recycling which are in practice, such as pyrolysis, gasification, leaching, biosorption. Reported literature includes stand-alone experimental works, sustainability analysis and systematic reviews of e-waste recycling technologies. Most of these recycling processes have some chemical engineering aspects which are inherent but yet overlooked in most of the cases. Studies envisaging the chemical engineering aspects of these technologies are scant. In this study, a detailed analysis of these e-waste recycling technologies from the chemical engineering perspective has been presented. Transport properties, kinetics, thermodynamics, etc., have been taken into consideration for carrying out the analysis. The findings of this paper will enable the researchers in this field for further process development.

Keywords E-waste · Technology · Recycling · Chemical engineering Kinetics

1 Introduction

The growth of electronics industry has been tremendous in the last two decades which ensured a lot of cash flow but it also contributed to the material flow stream of electronic waste. Globally, e-waste is the fastest booming waste stream in the world increasing at an annual rate of 3–5% [7, 27]. According to Basel Convention,

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e-waste defined as—“*substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law*” [2]. United Nations University estimated that globally 41.8 million metric tonnes of e-waste was generated in 2014 and it is forecasted to be 50 million tonnes by 2018 with a rise by 21% [1, 24]. Huisman [14] predict that by 2020, WEEE will grow by 2.5–2.7% annually making it up to 12.3 million tonnes. WEEE generation in China is estimated to be 6.033 million tonnes in 2014 which is second largest generator of WEEE while USA being the highest generator with 7.072 million tonnes in 2014 [1]. BRICS nations generated nearly 25% of the global WEEE generation in 2014 [10].

E-waste is a complex material and contains different types of materials including polymers, metals, ceramics. The lighter e-wastes such as mobile, laptop contain high amount of polymer, which are mainly flame retardants. Debnath et al. [9] reported that the amount of polymer and metals varies widely with type of e-waste based on weight, size and end application. For example, keyboards contain 95% polymer, whereas the printed circuit boards are rich in metals. There are different methods that are used for recycling e-waste. Debnath et al. [9] reported a study on different metal recovery technologies from e-waste discussed the sustainability of those processes. E-waste recycling includes physical recycling processes and chemical recycling processes. In most of the recycling units around the globe, use of physical recycling processes is dominant. However, the chemical recycling processes are required to be implemented for sustainable recycling and valorization. The only chemical recycling processes implemented in a few e-waste recycling facilities are modified versions of parent metallurgical technologies. These are mostly carried out by some third-party organization on regular or contractual basis. As reported by Khaliq et al. [19], the pyro-metallurgical and hydrometallurgical processes are followed by these industries during the metal recovery from electronic waste. However, the thermochemical processing of e-waste for the generation of fuels from the polymeric part of e-waste is still being investigated in laboratory scale. It is clear from the literature survey that most of the research studies on thermochemical conversion of e-waste are only focused on the determination of reaction kinetics of base process. For the commercial development of thermochemical processes for e-waste utilization, more thrusts should be given on reactor design along with development of process models taking both reaction kinetics and the mass and heat transfer limitations into account. This article will review the present status of the reported research studies in the area of thermochemical processing of e-waste. An attempt will be made to identify the research gaps to be mitigated for the further utilization of thermochemical processes for e-waste utilization, and finally, some recommendations will be made.

2 Methodology

Firstly, thorough literature review was carried out exploring SCI-indexed journals, Conference proceedings and Reports, etc. Different keywords such as 'e-waste recycling', 'metal recovery from e-waste', 'printed circuit board recycling', 'pyrolysis of e-waste', 'gasification of e-waste', 'transport phenomena in e-waste pyrolysis', heat and mass transfer in e-waste gasification', 'e-waste pyrolysis kinetics' were used for this purpose. The papers were screen and sorted. Further literature review was carried out to look for the cross references. Then, the papers were analyzed and the help of books was taken to understand the phenomena and the gaps.

3 Thermochemical Processes for E-Waste Recycling

3.1 Pyrolysis

Thermochemical processes such as pyrolysis, a common method for degradation of polymeric substances. A significant number of literature on pyrolysis of e-waste (printed circuit boards) depicts the importance and relevance of the topic [6, 11, 13, 32]. The typical product from pyrolysis of e-waste (mixed e-waste plastics) is 70.6% pyro-oil, 7.8% gases and 21.1% char and ash [13]. However, these compositions may vary depending on the type of e-waste, method of pyrolysis, presence of catalyst and additives, type of reactor, etc. Yang et al. [37] presented a review which provides insight on pyrolysis and dehalogenation of plastics obtained from e-waste. Investigation of vacuum pyrolysis of e-waste has been reported by a huge number of researchers [21, 28]. The key advantage of using vacuum pyrolysis is the low temperature and pressure. Another approach is the microwave-induced pyrolysis which is rarely adopted, though reported as a very energy-efficient process since the activation energy is much lower than other conventional pyrolysis method [29–34]. Catalytic pyrolysis is another route for treatment of e-waste (polymer fractions) [12] and has been reported by several researchers [11, 15], though maximum works focus on pure or mixture different plastics.

Different catalysts have been used—FCC catalysts [12], zeolites [30], silica-alumina [26], metal-based catalysts [15], meso-structured catalysts [22], minerals [23], low-cost materials such as red mud, limestone [35], oyster shell, calcium-based additives [15]. Co-pyrolysis, where the key is the synergistic effect of different reaction of different materials, is a good way of recycling e-waste. Co-pyrolysis of waste biomass and e-waste has been found to be beneficial [22]. This method is a green thermochemical processing alternative as it produces high-quality pyro-oil and it also prevents the generation of dioxins. Details on prevention of dioxins from pyrolysis of e-waste have been discussed and analyzed by Lai et al. [20]. Hence, pyrolysis is an environment-friendly chemical recycling method of e-waste.

3.2 Gasification

E-waste gasification is a comparatively unexplored area and a few literature reported are concentrated in either polymer gasification or polymer part of e-waste gasification. High-impact polystyrene (HIPS) resin containing poly-brominated diphenyl ethers (PBDE; mainly decabromo-diphenyl oxide), which is a brominated flame retardant, has been used as feedstock for a zero-emission recycling process which implements gasification followed by shock cooling. This method successfully prevented the formation of dioxins and furans and also recovered antimony present in the plastics in form of solids. A gaseous by-product called "thin gas" rich in hydrogen was found suitable for use as raw material in the chemical industry [36]. The effect of steam and sodium hydroxide on hydrogen production using dechlorinated PVC and activated carbon as feedstock has been reported by Kamo et al. [16]. Later, the influence of the mixed molten carbonate composition on hydrogen production by steam gasification of activated carbon derived from plastic waste materials was also reported [17]. Zhang et al. [39] performed kinetic study of epoxy resin board steam gasification in eutectic carbonate (Li_2CO_3, Na_2CO_3, K_2CO_3) mixture. It was revealed that the reaction follows pseudofirst-order kinetics. The order was found to be 0.91th power of the partial pressure and the activation energy was 122 kJ/mol. In case of the phenolic board, the shrinking core model and homogeneous model (kinetic controlled reactions where there are no mass transfer limitations) were used to describe the kinetics. Particles less than and equal to 0.15 mm follow the homogenous model, whereas particles greater than and equal to 1 mm follows some complex kinetics which was described using initial rapid pyrolysis, homogenous model gasification and the shrinking core model gasification [40].

4 Discussion and Analysis

The knowledge of chemical kinetics is essential to understand how the reaction proceeds. This knowledge accordingly helps in the development of the process and the design of the corresponding process equipment. Based on the available literature, it has been found that a good number of works on the kinetics of e-waste pyrolysis has been carried out. A detailed literature review has been presented in the preceding section. In most of the cases, the kinetic evaluation is limited within the primary reactions. In an ideal scenario, chemical kinetics should account for both primary and secondary decomposition reactions. Other parameters such as heating rate and possibility of autocatalysis of specific secondary reactions also play important roles. At higher pyrolysis temperature, the tar produced during the primary reactions undergoes further thermal cracking to produce more volatiles and char. These have not been considered so far in the reported literature in the kinetic evaluation processes of e-waste.

Table 1 Different reactions taking place during gasification reaction

Reaction type	Reaction
(a) Carbon reactions	
R_c1 (Boudouard)	$C + CO_2 \leftrightarrow 2CO\ \Delta H = +172\,kJ/mol$
R_c 2 (Water–gas)	$C + H_2O \leftrightarrow CO + H_2 \Delta H = +131\,kJ/mol$
R_c 3 (Hyrdrogasification)	$C + 2H_2 \leftrightarrow CH_4 \Delta H = -74.8\,kJ/mol$
R_c 4	$C + 0.5O_2 \rightarrow CO\ \Delta H = -111\,kJ/mol$
(b) Oxidation reaction	
R_O 1	$C + O_2 \rightarrow CO_2\ \Delta H = -394\,kJ/mol$
R_O 2	$CO + 0.5O_2 \rightarrow CO_2\ \Delta H = -284\,kJ/mol$
R_O 3	$CH_4 + 2O_2 \leftrightarrow CO_2 + 2H_2O\ \Delta H = -803\,kJ/mol$
R_O 4	$H_2 + 0.5O_2 \rightarrow H_2O\ \Delta H = -242 kJ/mol$
(c) Shift reaction	
R_S 1	$CO + H_2O \leftrightarrow CO_2 + H_2\ \Delta H = -41.2\,kJ/mol$
(d) Methanation reactions	
R_M 1	$2CO + 2H_2 \rightarrow CH_4 + CO_2\ \Delta H = -247\,kJ/mol$
R_M 2	$CO + 3H_2 \leftrightarrow CH_4 + H_2O\ \Delta H = -206\,kJ/mol$
R_M 3	$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O\ \Delta H = -165\,kJ/mol$
(e) Steam-Reforming reactions	
R_{SR} 1	$CH_4 + H_2O \leftrightarrow CO + 3H_2\ \Delta H = +206\,kJ/mol$
R_{SR} 2	$CH_4 + 0.5O_2 \rightarrow CO + 2H_2 \Delta H = -36\,kJ/mol$

[a]*Source* [3]

Kinetics for gasification reactions is well established and still a subject of intensive investigation. Gasification involves the primary reactions of pyrolysis. It is the char evolved during pyrolysis that takes active participation in the gasification reactions. There are series of reactions that take place during the char gasification, summarized in Table 1.

The determinations of kinetic parameters are imperative in case of pyrolysis of e-waste for a particular set of conditions. The deficiency of exact knowledge of the course of reactions and their degrees of completion is the main hindrance towards in-depth study of thermal behaviour of e-waste. During pyrolysis, a huge number of products, stable and unstable is evolved which makes it more complex. As a result, different set of values of reactions constant, pre-exponential factor and activation energy has been reported (Table 2). The heterogeneous nature of e-waste also plays a key role in this anomaly of different values of the aforementioned kinetic parameters.

The type of reactor used for pyrolysis or gasification plays a major role in the overall output of the process. Fixed bed reactor, fluidised bed reactor and tube reactor have been used so far for pyrolysis of e-waste and plastics derived from e-waste. Brominated high-impact polystyrene (HIPS) found in e-waste has been subjected to fast pyrolysis in fluidized bed reactor and proved to be beneficial for higher oil yield and less gas and char yield compared to the conventional pyrolysis

Table 2 Kinetic parameters of pyrolysis of e-waste reported by different authors

S. No	Type of pyrolysis	Activation energy	Frequency factor (min^{-1})	Order or reaction	References
1	Pyrolysis of e-waste from small household appliances	95.54 kJ/mol	1.06×10^8	3.38	[18]
2	Pyrolysis of PCB particle size 5, 10 and 40 mm	For 2 °C/min: 45.87–47.13 (kcal/mol)	For 2 °C/min: 1.73×10^{17}–4.28×10^{16}	For 2 °C/min: 1.24–1.47	[5]
		For 15 °C/min: 38.16–40.44 (kcal/mol)	For 15 °C/min: 1.05×10^{14}–9.05×10^{14}	For 15 °C/min: 1.23–1.58	
3	354 μm crashed PCB pyrolysis in fluidized bed	First-stage reaction: 90.49 kJ/mol Second-stage reaction: 137.80 kJ/mol	–	1	[11]
4	Pyrolysis of keyboard, PCB and telephone wire	Keyboard: 166.08 (kJ/mol)	Keyboard: 7.82×10^8	1	[29]
		PCB: 149.28 (kJ/mol)	PCB: 2.01×10^9		
		Telephone wire: 96.76 (kJ/mol)	Telephone wire: 2.54×10^5		
5	Microwave pyrolysis of e-waste in different carrier gas	142.99–165.04 (kJ/mol)	3.84×10^{11}–6.87×10^9	–	[41]

[4, 15, 25]. Despite other formats, it has been an undebated choice for the researcher favouring the fluidised bed configuration. Perhaps this is the reason most of the gasification of e-waste and e-waste plastics studies has been carried out in fluidised bed reactors. From a chemical engineering point of view, it can be said that fluidised bed helps to improve polymer degradation by acting as a good agent to heat and mass transfer and thereby dispersing the melting polymer in thin layers. However, the works on gasification of printed circuit boards reported have used semi-batch reactors instead of conventional updraft or downdraft gasifiers for gasification purposes. This is probably because PCBs are complex materials and there are many other materials which does not take part or degrade during the gasification process. In case of co-pyrolysis of e-waste and biomass, good results have been obtained in a fixed bed reactor [22]. From environmental sustainability point of view, it was confirmed that the pyro-oils did not contain bromine rather most of the bromine was fixed with the char, which enables the use of pyro-oil to a good extent and chances of environmental hazard occurring from brominated compound emission. Though this is a promising area and very less work has been done, there exists much scope for intervention. Other methods such as the use of catalysts for thermochemical conversion of e-waste have been implemented and good results have been obtained. More research in these areas is required.

5 Conclusion

E-waste is one of the fastest growing waste streams in the world and its environment-friendly disposal is now becoming harder. The challenge of developing a proper methodology for e-waste disposal is still ongoing because of the hazardous and heterogeneous nature of the waste stream. The mechanical recycling method is mostly opted globally as a recycling methodology. Other methods such as thermochemical methods have been reported for e-waste treatment. But these technologies are mostly concentrated within the laboratory. Good amount of literature is available that discusses the kinetics of e-waste pyrolysis. The choice of the reactor and the mode of pyrolysis play a big role on quality of output materials. Co-pyrolysis and fluidised bed reactor were found to be good combination for this purpose. The kinetics for gasification of e-waste is reported but not very much developed. There exists a lot of scope for reactor design and other process intensifications for gasification.

It is believed that with the contribution of stalwarts, the general modelling of pyrolysis and gasification is enriched enough. However, investigation on the mathematical modelling considering the effects of transport phenomena of e-waste pyrolysis and gasification is scant. With the growing concern of e-waste disposal, chemical treatment processes are becoming important and such investigations are required for further development and commercialization of these processes.

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Part XV
Plastic Waste Management

Modelling and Simulation of Microwave-Assisted Pyrolysis of Plastic

Kombath Sreelakshmy and Nangarthody Sindhu

Abstract A mathematical model for the microwave-assisted pyrolysis of plastic was simulated for different process conditions so that the behaviour of the system can be predicted without much error. This will help in the scale-up of the process and for further research can be made economically feasible. The importance of the process in current scenario is identified. Earlier efforts on studying the process were studied, and review of the study is done. A model of microwave heating was simulated using COMSOL Multiphysics software and validated with experimental results. The inverse temperature profile was obtained for all the samples. Analysis of variation for change in sample composition was studied.

Keywords Pyrolysis · Microwave heating · COMSOL

Notations

ε'	Dielectric permittivity
ε''	Dielectric loss factor
ω	Field frequency
$\tan\delta$	Loss tangent
ρ	Density
k	Thermal conductivity
C_p	Specific heat

Subscripts

m	Mean
HDPE	High density poly ethylene
C	Carbon

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1 Introduction

Microwave heating as an alternate method for heating of materials is gaining interest in many industrial applications which use low-temperature processing like food, polymers, rubber. Normally, 2.54 GHz is the frequency used for microwave heating but higher frequencies are being used in industrial applications. The characteristic feature of microwave heating is that unlike conventional heating processes energy conversion takes place instead of energy transfer. The microwave energy is converted into heat volumetrically. This feature results in energy saving and time reduction compared to conventional heating processes [1].

In the current scenario, plastics have become an important part in the daily life. This, in turn, contributes to the recurring problem of waste management and pollution caused by the open dumping and open burning of plastics. Microwave pyrolysis provides an efficient solution considering its many advantages. Development of microwave pyrolysis as a large-scale process requires analysis of various parameters ranging from electromagnetic field and heat transfer to reaction kinetics. Hence, a mathematical model becomes necessary. A proper modelling and simulation tool for analysis of microwave heating were required.

Though many papers are available for modelling and simulation of microwave process, papers specific to microwave pyrolysis of plastic using COMSOL were not found in the knowledge of the author. Maybe, the reason is the complexity in combining a process like pyrolysis with electromagnetic heating. Industrial application of this process is very limited. In the available papers found in modelling of microwave-induced pyrolysis of biomass by Ciacci et al., Maxwell's equations were made use to model microwave heating process, it was combined with kinetic modelling equations for pyrolysis reaction along with heat and mass transfer equations, and model was solved numerically [2]. A comparative study of the use of different power formulations was done by Ayappa et al. A comparison of the use of Maxwell's equations and Lambert's equation for modelling microwave heating was done, and the situation in which Lambert's law is applicable was identified [3]. These mathematical modelling strategies offer a cost-efficient way to optimize existing specifications.

Many papers are available for the simulation of microwave heating of various materials using COMSOL Multiphysics. The electromagnetic field and temperature distribution in a rubber glove were studied using COMSOL. The microwave cavity size and other parameters can be tuned according to the process. The influences of position, heating time, and rotation angle of electromagnetic field and temperature distribution were found. It established that temperature distribution and electric field increase with heating time [4]. Microwave pyrolysis of HDPE pellets was studied using Microwave Studio by Khaghanikavkani et al. Variation of '**S**' parameter was studied for the purpose of designing a microwave reactor to maximize the heating rate [5]. A comparison of continuous flow microwave heating model in COMSOL and ANSYS was done by D. Salvi et al. Numerical models were developed to evaluate the temperature profile of microwave heating of the continuous flow of

Newtonian fluids. Power losses in models were evaluated [6]. COMSOL eliminated the inconsistencies created by coupling the electromagnetic, heat transfer and fluid dynamics using separate program codes. Moreover, COMSOL provided an easy platform for those who are unfamiliar with a programming language for writing complex coding for electromagnetic field equations.

The samples considered for evaluation are all mixtures. So, there is a complication in estimating the dielectric properties of a mixture. Permittivity relationships were studied by S. Nelson et al. The best estimates of permittivity were provided by Landau and Lifshitz, Looyenga mixture equations [7].

1.1 Simulation

The model for analysing electromagnetic field variations and effect on heating rate is studied using COMSOL Multiphysics 4.3. COMSOL, like any other simulation software, involves three processing steps. First is geometry and designing the model, second is solving the model using proper assumptions, and the third is plotting and analysing the simulation results. An inbuilt model is available in the RF module of COMSOL, which can be used as we are only interested in analysing the electromagnetic effects on the sample. Reaction properties are not considered in this simulation. The inbuilt model was modified to suit the requirements of the experiment and was simulated taking assumptions of impedance boundary condition and perfect magnetic conductor in the frequency-transient solver. The material properties such as permittivity, loss tangent, thermal conductivity, specific heat were provided as input for simulation.

1.2 Physical Properties

The extend of Microwave heating depends on the material's capacity to absorb microwave energy, When the material is dielectric in nature, Presence of an external magnetic field results in polarization of the material due to realignment of bound charges. This is measured by a parameter called dielectric permittivity, ε'. When the external magnetic field is oscillating in nature, the dielectric response shows certain lag to change in magnetic field. So, permittivity is represented as a complex number that depends on field frequency ω.

$$\varepsilon(\omega) = \varepsilon'(\omega) + i\varepsilon''(\omega).$$

The imaginary part represents the lag. The microwave energy is dissipated along the depth of the material. This decrease in energy is characterized by loss factor, tan $\delta = \varepsilon''/\varepsilon'$ [1]. Plastics are nearly transparent to microwave radiation since they have low loss factor. So, the sample was prepared by mixing it with carbon, which has high dielectric loss factor so as to facilitate high heating rate required for pyrolysis reaction. Four sample mixtures were used in the experiment using different proportions of carbon.

1.3 Experimental Data

The experimental apparatus used for this experiment consists of a 5 kW domestic microwave oven of frequency 2.54 GHz. The reactor is a quartz vessel of diameter 180 cm and is placed on top of a microwave transparent base. To facilitate uniform distribution of heat, the reactor is provided with an agitator rotating at a maximum speed of 6 rpm with the help of a motor. The temperature of the system is measured at all times with the help of two thermocouples, one placed inside the sample through the centre of agitator shaft and other at the surface [8] (Table 1).

1.4 Calculation of Mixture Properties for Sample II

The dielectric permittivity of the mixture is calculated using Eq. (1), i.e. the Landau, Lifshitz, Looyenga mixture equation as it was in more agreement with the dielectric properties estimated using experimental methods compared to other methods like Rayleigh, Bruggeman–Hanai. Moreover, it is more reliable when mixtures contain strongly dissipative particles compared to others.

$$\varepsilon_m^{1/3} = v_1\varepsilon_1^{1/3} + v_2\varepsilon_2^{1/3} \tag{1}$$

where ε_m is the dielectric permittivity of the mixture, and ε_1 and ε_2 are two components in the mixture (Table 2 and 3).

Plastic: $\varepsilon_1 = 1.9591 - 0.00027j$
Carbon: $\varepsilon_2 = 2.355 - 0.09584\mathrm{j}$
Sample: $\varepsilon_m = 2.151 - 0.0178j$

Table 1 Experimental data

Sample No.	Sample	Sample quantity (g)	Carbon quantity (g)
1	LDPE	50	50
2	HDPE	50	50
3	Plastic with aluminium foil	50	50
4	Mixture	50	50

Table 2 Calculation of physical properties

Property	HDPE	Carbon	Property of the mixture	Mixture
Density (kg/m^3)	960	2185	$\rho_m = 0.5\rho_c + 0.5\rho_{\mathrm{HDPE}}$	1572.5
Thermal conductivity (W/mK)	0.25	0.14	$\frac{1}{k_m} = \frac{0.5}{k_c} + \frac{0.5}{k_{\mathrm{HDPE}}}$	0.2135
Heat capacity (J/kg K)	2200	1000	$Cp_m = 0.5Cp_c + 0.5Cp_{\mathrm{HDPE}}$	1600

2 Results and Discussion

The inbuilt microwave oven model available in the RF module of COMSOL Multiphysics 4.3 was modified to suit the sample and experimental conditions and was simulated for 1 h, and symmetry cut is applied vertically through an oven, waveguide, plastic, and pipe (Fig. 1).

The temperature profiles clearly show the development of an inverse temperature profile in the sample. Temperature is highest at the centre and decreases towards the surface. As time progresses, high-temperature region spreads towards the surface. The reaction and degradation occur in the temperature range 250–500 °C. A comparison of the experimental and COMSOL temperature profile was done before the reaction started to compare the effect of reaction. For this, simulation was done for a time less than 1800 s.

2.1 Temperature Profiles Obtained from Different Samples

Four different temperature profiles were obtained for the four samples due to the difference in physical properties. The temperature profile obtained at the end of simulation time is shown in Fig. 3. Important observations are given in Table 4.

The highest temperature was observed in the LDPE sample at the end of 1 h as per COMSOL results. Second highest in HDPE sample and lowest in sample 3 in which Aluminium foil was present along with HDPE. The temperature readings at an intermediate time also followed a similar trend. Temperature reading was higher in LDPE compared to HDPE sample.

All the physical properties of LDPE and HDPE are similar except density. So, this decrease in temperature may be attributed to changes in density. As the bulk density increases, porosity decreases this in turn affect dielectric permittivity which may result in the decrease in temperature. The lowest temperature was found in sample III, which may be due to the presence of aluminium foil in the sample. Aluminium foil like all metallic materials is a good conductor, and this prevents induction of internal electric field. So, pooling of electric charges occur on metal surface which in turn causes eddy currents and results in resistive losses. The slight

Table 3 Calculated physical properties of four samples

Property	LDPE	HDPE	Carbon	Aluminium	Sample I	Sample II	Sample III	Sample IV
Density (kg/m^3)	920	960	2185	2700	1552.5	1572.5	1997.5	1857.36
Thermal conductivity (W/mK)	0.33	0.25	0.14	237	0.1966	0.2135	0.2309	0.2247
Heat capacity (J/kg K)	1900	2200	1000	896.3	1450	1600	1199.075	1334.38

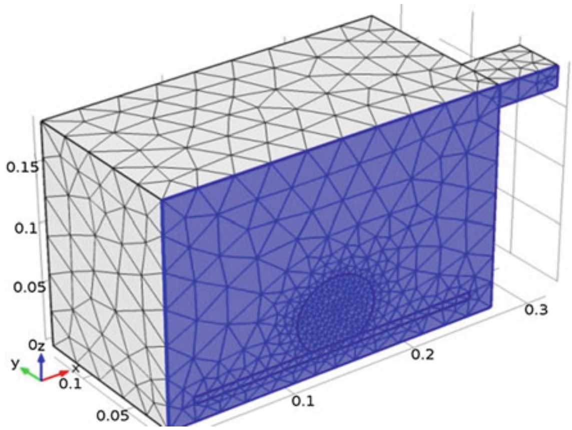


Fig. 1 Microwave oven model after meshing in COMSOL

increase in temperature in sample IV may be due to decrease in the relative amount of aluminium foil in the mixed sample. The temperature profile of the first and second sample showed the spread of the high-temperature region towards the surface at the end of one hour, while in sample III and IV the spread of the high-temperature region was restricted to the centre.

2.2 Temperature Profiles Obtained for Sample I

See Figs. 2 and 3.

3 Validation Using Experimental Results

The simulated models were compared with the experimental results. The experiment was conducted previously, and temperature data of the experiment were used to validate the models. In comparison with COMSOL model and experimental data, it is evident that the error is directly proportional to the increase in temperature. A comparison of simulated and experimental results before the start of reaction was done. In this case, the run-time was reduced to 1800 s to limit the temperature below 300 °C in the simulation. It was observed that the deviation was less than 50 °C. The simulation closely follows the experimental profile till 200 °C, and then the gap widens. This deviation is expected as at a higher temperature, losses due to radiation and convection are much higher than estimated. The plot of predicted versus observed data supports this inference. The data points were found more linear compared to the data including reaction time (Fig. 4).

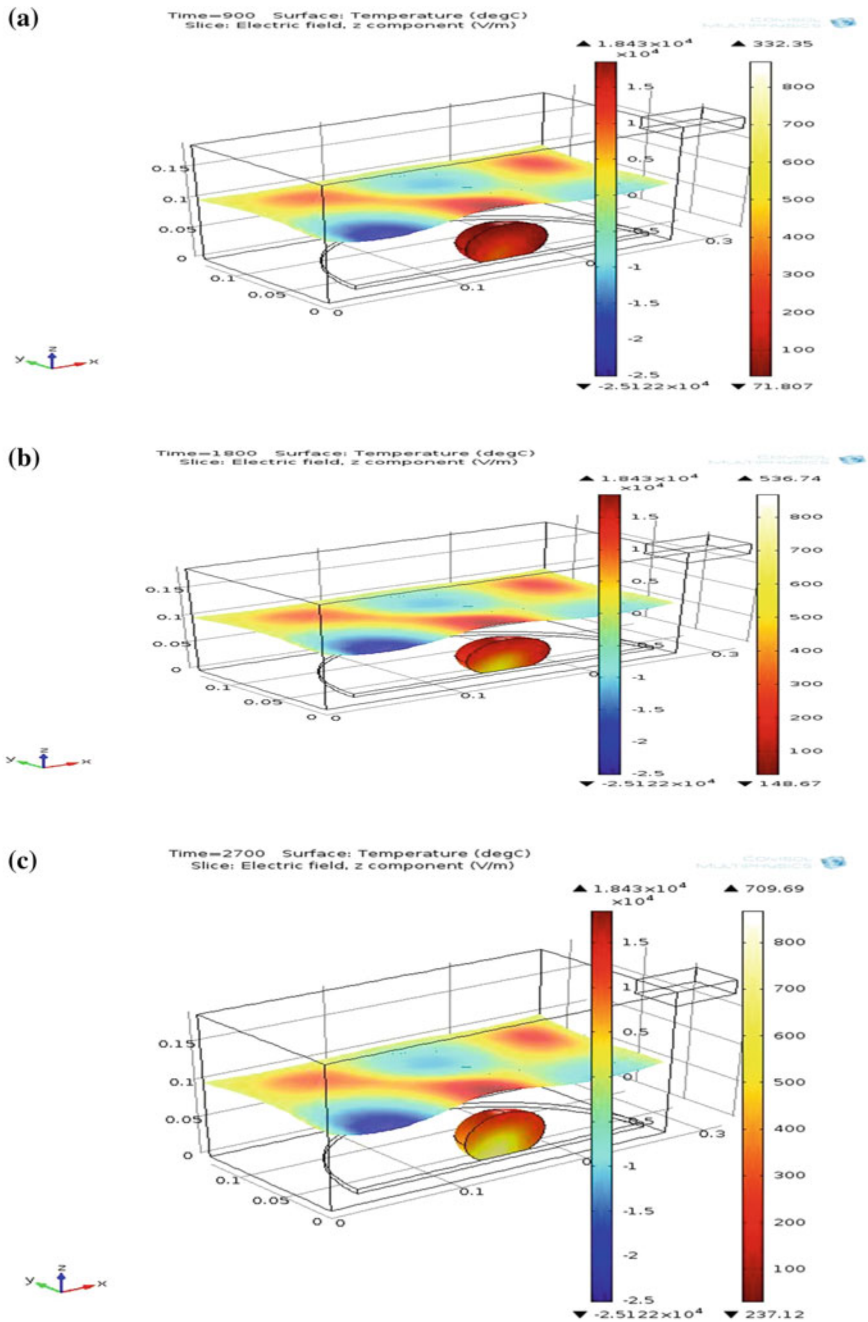


Fig. 2 Temperature distribution and electromagnetic field simulated through COMSOL at the end of: **a** 900, **b** 1800, and **c** 2700 s

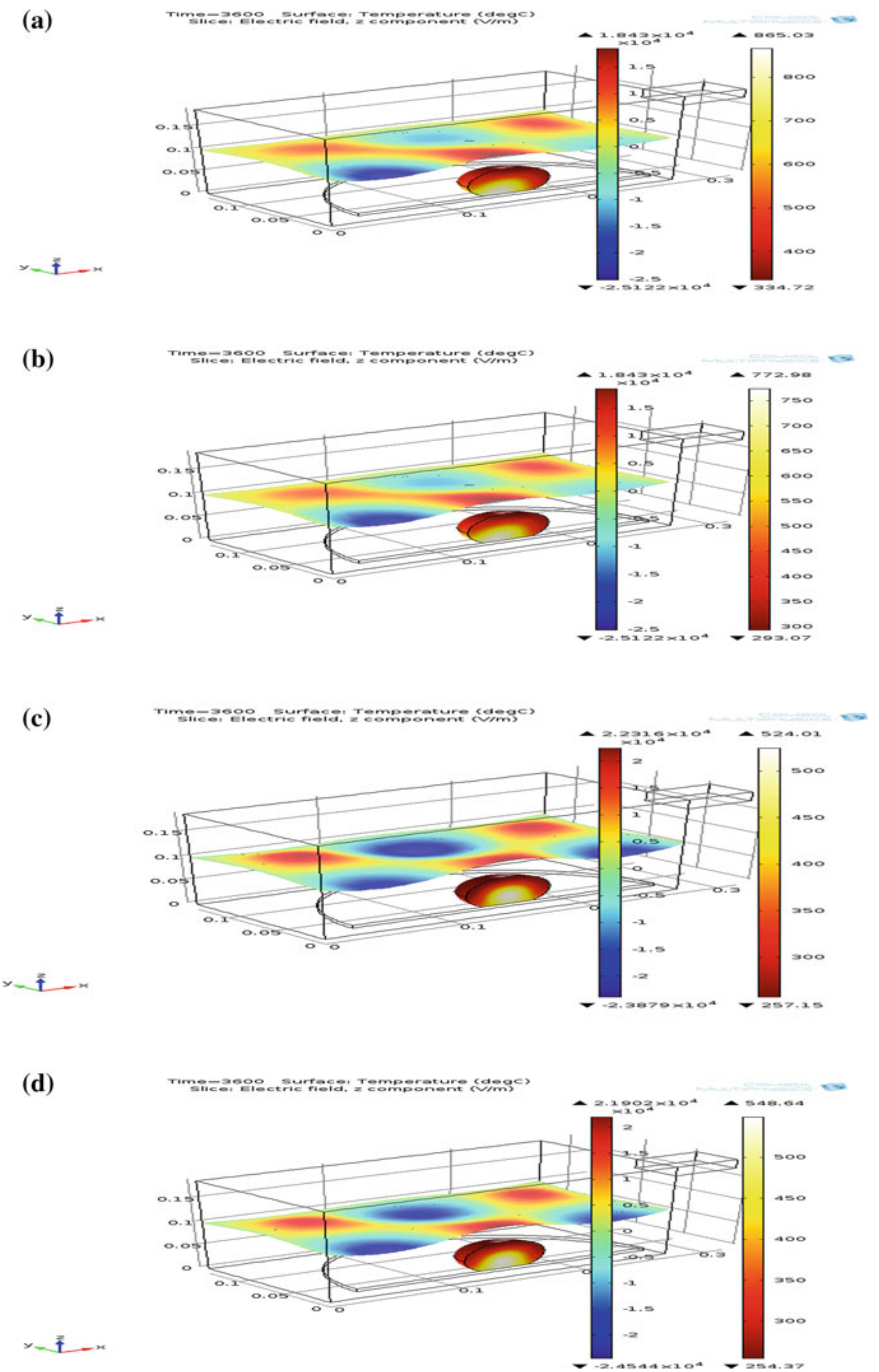


Fig. 3 Temperature distribution simulated through COMSOL at the end of 3600 s for samples, **a** I, **b** II, **c** III, and **d** IV, respectively

Table 4 Observations from simulated temperature profiles

Sample	Temperature at 3600 s		Temperature at 1500 s (°C)
	Highest (°C)	Lowest (°C)	
Sample I	865.03	334.72	350
Sample II	772.98	293.07	325
Sample III	524.01	257.15	300
Sample IV	548.64	254.37	300

Below temperature of 300 °C, error was limited to 200 but increases significantly after that. The deviation from the experimental result is expected as COMSOL does not account for the chemical reaction and conversion taking place. According to the simulated model, 700 °C is achieved in one hour, but the experimental results are quite different from what is observed. This is mainly because the heat generated is utilized for the reaction. Another possible explanation is heat loss which exceeds the theoretically estimated amount. COMSOL approximates the heat loss due to convection and radiation using the impedance boundary condition, but the actual heat loss is more. Reaction and the escaping gases play a major role in this.

In the case of the third sample, the results were quite different from sample II as the temperature profile in COMSOL was in more agreement with experimental data. This may be because microwave heating plays a more important role in the case of the third sample as the amount of plastic present is comparatively less. So, the dependence on reaction characteristics may be less compared to the previous sample. The simulated temperature profile shows considerable deviation at high temperature. This may be because of the degradation of plastic happening in higher temperatures, which is unaccounted for in calculation of physical properties. Also, the presence of other components like aluminium foil has an influence.

In the case of sample IV the results are very similar to sample III may be because of the similarity in composition. The error in COMSOL temperature profile is more compared to the previous sample.

The predicted versus observed data plots display an agreeable regression value for the model. The deviation from linear plot is observed around the intermediate temperature range (200–500 °C). Melting and decomposition of plastic occur in this temperature range. The deviation shows the inability of the model to completely encompass the mechanism of melting and decomposition of plastic as the simulation runs on the properties of mixture (Fig. 5).

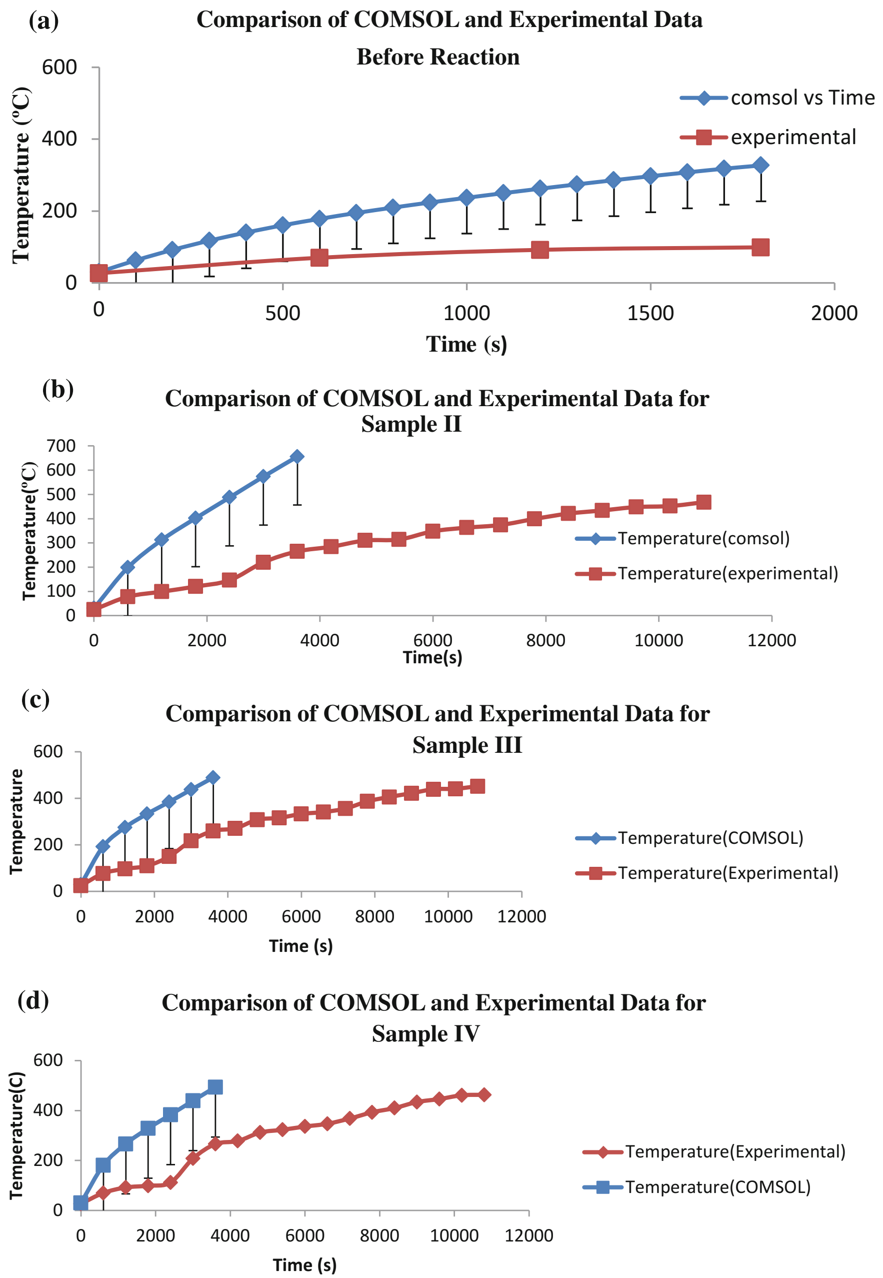
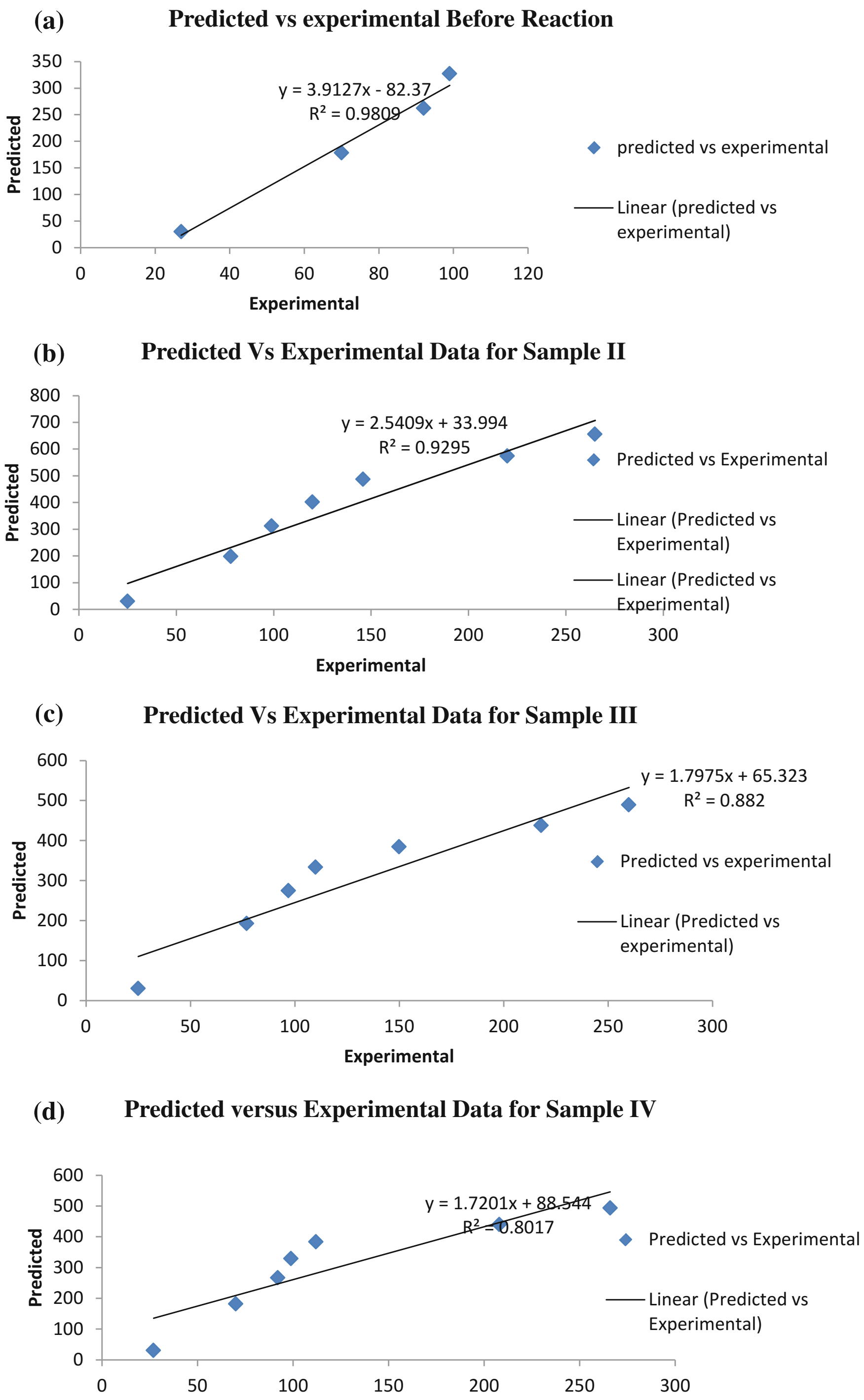


Fig. 4 Validation of temperature profile obtained using simulation for sample, **a** before reaction, **b** II, **c** III, **d** IV with experimental data


(a)
Predicted vs experimental Before Reaction
y = 3.9127x - 82.37
R² = 0.9809
Predicted
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
Experimental
predicted vs experimental
Linear (predicted vs experimental)
(b)
Predicted Vs Experimental Data for Sample II
y = 2.5409x + 33.994
R² = 0.9295
Predicted
800
700
600
500
400
300
200
100
0
0
50
100
150
200
250
300
Experimental
Predicted vs Experimental
Linear (Predicted vs Experimental)
Linear (Predicted vs Experimental)
(c)
Predicted Vs Experimental Data for Sample III
y = 1.7975x + 65.323
R² = 0.882
Predicted
600
500
400
300
200
100
0
0
50
100
150
200
250
300
Experimental
Predicted vs experimental
Linear (Predicted vs experimental)
(d)
Predicted versus Experimental Data for Sample IV
y = 1.7201x + 88.544
R² = 0.8017
Predicted
600
500
400
300
200
100
0
0
50
100
150
200
250
300
Predicted vs Experimental
Linear (Predicted vs Experimental)

◀**Fig. 5** Predicted versus experimental data for sample, **a** before reaction, **b** II, **c** III, **d** IV with experimental data

4 Conclusions

In this study, microwave-assisted pyrolysis of plastic was investigated with the help of COMSOL Multiphysics 4.3 software. Four samples that of variable composition were investigated, and a different temperature profile was obtained for each sample corresponding to the difference in the physical properties. The presence of good conductors and varying density seems to affect the temperature distribution which is a crucial parameter in microwave heating. The characteristic inverse temperature profile of microwave heating was observed in all samples. The simulation results were validated by experimental results and any variation may be due to effects of reaction which was not accommodated for in the simulation done using COMSOL. Detailed studies have to be done incorporating both microwave heating effects and reaction for a proper evaluation of process parameters. However, simulation using COMSOL Multiphysics 4.3 provided a clear understanding of microwave heating effects and its influence on temperature profile.

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Fly Ash as Backfill Material in Slopes Using Waste PET Bottles as Reinforcement

Maheboobsab B. Nadaf, Sushovan Dutta and J. N. Mandal

Abstract With the initiation of rapid urbanization and industrialization, there is an enormous demand for the power generation in India. Fly ash is a residue obtained in the thermal power stations by burning pulverized coal and lignite. It has been disposed and dumped off in abundance at these power stations and serious concerns regarding its utilization and safe disposal need to be addressed. This study proposed the use of fly ash as filling material in waste plastic polyethylene terephthalate (PET) bottles used as reinforcement for slopes. The PET bottles having diameter of 50 mm with variable heights of 15 and 30 mm were used. Length of cellular reinforcement strip used is 0.7 H with coverage ratio (Cr) of 0.6. The individual plastic bottles were joined in the form of three-dimensional strips with the help of tie wires. At the slope facia, jute geotextile was wrapped to plastic bottle internally throughout the width in order to avoid escaping of fly ash. The effect of change in length with constant spacing of strip on the footing capacity over the backfill was studied. From experimental model studies, it was observed that the strip reinforced fly ash slope showed better stability and improved the footing capacity significantly as compared to the unreinforced slope, while all the slopes were rested over a soft fly ash bed. The cellular strips of 30 mm height produced better slope performance as compared to the cellular strip of 15 mm height.

Keywords Fly ash · PET bottles · Reinforcement · Backfill · Slope

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1 Introduction

Nowadays, additional energy is needed for recycling in order to produce something usable materials, and thus, recycling process produces wastewater and air pollutants. Hence, the best solution is reusing for which no extra energy is required and does not contribute to pollution and not only the financial aspect is focused but even environmental aspect is also taken care. Plastics are considered as non-renewable resources because they are produced from the oil and it is considered as a sustainable waste and environmental pollutant and plastic has the intricacy about 300 years in the nature [28]. For mitigation of environmental impacts, reusing or recycling of it can be effectual and it has been proven that the use of plastic bottles as innovative materials for buildings, retaining walls, etc., can be a proper solution for replacement of conventional materials. We are running out of room for our garbage. Landfills all over the world are literally spilling over, and the oceans, once treated cavalierly as an infinite waste depository, have begun to wash back our own refuse to our shores. Though there are other wastes that form a part of garbage but plastics, being non-biodegradable are more visible than other trash, which are mostly biodegradable and it is especially true in case of polyethylene terephthalate (PET) bottles [18]. Plastic waste causes environmental pollution in the form of their disposal due to abundant increase of waste plastic bottles. So today, PET bottle waste is seen everywhere on railway tracks, on road, playgrounds, in garbage bins, etc. If it is possible to distribute a product over a wide area to a diverse population of end users, why should it not be possible to get the refuse from the product back to its source to be recycled/reused to a new product? "The term recycling refers to a system of empty container recovery; collection and reprocessing of the materials of construction to be used are source in the manufacture of a new product." Recycling is not always a closed loop; i.e., PET bottles are generally not remade into new PET bottles [20, 21]. With this question in mind, the researcher felt it would be worthwhile to find out what happened to the garbage generated by the use of PET bottles by commercial users and find out where there was a problem for disposal/collection and recycling of PET bottles.

Embankments for highway bridges and roads were built using fly ash produced from coal-sacked power plants. Behind the retaining walls, backfill material such as fly ash has also been used [23; 24; 27], in slopes [19]. Gray et al. [15] stated that fly ash has been also used as geotechnical properties for supporting structural loads as per earlier literature. For innovative structure and modernization, reinforced embankment structures are cost-effective alternatives over reinforced earth wall where the cost of fill and other concerns may make a steeper slope desirable. Reinforcement is mainly meant or used to construct an embankment at angle steeper slopes [33]. According to Perpetual Global Ltd, every year around 600 billion bottles are castoff all around the world and only 47% is collected. In country like India, disposal of used bottles is very critical where the collection rate for used PET bottles (75%) is well above the global average [30]. A substantial portion of collected bottles end up in landfills or incinerators, and the residue is mechanically recycled/downcycled. As per literature, experimental studies have been performed in the direction of using waste plastic bottles as cellular reinforcements with fly ash by Refs. [12, 23, 25, 26], as cells by Dutta and Mandal [12] and as geocell mattress by Dutta and Mandal [13]). Fly ash is a by-product which is generated from thermal power plants due to the combustion of pulverized coals, retains the properties that reproduce minerals present in the coals. In India, most of the thermal power plants generally use same types of coals. Efforts were made to use fly ash as majority fill material [15, 16, 22], for land reclamation [17] and for soil stabilization [11, 14, 29, 31, 32]. The objective of this paper is to examine the using of plastic bottles as municipal wastes in the slopes.

2 Materials and Methods

2.1 Properties of Fly Ash

The fly ash used in present study was collected from Dahanu Thermal Power Station, Thane, India. In this present study as per ASTM C618 [1], it belongs to Class F category. Chemical composition of the fly ash is determined by conducting X-ray florescence (XRF) test and mainly consists of silicon dioxide (SiO_2) 63.52%, aluminum oxide (Al_2O_3) 26.89%, iron oxide (Fe_2O_3) 5%, and calcium oxide (CaO) 1.23%. Sulfur trioxide (SO_3) is 0.072% and total loss on ignition is 1.49% [19]. Optimum moisture content and maximum dry unit weight which were determined by standard proctor test are 18.0% and 14.4 kN/m^3, respectively, as per ASTM D698 [2]. Cohesion and angle of internal friction which were found out by conducting consolidated drained triaxial test are 3 kPa and 31°, respectively, as per ASTM D7181 [3]. Specific gravity test of fly ash which is conducted as per ASTM D854 [4] is 2.15.

2.2 Properties of Reinforcement

To prepare cellular reinforcement strips, locally accessible wastewater bottles were used. The diameter of bottle was 50 mm. To form unit geocells, the bottle was cut across different heights. With a diameter of 0.6 mm, geocells were holed with a pointer at similarly spaced interims. The geocells which are in the form of cellular reinforcement were joined with plastic tie wires to form strips. For the plastic bottle of constant diameter of 50 mm, height of unit geocells was varied as 15 and 30 mm, respectively. In the present paper, cellular reinforcement is labeled as CRdh, where "d" and "h" are diameter and height of unit geocell in mm. $CR50_{15}$ indicates that the backfill is reinforced with a cellular reinforcement of diameter 50 mm and height 15 mm. The ratio of unit geocell height to its corresponding diameter is called as aspect ratio (h = d) of cellular reinforcement. As per ASTM D5035-11 (2011), the properties of cellular reinforcement for a 50-mm-diameter bottle have thickness 1 mm, tensile strength 8 kN/m, and initial modulus 195 kN/m [9].

A jute geotextile brought from locally available manufacturing company. At slope facia along the width of slope, jute geotextile was attached to the cellular reinforcement strip in order to prevent escaping of fly ash through the grid openings during loading. As per ASTM D5199 [6], jute geotextile thickness under 2 kPa normal pressure is 1.4 mm and mass per unit area is 0.6 kg/m^2 as per ASTM D5261 [7]. As per ASTM D4595 [5], tensile strength of geotextile is 11 kN/m with initial modulus 136 kN/m and apparent opening size of the geotextile is 133 μm (micron) as per ASTM D4751 [8].

3 Laboratory Model Test Setup

A laboratory test setup was planned to perform the entire experimentation considering the modeling laws and laboratory model limitations, and the test layout of reinforced fly ash slope model was designed. Position of hydraulic jack was adjustable to facilitate the variation of loading conditions, i.e., strip load at the edge of fly ash slope. All the potentiometers are planned to be held at the external face of test box with the help of a steel angle section. In order to perform the model tests, a custom-designed experimental test setup was fabricated as shown in Fig. 1. In this present study, the behavior of unreinforced and reinforced fly ash slope on soft foundation (fly ash bed) under strip loading was carried out. Coverage ratio (Cr) of

Fig. 1 Test setup

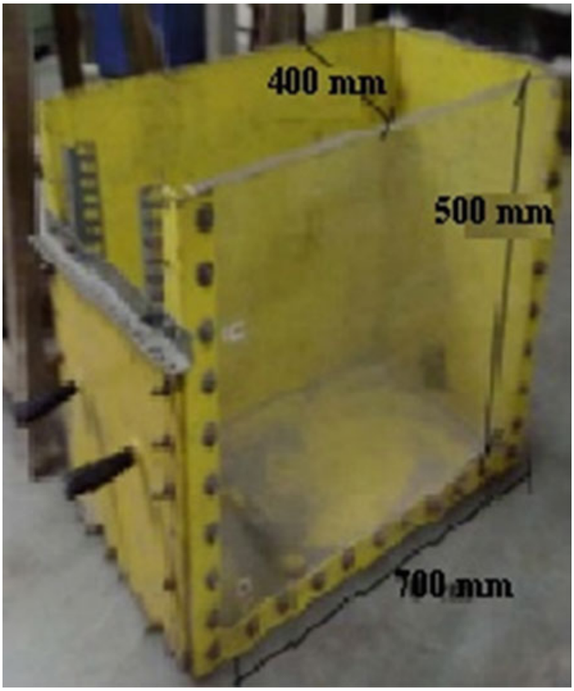

Table 1 Experimental test series

Model	Cellular reinforcement			
	Dimensions	Aspect ratio (h=d)	Vertical spacing (S_r)	Length (L)
Backfill reinforced with cellular reinforcement strips: Coverage ratio (Cr = 0.6)	$CR50_{15}$	0.3	0.3H	0.7H
	$CR50_{30}$	0.6	0.3H	0.7H

H = height of slope

0.6 is used in this experimental study for the length of reinforcement (L = 0.7 H). The coverage ratio is defined as the ratio of gross width of reinforcement strip to the center-to-center horizontal spacing between the strips [10]. Detailed experimental test series is tabulated in Table 1.

3.1 Test Tank

The internal dimensions of test tank were measured as 700 mm long × 400 mm wide × 500 mm high. The test tank was fabricated using 10-mm-thick steel sheets in order to ensure minimum deformations. The sidewalls were made from thick perspex sheet in order to allow clear observation of the failure. The test tank was facilitated to accommodate the cellular reinforced fly ash slope model of slope angle of 60°, length 500 mm, and height 300 mm, and foundation length 700 mm and depth 150 mm. For a strip loading system, a steel plate of thickness 8 mm having its length 360 mm, width 100 mm was used in present study.

The unreinforced slope before failure is shown in Fig. 2a. The failure surface of unreinforced slope and reinforced slope as acquired is shown in Fig. 2b, c. In this present study, cellular reinforcement of 50 mm diameter with varying heights of 15

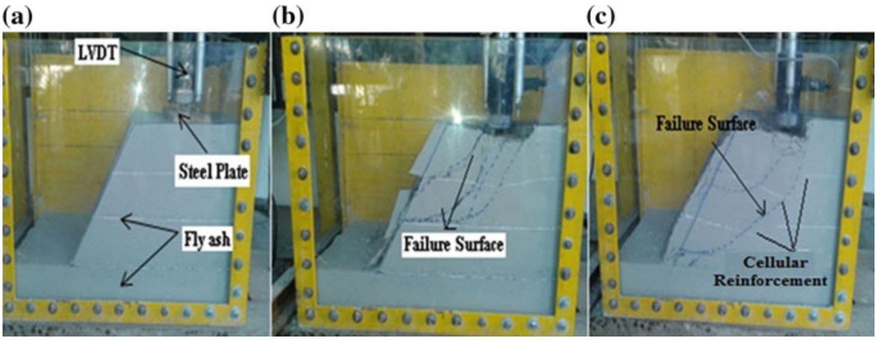

Fig. 2 **a** Unreinforced slope; failure surfaces after strip loading tests for $CR50_{30}$. **b** Unreinforced slope. **c** Reinforced slope

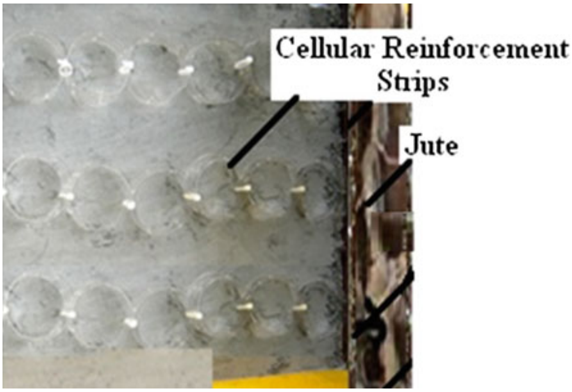

Fig. 3 Placement of cellular reinforcement strip $CR50_{30}$ in model test tank for L = 0.7H

and 30 mm was used. Placement of cellular reinforcement strip $CR50_{30}$ in model test tank for L = 0.7H is shown in Fig. 3.

3.2 Load–Deformation Curve

Backfill settlement was measured by LVDTs provided on top of the loading plate at different locations for individual load increment until failure occurred. The relation between backfill settlement and load was plotted and found nonlinear for L/H ratio. Figure 4 depicts the load–deformation responses under strip loading for unreinforced and cellular reinforced strip fly ash slope.

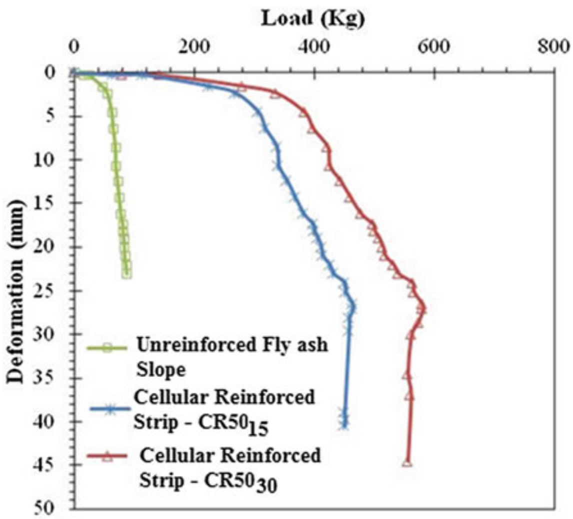

Fig. 4 Load–deformation responses of loading plate over slope under strip loading

Table 2 Load–deformation of unreinforced and cellular reinforced strip fly ash slope

Model type	Load (kg)	Deformation (mm)	Factor of safety (F.O.S)
Unreinforced	90	24.0	0.712
Cellular reinforced strip ($CR50_{15}$)	460	45.0	1.97
Cellular reinforced strip ($CR50_{30}$)	580	40.0	2.25

4 Result and Discussion

The load–deformation of unreinforced and cellular reinforced strip fly ash slope is tabulated in Table 2. From the experimental model studies, it has been observed that cellular reinforced strip of steep fly ash slope can take more load than that of unreinforced fly ash slope. The stress increment is due to the confinement effect of geocell sand or hoop stress. The factor of safety for unreinforced and cellular reinforced strip was determined by using simplified Bishop Method.

5 Conclusion

Slopes are widely used nowadays because it represents the most economical solution and also provides flexibility. Experimental model test setup is developed for carrying out tests on fly ash slope and fly ash with cellular reinforced strip under strip loading. From many decades, fly ash is a harmful waste material and difficult to dump, so it can also be used as a filling material in geotechnical application such as embankments, retaining wall, pavements. From feasibility study of fly ash and polymer cellular reinforced strip, fly ash slope following conclusion was made.

- The load taken by unreinforced fly ash slope is 90 kg when fly ash slope is overlaying fly ash bed for $L = 0.7H$. With coverage ratio of 0.6, the cellular reinforced strip of ($CR50_{30}$) with jute wrapping at facia as reinforcement, the load carrying capacity increases about 580 kg. Similarly, with cellular reinforced strip of ($CR50_{15}$) the load carrying capacity is 460 kg. Hence, cellular reinforced strip of ($CR50_{30}$) carries more load carrying capacity when compared with ($CR50_{15}$) of cellular reinforced strip in this model studies.
- From experimental model studies, we conclude that the fly ash slope overlying fly ash bed is soft foundation (fly ash bed), and the factor of safety for unreinforced fly ash slope is 0.712 and with cellular reinforced strip as reinforcement in fly ash slope, the factor of safety increases about 2.25 for ($CR50_{30}$) when compared to that of ($CR50_{15}$) is 1.97. Hence, fly ash slopes having cellular reinforcement of diameter 50 mm with height 30 mm make slopes more stable because of more strength and good bonding with fly ash as a material.

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Carbon Nanotubes as a Resourceful Product Derived from Waste Plastic—A Review

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Abstract Generation of wastes increases exponentially with the advancement of lifestyle, and out of different types of wastes in this planet, a behemoth portion of the waste is constituted of varying polymers. Researches are going on to mitigate this threat of leviathan quantities of waste plastics around the globe. Landfilling and incineration are one of the ways to eradicate the problems related to waste polymers but the processes of landfilling and incineration are not that amenable techniques. The process of incineration favours the recovery of energy but both social and economic limitations associated with it has made the process quite incompetent. Hence, it is imperative to find a new way to mitigate this problem. In the past decade, researchers after strenuous investigations have found that recycling of plastics can be utilized as one of the cardinal ways to mitigate the threat of the large quantity of waste plastics. Additionally, it has also been revealed that wastes' plastics can serve the purpose of being one of the consequential precursors of carbonaceous feeds that can be recycled under appropriate reacting conditions to produce carbon nanotubes (CNTs) of varying forms and qualities and also to meet the challenge of finite nature of fossil fuels. CNTs possess an exceptional chemical, mechanical, thermal and electrical properties which have attracted great scientific and technological interests to explore it for realistic and practical applications. CNTs with these unique properties have found numerous applications in various genres of science and technology innovations. Several methods have been developed and reported that is followed to synthesize CNTs of different forms under proper reacting conditions in the presence of suitable catalysts (nickel based, cobalt based, iron based, etc.). Different forms of CNTs are available among which the

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production of multiwall carbon nanotubes (MWCNTs) from waste polymers is feasible and satisfactory. Though there are various methods available for synthesis of CNTs, benchmark and feasible method for CNTs synthesis is yet to be reported. In depth, investigations are required to carry out to develop a feasible method that will utilize either virgin or waste plastics as the carbon precursors to synthesize CNTs, taking all the parameters under consideration influencing both the quality and quantity of it. The questions that need to find answer are—What are the parameters influencing the mechanism of growth of both the forms of CNTs (SWCNTs/MWCNTs) from plastics (virgin and waste)? How can the decomposition temperature be reduced to make the process not only efficient in terms of saving energy but also in terms of abjuring the formation of both dioxins and furans? How to make the process more feasible so that it can be a good alternative to improvise the quality of CNTs from wastes' plastics? In this paper, a review has been presented discussing various methods available till date for synthesis of CNTs from virgin and waste polymers ranging from polyethylene, polypropylene and polyethylene terephthalate to polyvinyl alcohol. Finally, the paper proposes an optimal route for the production of CNTs from plastics. It is evident that the genre of converting low-valued materials to value-added products such as carbon nanotubes that can be explored for various applications is not only a promising route in terms of recycling technology but also in terms of sustainability

Keywords Carbon nanotubes · Waste plastics · Value-added products
Sustainability · Recycling technology

1 Introduction

The consumption of plastics is increasing exponentially and so the generation of waste plastics that causes detrimental effect on the environment and human health. On the other hand, plastics offer features such as strength, lightweight, heat resistance and low cost, which make them versatile for commercial and consumer uses and is the best all-round environmental option for various applications. So, it would be purely impractical to ban them entirely. A survey by Central Pollution Control Board (CPCB) of India found that approximately 15,343 tonnes of waste plastics is generated every day from nearly 60 cities in India. Hence, researchers had been looking for decades to mitigate this problem of excess quantities of generated dross plastics. Presently, incineration and landfilling are the two most probable solutions of the problem [7]. Incineration is one of the ways to solve the problem of degradation of waste plastics but emission of flue gas containing contaminants such as dioxins and furans is a giant environmental and social issues associated with it which is making the application of this technology quiet stringent [34]. Hence, high cost, lower availability of space and environmental consequences together have made the implementation of the solutions restricted calling for more desirable alternatives. Though many other alternative routes have been proposed till date to address the environmental issues, none of the processes could be widely used because of lack of economic viability and environmental friendliness [1, 20]. Recycling of waste plastics can be one of the best possible alternatives to eradicate the problems associated with the degradation of waste plastics. After thorough investigations, researchers have found that different forms of carbon nanotubes (SWCNTs/MWCNTS) can be synthesized in a feasible way by potential recycling of virgin/waste polymers under proper reaction conditions. Since their discovery in the early nineties by Iijima (1991) [21], carbon nanotubes (CNTs) with their robust chemical, mechanical and thermal properties have generated a widespread interest in the field of science and engineering. There are substantial literatures available reporting the fact with enough evidences that the emergence and development of carbon nanotubes (CNTs) in recent years have opened up a new dimension of material development and have been identified with plethora of applications [11, 12, 41, 46] such as in gas purification, wastewater treatment, carbon dioxide capture, sensors, energy storage, super capacitors, coatings and many others [13, 26, 4]. Even with such behemoth assertive qualities of CNTs, it has still not been commercialized properly and hence fails to meet the passable demand of it. One of the major reasons is the lack of a benchmark process. Many processes have been reported in the literature including chemical vapour deposition, arc discharge, laser ablation. The processes have their intrinsic disadvantages as well as certain effects on the product specification. With the variation of the feed material, the final product and the process parameters vary in a wide range. Use of catalyst and other uncertainties pertaining to the processes is hindrance towards the commercialization. Hence, a benchmark process needs to be developed which should be sustainable. The questions that arise are—what are the parameters affecting the mechanism of growth of CNTs from plastics (virgin and waste)? How can the operating temperature be reduced to make the process more cost-effective and eschew the formation of dioxins and furans? How to improve both the quality and quantity of CNTs for industrial production from waste plastics? The paper aims to answer the questions by presenting a detailed review of CNT synthesis from selected waste plastics and proposing a possible sustainable route for CNT synthesis.

The paper has been divided into six sections. Introduction is the first section of the paper. Section 2 describes the methodology adopted in the paper. Section 3 gives a general idea about carbon nanotubes. The subsequent one describes synthesis methods of CNT from different waste polymers. In Sect. 5, product specification has been discussed. Then in Sect. 6, the final discussion and conclusion have been done.

2 Methodology

The contents of this paper are limited to the published literature, i.e. journals, conference proceedings and to some extent information from electronic media. Different databases such as Science Direct, Google Scholar, Wiley, Springer were explored. Keywords such as “Nanotubes”, “CNT from Waste plastics”, “Value-added products from plastics” were used. Cross references of each relevant literature were examined for additional information. In this research, nearly 60 publications have been considered and reviewed. All the literature has been studied and referred properly. This review is organized based on the various methods practiced to produce carbon nanotubes from waste polymers.

3 Carbon Nanotubes

Carbon nanotubes can be classified into two main forms based on the arrangement of graphene sheets. The first form of CNT is single-walled carbon nanotubes (SWCNTs). It is a continuous cylinder of a graphene sheet with hexagonal units and entirely composed of sp2-bonded carbon atoms [28]. The most important parameter that affects the electronic and mechanical properties of SWCNTs is the Chiral Vector $C = (n, m)$. It indicates the alignment of graphene sheet rolled to form SWCTNs and is determined by the integers and graphene vectors. Based on the integer values (n, m), SWCNTs can further be classified into three main types. The first one is zigzag structure which shows metallic characteristic when n is a multiple of 3 or otherwise exhibits semiconducting properties. Arm structure is another form of SWCNTs which exhibits metallic properties and finally the Chiral structure that exhibits metallic properties when $(2n + 3/m)$ is an integer otherwise shows semiconducting properties [31].

The second form of CNT is a multi-walled carbon nanotubes (MWCNTs) which consists of multiple rolled graphene sheets. When compared to SWCNTs, the structure of MWCNTs is not well defined because of its structural complexities and variations. The diameter of SWCNTs is in nanometer range whereas that of MWCNTs is of higher range.

Carbon nanotubes possess robust mechanical properties. For instance, its Young’s modulus is about 1 TPA and tensile strength is 100 GPA which is more than 100 times that of stainless steel [6], while their density is only about one sixth (1100–1300 kg/m^3). As a result, it is playing a significant role in reinforcement with polymer composites. Thermal conductivity of CNT is more than 3000 w/m * k and is often comparable to that of diamonds simultaneously electrical conductivity (10^6–10^7 S/m) of CNT is either semiconducting or metallic depending upon the structure and is often comparable to that of copper [5, 45]. It has large aspect (length to diameter ratio), high environmental and chemical stability [7]. All together CNT represents one of the best examples of novel nanostructures derived by bottom-up chemical synthesis approach [11].

4 Synthesis of CNTs from Waste Polymers

Recycling of waste polymers to produce highly value-added product that find potential applications in various fields of technology has obviously attracted researchers [24, 43]. CNTs can be produced from different carbon sources amongst which waste plastics as a carbonaceous feed is a feasible source both for mitigating the problem of wastes and producing a resourceful product. There are different methods practiced to synthesize CNTs that include (a) arc discharge method, (b) flame synthesis, (c) laser ablation method and (d) catalytic chemical vapour deposition method (CVD). Comparatively, catalytic chemical vapour deposition method [19, 29, 32, 43] and combustion method [23] are the most convenient methods to produce good quality and quantity of CNTs. Low-valued materials or wastes as carbon precursors can be broken down to synthesize resourceful one-dimension nanomaterials such as single and multiwall carbon nanotubes. Current trend of research supports conversion of waste or virgin polymers to useful nanomaterials [14, 43]. Different methods to synthesize carbon nanotubes proceed with a main objective and that is the breakage of larger to smaller carbon precursors by means of pyrolysis or thermal degradation in different types of reactors (fluidised bed reactor, crucible reactor, etc.) under varying reacting conditions. The following section describes about the various methods practiced to synthesis CNT from different virgin and waste polymers.

4.1 CNT from Polypropylene (PP)

Polyolefin is rich in carbon content with 85.7% of carbon in it. Hence, polypropylene and polyethylene, the prototype of polyolefin, are used extensively to produce carbon nanotubes [15, 16, 18, 22, 30, 39, 42, 48].

Liu et al. [27] explored waste PP to synthesize CNTs from a "two reactor system". The first one was a screw kiln reactor chosen to carry out the pyrolysis of PP at 1023 K in presence of zeolite catalysts followed by the catalytic decomposition executed in a tubular moving bed reactor at nitrogen atmosphere. MWCNTs with a mean diameter of 8 nm and hydrogen gas were generated between 723–1123 K in presence of nickel oxide (NiO) catalysts. CNTs synthesized were treated with acids with an aim to remove the traces of nickel oxide. Additionally, the catalytic decomposition temperature should be higher than 773 K in order to prohibit the formation of amorphous carbon to eschew the requirement of further purification of the product. However, the optimum temperature at which maximum CNTs generated using this method was at 973 K. Bajad et al. [4], on the other hand, utilised catalytic combustion to produce very high quality of CNTs. They carried out the combustion of the mixture of appropriate quantity of waste polypropylene and catalyst (Ni/Mo/Mgo) taken in a lid covered Si crucible to 1073 K for 10 min in a muffle furnace. Finally, it generated a high quality of MWCNTs with an inner diameter of 2–3 nm. To remove the residual metal catalysts and amorphous carbon from the surface of CNTs, they treated it chemically and thermally. Ni/Mo mole ratio imparted effects both on the synthesis and the size of CNTs. Additionally, the amount of Molybdenum (Mo) played a very significant role and lower concentration of it was complementary to obtain CNTs with larger diameter and well-aligned graphene wall. Again, lower content of it was equally favourable for the synthesis of approximately 46% of CNTs. Gong et al. [14] synthesized a new form of carbon nanotubes in the form of cup-stacks by the dual catalytic carbonization of powdered polypropylene in presence of organically metallic montmorillonite (OMMT) and nickel oxide (NiO) catalysts through "carbenium ions" mechanisms. The Carbenium ions generated endorsed both the degradation of PP and the formation of CNTs with higher carbon numbers. The mixture of PP and catalysts was taken in a crucible and heated to 923 K. Finally, the synthesized carbon nanotubes were treated with hydrofluoric acid (HF) and nitric acid to remove the traces of OMMT, nickel, and amorphous carbon in order to obtain high quality of CNTs. Pyrolysis of PP in presence of iron catalysts is another way to generate CNTs.

Chung and Jou [10] chose this technique and performed the experiment in a quartz tube furnace. Initially, the furnace temperature was maintained at 473 K for 15 min to make the specimen solvent free. Subsequently, the temperature was raised to pyrolysis temperature and pressure to 6.7×10^{-5} mbar. MWCNTs of desired diameter ranging from 16.5–40 nm and thickness 3.8–14 nm were gained. Pyrolysis temperature played a significant role on the morphology of the product. It was observed that at 923 K, generation of CNTs took place as the growth rate of CNTs was much higher than the coalescence rate of the iron particles. On the other hand, at 900 °C larger nanoparticles but with shorter nanotubes were produced with an irregular diameter. Mishra et al. [33] explored pyrolysis followed by a single-stage chemical vapour deposition to synthesize CNTs. They performed the experiment at different sets of temperature varying from 600 to 800 °C in presence of Nickel catalyst at hydrogen and argon atmosphere. The pyrolysis degradation in presence of transition catalyst resulted in the formation of approximately 20% by weight of high-quality MWCNTs. Gonget al. [15, 16] demonstrated the combined catalytic carbonization of polypropylene in presence of activated carbon (AC) and nickel trioxide (Ni_2O_3). Firstly, they prepared a mixture of PP, metal oxide and activated carbon in a Brabender mixer by mixing it for 10 min to 453 K. Subsequently, the mixture was taken in a conventional quartz tube reactor at nitrogen atmosphere at different carbonization temperature where CNTs were synthesized by carbonization. It was found that the combined effect of activated carbon and nickel trioxide had a synergistic effect on the carbonization of polypropylene into CNTs. Activated carbon not only promoted the fragmentation of long chain of PP but also assisted in situ Ni catalyst to catalyze the dehydrogenation and aromatization of intermediate aromatic compounds. Additionally, Fe and Co in the original activated carbon helped in the carbonization of PP. They named this technique as the layer-by-layer assembling mechanism on benzene ring to produce CNTs by the degradation of PP in presence of activated carbon and nickel trioxide. The method is cost-effective in terms of producing large quantities of CNTs with the aid of easily available cheap activated carbon as co-catalysts. Table 1 depicts the various technologies adapted till date to produce CNTs of varying forms from waste/virgin polypropylene in a terse way.

Table 1 Different types of processes or technologies used to prepare CNTs from polypropylene

Process/techniques	Reaction details	Product specifications	Reference
Catalytic pyrolysis followed by catalytic decomposition	Pyrolysis at 1023 K Catalytic decomposition 723–1073 K	8-nm-mean-inner-diameter MWCNTs	Liu et al. [27]
Degradation of polymer followed by the catalytic degradation	Temp: 973 K	Cup-stacked carbon nanotubes (CS-CNTs) with narrow length and diameter distributions	Gong et al. [14]
Single-stage chemical vapour deposition method	By exposing the catalyst and precursor to temperature 873–1073 K under argon and hydrogen atmosphere for an hour	MWCNTs	Mishra et al. [33]
Pyrolysis of polypropylene	The bubbling fluidized bed quartz reactor temperature maintained in the range of 723–1123 K, and the gas fluidization velocity maintained at 0.05–0.4 m/sec	MWCNTs	Arena et al. [2]
Catalytic combustion of PP/Ni_2O_3/OMMT	The optimized temperature was 1103 K prepared above an oxygen flame. Acid treatment was done. The optimized concentration of nickel was found to be 3.5% by weight	Tube-like MWCNTs were produced with main diameter 50–60 nm and the longest length obtained was 5 nm	Jiang et al. [22]
Catalytic carbonization of polypropylene overactivated carbon and Ni_2O_3	Mixture was prepared at 453 K for 10 min. CNTs were synthesized by carbonizing PP/M_2O_3/AC mixtures in a conventional quartz tube at nitrogen atmosphere.	Internal diameter of 30 with the outer diameter in the range of 10–40 nm	Gong et al. [15, 16]
Catalytic decomposition followed by pyrolysis	PP, MA-PP and nickel together taken in an autoclave and raised to 973 K for 12 h and then cooling it at vacuum for 6 h.	CNTs with larger diameter around 160 nm	Zhang et al. [47]

4.2 CNT Synthesis from Polyethylene (PE)

Zhuo et al. [48] performed a three-stage process to catalytically decompose the pre- or postconsumer polyethylene to produce carbon nanotubes. At the first stage, pyrolysis was carried out at 1073 K followed by exothermic combustion at Mixing-Venturi/burner producing light hydrocarbons, and finally, the combustion effluent was passed through the small screens of stainless steel to catalyze the formation of CNTs at 1023 K. Optionally, stainless steel can be coated either with cobalt (Co) or nickel (Ni) and can be used both as a catalyst and substrate. TEM images revealed CNTs were typically of 1–5 μ min length with a mean diameter of 30–85 nm. The yield of CNTs was over 10%. In this method, by-products of pyrolysis such as hydrogen and water proved to be advantageous not only in terms of controlling the rate of deposition of carbon but also in terms of forbidding the poisoning of the catalysts. A schematic diagram of the three stage system is illustrated in Fig. 1.

Arena et al. [2] performed a feasible and an economical experiment to obtain high quality and large quantity of CNTs carried out in a bubbling fluidized bed reactor by the pyrolysis of polyethylene (virgin or recycled). The temperature of the bed made up of alumina or quartz was maintained in between 723 and 1123 K. The bed of quartz or alumina catalyzed the degradation of waste polyethylene at nitrogen atmosphere purged at a velocity of 0.05–0.4 m/s to forbid the oxidation of carbon. The product found to contain traces of metal catalyst and bed materials was treated with aqueous hydrofluoric acid (HF) and nitric acid taken in 1:1 ratio by sonication which resulted a purity of about 90–95% of product purity. By the-mogravimetric analysis, it was found that the thermal decomposition of the polymer actually occurred at about 963–973 K. Processing of either virgin or recycled polyethylene separately or mixing the polyolefin does not make much difference in the yield and the quality of the product. Pol and Thiyagarajan [40] explored both the forms of polyethylene, i.e. high-density polyethylene (HDPE) and low-density polyethylene (LDPE) to produce CNTs by the thermal degradation in a closed reactor in an inert atmosphere followed by Thermolysis in presence of Cobalt

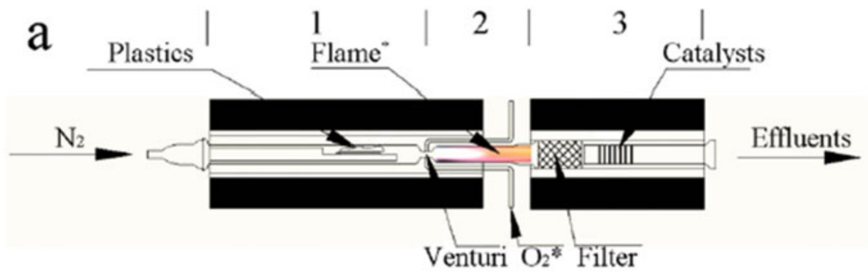

Fig. 1 **a** Three-stage laminar flow, electrically heated, muffle furnace, used for the CNT synthesis (1: pyrolysis zone, 2: combustion zone* and 3: synthesis zone) [48]

Acetate. MWCNTs with a diameter of 80 nm and a length of more than a micron were produced within 2 h of reaction time. To remove the traces of cobalt catalyst, the produced MWCNTs were treated with acids so that its quality could be enhanced. Gong et al. [17] performed the catalytic carbonization under the combined catalysis of Ni_2O_3 and polyvinyl chloride (PVC) resin of low-density polyethylene to synthesize long carbon nanomaterials. Amount and type of PVC resin found to be an influential parameter in the yield of CNTs. Kukovitsky et al. [25] used waste polyethylene to produce CNTs by catalytic decomposition. The pyrolysis products undergone decomposition between 973 and 1073 K in presence of nickel catalysts supported on an amorphous carbon which resulted in the formation of carbon nanotubes with a diameter ranging between 10 and 100 nm. Gong et al. [14] explored linear low-density polyethylene (LLDPE), high-density polyethylene (HDPE) and low-density polyethylene (LDPE) to produce varying amount of CNTs in presence of copper bromide (CuBr) and NiO as catalyst. The highest yield of CNTs was 56.5% from LLDPE. Table 2 presents the summary of the techniques that have been used to synthesis CNTs from polyethylene.

Table 2 Different types of processes or technologies used to prepare CNTs from polyethylene

Process/techniques	Reaction details	Product specifications	Reference
Polymer pyrolysis, followed by mixing-Venturi/burner	Feed (~1 g) inserted into pyrolyzer section of the furnace at 1073 K and nitrogen served as the inert carrier gas, the pyrolyzates gas was mixed in presence of air in the Venturi. Combustion gas was passed to the third stage at 1023 K	Lengths typically of 1–5 μm and mean diameter in the range of 30–85 nm	Zhuo et al. [48]
Thermal degradation of waste polymer (HDPE), thermolysis of LDPE in presence of cobalt acetate (CoAc) catalyst in a closed system	Mixture (HDPE and catalyst) incorporated into an autoclave in an inert nitrogen atmosphere at 973 K followed by cooling followed by acid treatment	MWCNT with 80 nm and a length of more than a micron is produced	Pol and Thiyagarajan [40]
Catalytic carbonization of LLDPE	2.5 g of the sample taken at the quartz tube crucible heated at 873 and 973 K or 1073 K in nitrogen atmosphere	Long carbon nanomaterials and amorphous CNFs	Gong et al. [17]
Catalytic decomposition of polyethylene pyrolysis products	The reaction was conducted at 973 and 1073 K	Carbon nanotubes of the range 10–100 nm is produced	Kukovitsky et al. [25]

4.3 CNT from Polyvinyl Alcohol (PVA)

Catalytic pyrolysis in an inert atmosphere to produce carbon nanotubes from polyvinyl alcohol is a convenient way and was performed by Nath and Sahajwalla [35] and his research team. Firstly, they prepared the composite film of PVA by treating PVA and FA in deionized water and casting the mixture in a glass Petri dish. After the mixture gets dry, a composite film of PVA and fly ash obtained and then the pyrolysis of the composite film was carried out at 723 K in a horizontal quartz tube reactor for 10 min. This resulted in the formation of carbon nanotubes ribbon of different shapes such as Knotted and twisted, U, spiral shaped.

Nath and Sahajwalla [36] again performed the experiment almost in the same way but by modifying the catalyst. Fly ash was treated with 2 M of sodium hydroxide at 358 K for 8 h to obtain modified fly ash (MFA). A composite film of 50–70 μm was prepared by mixing PVA and modified fly to synthesize carbon nanotubes. They obtained Carbon nano tubes in the form of varying shapes in the form of ropes, twisted ropes, Y branch ropes, and stacked cone sheet but with a better yield of 54% yield (Table 3).

4.4 CNT from Poly Ethylene Terephthalate (PET)

Waste PET is also another source to obtain carbon nanotubes. Berkmans et al. [8] followed a catalyst-free technique by to derive carbon nanotubes by the pyrolysis of PET followed by cathode arc discharge method. PET char was prepared at 1123 K for 20 min under nitrogen atmosphere flushed with a pressure of 0.1 bar in a stainless still container followed by the arc discharge carried out at a temperature up

Table 3 Different types of processes or technologies used to prepare CNTs from polyvinyl alcohol

Process/ technology	Reaction details	Product specifications	Reference
Catalyzed pyrolysis	Composite film of PVA and FA placed in the cold zone for 30 s under nitrogen atmosphere with a flow of 2 L/min and subsequently passed into the hot zone at 723 K for 10 min	CNT ribbon of different shapes such as Knotted and twisted, U, spiral shaped with a width ranging from 18 to 80 nm	Nath and Sahajwalla [35]
Pyrolysis	Composite film of PVA and FA placed in the cold zone for 30 s under nitrogen atmosphere with a flow of 2 L/min and subsequently passed into the hot zone and finally in the cold zone for 30 s	Carbon nanotubes ropes, twisted ropes, Y branch ropes, staked cone sheet	Nath and Sahajwalla [36]

to 2873 K. As a product, they obtain 39% by weight of ultrafine and nano-sized solid carbon spheres and tubules, i.e. nano-ultrafine carbon nanotubes (NUFCNTs) and multi-walled carbon nanotubes (MWCNTs) with a mean diameter of 20 nm. It was observed that temperature was an important factor to get the desired form of the carbon nanomaterials, i.e. spherical or tubular form (Table 4).

5 Product Specifications

Reaction conditions, type of the precursors and catalysts, weight of the polymer and catalysts, reaction temperature all together play a very important role that affects the morphology, structure and shape of the carbon nanotubes. CNTs consist of straight carbon layers either parallel or inclined to their tubular axis from Polyvinyl alcohol as the carbonaceous feed. CNTs from PP on the other hand comprise wavy carbon layers which approximately align with the axis of the nanotubes and are inclined to their tube axis in case of polyethylene [10].

Thickness of the carbon nanotubes is also affected by the type of the precursors used. For an instance, CNTs from PE contain hollow tubules generally, and from PP, they are generally thin walled compared to the CNTs from PVA that are thick walled. Various characterizations are done to find out the specifications of the synthesized carbon nanotubes along with the catalysts used and these are wide angle X-ray diffraction technique, Raman spectroscopy, electron microscopy (SEM and HRTEM). Table 1 shows the variation in the type of CNTs produced from polyolefin after thorough and rigorous characterization (Table 5).

Table 4 Process used to prepare CNTs from polyethylene terephthalate

Process/techniques	Reaction details	Product specifications	Reference
Pyrolysis followed by rotating cathode arc discharge method	Waste PET treated at 1123 K for 20 min under nitrogen atmosphere flushed with a pressure of 0.1 bar followed by the arc discharge method carried out at temperature up to 2873 K	Nanochanneled ultrafine carbon nanotubes (NCUFCNTS) and MWCNTs with a mean diameter of 20 nm	Berkmans et al. [8]

Table 5 Specifications of CNTs from polypropylene and polyethylene, two prototypes of polyolefin

Feed	Temperature of decomposition (k)	Outer diameter (nm)	Length	Shapes and form	Reference
Waste polypropylene	1073	15.5–18.5		MWCNTs	Bajad et al. [4]
Virgin or waste pp with activated carbon and nickel trioxide	973	outer diameter in the range of 10–40 nm was obtained	–	A lot of winding and short CNTs	Gong et al. [15, 16]
Polypropylene	973	16.5–40 nm	3.8–14 nm	MWCNTs	Chung and Jou [10]
PP AND MA-PP	873–973	Larger diameter with an average size of 160 nm	–	Tubular carbon nanomaterials	Zhang et al. [47]
PP and MA-PP	903–1103	Wide range of diameters and the main range is between 50 and 60 nm	Wide range of length is there and the longest length is 5 µm	MWCNTs	Jiang et al. [22]
PP and MA-PP	873	33 nm (outer diameter) 12 nm(inner diameter)		Tube-like structures, well aligned graphite sheets. MWCNTs with hollow centre	Tang et al. [43]
Polyethylene (HDPE, LDPE)	1073	Mean diameter in the range of 30–85 nm	length typically of 1–5 µm	16 layers of parallel graphene layers, MWCNTs	Zhuo et al. [48]
HDPE and LDPE (polymer waste)	973	Diameter of 80 nm	Length of more than a micron	MWCNTs	Pol and Thiyagarajan [40]
Virgin or recycled polyethylene	973	15–40 nm		Coiled and straight tubes as MWCNTs and multi-walled nanofibres	Arena et al. (2006) [2]
Polyethylene	973–1073	Diameter in the range of 10–100 nm		Carbon nanotubes (MWCNTs)	Kukovitsky et al. [25]

6 Discussions and Analysis

In this study, some methods have been discussed about the synthesis of CNTs from virgin and/or waste plastics as carbonaceous feed. Recycling of waste plastics has been attempted by a number of researchers [1, 3, 38, 44, 49]. Divergent methods to produce CNTs from waste plastics have made it possible to utilize this seemingly virulent waste as a feed and decimate problems associated with it. These processes for producing CNTs from plastics have caught the attention of the researchers around because of the unique and extraordinary properties of CNT. This method is found to be practical in comparison to landfilling or incineration which are malpractices of waste plastic disposal.

There are different issues associated with the preparation of CNTs from different types of plastics. One of the most intimidating issues is the operating temperature of the process. The temperature ranges vary in a wide limit and depend on the processes adopted for synthesis of CNT. Figures 2 and 3 present a brief idea about the temperature range of preparation of CNT from polyolefin. CNTs from polyolefin in presence of suitable transition metal catalysts can bring down the reaction temperature to a considerable degree. Hence, it not only becomes an energy-efficient process but also becomes one of the environmental-friendly and amenable practices (Figs. 4 and 5).

The formation of dioxins and furans during incineration of MSW-containing plastics is a daunting issue, though the role of different types of plastics is not very clear. Generally, the presence of halogenated polymer compounds such as flame retardants, PVCs is the reason for generation of PCCDs and PCDFs during Incinerations. It is suggested to adapt technologies like pyrolysis and gasification instead of incineration for plastics or mixture of plastics [9, 37]. As a result, employing pyrolysis during CNTs preparation has no such issues with generation of dioxins and furans which makes the process socially acceptable. Though the process of recycling wastes' plastics to CNTs is an acquiescent technique, still a huge development is required to make the process feasible and cost-effective such that large quantity of it can be produced to meet the demands of the society. Among all the parameters, variations among the processes are there because there are many parameters that affect the formation of CNTs from waste polymers. Types of catalysts, reactor design and temperature are the three most influential parameters that are to be considered seriously to make it a sustainable method. One such variation in reaction temperature is illustrated above (Fig. 6). Different factors of CNT synthesis such as temperature, reactor configuration, feed material processes adapted are responsible for a wide variety of output containing both SWCNT and MWCNT. Among the various methods discussed above, pyrolysis accompanied by catalytic chemical vapour deposition (CVD) is one of the most feasible and widely

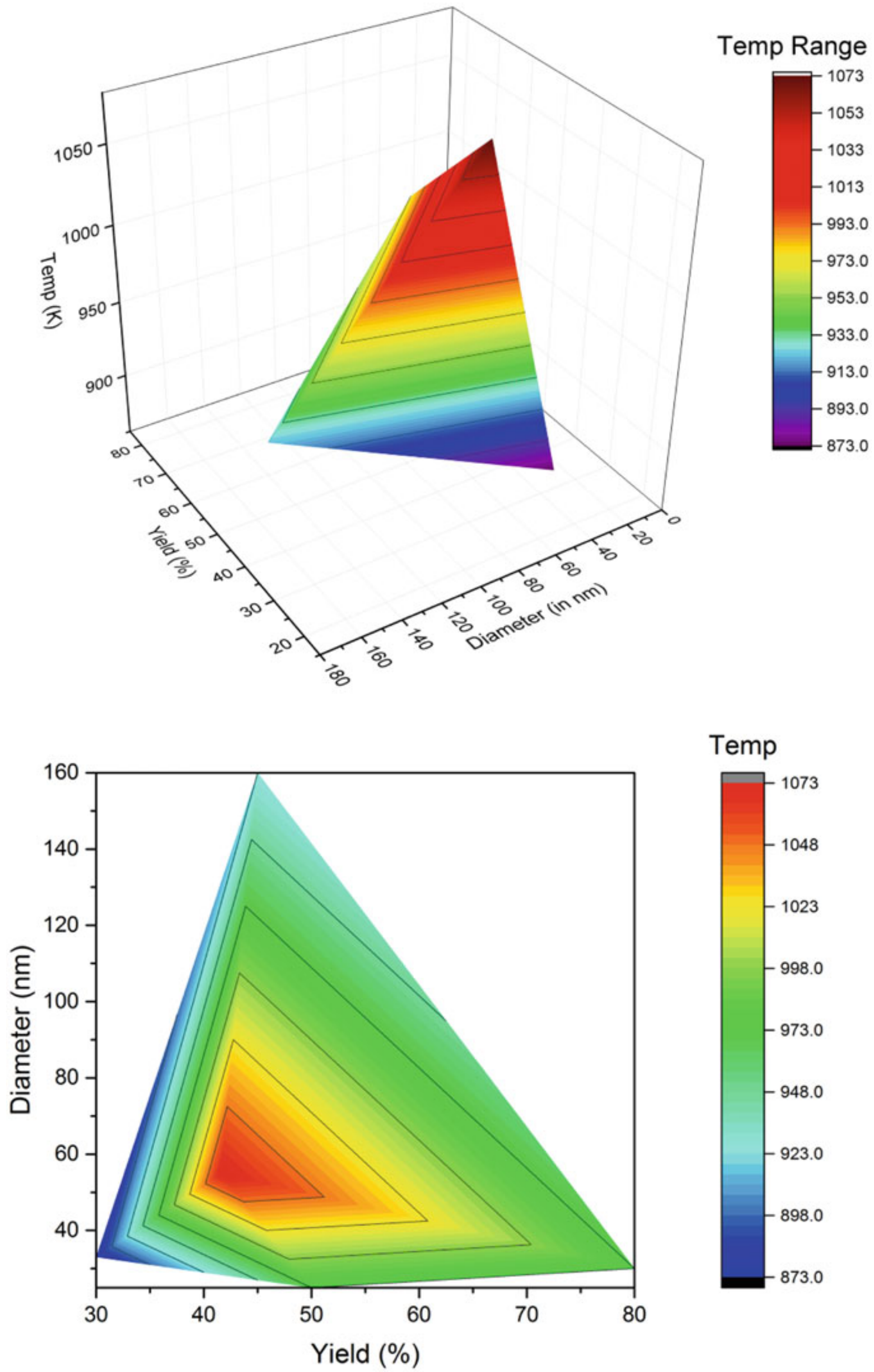

Fig. 2 3D and contour plot showing variation of the diameter (outer) and the yield of CNTs at different temperatures from PP

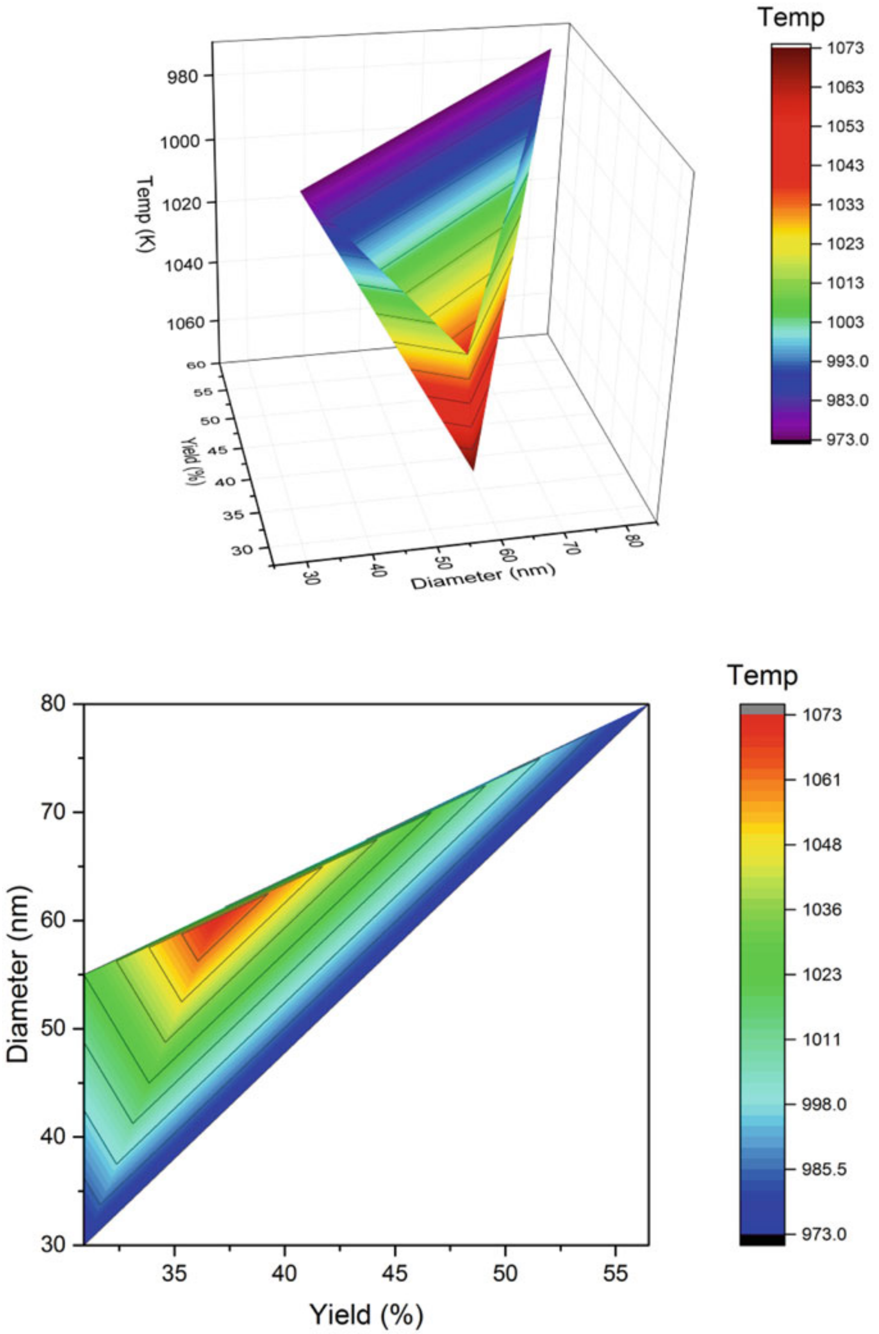

Fig. 3 3D and contour plot showing variation of the diameter (outer) and the yield of CNTs at different temperatures from PE

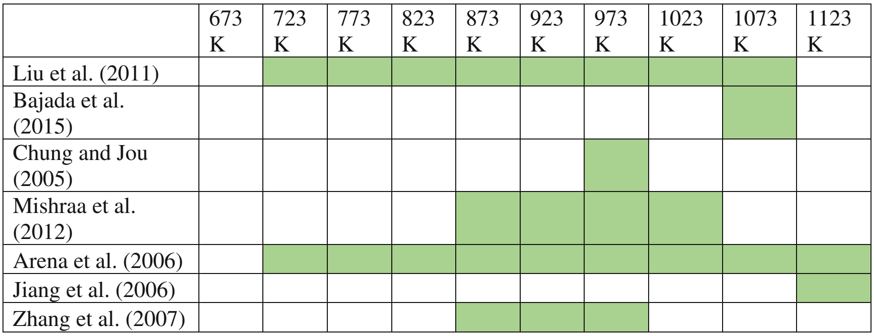

Fig. 4 Bar diagram showing the temperature range for CNT preparation from PP reported by different authors

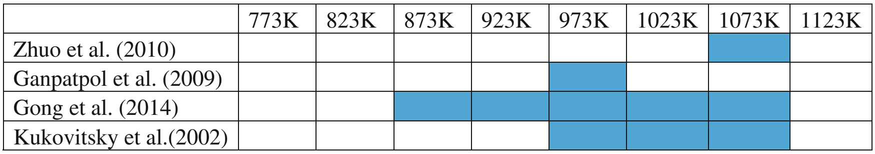

Fig. 5 Bar diagram showing the temperature range for CNT preparation from PE reported by different authors

used methods for large-scale production using suitable transition metal catalysts that can reduce the temperature range to a considerable degree from 873 to 1123 K to a range of 723–1023 K. Hence, pyrolysis with or without catalysts seems to be an efficient process for this purpose. It can also be operated at a temperature of 623 K, but it is highly dependent on the feed material and the kinetics of the decomposition. The use of pyrolysis in plastic degradation is also possible at 623 K, though the chances of evolution of dioxins and furans are higher at this temperature. That is why the range of 723–1023 K is optimum for this purpose. It may be considered that the high-energy penalty is nothing but an expense towards the environmental protection. It is suggested that further research work may be aligned with the findings of the paper for process intensification, modelling and scale up.

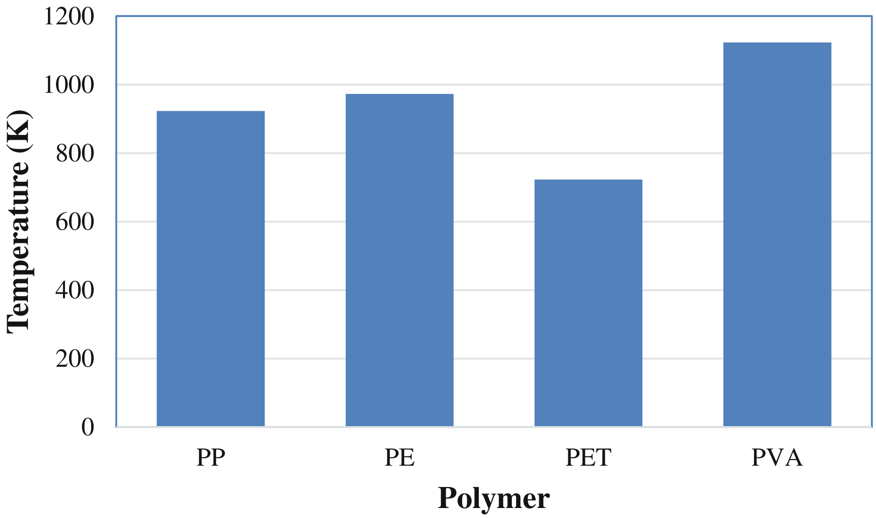

Fig. 6 Comparative temperature range for different polymers

7 Conclusion

In this paper, a comprehensive review has been presented on CNT production from waste plastics. The sustainability of the processes has also been discussed. It was found that the processes are mainly limited to laboratory and further research is required for scaleup. Despite the sustainable route for waste plastic management, issues such as high operating temperature, reactor design and conversion are the challenges faced by the researchers. The sustainability of the scaled-up processes will require fine tuning of these issues and challenges and their associated parameters.

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An Overview of Plastic Waste Management in India

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Abstract Plastics are the polymeric materials of high molecular weight and may contain other substances to enhance performance and/or to reduce cost. Plastics, because of their versatility, plasticity, durability, low weight, ease of manufacture and low cost, have replaced other materials like wood, glass, stone, ceramic, and metals from their traditional uses. Nowadays, plastics are used in almost all sectors like automobiles, packaging, agriculture, construction, textile, furniture, electronic, food processing, healthcare, and FMCG. Currently, we cannot think of life without plastics.

Keywords Plastic waste · India · 3R · Utilization

1 Introduction

Indian plastic industry is growing by leaps and bounds. This industry is driven by key factors like rising population, increase in income levels, and changing lifestyles. Presently, per capita plastic products consumption in India is much lesser than the developed countries suggesting excellent potential in terms of growth not only in manufacture but also in export (both raw material as well as products). Indian plastic industry is one of the fastest growing industries in the world. Compared to China (10% p.a.) and UK (2.5% p.a.), plastic consumption is growing 16% per annum in India.

With the increase in use of plastics, plastic waste is becoming a great environmental nuisance mainly because of its improper disposal. Plastic is generally non-biodegradable; i.e., it cannot be degraded into basic primary compounds by microorganisms, air, water, or soil within a reasonable time period. Thus, it is an environmental concern as it increases the burden of landfills and creates disposal

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issues. If plastic waste not managed properly, it would result in accumulation in environment and finally in plastic pollution. It is also creating serious health problems. Plastic pollution adversely affects land, water, air, and in turn wildlife, wild habitat, and also humans. Plastics release hazardous chemical substances into the ecosystem. These chemical compounds leach into groundwater and then mixes in the surrounding water sources thus polluting the ecosystem.

In India, 15,000 tonnes of plastic waste is generated daily 60% of which is collected and processed. Littering of plastic is probably the most visible aspect of the unmanaged plastic waste.

Waste plastic can be divided into two categories:

Pre-consumer Plastic Waste: This type of plastic material is diverted during a manufacturing process. It is sometimes called post-industrial plastic waste or production scrap.

Post-consumer Plastic Waste: Plastic material generated by the end-users and reached its end of lifecycle and no longer usable (including material returned from within the distribution chain). It is sometimes called post-use plastic waste.

Major sources of post-consumer plastic waste are—residential waste generated by households; commercial waste generated by commercial entities such as shopping malls, markets, offices; construction and demolition waste; industrial waste; waste electrical and electronic equipment (WEEE)/E-waste; and end-of-life automobiles. Pre-consumer plastic waste is possibly the prime source of plastics suitable for reprocessing. In some cases offcuts can be reprocessed in-house. Thus, the real problem lies with proper disposal of post-consumer plastic waste.

2 Plastic Waste Management Using 3Rs

In the present scenario, '*3Rs*'—*Reduce*, *Reuse*, *Recycle*—provides answer for current plastic related problems.

The use of plastics can be reduced through intelligent design of containers and through the distribution of liquid products in more concentrated form. Reduction can also be achieved by use little or no packaging (as and when applicable). Use of alternative biodegradable materials can help in reducing the plastic waste. Reduction in the use of disposable plastics will also help in reducing the environmental impact of plastics.

Reuse of the refillable containers can substantially reduce the plastic burden. However, while reusing the plastic containers, various factors need to be considered, for example, safety, migration, leaching of harmful chemicals, no. of times a container can be reused. Innovative methods of plastic reuse should be developed to reduce plastic burden.

Recycling seems to be the most promising method of plastic waste management because almost all varieties of plastics can be recycled. Recycling helps reduce pressure on the petroleum industry, carbon footprint, energy footprint, and adverse environmental impacts. Thus, recycling would help in saving the resources. For recycling, the key steps involved are collection, segregation, processing of plastic waste and proper use of recyclates.

3 Circular Economy and Plastic Waste Management

The world is now moving from liner economy, i.e., 'Take, Make, Dispose,' to circular economy which aims to keep products, components, and materials at their highest utility and value at all times. Circular economy supports the concept of 'Cradle to Cradle' by using closed-loop approach. Regeneration, substitution of material, reuse, restoring, optimization, and recycling are some of the important tools used in circular economy to reduce pressure on resources. By using this concept appropriately in plastic/plastic recycling industry, we would be able to mitigate plastic pollution.

4 'Swachh Bharat Abhiyan'—Initiative by Government of India

It is well known that littering majorly contributes to plastic pollution which harms the environment. It causes blockage of sewage systems, water logging problems resulting in unhealthy and unhygienic conditions. It sometimes also enters the food chains of animals. In addition, there are high possibilities of leaching of harmful chemicals like heavy metals, Bisphenol-A (BPA), phthalates, colorants from unmanaged, littered plastic wastes to ecosystem causing serious health problems in animals as well humans.

Government of India has very aptly launched a national campaign 'Swachh Bharat Abhiyan' to clean the streets, roads, and infrastructure of the country. This campaign is also aimed at curbing the littering problem. Under this campaign, industry can also take initiatives for creating awareness among common people regarding proper handling and disposal of plastic waste.

5 Indian Standards for Plastic Waste Management

Bureau of Indian Standards (BIS) is National Standards Body of India. BIS through a well laid down structure of Technical Committees publishes Indian Standards in almost all fields, plastics being one of them. Till date, BIS has published 18,862 Indian Standards on various products, their methods of test, codes of practices, terminologies, etc.

Standardization in the field of plastics is mainly dealt by Petroleum, Coal and Related Products Dept. (PCD). Some other departments of BIS are also dealing with subjects related to plastics; for example, Textile Dept. deals with Woven fabrics (including plastics), Civil Engineering Dept. deals with plastic products related to sanitary appliances, construction, etc.

In PCD, the subject of plastics is handled by three sectional committees, namely Plastics Sectional Committee, PCD 12, and Plastics Packaging Sectional Committee, PCD 21, and methods of test for Plastics Sectional Committee, PCD 27, with the help of 20 sub-committees under them. So far, a total of 276 Indian standards have been collectively published by these Committees. PCD 12 has a sub-committee on *Recycling of Plastics*, PCD 12:7, which has published following two important Indian Standards:

(1) **IS 14534:2016** [1] **Plastics—Guidelines for the Recovery and Recycling of Plastics Waste**

The IS 14534:2016 [1] standard prescribes guidelines for selection, segregation, and processing of plastics waste. It establishes several options for pre-consumer and post-consumer plastics waste recovery. The standard also presents the quality requirements for consideration in the steps of the recovery processes.

The standard also prescribes guidelines to the manufacturers of plastic products regarding the marking to be used on the finished product. This facilitates smooth identification of the basic raw materials, which makes sorting and recycling easier (Fig. 1). As per the standard, the manufacturers of plastics end products from either virgin or recycled plastics shall mark following symbols at the time of processing in order to help the re-processors to identify the basic raw material (IS 14534:2016 [1]).

This standard includes the following codification for end product made out of recycled/reprocessed plastics. This coding system helps in identification of the feed material used is virgin, recyclate, or a blend of both (Table 1).

As per the standard, carry bag/containers made out of recycled plastics shall be labeled as 'Not suitable for packaging/carrying food products, pharmaceuticals and drinking water.' A typical list of end products using appropriate types of recycled/reprocessed plastics waste/scrap is also suggested in this standard.

(2) **IS 14535:1998** [2] **Recycled Plastics for the Manufacturing of Products—Designation**

The IS 14535:1998 [2] standard is speculated for the identification and classification of the recycled plastics material on the basis of its basic properties and applications. The standard is applicable to recycled plastics ready for general use without any further modifications (IS 14535:1998 [2]).

Fig. 1 Marking of plastic products

Table 1 Plastics coding

Code No.	Percentage	Code No.	Percentage
R0	No recycle/ reprocess	R6	51–60%
R1	Less than 10%	R7	61–70%
R2	11–20%	R8	71–80%
R3	21–30%	R9	81–90%
R4	31–40%	R10	Over 90%
R5	41–50%		

**Source* IS 14534:2016 [1]

As per the standard, the designation system of recyclate, in general, shall have eight blocks presented in Table 2.

Under Action Plan on 'Swachh Bharat Abhiyan,' the Committee is formulating following new standards on priority which would help in effective use of recyclates.

(i) Mixtures of polypropylene (PP) and polyethylene (PE) recyclate derived from PP and PE used for flexible and rigid consumer packaging—Part 1: Designation system and basis for specification (*standard under print*)
(ii) Mixtures of polypropylene (PP) and polyethylene (PE) recyclate derived from PP and PE used for flexible and rigid consumer packaging—Part 2: Preparation of test specimens and determination of properties (*standard under print*)
(iii) Post-consumer polyethylene terephthalate (PET) bottle recyclates—Part 1: Designation system and basis for specifications
(iv) Post-consumer polyethylene terephthalate (PET) bottle recyclates—Part 2: Preparation of test specimens and determination of properties

These standards provide designation systems and test methods for determination of properties for each designation system. These systems may be used as basis for recyclates' specifications for their intended use/purpose.

Table 2 Eight blocks as per IS 14535:1998 [2]

Block No.	Details
Block 1	Indian standard
Block 2	Identification of plastics by its recycling symbol
Block 3 (alphabets)	Source of waste or scrap
Block 4 (2 numerals)	Material detail
Block 5 (alphabets and 2 numerals)	Density
Block 6 (alphabets and 2 numerals)	Melt flow rate (MFR)
Block 7 (alphabets and 2 numerals)	Filler detail and ash content (percentage)
Block 8 (alphabets)	Physical foam

6 Way Forward

The relevant technical committee has taken an initiative to develop more standards on criteria for the acceptance of different recyclates, plastics recycling tractability, and assessment of conformity. Presently, standards are not available on optimization of the packaging systems, reuse/recycling of packaging materials, etc. Relevant technical committees should take up such subjects for standard formulation.

In order to make standards implementable and more beneficial for the stakeholders, their involvement in standardization activity is essential. Experts from industry are the right people to identify the subject on which standards are needed by the industry. Their involvement at every stage of standardization starting from decision making whether to take up new subject, to what should be the technical content of a standard. Getting involved in this process will also bring significant advantages to their business by having an early access to information that could shape their market in the future. Thus, BIS always encourages stakeholders' involvement in this activity by creating awareness through seminars, workshops, media, publications, etc.

7 Plastic Waste Management Rules, [3]

The Ministry of Environment, Forest and Climate Change (MoEFCC) has notified the plastic waste management rules, [3] to provide a regulatory guideline and framework for plastic waste management in India. The rules give thrust on minimization of plastic usage, segregation at source, environmental friendly recycling by involving ragpickers, recyclers, and waste processors in collection chain of plastic waste. The collection can occur from households, malls, shops, markets, intermediate material recovery facility, etc. The rules adopt polluter's pay principle to ensure sustainability of the plastic waste management system [3].

In the revised rules, the minimum thickness of plastic carry bags has been set to 50 µm (previously 40 µm). The applicability of the rules has been extended to all villages. The rules further state that manufacture and use of non-recyclable multilayered plastics should be phased out within two years from the date of implementation of the rules. As per these rules, '*all institutional generators of plastic waste*, *shall segregate and store the waste generated by them in accordance with the Solid Waste Management Rules*, *and handover segregated wastes to authorized waste processing or disposal facilities or deposition centers*, *either on its own or through the authorized waste collection agency*' [3].

8 Indian Standards in Plastic Waste Management Rules, [3]

A number of Indian Standards are referred in PWM Rules [3] for the following requirement/purpose:

(a) Pigments and colorants if added in carry bags and plastic packaging shall conform to IS 9833 'List of pigments and colorants for use in plastics in contact with foodstuffs, pharmaceuticals and drinking water,'
(b) Recycling of plastic waste shall conform to the IS 14534 'Guidelines for the Recovery and Recycling of Plastics Waste.'
(c) Carry bags made from compostable plastics shall conform to IS/ISO 17088 'Specifications for Compostable Plastics'.

Table 3 List of Indian standards to determine the degree of degradability and degree of disintegration of plastics

Standard	Details	References
IS/ISO 14851 [4]	Ultimate aerobic biodegradability of plastic materials Method: measuring the oxygen demand in a closed respirometer	IS/ISO 14851:1999 [4]
IS/ISO 14852 [5]	Ultimate aerobic biodegradability of plastic materials Method: evolved carbon dioxide analysis	IS/ISO 14852:1999 [5]
IS/ISO 14853 [6]	Ultimate aerobic biodegradability of plastic materials Method: measurement of biogas production	IS/ISO 14853:2016 [6]
IS/ISO 14855-1 [7]	Ultimate aerobic biodegradability of plastic materials under controlled composting conditions Method: analysis of evolved carbon dioxide. (Part-1 general method)	IS/ISO 14855-1:2012 [7]
IS/ISO 14855-2 [8]	Ultimate aerobic biodegradability of plastic materials under controlled composting conditions Method: analysis of evolved carbon dioxide (Part-2: gravimetric measurement of carbon dioxide evolved in a laboratory—scale test)	IS/ISO 14855-2:2007 [8]
IS/ISO 15985 [9]	Ultimate anaerobic biodegradation and disintegration under high-solids anaerobic digestion conditions Method: analysis of released biogas	IS/ISO 15985:2014 [9]
IS/ISO 16929 [10]	Degree of disintegration of plastic materials under defined composting conditions in a pilot—scale test	IS/ISO 16929:2013 [10]
IS/ISO 17556 [11]	Ultimate aerobic biodegradability in soil Method: measuring the oxygen demand in a respirometer or the amount of carbon dioxide evolved	IS/ISO 17556:2012 [11]
IS/ISO 20200 [12]	Degree of disintegration of plastic materials under simulated composting conditions in a laboratory—scale test	IS/ISO 20200:2015 [12]

(d) Each recycled carry bag shall conform to IS 14534.
(e) Each carry bag made from compostable plastics shall conform to IS/ISO 17088.
(f) Schedule-I of PWM Rules [3] lists the following Indian standards for determination of the degree of degradability and degree of disintegration of plastic materials (Table 3).

9 Conclusion

- Plastic Waste Management Rules [3] and Indian Standards on recycling of plastics are well in place. However, for their effective implementation, there is a strong need for creating awareness among the actual users regarding effective handling and management of plastic waste through PWM rules and standards.
- There is a need to provide skill sets for segregation, recycling of plastics to rag pickers, scavengers, sanitary, and conservancy workers and all others involved. Thus, it is desired to create training programs specifically for the people involved in various recycling processes on how to implement such standards in their systems and accordingly to organize, recognize, and train them.
- In view of no or meager economic benefit in collection and segregation of some recyclable plastic waste materials like plastic carry bags, milk, and milk product pouches, multilayered plastic bags, Govt. of India may have to make some policy for giving incentives to the rack pickers for collecting/segregating such plastic wastes. Govt. should also have some system for providing loans to domestic recycling industry with subsidy for procuring recycling machinery.
- Municipal corporations, gram panchayat or any such local body also need to share the responsibility of plastic waste management.
- A system needs to be shaped to ensure effective implementation of extended producer responsibility.
- Awareness about plastics, plastic waste handling, recycling of plastic, etc., should be created among common people through platforms like media, education systems (schools/colleges/institutions), nukkad natak, jan sabha.
- Regulations should also be strengthened for import of plastic/plastic products.

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5. IS/ISO 14852:1999. Determination of the ultimate aerobic biodegradability of plastic materials in an aqueous medium—Method by analysis of evolved carbon dioxide.
6. IS/ISO 14853:2016. Plastics—Determination of the ultimate anaerobic biodegradation of plastic materials in an aqueous system—Method by measurement of biogas production.
7. IS/ISO 14855-1:2012. Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions—Method by analysis of evolved carbon dioxide (Part-1 General method).
8. IS/ISO 14855-2:2007. Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions—Method by analysis of evolved carbon dioxide (Part-2: Gravimetric measurement of carbon dioxide evolved in a laboratory—Scale test).
9. IS/ISO 15985:2014. Plastics—Determination of the ultimate anaerobic biodegradation and disintegration under high-solids anaerobic digestion conditions—Methods by analysis of released biogas.
10. IS/ISO 16929: 2013. Plastics—Determination of degree of disintegration of plastic materials under defined composting conditions in a pilot—Scale test.
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12. IS/ISO 20200:2015. Plastics—Determination of degree of disintegration of plastic materials under simulated composting conditions in a laboratory—Scale test.

Part XVI
Chemical Engineering in Waste Management

Recycling of Solid Waste to Heterogeneous Catalyst for Production of Valuable Fuel Additives

P. Mukhopadhyay and R. Chakraborty

Abstract The rising alarm regarding solid waste accumulation and waste disposal problems has driven the researchers to explore possible technologies for the reduction, reuse and recycling of solid waste that could subsequently negate the environmental concern by its transformation into value-added products. Present literature enunciates that the solid waste materials in all its manifold forms could be effectively transformed into valuable chemicals which could serve as an alternative for attenuation of the problem related to environmental pollution. Furthermore, the heterogeneous solid catalysts derived from waste resources are found to be cost-effective and environmentally benign when applied in chemical reactions. It showed equivalent efficacy with respect to commercially available catalysts in terms of physicochemical properties (viz. specific surface area, surface acidity, crystallinity, catalyst stability and reusability). In need for production of cleaner and greener fuels and to combat the climate change issues, biofuel specifically biodiesel has gained the attention of researchers as promising diesel substitute. However, biodiesel has few limitations viz. high NO_x emission, high pour point and higher cold filter plugging point. Thus, the requirement of fuel additive has become a mandate to overcome such pitfalls of biodiesel and to promote the usage of biodiesel. Nevertheless, the production of such fuel additives either accompanies detrimental reaction conditions viz. high reaction temperature, augmented reaction time, high consumption of reactants or expensive catalyst usage, thus making the overall production process highly uneconomic. Yet, in order to overcome such downsides of fuel additive synthesis, the ongoing researches are focusing on the application of waste-derived solid catalysts. The present article provides a comprehensive review on the application of solid waste as low-cost catalyst (s) or catalyst support (s) for the synthesis of valuable fuel additives that can improve fuel properties when blended with diesel/biodiesel.

Keywords Solid animal and plant biowaste · Heterogeneous catalysts
Catalytic performance · Synthesis of biodiesel additive

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1 Introduction

The emerging developmental activities around the globe have resulted in huge amount of waste generation that has augmented waste disposal problem. Therefore, to maintain environmental and economic sustainability, researchers have been focusing on the resurrection of generated wastes into high-value products. Every year, more than 70 MT of biowastes comprising of animal shells and scales, animal manure, waste biomass including fruit and food waste are generated. Additionally, 8 MT of seafood wastes is produced every year amongst which Asia contributes 1.5 million which could be effectively used as a promising route for the generation of various platform chemicals [1].

Literature study enumerates that apart from usage of waste biomass as a source of bioenergy, it had also been effectively utilized for synthesis of activated carbon which finds its application as adsorbents for heavy metal removal [2]. Furthermore, CaO, a solid base catalyst derived from animal shells [3] and bones [4] had proven its catalytic efficacy in biodiesel production. Likewise, Maneerung et al. [5] reported the use of animal manure (chicken) to develop a cost-effective catalyst which outperformed in biodiesel production from waste cooking oil [5]. Thus, these anthropogenic waste materials either can be directly applied as a catalyst or can be modified using metallic precursors whose functionality could be well comparable to commercial grade catalyst in a chemical reaction [6].

Moreover, owing to heavy fuel (diesel) consumption and increasing emission rates of tailpipe pollutants [7] recent research has focused on the blending possibilities of eco-friendly, biodegradable and clean burning biodiesel with diesel [8, 9]. However, biodiesel also possesses certain limitations viz. poor operability in a colder climate and increased NO*x* emission due to high fuel density and viscosity [10]. Thus, ongoing efforts for extenuating the pitfalls of biodiesel strongly consider the blending of effective fuel additives either with neat biodiesel or diesel–biodiesel mixture that will eventually render more cleaner burning of fuel without considering any compromise towards engine performance [11].

Several fuel additives viz. straight and branched chain esters of fatty acids could render noteworthy enhancement in biodiesel properties and engine performance comparable with conventional fuels [12]. Palmitic acid esters of 2-butanol and isopropanol had provided an appreciable reduction in crystallization point of biodiesel [13]. Furthermore, methyl esters of stearic acid exhibited high cetane value (101) with remarkable oxidation stability that could reduce the rate of biodiesel deterioration [14]. Additionally, recent articles also exemplify the efficient application of triacetin as fuel additives that could improve the oxidation stability and cold flow properties of biodiesel derived from different resources [15, 16].

Therefore, both the tables (Tables 1 and 2) depict that synthesis of such valuable fuel additives requires expensive solid catalysts which are either commercial grade or prepared using cost-intensive chemicals. Therefore, this present article encompasses the recent trends of employing low-cost, waste-derived efficient catalysts

Table 1 Commercial and chemically synthesized heterogeneous catalysts for synthesis of straight chain esters

Fuel additive	Catalyst used	Conversion (C) or product yield/ selectivity (%)	Remarks	Reference
Ethyl oleate	Amberlyst 15	53	Low reusability, low mechanical strength	Hykkerud and Marchetti [17]
	Ce^{3+} (La^{3+} or Sm^{3+}) ~ β/Al–MCM–41	62.4	Involvement of multiple active sites	Wang and Yu [18]
Methyl oleate	Amberlyst 46	98.6 (C)	Cost-intensive catalyst	Ilgen [19]
Methyl stearate	Sulphated ZrO_2–SiO_2 aerogel	91	Requires pretreatment (thermal treatment at 600 °C) before reuse	Saravanan et al. [20]
Methyl stearate	Nanocrystalline mesoporous sulphated zirconia	88	Leaching of sulphate species	Saravanan et al. [21]

Table 2 Salient process features of commercial and chemically synthesized heterogeneous catalysts applied for synthesis of fuel additives

Fuel additive	Catalyst used	Conversion (C) or product yield/selectivity (%)	Remarks	Reference
Di-tert butyl glycerol (DTBG) and tri-tert butyl glycerol (TTBG)	Amberlysts (15, 35, 31, and 119)	17.1	Low desired product yield; lower reactant access to catalyst pores	Klepáčová et al. [22]
Glyceryl monooleate	Tin-organic framework	40 (C)	Very low reusability characteristics with high leaching of tin from organic framework	Wee et al. [23]
	Silico-tungstic acid on ionic liquid	96	Expensive catalyst; requirement of organic solvent along with fresh ionic liquid after each cycle	Isahak et al. [24]
Glyceryl monostearate	Zinc oxide	82	Low fatty acid conversion	Pouilloux et al. [25]
Diacetin and triacetin	SO_4^{2-}/SnO_2	75	High consumption of reaction time.	Mallesham et al. [26]
2-butyl oleate	Metal-organic framework MIL-101(Cr)–SO_3H	90	Low reusability	Hasan et al. [27]

having high reusability and appreciable selectivity towards desired product, thus attenuating solid waste disposal problem in a sustainable and economic pathway.

2 Catalyst Types

2.1 Animal Waste-Derived Catalyst

Over recent past, researchers have been focusing on the utilization of animal parts as a promising source for the development of heterogeneous catalysts. Various studies are available regarding the application of animal parts as solid catalyst for biodiesel production [28, 29]; however, very few literature is available regarding the application of animal wastes as reusable catalyst in esterification of alcohol and fatty acids. Chakraborty and Roy Chowdhury [30] employed waste fishbone for the development of hydroxyapatite (HAp) as a catalyst support for CuO catalyst for ethanol and oleic acid (OA) esterification. The prepared catalyst resulted in 91.86% conversion in 1 h with promising recyclability characteristics. Again, Chakraborty and Roy Chowdhury [31] reported a similar catalyst; i.e., HAp supported Fe catalyst which also exhibited a promising performance in methanol–OA esterification resulting 93% OA conversion. The prepared catalyst exhibited irregularly distributed void spaces with good dispersion of active sites, thus depicting promising catalytic attribute. More recently, Noshadi et al. [32] reported a highly porous carbonaceous solid acid (NPC-[C4N][X]) derived from cow manure which had been functionalized with ionic liquids. The developed catalyst depicted appreciable BET surface area (814 m^2/g) with a surface acidity of 1.21–1.25 mmol/g. Furthermore, the catalyst was employed in OA–methanol esterification and resulted in 98% OA conversion in 4 h. More recently, Chakraborty et al. [33] reported a promising HAp supported antimony (Sb) catalyst derived from waste pork bone for diacetin and triacetin (DT) synthesis. The catalyst rendered 88% combined yield of DT with excellent reusability characteristics up to eight recycles (Fig. 1).

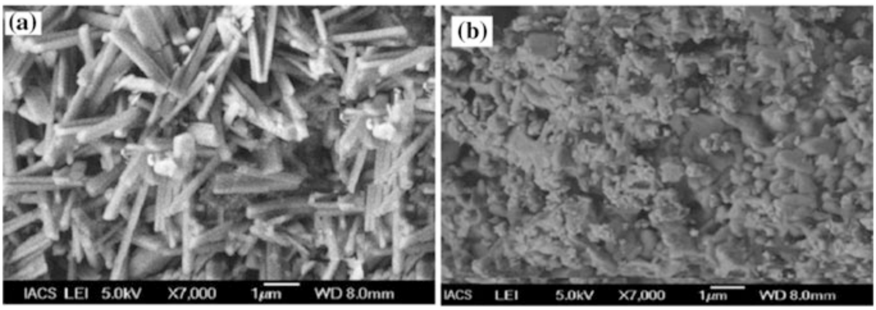

Fig. 1 FESEM of **a** before calcined and **b** after calcined hydroxyapatite supported Fe catalyst [31]

Table 3 Surface acidity and textural properties of different waste-derived and chemically synthesized catalysts

Catalysts	Source	Acid content (mmol/g)	BET surface Area (m^2/g)	Pore volume (cc/g)	Reference
Hydroxyapatite supported copper acid catalyst	Fish bone	11.22	16.78	0.0313	Chakraborty et al. [30]
Biological hydroxyapatite supported iron catalyst	Fish bone	10.336	14.9	0.0335	Chakraborty et al. [31]
Pork bone supported Sb catalyst	Pork bone	4.251	40.02	0.0485	Chakraborty et al. [33]
SBA-15-SO_3H	Chemically synthesized	1.98	814	1.4	Noshadi et al. [32]
Amberlyst 15	Commercial	4.7	45	0.31	
NPC-[C4N][SO_3CF_3]	Cow manure	1.25	726	1.31	

2.2 *Comparative Assessment with Commercial Catalysts*

In comparison with macroporous polymeric resins or mesoporous solid acids, application of carbonaceous network as catalyst has gained immense attention due to its promising thermal and mechanical stability, pronounced acidity and large specific surface area [34, 35]. Moreover, in Table 3, a comparative assessment has been presented on the basis of surface acidity and textural properties of the catalysts. Ionic liquid functionalized NPC catalyst derived from cow manure [32] showed equivalent catalytic properties and outperformed in methyl oleate synthesis compared to commercial or reagent grade catalyst (Fig. 2).

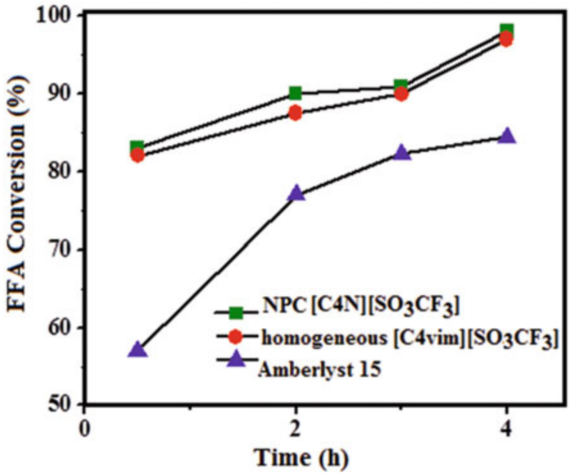

Fig. 2 Progress of OA (i.e. representative FFA)–methanol esterification using different catalysts (data from Noshadi et al. [32])

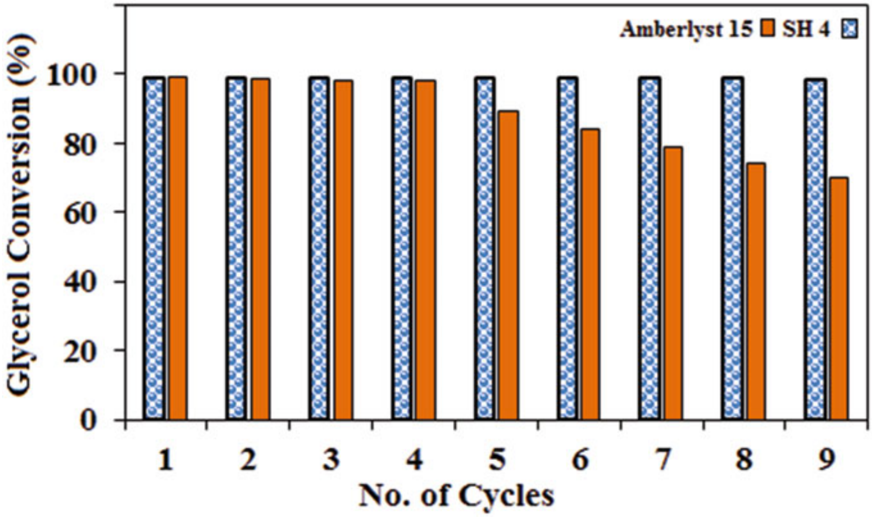

Fig. 3 Reusability attributes of pork bone supported Sb and Amberlyst 15 catalysts in esterification of glycerol with acetic acid [33]

Similarly, waste pork bone-derived catalyst reported by Chakraborty et al. [33] also depicted appreciable surface acidity and desired product yield; however, the BET surface area was relatively lower compared to the commercial and reagent grade catalyst. This limitation had been nullified by the reusability attribute of antimony supported HAp catalyst as represented in Fig. 3 which depicted uninterrupted glycerol conversion for diacetin and triacetin synthesis up to eight reaction cycles which were superior to Amberlyst 15.

3 Biomass-Derived Catalyst

In view of converting lignocellulosic biomass into value-added chemicals, developments of proficient catalyst using this kind of biomass have opened a new avenue in reduction, recycling and reutilization of such biowastes. Zhao et al. [36] employed peanut shell as carbonaceous catalyst for etherification of isobutylene with glycerol. Furthermore, Liu et al. [37] applied carbon-based solid acid catalyst derived from corn straw for OA–methanol esterification. Although the catalyst possessed mild acid strength (2.65 mmol NaOH/g), the catalyst rendered substantial product yield. Ezebor et al. [38] fabricated sugarcane bagasse and oil palm trunk (OPT)-derived solid acid catalysts for fast esterification of palmitic acid with methanol. The catalyst showed excellent thermal stability up to 288 °C with acid density of 0.054 mmol/g for sugarcane and 0.109 mmol/g for OPT-derived catalyst resulting in 93% methyl ester yield within 45 min. Nonetheless, the catalyst

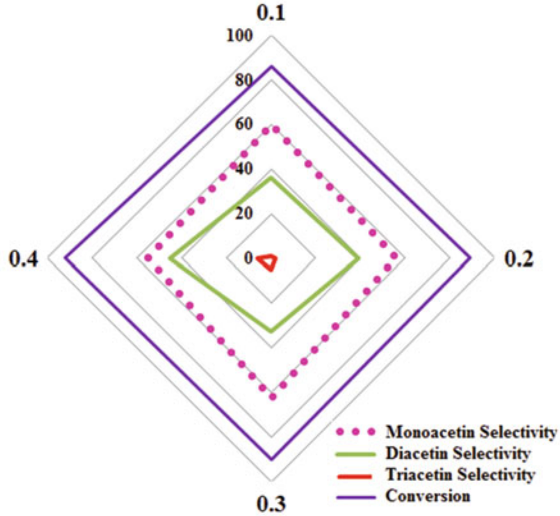

Fig. 4 Effect of catalyst weight on desired product selectivity and conversion (data from Rafi et al. [41]

demonstrated acceptable reusability characteristics up to seven recycles; however, the reduction in product yield can be attributed to the leaching of polycyclic aromatic hydrocarbons comprising of –SO_3H groups. Gonçalves et al. [39] reported black carbon derived from coffee ground waste as a cost-efficient catalyst for synthesis of a promising fuel additive, i.e. DTBG and TTBG [40]; notably, the surface area of the developed catalyst was quite low which could be attributed to the carbonization and sulphonation method that was applied during catalyst preparation. Rafi et al. [41] applied Karanja seed shell-derived biochar catalyst for acetylation of glycerol. The catalyst rendered 88% glycerol conversion with promising selectivity towards the di- and tri-substituted esters as illustrated in Fig. 4.

Tao et al. [42]employed catkin for the preparation of a sulphonated carbon (microtubular) catalyst for glycerol–acetic acid esterification in the synthesis of DT. The catalyst resulted in high selectivity and the results were comparable to Amberlyst 15. The prepared catalyst also showed high water-tolerant activity and increase in catalyst loading had rendered an increase in DT yield (Fig. 5) due to more availability of acidic sites of catalyst.

More recently, Zhou et al. [43] investigated the application of sulphonated bamboo-derived heterogeneous carbon catalyst for ethanol–OA esterification resulting 98.4% conversion and recyclability up to five experimental cycles. The catalyst depicted good thermal stability below 220 °C; however, the developed catalyst demonstrated very low surface area (2.75 m^2/g) and insignificant pore volume of 0.0018 cc/g which restricts its use in reactions involving bulkier reactants.

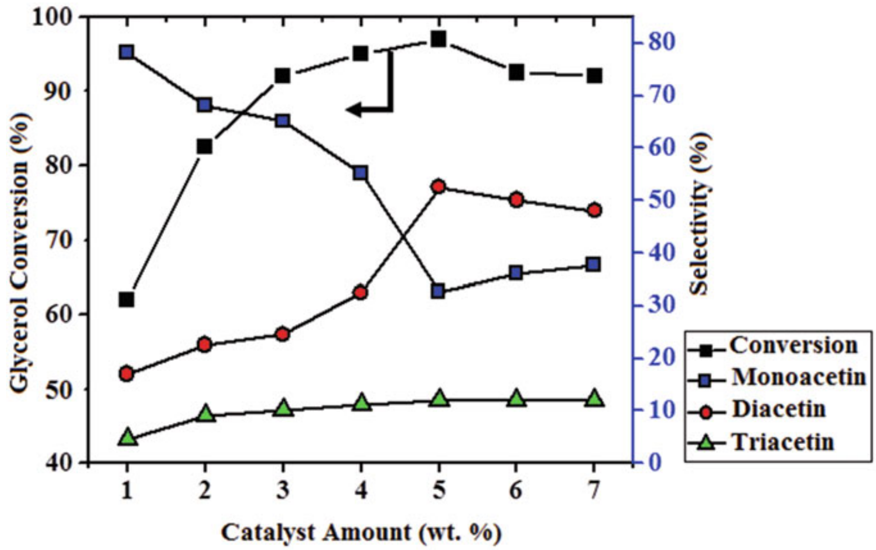

Fig. 5 Catalytic performance of catkin-derived sulphonated carbon catalyst (data from Tao et al. [42])

3.1 Comparative Assessment of Commercial and Biomass-Derived Catalysts

Table 4 presents the fact that biomass-derived catalyst exhibits equivalent potential with respect to chemically synthesized and commercially available solid catalysts. The catalysts derived from waste biomass displayed good reusability characteristics. Additionally, biomass-derived catalyst resulted in higher product yield in much shorter time as revealed elsewhere [41]. However, the only limitation was ascribed to lower BET surface area and pore volume of the catalyst compared to the commercially available catalysts.

4 Emerging Trends and Future Prospects

Catalysts discussed in the present article were either prepared by wet impregnation method or by sol–gel method. However, the developed catalyst lacks in certain aspects viz. surface area, pore volume, thermal stability. Recent literature survey illuminates the application of different electromagnetic radiation that has immensely improved the surface properties of catalyst [44]. Recently, Oliveira et al. [45] reported application of microwave (400 W) during activation of waste flint kaolin. The catalyst resulted excellent thermal stability with high surface area (187 m^2/g)

Table 4 Comparative study between commercial and biomass-derived catalyst

Catalysts	Source	Acid content (mmol/g)	BET surface area (m^2/g)	Pore volume (cc/g)	Product yield (%)	Reusability	Reference
Biomass carbon-based solid acid	Corn straw	2.64 (NaOH)	–	–	98	–	Liu et al. [37]
Amberlyst 15	Commercial	4.7 (KOH)	45	0.31	85	–	
Fuming sulphuric acid functionalized black carbon	Coffee ground waste	4.0 (H^+)	<10	–	20 (DTBG + TTBG)	Consistent for 5 recycles after 10 h reflux with hot water	Gonçalves et al. [39]
Amberlyst 15	Commercial	Same as above				Catalyst loss due to attrition	
Biochar	Karanja kernels	3.877 (NH_3)	16	0.027	44 (diacetin + triacetin) at 4 h	Consistent for 5 recycles after methanol wash and oven drying	Rafi et al. [41]
Amberlyst 36	Commercial	–	33	0.2	4.5 (diacetin + triacetin) at 12 h	–	
Sulphated zirconia	Chemically synthesized	–	–	–	1.2 (diacetin + triacetin) at 24 h	–	

that has favoured good conversion of oleic acid into methyl oleate. Likewise, Cheng et al. [46] employed microwave for preparation of activated carbons from walnut shells resulted in high BET surface area (732 m^2/g), total pore volume (2.278 mL/g) and mesopore volume (0.661 mL/g) of the developed catalyst. More recently, Mijan et al. [47] employed sonochemical-assisted wet surfactant treatment for preparation of nano-$Ca(OH)_2$ from waste clam shells having the significant surface area of 130 m^2/g. It had been identified in this study that integration of ultrasonication during catalyst preparation had greatly increased the surface area. Thus, the application of waste-derived catalyst prepared under energy efficient electromagnetically assisted hydrothermal activation [48] will not only create a new feature for enhancement of catalytic activity through a more cleaner and greener route but will also become an efficient alternative for high-cost commercial and chemically synthesized catalyst which will finally render a cost-effective avenue to waste recycling, thus curtailing the waste disposal problem through an economical green pathway.

5 Conclusion

This study demonstrated the recent trends in utilization of abundantly available animal waste and biomass for the development of cost-effective and environmentally benign solid catalysts which serve as a promising alternative to the already existing commercial or chemically synthesized heterogeneous catalysts. Thus, successful use of such animal and plant derived naturally occurring waste materials will not only mitigate the waste disposal issue but will also create an economic equilibrium between the catalyst cost and the overall operational costs. Furthermore, from the literature study it has been identified that catalyst derived from animal resources is comparatively more efficient in terms of BET surface area, pore volume and catalyst reusability compared to their plant-derived biomass counterpart. However, a more systematic and comprehensive study should be undertaken to sustainably exploit the effects of catalyst preparation protocol on catalytic properties and performances in order to develop a more proficient yet economical catalyst.

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Effective Removal of TDS and COD from Sugar Effluent Using Green Synthesized Magnetic Iron Nanoparticle with *Trigonella foenum-graecum* Seed Mucilage

B. Sowmiya Rajalakshmi, A. Ancy Jenifer, K. G. Ahila, M. Vasanthy and C. Thamaraiselvi

Abstract In the present investigation, magnetic iron nanoparticle was synthesized using polysaccharide mucilage obtained from the seeds of fenugreek (*Trigonella foenum-graecum* L). The nanoparticle was characterized by XRD, FTIR, SEM and EDX analyses. The morphology of the nanoparticle was irregular spherical shape, and functional groups present in the mucilage act as a capping and reducing agent for the synthesis of magnetic FeNP. The physical and chemical characteristics of the effluent including colour, odour, pH, COD and TDS were analysed before treatment. Treatment was done by different dosage of magnetic nanoparticles and raw mucilage (0.2, 0.4, 0.6, 0.8 and 1 g). Higher reduction of TDS (77%) and COD (75%) was observed in 0.8 g of raw mucilage, and nanoparticle showed 91% of COD reduction and 86% of TDS removal in 0.6 g of dosage. The amount of iron nanoparticles required for pollutant removal was lesser than raw mucilage required for the same. Antimicrobial activity of FeNP against gram-positive and gram-negative organisms showed good zone of inhibition up to 20 mm diameter for *Escherichia coli*. Magnetic nanoparticles contain huge surface area, which is responsible for binding and removal of contaminant.

Keywords Mucilage · Magnetic iron nanoparticle · TDS · COD Antimicrobial · Functional group

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1 Introduction

Mucilage is a type of polysaccharide, which is widely used as adjuvant, and it is made up of sugar molecules and units of uronic acid. These compounds possess gelling nature, and due to this property, it gets swell in water and the property is called rheology synergism. Because of the gelling nature and binding capability, mucilage is used for the production of pharmaceutical products [1, 20]. It is a normal physiological product synthesized inside the cell and stored in the surface like a layer [13].

Plant-based mucilages are eco-friendly, economically inexpensive which is used as a substitute for the artificial gelling or solidifying agent. *Trigonella foenum-graecum Linn.* is a perennial plant which belongs to the family Leguminosae (Fabaceae). The seeds and leaves of this plant are utilized as food in most of the countries. In addition, various parts of this plant contain medicinal and aesthetic properties. Mucilage of various seeds has been used as granulating and binding agent due to its non-toxicity, low cost, free availability, emollient and non-irritating nature (Nitalikar et al. 2010). Dicotyledonous fenugreek seeds consist of brown husk mainly composed of soluble galactomannan polysaccharides. Dry seeds contain 3–6% moisture, 25–30% protein, 20–25% insoluble fibres and 3–4% ash. The mucilage possesses various pharmaceutical properties such as binding, gelling, emulsifying and suspending agents [3, 15].

Coagulation is a conventional process which is widely used for the treatment of industrial effluent. Coagulants bring coagulation process and are of two types: chemical-based and plant-based coagulating agents. These agents destabilize the colloidal particles and allow it to sediment for easy separation. Typically used chemical coagulants are iron salts, aluminium salts and polymers including polyacrylamide. The major demerits of chemical coagulants are the traces of these products may enter into the drinking water which could cause harmful effect to human beings, alter the pH of treated water and huge quantity of sludge may be produced [10, 14, 17, 22]. As an alternative, polysaccharides, proteins, tannin present in the plants are the natural coagulating agents. Currently, nanoparticles are applied to remove impurities and heavy metals from the industrial effluent.

Sugar industry is one of the most economically valued industries in the world. These units utilize large volume of water for sugar manufacture and large amount of wastewater with toxic pollutants are released to the aquatic environment [6]. The sugar effluents are characterized with higher TDS and COD. The present study was conducted to treat the sugar effluent using magnetic nanoparticles synthesized by fenugreek seed mucilage and raw mucilage. The antibacterial activity of the raw mucilage and magnetic nanoparticles against gram-positive and gram-negative bacterial strains was also checked.

2 Experimental Set-Up

2.1 Separation of Mucilage from Fenugreek Seeds

The fenugreek seeds were obtained from the local market and were washed thoroughly with sterile distilled water. About 50 g of the seed powder was boiled with 250 ml double distilled water and was continuously stirred for slurry formation. The content was kept for 3–4 h to cool, in order to collect the supernatant, and was centrifuged at 500 rpm for 20 min. The supernatant was concentrated through heating at 60 °C using water bath. The content was cooled, and thrice the volume of acetone was added with continuous mixing. The precipitate was washed thoroughly with distilled water and was dried under vacuum at 50–60 °C.

2.2 Proximate Analysis of Fenugreek Mucilage

The colour, odour and texture of the mucilage were characterized. The proximate principles analysed were solubility, loss of drying, swelling index, ash, carbohydrates, fibre, protein, moisture content, ash content, pH, etc., according to Indian Pharmacopoeia procedures [5, 7].

2.3 Synthesis of Magnetic Iron Nanoparticles from Fenugreek Seed Mucilage

The boiled extract of plant was prepared by boiling 2 g of powder in 100 ml deionized water and boiled for 10 min with mild heat. About 100 ml of 0.1 M ferric chloride was prepared and mixed with the extract in 1:1 ratio, and orange yellowish colour changed to light blackish green. The tightly capped flasks were kept in a hotplate with stirrer at 60–70 °C. The change in the colour of solution to dark brownish black was noted after reaction period which indicates the formation of iron nanoparticles. The pellet was washed with deionized water and finally with ethanol.

2.4 Characterization of Mucilage Magnetic Iron Nanoparticles

The dark brownish black coloured solid precipitate obtained was characterized by using XRD and Fourier transform infrared spectroscopy (Perkin Elmer RX1). The morphology of magnetic iron nanoparticle was identified by SEM analysis. The purity was accessed by EDX analysis through elemental analysis.

2.5 Antimicrobial Activity Assay for Mucilage Raw and Iron Nanoparticle

Both the gram-positive and gram-negative strains of *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa* and *Bacillus subtilis* were subjected to antibacterial assay under aseptic condition against the mucilage and FeNP. The antibacterial effect against the microbes was measured in terms of zone of inhibition (mm).

2.6 Sugar Effluent Collection

Sugar effluent was collected from a sugar cum distillery unit located at Karur, Tamil Nadu, India, in pre-cleaned polyethylene bottles. The effluents were safely transported to the laboratory and maintained at 4 °C to minimize microbial contamination and also for further analysis [21].

2.7 Physico-Chemical Characterization of the Effluents

Standard analytical procedure (APHA, 2012) was followed during the collection and analysis of the effluents. The colour, odour, pH, total dissolved solids (TDS) and chemical oxygen demand (COD) were analysed.

2.8 Effect of Mucilage and Nanoparticles on the Removal of TDS and COD from Sugar Effluent

About 100 ml of effluent was taken in individual conical flasks and treated with different doses such as 0.2, 0.4, 0.6, 0.8 and 1 g, of raw mucilage concentrate and mucilage magnetic FeNP. The treatment sets were left without agitation as such for about 2 h and centrifuged at 3000 rpm for 10 min. The filtrate was further analysed to test the reduction of TDS and COD.

3 Results and Discussion

3.1 Proximate Analysis of Raw Mucilage

The results confirmed that 60% of mucilage was obtained from 50 g of *Trigonella foenum* seed powder. The mucilage was exposed to sunlight for particular duration, and no change was observed. Various properties of mucilage were analysed based on the Pharmacopoeia protocol and illustrated in Table 1. The pH of the raw mucilage was 6.89, and the swelling capacity was 17%. The results confirmed the solubility capacity of the mucilage in warm water and were insoluble in certain organic solvents. The test for mucilage was conducted with ruthenium red test which showed positive results. Similar results have been reported by Mundhe et al. [9].

3.2 Characterization of Mucilage Iron Nanoparticles

The co-precipitation of ferric chloride and ferrous sulphate with mucilage as reducing agents forms a brownish black precipitate, and the solution turns to acidic condition. Ammonium addition increases the pH, and black precipitate was obtained at thermal condition. The acetone-treated black precipitate was used for the characterization and treatment of sugar effluent.

The XRD result pattern confirmed the synthesis of iron nanoparticle, and it showed the characteristic peaks with intensity of 44.4°, 77.0°, 55.5°, 35.6° and 39.9°. From this peaks, magnetic nanoparticle synthesis was confirmed (Fig. 1).

Table 1 Proximate characterization of *Trigonella foenum* mucilage

S. No.	Characteristics	Description
1	Solubility nature	Soluble in warm water and insoluble in certain organic solvents
2	Swelling test (%)	17
3	Loss on drying % (moisture)	5
4	pH	6.89
5	Ash (%)	3
6	Test for carbohydrate (Molisch's test)	+
7	Protein	+
8	Texture and colour	Dusty and pale yellow
9	Mucilage (ruthenium red test)	+
10	Fibre (%)	4

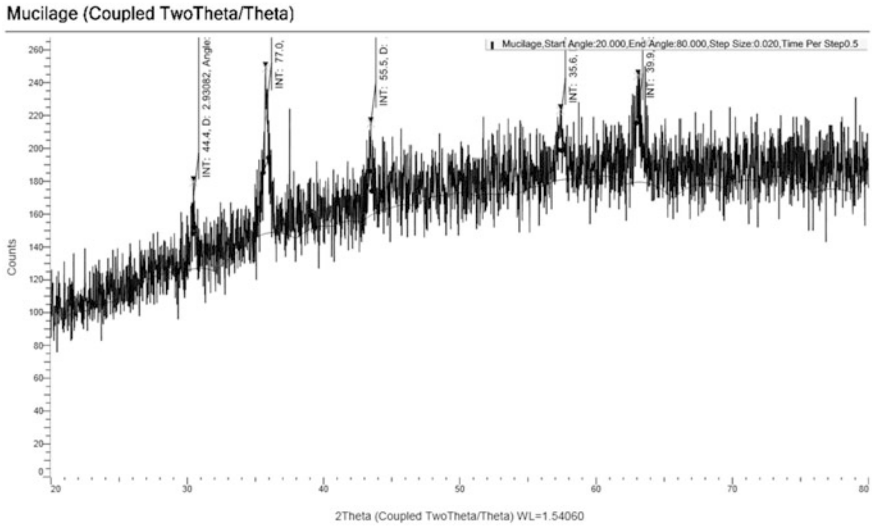

Fig. 1 XRD analysis of fenugreek iron nanoparticles

Hariani et al. [4] reported that characteristic peaks in the XRD pattern of the Fe_3O_4 at 30.2050°, 35.5150°, 43.3250°, 53.7110°, 57.2150° and 62.9450° consequent to crystal planes of a Fe_3O_4 with a spinal configuration. The average crystallite size was measured by Scherrer's formula, $D = 0.94\lambda/\beta\cos\theta$. The crystallite size of the synthesized magnetic nanoparticle was 51.4 nm [12].

FTIR measurements of raw mucilage and magnetic iron nanoparticles were conceded to recognize the functional group liable for capping and reduction of iron molecules to nanoparticles. The peaks at 698, 820, 1124, 1155, 1460, 1643, 2816, 2909 and 3762 cm^{-1} absorption bands showed the functional groups. The peaks observed from 698 to 1460 cm^{-1} indicates the presence of =C=H bending with alkynes groups. The peak found in the region 1643 cm^{-1} correponding to alkene group with –C=C= stretching and the absorption peaks found in the region 2816 cm^{-1} and 2909 cm^{-1} indicates the presence of $-OCH_3$ group and $-CH_3$ group respectively. Mishra et al. [8] reported –OH group, –CH stretching, –CO stretching in the region 1018 cm^{-1}. The FTIR spectrum of iron nanoparticle shown the presence of peaks in the regions 591.497 cm^{-1}, 1018.079 cm^{-1}, 1124.725 cm^{-1} and 1597.483 cm^{-1} correponding to FeO group, S=O stretching, silicon compounds with Si-O-C stretching and C=C group respectively (Figs. 2 and 3).

The morphological structure was found by SEM analysis, and it shows the irregular sphere-shaped particles with uneven surfaces (Fig. 4). This nature can facilitate the absorption of the pollutant from wastewater. Similar results were reported by Balamurughan et al. [2].

EDX characterization result was depicted in Fig. 5. The EDS spectrum showed the peaks corresponding to Fe and O. The components of Fe_3O_4 **s**ynthesized through mentioned protocol illustrate that the elemental percentage of Fe was found

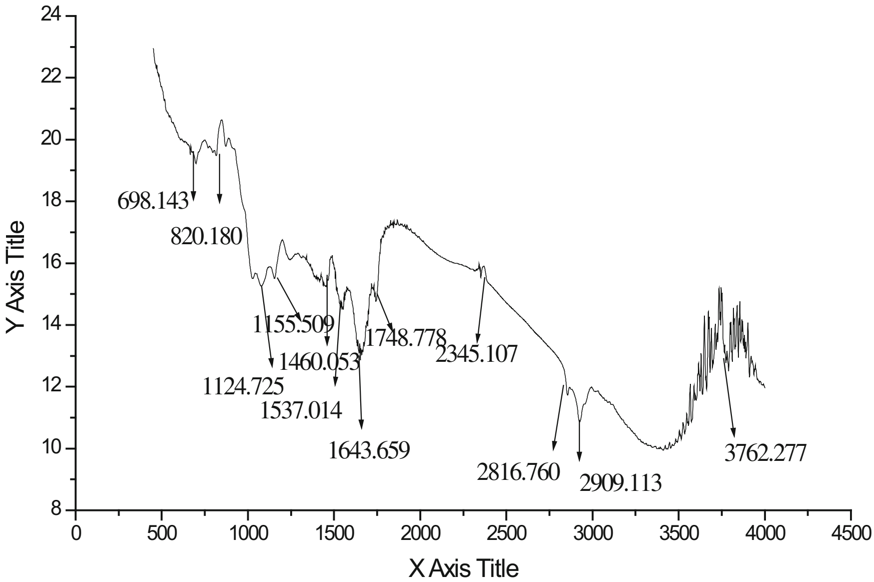

Fig. 2 FTIR spectroscopic analysis of raw fenugreek seed mucilage

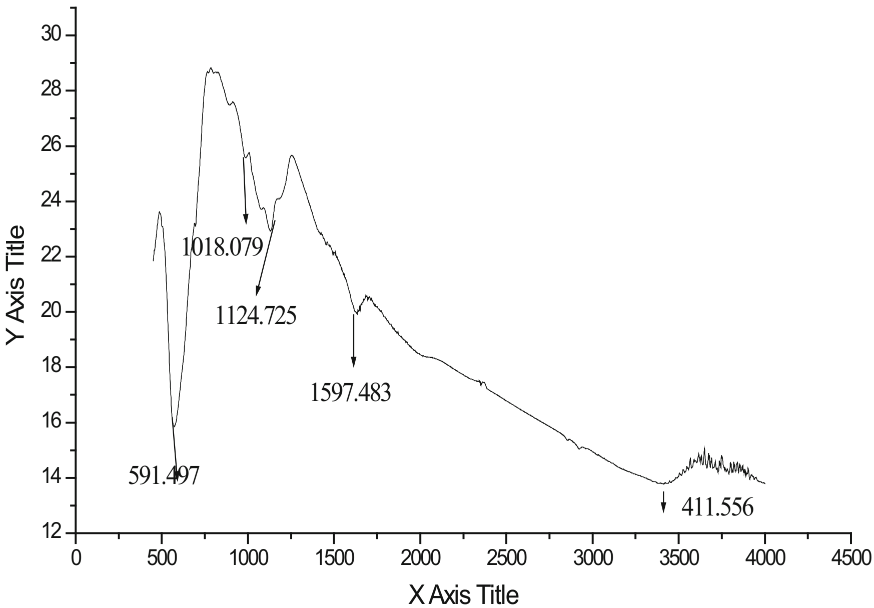

Fig. 3 FTIR spectroscopic analysis of fenugreek seed mucilage magnetic FeNP

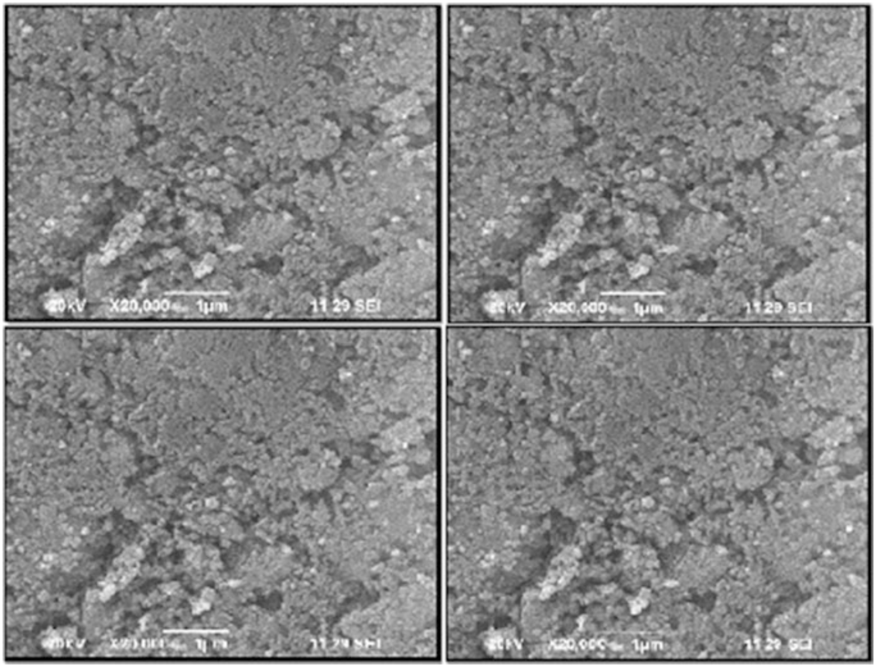

Fig. 4 SEM analysis of mucilage magnetic iron nanoparticle

to be 67.31% and O was 32.69%. It indicates the purity of nanoparticles. The purity percentage (73.36% of Fe and 21.02% of O) coincided with Hariani et al. [4] (Table 3).

3.3 Physical and Chemical Characterization of the Sugar Effluent

The physical and chemical characteristics of the sample were depicted in Table 2 and Fig. 3. The pH of the effluent was 5.1 due to the addition of H_2SO_4 and phosphoric acid for the clarification of sugarcane juice, and it was characterized with 25, 150 mg/L of TDS and 40,000 mg/L of COD. The results agreed with the findings of Saurabh and Shailja [16].

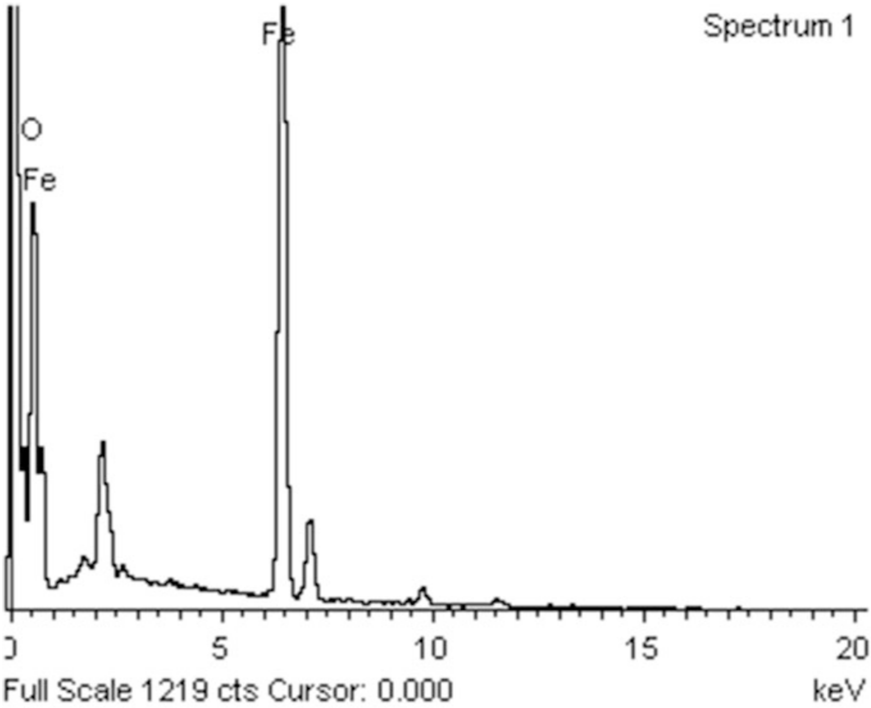

Fig. 5 EDX analysis of mucilage magnetic FeNP

Table 2 Physical and chemical characterization of sugar factory wastewater

S. No.	Characteristics	Results (mg/L)
1	pH	5.1
2	Colour	Pale yellow
3	Odour	Objectionable
4	TDS	25,150
5	COD	40,000

3.4 Effect of Mucilage (Raw and Nano) for Removal of TDS and COD from Sugar Effluent

The removal of impurities was increased when increasing the dosage of mucilage up to 0.8 g. Increased dosage of mucilage powder after the addition of optimum dosage, decreases the reduction of TDS and COD from the treated sugar effluent. Sabale et al. [15] have been reported the fenugreek seed contains galactomannan polysaccharides. Several researchers reported the coagulating property and pollution removal property of galactomannan. Siva et al. [18] also reported the nitrate removal capability of galactomannan from *Strychnos potatorum.* Nitalikar et al. [11]

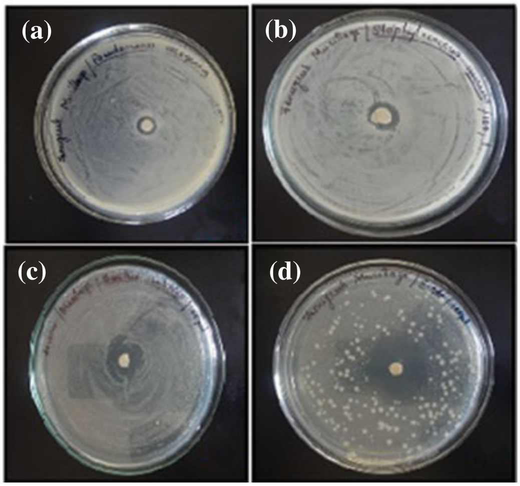

Fig. 6 Antibacterial activity of *Trigonella foenum* mucilage: **a** antimicrobial activity of raw mucilage against *Pseudomonas aeruginosa*, **b** antimicrobial activity of raw mucilage against *Staphylococcus aureus*, **c** antimicrobial activity of raw mucilage against *Bacillus subtilis*, **d** antimicrobial activity of raw mucilage against *E.coli*

have reported the binding property of fenugreek seed. Hence, the removal was attributed by the coagulating as well as binding nature of galactomannan present in the fenugreek with COD causing species. Similarly, the mucilage iron nanoparticles showed the gradual removal of TDS (86%) and COD (91%) up to 0.6 g treatment (Table 3). After that, the TDS and COD were slightly increased, because of the mucilage nanoparticle causing turbidity. The excess dose of mucilage nanoparticle may induce turbidity. The removal of impurities from the effluent might be through adsorption or coagulation mechanism. When compared to both the treatments, magnetic iron nanoparticles were found to be effective than the raw mucilage treatment of sugar effluent. The findings are coincided with the Luis et al. [19] studies. Finally, the potential of mucilage and FeNP was examined for

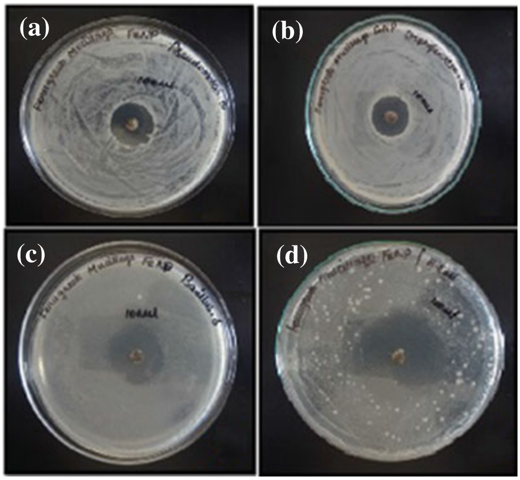

Fig. 7 Antibacterial activity of *Trigonella foenum* mucilage magnetic FeNP: **a** antimicrobial activity magnetic FeNP against *Pseudomonas aeruginosa*, **b** antimicrobial activity magnetic FeNP against *Staphylococcus aureus*, **c** antimicrobial activity of magnetic FeNP against *Bacillus subtilis*, **d** Antimicrobial activity of magnetic FeNP against *E.coli*

Table 3 Effect of *Trigonella foenum* mucilage and magnetic FeNP in TDS and COD removal from sugar effluent

S. No.	Dosage (g)	TDS removal (%)		COD removal (%)	
		Raw mucilage	Magnetic FeNP	Raw mucilage	Magnetic FeNP
1	0.2	10	52	50	55
2	0.4	24	68	57	67
3	**0.6**	59	**86**	70	**91**
4	**0.8**	**77**	72	**75**	80
5	1.0	49	66	66	75

Table 4 Antibacterial activity of mucilage and FeNP

S. No.	Microbes	Strain	Zone of inhibition	
			Raw mucilage (mm)	Iron nanoparticle (FeNP) mucilage (mm)
1	*E. coli*	−ve	12	20
2	*Staphylococcus aureus*	+ve	3	10
3	*Pseudomonas aeruginosa*	−ve	3	13
4	*Bacillus subtilis*	+ve	8	15

antibacterial assay. The iron nanoparticle mucilage showed increased diameter zone of activity against four different organisms when compared to raw mucilage (Table 4). Among the entire assay, both mucilage and FeNP showed higher activity against the microbe *E. coli* (Figs. 6 and 7).

4 Conclusion

The present investigation concluded that the mucilage separated from fenugreek seed is a good, compatible, eco-friendly biosource, for the treatment of sugar effluent. And also, it revealed the iron nanoparticle synthesizing capability. The present investigation concluded that the mucilage separated from fenugreek seed is a good, compatible, eco-friendly bioresoruce for the treatment of sugar effluent. The present work confirmed the seed mucilage as an efficient reducing agent for the synthesis of iron nanoparticles. The raw mucilage and iron nanoparticle were utilized for the treatment of sugar effluent and the nanoparticles reduced higher level of pollutants from the effluent than the raw mucilage. It concluded that the green synthesised nanoparticles can be used as an alternative for the chemical coagulants for the treatment of sugar industry effluent. It can be used as an alternative coagulating–flocculating agent for chemicals even at a very low dose for water and wastewater treatment.

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Part XVII
Waste Utilization and Minimization

Material Flow Analysis for a Sustainable Waste Management System in a Hypermarket

P. Agamuthu, W. J. Hong and S. H. Fauziah

Abstract Integrated waste management can bring about huge economic gains. This is applicable in dealing with municipal solid waste, or in any other sector including the commercial sector. Reluctance to invest in the analysis to understand the flow of quantifiable items within the system is the main challenge among the stakeholders, especially from the small and medium enterprises. Failure to comprehend the existence and management of the components within their system boundaries will result in significant economic loss, particularly in the form of waste. Thus, this paper is aimed to study the input and output of materials in a commercial sector, namely a hypermarket, to develop a material flow chart using Substance Flow Analysis software (STAN) and to postulate possible waste reduction via 3R practices. Total consumption at the study premise was then analysed through material flow system analysis, namely via the use of STAN and Microsoft Excel, to produce the material flow balance. The electricity consumption was 3,060 kWh/d while water consumption was 20 m^3 and material input averaged at 650 kg per day. The output for energy loss was 3,060 kWh, water discharged was 19 m^3, recyclable wastes were 224 kg/day and non-recyclable wastes were 96 kg/day. The premise wasted approximately 2% electricity, 5% water and 43% recyclable materials. Thus, proposed actions by adopting sustainable use of resources and 3R were listed to determine the economic benefits. The study indicated that with appropriate data collection on the input and output of materials one could initiate sustainable practices in resource utilization. Material flow results can be very useful to postulate possible waste reduction via 3R practices. Significant cost reduction can be obtained with the implementation of appropriate sustainable resource usage

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strategies and 3R practices. Therefore, it is crucially important that the management takes a proactive action to promote sustainable housekeeping practices in the commercial areas.

Keywords Material flow analysis · Commercial waste · 3R · SME

1 Introduction

Hypermarket is a superstore found throughout the globe mainly in cities where the facility carries a wide range of products under one roof together with groceries lines and other range of goods. Like other huge commercial stores, the business model of hypermarkets targets high-volume and low-margin sales. Normally, it will cover an area of 5,000–15,000 m^2 with more than 200,000 different products. In 2015, Food Marketing Institute reported that there were more than 38,000 supermarkets in USA alone [2]. As a result, it has a much larger footprint than other commercial centres.

Tesco, the biggest hypermarket chain in the market was reported to have a global carbon footprint of 5.44 million tonnes of CO_2 eq, and 53.26 kg CO_2 eq per square foot of selling place and emitted 655,669 CO_2 eq through transport at 0.141 kg CO_2 eq per case of goods delivered in 2011 [3]. Due to the huge ecological footprint caused by these facilities, many countries have started to implement stricter regulations on the waste disposal policy. Among these is France that has become the world pioneer in banning supermarkets from discarding or destroying unsold food or expired goods, by introducing food banks, to reduce French contribution to 1.3 billion tonnes of food wasted worldwide [4].

As for other parts of the world issues on the ecological footprint from these commercial centre is yet to be a matter of discussion. Nevertheless, it is very important that research is conducted to understand the pros and cons of this sector from the economic and environmental point of view. Among the most rapidly addressed to reduce the ecological footprint of a hypermarket is the waste generation. It is a known fact that an integrated waste management can bring about huge economic gains to any entity including hypermarket establishments [5].

The main challenges in the implementation of an integrated waste management system are the reluctance of the administration of hypermarket to change their business strategy and the lack of reliable data on their input and output materials. Failure to comprehend the existence and management of the components within their system boundaries will result in significant economic loss, particularly in the form of waste. Thus, this paper is aimed to study the input and output of materials in a commercial sector, namely a hypermarket, to develop a material flow chart using Substance Flow Analysis software (STAN) and to postulate possible waste reduction via 3R practices.

2 Materials and Method

In this study, the inputs and outputs of a hypermarket were analysed. The hypermarket involved was Giant Pvt. Ltd., a hypermarket chain store that supplies groceries throughout Malaysia. The substance or input of the resources was identified such as the goods, the electricity and water consumption and waste generated by the supermarket. The goods in the input are those materials such as the stock, the raw materials that have been used by the supermarket in their daily production and the waste that is generated by the customer. The output of the goods was the waste generated. Also, the total amount of electricity and water consumption were determined. The inputs and outputs were accounted to produce balance of goods carried out in the system. All the processes were balanced according to the mass balance principle where the mass of all inputs into a process will be equivalent with the output of the process plus the mass of storage using the following formula [1].

$$\sum_{k_1} m_{\text{input}} = \sum_{k_0} m_{\text{output}} + m_{\text{storage}}$$

Next, mass flows, stocks and concentration that were obtained were computed and analysed using Microsoft Excel and Substance Flow Analysis software (STAN). The amount of materials in stock was assessed by determining either direct measurement of the mass or assessment of the volume and the density of the stock. The total consumption at the study premises was then analysed to produce the material flow balance.

3 Results and Discussion

The overall material flow for the hypermarket was drawn out by using Substance Flow Analysis software (STAN) (Fig. 1) and Microsoft Excel (Fig. 2). From these figures, the input of the three materials, stock and output of the materials per day were 3,730, 331 and 3,399, respectively. The input of materials such as electricity consumption (kWh), water consumption (m^3) and materials (kg) was quantified and defined. The output materials are the energy loss from the electricity (kWh), wastewater (m^3) and the waste generated which includes recyclable and non-recyclable wastes (kg), within the system boundary.

From the material flow, the input of electricity consumption was 3,060 kWh/d, water consumption was 20 m^3 and the materials were 650 kg, respectively, per day. The output for energy loss was 3,060 kWh, wastewater was 19 m^3, recyclable wastes were 224 kg/day and non-recyclable wastes were 96 kg/day. According to Brunner and Rechberger [1], the mass of all inputs is the sum of the mass of output and stock. Hence, the stock for the materials flow was 331 kg.

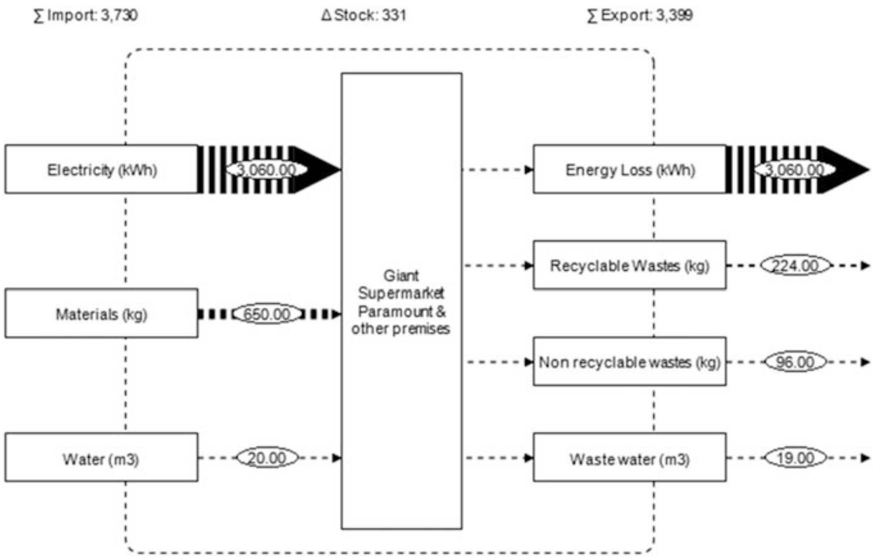

Fig. 1 Daily material flow in the hypermarket using STAN

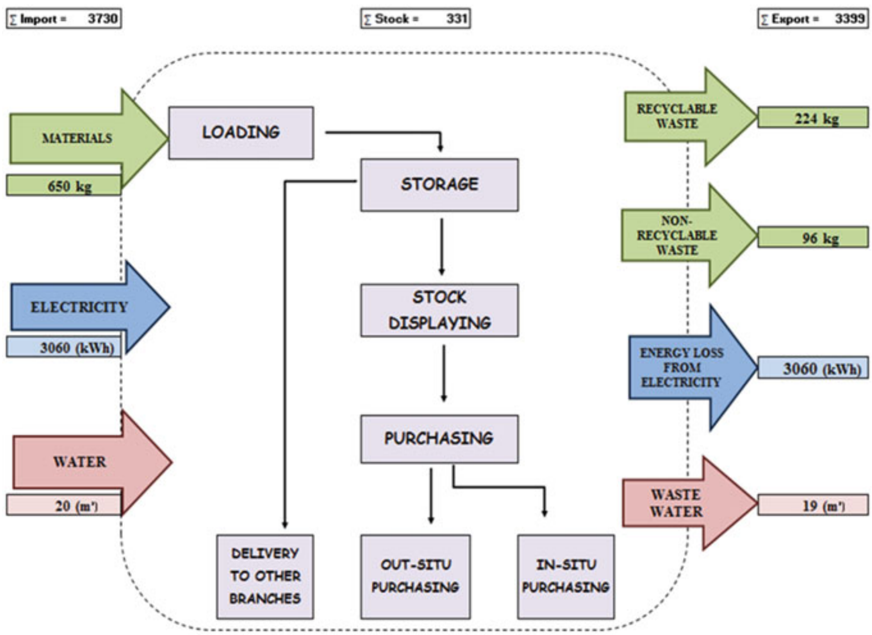

Fig. 2 Daily material flow in the hypermarket using Microsoft Excel

The hypermarket consumed altogether 5,300 kWh of electricity per day which includes all the premises. The electricity flow within the hypermarket is illustrated in Fig. 3.

The water consumption was defined within the system boundary of the study premises. Figure 4 illustrates that the supermarket was the largest consumer followed by the restaurant. From this, the supermarket consumed 47.62% or 20 m^3 of water daily, followed by the restaurant which utilized 14 m^3 or 33.33% of total water supplied to the hypermarket.

Waste segregation was not practised except for the corrugated papers that are to be used for goods packaging. Clean and undamaged corrugated papers were placed in a special compartment for other purposes. Wastes were segregated into two categories, namely recyclable material and non-recyclable waste.

Figure 5 shows the waste flow in the hypermarket premises. The import of goods per day was approximately 650 kg/day while the waste generation was about 320 kg/day. Among these wastes, only 30% (96 kg) was non-recyclable. On the contrary, the balance of 70% or 224 kg was recyclable material.

Recyclable material was the largest waste generated in a day (70% or 224 kg). Examples of recyclable wastes were plastic wastes, paper wastes and others. Among the recyclable wastes, paper wastes were the highest which was around 65% (146 kg), followed by plastic wastes which was 30% (67 kg) and others such as scrapped metal, 5% (11 kg). The material balance enabled the hypermarket administration to implement suitable options and alternatives to reduce the cost in managing waste within their premises.

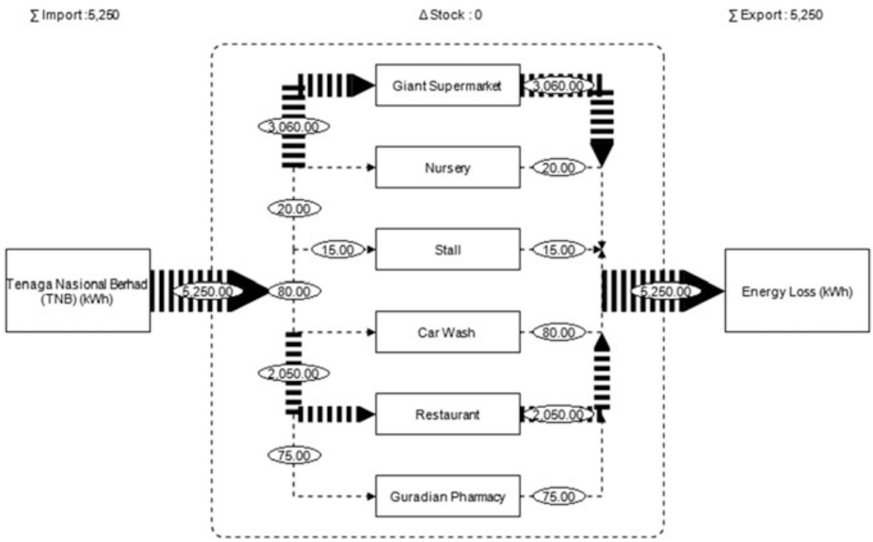

Fig. 3 System boundary of the electricity flow within the hypermarket

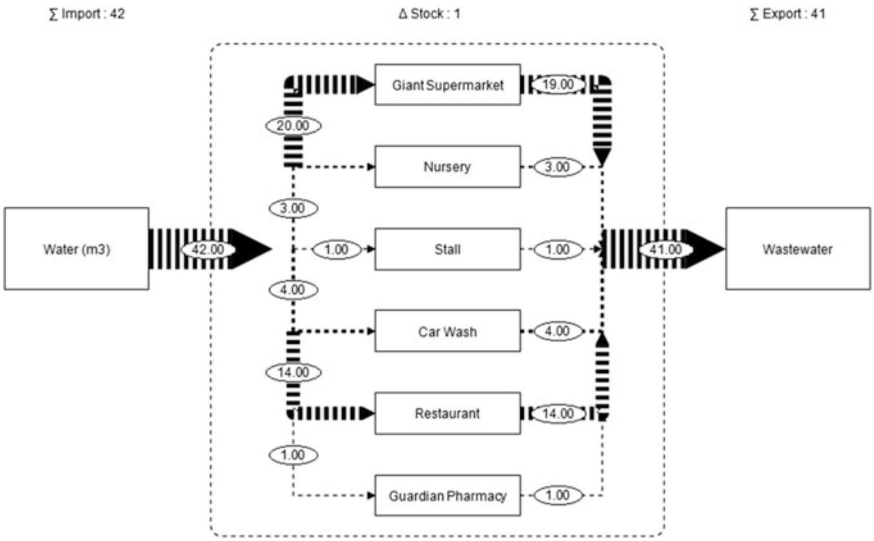

Fig. 4 Water flow analysis of the hypermarket

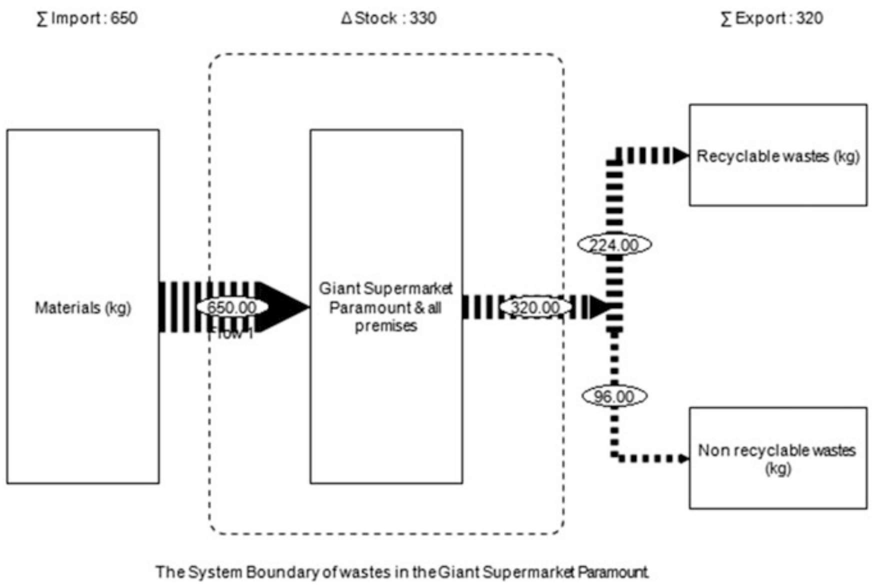

Fig. 5 Waste flow analysis at the hypermarket premises

The expected cost savings if 3R options were to be implemented are shown in Table 1. This potential cost saving is identified via the material flow analysis conducted in this study.

Table 1 Cost saving by the premises should 3R be implemented

Wastage	Cost saving (RM per day)	Cost saving (RM per week)	Cost saving (RM per month)	Cost saving (RM per year)
Electricity	25.00	175.00	700.00	8,400.00
Water	2.00	14.00	56.00	672.00
Wastes	30.0	210.00	840.00	10,080.00
Total	57.00	399.00	1596.00	19,152.00

Table 2 Total cost incurred before and after implementation of the 3R program

3R options	Electricity (RM)	Water (RM)	Waste disposal (RM)	Wastewater treatment (RM)	Total (RM)
Before	50,000.00	3,000.00	800.00	495.00	54,295.00
After	49,300.00	2,944.00	650.00	495.00	53,389.00
Reduction					10,872.00

The implementation of 3R may also reduce the waste management cost by 17% since wastes that need to be disposed will be reduced accordingly. The total cost was also calculated before the implementation and after the implementation of the 3R program and is shown in Table 2.

More reduction in cost can be achieved if more strategic business plans can be implemented to improve the sustainability of the hypermarket management. As a result, it does not only benefit in terms of monetary value, but it will also generate good public image for better marketing strategy as well as significantly reduce the ecological footprint of the hypermarket establishment.

4 Conclusions

The study indicated that appropriate data collection on the input and output of materials is important to initiate sustainable practices in resource utilization. Material flow results can be very useful to postulate possible waste reduction via 3R practices. Significant cost reduction can be obtained with the implementation of appropriate sustainable resource usage strategies and 3R practices. Therefore, it is crucially important that the management takes a proactive action to promote sustainable housekeeping practices in the commercial areas.

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Problematic of Solid Waste Management in Pobe Commune (Benin, West Africa)

Léocadie Odoulami and Mireille et Olatoréra Ladeyo

Abstract The population and the municipal authorities of Pobè are confronted to the insufficiency in the management of solid wastes that are proliferating. This work studies the solid wastes produced management methods in this Pobè commune. The literature search, surveys conducted in 384 households and with the authorities and agents suitable for communal services of the boroughs of Pobè center, Igana, and Towé affected by the proliferation of waste and the treatment of the collected data (demographic, socioeconomic, etc.) and analyzes are carried out. The result is a production of 13 tones of solid waste per day in Pobè municipality. However, only 2.5% of survey households use the services of NGOs for waste disposal, 55.6% still reject on public roads or in nature, 19.40% of survey households conduct their burning, 15% bury their wastes, and 7.50% use them in agriculture. This disparity in solid waste management is linked to low-income households that cannot easily subscribe to pre-waste collection services, to inadequate sanitation facilities and hygiene and sanitation education deficits. This insufficiency waste management is causing nuisances that affect the environment and human health. New development strategies in the commune are recycling, processing, composting, etc., who are the new sources of revenue. These new strategies are to provide financial support by national and international actors for the promotion of entrepreneurship.

Keywords Benin · Pobè commune · Waste management · Environment and health degradation · Waste valorization

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1 Introduction

During the twentieth century, the world has experienced rapid population growth. From 1.6 billion in 1900 to 7.2 billion in 2015, the world population is estimated at 9.6 billion in 2050 (United Nation quoted by Vigninou et al. [5]). In developing countries in general and Africa in particular, this population explosion has led to the accumulation of household waste, etc., from human activities despite the numerous actions undertaken by States [4]. In Benin, most of the environmental management and planning systems set up by the authorities at various levels face increasing waste give little satisfaction (Vigninou 2001). In the Municipality of Pobè, population growth and changes in income-generating activities have resulted in increased production of large amounts of household waste [2]. But these wastes are managed in a manner contrary to those prescribed by the regulations in the matter. This has serious environmental impacts.

The Municipality of Pobè is in the Plateau district, southeast of the Republic of Benin on the Atlantic coast between 6° 7° 56′ 36″ and 12′ 52″ north latitude and 2° 35′ 32″ and 2° 46′ 25″ east (Fig. 1). The Pobè Municipality covers an area of 400 km^2 and has a population of 122,599 inhabitants in 2013 [3].

This study aims to diagnose the current methods of solid waste management in the municipality of Pobè to make sustainable proposals to place populations and policymakers.

2 Data and Methods

2.1 Data

The study took into account several data. These are the statistics on pre-collection of household waste obtained from the NGO APESaB, neighborhood leaders/village districts, and in the documentation for mayor of Pobè. The disease statistics were also collected. They cover the period 1999–2013 due to data available at the Pobè area hospital and the Departmental Directorate of Health/Ouémé Plateau. These data were supplemented by data collected from 384 households investigated taking into account the state of unhealthiness of their surroundings.

2.2 Methods

The various waste management methods have been reported from field surveys. Their analysis was done using the literature review based on waste management standards in Benin. In addition, the various notes from the comments on it have been comparison, assessment, and synthesis. Health statistics were processed and analyzed using the tools of descriptive statistics.

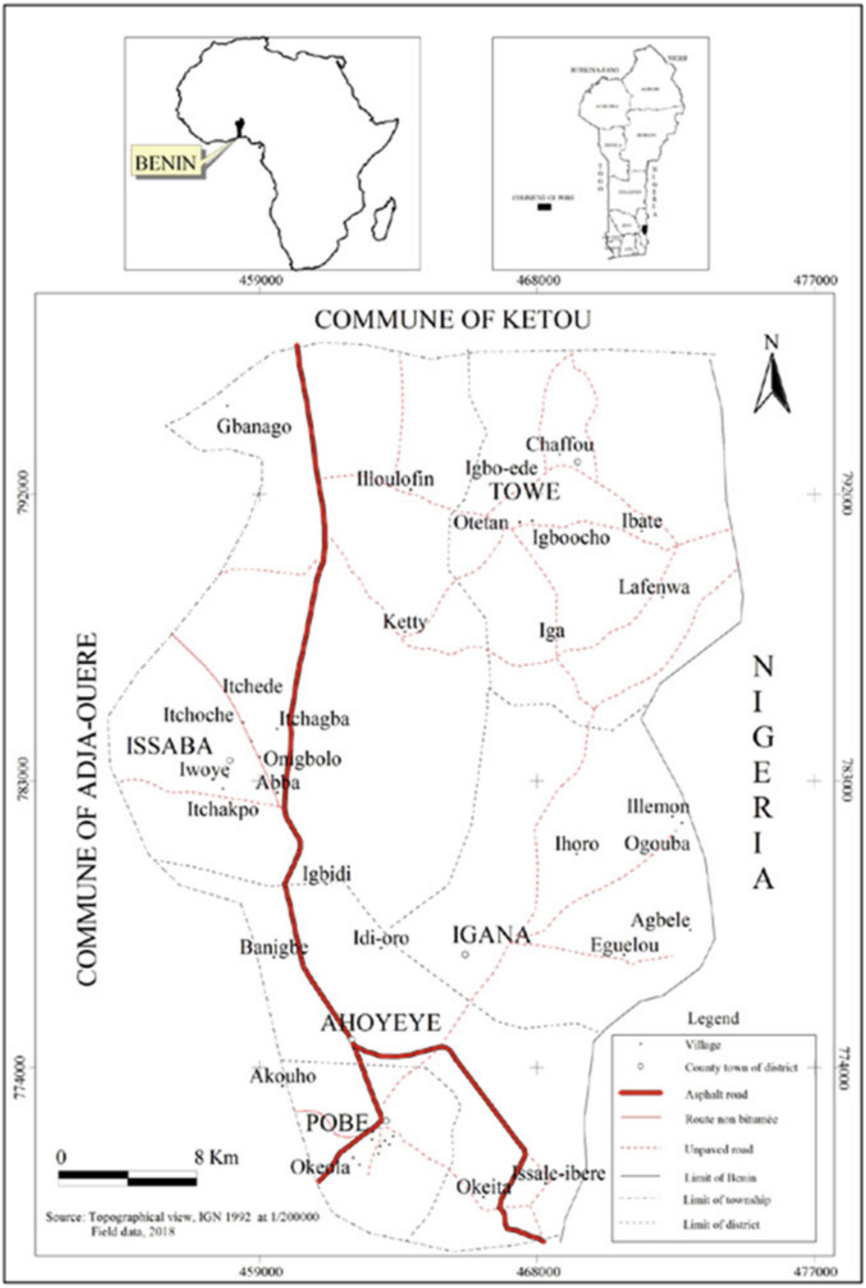

Fig. 1 Location of the municipality of Pobè

3 Results and Discussion

In the commune of Pobè, population growth is a factor in the generation of waste in households.

3.1 Population Dynamics, Waste Generation Factor

The population was 54,181 inhabitants in 1992 increased to 82,910 inhabitants in 2002 and is estimated at 122,599 inhabitants in 2013 ([3] and calculation results; Fig. 2).

Figure 2 shows that from 1992 to 2013, the population of the five boroughs of the City of Pobè has evolved. The districts of Pobè and Issaba are, respectively, the most populous, with 49,165 inhabitants and 29,178 inhabitants in 2013. Then comes the districts of Towe of Ahoyéyé and Igana. This fact is justified by the arrival of the coming of Ouinhi Mahi, Covè, Zagnannando; Gun from the Porto Novo and suburbs; from the Mono-Adja Couffo Ibo from Nigeria, etc., practicing either in the administration and is in the cement plant Onigbolo especially [2].

Population growth and migration of populations are crucial in the production of waste in the Municipality of Pobè because as and as the population size increases the amount of solid and liquid waste increases. Given these findings, despite the benefits of population growth, it is nevertheless a factor of sanitation problems in the municipality of Pobè.

The expansion of built spaces is also another crucial factor in the production of waste. Indeed, from 1992 to 2013, the population density in the municipality of Pobè increased from 35 inhabitants/km^2 at 306 inhabitants/km^2 ([1] and calculation result). The spatial extension is also justified by the decline in some areas occupied by the mosaics of crops and fallow land at the expense of cities.

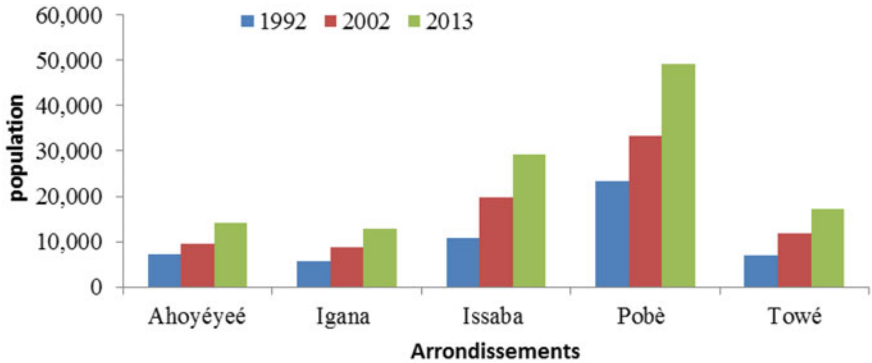

Fig. 2 Population trends of the town of Pobè 1992–2013. *Source* INSEA [3]

Furthermore, in addition to the spatial dynamics, there are certain economic activities that contribute to unsafe Pobè of the commune. There are the crafts, the livestock, the trade, the agriculture, the industry, and the small displays. Factors such as population dynamics, spatial extension, and socioeconomic activities are crucial in the production of several types of waste in the municipality of Pobè.

3.2 Types and Amount of Solid Waste Generated in the Municipality of Pobè

The increase in the population of the municipality of Pobè causes increasing waste generation. In Pobè, waste products were grouped into six categories as shown in Fig. 3.

Figure 3 shows that food wastes ares at first place with 35%. So, household waste comes from kitchens, dining rooms and generally reflects the dietary habits of the population. Sweepings ranked second with 25% of waste. This is the case of the use of plastic bags that people in the Municipality of Pobè appreciate because of its lightweight and ease of transport. According to garbage collection structures, it produces nearly 13 tons of waste per day or about 0.55 kg of waste on average/capita/day. It should be noted that this rate varies between periods and locations (Table 1).

Table 1 shows the daily output of solid waste per capita according to different periods. The production of waste is relatively high at the beginning of the three types of neighborhoods and diminishes at the end of the month. The suburbs produce less waste during the month. This can be explained by low-income households in outlying neighborhoods. The composition of the waste is not always identical. It is observed in the production of waste a clear predominance of kitchen waste and enough leftover food in early unlike the end where the packages are more

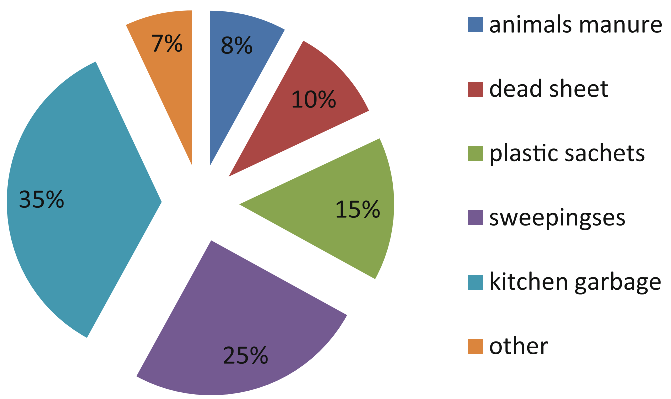

Fig. 3 Categorization of waste in the municipality of Pobè. *Source* Field Survey, November 2012

Table 1 Daily production of garbage per capita according to the periods in the city of Pobè

Different sectors	Central districts	Suburbs	New districts
Period of months	(kg/habt/jr)		
Beginning of months	0.55	0.50	0.55
End of months	0.53	0.48	0.51
Average amount by district	0.54	0.49	0.53
Overall average	0.55		

Source Survey Results, November 2012

important. Consequently, the early months are periods where the waste is more and coincides with the times when households still have a share of their income. The waste produced in the Municipality Pobè is then managed.

3.3 Solid Waste Management Strategies in the Town of Pobè

The household waste disposal is done in many different ways in the Municipality of Pobè. Some of the waste is discharged directly in nature, while the other part is used by people to backfill the shallows or buried or cremated. Figure 4 shows the different discharge modes of solid waste in the Municipality of Pobè.

It is clear from Fig. 4 that only 2.5% of survey households use the services of NGOs for waste disposal, 55.6 and 15% of household survey prefer rejection, respectively, in nature and landfill garbage. This is due to lack of financial means of some households to subscribe to the pre-collection structure. There is, thus, the

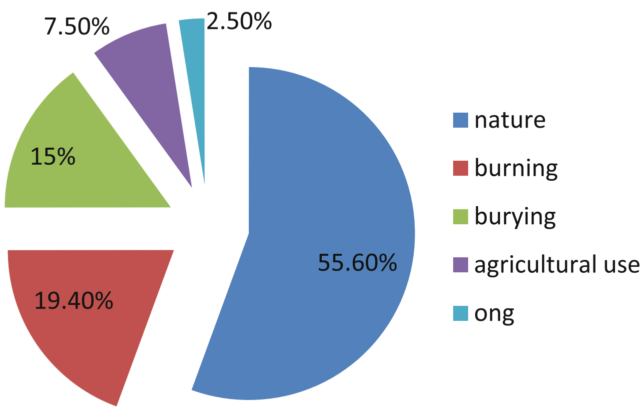

Fig. 4 Various household waste management practices in the municipality of Pobè. *Source* Field Survey, November 2012

absence of the pre-collection structure in some, especially rural areas. According to officials of the NGOs, it is related to an equipment failure and a profitability problem. This poses a real health problem. Thus, the solid waste management as carried out in the Municipality of Pobè does not solve the sanitation problems and unsafe persists with health hazards.

3.4 Measures for the Organization of the Waste Stream

The efficient management of solid waste is to respect all the steps that are the pre-collection, the collection, the transportation, and the treatment or final disposal. The waste management chain consists of those four inseparable links. During the field survey, it is found that these steps are not followed.

Regarding the production of waste, that is today, the analysis showed that the population growth also induces an increase in waste production. The problem of management is related to antisocial behavior and the level of living. Thus, we must raise awareness and highlight the risks associated with poor waste management. To get people to change their ability, provide poor households bins to consolidate their waste.

Education shall be established by the municipality authorities and can affect all types of neighborhoods and must go through the forms of communication such as the popularization of the information by district bawlers and modern media in the different languages of the city; the artist actors could use some skits during monthly days for a healthy environment to inform the crowd; the religious leaders could be together to educate the faithful on the cleanliness methods as the good waste management and ways benefits to be gained from that. It has been shown that any human being is easily vulnerable spiritually and emotionally (Dekin 2007). This can be an effective channel to achieve results; the women group, especially since they are responsible for household hygiene according to African tradition. These can help in households to separate waste at source, reducing the amount of waste for disposal.

The municipality in collaboration with its financial partners must provide free pre-collection to people in the first month to lead households to get used before requesting consideration. In fact, the municipality must encourage the sector through subsidies while signing a contract and transfer to private structures. As for private structures, they must organize their pre-collection activities; review the fee schedules to be determined by household and always respect the clauses of the contract by giving beneficiaries a quality service. Regrouping points are well defined by the city in collaboration with officials of the pre-collection structures. Regarding treatment, there are several types of treatment given the composition of household waste.

4 Conclusion

In Pobè commune, the problems of the waste management increase each year dues to human activities. Population growth, the proliferation of non-biodegradable packaging and the development of economic activities are the basis of strong production of solid waste source of environmental degradation and human health. The sanitation situation remains worrying in the municipality of Pobè. There is only one NGO (APESaB) that deals with the pre-wrestles with a very low coverage rate of 2%, a multitude of illegal dumping. Given all this, it would be desirable that steps be taken by the communal authorities and development partners for recycling, processing, composting, etc., who are the new sources of income are a reality in the municipality of Pobè. These innovative strategies deserve to be encouraged and supported financially by national and international actors because they are sources of green employment for the youth.

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Solid Waste Management Scenario in Public University Campuses of Bangladesh: A Comparative Study Between KUET and Khulna University

T. K. Roy, K. M. M. Ekram, G. Barua, S. T. Hossain and F. Akter

Abstract Solid waste management (SWM) at university level is crucial for maintaining health and safety of the students, teachers, and staffs. It also contributes to the campus environment and aesthetic beauty. Khulna University of Engineering and Technology (KUET) and Khulna University (KU) are the two most prominent public universities in Bangladesh. The universities have 101 acre and 105.75 acre land, respectively. Presently, there are 4000 students, 300 teachers, and 200 staff in KUET. Khulna University has 7000 students, 450 teachers, and 550 staff. A significant number of waste bins are located at various points of KUET campus. Wastes generated in the students' halls, staff and teachers' quarters, academic and administrative buildings are collected separately based on biodegradability. Average amount of degradable and non-degradable wastes generated in KUET campus per day is about 240 and 290 kg. The biodegradable wastes are converted into compost, which is used for the flower plants and agro-forestry gardens of the campus. On the other hand, the non-degradable wastes are further screened and sold away or burnt in SWM plant. KU generates about 140 kg degradable and 170 kg non-degradable wastes per day. Unlike KUET, there is no fixed waste management and processing system prevalent in KU. However, the presence of waste bins at various locations in the campus is a good indicator of waste management. Wastes generated from the student halls and other places of the campus are collected regularly by the cleaners and finally taken away by Khulna City Corporation (KCC) for dumping in landfill sites. This paper focuses on the prevailing waste management practices and facilities of KUET and KU campuses providing a comparative analysis both from the qualitative and quantitative perspective. Finally, it also draws some recommendations for the improvement of overall waste management scenario of the university campuses.

Keywords Solid waste management · Public University · KUET
Khulna University

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1 Introduction

Waste management is a very prominent issue nowadays. With the increase in the population the amount of waste generation is increasing and improper management of this subject is resulting into environmental degradation. A proper waste management system helps to make the environment safe and sustainable. Institutional solid waste management is a kind of managerial process which is practiced worldwide. These institutions include educational institutes, office, and other type of institutions. Among these, educational institutes are an important place to implement waste management system as majority of the population is involved with it and the generation of the waste here is quite high. In the twenty-first century, educational institutions have to face a series of challenges such as the promotion and implementation of sustainable practices through the participation of faculty, students, and staff which should be compromised in building a better future for the generations to come [4]. In the Philippines, there is an example of proper waste management system. The Philippine government enacted an Act which involved the educational institutes in the process and imposed many restrictions to minimize the illegal dumping of the wastes [1].

Educational institutes mainly generate two types of solid wastes biodegradable and non-degradable. Biodegradable wastes are those which can be decayed or degraded. These include food leftovers, papers, kitchen wastes. Non-degradable wastes are not degradable or decayed naturally. These include plastic materials, pens, etc. The students generally dump their wastes into trash cans in their classrooms if there is any. Then the wastes from those trash cans are collected and dumped into the nearest dustbin or dumping zone. Along with the students, there are also some staffs who work to keep the campus neat and clean. There is sometimes a regulatory body that monitors the whole process [3]. In the developing countries like Bangladesh, a common tendency is seen that the people are less concerned about dumping waste. It is regularly observed that students in the educational institute dump wastes wherever they want even if there are trash cans available. Again, the trash cans are not always available. Though there is some theoretical knowledge available in the books about waste management, there is less practice among the students to implement the theoretical knowledge into practice. Even the institutional bodies are not that much concerned about this situation. Though some institutes have a concerned body to monitor the situation, most of them do not have. So, it is important to conduct study on different aspects of SWM in educational institutions, especially in public universities.

2 Objectives

- To investigate the existing solid waste management (SWM) system of KUET and Khulna Universities in terms of facilities, problems, and limitations; and
- To provide some recommendations for improving the SWM system of the universities

3 Methodology of the Study

Interviews are conducted with concerned stakeholders, namely university students, teachers, and waste management staff; data on existing waste management system, facilities, and problems are collected using questionnaire, checklists, and taking photographs. Relevant secondary documents in the form of journals, conference proceedings, reports, etc., are reviewed.

4 KUET and Khulna University as Study Area

The study area for this paper includes two of the leading universities of Bangladesh, more specifically in the southwestern part of Bangladesh. These are Khulna University of Engineering and Technology (KUET) and Khulna University (KU). Khulna University of Engineering and Technology (KUET) is situated at Fulbari gate area, 13 km away from the core of Khulna City. It was established initially as Khulna Engineering College in 1969 and was eventually upgraded to Bangladesh Institute of Technology (BIT), Khulna and finally granted as a University in 2003. Presently, there are 11 distinct departments under 3 faculties, namely Faculty of Civil Engineering, Faculty of Electrical and Electronics Engineering, and Faculty of mechanical Engineering. There are also two institutes, namely Institute of Information and Communication Technology (IICT) and Institute of Disaster Management (IDM). The 101 acre campus consist of four functional zones, (1) Residential Zone for Students (six halls for male students and one for female students), (2) Residential Zone for Faculties and Staffs, (3) Academic and Administrative Zone, (4) Cultural cum Social and Recreational Zone (including cafeteria, playgrounds, etc.).

Khulna University (KU) is situated at Gallamary on southern side of Khulna Satkhira Highway. It is about 5 km away from the core of Khulna City. Established in 1991, the university now consists of 22 disciplines under five schools, namely Life Science School, School of Arts and Humanities, School of Management and Business, School of Social Science, and Science Engineering and Technology School. There is also one institute in the campus, namely Institute of Fine Arts that bears the legacy of a century old art educational school in Bangladesh. The 105.75-acre campus also consists of three halls for male students and one for female students. Another students' hall for female students is under construction.

5 Category and Amount of Solid Waste in KUET and Khulna University

The universities mainly generate two types of solid wastes—biodegradable and non-degradable. Biodegradable wastes are those which can be decayed or degraded (e.g., food leftovers, papers, kitchen wastes). Non-degradable wastes are not degradable or decayed naturally (e.g., plastic materials, pens).

The amount of wastes collected from different zones of KUET campus is 530 kg, and Khulna University is 310 kg, respectively, shown in Table 1.

6 Stakeholders of University Solid Waste Management

There are different types of stakeholders for managing solid wastes in university. The stakeholders are mentioned in Table 2.

Table 1 Amount of solid wastes generated in KUET and Khulna University

University	Amount of degradable wastes (kg)	Amount of non-degradable wastes (kg)	Total wastes (kg)
KUET	240	290	530
Khulna University	140	170	310

Source SWM plant of KUET, 2016 and SWM staff of Khulna University, 2016

Table 2 Stakeholders involved in university solid waste management

Stakeholder category	Stakeholders
Primary	Students, teachers; voluntary organizations active in the university; canteen operators
Secondary	Household members of teachers' and staff quarter; shopkeepers within and adjacent university campus
Tertiary	Khulna city corporation (KCC); Khulna development authority (KDA); non-government organizations (NGOs) and community-based organizations (CBOs) involved in waste management; researchers; volunteers as development activists; universities and colleges (as researchers and consultants)

KCC is responsible for the urban Solid Waste Management (SWM) of Khulna City. The SWM by the Conservancy Department of KCC organizes waste collection from the city corporation bins and secondary transfer stations located on different major roadsides throughout the city. There are about 10 (non-government organizations) NGOs and (community-based organizations) CBOs in Khulna City that are involved in door-to-door collection system with small-scale organic solid waste composting and organic fertilizer preparation [2, pp. 148 1–10]. KCC trucks pick up waste from the roadside bins and transfer stations having demountable containers. Though statutorily Khulna City Corporation (KCC) is responsible for managing the solid wastes of Khulna City, it has no separate SWM Master Plan for improving the SWM system of Khulna City. Khulna Development Authority (KDA), a local city planning and development controlling authority, prepared the City Master Plan and Structure Plan for the period of 2001–2010 and 2001–2020 in 2001, respectively. The Plans have a number of SWM improvement proposals. KDA proposed five (five) new solid waste disposal or dumping sites for Khulna City within its Khulna Master Plan and Structure Plan area. Improvement of municipal SWM system for Khulna City largely depends on successful implementation of the proposals mentioned in the Khulna City Master Plan and Structure Plan [2, pp. 148 1–10].

KUET and Khulna University are located within Khulna metropolitan area but adjacent outside of KCC boundary. As the university authorities request KCC, KCC collects wastes from the universities by its trucks. The administrative process for inclusion of the two universities within KCC jurisdiction is at final stage.

7 Waste Management Scenario of KUET

KUET is one of the most well-organized campuses of the country as far as waste collection and management is concerned. A noteworthy number of waste bins are located at various points of the campus. Solid wastes generated from the residential halls, staff and faculty quarters, academic and administrative buildings and such other places are collected in separate waste collecting vans based on their biodegradability (Fig. 1).

The collected wastes are then taken to the KUET Solid Waste Management Plant, located adjacent to the bachelor quarter no. 19. In the plant, biodegradable wastes are processed through aerobic decomposition for composting. The decomposition process continues for 90 days within which the wastes get converted into compost. The compost thus produced is being used the flower plants and agro-forestry gardens of the campus. The compost is also sold at the rate of BDT 12 per kg. On the other hand, the non-degradable wastes are further screened and sold away or burnt by the incinerator in SWM plant.

Photo 1: Waste bin in front of administrative building of KUET

Photo 2: Waste bin established by Chatra (Student)League

Photo 3: Roadside waste bin in KUET campus

Photo 4: Waste collection from campus by van

Photo 5: Green Watchman in waste collection in KUET

Photo 6: Waste Management Plant in KUET

Photo 7: Degradable and non-degradable wastes in SWM plant

Photo 8: Compost produced in SWM plant

Fig. 1 Existing solid waste management practice and facilities in KUET. *Source* Field survey, 2015–2016

8 Waste Management Scenario of Khulna University (KU)

Unlike KUET, there is no fixed waste management and processing system prevalent in Khulna University campus. However, the presence of waste bins at various locations in the campus is a good indicator of the awareness regarding waste collection and management. Khulna University administration took initiative in 2015 to impose the management of solid wastes generated in the administrative and academic buildings.

A temporary contractually appointed van driver with a van collects solid wastes generated in administrative building, three academic buildings, central library, and medical center. The collector disposes of the wastes in a secondary dustbin or disposal site measuring 120 ft^2 encircled area at the southern side of Khulna Satkhira Highway (Fig. 2). University authority requests KCC to dispose of the wastes from this site to its final disposal site at Rajbandh. There are two four-storied buildings as teacher–officer quarter and two four-storied buildings as staff quarters in Khulna University campus. Twenty (20) families of teachers and officers and thirty-two (32) staff families live in these buildings. There is no systematic solid waste management system for the teacher–officer and staff quarters. Household members indiscriminately dispose of the wastes in quarters nearby space. Noteworthy here is the fact that, although KU lacks the on-site waste processing system, it has a fairly good system of waste storage, collection, and transportation. The University Authority is pretty aware about this issue and is trying its level best to ensure that the waste management processes run smoothly and efficiently.

Photo 1: Scattered wastes in the courtyard of 1st academic building

Photo 2: Scattered waste in the courtyard of 2nd academic building

Photo 3: Indiscriminate dumping of wastes near Khan Bahadur Ahsanullah (KBA) Hall

Photo 4: Wall campaign in 2nd academic building for throwing waste into dustbin

Photo 5: Plastic waste bin and basket in the administrative building

Photo 6: Plastic drum as waste bin in KBA Hall

Photo 7: Waste collection from the administrative building area

Photo 8: Secondary waste transfer station or dumping site of Khulna University

Fig. 2 Existing solid waste management practice and facilities in Khulna University. *Source* Field survey, 2015–2016

9 Comparative Analysis of Waste Management Scenario of the Two Campuses

Both KUET and KU campuses have a satisfactory waste management system in them. However, it must be admitted that KUET does have the added advantage of on-site waste processing and hence a better waste management approach. The waste collected and processed in the SWM plant is also weighed regularly and other related data are collected so as to facilitate further research by students of the university. KU having no such facility, no exact data could be collected about the amount of different category wastes generated in the campus. There is only one waste collecting van in KU, whereas KUET has three waste collecting vans. There are separate staffs for SWM and toilet cleaning in KUET. But, in Khulna University

Table 3 Staff in SWM and toilet cleaning in KUET and Khulna University

Name of university	Staff designation	Nature of service		Total
		Permanent	Temporary/ master roll	
KUET	Waste collector/sweeper	06	14	20
	Toilet cleaner/sweeper	03	07	10
Total		**09**	**21**	**30**
Khulna University	Toilet cleaner/waste collector/ sweeper	12	14	26
Total		**12**	**14**	**26**

Source Office survey, 2016

same staffs are engaged both for SWM and toilet cleaning. The number of staffs for SWM and toilet cleaning in KUET is 30, which is 26 in Khulna University (Table 3).

KUET for the first time in 2015 has introduced a new mechanism for managing its campus solid wastes efficiently and making the campus clean in sustainable manner. It orients the new students on proper waste management system during orientation program organized just before starting the academic class. Besides orientation, the students undergo a written agreement/commitment and oath for disposing their wastes in waste bins and taking responsibility to make the campus clean and environmentally sound. The important positive components of SWM exist in KUET campus are: separate bins by waste type at source, students committee/association for SWM, composting from wastes, income from selling of compost and recyclable inorganic wastes, holding regular international conference on SWM etc. These components are absent in Khulna University. Open dustbins, indiscriminate dumping of wastes, open and uncontrolled burning of wastes etc. are also found in Khulna University (Table 4).

Table 4 Solid waste management components in KUET and Khulna University campus

Components on SWM	Universities with status of SWM components	
	KUET	Khulna University
Waste bins in front or beside the entrance of campus	No	No
Waste bins in the corridors and classrooms	Yes	Yes
Waste bins in teachers'/officers'/staffs room	Yes	Yes
Waste bins by waste type at source	Yes	No
SWM committees by teachers/students/staff	No	No
SWM and campus environment as meeting agenda	Yes	Yes
SWM by students committee/association	Yes	No
Composting from wastes	Yes	No
Income from composting	Yes	No
Recyclable wastes are sold	Yes	No
Income by selling of recyclable wastes	Yes	No
Open burning of wastes	No	Yes
Controlled burning (incineration) of wastes	Yes	No
Stakeholders are actively involved in SWM	Yes	No
Stakeholders are fairly involved SWM	No	Yes
SWM directions by university authority	Yes	Yes
Published waste management guideline	No	No
Designated site or land for composting	Yes	No
Exists open dustbins in the campus	No	Yes
Indiscriminate dumping of wastes at some locations	No	Yes
SWM related conference or seminar in the campus	Yes	No

Source Office and field survey, 2016

10 Problems and Limitations of SWM Management in KUET and Khulna University

The study finds some problems and limitations of SWM in the universities. The problems and limitations are:

(1) Inadequate budgetary allocation for SWM in the universities
(2) Inadequate number of permanent staff for SWM and most of the staffs are appointed on temporary or Master roll basis
(3) Lack of facilities for the staffs involved in SWM
(4) Inadequate number of trash cans in Khulna University
(5) Absence of separate zone or space for secondary waste transfer stations and compost plant in Khulna University Master Plan
(6) The universities do not have voluntary organizations formed by students, teachers and others for SWMS
(7) KCC has no regulatory bindings especially dedicated to the SWMS of the universities and other educational institutes
(8) KDA could not keep special provisions for SWM of educational institutes in the SWM chapter of its City Master Plan and
(9) Absence of guideline on university SWMS specifying the roles of stakeholders.

11 Recommendations for Improving the SWM System of KUET and KU

Some recommendations are made for the improvement of SWMS of the universities. The recommendations are as follows:

(1) Keeping adequate budgetary allocation for the SWM in universities
(2) Increasing number of permanent staff for SWM
(3) Increasing facilities for the staffs appointed on temporary or Master roll basis
(4) Putting trash cans in every classroom and also in some other appropriate locations
(5) Forming voluntary organizations in university by students, teachers, and others for educating students about waste management system and adverse impacts of improper waste management
(6) KCC can incorporate the issue of university SWMS in its ordinance and legal documents
(7) KDA should keep special provision for SWM of universities and other educational institutes in its City Master Plan
(8) Formulating guideline on university SWMS specifying the roles of stakeholders

(9) Provision of separate zone or space for secondary waste transfer stations and SWM plant in Khulna University Master Plan
(10) The universities especially Khulna University can take step to ensure involvement of tertiary level stakeholders, i.e., Khulna City Corporation (KCC), Khulna Development Authority (KDA), non-government organizations (NGOs), community-based organizations (CBOs), and students' voluntary organizations
(11) More studies can be conducted on different aspects like volume of wastes; problems, scopes, and potentials of resource recovery from wastes; behavioral pattern of students, teachers, and concerned stakeholders, etc.

12 Conclusion

Apart from the other universities of Bangladesh, KUET and Khulna University have potentially succeeded to manage the wastes at a significant level. The authorities are concerned about the cleanliness of their campuses and definitely aiming to create an environmental-friendly sustainable premise. Though there are some problems and limitations in the waste management system, both the universities can overcome the problems and limitations in coordination and cooperation with all stakeholders.

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Future Challenges of Overburden Waste Management in Indian Coal Mines

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Abstract Power consumption by Indian household and industries are mainly furnished by coal-based power plants, and its dependency is increasing with time due to more focus on the energy security for all policy aimed by the central government. With recent plan of increasing the coal production by state-run Coal Indian Ltd. (CIL) to ambitious 1 billion tons per annum (TPA) by 2020, the prerequisite of developing coal-based mines and their auxiliary infrastructure remains the primary focus. Although government is dedicated to bear capital requirement of modernization, it is always not possible to extract as much as coal from mines due to various geo-mining constraints. As most of the coal production, more than 90% comes from opencast operation, which always associated with a vast amount of overburden (OB) waste removal, the feasibility of doubling the production within a mere 5 year from now is mostly hindered by waste handling and storage limitations. As per this study, the associated OB waste is estimated to be in the range of 2–3 billion TPA, which is almost 3–4 fold increase from current value. This paper describes the calculated risk and problems that may hinder the future practice of sustainable coal mining and OB waste handing in India.

Keywords Industrial growth · Coal production · CIL · Overburden waste (OB)

1 Introduction

Due to energy and industrial requirement, nearly every country on the globe is associated with the mining industry and hence the generated waste during mining operations. Historically, Indian economy has long been underperforming due to lack of energy security. But, it is projected to grow at a faster rate than any other in the world for the entire period to 2040, by an average of 6.5% per year and so the energy demands [18]. Coal mostly used in thermal power plants contributes about

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60% of total electricity generation in India [3]. Coal remains the primary source of energy and predicts to increase its overall share from 44% in 2013 to 49% in 2040 with an predicted coal consumption of 1300 million tonnes of coal equivalent (Mtce) in 2040, which is 50% more than the combined demand of all OECD countries and second only to China in global terms [18]. State-owned Coal India Ltd. (CIL), a major coal producer in India with a share of 80% of total coal production, although increasing its potential, it has consistently failed to meet its domestic demands despite sitting on the world's third-largest hard coal reserve [18]. Although, many improvements in technology, equipment, logistics infrastructure are now began to realize, the importance of waste management especially generated from mining operation is still a tedious task lagging behind. Waste generation is an inherent part of coal production; it is of equal importance, if not economically, for planning and designing of new and existing mines. Various methods are used to extract raw minerals from the earth's crust and with further beneficiation to obtain the valuable minerals with the rejection of generated wastes [1, 6, 11]. In excavation of coal by open-pit method, two distinct stages of operation, namely overburden (OB) removal and coal extraction, are followed [2]. The striping nature of extraction in open-pit mining generally end up with creation of a massive volume of waste, which is almost equal or even more than the economic material produced in the mining operation. Coal seams available at shallow depth further promote opencast operation with added advantage of bulk production at a cost of initial capital investment in overburden removal. Due to improvement in mining and mineral processing technology, opencast mines, a predominant method of coal extraction in India, are gradually becoming deeper resulting in production of massive amount of OB spoil material. With the increasing size of spoil dumps, the risk of their becoming geo-technically unstable and economically unviable are increasing exponentially. Inadequacy of available land within leasehold area results in unplanned deposition of waste piles within and around the mines [5]. Opencast mines being a major source of coal production in India, the ratio of waste generated is much higher than the underground operation due to stripping nature of extraction. With the depth of mining going deeper day by day and CIL, still competing to achieving a target of 1 billion TPA by 2020, the volume of waste produced is likely to be uncontrollable in the near future.

Whatsoever, if India is supposed to achieve the desired target, only providing the necessary capital and mineral resources is not sufficient to accommodate such a huge production and associated auxiliary operations. Apart from that, the other process like infrastructure development, workforce management, logistics and transportation, waste management and handling, environmental cost are not doable overnight. Targeting such a cumbersome task at a short span of time requires meticulous planning and development to handle all operations seamlessly. Production improvement most of old mines is not always feasible due to conventional production scheduling and geo-technical constrains in pit or support design in both opencast and underground mines. Many of the existing mines are not designed to produce a large tonnage all of sudden. This paper describes the feasibility of achieving the target by Coal India Ltd. by 2020 and focuses how unplanned management of massive solid mining waste can derail the future production schedule in Indian coal mines. The concept of waste generation and its storage, handling and its importance are described herein.

2 Coal Mining in India

The coal deposits in India are primarily concentrated in the Gondwana sediments (Upper Paleozoic to Mesozoic systems) located in the Eastern and Central parts of Peninsular India and also in parts of North Eastern Regions, viz. Sikkim, Assam and Arunachal Pradesh [10]. The coal is of bituminous to sub-bituminous rank and is restricted to the sediments of Permian age. Suitability of the geo-mining condition of the ore body is the common deciding factor between opencast and underground mining operation. Surface mining having the advantage of huge production rate with lower risk of hazards to mine personnel is much more profitable over underground mining provided that the stripping ratio is low. Underground mining, on the other hand, due to the selective nature of extraction, generates less waste material at a cost of safety of mining personals and resources.

Mining continues to be an important sector of Indian economy with a GDP share of about 2.39% in 2013–14 [12] and ranked fourth on the basis of volume of production amongst the top mineral-producing country behind China, USA, and Russia [10]. India, ranked second in term of coal production is only behind China in the Asia-Pacific region. In the year 2013–14, three major states located in the eastern region of the country, namely Chhattisgarh (22.5%), Jharkhand (20.0%) and Odisha (20.0%) altogether account for about 62.41% of the total coal production [9]. The coal generated is mostly used in thermal power sector for electricity generation both for public and captive purpose. As of March, 2015, from the combined electricity generation by thermal and hydrosector, coal-/lignite-based thermal power plant has a huge contribution of about 60% [3].

3 Current Coal Production Target

Coal generated in India mostly comes from opencast mines since long, with a mere 7–9% share from underground in the last decades [16]. This is due to the availability of near depth deposits with almost 76% of proved reserve is located at a depth range of 0–300 m [10]. Indian coal production mostly comes from opencast operation with a massive share of 91.22% in 2013–14 [10]. Figure 1 shows the coal production (MT) data over last decades (2004–05 to 2013–14) for both opencast and underground operation which clearly indicates the dominance of opencast mining in India [9].

A study to estimate the time to achieve the ambitious target at different annual growth rate and the estimated waste production and its management was done here.

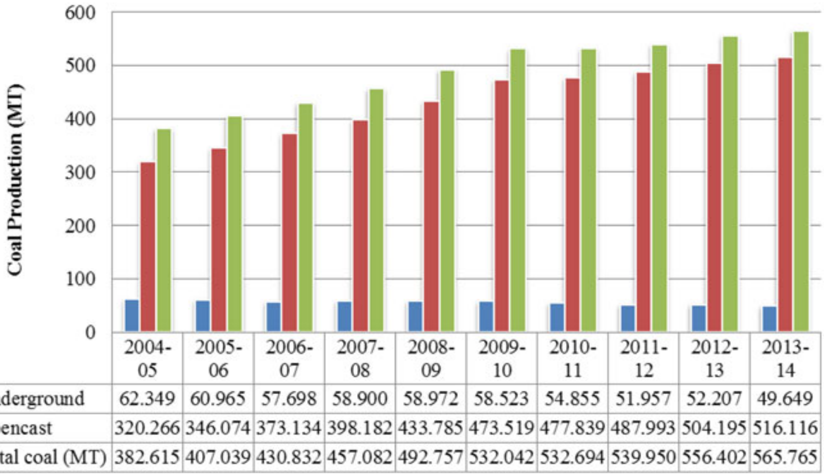

Fig. 1 Production of coal by mines type from 2001–05 to 2013–14

The coal produced was estimated assuming at four different possible growth rates of 6, 8, 10, and 15%, respectively, until the target of 1 billion TPA is achieved and the subsequent waste production is projected from stripping ratio calculation (Table 1).

From the table above, it can be observed that the target of 1 billion TPA coal production can be achieved in 2027–28, 2024–25, 2022–23 and 2020–21 if the growth rates are 6, 8, 10, and 15% per annum (from current value), respectively.

Table 1 Projected coal production data at different growth rates

Year	Projected coal production			
	6% rate	8% rate	10% rate	15% rate
2015–16	523.8944	533.7792	543.664	568.376
2016–17	555.3281	576.4815	598.0304	653.6324
2017–18	588.6477	622.6001	657.8334	751.6773
2018–19	623.9666	672.4081	723.6168	864.4288
2019–20	661.4046	726.2007	795.9785	994.0932
2020–21	701.0889	784.2968	875.5763	**1143.207**
2021–22	743.1542	847.0405	963.1339	
2022–23	787.7435	914.8037	**1059.447**	
2023–24	835.0081	987.988		
2024–25	885.1086	**1067.027**		
2025–26	938.2151			
2026–27	994.508			
2027–28	**1054.178**			

4 Overburden Waste in Indian Coal Mines

Waste products from coal mining comprise mainly of overburden and washery rejects. This overburden is stored in the form of external or internal spoil piles or backfilled in abandoned open-pits or in underground voids. The coal mine overburden is generally deposited in the form of spoil heaps by using truck/dumper, dragline or stacker-belt conveyor combinations. The wastes are generally piled up in the form of benches with a common height of 30 m in single lift with the slope angle being the angle of repose of the waste material. The structures of Indian coal mines waste dumps are not much as compared to global practice; as of now, a maximum height of 90–120 m in multiple lift is followed to store the overburden material.

To estimate the volume of waste generated, a series of historical stripping ratio (SR) data of many opencast coal projects is taken from CIL the average and most common value is used to predict the future production of waste materials. Stripping ratio is defined as the ratio of waste excavated (m^3) for unit ton removal of coal. Although stripping ratio is of many types like instantaneous SR, incremental SR, overall SR, breakeven SR and its value changes during the life of mines. For instance, during starting of mines, we need to initially remove the overburden material to get access to the coal deposit; the SR will remain high at starting and go on decreasing time.

As evident from the stripping ratio data in Table 2, it varies from a minimum of 0.7 to a maximum of 13. A similar trend of SR is also observed globally. As per a report by Doka [4], the average height of deposited coal spoil bodies using a worldwide weighted mean of opencast vs. underground mines, with a height of 200 m for opencast mines and 30 m for underground mines, the average height of coal soil dumps weighted according to annual coal spoil generation, is 130 m, using photographs of various mines in the world where the average stripping ratio stands at 4.74. As SR of any given mine changes periodically depending upon its

Table 2 Stripping ratio of various subsidiaries of CIL [9]

Mines	Stripping ratio (m^3/ton) (2011–12)	Stripping ratio m^3/ton (2014–15)
ECL	2.400	2.874
BCCL	3.288	3.197
CCL	1.351	1.776
NCL	2.750	2.905
WCL	3.314	3.660
SECL	1.434	1.410
MCL	0.904	0.742
NECL	5.290	13.064
CIL Total	1.871	1.930

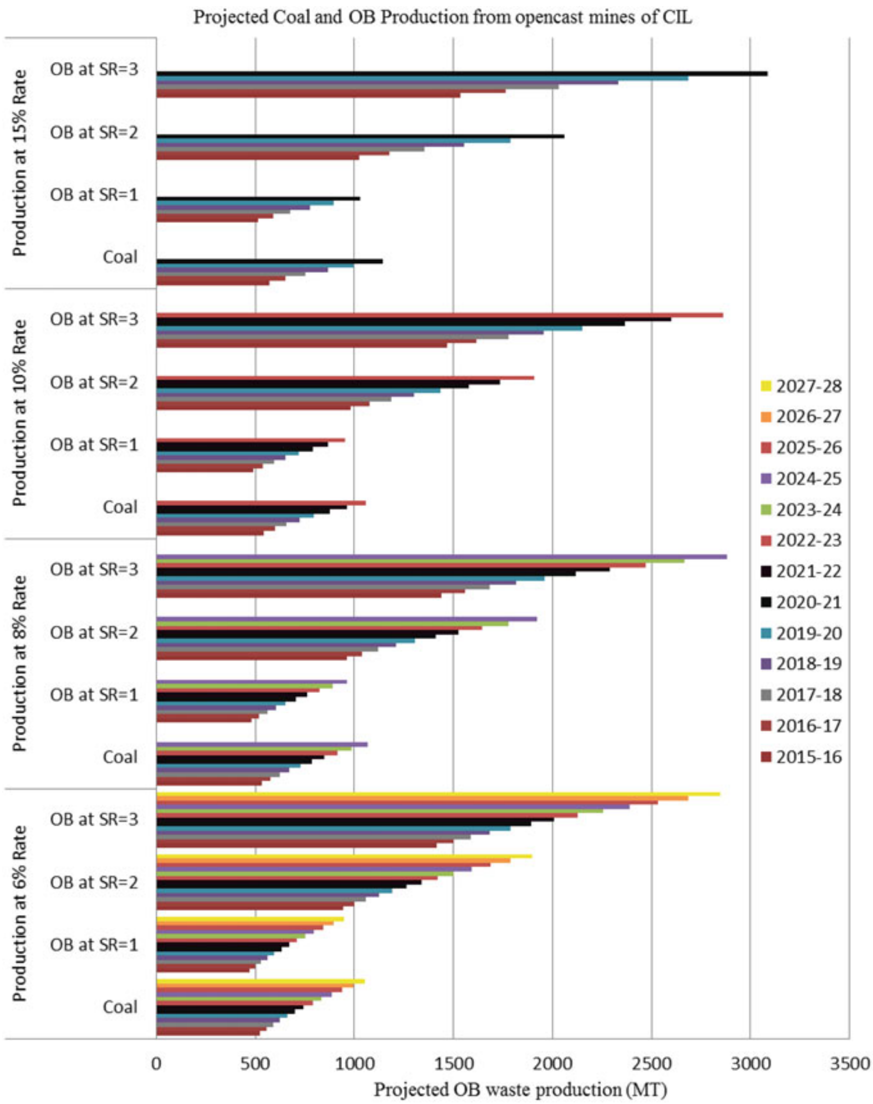

Fig. 2 Project coal and OB production data for reaching 1 billion TPA target

topography, depth, mechanization adopted, etc., three most feasible and appropriate values of SR, i.e., SR = 1, 2 and 3 are taken to estimate the likely amount of overburden waste generated in Indian opencast coal mines at different annual growth rate to achieve the targeted coal production (Figure 2).

5 Challenges in Waste Management

Spoil piles themselves create the problem of slope instability, damages to landscape, surface water pollution, and air pollution, etc. which can lead to changes in ecosystems and limit the options for post-mine land uses [19]. Waste produced by the mining industry perceives less attention because of remoteness from population, lower land valuation and casual environmental consideration. Considering as a part of unwanted expenditure, overburden materials in Indian mines is extremely poor. In most cases, the waste is just piled up in huge heaps, around the mines without much technical evaluation being done on it. Also, the variation in geo-mechanical properties of dump material both due to uneven distribution of particle size and constituents material have resulted in improper estimation of strength parameters which may affect its stability. Unavailability of large size testing equipment to accommodate the true material size in field and lack of proper planning have resulted in vague understanding on the stability of many existing and failed waste dumps. This nature of mine waste dumps mainly cause an overestimation or underestimation of their optimal maintenance criteria and factor of safety which may be leading to huge economic losses.

Given the size coal mining industry In India, it is no surprise that its environmental impacts are considerable. Opencast method of mining largely affect the surface landscape, both by creating excavation and leaving heaps of almost barren spoil. The type and composition of waste material significantly affect the environment and stability [14]. Loss of land usage in waste rock storage and subsequent environmental impact of acid rock drainage (ARD) are the most common problems of waste generation [8, 13, 14]. Waste material often contains high amounts of alkali, metals, alkaline earth metals, sulphides and other constituents that lead to pollution of surface and underground groundwater [7]. With the storage of waste material, the risk of contamination of both soil and water becomes more prominent. The presence of some percentage of low-grade coal present in waste dumps raises the possibility of spontaneous heating and fire [15] with release of sulphur oxides and other gases. But, there is no generalized management practice of waste dumps as the parameter like cost, method and type of dump, environmental impact, and risk of failure, which varies from mines to mine due to different site condition and requirement [17].

6 Discussion and Conclusion

There is significant improvement in the rate of coal production, mostly in last two-quarters of FY2016. The coal production through state-own CIL is reaching its high simultaneously eliminating the need of coal import. However, increased production may seem a good move to both government and an outsider, the challenges in maintenance and handling of huge amount of overburden waste remains high. Most of the wastes generated in mines are either disposed off to the void space created within the decoaled area inside the lease boundary or stored outside the mines, mainly due to unavailability of land. But, handling an unprecedented amount of waste, about 2–3 billion tonnes per annum by 2020–21, both in terms of economic and technical point of view, the required expertise is yet to achieved by CIL. Unavailability of land is going to create many problem in long-term sustainable practice in a populated country like India. The main issue of waste storage and management in opencast mines is not an easy task, citing the previous issues of dump failure and environmental degradation in past. The severe environmental pollution along with the issues of reclamation and rehabilitation of the affected community may likely to impact the working practice of many coal mines.

It is not clear, how the government is prepared to handle such issue in many aspects like workforce and skill management, logistics infrastructure, environmental issues, land resource management. It may be helpful if both industry and research institutions must find some way to safely handle the mine waste dumps, which historically had been known to be problematic around the globes. Proper maintenance and stabilization measures with sustainable environmental practice may help the industry to manage the vast amount of waste, but its technical study and stability need more acute attention from all stakeholder.

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Solid Waste Management (SWM): Case Studies at an Educational Campus and in the Neighbourhood of Panihati, North 24 Pargana, West Bengal, India

Sucharita Bhattacharyya

Abstract The rapid growth of worldwide population and urbanization is a significant challenge for the Global Waste Management Industry including Solid Waste Management System (SWMS). Being a responsible citizen and teaching professional at a self-financing institute of technology, located at Panihati, a suburb near Kolkata, the author is also very much concerned about the issue. Very poor SWMS outside the institute campus under A category Panihati Municipality within Kolkata Metropolitan Area (KMA) creating horrible and absolutely unhygienic environmental condition and the lush green, clean campus inside as maintained by the institute owner, creates such a contrasting scenario that the present study is undertaken to unveil the reasons behind. The study is executed in two parts. In the first part, detailed survey is conducted on the existing facilities of Panihati Municipality SWMS including manpower resources, the management techniques, associated technologies and their utilization through the segregation, collection, transportation, treatment and disposal for generated amount of solid wastes to make pollution-free environment in the locality. The relevant data is obtained from Panihati Municipality and individual field visit. The study reveals several lacunas in the existing government-run system. In the second part, the SWMS of an educational campus in Panihati Municipality area is highlighted. It is interesting to mention that in the same campus, there are Dental College and Hospital, Hotel Management Institute, Pharmaceutical Institute and Engineering College along with the students' hostel and staff quarters which are growing day by day. So an well-planned management system for generated Clinical and Pharmaceutical Wastes, Food Wastes, E-wastes and Constructional Wastes—the well known solid

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wastes, is very crucial. The present study reveals that greater public awareness and application of systematic waste management techniques as adopted by the private management, keeps the campus clean and healthy for the residents including the students, to meet the challenges of present-day SWMS successfully.

Keywords SWMS · Panihati Municipality · Self-financing educational campus Contrasting scenario · Public awareness · Systematic waste management system

1 Introduction

Throughout most of the history, the amount of waste generated by humans was insignificant due to low population density and low societal levels of the exploitation of natural resources. But following industrialization and the sustained urban and population growth throughout the world, the build-up of wastes, mostly in the cities, caused a rapid deterioration in the general quality of urban life. However, it was only in the mid-nineteenth century, spurred by a devastating c-holera outbreak in England [1], the concept of waste management was formalized.

Solid waste [2] typically refers to the range of garbage arising from animal and human activities that are discarded as unwanted and useless. These are generated from industrial, institutional, construction and demolition and domestic activities in a given area, identified as Municipal Solid Waste (MSW) [2, 3] as well as from hospital and clinical activities in the form of Biomedical Waste (BMW) [4–6]. They can be further categorized based on its contents including materials as plastic, paper, glass, metal, and organic waste and also on hazard potential, including radioactive, flammable, infectious, toxic, or non-toxic wastes. Whatever be the origin or content is, as solid waste is a critical aspect of environmental hygiene [7], it must be managed systematically by incorporating proper planning to ensure best practices for the society.

The role of municipalities is of immense importance here. But unfortunately, it is found that an established municipality under KMA with government-funded infrastructural facilities [8, 9] is unable to carry out its responsibilities to manage solid wastes properly creating all nuisance in the locality under its control. Surprisingly, the opposite situation is encountered in a self-financed educational campus in the same area where institute-run SWMS successfully maintains a clean and fresh atmosphere inside the campus even after supporting a huge economic development of a mass population in a much better way. Naturally, the question arises that how and why these differences appear. The present study is an endeavour to search the answers through some detailed analysis.

2 Solid Waste Management: The Methodology

Ideally, Solid Waste Management (SWM) is defined as the discipline associated with the six functional components of the waste management system [3] in the form of control of generation, storage, collection, transport or transfer, processing and disposal of solid waste materials in a way that best addresses the range of public health, conservation, economics, aesthetics, engineering and other environmental considerations. So the methodology followed here is based on the existing guidelines as per the Municipal Solid Waste Management and Handling Rules, 2000 [10], addressing all of the above components including planning and administrative set-up, finance, technology support and their interdisciplinary relationship and applicable for the entire population in the two specific cases.

3 Case Study 1: SWM Under Panihati Municipality Area

3.1 Selection of Study Area

It is under Panihati Municipality which lies in North 24 Pargana with total area of 19.38 km^2. Being the largest municipality in the undivided 24 Pargana District [4], Panihati Municipality is situated on the eastern bank of the river Ganga in the industrial belt of Kolkata. To analyse the initiative taken to develop and run the SWMS by the Panihati Municipality and to get a perception of urban governance in this area, studies have been done [11], but the reasons behind the insufficient municipal services were not exposed. So this place has been selected for further study.

The present work includes the effort for waste characterization, and the results are studied thoroughly in the light of different aspects [3] including possibilities of energy recovery potential of solid waste [4] (Fig. 1).

3.2 Brief General Information About the Municipality

This is given in Table 1 [8, 9] which shows an average population growth rate of 6% within the specified area over last 5 years.

Here, it may be mentioned that the total no. of slums under this area is 196 with population of 115,661 indicating nearly 28% slum population as per 2016 census.

Fig. 1 Map of the study area [8]

Table 1 General information of Panihati Municipality

Total no. of wards	Total population (census 2011)	Total population (census 2016)	Total no. of households	Total area (km^2)	Population density (km^2)
35	377,347	400,000	85,985	19.38	20,640

3.3 Study of Municipal Solid Waste (MSW) and Management

Waste Generation: The total quantity of waste generated/day from 35 wards is around 120 MT. Depending upon food habits, standard of living, degree of commercial activities of the local population, around 30% is found to be domestic/household waste, 36% commercial and market waste, 6% is from institutions, 23% from street sweeping, and 5% is clinical waste. More commercial activities and growing preference for consumption of packaged food in recent years in the locality are found in the increased rate of use of metals, papers, plastics, cardboard and metal sheets/cans indicating decrease of organic constituents in solid wastes.

Waste Collection: The total amount of waste generated and collected is given in Table 2. To enable residents to dispose waste and to prevent littering, community bins are provided at reasonable distances and municipal workers and sweepers are engaged with collection tools and vehicles in door-to-door collection and in road sweeping depending on local requirements and to transfer them to open storage enclosures or dumpers at collection points as given in Table 3.

Storage Facilities: The storage facilities as set up by municipal authorities (given in Table 4) are supposed to be attended daily at least for once to clear the wastes. But in areas with high density of retail shops, slaughterhouses, restaurants and marketplaces, these arrangements are found to be insufficient and the community bins regularly overflow and even in some area clearing is done once a week without having a proper supervision. Also for improper placement of some bins and containers and because of lack of awareness, many of the slum population and common people at Panihati are found to throw the wastes in open spaces creating nuisance.

Vehicles and Transportation Facility: The transportation stage of collected wastes at Panihati is mechanized using trailers and other refuse carriers whose nos. are given in Table 5. Routing of transportation vehicles is proposed to use the traffic-free portions of the city for their movement. But most of them are not covered resulting in exposure of wastes to open environment causing scattering and city air pollution with odour and smell.

Processing and Treatment of MSW: Panihati Municipality is trying to reduce pressure on landfills and recover wealth from waste through processing of organic waste by practising vermicomposting after source segregation in some selected area through awareness campaign and by trained collectors though it is not very successful till now due to scarcity of more efficient African earth warms and mostly collections are mixed wastes (biodegradable and recyclable). Biodegradable wastes (around 48%) are processed through a treatment plant at ward no. 7 using anaerobic

Table 2 Waste generation and collection by Panihati Municipality

MSW generation and collection status	MSW generated/day in MT	MSW collected/day in MT	Collection efficiency	Collection methodologies	
120		100 (approximately)	83%	Door to Door	Roadside sweeping

Table 3 Collection tools and vehicles of Panihati Municipality

Collection tools and vehicles	RCC bins	Trolleys	Containers	Handcart/ tricycle
No. with capacity	164	22, 1.5 T	55, (2–2.5) T	148

Table 4 Collection and storage status of Panihati Municipality

Total solid waste generated/day in MT	Total municipal solid waste collected/day in MT	Total biomedical waste collected/day in MT from hospitals/clinics run under the control of Urban Local Bodies (ULBs)	Total solid waste remain uncollected/day in MT	No. of collection points for temporary storage of MSW with masonry storage enclosures, trash bins, and dumpers	No. of manpower involved
120	94	6	20	43	600

Table 5 Vehicle and transportation used for SWM of Panihati Municipality

Auto tipper	Trailer	Municipal tractor	Dumper placers	Compactors	Trucks
3 trips/day by poach car	12	18	1	3	4

digestion where the chemical energy in MSW is recovered as biogas and used as fuel, though infrastructural facility is still insufficient for better output. Mechanical composting using compactor machines, which can reduce waste to 25–30% making odour-free dry waste to create tremendous positive impact on the environment, is very popular at present in KMA, but unfortunately, till date Panihati Municipality could not install them due to lack of initiatives, depriving the local people to enjoy germ-free, fresh and clean environment.

Disposal of MSW: It is the most important functional element involved to avoid environmental and health hazards where in the absence of effective composting and landfill facilities, the SWM of the Panihati Municipality is limited to collection, segregation and transportation. A private agency [9] is responsible for collecting waste from ward nos. 1–14, while rest of the wards in the town is served by Municipal Public Health and Sanitation Department of the ULB. Using tractors, trailers and trucks, these are dumped in open pits to the trenching ground of Ramchandrapur at ward no. 23 for disposal by around 200 workers which causes air pollution and groundwater contamination by leachate percolation unless degrades naturally. Here, land available for MSW disposal is 1.34 acres. Open-dumped garbage is serving as breeding ground for disease vector as flies, mosquitoes, cockroaches and rats.

Inferences: Around 800 municipal workers are involved in the solid waste collection and management process which is found to be highly insufficient for proper SWM in all parts under the municipality. Also clearing of stored wastes should be monitored regularly. Immediate installation of highly efficient compactor machines not only can solve these major problems as identified, but produced dry

Table 6 Biomedical waste management under Panihati Municipality

Healthcare units (HCU) to produce BMW	No. of clinics/ patho-laboratories	No. of municipal HCU	No. of government HCU	No. of private HCU	No. of subcentres
	6	1	1	7	40
Bed capacity for generation of BMW	Total beds	BMW generation/ day in MT	Collection and disposal facility		
	289	0.072, considering 250 g/bed/ day	No separate collection and disposal system exists; these are handled by a private agency at Kalyani (*M/s Medicare Incineration Pvt. Ltd.*)		

solid wastes can also help immensely in realistic outcome of their proposed Thermal Power Plant at Bilkanda 2, the Panchayat Area, where no objection is awaited from the concerned authority.

3.4 Study of Biomedical Waste (BMW) and Management

A large no. of hospitals/clinics and other healthcare facilities under Panihati Municipality generate harmful biomedical wastes as given in Table 6 during the diagnosis, treatment or immunization of human/animals or in research activities [5]. So following Biomedical Waste Rules 1998, collection, treatment and disposal of these wastes are processed separately by private agency mostly through 'thermal treatment' [6] commonly called the incineration. Microwaving, autoclaving and deep burial are also used in specific cases.

Inferences: Here, it is mentioned that a common Bio-medical Waste Treatment Storage and Disposal Facility (BMWTSDF) is set at Kalyani [4]. This facility also has autoclaving and incineration arrangements, and all the municipalities in association with some private agencies collect waste from the units located at North 24 Pargana under KMA and manage to keep away the harmful effect of BMWs from local environment including Panihati Municipality.

4 Case Study 2: Solid Waste Management at an Educational Campus

4.1 Selection of Study Area

A highly diversified educational campus of a private owner in Panihati Municipal area is chosen inside which there are number of academic institutes with large population of students and staff members along with a specialized hospital, canteen, students' hostel and staff quarter. Naturally, to maintain the healthy campus environment, proper management and sincere handling of generated solid wastes inside the campus (given in Table 7) of total area of 84,292 m^2 is the necessity.

The solid waste generation and their managements are discussed below for each case.

4.2 Institute of Dental Science and Research

Established in 2003 and affiliated to Dental Council of India, this institute is very popular in Kolkata for its efficient and cost-effective treatment as well as for its academic facility and standard. Naturally, the clinical wastes/BMW generated (given in Table 8) increases day by day and their management by maintaining proper disposal procedure [12] possesses a huge challenge for the authority of the campus which are discussed below.

Waste Containing Mercury, Silver and Lead: These are generated from dental amalgamation, X-ray fixer and from the foils to shield X-ray film respectively. Mercury waste is stored in a tightly sealed container without mixing with common garbage. X-ray fixer was handled after desilvering with recovery unit, but during last two years, digital X-ray unit is used minimizing purchase of new X-ray films and so use of silver and lead is automatically minimized.

Sharps and Blood-soaked gauze: These are collected in puncture-resistant containers and biomedical waste bags with proper labelling using biohazard symbol.

Chemicals and sterilizing agents: Steam or dry heat is used to sterilize dental instruments.

In all cases, trained staff handle these materials, and once the containers and packets with wastes are full, the final disposal is done through the certified biomedical waste carrier (CWC), the *Medicare—Environmental Management Pvt. Ltd.*, K-26 Phase III Growth Centre, Kalyani, Nadia-74123.

Non-hazardous waste generation is minimized as these are difficult to recycle.

A. **Institute of Pharmaceutical Science and Technology**: Established in 2008, it educates around 240 students/day in developing formulation, manufacturing and evaluating new drugs to improve pharmaceutical services. So the students and the teachers encounter various pharmaceutical sources of contamination daily in the laboratory. Also unused pharmaceutical samples in the form of wastes are handled by working closely with the collection centre, the *Medicare—Environmental Management Pvt. Ltd.* at Kalyani as per the Drug Enforcement Administration (DEA) regulations ensuring proper protective measures including aprons and gloves for all students and teachers in the laboratory classes, using masks when tablets/capsules are being crushed with a risk of powders being liberated to the environment, and neutralising accumulated unwanted pharmaceuticals primarily by dissolving those in water,

Table 7 Solid wastes generated at the campus

Institutes	Institute of dental science and research	Institute of pharmaceutical science and technology	Institute of technology	Institute of hotel management	Students' hostel and staff quarter	Entire campus
Major solid waste produced	Biomedical waste	Biomedical waste, paper and e-waste	Papers and e-waste	Food waste	Food waste	Constructional waste
	25%	10%	10%	15%	10%	30%

Table 8 Biomedical waste generated at the campus dental hospital

No. of departments	No. of chair units	No. of patients treated/day (Av.)	Amount of wastes generated/patient/day (Av.)	Hazardous wastes generated (in %) with effect			Effect of non-hazardous wastes generated
				Mercury, lead and silver pollute environment through wastewater and scrap amalgam vaporization, affect neurological development, lead to carcinogenicity and hypertension	Sharps and blood-soaked gauze transmits infectious diseases through contamination	Improper handling of chemicals, disinfectants and sterilizing agents creates serious health hazards	Paper, cardboard, the plastic containers or packaging made of PVC can produce acid gases if incinerated
18	252	400	(100–120) g	6%	35%	20%	39%

solidifying the waste liquids by mixing 1 part liquid to 2 parts kitty litter and sawdust in a large container prior to disposal.

B. **Institute of Hotel Management**: Established in 2005 and affiliated to National Council for Hotel Management and Catering Technology, Ministry of Tourism, Govt of India, it trains 180 students/day with a big infrastructure catering food along with the campus canteen. The curriculum includes front office management as well as food processing in various forms. Naturally most of the waste is generated from the kitchen and the rest from the office as shown in Table 9.

The biodegradable wastes generated are disposed off to the local pig farms through private contractors, and the rest non-biodegradable part is collected by them for disposal at the nearby collection point.

A. **Institute of Technology**: Established in 2003, it serves around 2300 students/day. It generates mostly non-hazardous solid wastes in the form of papers, cardboards and broken/damaged parts of some laboratory equipment. But the engineering institute, running for 13 years with huge no. of students, is now generating sizeable amount of e-wastes. These contain potentially harmful components having adverse effects on environment as well as on human/animal health as given in Table 10.

Table 9 Waste generation at hotel management institute and the campus canteen

No. of plates served/day	Biodegradable waste (wet) generated		Non-biodegradable waste (dry) generated	
	Amount (%)	Types	Amount (%)	Types
450 (Av.)	75	Food, vegetable and non-veg. waste, cooking oils	25	Plastic bottles, papers, plastic wrappers, aluminium cans, etc.

Table 10 Generation and effect of e-wastes on environment and population

Electronic/e-waste components	Percentage of e-waste produced at		Effect of e-waste produced	
			On environment	On human/animal health
CRTs used in computer monitors, circuit boards with chips and other electronic components having lead, cadmium, barium, silver and gold, plastics from printers, keyboards, monitors computer wires, etc.	Institute of technology	(80–85) %	Pollution of air	Lung cancer
	Other institutes of the campus	(15–20) %		Damage to heart, liver, etc.
			Soil and water bodies acidification	Affects fish and flora
			Landfill contamination by lead, barium and other heavy metals leaching into groundwater	Chronic damage to the brain and DNA damage

So to avoid unsafe exposure of these wastes in recycling operations and to follow E-waste Management and Handling Rules 2011, campus owner made a contract with Hulladek, an international certified company, for safe handling of these materials who collects the accumulated e-wastes from the campus at regular intervals ensuring strict environmental standards. It is to be noted that the recovery of valuable elements like lead, copper, silver, gold from computer components and the circuit boards maintaining high recycling efficiency in a cost-effective way is a big challenge for a self-financed institute.

B. **Construction and Demolition (C&D) Waste**: The construction and demolition waste, one of the heaviest and voluminous wastes among all MSW, is generated inside the campus mostly to construct new buildings for different departments along with some regular repairing (13 years' old campus) and reconstruction works held on to give a final shape to the campus beautification.

They have serious impact on environment as well as on human health due to the extraction of raw materials, processing, manufacturing, transportation and disposal at the end. So elimination of these wastes is essential, but that is expensive as there is an appropriate disposal pricing structure [9]. So these materials receive priority attention for recovery and reuse in the C&D sector.

Now the wastes generated in the campus are mostly concrete and bricks. Depending upon conditions, they are used either in all weather applications as roads inside the campus, and as pavement bases or as rubbish to fill lowland area inside. Recycled asphalt and bitumen are also used to create asphalt concrete for road base layers. Component like doors, windows in good condition is reused as a substitute in another project of the campus.

Inferences

It is easier to maintain SWM in an Academic Campus as aware and educated people are involved here with a very close and effective monitoring team along with a highly organized management system of the private owner.

5 Conclusion

The study reveals totally different pictures in two cases. The self-financing educational campus maintains SWM in a very systematic manner accommodating around 2700 students, 150 residents along with 400 patients and 250 teaching and staff members daily, mainly because of the environmental awareness and necessary involvements of all and deputing trained manpower by the campus owner in all institutes for waste handling and disposal. The net result is neat and clean picturesque campus.

On the other hand, Panihati Municipality enjoys 80% Government Fund in addition to scheme-specific special funds for developing the required infrastructural facility to provide standard municipal service including SWM. But it is found that common people are unaware to handle solid wastes properly and available infrastructure with only 800 manpower is far from meeting the standard of SWM for 400,000 population.

So municipality should be proactive to take the necessary steps so that all citizens can respond positively in their own houses' and surroundings' waste management and feel proud to be a part of the Government of India's noble mission of Swachh Bharat Abhiyan.

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Solid Waste Management in India: A Brief Review

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Abstract In the twenty-first century, major emphasis should be levied on environmental safety and concern regarding human health. In this relevance, solid waste management need major attention. Awareness in society is profusely obligatory for minimization of solid waste generation. Careful study reveals that municipal solid waste (MSW) provides a major contribution to the total amount of solid waste. But e-wastes are the most frequently growing waste which is also an efficient source of various toxic elements. Globally, upsurge in the demand of nuclear energy enhances the generation of radioactive solid waste (RSW) that may be responsible for harmful effect of radiation. On the other hand, hospital solid wastes (HSWs) have great impact on environment and public health as it is the carrier of infectious diseases and other toxic elements. Biodegradable organics are the major content of agriculture solid waste (ASW) along with some pesticides and heavy metals. The total amount of solid waste (SW) is enhancing day by day, and as a consequence proper solid waste management (SWM) methods are necessary which could minimize the total amount of SW as well as its hazardous effect on environment. This review is focused on generation of different SWs and corresponding techniques of SWM starting from conventional tools to modern technique like refuse-derived fuel (RDF), pyrolysis, incineration together with their advantages and limitations.

Keywords Solid waste management · India · Resource efficiency Utilization

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1 Introduction

In today's world, one of the most concerning issues is protection of human civilization from the threatening effect of man-made wastes. Indeed, wastes are the residue part of raw materials, which are generally unwanted after primary use. Among different waste materials, solid wastes are generated in our society through various humans' activities. In its consequence, population and their education level, monthly income is also a contributing factor in waste generation [1]. The waste management is easy for limited population [2]; however, in India due to rapid increase in population together with modern urbanization the lifestyle has also been simultaneously changed. In turn, this leads to amplification of solid wastes [2, 3]. In its connection, the improper solid waste management improvises the rigorous outcome on public health and environment. Consequently, solid waste management becomes a major concern in the twenty-first century [2].

Several hazardous solid wastes [4] from various sources are further characterized as organic, reusable and recyclable waste [5]. Solid wastes mainly includes village, agriculture, municipal and hospital solid wastes. Village wastes (VWs) contains a major part of decomposable and recyclable materials [6]. On the other hand, agriculture solid wastes (ASWs) may exert groundwater contamination and soil infertility [7]. Toxic organic materials and metals are the main sources of this contagious effect. The majority of solid wastes are originated from the municipalities where the amount is thousands of tons per day; municipal solid waste (MSW) contains all types of hazardous, non-hazardous and organic waste, and a few extents of MSW is compostable. The increasing rate of MSW generation annually is around 1–1.33% per capita. In India, the MSW generation rate per capita is around 0.2–0.5 kg per day in small towns [8]. MSW causes release of many toxic gases and substances which further can contaminate the soil, groundwater and the environment. Contamination of these toxic elements to the food chain results in harmful effect on the ecosystem [9]. In case of hospital solid wastes (HSWs), the scenario is more alarming! HSWs are generated during observation, diagnosing, treatment and curative process of a patient in any field of humans or veterinary. Production and testing of biological product also generate harmful waste. In general, HSW is hazardous, of which only 5% is non-infectious and remaining considered as infectious waste [1, 10–12]. Infectious wastes are expected that it is abounding of pathogens which are spreading or capable to cause disease to humans and animals. HSW may cause flare of dangerous disease like AIDS, hepatitis A, B, C, tuberculosis, pneumonia, diarrhoeal diseases, tetanus and whooping cough [1, 12, 13]. Some toxic chemicals such as dioxins and furans are generating from HSW which have significant harmful effect on health of animals and birds [14]. HSW contains some radioisotopes in very small extent which are used during therapeutic and diagnosis studies. These are mainly containing technetium-99, iodine-131, iodine-125, iodine-123, flourine-18, tritium and carbon-14. In its connection, another type of solid waste with detrimental effect is radioactive solid waste (RSW). RSW mainly contains uranium and plutonium.

These heavy metals are emitting health hazard elements like alpha, beta and gamma rays which may cause skin cancer, birth of defective child [11]. Major source of production of RSW is military weapon production sectors and nuclear power plants. The increasing demand of nuclear energy in producing electricity increases the uranium demand which subsequently enriches the amount of RSW. These heavy metals are discharging approximately 10,000–12,000 tons every year. Only, 30% of total discharged material is reprocessed and reused in storage condition [2].

In the era of globalization and fast life, electronic waste (e-waste) is one of the solid wastes generated every day in a mammoth rate. A survey reveals that approximately 4 out of 7 people in only 4 billion people of constitutional regions were generating e-waste around 41.8 million tonnes (MT) through all over the world in 2014. It is expected that sitting on growth rate 4–5% annually, the quantity of e-waste will reach around 49.8 MT by 2018 [15]. That huge quantity of e-waste is generating from the discarded electrical and electronic equipment. Rapid obsolescence of technology reduces the lifetime of electrical and electronic product which in turn results in a rapid enhancement in amount of e-waste [16]. E-waste contains toxic elements such as acids, polychlorinated biphenyls, hexavalent chromium (PVV) [15]. These may cause bronchial maladies, lung cancer, damage in liver and kidneys. Some heavy metals like lead, mercury, cadmium, arsenic are present in e-waste possessing serious effect on central nervous system, immunology system of our human body. On contamination to groundwater, these wastes may cause detrimental effect to children and cause several diseases (i.e. *Minamata*, *Itai-itai*) [17, 18].

In line with prior discussion, it could be understandable that the harmful effect of SW on human civilization is caused due to improper management of solid waste. To minimize the adverse effect and up growing quantity of solid waste, their proper management is very necessary [19]. Solid waste management (SWM) process includes various actions related to generation, storage, collection, transfer & transport, processing and disposal of solid wastes [3, 8]. Solid waste generation and its management depend on national income and legal policies of the nation. Application and maintenance of these facilities like collection, recycling, treatment and disposal of solid wastes needs a large amount of finance. Moreover, for waste treatment there needs a suitable locations which is gradually more difficult to find due to the most popular attitude Not In My Backyard (NIMBY) throughout all the communities. Reduce, Reuse, Recycle (3Rs) and integrated solid waste management, these pursue greater interested on waste prevention, reduction and waste recycling rather than waste treatment and disposal [2, 5]. Disposal of solid waste is very important and this disposal technique comprises landfilling, Incineration, pyrolysis, composting etc. [20].

The present study deals with different methods for safe disposal of the mountainous amount of solid waste in India. Different SWs and their generation have been discussed together with the safe disposal method starting from conventional method to modern plasma arc pyrolysis. The possible use of solid waste as efficient energy resources has also been emphasized.

2 Result and Discussion

Depending upon sources of solid waste is categorized in different types which needs more priority for discussion.

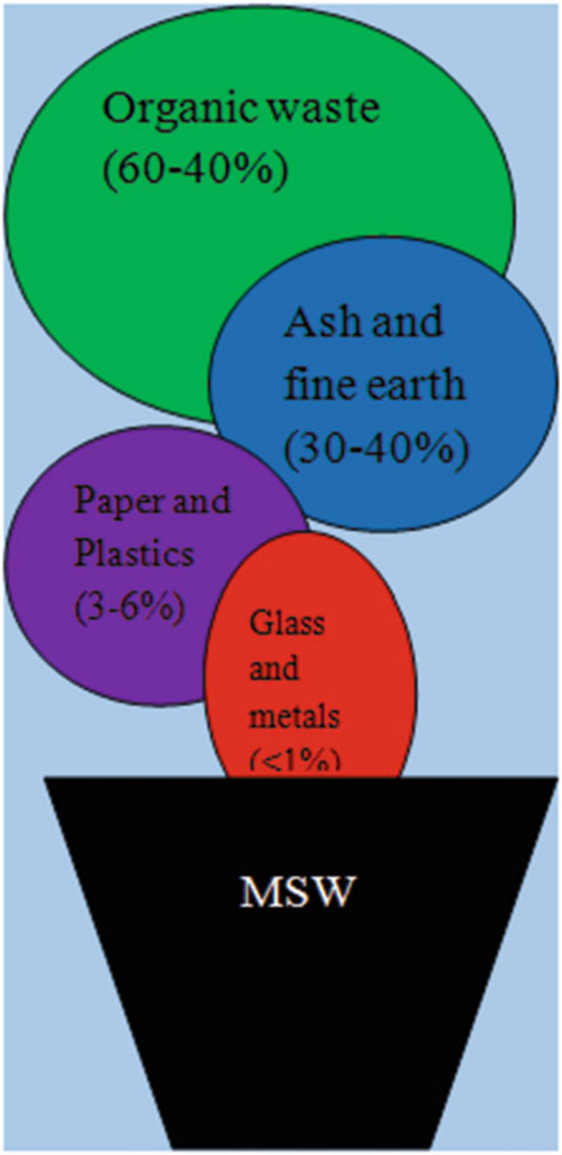
2.1 Municipal Solid Waste (MSW)

In search of better facilities and lifestyle, people day by day are moving towards the cities [2, 3]. Population boom and ongoing industrialization are also influencing factor for these migration which causes large amount of MSW generation including Biodegradable waste, Recyclable materials, Inert waste, Composite wastes, Hazardous waste, Toxic waste, construction and demolishing waste etc. [8]. Elements regarding to these wastes are given in Table 1. On viewing the elements weight, MSW contains major fraction of organic than ash and fine earth as well as paper and plastics, where glass and metals are present in very little amount which is shown in Fig. 1.

Table 1 Various municipal solid waste and corresponding sources

Type of MSW	Composition of waste	Sources
Biodegradable waste or organic waste	Food and kitchen waste, fruit and vegetable peels, green waste, yard waste (like garden trimming), wood, animal wastes, paper, rubber and leather	Household and kitchen, food processing industries, farms
Recyclable waste	Paper, cardboard, glass, bottles and jars, tin cans, aluminium cans, aluminium foil, metals, certain plastics, fabrics, clothes, tires, and textile	Office, shops, scraps yards, car and automobile industries, textile industries
Inert waste	Construction and demolition waste, dirt, rocks, debris, sands	Constructional sites, demolished buildings
Hazardous waste	Most paints, chemicals, tires, batteries, light bulbs, electrical appliances, Fluorescent lamps, aerosol spray cans, and fertilizers	Household, paint industries, chemical industries
Toxic waste	Including pesticides, herbicides and fungicides	Chemical industries, various pesticide and herbicide manufacturing industries

Fig. 1 Distribution of various waste elements under MSW (%)



2.2 Extent of MSW

In various countries with growing development and gradual improvement of national gross domestic product (GDP) the generation rate of MSW increases rapidly [5]. Nowadays, only in India MSW generation rate is eight times higher than 1947. Globally with a rate of incremental growth $\sim$1–1.33% annually, these amounts exceed 2 billion tons per year [8]. Organization for Economic Co-operation and Development (OECD) countries [2] contributes more in total amount of weight around 619 million tonnes, and as per capita USA holds the highest rate of 750 kg. India and China are the major contributors among the developing countries with a rate of 0.5 and 0.9 kg/day/capita, respectively [2]. In India every year, 48 million tonnes of MSW is generated including 7.2 Mt of industrial waste and 1.5 Mt of plastic waste [18]. On basis of GDP, it is expecting that by 2030 these rates will increase to 1.8 kg/day/capita in China. Meanwhile, China generates highest amount of MSW and India just exceed USA [2].

2.3 Radioactive Solid Waste

Nuclear power plants are the foremost and upcoming power source to compensate the demand of power for this increasing population. There are also backsides, each step including reprocessing of commerically utilized nuclear fuel for these nuclear power plants are responsible for radioactive waste generation. Nuclear weapon production for defence programme and research reactors also contributes to a greater extent [2, 21]. In USA, 95% of total volume of radioactive waste is generated by the defence research programme in which only 9% accounts for total radioactivity [21]. Uranium and plutonium are major contents with some other heavy metals like cerium and strontium in radioactive solid waste. These heavy metals emit radiation which has drastic effect on human health and environment [2, 21]. Some major accidents reveals the detrimental effect like Chernobyl disaster in Ukraine, Soviet Union (USSR) in 1986 and Fukushima Daiichi nuclear disaster in Japan in 2011. After that, there are high amounts of cancer [22], and thyroid cancer [22], birth defects, and tumours [2] were speeded up in epidemic rate which haunted victims. Moreover as an artefact, soil are also contaminated with heavy metals [2, 22]. Through food chain heavy metals are consumed by humans. After Chernobyl disaster, such type of metal pollutant like strontium-90 was found in root of plants and also in cow's milk. Consuming these as food, results in weakening of the bone and bone marrow which can cause bone cancer in humans [22].

2.4 Extent of Radioactive Solid Waste

Commercial nuclear power plants generate 290,000 tons of heavy metals per year. Only, 30% of heavy metals are generally recovered. Globally, the reprocessing capacity is only 5500 tonnes of heavy metal per year. Around 10,000–12,000 tonnes of heavy metals are produced from the spent fuel, most of which are kept in storage [2]. In USA, major defence research sites (like Savannah River, Hanford, West Valley Demonstration Project and Idaho Chemical Processing Plant) are contributing greater amount of waste with total 120 million Curies activity. An amount of 6900 metric tons of nuclear materials are discharged by Hanford site with a total activity of 44.6 million Curies [22], where uranium content is 4100 metric tons together with 15 metric tons of Cs and Sr [22].

2.5 Electronic Waste (E-Waste)

The term e-waste or waste electrical and electronic equipment (WEEE) includes entire electrical or electronic devices which are loosely discarded, surplus, obsolete, broken at the end of their lifetime [23, 24]. Concomitantly fast growing change in new technology with life-style the life span of earlier technology becomes reduced and obsoleted. These obsoleted products are enriching e-waste day by day [15, 16, 18]. For example, in 1992 the average lifetime of a computer is 4.5 years which is in certainly decreasing to 2 years and continuously decreasing resulting in major content in e-waste [17]. Thus, annually 130 millions of computers, TV, monitors are expelled form of use [17]. The lifetime and approximate mass of major electric equipment are shown in Fig. 2.

Availability of the technology and continuous growth in economy leads to rapid increase in GDP [5, 16]. Since a country's GDP is related to its total number of PCs, so increase in GDP enhances the purchase of electronic equipments that leads to increase in generation of e-waste globally. Globally, 20% increase in GDP causes generation of 20–50 metric tons of e-waste in last 6 years [16].

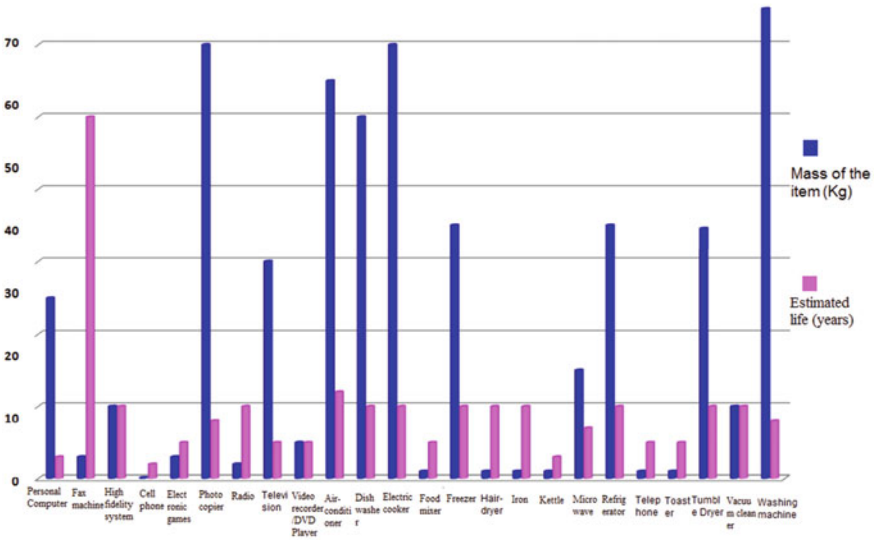


Fig. 2 Types of e-waste and their life cycle

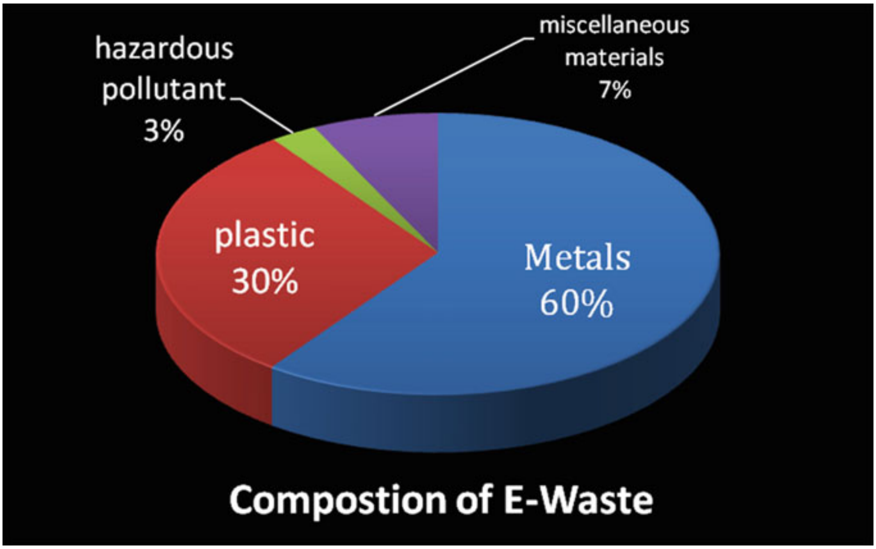


Fig. 3 Composition of e-waste

E-waste is broad composite of metals, plastic, hazardous pollutant and miscellaneous materials where in a greater extent heavy metals are present (Fig. 3) [16, 23].

Heavy metals and some halogenated compounds are mostly known for their drastic effect on human health. Since major source of these toxic substances is the composition of e-waste, there is an adverse effect of e-waste on human health [16]. The various sources of these substances and its effect and quantity per year are mentioned in Table 2 [16–18, 23].

2.6 *Extent of E-Waste*

Due to the rigorous exploitation of electronic goods with every passing day, the generation of e-waste is unavoidable. From 1998, only use of household electric appliance increases by 53.1% in 2002 [23]. These cause around 41.8 million tons (Mt) of e-waste only by 4 billion people up to 2014 which further increase to 49.8 Mt in 2018 around the world [15]. Globally, every year the amount of e-waste generation is about 20–50 Mt which has been increased with a growth rate 4–5% in recent days. In 2014, highest amount of waste is generated by Asia (16 Mt) and lowest position occupied by Oceania (0.6 Mt). Considering e-waste per habitat, Europe got highest rate of 15.6 kg/inhabitant and Oceania is next to it with a rate of 15.2 kg/inhabitant where Asia is so far with a rate 3.7 kg for each inhabitant [15]. Africa is generating the lowest amount of e-waste, only 1.7 kg as per inhabitant and

Table 2 Various toxic elements and its source, global quantity of generation per year and corresponding health effect

Substance	Source	Global quantity (tonnes)	Environmental and health effect
Metals and heavy metals			
Antimony (Sb)	Fire retardant, plastic computer housings and a solder alloy in cabling, also in melting agent in CRT glass	34,000	Antimony is carcinogen to human health. Due to this, various disorders arise like diarrhoea, stomach pain, vomiting, and inhalation of high antimony levels over a long time period may cause stomach ulcers
Arsenic (As)	Gallium arsenide within light-emitting diodes. Semiconductors, diodes, microwaves, solar cells		It can cause skin disease. Much chronic effects on human like lung cancer and impaired nerve signalling
Barium (Ba)	Spark plugs, getters in CRT vacuum tubes, electron tubes, fluorescent lamps filler for plastic and rubber, lubricant additives		It causes damage to the heart, mainly affects brain swelling, muscle weakness liver and spleen through short-term exposure
Beryllium (Be)	Power supply boxes which contain silicon-controlled rectifiers and X-ray lenses, motherboard, power supply boxes, relays and finger clips, also found in switchboards and printed circuit boards		Very carcinogenic which causes lung cancer, inhalation of fumes and dust causes chronic beryllium disease or beryllicosis
Cadmium (Cd)	Rechargeable NiCd batteries, fluorescent layer (CRT screens), pigments, printer inks and toners, chip resistors and semiconductors, photocopying machines (printer drums), solder, monitors, alloys, circuit boards	3,600	Irreversible toxic effects on human health especially in kidney cause neural damage; a long-time exposure causes *Itai-itai* disease, which causes severe pain in the joints and spine
Chromium (Cr)	Data tapes, floppy disks, galvanized steel plates and decorator or hardener for steel housing	198,000	Inhaling hexavalent chromium or chromium 6 can damage liver and kidneys and cause bronchial maladies including asthmatic bronchitis and lung cancer; it may cause DNA damage and permanent eye impairment
Copper (Cu)	Cabling, copper wires, printed circuit board. Tracks, pigments, copper ribbons	820,000	Its accumulation causes stomach cramps, nausea, liver damage, or Wilson's disease

(continued)

Table 2 (continued)

Substance	Source	Global quantity (tonnes)	Environmental and health effect
Lead (Pb)	CRT screens, glass panels, batteries, solder in printed circuit boards and gaskets in computer monitors, printed wiring boards	58,000	It has dangerous effect that damages the brain, nervous system, kidney and reproductive system and causes blood disorders. In foetuses and young children, even low concentrations of lead can damage the brain and nervous system
Lithium (Li)	Li batteries		Nursing baby may harm when lithium pass into breast milk, on inhalation of the substance may cause lung oedema
Mercury (Hg)	Fluorescent lamps that provide backlighting in LCDs, backlight bulbs or lamps, flat panel displays, in some alkaline batteries and mercury wetted switches	13.6	Chronic damage to the brain. Bioaccumulation in fishes causes respiratory and skin disorders. It can pass into mother's milk, impair foetus growth, and harm infants
Nickel (Ni)	Nickel–cadmium rechargeable batteries, electron gun in CRT, cathode ray tube and printed circuit boards	206,000	Allergy of the skin to nickel results in dermatitis, while allergy of the lung to nickel results in asthma and reduced lung function leads to lung cancers, bronchitis
Selenium (Se)	Older photocopying machines (photo-drums)		High concentrations of selenium consumption cause selenosis
Halogenated organic compounds			
PCB	Condensers, transformers	280	During combustion, printed circuit boards and plastic housings emit toxic vapours known to cause hormonal disorders
TBBA, PBB, PBDE	BFRs are used to reduce flammability in printed circuit boards and plastic housings, keyboards and cable insulation		Burning may cause toxic gas emission which causes various disorders in hormonal and neural system
CFC	Cooling unit, insulation foam		It is damaging the ozone layer which can lead to greater incidence of skin cancer
PVC	Cable insulation, computer housing		Incomplete and complete combustions generate toxic gas that causes air pollution and also produces dioxin that causes reproductive and developmental problems

1.9 Mt of e-waste generated by the whole continent. In comparison, South America (2.7 Mt), North America (7.9 Mt), Central America (1.1 Mt) generate a total amount of 11.7 Mt of e-waste that presenting per inhabitant generation is 12.2 kg [15]. In developing countries like India and China, e-waste generation is less than 1 kg/inhabitant/year where Hong Kong (21.5 kg/inhabitant), Singapore (19.6 kg/ inhabitant) and Brunei (18.1 kg/inhabitant) are the top three Asian countries. However, highest amount of e-waste is generated by China (6 Mt) along with Japan and India of a total amount of 2.6 and 1.7 Mt, respectively, in Asia [15]. It is estimated that from 2007 to 2020 the e-waste generation only from old computers is hiked by 400 and 500% in China and India, respectively, where mobile phones will cause 18 times and 7 times increase [18].

2.7 Agriculture Solid Waste

Agriculture waste mainly covers the waste generated from agriculture fields, firms, hatcheries and woods. These wastes are highly enriched with biomass and reusable biodegrading materials [25]. These also have some other substances generated during various agricultural activities given in Table 3.

Wastage from agriculture field is the supplier of toxic compounds towards groundwater and surface water contamination [7, 25]. This wastage is coming from the excess use of fertilizer on fields where Nitrogen (N) and Phosphorus (P) are results of eutrophication of surface water. Eutrophication results allege boom and damage the ecological system of aquatic body. Thus, it increases the growth of aquatic weed and decreases the oxygen level which can cause death of flora and fauna. Excess use of pesticide may come in contact with living society which results in several health hazardous effects [26]. Poultry firm wastage is also contaminating the groundwater and surface water by generating heavy metals, pesticides and pathogens to soils. Most importantly, poultry waste contains nitric nitrogen (NO_3–N) which is responsible for 'blue baby' syndrome of human infants. In which bacterial reduction of NO_3^- converts to nitrite $\left(NO_2^-\right)$ which oxidizes iron in haemoglobin and results in the formation of methemoglobin. Methemoglobin choked the oxygen transport function which is called 'methemoglobinemia'. It increases the acidity in an adequate level for many bacterial functions in human stomach [25].

2.8 Extent of Agriculture Solid Waste

Agriculture solid waste composed with various wastes generated from different processes; for example, each year food processing units produces almost two million tons of solid wastes in which 40% is vegetable waste in USA. There is only 19% of total crop utilized for feeding and around 75% released to soil [25].

Table 3 Solid waste generation in various agriculture activities

Activity	Composition	Primary component
Leather tanning	Fleshing, hair biological sludge, grease, lime and chrome sludge, raw and tanned hide trimmings	Biodegradable organics, bacteria, chlorides, sulphide, nitrogen, chromium, grease
Animal production (feedlots)	Manures	Biodegradable organics are major content along with bacteria, nutrients, medicinal, salts, inorganic additives such as copper, arsenic
Sugar processing (beet sugar, raw cane bagasse, soil, pulp, lime animal feed bacteria, nutrients sugar, cane sugar refining)	Biological sludge, bagasse, soil lime mud, filter mud, pulp	Biodegradable organics, nutrients, bacteria
Crop production and harvest	Stover and straw	Biodegradable organics, bacteria
Fruit and vegetable processing	Biological sludge trimmings, peels, seeds and pits leaves and stems, soil	Biodegradable organics, nutrients, bacteria, salts, grease pesticides
Grain processing	Biological sludge, spilled grain	Animal biodegradable organics
Meat processing	Biological sludge product trimmings, bones feathers, hides, grease	Biodegradable organics, nitrogen, bacteria, chlorides
Timber production	Branches, leaves, small trees	Slowly biodegradable organics
Dairy product processing	Biological sludge	Biodegradable organics
Wood processing	Bark, small pieces, sawdust	Slowly biodegradable organics

2.9 *Hospital or Biomedical Solid Waste (HSW or BSW)*

The institutions like hospital and other healthcare centres are the places which provide treatment and assurance of public health irrespective of social and economic background. In the healthcare processing, these institutions may generate infectious waste which may be responsible for spreading diseases. These healthcare facilities are origin of vast wastes which are specifying as hospital waste. Hospital waste is also known as biomedical waste which can be defined as 'any waste which is generated during diagnosis, treatment or immunization of human being or animals, or in research activities pertaining thereto, or in the production or testing of biological product' [1].

Total hospital waste is generated from a health care establishment, research facilities, laboratories, and emergency relief donations. Generally, hospital waste is major content of non-hazardous and combustible materials. Remaining part is

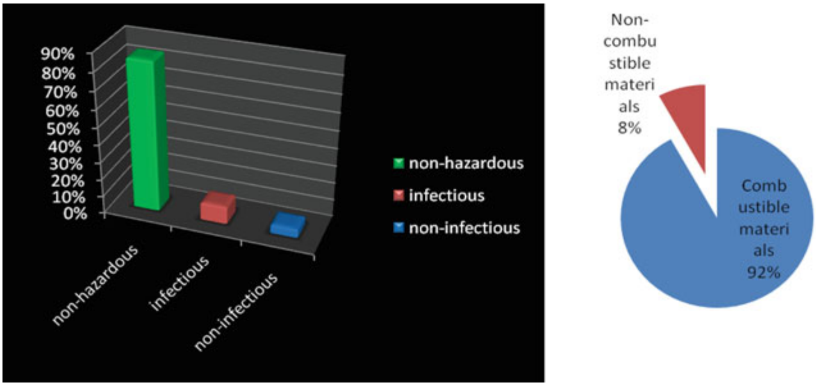


Fig. 4 Composition of hospital solid waste

consisting of infectious and non-infectious wastes [4, 10]. Percentages are given in Fig. 4.

Infectious wastes have hazardous effect on public health and environment. Where depending upon total amount of hospital waste in India, the percentage of infectious waste may vary from 15 to 35%; in USA the amount is $\sim$15% [12]. Primary source of hospital waste are hospitals (Govt. hospitals/private hospitals/ nursing home), veterinary hospitals (including research centres), clinics, Primary health centres dispensaries, Medical colleges and research centres/paramedic services, Blood banks, mortuaries, autopsy centres, slaughter houses, Blood donation camps, Vaccination centres [12]. Other sources are household, acupuncturists, cosmetic piercing, funeral services, institutions for disabled persons [12]. Generated HSW are categorised in different ways, more general is tabulated depending on their source and composition in Table 4. Where also corresponding hazardous effect is also mentioned [1, 4, 10, 12, 27].

Focusing on the health issue related to HSW, sharps includes contaminated needles, broken glass, glass pipette, IV tubes, blades, slides it further classified in (i) sharps (contains contaminated or non-contaminated glass materials), (ii) radioactive sharps (contaminated with radioactive material such as in chemotherapy), (iii) chemical sharps (apparatus contaminated with chemotherapy drugs, broken thermometer contaminated with mercury). These cause severe effect of mercury contamination and spread infection like hepatitis, HIV, and some viral diseases [1, 28]. Other some infection are also potentially risky like plague, shigellosis, TB, diarrhoea, typhoid, VDRL, leprosy [29].

Infectious waste mainly generates from the material and equipment in contact with infected patient, body parts, discharge, blood, or fluid. Infectious wastes contains pathogens (i.e. fungi, bacteria, virus, parasite) which generates from pathological laboratories can be considered as pathological waste. Human and animal body parts are also recognized as anatomical waste [1, 5].

Table 4 Various categories of hospital waste

Category	Waste content	Source	Composition	Effect on environment
1	Human anatomical waste	Morgue, human anatomical research centres, hospitals	Human tissues, organs, body parts, foetuses, unused blood products	Can spread infectious disease like AIDS, hepatitis (A, B and C), influenza (H1N1)
2	Animal waste	All types of animal tissues, organs, body parts carcasses, bleeding parts, fluid, blood	Experimental animals used in research, waste generated by veterinary hospitals/ colleges, discharge from hospitals, animal houses	It can potentially spread various viral disease like haemorrhagic fever (Ebola), pledge
3	Microbiology and biotechnology waste	Wastes from laboratory cultures, stocks or specimens of micro-organisms used in research	Research laboratories, wastes from production of biological, toxins, dishes and devices used for cultures	Micro-organs can contaminate to environment and cause anthrax, meningitis
4	Waste sharps	Healthcare waste, clinical waste, hospitals, medicinal centres, research laboratories	Needles, syringes, scalpels, blades, glass, glass slides and cover slips, broken glass and splintered plastic, when contaminated with blood or other potentially infectious material	Various infected disease are spread through contaminated needles, syringes like AIDS, hepatitis (A, B and C), influenza (H1N1), anthrax and meningitis
5	Discarded medicines and cytotoxic drugs	Medicinal centre, hospital, chemotherapy centre, household	Outdated, contaminated and discarded medicines	The hazardous cytotoxic gas can serve as alkylating agent, antimetabolites and mitotic inhibitors
6	Solid waste	Various human and animal diagnosis and treatment centres	Blood contaminated cotton, dressings, soiled plaster casts, lines	It has the potential to spread diseases from the corresponding holder
7	Disposable solid waste	These types of waste are generated from more or less kind of biomedical centres	Tubing's, catheters, intravenous sets	They may be contaminated with heavy metal and harmful organic molecules

(continued)

Table 4 (continued)

Category	Waste content	Source	Composition	Effect on environment
8	Liquid waste	Every health centre including household, research laboratories, pathological centres	Waste generated from laboratory and washing, cleaning, housekeeping and disinfecting activities	Wastewater contains toxic substance like heavy metals, pathogens, which can cause contamination of groundwater and surface water
9	Incineration ash	Incineration plants of biomedical waste	Ash from incineration of any biomedical waste	Ash may contain neurotoxic element like mercury, its leach to food chain through water
10	Chemical waste	Disinfection section in health institutes, research laboratories	Chemicals used in production of biological and disinfection activities like insecticides	Disinfection, as insecticides

2.10 Extent of HSW

Depending upon national income and available waste treatment facilities, the total HSW generation varies nation to nation. In USA daily 10.7 kg of HSW is generated by a patient only in major hospitals in which 2.79 kg/bed/day is infected waste [10]. Those types of financially strong nations are generating waste normally 4–9 kg/bed/day, whereas moderated and lower income countries contribute 0.5–6 kg and 0.5–4 kg per each person of its population [1, 30]. As an example, Tanzania is generating around 0.3 kg of HSW per bed every day as well as Vietnam, Mongolia, Ecuador, Peru are also generating waste as per increasing order of per capita gross national income (GNI) which is shown in Fig. 5 [10].

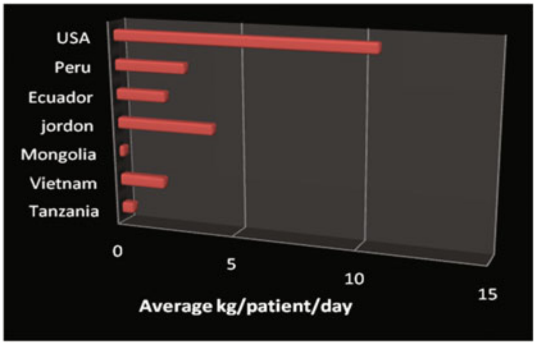


Fig. 5 Hospital waste generation with increasing order of per capita gross national income

In India, on basis of per bed/day HSW generation varies on type of hospital and its localization as government hospital generates 5–7 kg and private hospitals produce 2–4 kg in southern India. In the western India, the HSW is around 1–3 kg/bed/day for west India [1]. Only in Delhi, 65 tons of HSW is generating out of 6500 metric tons of total solid waste [27].

2.11 Solid Waste Management (SWM) Process

Globally, solid waste generation is growing day by day with the increasing population. Only in India, it is ranging around 0.2–0.6 kg/capita in cities which is generating 42 million tonnes of total solid every year, and these figures will cross 260 million tonnes in 2047 [20].

Therefore, for healthy environment proper integrated solid waste management (ISWM) is essential rather than conventional SWM which only involves waste collection, treatment and disposal. But ISWM focused on the reduction of waste at source, reuse of recovered resource and recycle of residue. With economic efficacy, reduction on environmental impact and ensuring multi-stakeholders participation the ISWM are more advantageous to the conventional waste management. The complete cycle of SWM contains waste collection, separation, storage, transportation, treatment and disposal [5].

Solid are waste are collected from various source and characterized upon there category like recyclability, combustibility, reusability, disposability and accordingly accumulate in corresponding places. As an example, hospital wastes are collected in different bins according to their colour code [12]. Stored solid wastes are transported to various treatment facilities like thermal, mechanical-biological, mechanical biological, material reclamation facility and some waste along with residual part of treatment facilities transported to final disposal [31].

Lack of awareness and modern facilities of proper waste management can cause serious health issues and environmental impact. The elementary level of waste management is not properly mentioned as an example during the production and collection of different categories (recyclable with hazardous) wastes are mixed. Furthermore, It is transported in inadequate manner like in tricycle, open truck using poor containers [32]. Rag pickers are responsible for recycle and reuse of this wastage with their bare hands [5]. After that, it goes for disposal in open land (dumping yard), incineration, combustion which liberates hazardous material that have various chronic effects on ecosystem [19]. Some of the treatment technology and disposal methodology are very usual and some are too specific for classified wastes (like hospital solid waste, municipal solid waste) [8, 12]. With limitation and advantage the main technologies in solid waste disposal and treatments are landfilling, composting, vermi-composting, biomethanation are the Mechanical Biological Treatment (MBT) methods [31] and some thermal treatments [33] like incineration, gasification and pyrolysis, plasma pyrolysis, production of Refuse-Derived Fuel (RDF) are the main technologies in solid waste disposal and treatment. RDF is also known as pelletization which is notable for municipal solid waste [20].

2.12 *Mechanical Biological Treatment*

Mechanical Biological Treatment (MBT) technologies are pre-treatment technologies for any waste treatment. Basically, MBT provides a diversion of SW from direct exposure of waste [34].

2.12.1 Landfilling

Landfilling is the most general and ultimate way of waste disposal though it ranked lowest in quality of waste management. All types of inert, remaining and residual part of waste treatment, organic waste, and mixed waste are dumped in lands which are the major source of greenhouse gases (CO_2, CH_4) [20, 31, 32]. Some heavy metals and organic material are responsible for groundwater contamination which results in lead, mercury, cadmium toxicity and other diseases [2, 13, 16]. Landfilling sites are breading house of insects, vermin which can spread malaria, cholera, etc., and rag pickers are searching this sites for their daily income, as a result but they are most exposed to, tetanus, respiratory problem, neural disorder [2]. People live around or downwind; these sites are also suffering from respiratory problem, headache and irritation due its odour [2, 20].

Advantage of landfilling [2, 8, 20]

- No need of highly skilled employees.
- Low cost for waste treatment.
- Highly potential for gas recovery which can use as source of energy.
- Through burying organic waste leads net gain for environment.

Limitation of landfilling

- Costly transportation to dumping land sites.
- Choke the drainage system and can contaminate both the groundwater and surface water.
- Major source of greenhouse gases.
- Need a large area of land for dumping.
- Birthplace for vermin, insect and may be origin of various diseases.

2.12.2 Composting

Farmers have been composting compostable organic material (cow dung, agro-waste) from the immoral time [20]. Micro-organism plays the main role in this technology for decomposition in various environments like warm, moist, aerobic and anaerobic [8, 20]. This technology is simple and commercially viable, and it is effectively applied in agricultural lands, fruit orchards, farmland, tea gardens, also in parks, gardens, etc. [20]. Some plants are established in Baroda, Mumbai, Calcutta, Delhi, Jaipur and Kanpur with capacities ranging from 150 to 300 tons per day during 1975–1980 [8].

Advantage of composting

- Augmentation in micronutrient deficiencies and improvement in soil texture.
- It maintains the soil health through increasing moisture-holding capacity and recycling nutrients into soil.
- It is very much straightforward and simple as well as cost-effective.
- Reduce the dependency on chemical fertilizer in agriculture field.

Limitation of composting

- Not suitable for all types of waste.
- Large open land required.
- Composting plants emits methane, odour and flies.
- Soil can contaminate with entering toxic materials.
- Lack of awareness and proper marketing of compost material [2, 8, 20].

2.12.3 Vermi-Composting

Vermi-composting is a process where biodegradable part of solid waste which is composted with the assistance of earthworms [8, 20]. Resultant part of vermi-composting is very much nutrient-rich, and further it can use for fertilization of agriculture field. *Pheretima* sp., *Eisenia* sp., *Perionyx excavates* sp., these worm species only survive in 20–40 °C and moisture ranges from 20 to 80% and responsible for generation of 50 MT of solid waste per day in town and cities [35]. These worms consume waste five times more than their body weight [8]. Largest vermi-composting plant with capacity of 100 MT/day is situated in Bangalore, India [20]. Some plants in Hyderabad, Bangalore, Mumbai and Faridabad are established for vermi-composting. Introduction of toxic materials in waste can kill these earthworms and the process requires a large area of land composting [8].

2.12.4 Anaerobic Digestion and Biomethanation

In recent time, this technology is less expensive for disinfection and stabilization of waste like farmland residue, industrial sludge and animal slurries [20]. The main objective of this process is generation of biogas which contains 50–60% of methane through composting of organic waste [8]. Production of bio-gas can source of power generation. The value-added part of this process is that the residual part is enriched with nutrients and could be as composting fertilizer which results in environmental a net gain. Efficiency and energy recovery of biomethanation are better than composting [8, 20]. In 3 weeks, 1 ton of waste produces 2–4 times of methane than the landfilling of 1 ton waste in 6–7 years and energy production of

100–150 kWh per tons [8]. These plants need less land area and treating in a closed system, and it also free from bad odour, rodent and fly menace, visible pollution. But the method is only suitable for biodegradable organic waste that is why before using this treatment waste must go through segregation [20]. In India, BARC has developed this technology which commercialized as Nisarguna Biogas Plant. Earlier A 5 MW power plant was established in Lucknow, India. Unfortunately due inadequate supply of waste it was close down. A few small-scale power plants are still actively working in Vijayawada [8, 20].

Globally there are many active plants of MBT, but Europe has most number of plant around 330 with a capacity ranges from 50000 to 305,000 tonnes annually where permitted capacity is 2,728,300 tonnes waste.

MBT plant at Waterbeach, Cambridgeshire operated by AmeyCespa with highest capacity of 179,000 tonnes per annum. Later on, a few successor MBT plants were established in Frog Island and Jenkins Lane, East London and Farington, Lancashire which are operated successfully with 180,000 tonnes capacity (by Shanks and Global Renewables). A plant in Bredbury Parkway, Stockport and Reliance Street, Manchester, run by Viridor Laing is capable of 100,000 tonnes of waste treatment per year. Cotesbach, Leicestershire and Southwark plants are controlled by New Earth Solutions and Veolia, respectively, with capacity ranging from 50,000 to 90,000 tonnes per year [34].

2.13 Thermal Treatment

The main aim of this technology is to minimize the release of toxic waste and treatment residual part, and principle technologies are incineration, gasification and pyrolysis [33].

2.13.1 Incineration

Incineration is subjected to disposal of solid waste through high-temperature combustion in control with proper way [8, 20, 31]. The incineration temperature belongs within the range 980 to 2000 °C [8]. At this high temperature, wastes are converted into ash as a residual part with emission of gaseous product gas. This process leads to destructions of toxic material as well as recovery of energy. Incineration reduces volume upto 80–90% of the total volume of combustible waste [8]. This feature can be developed with enough high temperature, and it reduces up to 5% of its original volume. Additionally this process is noise free, odorless and hygienic [8, 20]. These thermal plants can be constructed nearer to the source of the waste which will minimize the transportation cost. In developed countries like japan having insufficient place for landfilling, therefore such incineration methodologies are most commonly used in this countries keeping in mind lack of large area for landfill [8, 33].

Flipping other side, incineration may cause potential emission of pollutant like dioxins, furans and PAHs [2, 31, 33]. Among these persistent organic compounds more specifically polychlorinated dibenzo-p-dioxins, (PCDDs), polychlorinated dibenzofurans (PCDFs) and polychlorinated biphenyl (PCBs). PCDDs and PCDFs are the mostly coming out due to incomplete combustion of municipal waste, medical waste and household waste. SO_x, NO_x are also emitted by this process [2, 8, 20, 31, 33]. It needs large operation and high maintenance cost with skilled personnel [20].

In 1987 at Timarpur, Delhi an incineration plant installed Miljotecknik volunteer, Denmark, with a cost of Rs. 250 million for Delhi Municipal Corporation [8]. This plant has capacity of 300 tonnes per day and 3.75 mw of power generation [20]. But due to its low performance and high maintenance charge, it was forcedly shut down [8]. Solid wastes are high content of organic waste, inert material, moisture and wet containing wastes; this is why incineration is not a well-practiced scenario in Indian methodology [8, 20].

In small cities, this method is used in lesser extent only for hospitals and institution like BARC has constructed a plant in Trombay, Mumbai, for their institutional waste [8].

2.13.2 Pyrolysis

A substance when thermally degraded without oxygen that process is called pyrolysis [20, 33]. In pyrolysis, required temperature ranges is in between 300 and 850 °C and for thus a continuous external heat source is continuously required [33]. Synthetic gas and char are the products of pyrolysis of waste material. Carbon and non-combustible materials are the main constitution of char, wherein syngas like methane, carbon mono oxide, hydrogen are major content [20, 33]. These gases further can be used for fuel oil generation and condensed for wax and tar preparation [20].

2.13.3 Gasification

Gasification is a partial oxidation process of substance with insufficient oxygen and resulted in a process between the combustion and pyrolysis [33]. The operating temperatures are typically above 650 °C of this exothermic reaction [33]. Before application wastes are required to be dried and then segregated. During the operation the syngas so generated comprises of hydrogen, carbon monoxide and methane [8, 20]. This syngas can be used instead of natural gas as fuel gas and energy recovery could be possible with this method. In compared to incineration, gasification does not emit any toxic gas like SO_x, NO_x because of insufficient oxygen [20]. This process needs high amount of financial support and power source, and the efficiency can be affected by the presence of high moisture and inert content in waste [8, 20]. Production of high viscosity may cause in operation and its transportation [20]. After gasification, the solid non-combustible residual part needs proper handling and disposal. In plasma gasification technology high temperature (electric arc) is applied to the waste material thereby converting it to an inert residue (ash). This result in vitrification of the inert material accompanied with cracking of the tar component that eventually leads to emission of clean syngas [33]. Initially two gasification units are installed in India, first one (NERIFIER) by Narvreet Energy Research and Information (NERI) at Nohar, Hanungarh, Rajasthan and the second one at Gaul Pahari campus, New Delhi, Tata Energy Research Institute (TERI) gasification unit by Tata Energy Research Institute (TERI). NERIFIER operates with an efficiency of about 70–80%, and the waste treatment rate is ∼ (50–150) kg per hour [8].

2.13.4 Refuse-Derived Fuel (RDF)

This method is useful for producing improvised solid fuel or pellets which can further use in industrial furnace from mixed municipal solid waste [20]. As gasification, RDF is also capable of reduction of pollution and more in recovery of energy through producing power [8, 19, 20]. RDF is much prominent fuel when it is mixed with coal or that type of conventional fuel [8]. Although this expensive method requires well trained expertise to operate, however, owing to its efficiency in energy recovery process developing countries are applying this technique in large number [8, 20]. A RDF plant near Golconda dumping yard in Hyderabad, India, is constructed in 1996 with a capacity of 1000 tons waste feeding per day. This used to produce about 6.6 MW of power with 210 tonnes of pellets per day [8]. Another large-scale RDF plant is in installed Deonar, Mumbai, that operates by Excel India. In Bangalore the amount of production is about 5 tons of fuel pellets for domestic and industrial purpose by compacting 50 tons of MSW per day [8, 20]. A same type of plant is constructed by M/s Shriram Energy Systems Ltd. at Vijayawada which is operational since November 2003 [20].

3 Conclusion

Human civilization consciously or unconsciously is on the verge of generating a tremendous amount of solid wastes that consequence in serious health-related issues. ‘Prevention is better than cure’ is a very popular adage; abided by it here too prevention of these practices is superior to curing the detrimental effect on living system and environment. However, this can only be feasible by proper system of waste management and most significantly public awareness. Waste management not only deals with its treatment and disposal; it is a whole system that incorporates reduction of waste generation, collection, segregation and proper transportation to its corresponding recycling hub. Disposal of solid waste with conventional way is not so effective in reducing its noxious effect. As a consequence, for biodegradable waste, composting is a very useful method since here the residual part can be further used as fertilizer. Some disposal methods like gasification, pyrolysis, RDF can minimize the solid waste volume and its lethal effect. These methods are very efficient for generating fuel, for instance syn gas which can be a prominent source of energy in the recent future. Our research on different technologies such as plasma arc pyrolysis or autoclaving for safe disposal of solid waste is under active progress.

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Hazardous Waste Generation and Management in Ship Recycling Yards in India: A Case Study

J. M. Vivek, R. Singh and S. R. Asolekar

Abstract From time immemorial, ships are considered as a vital part of international trade and contribute a lot to the economic prosperity of a country. But after an average life of thirty years at sea, vessels are sent to ship breaking yards for demolition. The main categories of ships include general cargo, bulk freighter, oil and chemical tankers, container cargo, reefer and passenger vessels. Over the last few decades, recycling of end-of-life vessel is a key economic activity and has been concentrated in a few developing South Asian countries namely India, Pakistan and Bangladesh. The extraction of economically reusable materials like steel from vessels is often encountered with hazardous materials. The hazardous wastes created from ship recycling activity mainly consist of asbestos, glass wool, bilge water, polychlorinated biphenyls (PCBs), ozone-depleting substances (ODSs), paints, tributyltin (TBT), heavy metals, waste organic and inorganic liquids (acids), oily rags, oily sludge and miscellaneous (like sewage). The workforce engaged in this sector gets exposed to various contaminants during vessel dismantling process as well as some portion of hazardous wastes may get released into the surrounding environment. The demolition and recycling of ships is a hazardous endeavour that involves a necessity for adequate measures to protect the marine environment, to ensure environmentally safe and sound management of hazardous waste and to guarantee health and safety requirements for the workforce. This present paper will provide a short overview of the hazardous wastes generated at ship breaking yards and current practices for management of such wastes. India accounts for around 20–30% of the ship demolished and recycled at the international maritime market. Hence, the implications of such hazardous waste management to India and the need for promoting research for clean and green practices along with stringent measures are discussed in this paper. The overview touches upon the legal framework under Indian and international purview in dealing with safe recycling of ships. The suggestive measures for the improvement of the hazardous waste management are also articulated in this paper. The research work is in progress.

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1 Introduction

The demolition and recovery of useful materials from end-of-life ships has been accepted as one of the key economic activities for GDP growth of particularly South Asian countries like India, Pakistan and Bangladesh. Ship dismantling and recycling activities are performed in ship recycling yards (SRYs). The ship recycling process consists of wide array of actions, commencing from inspection followed by removing all the equipment and machinery left on a ship, such as parts of engine, associated fittings, coolants, freon cylinders, personal appliances and cargo items and closure of activity by selling the scrap items recovered from the vessel. In recent years, annually around 1000 ships reach to their end of service life and are sent to demolition sites to recover steel and other valuable materials. As per NGO ship breaking [17], around 768 ocean ships were dismantled in 2015. India had scrapped fewer vessels as compared to the previous year, mainly due to the weak market conditions like low prices of scrap steel, cheap Chinese steel imports and depreciation of rupee. The recovery processes raise concerns related to occupational health, safety and environment. The main issues include workforce exposure to hazardous materials and wastes during vessel breaking operation as well release of toxic gases and particulate matter to surrounding environment. The other matter of concern is physical risks to the workers during the dismantling operation. Demaria [5] had reported that the annual average occurrence of fatal accidents in the Alang-Sosiya ship breaking industry in India is 2 per 1000 workers (based on official data from 1995 to 2005). The workers engaged in the process of ship dismantling are generally unaware about the health implications of their occupation and often lack personal protective equipment (PPE) [20], which ultimately opens up many pathways of exposure to hazardous pollutants.

The demolition of ships is a complicated and hazardous endeavour that requires ample measures to protect the marine environment, to ensure environmentally safe and sound management of hazardous wastes and to guarantee high health and safety standards for workers. Yet only a fraction of decommissioned ships is handled in a safe and sustainable manner. More than 70% of the end-of-life vessels are sold for dismantling today end up in South Asia, the region that has served as the main destination for obsolete tonnage in the last two decades. The end-of-life vessels are run up on the tidal shores of India, Bangladesh and Pakistan, where they are dismantled mainly manually by a migrant workforce. The most widely used beaching method is the source of severe coastal pollution and dangerous working conditions. Moreover, ship breaking activity often ends up in blatant violation of international hazardous waste management laws. Hence, there is a major issue of concern to researchers trying to bridge the gap in the scientific and policy dimensions to ensure a safe and sound management of wastes.

2 Ship Breaking Activity in India

India is one of the leading ship recycling countries in the world, and this activity is contributing potentially for the economy of the state [11]. There are many ship recycling yards in India including Mumbai (Darukhana), Kolkata (Port area), Gujarat (Alang-Sosiya), but Alang-Sosiya is considered as the largest graveyard of the ships in the entire country. It contributes half of the total ships dismantled in the world. In a study done by Deshpande et al. [7], it was found that around 350 ships are dismantled and recycled every year at Alang-Sosiya ship breaking yards. As per the estimates of Gujarat Maritime Board (GMB), these yards have the ability to recycle about 450 ships per year producing around 4.5 million MT of re-rollable steel [9]. The hazardous and non-hazardous waste generation and disposal to TSDF Site, Alang-Sosiya, are given in Table 1.

The recyclability of the ship is dependent upon its cumulative weight, which is expressed in terms of “Light Displacement Tonnage”. In the year 2015–16, 249 ships were dismantled in India generating LDT of around 24, 31,752.35 MT. The graphical representation of number of ships dismantled *vs* total hazardous waste generated is given in Fig. 1.

Table 1 Waste generation and disposal to TSDF Site, Alang-Sosiya

Year	No. of ships	LDT	Hazardous waste		Municipal solid wastes	
			HW generation in MT	% of waste to the weight of the ship	MSW generation in MT (GMB)	% of waste to the weight of the ship
2006–07	136	760800	1032.861	0.13	46.205	0.006
2007–08	136	643437	2017.025	0.31	828.425	0.129
2008–09	264	1944162	5027.841	0.25	855.265	0.044
2009–10	348	2937802	5418.040	0.18	726.175	0.025
2010–11	357	2816236	8215.310	0.29	729.100	0.026
2011–12	415	3847000	8318.979	0.22	552.430	0.014
2012–13	394	3847566	10555.355	0.27	770.550	0.020
2013–14	298	3059891	7505.890	0.24	889.025	0.029
2014–15	275	2490152	7279.395	0.29	305.865	0.012
2015–16	249	2431752	4996.310	0.20	368.655	0.015

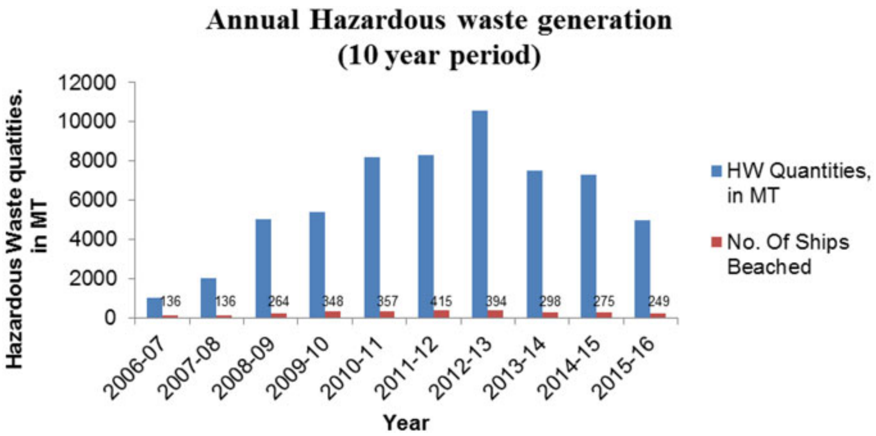

Fig. 1 Total ships beached vs hazardous waste generated for a 10-year period

3 Hazardous Wastes Generated from Ship Dismantling Activity

At the end of useful period of a vessel, it is observed that the vessels contain not only various recyclables, but also a range of hazardous substances that includes asbestos, glass wool, thermocol, oily rags, oily sand and sludge, polychlorinated biphenyl (PCB) and organotins like tributyltin (TBT), [4–7, 14, 18]. The pollution caused in ship recycling sector leads to detrimental human health issues. The hazardous and non-hazardous waste streams (explained in Table 2) coming out of the ship recycling practice create pollution of land, water (sea) and air. This may destroy the balance of the marine ecosystem. Constituents of ship subjected to recycling can vary from ship to ship and will depend on several aspects including the purpose of ship. Hence, the wastes from recycling activity will also vary [19]. The main pathways of hazardous material generation are elucidated in Fig. 2.

Ships that are being dismantled contain a variety of hazardous and non-hazardous wastes. Many parts of ships often contain hazardous wastes such as asbestos, ammonia, chlorofluorocarbons (CFCs), oily residues and heavy metals [16]. However, the commonly occurring wastes during ship breaking are shown in Fig. 3.

The main hazardous wastes having potential for environmental damage and detrimental human health effects are described below.

3.1 Asbestos

Asbestos has unique properties of resistance to abrasion and corrosion, inertness to acid and alkaline solutions and stability at high temperatures. However, all forms of

Table 2 Common waste generated at SRY

Solid wastes
• Paint chips, flakes of rust, scales generated during gas cutting of steel and re-rolling • Concrete slabs used as ballast, ceramic tiles, thermocol, rags and sackings • Glass wool and fibrous insulations, asbestos and ACMs • Fuel and furnace oil, engine oil, lubricants, oily sludge at bottom of fuel tanks and cargo • Plastic, fibre glass, linoleum, broken ceramics, glassware, paper, wood, all sort of junks • Leftovers of cargo, human excreta
Liquid wastes
• Waste oil, ballast and bilge water
Gaseous wastes
• CO_2 from fire equipment • Ammonia, CFCs, from air conditioning systems • Inflammable gases present in pipelines of oil tankers and LPG/ LNG carriers • Emissions due to plate cutting • Particulate matter re-suspension due to vehicle movement

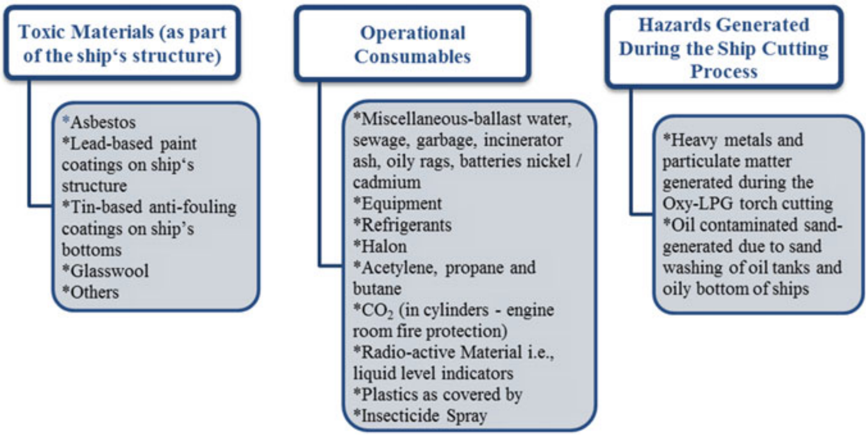

Fig. 2 Main hazardous material generation routes from ship recycling/dismantling industry

asbestos (including chrysotile asbestos) are assessed to be carcinogenic on the basis of sufficient verification on carcinogenicity in humans [2]. The prime routes of possible human exposure to asbestos are inhalation and ingestion. As per Hiremath et al. [12], the quantum of AW and ACM generated from the ship breaking yards in India, particularly Alang-Sosiya, is on an average of 1300 MT/annum. The scrapping off, handling, bagging and disposal of asbestos is a prime environmental as well as health concern. The main issues are encountered by workers, while they remove ship components like asbestos-bearing thermal insulations, gaskets with

Fig. 3 Main types of waste generated from ship dismantling activities

piping and electrical systems as well as moulded plastics, circuit breakers, cables, floor and tiles. In India, none of the studies so far, have reported the occupational health impacts due to asbestos exposure. In a study conducted on health hazard at ship dismantling yards in Taiwan, it was observed that there was an elevated trend of asbestos exposure with cancer incidences, oesophagus cancer, and trachea, bronchus, and lung cancer among ship breaking workers [22].

3.2 Glass Wool

Glass wool is another type of waste which is generated in huge volumes during the ship dismantling activity. These are generally used for insulating purposes and found in various locations inside an obsolete ship such as engine room, heating systems, ventilation systems, electrical equipment, doors and side walls of cabins, ceilings and door panels. As compared to other friable hazardous materials like asbestos, glass wool alone is not hazardous, but when it gets mixed with toxic pollutants such as heavy metals, PCBs, TBTs, the matrix becomes hazardous. Glass wool is an insulating material having small pockets of air between the glasses leading to its high thermal insulation properties. It is observed that glass wool removal at SRY was found to cause severe itching around exposed sensitive areas of body like skin, eyes and nose. Typically, the emissions of glass wool from all types of ships are significantly higher when compared with the other types of landfillable wastes, especially asbestos and asbestos-containing materials.

3.3 Polychlorinated Biphenyls (PCBs)

PCBs and its congeners are known to be carcinogenic substances. They are present in capacitors in light fittings, oil residues, oily rags, gaskets, couplings, wiring and cables, transformers, voltage regulators, switches, electromagnets, adhesive tapes, etc. Since asbestos in the vessel occurs to be at the same area of occurrences of PCBs, it is likely that those samples might have PCB contamination.

3.4 Paints and Coatings

Paint waste is one of the major hazardous waste materials from ship breaking industry. Paints are used in many parts of the ship for anti-corrosion and anti-fouling purpose. Paint waste is toxic due to its chemical composition. The paints are applied in order to prevent hull of ship from overgrowing algae, molluscs and barnacles, which create frictional drag and increase fuel consumption. Anti-fouling paints containing mercury, arsenic, lead and also tributyltin (TBT) are used to prevent colonization on outer surface of hull. Zinc chromate, strontium chromate and lead carbonates are toxic compounds that are also present in paints. It is known that paint chips are the main polluting agents which contaminate soil. Approximately, 9,500 tonnes of steel is used in a ship of 10,000 tonnes which is coated by paints [14]. Paint chips and soil were analysed by Mahindrakar et al. [14] and were found to have heavy metals like lead, cadmium, zinc, nickel and chromium in considerable amounts.

3.5 Bilge and Ballast Water

The term bilge refers to the lowest compartment inside the hull of a ship which collects the water, mainly originated from the engine components room. Untreated bilge water mainly consists of oil and grease (O&G) and a mixture of oxygen-demanding substances (organic and inorganic materials). These are dangerous to human health if they get into the food chain and the ecosystem. The stability of the ship is essential to be managed for floating in seas. Ballast plays a vital role in the stability aspect. Water added for stability helps to save time, but the major problem occurs during transfer of ballast water when ship demolition activity is initiated. The main issues include transport of harmful organisms as well as disruption of marine ecology

3.6 Radioactive Wastes

Large variety of vessels, offshore oil-drilling and production platforms undergo recycling at Alang. These include warships which may have carried nuclear weapons or any such devices. It has also been recognized that the other vessels (non warships) may contain radioisotopes at certain locations such as smoke detectors (found in most of the ships), liquid level indicators (found in <5% of ships), etc.

3.7 Other Solid Wastes

Other solid wastes which are generated are remnants of cargo, packaging material (wood, cardboard, paper), insulating material like polyurethane foam rubber, expanded polystyrene (thermocol), plastics, metal chips, contaminated soil, etc. [3].

4 Challenges Posed by Hazardous Wastes

There are serious threats posed by the hazardous materials liberated from the SRY on environment as well as health and safety of the workers. This concern is also reinforced by the fact that developing and underdeveloped countries have been increasingly explored as a grave for toxic industrial wastes by the developed countries [5]. The major challenges caused by ship dismantling/recycling activity on society and environmental are briefly discussed below.

(a) The in-built hazardous and non-hazardous wastes range between 0.5 and 10% of the ship's total weight. The substances are significant in both quantity and toxicity. Absence of environmentally sound dismantling facilities and reluctance of ship owners towards decontamination of ships prior to export compel the yard owners to adopt direct dumping of hazardous wastes. Hence, these wastes are directly released into the environment and posed a serious threat to surrounding environment [5].
(b) Pollutants are in the form of oils, oil-containing sand, asbestos, heavy metals, electrical wire and sheathing materials and persistent organic pollutants, and many more are discharged into the environment during the ship recycling activity. In a study on the heavy metals concentration near Alang-Sosiya yards, it was reported that the concentration of the heavy metals such as Cd, Co, Cu, Cr, Fe, Pb and Zn were found 2 to 19 times higher when compared to the control locations [5, 19]. This clearly indicates the excessive presence of heavy metals at the ship recycling yards.
(c) Deterioration in physico-chemical properties of sea water with significant negative impacts on aqueous biota in the regions of ship dismantling activities has been observed.
(d) The particulate matter (PM) exposure to the workers who work as plate cutters in SRY is a major issue of concern.
(e) Many of the workers are illiterate and handle the hazardous wastes without any PPE which lead them to many lung, dermal and fatal diseases. The workers who handle asbestos are more vulnerable to fibre exposure which can lead to diseases like asbestosis. No comprehensive study has been done on this aspect till now.
(f) Oil contamination to the sand and beach is a major problem for the ship recycling industry. Fresh dry sand from the immediate beach is used to clean residual oil remains in oil tanks of ships poses serious threat to marine life when directly disposed into ocean without any treatment. Usually, oily sand is sent to dedicated landfill facility (at TSDF). Disposal of oily sand into the landfill without any treatment causes excessive volume occupation in the landfill and regular excavation of sands from the beach causes deterioration to the natural beach.

5 Laws and Regulations for Safe Handling of Hazardous Wastes

As a joint effort by the ship sellers, recyclers and various international organizations like United Nations, new rules and regulations came into effect. The Basel Convention was established to control the transboundary movements in hazardous waste and their disposal. The convention is designed to stop the "uncontrolled movement and dumping of hazardous wastes, including incidents of illegal dumping in developing nations by companies from developed countries" [1]. Later, the Hong Kong International Convention (HKC) for the Safe and Environmentally Sound Recycling of Ships was adopted in 15 May 2009. Before the HKC, there were no standard ship breaking procedures. HKC tries to ensure that ship recycling activity do not pose any unnecessary risks to health and safety of workforce and surrounding environment. It also addresses the issue of hazardous waste generation and management. It also ensures the detailing for design, construction, operation and maintenance of ships [13, 15]. The European Union (EU) has passed a new legislation entitled "Ship Recycling Regulation" on 10 December 2013 [8]. This regulation enlists the need of inventories of hazardous materials (IHM) required for all ships entering EU ports, as well as for EU-flagged ships. Some of the International Conventions relevant to India, laws enacted by the Central and State Governments currently enforced for regulation of ship dismantling and recycling are given in Fig. 4. These regulations serve as guidance documents and act as watchdogs ensuring sustainable practices in handling hazardous waste at the ship recycling yards.

Fig. 4 Major laws and regulations for the environmentally safe and sound dismantling of ships

6 Current Practices for Management of Hazardous Wastes

Ship recycling yards have to be authorized and regulated by authorities taking into account of the guidelines developed by the HKC 2009. The convention demands safe and environmentally sound removal of hazardous materials from the obsolete vessels as per the regulation 11 or 12. It is also essential to ensure that all hazardous materials listed in the inventory are identified, properly labelled and bagged and sent to the disposal facility. As per [21] verdict, GMB has directed for a complete inventory of hazardous wastes on board of ship as a mandatory requirement for the ship recycling owners. Negligence of the instruction will void the yards of their permission to operate. The inventory generated at yards shall be submitted by GMB to GPCB to ensure the safe disposal of hazardous wastes [21]. It is also essential that hazardous wastes like oil cakes, asbestos, glass wool shall never be thrown into sea but kept safely packed and freon cylinders shall be safely kept in yards so that proper disposal at later stages is ensured. The open burning and sea dumping of wastes are prohibited by rules.

Under the GMB's regulation, the ship recyclers at Alang-Sosiya are supposed to temporarily store the hazardous waste generated after the removal from ships. Special wastes such as asbestos are handled by GMB authorized company called 'Industrial Hygiene and Safety (IHS)'. The designated agencies handle the collection, transport and disposal of hazardous waste generated in the area. The hazardous wastes generated at the ship recycling yards are regulated as per the Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016 [10]. GMB designed TSDF manages waste from SRY. The facility receives all categories (landfillable, incinerable, bilge water) of hazardous waste obtained during ship demolition activity. It also permits municipal solid waste from Alang-Sosiya ship recycling yard area for disposal. The facility has landfill cells (three in numbers) for hazardous wastes, landfill cells (two in numbers) for non-hazardous wastes, incinerator, effluent treatment plant and a laboratory too. The current reciprocate measures for sound management also include sufficient oil recyclers, outsourcing asbestos-containing material (ACM) removal, handling and packing activity as per national and international guidelines.

7 Assessment of Present-Day Regulatory Actions

Due to the implementation of the stringent and systematic guidelines and protocols by the national and international agencies as well as the Indian government, the ship breaking industry in India has been transforming into a greener sector. Alang-Sosiya-SRY has undergone tremendous change as far as aspects of environmental protection, health, safety and security standards are concerned. As per the directions by the Hon. Supreme Court of India along with IMO convention guidelines, the safety of workers has become a high priority in SRY. The personnel from Gujarat Maritime Board (GMB), Gujarat Pollution Control Board (GPCB), Atomic Energy Regulatory Board (AERB), Customs, and Explosives Department go on board the vessel for inspection before granting the permission for beaching the vessel. Despite pollution control measures and initiatives taken by the regulatory authorities, this sector has come to limelight because of its bad record of occupational health and work place safety and environmental degradation.

The Gujarat Maritime Board (GMB) joined hands with the ship recycling industry at Alang-Sosiya for the safe ship recycling in the year 2004, thus imposing strict rules and regulations before and after beaching obsolete ships for recycling. GMB has stipulated most of the guidelines given in the Hong Kong convention. Some of them are inspection before and after beaching for stored hazardous material by concerned authorities, SRY inspection by concerned authorities, ship recycling facility plan before beaching, ship recycling plan, safety officer and production manager for each yard, training to the workers, use of personal protective equipment (PPE), asbestos removal room, hazardous material storage and disposal, recording and reporting of accidents in the yard to the concerned authority, free from contamination and hot work certificate after removing all the flammable gases and oils from ship, etc.

The need of the hour is technological advancements and awareness to prevent workers from getting exposed to hazardous materials. The guidelines provided by GMB are already complying with the IMO guidelines, and most of the existing ship recycling yards in Alang-Sosiya are certified with ISO certifications such as 9000, 140001, 18000 and 30000.

8 Potential Interventions for Environmental Sound Management of Hazardous Waste

Some specific interventions and their outputs if they are implemented are articulated in Table 3.

Table 3 Suggestive interventions for improvement of hazardous waste management at yards

Potential interventions for improved management of hazardous wastes	Expected output if the interventions are implemented on field
Inventory of hazardous materials	The inventory shall be regularly checked and updated during the lifetime of ship operation and must reflect the new installations. This will aid in the process of hazardous waste management
Extended common hazardous wastes Treatment storage and disposal facility (CH-TSDF) for wastes generated	In order to meet the future projected growth of ship recycling industry in India
Need for a hazardous material removal pre-treatment facility	It will aid in the removal of hazardous paint and pre-cleaning of residual oil and other potential explosive materials. This will also ease the disposal process pathways in the TSDF
Co-processing of hazardous wastes in cement kilns	High calorific value wastes from SRY can be used as an alternative fuel or raw material in cement kilns. "Resource conservation" and "pollution control" can be achieved if co-processing of hazardous wastes is done
Common incinerator facility for disposal of wastes from ship repairing and recycling industries	The thermal treatment of wastes through incineration destroys the waste completely, thereby minimizing direct risk to the environment
Collection, solidification, stabilization and disposal or reuse paint flakes and chips for the minimization of emissions of heavy metals to inter-tidal zone	Solidification and stabilization of wastes with binders and reagents reduce the leaching of contaminants. This intervention will develop management strategy for paint chips generated from ship recycling
Stabilization and disposal of asbestos and glass wool for minimizing the emissions to primary and secondary zones of plate cutting operation in SRY	The stabilized waste matrix has better environmental acceptance and lesser environmental footprint
Personal protective equipment (PPE) for workers	This will reduce respiratory diseases and skin exposure to hazardous wastes

9 Summary and Discussion

In order to develop interventions for the management of hazardous wastes originated from the ship recycling industry, it is imperative to have a better understanding of the mechanisms involved in this process. Sources and locations of hazardous materials in the ships, removal techniques, inventorization of hazardous materials, proper packaging, treatment and disposal are necessary to be known in detail to formulate strategies for hazardous waste management. Transportation, handling, storage and disposal of hazardous wastes such as asbestos, glass wool and paint chips will be the major challenges for ship breaking and recycling industry in Alang in the coming years.

Appropriate studies bridging the gap in research and policy will aid in framing strategies for management of hazardous wastes at yards. “Epidemiological studies” aimed at monitoring workers’ health will help to identify diseases like asbestosis, lung fibrosis among labour force. This will help in deciding the need of efficient PPE, safeguarding workforce from hazardous waste exposure and minimizing the frequency of accidents. Likewise, “risk assessment” studies will guide more for the clean and green ship recycling practices. Also, “ecological studies” for minimizing the impact of ship dismantling and recycling industry on the marine environment should be encouraged. Cleaner technologies can be adapted in order to generate less or no pollution. Hence, in the future work, identification of opportunities to apply clean technologies in various processes during the ship dismantling/repairing can be continued in order to further minimize the environmental pollution. More holistic work has to be exercised in the area of hazardous waste management at the ship dismantling yards.

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An Approach Towards Sustainable Municipal Solid Waste Management in India

K. V. Shah and D. D. Shah

Abstract In this paper, the author will discuss his perspectives on some of the most important approach and suggestions to challenges faced by the solid waste management sector. The given approach, in general, will be divided into those faced by the industry as a whole on different parameters which affect the solid waste industry. In addition, the author will review how solid waste management can be put to practice by using some brainstorming techniques, urban local bodies' methodology, Strength, Weakness, Opportunities and Threat (SWOT) analysis, with respect to Gujarat State. Along with that at times putting emphasis on technology development for 40% of the waste treatment and scientific disposal of solid waste, remaining waste needs to be recycled as much as possible (National Master Plan for Development of Waste-to-Energy in India) [1]. Finally, the author will review, what in his opinion are, some of the most emphasizing approach for the Indian conditions (especially Gujarat) which can be adapted to manage solid waste in India.

Keywords Approach and suggestions · Brainstorming techniques
SWOT analysis · Technology development

1 Introduction

A tremendous increase in the developing countries population leading to increase in pollution is seen because of industrialization and urbanization. The current problem is like a tip of the ice berg whilst the real issue has greater depth and breadth to be addressed. Indian waste generation growth rate is 1.3% per annum which signifies the economic development and living standards of the society. In the current

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scenario in order to cater the need of reduction in solid waste and to meet the energy crisis, adaptability of technology for the given region to process solid waste is there. Western style of living and "throwaway" nature of people has lead to increase in the humongous amount of waste, and also, the not in my backyard (NIMB) psychology plays a vital role [2, 3]. The gravity of the problem needs to be addressed by taking prudent steps for processing of waste through suitable technology selection and its implementation for regional solid waste management.

2 Objective

Poverty alleviation, reduction, infrastructure development in urbanities, providing service facilities are essential for a developing country like India. Additional funding in urban areas will cater to the growth of economy of the region. In this study, municipal solid waste is taken under consideration excluding industrial hazardous waste, biomedical waste and E-waste which does not come under Municipal Corporation; along with that the need for adaptability, suitability, reliability, sustainability, justifying the workable approach with its implementation part, an important factor that helps in freezing upon the scope of study considering

Table 1 Solid waste management approach for Gujarat State

Waste type	Responsibility of management	Approach	Remarks
Municipal solid wastes (MSW)	MC/ULBs	40% wet waste to be composted, bio digested, anaerobically treated	Swachh Bharat Mission, Gujarat, plays implementation role
Plastics wastes	MC	Recyclables, belled and transported to the recycler	GPCB supervises the generation and disposal
Wastes (C&D wastes)	MC/ULBs	Shredded and used in making bricks, roads, pavement blocks, etc.	Initiation necessary
Biomedical wastes (BMW)	MC/District Officers	Utmost care not to get mixed it with MSW. Separate van collection system	Stringent rules for the implementation
Hazardous wastes, batteries	MC/ULBs	Follow industry standards and dispose off with the outlets' centres constructed by the State government	Industries to follow the guidelines
Electronic wastes (E-wastes)	MC/ULBs	Dispose off with the outlets' centres constructed by the State government	Industries to follow the guidelines

DoM Directorate of Municipalities; *GPCB* Gujarat Pollution Control Board the waste physical and chemical characteristics, regional conditions as well as technical assessment of the different type of waste treatment options.

Safeguarding public health and environmental safety should be the utmost priority to be considered precisely while designing processing technologies for solid waste [4–6]. If the said precautions and conditions are cogently considered, it can be a big paradigm shift from the material recovery facility, composting and dumping in urban regions, also sufficing the power need in India. While keeping in mind, the most emphasizing approaches for the Indian conditions (especially Gujarat) can be adapted to solve the existing issues on a larger scale (Table 1).

3 Problems in Management and Treatment of Solid Waste

Issues to be addressed are the ample amount of food waste, municipal solid waste and lags in selection of sustainable waste to energy technologies for systematic solid waste management (SWM) to have proper sanitation [7, 8]. Due to urbanization and higher economic standard of 42% of Gujarat people living in urban areas, municipal solid waste has increased in humongous manner. Many urbanites are regularly threatened by poor sanitation issues and adulteration. Many health and environmental issues have raise because of improper waste management.

In India, 94% and in Gujarat 75% of waste is disposed of unsafely, either burned or dumped, causing air, water and land pollution. This requires proper planning, management, technical expertise making use of decision support tool for selection of sustainable waste-to-energy processing technology for solid waste management (SWM) on vulnerable parameters. Waste generation rate in Gujarat towns ranges between 300 and 670 g/day, depending upon the size and region's lifestyle of the town. The per capita waste generation is increasing by about 1.3% per year in Gujarat and India [9]. Gujarat has approximately 10,145 Tones/per day of waste generation out of which only 2600 TPD is processed, and thus, a gap of 7545 TPD of unprocessed waste is there which is simply dumped unscientifically [10, 11].

4 Focus Points

Integrated Solid Waste Management Model, Financial model for Solid Waste Management, Data and measurement for each ULBs w.r.t. Solid Waste, Capital expenditure for construction and development of waste processing plant, recurring (O&M) expenditure on treatment of solid waste, land requirement for establishment of plant, market for the product are the parameters which are to be focused very precisely.

Analysis based on certain factors and approach that makes the Role of Management for Solid Waste Management in the ULB an achievable task (Fig. 1).

Hereby, the factors which are considered can make sound full results for waste management in the state.

Factors like people, social, economical, technological, socio-economical, financial, techno-commercial, political are taken under consideration and cross-verified for proper analysis and finding out the most crucial and important among them for the aforesaid purpose (Table 2).

Few approach other than mention above can also be looked upon:

1. Use of user-friendly technologies to sustain the waste model should be there.
2. Tie up with Telecom companies, Amazon-type marketers, social media campaign, and giving award in form of gift by renowned celebrity.
3. Need to play with the mentality of humans.
4. Make them do the work rather them ULB doing the same.
5. Make them walk a distance to put bags in the bins, than emptying dust in their bins at households.
6. Use of technologies should be more with less people movement.
7. Give ULB people incentives rather than burdening them with levy or taxes.
8. Give quality work output by send messages, updates, etc.
9. Try to connect at each and every aspect to make them feel happy about the ULB rather than saying negative things.
10. Give sweeper, maidservant credit by giving coupons, talktime, incentive for storage of segregated waste.
11. Indian people are ready for storage of segregated waste to get something out of it.
12. Conduct the collaboration activity that involving the NGO and community group to educate the community about the waste management.

Fig. 1 Role of Management in Solid Waste Sector

Table 2 Swot analysis of Gujarat State for SWM

Parameter	Strength/Opportunities	Weakness/Threats
Segregation at source	Innovative approach is welcome in the field by the government	Mindset of people not to segregate due to lack of awareness, responsibility, patriotism
Primary collection	State government conducting the agreement with the municipalities to implement the collection modules	Lack of facilities and infrastructure to support waste coverage (SLB* report)
Street sweeping	Solid waste management system was established	Habit of using plastic bags threat to the society and damage to the infrastructure and environment
Storage of waste	Few ULBs have storage facilities	People not willing to put bags in storage bins, due to bad odour
Secondary collection	Strong at ULB level at more than 90% coverage	Breakdown of equipment due to automation
Transport	Min truck and refuse compactor vehicle very useful	Skilled manpower is required with adequate salary package
Processing facility	93 ULBs having land for processing, 56 doing Vermi composting	Lack of infrastructure facilities and will to process, lack of tipping fees
Disposal	13 sanitary landfill established	Unwillingness to increase tipping fees per tone of waste disposal
Community participation and public awareness	IEC activities at State level in full fledge, waste awareness high profile events	Willingness to participate is lacking, incentive is not given

13. Provision the budget to constructing the environment-friendly facilities and infrastructure to support and maintain the solid waste management system.
14. Propose the education program for community to increase the effort of composting to cover the shortfall of covering service of solid waste management.
15. Provoked the student as young people involvement in NGO as the active agent for involving in the solid waste management system.

5 Strategic Direction (Tool to Use)

Based on the feasible condition of the ULBs, following tool should be used (Table 3).

Due to vulnerable parameters, each tool should be vividly seen with flexibility to implement it at the MC/ULB level (Fig. 2).

Formulation of strategy must be looked upon after going through the parameters and policy-level decisions to achieve the targets for the MC/ULB (Fig. 3; Table 4).

Other ways as per the Author's opinion are as follows:

Table 3 Phases of SWM and Strategic Tools to use

Activity	Tool
Collection, transportation and cleaning	Management contract MC/Private based
Building transfer station and transportation	BOOT/DBFOT/Role of MC
Waste treatment facilities	BOOT/DBFOT, Role of ULB/MC
Making of sanitary landfill and its operation and maintenance	MC/DBF/Role of ULB/MC
Integrated solid waste management system	Mostly on BOOT

(1) It is to keep in mind that though the cost of technology might be more as per the PPP mode of contract that the processing of maximum waste generated from the city should be done as early as possible, waste to energy technologies should be given promotion.

(2) Market for the product generated at the end should be there, in current scenario is doesn't seem to be there. If at all the technology supplier proposes its technology providing full capex and opex, the question arises whether they would be able to achieve the breakeven. The ground reality is, there isn't any sufficient open market for the compost produced. Even the electricity prices for the generation are high enough would REC or GEC buy the electricity at such rates.

(3) One more thing to be focused is the public acceptability, and it is noted that the plant using advanced technology are emitting maximum pollution in the form of gases or residue. Thus, an issue of public acceptability should also be considered. It is to be noted that the parameters like Readiness - detailed information, Size and Flexibility, Maintenance and Operations involvement in

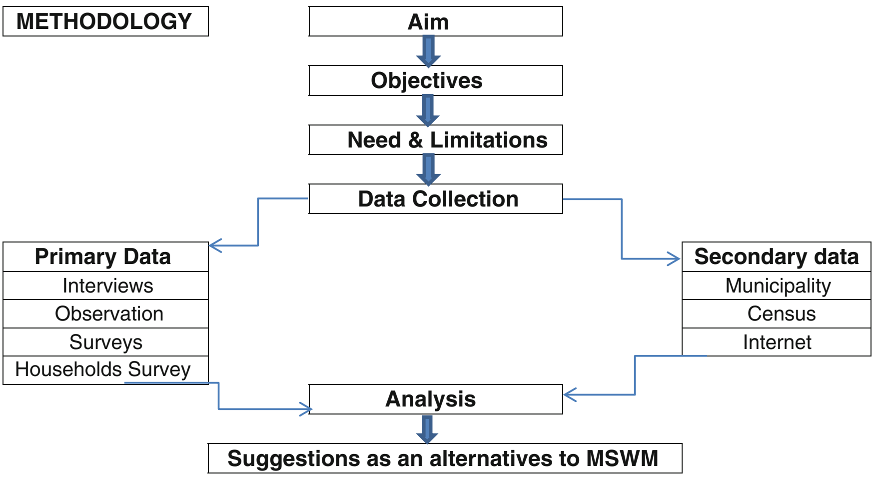

Fig. 2 Tool for the SWM MC/ULB

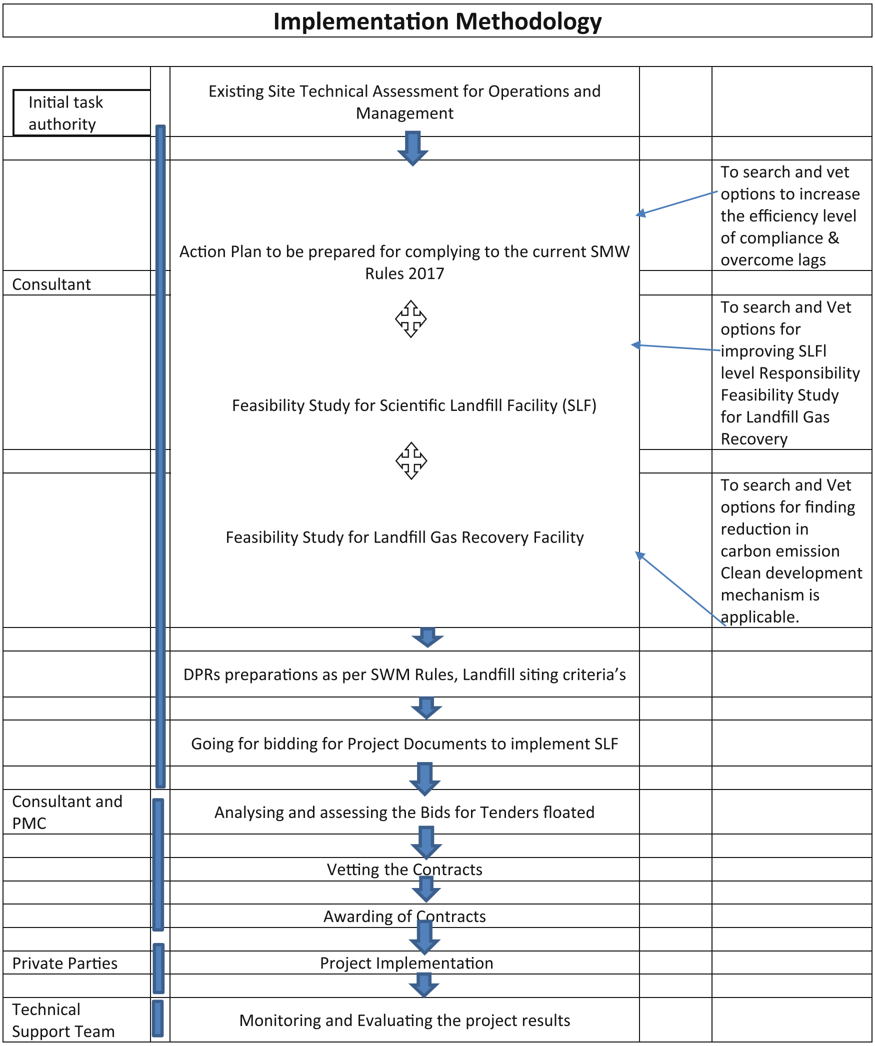

Fig. 3 Implementation methodology
Source Approach for Integrated Solid Waste Management Plan, Pune (Volume I) August 2007, Prepared for UNEP DTIE IETC and Pune Municipal Corporation (PMC) Prepared by Dr. Prasad Modak Consultant With support from Environmental Management Centre, India

processing, Marketability of Product, Quantity of Residuals Requiring Landfilling, Environmental Impacts, Public Acceptability and Risk Profile (end-product risk) are the eight parameters considered which stands out to be important.

(4) For the collection, primary and secondary transportation of solid waste from individual door to door can be given contract. Negligible amount of fees can

Table 4 Stagewise approach for Integrated Solid Waste Management Plan

Stages	Description of the parameter
Stage 1	Responsibilities to be clearly define by the Authority
Stage 2	Consultant to be appointed for a specific designed role
Stage 3	PMC to be appointed to monitor the consultant activities within scope of work
Stage 4	Private agencies to make accountable for the implementation of the project
Stage 5	Consultants to have constant evaluation and precise monitoring post-commissioning of the plant for define period

be taken from each household as per the rules set. If we talked about informal sector, then it could be standardized and made use to its full strength. Making informal sector more standardized can play a vital role. CSR activities for the rag pickers can be carried out for the individual as well as for the families of rag pickers.

(5) Why to give resources free of cost when you are giving them facility till the site; i.e., collection and transportation is done by government. Inviting national/global technology suppliers and more efficient work can be achieved going for request for proposal (RFP) mode.

(6) At landfill site, dumped waste is lying from years, also known as the best resource for refuse-derived fuel (RDF) which can be used in boiler section in power plants operation. If government tend to change it's policy and gives support in this direction most of the waste lying there can be used. MSW to energy generation is also a viable option.

(7) A decentralized system of processing of solid waste can also be implemented (role model: Pune, India). A collective wisdom can be established so as to make the system more powerful.

(8) Policy reforms for the MSW rules 2000 and 2016 are an urgent need. Separate bye-laws need to be made for this purpose (e.g. AMC). Monitoring and supervision as well as measurement are the three most important steps which need to be carried out only monitoring is done while the city lacks in supervising as well as measuring the process of transfer as well as treatment of solid waste [2].

9) A dynamic combination of government R&D laboratories and institutes should be there so that proper views, experience and a quality output are obtained.

(10) Moreover sensitizing the technology thereby the civil society is the need of the hour, which technology to use for a particular kind of waste generated should be known then only suitable technology can be used.

(11) Other city case studies should be exploited and implemented, e.g. Hong Kong, Brazil, Kerala.

(12) A society/cell looking after it may be appointed so that proper concentration and efforts can be made.

(13) Proper financial arrangements should be done and willingness to undergo the processing of solid waste treatment should be generated among the government and people.
(14) Well-established technology know-how is lacking which should be focus on.
(15) Issues related to separation and segregation of solid waste from household play a vital role. Separate bins for biodegradable as well as non-biodegradable material need to be put.

6 Conclusion

Rudiment step is to focus on the mindset of ULBs conditions and willingness to manage municipal solid waste as per the 72nd Amendment Act of the Constitution of India. Scientifically speaking, managing waste should be the generators responsibility. Due to lack of awareness and self-discipline the segregation of waste streams isn't getting up to the mark, responsibilities of general public is not accountable at the moral ground. ULBs should focus solely on sanitation rather than depending on Central and State government help. PPP should be seen as a favourable strategy to prepare models with respect to the individual regions. Waste sector is seen as the gold market for the private players and budding entrepreneurs in the coming future. Weakness in political will and administrative skill need to be overcome as soon as possible [12]. The strategies and suggestions referred above are as per the Environment Protection Act, and the inputs recommended may see the light of the day if incorporated after a thorough analysis.

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Reliability Modeling of Railway Signaling System by Markov Process

Nikesh Kumar, Subhash Chandra Panja and Rahul Baidya

Abstract Railway signaling system is the most important system for efficient and reliable operation of trains. The signaling systems are divided into subsystems, namely signal unit, track unit, and point-and-point machine. Further, the reliability, availability, and maintainability of signaling system and subsystems are required for safe operation. The study uses Markov process to gauge the reliability of the system and subsystem. Markov process is a mathematical technique that undergoes transitions from one state to another, between a finite or countable number of possible states. Then, a case study was developed in one of the busiest tracks in eastern India. The data obtained was used to analyze the reliability pattern of three signaling subsystems. Special attention in relation to maintenance and inspection activities and logistics support is required to improve the reliability and maintainability of signaling subsystems and system, so as to make the railway signaling system sustainable in long run. The Indian Railway (IR) on an average carries 22 million passengers a day. It is estimated that IR solid waste generated at major railway stations across the country is nearly 670 tons per day (TPD) (or 245,000 TPY). Thus, efficient and reliable signaling system is necessary to reduce the waste generation at the station as waste generation at the station is directly proportional to the time it is waiting in the station/line. Thus, efficient signaling will make the station/line cleaner.

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1 Introduction

Signaling system is an integral part of Indian Railways, so it should be very reliable and should be maintained effectively and efficiently [1]. In this study, we classified the signaling system in different subsystems like track circuit, signal unit, and point-and-point machine and then reliability and maintainability of every subsystem are evaluated and graph is plotted for different time intervals. Reliability of different subsystems and steady-state reliability of different subsystems is calculated with the help of Markov chain process so that rail maintenance cost can be decreased and also danger of accidents can be reduced. Information on system behavior and failure modes is extremely important for taking decisions on maintenance strategy [2, 3] or action as well as waiting time of the train at the platforms can be reduced which will also reduce the cost related to the managements of waste generated. The reliability of the signaling system is analyzed based on a five-and-half-year failure database. The reliability estimation by using non-homogeneous process and homogenous renewal process is explained. Reliability pattern at different operating intervals was drawn, and the behavior was analyzed. The behavior shows abnormality in some component levels. Finally, reliability pattern at system level was analyzed by the reliability pattern at different operating intervals. This study deals with the performance analysis of signaling system failure data analysis using a Markov model. Reliability block diagram (RBD) of the signaling system has been developed. Markov's transition diagram has been presented. From the transition diagram, state transition linear differential equations are derived for the Markov process and then the steady-state performance of signaling system has been discussed. Again, special attention in relation to maintenance and inspection activities and logistics support is taken to improve the reliability and maintainability of signaling subsystems and system which will also reduce the waste generated at the stations. The Indian Railways has traditionally been already overburdened. The development of more efficient signaling system will reduce the waste generation. Preventing/minimizing waste at source has significant potential to avoid waste and in reducing the cost of managing it.

2 Methodology

The methodology adopted in the study involves the following steps: Firstly, a literature review was carried out to find the challenging issues for a practical application of a RAM modeling and finding the constructs for the strategic managerial requirements. Secondly, a survey was carried out to determine the critical parts and the applicable technology for the railway signaling systems; these findings were also supported by the literature. Thirdly, the failure data of 5 years of signaling system from Kharagpur to Bali chalk is taken as our maintenance study. Total numbers of failures from January 1998 to 2002 are taken for the analysis. Most of the failure data is taken from the maintenance logbook maintained by different sections of the five local stations. Fourthly, a model was developed based on the Markov process. Markov model is selected for the analysis of railway signaling subsystems and reliability. With the help of data collected from Indian Railways, the reliability pattern of three signaling subsystems are calculated, graph is plotted, and also maintenance interval is calculated.

3 Discussion and Results

Railway signaling system consisting of three main subsystems, viz. track circuit, signal unit, and point-and-point machine, plays an important role to control and monitor the train movement. Railway signals are used to indicate different aspects and indications such as red, yellow, double yellow, proceed, proceed with attention, and stop. So it has to be reliable and maintained effectively and efficiently. Keeping this in mind, reliability, availability, and maintainability of signaling system and subsystems may be considered as key issue for safe operation of trains and hence minimize the downtime of the entire system [6]. One of the important and suitable tools of these analyses is Markov process. A Markov chain, named after Andrey Markov, is a mathematical system that undergoes transitions from one state to another, between a finite or countable number of possible states. The next state depends only on the current state and not on the sequence of events that preceded it. Markov model is a better technique that has constant failure hazards and repair hazards [4]. Modern probability theory studies chance processes for which the knowledge of previous outcomes influences predictions for future experiments. In principle, when a sequence of chance experiments, all of the past outcomes could influence the predictions for the next experiment. Various degradations on signaling system can be viewed as different Markov states, and further degradation can be treated as the outcome of the present state [5]. The signaling system is treated as a discrete-state continuous time system with four possible outcomes, namely s1: good condition, s2: system with partial degradation failures, s3: system with major faults, and s4: system completely fails. Markov model is a better technique that has much appeal and works well when failure hazards and repair hazards are not changing. The assumptions are as follows: Time between failure (TBF) and time to repair (TTR) data are exponentially distributed [7]. So there are no simultaneous failures of subsystems, and the probability of more than one failure or repair in a time interval is zero. Markov process is a mathematical technique that undergoes transitions from one state to another, between a finite or countable number of possible states [8]. Its next state depends only on the current state and not on the sequence of events that preceded it. It is assumed that time between failures (TBFs) and time to repairs (TTRs) factors are exponentially distributed [9, 10]. Thus, there are no simultaneous failures of subsystems and the probability of more than one failure or repair in a small time interval is zero.

From Fig. 1, linear differential equations are derived for railway signaling system with the help of the Markov process. The transition probabilities P_{ij} of a homogeneous Markov chain form an $n \times n$ matrix, called a transition matrix where P_{ij} is the probability of failure of *i*th component at *j*th state are as follows. The transition probabilities P_{ij} of a homogeneous Markov chain form an $n \times$ n matrix, called a transition matrix which is:

$$[P_{ij}] = \begin{bmatrix} P_{11} & P_{12\ldots} & P_{ij} & P_{in} \\ P_{21} & P_{22\ldots} & P_{2j} & P_{2n} \\ . & . & . & . \\ P_{n1} & P_{n2} & P_{nj} & P_{nn} \end{bmatrix}$$

By using the above transition diagrams of Fig. 1 and applying assumptions, steady-state reliability for signaling system is formulated as follows.

Since all the components of signaling system are in series, so the reliability of whole system $R(t)$ is found as

$$= \prod R_i = R_1 R_2 R_3 \text{ (for three components of signaling system.)}$$
$$= e - \lambda_1 te - \lambda_2 te - \lambda_3 t$$

From the transition diagram presented in Fig. 1 and the Markov equations, availability of the signaling system is found as

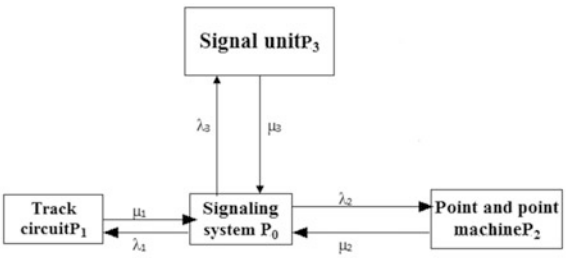
$$P_0 = 1/[1 + \sum (\lambda_i/\mu_i)] = 1/(1+D) \quad \text{where} \quad D = \sum (\lambda_i/\mu_i)$$

The formulas used are shown below. From transition diagram presented in Fig. 1, Markov equations can be derived. The probability of the signaling system is in the operating state after time interval d*t*, i.e., at time (t + d*t*) is given by

$PS_0(t + dt)$ = [Probability of being in working state at time *t*) and (Probability of not failing between *t* + d*t*] + [Probability of being failed states at time *t*) and (Probability of being repaired between *t* and *t* + d*t*) [6].

Probabilities of failure between *t* and d*t* are λ_id*t*, and probabilities of not failing between *t* and d*t* are ($1 - \lambda_i$d*t*). Similarly, the probabilities of repair are μ_id*t*. Using the addition and multiplication rule for probabilities gives

Fig. 1 Transition diagram



$$PS_0(t+\mathrm{d}t) = PS_0(t)[(1-\lambda_1\mathrm{d}t)+(1-\lambda_2\mathrm{d}t)+(1-\lambda_3\mathrm{d}t)]$$
$$PS_0(t+\mathrm{d}t) - PS_0(t) = (-\lambda_1\mathrm{d}t-\lambda_2\mathrm{d}t-\lambda_3\mathrm{d}t)PS_0(t)+\mu_1\mathrm{d}tPS_1(t)$$
$$+\mu_2\mathrm{d}tPS_2(t)+\mu_3\mathrm{d}tPS_3(t) \text{ (Rearranging)}$$
$$[PS_0(t+\mathrm{d}t)-PS_0(t)]/\mathrm{d}t = (-\lambda_1-\lambda_2-\lambda_3)PS_0(t)+\mu_1PS_1(t)+\mu_2PS_2(t)+\mu_3PS_3(t)$$
$$\mathrm{d}t\to 0$$
$$\text{or } [\mathrm{d}PS_0(t)/\mathrm{d}t] = -PS_0(t)(\lambda_1+\lambda_2+\lambda_3)+\mu_1PS_1(t)+\mu_2PS_2(t)+\mu_3PS_3(t)$$

$$= \sum \mu_i PS_i(t) - PS_0(t)\sum\lambda_i \quad (1)$$

Similarly, for other states will be

$$\begin{aligned}[\mathrm{d}PS_1(t)/\mathrm{d}t] &= \lambda_1PS_0(t)-\mu_1PS_1(t)\\ [\mathrm{d}PS_2(t)/\mathrm{d}t] &= \lambda_2PS_0(t)-\mu_2PS_2(t)\end{aligned} \quad (2)$$

Equating first-order derivative to zero for a steady state, these equations will take the following form for three signaling subsystems only,

$$P_0(\lambda_1+\lambda_2+\lambda_3) = \mu_1P_1+\mu_2P_2+\mu_3P_3$$
$$[(\text{i.e. taking } Ps_i(t) = Pi(i=0,1,2,3)].$$
$$P_1\mu_1 = P_0\lambda_1 \text{ so } P_1 = (\lambda 1/\mu_1)P_0$$
$$P_2\mu_2 = P_0\lambda_2$$

$$P_3\mu_3 = P_0\lambda_3 \quad (3)$$

$$P_0+P_1+P_2+P_3 = 1 \quad (4)$$

Substituting the value of $P_{1,}$ $P_{2,}$ P_3 in Eq. (4), availability of signaling system in the steady state is found as

$$P_0 = 1/[1+\sum(\lambda_i/\mu_i)] = 1/(1+D) \quad \text{where} \quad D = \sum(\lambda_i/\mu_i) \quad (5)$$

Machine residing in other subsystems is as follows

$$\begin{aligned}P_1 &= (\lambda_1+\mu_1)[1/(1+D)]\\ P_2 &= (\lambda_2+\mu_2)[1/(1+D)]\\ P_3 &= (\lambda_3+\mu_3)[1/(1+D)]\end{aligned} \quad (6)$$

The reliability of different subsystems is

$$R_1(t) = e^{-\lambda_1 t}$$
$$R_2(t) = e^{-\lambda_2 t},$$
$$R_3(t) = e^{-\lambda_3 t}.$$

Assuming different parts of signaling system considered for this study are connected in series, so the reliability of the signaling system will be the product of the individual subsystem reliabilities.

$$R(t) = \prod\sum R_i = R_1 R_2 R_3 = e - \lambda_1 t.\, e - \lambda_3 t$$

Three signaling subsystems are calculated, and graph is plotted as shown in Fig. 2. The maintainability of different subsystems and machine is as follows:

$$M_1(t) = 1 - e - \mu_1 t, \text{ where } U \text{ is the repair rate}$$
$$M_2(t) = 1 - e - \mu_2 t,$$
$$M_2(t) = 1 - e - \mu_3 t,$$

Mean time to failure $\text{MTTF} = 1/\sum \lambda_i = 1/F$.
Availability of the system $(A) = \text{MTTF}/(\text{MTTF} + \text{MTTR})$.
Now mean time to repair $\text{MTTR} = \text{MTTF} \times D$, where $D = \sum \lambda_i/\mu_i$.
Repair rate of the system $(\mu s) = 1/\text{MTTR} = 1/\text{MTTF} \times D$.
Maintainability $Ms(t) = 1 - e - (\mu st)$.
Again, $R(t) = e - Ft$.

$$\therefore t = -\ln R(t)/F$$
$$Ps_0(t + \mathrm{d}t) = Ps_0 t[(1 - \lambda_1 \mathrm{d}t) + (1 - \lambda_2 \mathrm{d}t) + (1 - \lambda_3 \mathrm{d}t)] + \mu_1 \mathrm{d}t Ps_1(t) + \mu_2 \mathrm{d}t Ps_2(t) + \mu_3 \mathrm{d}t Ps_3(t).$$

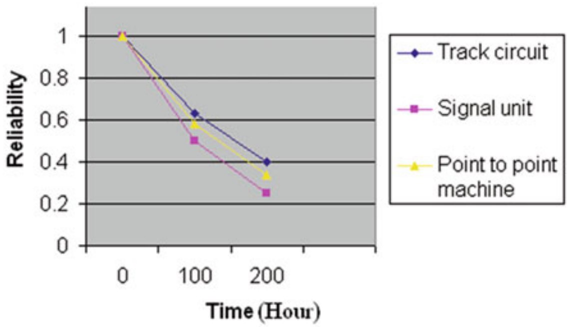


Fig. 2 Reliability pattern of signaling subsystems

Table 1 Repair rate and failure rate of different signaling subsystems

Components	Failure rate (λ)	Repair rate (μ)
Track circuit	0.00458	0.131
Signaling unit	0.00692	0.728
Point-and-point mechanism	0.00491	0.122

Steady-state reliability $P_1 = \lambda_1/\mu_1[1/(1+D)]$, $P_2 = \lambda_2/\mu_2[1/(1+D)]$, $P_3 = \lambda_3/\mu_3[1/(1+D)]$.

Where λ be the failure rate and μ is the repair rate.

The failure data of 5 years of signaling system from Kharagpur to Bali chalk is taken as our maintenance study. Total numbers of failures from January 1998 to 2002 are taken for the analysis. Most of the failure data is taken from the maintenance logbook maintained by different sections of the five local stations. With the help of data collected, repair and failure rates calculated are shown in Table 1.

From the above repair rate and failure rate of different signaling subsystems, viz. signal unit, track circuit, and point-and-point mechanism, the reliability at different time intervals is calculated which is given in Table 2.

Based on the above data in Table 2 the reliability of different signaling subsystems is calculated, and graph is plotted which is shown in Fig. 4. The collected data from Indian Railways was used to analyse the reliability pattern of railway signalling system.

From the above graph, reliabilities of signal unit, track circuit, and point-and-point mechanism are, respectively, 0.22, 0.41, and 0.27, respectively, after 10 h. So the reliability of signal unit is lowest between three subsystems; hence, it requires more attention than track circuit and point-and-point mechanism. The maintainability patterns of three signaling subsystems are calculated and are plotted as shown in Fig. 3.

From Fig. 3 for 100% of expected reliability maintenance interval should be zero for any system. From Fig. 3, it is clear that after certain time interval maintainability of signal unit is lowest. From figure, maintainability of signal unit, track circuit, and point-and-point mechanism after 20 h is 0.55, 0.65, and 0.75, respectively. For different percentage of expected reliability, we got different maintenance intervals from the Indian Railway data. From Table 3 for expected reliability of 0.10, maintenance interval is 140 h, for expected reliability of 0.20 maintenance interval is 98 h, for expected reliability of 0.30 maintenance interval is 74 h, and for expected reliability of 0.40 maintenance interval is 56 h. On this way, we need a

Table 2 Reliability of different signaling subsystems for different time intervals

Time (h)	Track circuit	Signaling unit	Point-and-point machine
0	1	1	1
100	0.6325	0.5001	0.5810
120	0.4001	0.2501	0.3376

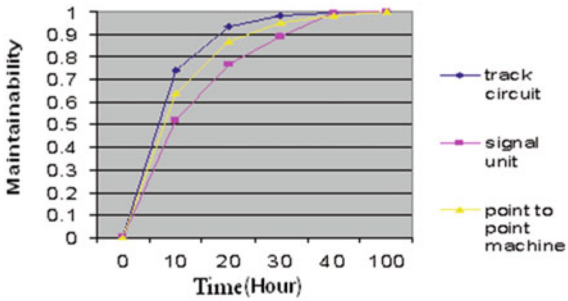


Fig. 3 Maintainability pattern of signaling subsystems

small maintenance interval for high reliability of signaling systems. For different percentage of expected reliability, corresponding maintenance intervals with the help of Markov chain are developed and presented in Table 3 and graph is plotted which is shown in Fig. 4.

From Table 1, there is a 100% chance that any failure in the system will be repaired within 140 h. It is also seen that the system will not fail for 20 h of working. It is observed that the reliabilities of the subsystems are decreasing overtime and reliability of track circuit, signal unit, and point-and-point machine will be 40–60% after 50 h and similarly maintainability of track circuit, signal unit, and point-and-point machine will be 50–70% after 10 h. Again, special attention in relation to maintenance and inspection activities and logistics support is required to be taken in improving the reliability and maintainability of signaling subsystems and system.

Table 3 Expected reliability for different maintenance intervals

Expected reliability	10	20	30	40	70	80	100
Maintenance interval (h)	140	98	74	56	22	13	0

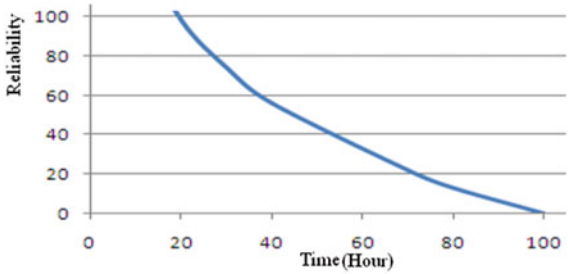


Fig. 4 Expected reliability for different time intervals

4 Conclusions

The reliability and maintainability of track circuit, signal unit, and point-and-point machine are evaluated at different time intervals. The reliabilities as revealed by the analysis are 0.22, 0.41, and 0.27 after 10 h for signal unit, track circuit, and point-and-point mechanism, respectively. Similarly for the maintainability of signal unit, track circuit, and point-and-point mechanism after 20 h were 0.55, 0.65, and 0.75, respectively. The inspection intervals of track circuit, signal unit, and point-and-point machine are found to be 3, 7, and 5 times in a month from model 1, and inspection intervals for track circuit, signal unit, and point-and-point machine are 1.06, 0.9, and 1.3 months, respectively. Maintenance intervals for 20% of expected reliability of signaling system are found to be 98 h. The reliability of system will lead to the sustainability of the railway system as it will reduce the waste generation at the source station.

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Multi-stakeholder Partnership for Managing Solid Waste: A Case Study of ITC Limited

Giresh Mohan and Akhilesh Kumar Yadav

Abstract Solid waste management is fast becoming an insurmountable challenge across urban India, requiring urgent solutions, especially in view of rapid urbanization and inability of local urban authorities to tackle it. In order to come up with viable solutions to this problem, ITC Limited has initiated public–private partnership initiatives in different parts of the country. For large cities with buyback opportunities, Well-Being Out of Waste programme is being designed, whereas for smaller towns and rural areas, decentralized waste management system is promoted. Integral to these models is involvement of rag-pickers in collection and processing, payment for these services by households, focus on source segregation and processing and close involvement of local bodies. This paper analyses approach of such decentralized models and challenges for scale up.

Keyword Solid waste management · Municipal waste · Public–private partnership

1 The Growing Challenge of Handling Urban Waste in India

Managing solid waste is going to be a major challenge faced by urban India in the current context of rapid urbanization. The problem is bound to worsen going forward: the quantum of waste generation in 2025 is expected to be double the amount generated in 1997 [9]. Moreover, lifestyle changes, poor planning, unavailability of infrastructure and apathy of local municipal bodies have exacerbated and added to the complexity of solid waste management (SWM) in India.

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The proliferation of solid waste in urban areas pose several unique challenges to urban planners:

(a) Several factors are responsible for the rapid and untrammelled growth of solid waste in urban India of which urban population, growing by 3.35% annually, undoubtedly tops the list. The total population living in urban areas has grown from 17% in 1951 to 31% in 2011 [2], and for the first time since independence, absolute increase in population in urban areas has exceeded the increase in rural areas during 2001–2011 [9]. Diminishing livelihood opportunities in an already low-paying agriculture sector is pushing people in large numbers to cities, which is expected to result in approximately 50% of the population living in urban areas by 2021 [5]. Further, rapid urbanization coupled with changes in consumption behaviour patterns is contributing significantly to the explosion in the quantum of waste generation.[1]
(b) With per capita waste generation in cities ranging from 0.2 to 0.6 kg,[2] India generates about 1.5 lakh MT waste per day [4]. The per capita waste may be relatively low compared to other countries, but the sheer size of our population leads to high quantum of waste generation in absolute terms. The nature of waste generated in Indian urban areas is very different from that of developed nations as it has a higher proportion of biodegradable waste. Studies show that biodegradable waste generation goes down with rising income, but this does not seem to be borne out in India: while the proportion of recyclable non-biodegradable material increased from 13 to 27% between 1996 and 2005, the period witnessed a simultaneous increase in biodegradable waste from 42 to 48% [3]. This indicates that there is an immense opportunity for recycling and composting of municipal waste in India, provided source segregation of waste is inculcated as a habit.
(c) The new "Solid Waste Rules, 2016", set the clear responsibility of waste management on urban local bodies (ULBs). Despite the emphasis on "recycle before disposal" in all the versions of legislation [11], it is estimated that 94 per cent of the total waste collected is disposed unscientifically, resulting in the pollution of surface water, groundwater, as well as the air [10]. Despite SWM being labour intensive, only 2–3 workers are deputed per 1,000 inhabitants for providing services and ULBs spend in the range of Rs. 75–250 per capita per year, a pittance compared to the enormity of the problem [6]. Since most municipal bodies are cash-strapped, partnerships with private and civil society

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[1]Municipal Solid waste "includes commercial and residential wastes generated in a municipal or notified areas in either solid or semi-solid form excluding industrial hazardous wastes but including treated biomedical wastes" As per decomposability, solid waste is divided into two categories, viz. biodegradable and non-biodegradable. Non-biodegradable waste is further divided into recyclable and non-recyclable waste (Source: http://upenvis.nic.in).

[2]This is relatively low compared to many developed countries of the world. USA with waste generation of 1.9 kg per day per person tops the list followed by the Netherlands (1.41) and Brazil (1.4) [3].

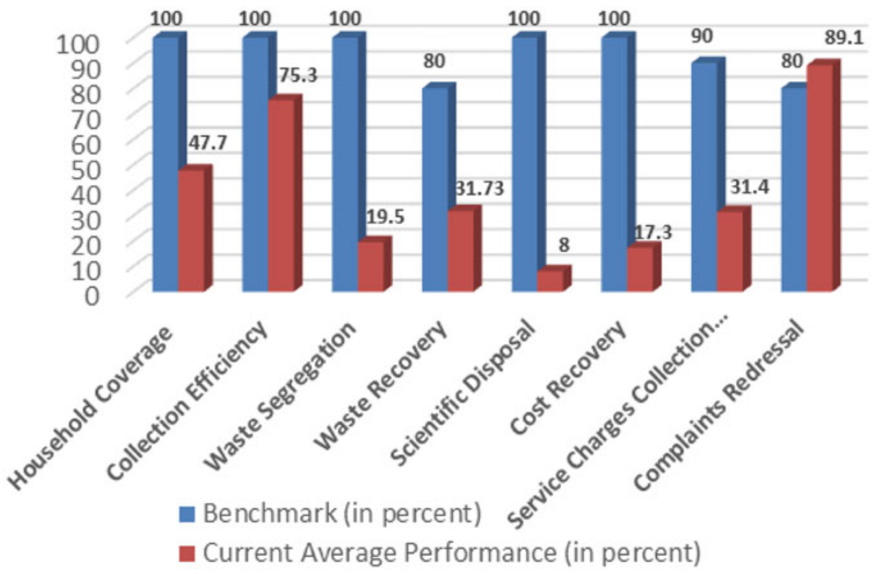

Fig. 1 Service-level benchmarks for SWM and average performance of ULBs. *Source* Chatri et al. [3]

organizations for scientific management of solid waste with all partners contributing as per their strengths would be of immense benefit (Fig. 1).

(d) The Ministry of Urban Development (MoUD) has defined eight service-level benchmarks[3] (SLBs) for SWM. However, an assessment of the average performance of 28 ULBs revealed that none of these benchmarks are achieved except for complaints redressal. Against the benchmark of 100% household coverage and cost recovery, only 48% and 17% level is achieved, respectively. Waste recovery has been as low as 32% against the desired benchmark of 80% and collection of service charges from households stands at 31%, which is not even half of the desired benchmark of 90% [3].

(e) It is to be noted that private sector participation in waste management is not new to India and in fact dates back to 1985. However, services provided by the private sector are mostly contractual in nature and limited to a few segments of the SWM (ibid.). The “Municipal Solid Waste Management Rules, 2000”, under its Article IV, for the first time clearly sought private sector participation in service delivery, leading several players to explore the development of

[3]Ministry of Urban Development, Government of India has developed performance indicators related to urban management and service delivery in four basic urban services, viz. water supply, sewage, solid waste management and storm water drainage. These indicators are termed as “service-level benchmarks”.

profitable projects under PPPs. Citizens' participation, however, was not explicitly articulated in the legislation. Also, reliable information on the extent of community participation in PPPs in SWM is not available to the required degree in the public domain [11].

To summarize, Indian cities and towns are confronted with the challenge of effectively managing a rapid expansion in solid wastes. The main agencies at the forefront of this battle are the ULBs, which suffer from poor financial health, lack trained human resources and do not deploy scientific principles and methods for waste management [7]. It is the contention of this paper that solid waste in cities and towns can be managed through integrated plans, implemented through multi-stakeholder alliances and premised on behaviour change to minimize the waste load that municipalities are expected to handle.

2 Lessons from Successful Projects

The Pune Municipal Corporation (PMC) has successfully tried out different methods and technologies of waste management. With the support of SWaCH, an NGO and involvement of rag-pickers, around 56% of the waste is segregated resulting in the processing of about 80% of it [8]. The PMC has established a number of waste-to-energy plants and composting units in different localities in collaboration with private vendors. This partnership model, which evolved gradually through dialogues and deliberations, saves around Rs. 150 lakhs annually to the PMC besides reducing the cost associated with environmental degradation. Contrary to the reluctance displayed by many municipalities to collect service charges, this initiative successfully executed it, which is a positive change towards sustainable waste management practice [8].

The Ahmedabad Municipal Corporation (AMC) has developed a detailed master plan for city SWM with active engagement of stakeholders, keeping an eye on the future growth of the population and projections of waste generation. The corporation has framed public health by-laws for creating standards and norms for SWM processes and established the country's first mobile court to deal with violation of health and sanitation laws [1]. Ahmedabad became the first Indian city to be a signatory to the United Nations "Zero City Waste Declaration" that helped in leveraging national and international expertise. Strong commitment and the robust systems have helped the city in achieving the milestone of 98% waste collection by the corporation. The AMC spends around Rs. 2,500 per metric ton of solid waste collected [8]. Such an expenditure on SWM however may not be possible for many other municipalities of the country, especially for the smaller cities due to their meagre resources.

Apart from SWaCH, there are a few other examples of civil society organizations, which have helped the municipalities in successfully piloting SWM models by involving waste pickers. For instance, Stree Mukti Sanghatana (SMS), a Mumbai-based NGO, covers 10,000 household of the city for SWM by organizing close to 3,000 waste pickers. Similarly, Exnora Green Pammal (EGP) NGO has successfully initiated a waste collection programme in Pammal town of Kancheepuram district, Tamil Nadu, with waste pickers where 994 MT of waste is collected monthly from households [8]. These two models have been able to enforce service fees and households responsibility towards waste management with strong support from ULBs.

3 Case Study from ITC

3.1 ITC's Social Investments Programme

ITC is one of India's foremost multi-business enterprises with a market capitalization of US$40 billion and a turnover of US$8 billion. ITC is India's leading Fast Moving Consumer Goods Company, the market leader in the Indian Paperboard and Packaging industry, an acknowledged pioneer in farmer empowerment through its agri-business and runs the greenest luxury hotel chain in the world. ITC Infotech, a wholly owned subsidiary, is one of the India's fast-growing IT companies in the mid-tier segment.

ITC has adopted the "triple bottom line" performance approach of contributing to the economic, environmental and social capital of the country. This approach makes ITC the only company of comparable dimension in the world, to be carbon positive, water positive and solid waste recycling positive. The company's value chain generates livelihoods for over six million people, many of whom represent the weaker section of the society.

Under its social investments programme that helps in building capacity of the weakest section in society, ITC has designed development interventions which created large-scale sustainable livelihoods for the marginalized along with environmental enrichment. The company's health and sanitation initiatives aimed at creating healthy and hygienic environment for its stakeholders and have covered over 50,000 households till date, in various parts of the country.

3.2 ITC's Solid Waste Management Programme

3.2.1 Well-Being Out of Waste (WOW) Programme: A Waste Management Approach for Metro and Big Cities

ITC has been running Well-Being out of Waste (WOW) programme since 2007 to inculcate the habit of recycling among households, corporates and other establishments to reduce the garbage load through source segregation. The WOW programme is operational in Hyderabad, Bangalore, Coimbatore, Warangal, Mahabubnagar, Siddipet, Medak, Gajwel and Sircilla covering over 11 lakh households.

The WOW intervention, which was initiated to augment supply of paper fibre for ITC's paper factories, has evolved over time to a comprehensive MSW management programme, with the major thrust on improving economic status of waste collectors by promoting source segregation at the household level. Segregation at source between dry, wet and sanitary waste has reached a success rate of 90% in some of the wards in Bengaluru where WOW has been operating, which compares well with India's average of around 10%. There is almost zero waste diversion to landfill of the dry waste, and ITC is working towards elimination of wet organic waste going to landfill, by facilitating its diversion for bio-methanation.

Key factors and the way forward for the WOW model are:

- Partnership with existing municipal corporation workers for household to household waste collection and inclusion of rag-pickers in segregation of dry waste into different categories.
- Infrastructure and logistics support from the municipal corporation.
- Educating households and continuous monitoring/follow-up on source segregation.
- Enabling management of both wet biodegradable and dry waste streams—almost zero diversion to landfills.
- Project sustainability by achieving maximum value realization of segregated dry waste streams in the supply chain, revenue from wet waste as a resource for industrial conversion to renewable energy and manure.
- With the introduction of Solid Waste Management Rules 2016, which requires all waste generators to pay user fee for solid waste management as specified by the local body, the applicable household levy will further add as a revenue stream to the model.

Different stakeholders involved in the WOW programme and the transactions between different stakeholders of the PPP model are given in Fig. 2.

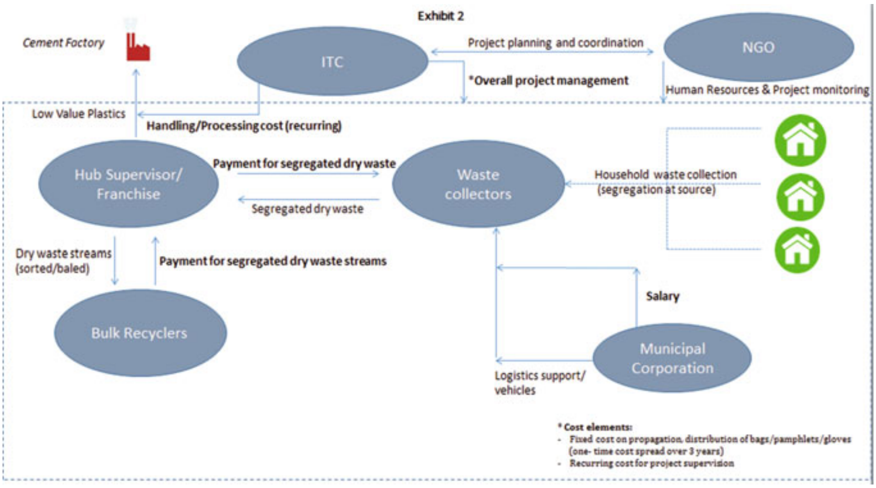

Fig. 2 Well-being out of waste model

The essence of this successful MSW management comes down to achieving highest possible segregation levels at source which in turn facilitates value capture by the operating agency/waste pickers from each waste stream. While waste segregation at source can be mandated, it is essentially a behavioural change that has to be brought about and requires sustained work at the individual level through trained facilitators. Maximization of value realization from each waste stream requires a combination of technical know-how which businesses can facilitate, enabling regulations that governments must consider.

3.2.2 Decentralized Waste Management System: An Approach for Smaller Cities and Towns

In line with its commitment to environmental goals, ITC initiated first solid waste management (SWM) programme in Saharanpur City of Uttar Pradesh in 2006, in collaboration with partner NGO, Muskan Jyoti Samiti, and the local municipality. The objective of this PPP was to develop a replicable and financially viable model to manage waste and reduce the quantity of solid waste disposed in landfills. Integral to the project was also the objective of providing a decent and sustainable source of livelihood to waste collectors and rag-pickers.

Against the general practice followed by ULBs of collecting waste from community bins, this model emphasized on door-to-door collection of waste for 6 days in a week. Model focused on a decentralized waste management system[4] where waste collected from households is transported by waste collectors for secondary segregation to the waste management sites located within city in the land provided by the SMC. Rag-pickers are involved in segregation at these waste management units. Biodegradable waste is separated from the waste and is processed to make compost. Non-biodegradable recyclable waste is sold to private vendors, and the remaining non-recyclable waste goes to landfills. The process flow of the model is given in Fig. 3.

Since this initiative had introduced a different way of waste handling in 2006, it took some time to overcome initial inhibitions and win the confidence of the community and other stakeholders. Taking Saharanpur experience forward, ITC expanded decentralized SWM programme to other geographies in 2015–16 like Tribeni (West Bengal), Munger (Bihar), Nandigama (Andhra Pradesh), Shirur (Maharashtra) and Madurai (Tamil Nadu) covering over 42,000 households by March 2016. The cumulative results of these projects are analysed below:

[4]In the decentralized waste management approach, municipal waste is processed at various small units within the locality. The centralized waste management system is a technology-driven and mostly mechanized system where waste is transported to a central facility for processing, generally outskirts of the city.

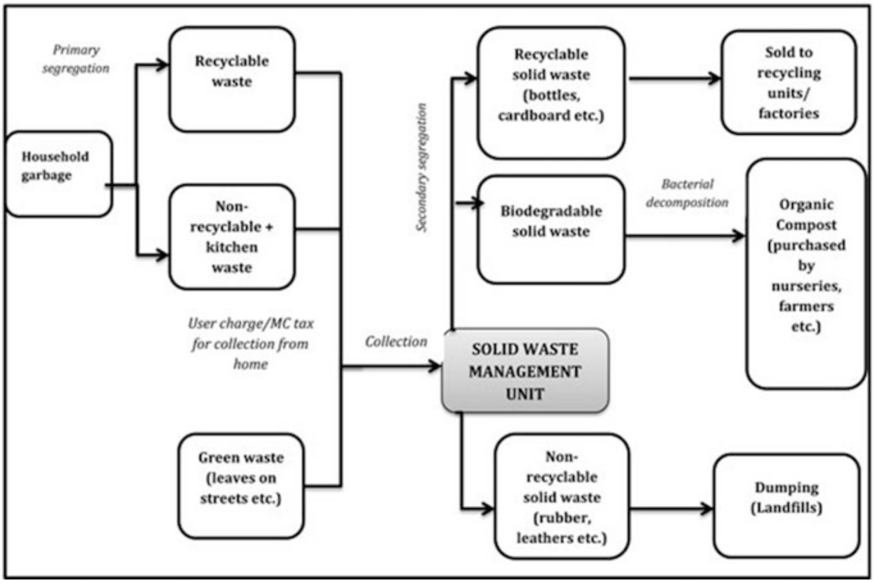

Fig. 3 Process flow of the waste management model

(A) Waste Recovery and Composting

On an average, the recovery of biodegradable material in the total waste is around 63% for the 9-year period in these projects (Fig. 4). Over the last 4 years (2012–13 to 2014–15), there has been steady increase in the recovery of biodegradable waste due to focused campaigns on segregation and recycling of waste at household level as well as improvement in waste processing. The non-recyclable waste, which goes to landfills, was confined to average 18% in these years, which was considerably low compared to many other successful models in cities like Pune, Ahmedabad.[5]

Recovery (82%) of waste under these initiatives is not only notably high compared to the average performance of ULBs (31.73%), but also **exceeds the desired national benchmark of 80%** (see Fig. 1). It is therefore important to note that the model adequately fulfilled one of its objectives: compared to the practice of dumping everything in landfills as is done in the traditional ULBs model, which causes immense environmental and public health hazards, **most of the waste in this model is decomposed and recycled**.

[5]As per a survey done by FICCI in 2009 for 22 class I and class II cities, Ahmedabad and Pune supply 78 and 90% of its waste to dumpsite, respectively. Guwahati (42%) followed by Kozhikode (16%) and Kochi (10%) are the lowest suppliers to landfill [9]. Pune improved later where it is reported that only 20% waste is sent to landfills [8].

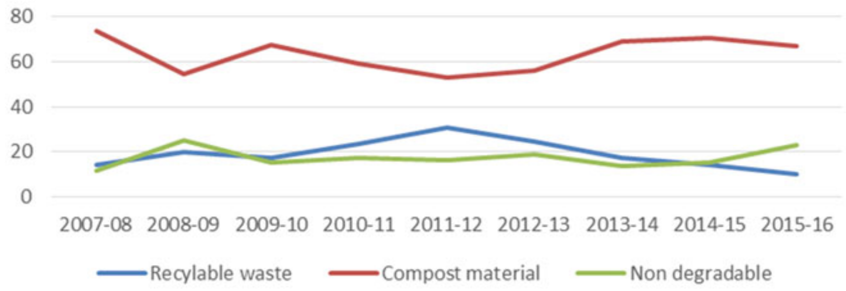

Fig. 4 Trend of various components of the waste recovered

The organic material present in municipal waste is converted into compost by aerobic decomposition. Samples from each lot of the compost are tested in the accredited laboratories, to know the nutrient levels before marketing. Till March 2016, over 9,000 tons compost has been sold to the market.

(B) **Revenue Generation: A Step Towards Sustainability**

User charges, sale of recyclable waste and compost are the major sources of revenue in these projects. Recyclable waste is sold to local vendors, and compost produced is sold to the bulk buyers and nurseries within and outside the district at Rs. 4–7 per kg. ITC's model firmly focuses on the "polluter pay" principle, and thus, households are charged with Rs. 10–30 as monthly service fee. Out of the total revenue generated in the last 3 years, the highest (around 51%) comes from user charges (Fig. 5), which is a positive indicator for the sustainability of the model as it displays the community's willingness to pay for provision of quality and reliable services.

Fig. 5 Different segments of revenue

(C) Stakeholder's Participation

ITC's model includes inter alia the participation of various stakeholders in SWM programme as:

- Partnership with municipal corporations/gram panchayats for support in providing infrastructure/facilities including land, utilities and transportation, communication on household charges. The model helps reduce the logistic costs for the municipal corporation, and also its workload. The corporation acts as a facilitator keen to see the coverage of this programme expanded to larger area of the city.
- These projects support not only the livelihoods of over 250 workers, but have also organized them into a waste collector's institutions, responsible for handling the project of this scale. Revenue sharing by them is resulting in a high sense of ownership.
- Residents organized into informal ward committees keep a check on the quality of work and put peer pressure on households to minimize default on service fee payments. These groups also help to disseminate awareness on source segregation, environment degradation and related health hazards. Since households are getting quality waste management services at their doorsteps, they have a strong motive to ensure that the programme runs successfully in the long run.

3.2.3 Challenges and Way Forward: Shift in Approach

With initial experience of Saharanpur project and experience of other locations, ITC's social investments programme has redefined the objective of its solid waste management programme "to ensure waste management by the generator and zero waste at landfills in identified project habitations". This objective is not only in line with SWM 2016 rules but also focuses on dealing with waste at the source of generation. Behaviour change, integration of rag-pickers as a stakeholder in collection and processing, ownership of RWAs and partnership of local bodies are the key tenets of the model.

Replication and scale up of such decentralized partnership-based model can go a long way to resolve the endemic waste challenges across various cities in India. However, there are few bottlenecks that need to be addressed for the success of such initiatives:

(a) Convincing households to pay is a tough task primarily due to the popular belief that providing free SWM services is a responsibility of the government since residents pay taxes. Also, those who pay are reluctant to pay annual increases in user charges, which would eventually lead to a plateau in revenue generation. Government authorities, due to various sociopolitical compulsions, remain unwilling to administer user fee collection. However, the experience of the likes of Pune Municipal Corporation, SwACH, and EXNORA, Pammal, models suggest that it can be enforced even at large scale with strong conviction. Indeed, governments should not only make it mandatory for households to pay for SWM services, but should also devise mechanism of charging fees propionate to the weight of waste, as it will force people to recycle and reduce the waste.

(b) Inculcating habit of waste segregation at source is an enormous challenge due to poor education and consciousness towards it. Mixed waste not only increases the cost of processing but also reduces waste recovery and cost recovery. Although in a welcome move, the Solid Waste Management Rules, 2016, put an obligation of waste segregation on the generator, and authorities need to ensure its compliance, at least with institutional waste generators to start with. Establishing mobile courts to deal with offenders, as done by the Ahmedabad Municipal Corporation, is an idea worth replicating in other cities.

(c) The decentralized model requires land within the city for processing of the waste, which is becoming gradually difficult due to increasing urbanization and mounting land value. Unfortunately, such land requirements are not taken care of during town planning. With segregated waste, provision of even small piece of land will support the management of solid waste in neighbourhoods through the active participation of Residents' Welfare Associations. Such a model can minimize the cost of collection and transportation of waste to centralized processing facilities.

(d) Encouraging households to minimize the waste generation by managing biodegradable part of the waste through home composting methodologies is also a strategy that can help in cutting out the need for land for secondary segregation. Non-biodegradable waste can be collected by waste collectors from households for direct sale. Government should fund research, new technologies and processes for waste minimization and establish policy and price structures for tackling of this burgeoning issue.

(e) Community-centric PPP models of SWM are usually labour intensive due to manual processes. Although these models integrate livelihoods of rag-pickers, waste workers in SWM thus cannot completely be replaced by mechanization. However, there is a scope for technological interventions and manual processes to coexist in a manner that can reduce drudgery and health hazards for these people. Most of the technological advancement has taken place only for the centralized and mechanized models due to pure cost–benefit considerations by private operators. The policy framework needs to recognize requirements of technologies for such model, as it is not possible to deal with the growing problem of SWM only through large, expensive, mechanized projects, particularly for smaller cities.

4 Conclusion

Urban local bodies are facing a challenging task of providing essential SWM services to its residents. The solution, as evident from the model discussed in this paper, is through a cost-effective, well-designed decentralized "Public–Private–

People Partnership" approach to waste management, which focuses on behaviour change for source segregation, waste collection from households and recycling of most of it in a scientific manner. Being revenue driven, such 4P models have the potential to become financially viable. However, such models, which are at a nascent stage of development, require strong institutional, governance, policy and market support to become successful on a large scale.

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Non-burn Technologies (NBT) in Management of Food Wastes—A Possible Paradigm for Smart Cities

Pinaki Dasgupta and Rajender Gondane

Abstract Management of solid waste especially the municipal solid waste and in turn food wastes has been a serious challenge for both urban and rural settings. The basic flaw of segregation at source as well as non-uniformity of processing wastes leads to severe environmental and societal pressure. Presently, large-scale management of municipal solid wastes generally is taken care of by integrated solid waste management plants producing refuse derived fuels, compost, landfill of inert materials and recycling of appropriate materials. However, as we move towards smart cities along with a population with mixed aspirations, dynamic food habits with enhanced mobility, there is an urgent requirement of revisiting management of food wastes with a new dimension that addresses issues of land requirement, pre-treatment and utilization of biodegradable component with alternate end uses. Every day thousands of tons of consumed food is wasted in the country. Non-burn technologies (NBT) and thermo-mechanical processes can assist the management of food wastes without being too harsh on resources. These can also be of great use, where there are smaller lots of food waste or municipal solid waste generated on a daily basis. These technologies which were erstwhile utilized for treatment of biomedical wastes are being tested for pre-treatment of municipal wastes across the globe. This paper attempts to cover the status and relevance of such technologies including one which has been designed and developed in India, available processes which can be adapted in existing end-use sectors, in a systematic and planned manner with the involvement of relevant stakeholders. The major advantage of such technologies and processes would be the low time conversion, ease of handling the wastes and use of resultant products as energy resource or simply as compost or further processing.

Keywords Non-burn technology · Food wastes · Market potential Sensitization · Smart cities

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1 Introduction

The Government of India in January 2016 brought out the initial list of 20 smart cities out of 98 which were shortlisted. Point 3 of the core infrastructural elements of smart cities includes solid waste management as a part of sanitation. However, there is no mention of waste or its management in the smart city features document. These cities are meant to be designed on sustainability concepts with core focus on IT-enabled services and state-of-the-art facilities.

In the first list, there are three cities from Madhya Pradesh, two cities each from Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Rajasthan and Tamil Nadu and one each from Assam, Kerala, Delhi, Odisha and Punjab. Region wise, the following distribution emerges, considering the list of 20 cities. Figures in bracket indicate states. Southern states lead the list with 35% of cities share.

(1) North—4 (3)
(2) Central—3 (1)
(3) South—7 (4)
(4) East—1 (1)
(5) North-East—1 (1)
(6) West—4 (2)

This calls for systems which can be installed for management of wastes in a "smart" way. Waste post-food consumption among others will invariably be generated.

A 2011 study done by the Swedish Institute for Food and Biotechnology (SIK) on behalf of FAO [1], "*Global Food Losses and Food Waste*", defines food waste as food loss occurring during the retail and final consumption stage due to the behaviour of retailers and consumers, that is, "the throwing away of food".

A report by the Global Food Security Programme (GFS) in the UK [2] defines food waste as "most commonly refers to edible food products, which are intended for the purposes of human consumption, but have instead been discarded, lost, degraded or consumed by pests, and does not include the inedible or undesirable portions of foodstuffs".

Schneider [3] has classified food waste into four groups: original food, partly used food, leftovers (plate waste) and preparation residues. Except for original food, rest of the three occurs at consumption level which can further be divided into two groups: (i) food wastes at household level and (ii) food wastes at social gatherings. Currently, these food wastes are disposed through landfill composting, pit composting, or in worst case, just left at a site attracting rodents, insects and microorganisms which could pose severe health risk.

This paper focuses on non-burn technologies (NBT) for management of post-consumption food wastes, which can be an excellent option for execution in smart cities where waste management will be a key challenge. Such concepts and technologies have been researched in the UK, and a similar system has been designed and developed in India recently on a pilot scale. The key objective of this paper is established that these technologies could be a viable supporting decentralized system in the small to medium scale and in turn can be integrated for strengthening present waste management systems. It has been attempted to address consumption pattern, domestic demand projection, export potential, market size and the like for similar technologies. This paper serves as a preliminary investigation which could be further evolved into a full-fledged implementation by various urban local bodies as well as other prospective end users in government and private sector.

2 Paper Coverage

The main coverage of this paper is to provide an overview about the existing and potential market for non-burn technologies (NBT) along with a demand and supply projection in different end-use applications.

3 Research Methodology

The methodology adopted for this paper consisted of desk research sourcing available data and information from Internet search and the published literature in the public domain. In addition to the above, a techno-commercial meeting with the concerned Indian innovator facilitated by the National Research Development Corporation (NRDC) was arranged to obtain a better understanding of the application and utilization of the product.

4 Basis

Food is the basic necessity of life along with air, water, shelter and clothing. However, among the other parameters, it is the highest, when it comes to the waste category. Food is served anywhere and everywhere across the country in family and several types of social gatherings. It assumes equal importance irrespective of the life journey from birth to death especially in India. During wedding ceremonies which can last up to a week, food has a special place among all the deliverables and receivables too. There are very large weddings where there are more than 1000 guests with more than 100 dishes on offer. In real time, it is nearly impossible for the guests to sample all the dishes on offer and hence there is huge food wastage from the occasion.

It is the biodegradable component of MSW, if unattended, comprising of food waste that is most damaging to the environment compared to inert waste (construction waste, etc.) and plastic wastes due to faster rate of microbial attack and hence decomposition.

The Food and Agriculture Organisation (FAO) [4] states the following:

- Food losses and waste amount to roughly US$680 billion in industrialized countries and US$310 billion in developing countries.
- Industrialized and developing countries dissipate roughly the same quantities of food, respectively, 670 and 630 million tonnes.
- Fruits and vegetables, plus roots and tubers have the highest wastage rates of any food.
- In developing countries, 40% of losses occur at post-harvest and processing levels, while in industrialized countries more than 40% of losses happen at retail and consumer levels.

Food waste post-consumption generally ends up in a landfill or non-designated places which could give rise to ecological nuisance. Hence, management of food waste post-consumption is a vital link in the life cycle of food from farms to the plate and disposal thereof. On analysing food waste scenario, the authors believe that mechanical heat treatment (MHT) through autoclaving could be an effective and smart process for management of food wastes.

A Government of UK report [5] explains these types of technologies as pre-treatment technologies which assist in preventing waste reaching a landfill in the wider context of waste management cycle. According to a Friends of Earth publication [6], autoclaving has been described as a method which involves sterilization of waste under high pressure and application of steam. This process "cooks" the waste and destroys bacteria.

The technology of autoclaving (indirect heating with steam and heat) of leftover food waste with the help of a boiler already exists in various European markets such as the UK. The process of waste autoclaving has been in practice for sterilizing medical equipments, treatment of clinical wastes and syringes. Such systems utilize a combination of heat, steam and pressure to destroy harmful enzymes. Some systems deploy rotation action to treat residual waste (waste that has not been collected for recycling or composting).

The end mass is claimed to be directly utilized as manure or compost or can be utilized as feed for compost or even fuel. The output from these processes is often termed as floc, which has been described as a material similar to fibre in texture and physical examination [7].

5 Technology Assessment–Case Study in India

The indigenous process developed by Air Marshal (Dr) L. K. Verma AVSM (Retired) has been considered for case study purpose. The case study has been sourced from NRDC, Govt. of India. The present system proposed by the inventor works on similar MHT principle, with the destruction of enzymes (protease, amylase and lipase) responsible for continuing putrefaction in the food waste, while retaining the calorific value and soil nutrient qualities. This way it retains and preserves natural resources rather destroying it by burn technologies. The technology destroys enzymes, the agent that carries on with putrefaction even when food waste is discarded. This has been tested and found that in the treated end product, enzymes were found absent, whereas these were present in the waste input.

It is a machine treating food waste with application of indirect thermal energy to stabilize the waste, whereby further putrefaction and degradation of waste molecules get arrested. Food waste is greatly polluting to the environment and attracts not only scavengers, flies, rodents, etc., but also birds causing aviation hazard. The concept is at least novel for Indian context, while there are large plants which run around the world and has great potential for replication. The set-up consists of a cylindrical vessel, an outer jacket, an in-built motor-driven shredder, a boiler (5 kg steam/h capacity), safety valve, small water tank, motor-driven water pump for the boiler, inlet and outlet openings, variable motor device to run the motor at variable RPM.

Each cycle lasts for about 30–50 min depending upon moisture content. Indirect heat is applied to the waste mass under controlled conditions. The waste is fragmented with an in-built shredding device. Destruction of enzymes/amino acids by thermal energy is an irreversible process. Treated product retains calorific value and the usual ingredients but stabilizes the waste so that degradation and putrefaction is arrested and the end product poses no attraction to scavengers, rodents, birds, etc. (Fig. 1).

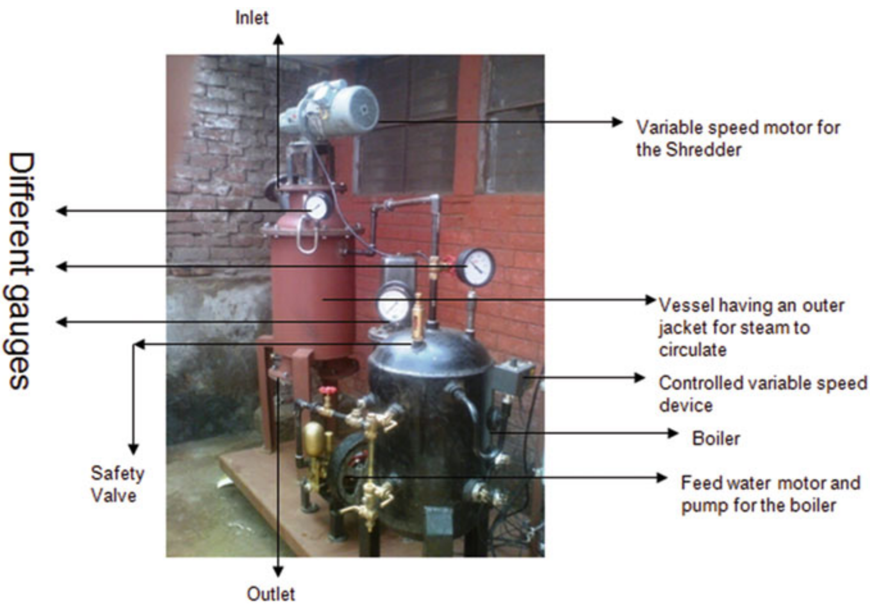

Fig. 1 Food waste processing machine, VEGMA FOODSTER designed and developed by Laljee Verma

6 Testing

The product has been tested for food waste products. It can also be tested for biodegradable wastes such as leaves, twigs. The test results show that energy increment is about 50% compared to inlet wastes with destruction of enzymes. However, the efficacy of the product lies in food waste management as it turns the waste into a dry mass.

7 End Uses

The target clients could be the Railways, municipal corporations, hotels and restaurants, food processing industries, etc. It is a non-burn technology and environment friendly. There is no emission, and the end product can be used as a source of fuel or as manure. Hence, the end-use application sectors could be potentially any establishment where food is handled, served or consumed.

Similar products have also been reported [7], to be utilized as a refuse derived fuel (RDF).

8 Raw Materials

Raw material for the product is food waste in any form, which is not priced at present.

Transportation from the origin to the machine site would be charged. At present, a small truck charges around Rs. 1000/- for a distance of 25–50 km.

9 Existing Decentralized Products in Market

There are several similar products in the market which transform food waste to compost utilizing electrical energy and other additives. However, the proposed product deploys non-burn technology to eliminate odour-related enzymes with the help of autoclaving. Similar products are available with international suppliers.

Dr. Mohd Suffian Yusoff et al. describes a similar experimental set-up in the Universiti Sains Malaysia, Malaysia [8]. In their experimental set-up, typically, the temperature and time used for autoclaving were maintained between 120 and 160 °C for less than an hour. This condition applied was considered sufficient to sterilize waste and change the characteristics of waste. In this research, food waste was treated at saturated steam temperature of 121–127 °C for 35–60 min. The end product was found deemed fit to be used as a compost with lesser heavy metals compared to wet waste. However, the feed was segregated before feeding it to the machine.

10 Patents on Similar Technology

Patents were searched online from Indian Patent Office website for composting of wastes. The results gave 18 cases. There are none for non-burn technology or process.

11 Indian Manufacturers

There are many companies who manufacture compost machines which utilize electricity to convert food waste to compost without burning it. Machine for autoclaving food waste is not presently being manufactured.

12 Global Food Waste Estimates

There are several estimates which have been published for food wastage. Table 1 provides a list of the percentage or value as retrieved from sources.

Table 1 Food wastes' estimates

Source	Estimate of food waste	Country/Region
FAO [4]	33%, 1.3 billion tonnes per year	Global
The Economist [9]	40%, $165 billion	USA
Julian Parfitt [10]	14%, 211 kg per year, 14% of the purchase	USA
USEPA [11]	12.5%, 32 million tonnes	USA
Food World News [12]	35 million tonnes	USA
Brazilian Company of Agriculture Research [13]	10% of 40,000 tonnes per day = 4000 tonnes, consumer end	Brazil
Chinese Academy of Sciences, Beijing [14]	23.5% ordered food, 200 gm per capita per meal	China
Australian Govt. [15]	33% of MSW, 20% of commercial, 7.5 million tonnes	Australia
Julian Parfitt [10]	8–11% of the purchase, 43–60 kg per year per person	Netherlands

(continued)

Table 1 (continued)

Source	Estimate of food waste	Country/Region
The Economist [9]	40%	India
The Straits Times [16]	4.82 million tonnes, 2014	Korea
Julian Parfitt [11]	298 kg per household per year	Turkey
Global Food Security [4, 13]	15 million tonnes, 50% from households, 3% from within retails and distribution	UK
Julian Parfitt	8.3 million tonnes, 25% of households	UK
EU, PLASCARB [17]	3.5 million tonnes, household	France
The Guardian [18]	7 million tonnes	France
EU, PLASCARB [17]	Average 6.5 million tonnes, household	Germany
FAO [4]	Per capita waste: 95–115 kg/year	Europe and North-America
FAO [4]	Per capita waste: 6–11 kg/year	Saharan Africa and South/Southeast Asia
UNRIC, Western Europe [19]	89 billion tons of food	Supermarkets, Europe

As per conservative estimates, around 15–25% of all food purchased or prepared during Ramadan finds its way to the garbage bin before even being used or consumed [20]. In Pakistan, according to newspaper article estimates, some 15–20% of food is wasted in wedding functions. In some cases, the waste is to the extent of 20–25% when the number of dishes exceeds the number of guests invited to the marriage halls [21].

13 Estimation of Indian Food Waste Scenario

13.1 National

According to the UNDP estimates [22], up to 40% of the food produced in India is wasted. There is no organized research on consumer-end food wastes in India by any agency. Post-consumption food wastage occurs at family and social gathering like parties, functions, weddings and restaurants. Such wastage based on an informal survey done by the authors in friends and family circles over social media has been estimated to be between 5 and 40% depending on several parameters such as size, cuisine, weather. No detailed organized estimates are available on post-consumption food wastes in India.

The overall food consumption in India is of the tune of 1500–200 kg per capita annually depending on urban and rural context, food consumption habits, nutrition

Table 2 Food waste pattern in India

Respondent %	Occasion where food waste happens	Waste severity
89.1	Weddings	Highest
32.5	Anniversaries and birthdays	High
50	Seminars and conferences	Least

Table 3 Food waste range

Respondent %	Waste range %
18.0	20–25
43.3	15–20
17.3	10–15
14.0	5–10
6.7	5

requirements and ability to pay for a nutritious and wholesome meal. Out of these 15% goes waste post-consumption [10]. Food constitutes a major part of the expenditure, and the weddings are known for their sumptuous food. Any wedding is considered incomplete without delicious food. Today, the number of dishes at times is 250–300.

As per in-house estimates, the food waste in weddings is around 200–300 g per guest per occasion.

According to a study by Department of Consumer Affairs in 2010 [23], the following outcomes were reported (Table 2). The survey gave respondents multiple choices on which they exercised appropriate decisions.

Additionally, the following outcomes are reflected from the report.

It can be observed from Tables 2 to 3, that majority of the respondents in all possibility felt that 20–25% wastage occurs during weddings.

13.2 Smart Cities

The list of smart cities alphabetically is provided in Table 4 along with the waste generation rate derived from various sources [24–29]. The figures of waste quantity vary according to sources. It can be observed that compostable vary from 40–60% in smart cities. It can be inferred that considering an average of 450 g of MSW generated per capita daily, around 200–300 g should be food wastes per capita daily. Several online sources estimate the growth rate of MSW to be 1.33% per year.

Table 4 MSW generated in smart cities

S. No.	Name of State/UT	Cities shortlisted	Population	Waste quantity TPD	Waste generation rate kg/capita daily	Compostable %
01	Andhra Pradesh	Kakinada	325,985	1302	0.37	40.81
02	Andhra Pradesh	Visakhapatnam	2,035,922	584	0.59	45.96
03	Assam	Guwahati	963,429	166	0.20	53.69
04	Gujarat	Ahmedabad	5,577,940	4000	0.66	55.00
05	Gujarat	Surat	4,467,797	1000	0.41	56.87
06	Karnataka	Belagavi	488,292	180	0.37	70.00
07	Karnataka	Davangere	435,172	220	0.51	50.00
08	Kerala	Kochi	601,574	400	0.67	57.34
09	Madhya Pradesh	Bhopal	1,798,218	700	0.40	40.00
10	Madhya Pradesh	Indore	1,960,631	557	0.38	48.97
11	Madhya Pradesh	Jabalpur	1,054,336	216	0.23	58.07
12	Maharashtra	Pune	3,124,458	1175	0.46	62.44
13	Maharashtra	Solapur	951,118	420	0.47	51.00
14	New Delhi	New Delhi	11,034,555	5922	0.57	54.42
15	Odisha	Bhubaneswar	837,737	234	0.36	49.81
16	Punjab	Ludhiana	1,613,878	735	0.53	49.80
17	Rajasthan	Jaipur	3,046,163	904	0.39	45.50
18	Rajasthan	Udaipur	451,735	60	0.30	50.00
19	Tamil Nadu	Chennai	6,727,000	3036	0.62	41.34
20	Tamil Nadu	Coimbatore	1,601,438	530	0.57	50.06

14 Potential Demand

An estimated conservative figure for MSW generation in urban cities could be around 150,000 tons per day or about 55 million tons per annum for 2013–14. However, a report by the Planning Commission, Govt. of India, estimates it to be 1,70,000 tons per day or 62 million tons based on 377 million people living in 7,935 urban centres (with 4,041 statutory municipal authorities and 3,894 town with more than 5,000 population [30]).

As per World Bank study [31], India would generate more than 370,000 tons in municipal solid waste per day by 2025. As per the position paper on the Solid Waste management sector in India, Department of Economic Affairs, Ministry of Finance, Government of India, 2009, it is estimated that 1400 square km (km^2) of land would be required by 2047 [19] for municipal waste, which may rise to 260 million tons per annum at an annual rise of 1.33%. In addition, due to several losses in the food supply chain, especially in the post consumer stage, the municipal waste will also increase [32].

The present demand has been estimated based on the market penetration as well as the potential for similar projects in and around NCR region in addition to the national domestic demand. At the same time, the opportunity for the machine in other parts of India, wherein the penetration can be much more to the tune of 15–20% if all techno-commercial aspects could be managed.

The present demand for autoclave food waste management machines could be 100–120 machines a year, while the national demand in selected states could be 150–200 machines a year. The key to have the estimated demand fulfilled is the maximization of marketing with a very competitive pricing. The national demand has been estimated assuming orders from medium-size hotels and commercial establishments, railways as well as other educational institutes. As can be observed, every year taking the most conservative scenario, around 100–150 machines are sold to hotels, big food chains, universities, large schools and institutions all over India. This can spurt up if there are strong regulatory backup with the help of relevant laws, which mandate the implementation of such systems in every commercial establishments. By the year 2030, this demand would be around 380–400 machines per year.

15 Demand and Supply Gap

The demand and supply was estimated based on the present supply of waste management machines which could be around 10–20 a year. This will increase as the awareness among the end users goes up along with the stricter local and state legislations on solid waste management issues which may evolve in the next few years. Demand has been assumed following a straight growth path and evolving based on several societal and environmental factors. In addition to the above, the need for implementing such systems coupled with increased awareness among public and other stakeholders could lead to a spike in demand in the next 5–7 years (Table 5). The demand has been estimated by the authors in-house.

Table 5 Demand and supply gap for decentralized autoclaved waste management equipment

Year	2016	2017	2018	2019	2020
Demand	100	110	120	130	150
Supply	20	30	40	50	60
Year	2026	2027	2028	2029	2030
Demand	260	290	310	350	380
Supply	70	80	90	100	110

There would be a fair demand and supply gap by 2025 and 2030. However, supply would still be lower than the demand due to improvization in machine design and operations with the requirement of a robust field testing before actual commercialization can commence.

The prospective clients for know-how are the various hotels, educational institutions, religious places where there is provision for space and waste handling are permissible.

As the utilization of these products is directly attached with the know-how, the clients who procure the know-how would in turn utilize the product for their own in-house consumption.

16 Conclusions and Next Steps

Smart cities are an ambitious concept for transforming cities world class with "smart solutions" for enhanced civic experience. However, the success depends on a strong framework, among others, the management of waste through decentralization as well as novel yet effective ideas and establishing a strong monitoring network. Autoclave technologies for food waste management are based on a non-burn technology. These kinds have existed in the form commonly known as "Autoclaving" or "High Heat Technology" or "Mechanical Heat Treatment".

The product can easily be integrated into the existing municipal solid waste management policies and implementation framework with optimum costs and human resources. The World Bank estimates [33] that the costs for managing solid wastes globally will increase from 205.4 billion USD in 2012 to 375 billion USD in 2025. The advantage of the fact that food waste can be converted into a more useful product through different treatments gives the urban local bodies several viable choices for implementation as per the convenience and ease of operation. In addition, the country as well as the ULB requires a strict food waste policy. For example in South Korea, food waste is banned in landfills. The compostable fraction ranges from 24 to 58%, with an average of 35% by weight for Class-l cities. The Food and Agriculture Organisation (FAO) of the United Nations [34], estimates that food waste at consumption stage vary from 1% for milk to 7% for fruits and vegetables. Further the study states that wastage of 3% occur in cereals, roots and tubers, while 4% of the meat at consumption stage is wasted by the people. Food wastes typical range from 25 to 40% of the total volume of MSW. Food wastage in social gatherings is also due to the change in the method of serving food. Controlled conditions such as family serving or sit and eat lead to reduced wastage. Buffets often lead to higher wastage. The major resources for a successful and sustainable implementation are: competitive technology, community ownership and social enterprise model. The concept of installing a suitable system in railways operated kitchen, or class A and B stations, community halls, religious establishments, housing colonies and industrial parks can go a long way in creating sustainable habitats in smart cities considering limited land resources, transportation costs and high operational costs in traditional treatment. These systems can also offer greater role in employing local youths.

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Part XVIII
Air Pollution

Air Pollution from Municipal Solid Waste Management Techniques

Dipanjali Majumdar and Suparna Ganguly

Abstract The rapid development of cities, increasing population and improper disposal of municipal solid waste (MSW) leads to human and environmental problem. Emission of various harmful inorganic and organic gaseous pollutants are unavoidable even when scientific methods of waste management are followed. The present study was undertaken to compare the ambient air quality at different types of solid waste management sites adopting different processes such as composting, mechanical waste management, open dumping, sanitary landfill. The study focused to assess the air quality with respect to a few selected inorganic gaseous pollutants and non-methane volatile organic compounds (NMVOCs) emitting from five municipal solid waste disposal sites within Kolkata metropolitan area (KMA) which adopt different management techniques. Air sample was collected by low-volume sampler and analysed according to CPCB standard methods and USEPA TO-17 methods for inorganic gases and NMVOCs, respectively. The study suggests that there are variations in pollutant emission across different waste management techniques. However, other local sources such as vehicular emission, residential emission also contribute to ambient level near management sites. Hence, to determine the contribution of the various waste management processes detailed sources apportionment study is required.

Keywords Air pollution · Solid waste · Management techniques
NMVOC · Inorganic gases

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1 Introduction

Municipal solid waste management (MSWM) is a major challenge in urban areas all over the world, which especially effects felt in the rapidly growing cities and towns of developing countries. Unsystematic disposal causes an adverse impact on all components of the environment and human health. Major challenges of MSWM policies in developing countries is the rapid removal of wastes from densely populated areas to maintain public health and hygiene.

Landfill gas (LFG) is created during the decomposition of organic substances in MSW. It consists of 45–60% methane, 40–60% carbon dioxide, 2–5% nitrogen, 0.1–1% ammonia, 0–1% sulphides. Non-methane organic compounds (NMOCs) such as aromatics (e.g. benzene, toluene, ethylbenzene, xylene); chloro-compounds (e.g. 1,1-dichloroethane, dichloroethylene, dichloromethane, trichloroethylene, tetrachloroethylene, vinyl chloride); carbonyls (e.g. methyl ethyl ketone, acetone); and nitro compounds like acrylonitrile usually contribute 0.01–0.6% of landfill gas [2, 7, 9]. The surface emissions of some of trace volatile organic compounds (VOCs) present in the waste which are formed as a result of biological decomposition of the waste are of major concern [4, 8, 11]. Gases such as SO_x, NO_x and carbon dioxide play a important role in global warming.

As in other developing countries, India is in the midst of massive urbanization. The present annual quantity of solid waste generated in Indian cities has increased from 6 million tons in 1947 to 48 million tons in 1997 with an annual growth rate of 4.25%, and it is expected to increase to 300 million tons by 2047 [3, 6]. The problem is already acute in cities and towns as the disposal facilities have not been able to keep up with the quantum of wastes being generated. In India, municipal authorities are responsible for managing their own municipal solid waste. They are employing various management and disposal techniques such as composting, mechanical processing, open dumping, sanitary landfill. All such methods are associated with air emission of various inorganic and organic gases. The objective of present work is to study the variation of air quality, with respect to selected inorganic pollutant such as suspended particulate matter (SPM), sulphur dioxides (SO_x), nitrogen dioxides (NO_x), hydrogen sulphide (H_2S), ammonia (NH_3), ozone (O_3) and volatile organic pollutants (VOC) such as benzene, toluene, ethylbenzene and xylene across various management techniques presently in practice around different municipalities of Kolkata metropolitan area (KMA) (Fig. 1).

Status of Municipal Solid Waste System in Kolkata Metropolitan Area (KMA)

The source of MSW in the KMA are residential areas, commercial or market area and some floating wastes also coming from riverside area. KMA consists of three municipal corporations, i.e. Kolkata Municipal Corporation (KMC) which consists of 144 wards, Howrah Municipal Corporation (HMC) which consists of 50

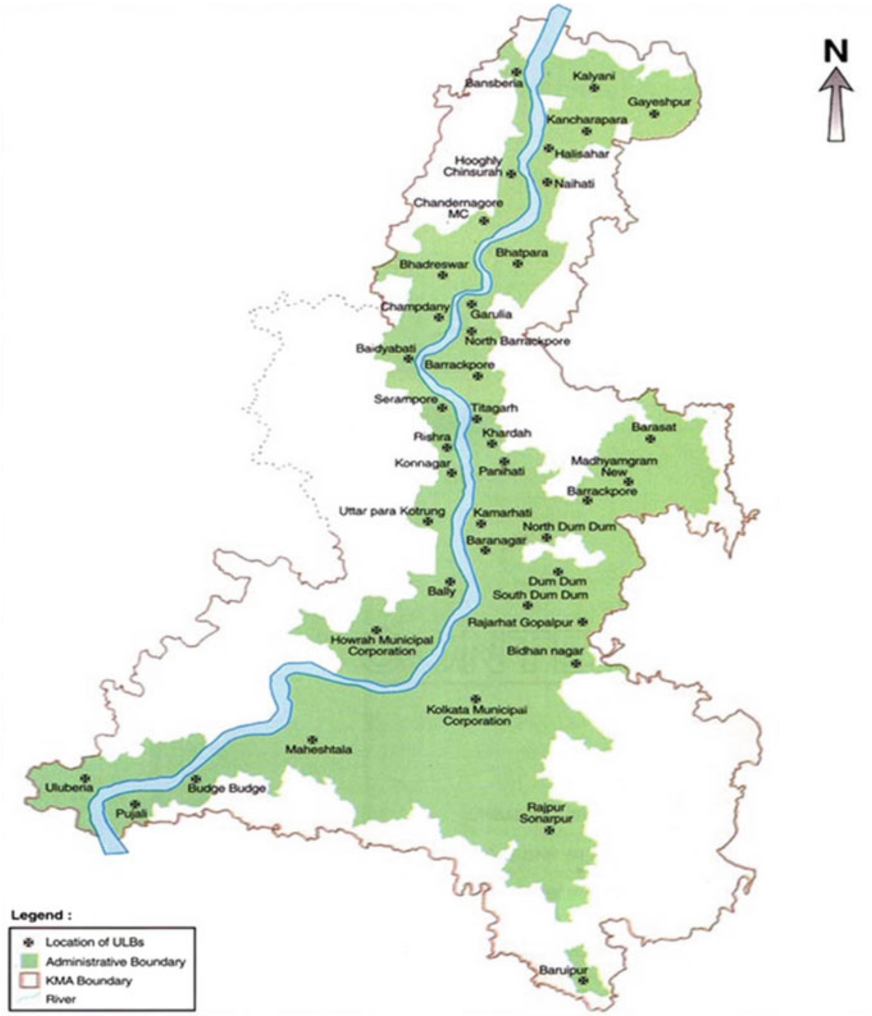

Fig. 1 Location map of Kolkata metropolitan area. Ref.: website; Dept. of Municipal affair, GoWB, India (http://www.wbdma.gov.in/HTM/map-of-wb-showing-kma-ulbs.htm)

wards and Chandannagar Municipal Corporation (CMC) [5]. According to the **2011 census** data [1], the total population of KMA is 14,112,536 and as per KMDA report, the total area is 1886.67 km^2 and population density is 7,480 per km^2 which indicates that Kolkata is India's one of the highest populous metropolitan areas. The details of various municipalities and their population and amount of MSW generation are given in Table 1.

Table 1 Municipal solid waste generation in different municipalities under KMA

Municipal corporation	Total population (2011 census data)	Area (km^2)	Waste generation (MT/day)	Waste collection (MT/day)	Per capita waste generation (gm/day)
Kolkata Municipal Corporation (KMC)	4,496,694	197.54	300	2800	873.1
Howrah Municipal Corporation (HMC)	1,077075	51.74	600	550	654.8
Chandannagar Municipal Corporation (CMC)	166,867	22.03	45.5	36.4	280.8
Bidhannagar Municipal Corporation (BMC)	215,514	33.50	110	110	654.7
Municipalities					
Baidyabati	121,110	9.06	35.0	30.0	324.0
Bhadreswar	101,477	6.48	24.7	24.0	245.3
Bansberia	103,920	9.07	60.0	50.0	576.9
Rajarhat Gopalpur	402,844	28	100	90	369.0
Hugli-Chuchura	177,259	21.52	110.0	100.0	647.0
Konnagar	76,172	4.33	30.0	25.0	416.6
Rishra	124,577	6.48	57.0	50.0	504.0
Champdani	111,251	6.47	75.0	70.0	728.1
Serampore	181,842	5.88	100.0	90.0	505.0
Uttarpara-Kotrung	159,147	18.15	90.0	80.0	600.0
Bally	293,373	11.81	120.0	110.0	425.5
Uluberia	222,240	33.72	115.0	100.0	569.3
Gayeshpur	58,998	30.00	20.0	15.0	363.6
Kalyani	10,057	29.91	31.0	30.0	378.0
Baranagar	245,213	7.12	140.0	130.0	560.0
Barasat	278,435	31.41	45.0	40.0	193.9
Barrackpore	152,783	11.65	85.0	75.0	590.0
Bhatpara	383,762	34.49	230.0	230.0	520.3
Dumdum	114,786	8.81	26.0	20.0	257.4
Garulia	85,336	6.48	25.0	20.0	347.2
Halisahar	124,939	8.28	35.0	30.0	282.0
Kamarhati	330,211	10.96	110.0	100.0	350.3
Kanchrapara	120,345	9.97	70	65.0	555.5
Khardah	808,496	6.87	75.0	68.0	646.5
Madhyamgram	196,127	21.32	100.0	85.0	641.0
Naihati	217,900	11.55	80.0	60.0	372.0
New Barrackpore	76,846	17.17	21.5	17	259.0
North Barackpore	132,806	8.42	43.0	41.0	346.7

(continued)

Table 1 (continued)

Municipal corporation	Total population (2011 census data)	Area (km^2)	Waste generation (MT/day)	Waste collection (MT/day)	Per capita waste generation (gm/day)
North Dumdum	249,142	26.45	102.0	92.0	436.6
Panihati	377,347	19.40	70.0	60.0	201.1
South Dumdum	403,316	15.49	120.0	100.0	306.1
Titagrah	116,541	3.24	60.0	50.0	483.8
Baruipur	53,128	9.07	20.0	16.0	444.4
Budge Budge	76,837	9.05	20.0	15.0	266.6
Mahestala	448,317	44.17	90.0	70.8	232.6
Pujali	37,047	8.50	15.0	10.0	441.1
Rajpur-Sonarpur	424,368	57.90	117.0	75.0	348.2

Source Census report 2011 [1] (http://www.census2011.co.in/census/metropolitan/184-kolkata.html) and Das Sanyal et al. [5]

2 Methodology

2.1 Study Sites

The study was done in two phases. In the first phase of present study, a questionnaire survey was carried out on fifteen municipalities under KMA. It is mainly based on municipalities' current status regarding disposal techniques and ongoing disposal process and discussion with municipality representatives.

The second phase of the study consisted of assessment of air quality with respect to selected inorganic and organic pollutants including particulates from five municipal solid waste processing and disposal sites and one typical urban ambient site at Kasba for comparison. Details of the sites for air quality assessment are given in Table 2. The concentration of inorganic pollutants like suspended particulate matter (SPM), sulphur dioxides (SO_x), nitrogen dioxides (NO_x), hydrogen sulphide (H_2S), ammonia (NH_3), ozone (O_3) and organic pollutants like VOC was carried out in five selected waste management sites, to understand ambient air quality status in Kolkata metropolitan area (KMA). The sample was taken twice in each MSW management sites within the study period.

2.2 Determination of SPM

For SPM analysis, a low-volume air sampler pump was used. The concentration was measured gravimetrically using glass fibre filter paper.

Table 2 Details of study sites for air quality assessment

Site Id	Municipality	Process/ technique	Location	Site details
BD CP1	Baidyabati	Composting	This compost plant was situated at a far distance from Baidyabati main road at ward no 14, Baidyabati	This compost plant and transfer station for Baidyabati municipality is mainly concerned about waste recycling and separation of inert waste; the compost plant was separated from the dumping sites; and the area of the plant was quite large, so air can circulate freely
UP CP2	Uttarpara Kotrung	Composting	The compost plant of Uttarpara municipality situated at Makra, Uttarpara near the railway station	Collected waste was dumped in this compost plant and then segregated the biodegradable wastes for composting. This plant was quite old. An cattle husbandry was observed in front of the dumping site
BD SL	Baidyabati (RWMC)	Sanitary landfill	TS and SLF at dhargangamouza, Baidyabati (RWMC)	The sanitary landfill (SLF) site of Regional Waste Management Center (RWMC), Baidyabati, was covered with a green vegetation. SLF consists of four separated chambers, and all chambers connected with a pipe to carry the generated leachate from waste to the leachate tank. After purification, the leachate was transferred into a large water reservoir and this water is used for plantation. The harmful gases were also collected through a gas pipe in a gas chamber to produce commercial gas

(continued)

Table 2 (continued)

Site Id	Municipality	Process/ technique	Location	Site details
BR OD	Baruipur	Open dumping	Joynagar road, near Baruipur crimatorium	This open dumping ground situated within a locality near Baruipur crematorium and beside Joynagar road. This dumping site was encircled by guava garden, litchi garden and mango gardens
SD CO	South dumdum	Compactor	Promodnagar dumping ground beside of delhi road, Dumdum	The compactor station was situated beside Dumdum road with in a dense locality and traffic. The compactor machine was washed regularly in order to minimize the obnoxious odour
U-Amb	KMC	Background site	Urban residential area near busy road EM bypass	Typical urban ambient

2.3 Determination of SO_x

The SO_x concentration was measured by SO_x absorbing media which was prepared by dissolving mercuric chloride, potassium chloride, EDTA disodium salt in double-distilled water. Then, 20 ml of SO_x absorbing media was taken in impinger; then, air sample was passed using a low-volume air sampler. This process was continued for 4 h, and flow rates were checked by rotameter at regular interval.

2.4 Determination of NO_x

To estimate the concentration of NO_x, by using NO_x absorbing media which was prepared by dissolving NaOH, sodium arsenite, *N*-butyl alcohol in double-distilled water, 20 ml of NO_x absorbing media was taken in impinger and then air sample was passed using a low-volume air sampler. This process was carried out 4 h in different disposal sites, and flow rates were checked by rotameter at regular interval.

2.5 Determination of NH_3

The NH_3 concentration was measured by NH_3 absorbing media which was prepared by conc. H_2SO_4, and distilled water 30 ml of NH_3 absorbing media was taken in impinger; then, air sample was passed using a low-volume air sampler. This process was continued 4 h in various disposal sites, and flow rates were checked by rotameter.

2.6 Determination of H_2S

For detection of H_2S, ambient H_2S was absorbed in absorbing media which was prepared by dissolving cadmium sulphate and sodium hydroxide. Then, 20 ml of H_2S absorbing media was taken in impinger and continuously bubbled by low-volume air sampler. This process was continued 4 h in various disposal sites, and flow rates were checked by rotameter.

2.7 Determination of O_3

The O_3 concentration was detected by O_3 absorbing media which was prepared by potassium iodide, potassium dihydrogen phosphate and anhydrous disodium hydrogen phosphate. Then, 20 ml of O_3 absorbing media was taken in impinger and air is drawn by low-volume air sampler. This process was carried out for 4 h @ 80 ml/min.

2.8 Determination of VOC (Volatile Organic Compound)

For detection of volatile organic compound, custom-made charcoal sorption tube was used. Air was drawn for 4 hour using low-volume air sampler and flow rates fixed at 80 ml/min; analysis was done following USEPA TO-17 [10] method. The target compounds were thermally desorbed and analysed in gas chromatography/ mass spectrometer (GC-MS).

3 Results and Discussion

The first phase of present study was questionnaire surveying different municipalities under Kolkata metropolitan area (KMA). As per survey report of 15 municipalities under KMA, it is shown that the amount of waste collection from door to door varies between 195 and 8 MT/day, and it is mainly generated by a household which lies between 1300 and 103,191. The waste is collected by different transport vehicles such as cart, truck, dumper, tricycle van tractor, auto tripper, hand cart. Mainly municipalities collect waste at regular interval from door to door. Some of the municipalities also collected waste from secondary point, and the amount of such waste ranges from 150 kg/day to 90.71 MT/day. The present study based on the MSWM techniques in 15 different municipalities under KMA. Most of the municipalities dumped their waste in the designated open dumping ground; some of them have started to manage their waste by various other techniques such as mechanical processing in Howrah Municipal Corporation, compactor in South Dumdum Municipality, sanitary landfill in Baidyabati Municipality, composting in Uttarpara-kotrung Municipality and Baidyabati Municipality, vermi compost in Mahestala Municipality. These municipalities also segregate biodegradable and non-biodegradable waste for proper management. The waste detail is given in Table 3.

Table 3 Waste details of municipalities under KMA (present study)

Municipality	Collection	Households	Door-to-door collection	Sorting at source	Secondary point	Amount of waste from secondary point
Baruipur	Door to door, hotels, markets	1300	45 MT/day	No	–	–
Rajpur-Sonarpur	Door to door	1,13000	70 MT/day	No		–
Budge Budge	Door to door	7000	40 MT/day	No	100	15 MT/day
Howrah Municipal Corporation (Bally office)	Door to door, markets, industrial road, liquid	20,000	100 MT/day	No	–	–
Chandannagar Municipal Corporation	Door to door, road site	38,000	36.4 MT/day	No	dustbin—488	3.5 MT/day 4.5 MT/day
South Dumdum	Door to door	1,30791	160 MT/day	No	100	100 Tonnes/day, (90.71 MT/day)
Mahestala	Door to door	80,000	8 MT/day	Yes	42	10–12 MT/day
Barrackpore	Door to door	33,000	40 MT/day	No	25	1 MT/day
Khardaha	Door to door, market	22,000	46.5 MT/day	No	91	–
Rishra	Door to door	27,000	57 MT/day	Yes	8	150 kg/day
Bhatpara	Door to door	87,701	195 MT/day	No	36	100 MT/day
Baidyabati	Door to door	32,000	9.07 MT/day	Yes	88	30 Tone/day
Naihati	Door to door	12,171	90 MT/day	No	–	–
Konnagar	Door to door	19,791	14.5 MT/day	Yes	56	18 Tonnes/day
Uttarpara Kortung	Door to door	41,099	60.86 MT/day	Yes	48	38.86 MT/day

Figure 2 shows the generation of waste per day from households in various municipality. Figure 2 indicates that the waste generation varied from 195 MT/Day in Bhatpara municipality to 8 MT/Day in Mahestala among the surveyed municipality.

Table 4 describes the ongoing process of huge amount of municipal solid waste in various municipalities under Kolkata metropolitan area (KMA). From the present survey work, most of municipalities dump their waste in designated open dumping site. Some of municipalities such as HMC (Bally office), South Dumdum, Mahestala, Uttarpara Kotrung Baidyabati use some other technique for managing their waste and to reduce and recycle into a valuable product.

Figure 3 shows that the concentration of SPM is highest in South Dumdum compactor site, i.e. 388.93 μg/m^3 and the lowest SPM concentration is found in Baidyabati Sanitary landfill site, i.e. 87.1 μg/m^3. The higher concentration of SPM in South Dumdum compactor site than that in typical urban ambient at Kasba station may be due to the contribution from of a busy road situated beside the establishment of the compactor in addition to the contribution from the waste management process here. High load of vehicular emission may contribute to the high load of SPM in that site. On the other hand, the sanitary landfill has been established at a considerable distance from the busy road. Also the site was evidently well planned and very well maintained. Therefore, there is considerably less effect of the vehicular pollution to contribute in the concentration of SPM in that site.

Fig. 2 Door-to-door waste collection (MT/Day) from various municipalities

Table 4 Waste dumping techniques details in various municipality under KMA

Municipality	Ongoing dumping process	Dumping site location	Dumping site area	Sorting of waste before/ after dumping
Baruipur	Open dumping	Joynagar road, near Baruipurcrematorium	2 acre	No
Sonarpur Rajpur	Open dumping	Moilapota, Rajpur	25 acre	No
Budge Budge	Open dumping	A.M. Ghosh road, Ward 19 Budge Budge	4 acre	No
Howrah Municipal Corporation (Bally Office)	Mechanical	Sapuripara (Chadmani) under Bally Ghoshpara Gram Panchayat	2.5 km^2	Yes
Chandannagar Municipal Corporation	Open dumping	Nabogram, Kolupuker	–	Yes
South Dumdum	Compactor	Promodnagar dumping ground beside of Delhi road, Dumdum	57 bigha	Yes
Mahestala	Vermi-composting	Sarengabad under municipality Ward no 35	42 acre	Yes
Barrackpore	Open dumping	Muktapukur old Kolkata road	5 acre	No
Khardaha	Open dumping	Dangadigila (Bandipur panchyat area)	13.5 acre	No
Rishra	Open dumping	Rishra near municipality	4 acre	No
Bhatpara	Open dumping	Ward no 34, Narayanpur near SSG brickfield Ward no 6, Madral	10.33 acre 8.84 acre	No
Baidyabati	Composting, sanitary landfill	Compost plant at trenching ground Ward no 14, Baidyabati, TS and SLF at Dhargangamouza	4.5 acre 52 acre	Yes
Naihati	Open dumping	R.B.C. road Naihati near Naihati municipality	2 acre	No
Konnagar	Open dumping	S.R. Duttasarani (Ward-11)	20 bigha	No
Uttarpara Kortung	Composting	Dirghangi, Baidyabati (RWMC) and Makra, Uttarpara	125 acre and 2 acre	Yes

Air Quality in Municipal Management Sites

The concentrations of suspended particulate sulphur dioxides (SO_x), nitrogen dioxides (NO_x), ammonia (NH_3), ozone (O_3) concentration in ambient air of different waste processing sites are tabulated in Table 5.

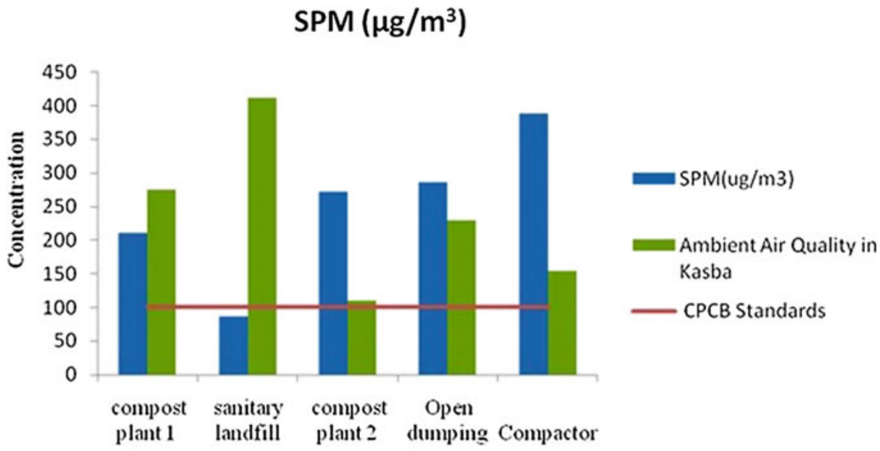

Fig. 3 Concentration of suspended particulate matter in various municipal dumping sites

Table 5 Concentration of particulates and inorganic pollutants present in various municipal management sites

Disposal technique	SPM (µg/m^3)	SO_x (µg/m^3)	NO_x (µg/m^3)	NH_3 (µg/m^3)	Ozone (µg/m^3)	H_2S (µg/m^3)
Compost plant 1	210.96	19.09	68.98	229.94	57.38	BDL[a]
Sanitary landfill	87.1	10.42	58.59	234.37	149.98	BDL
Compost plant 2	272.15	27.78	111.9	125.25	12.79	BDL
Open dumping	2857.5	19.09	122.35	270.2	33.09	BDL
Compactor	788.93	13.88	393.87	230.93	331.02	BDL
Urban ambient at Kasba	236.31	4.63	76.06	31.66	179.36	BDL

[a]*BDL* below detectable limit. The detectable limit of H_2S is 5 µg/m^3

According to National Ambient Air Quality Standards by Central Pollution Control Board notification November 2009, the permissible limit of SO_x was 80 µg/m^3. From Fig. 4, the highest concentration of SO_x is found in Uttarpara Kotrung compost plant, i.e. 27.78 µg/m^3 and the lowest concentration of SO_x is found in Baidyabati sanitary landfill sites, i.e. 10.42 µg/m^3. All the concentrations are below the CPCB permissible limit. The primary source of SO_x in air is vehicular pollution and degradation of agricultural waste, which may result in high concentration of SO_x in dumping sites than ambient air.

Figure 5 shows the NO_x concentration in different municipal dumping sites. The highest concentration of NO_x was found in South Dumdum compactor site, i.e. 393.87 µg/m^3 and the lowest concentration of NO_x was found in Baidyabati

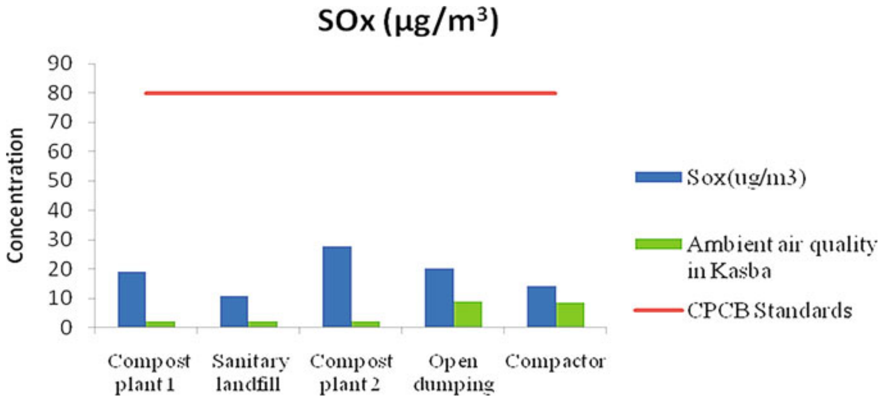

Fig. 4 Concentration of SO_x in various municipal dumping sites under KMA

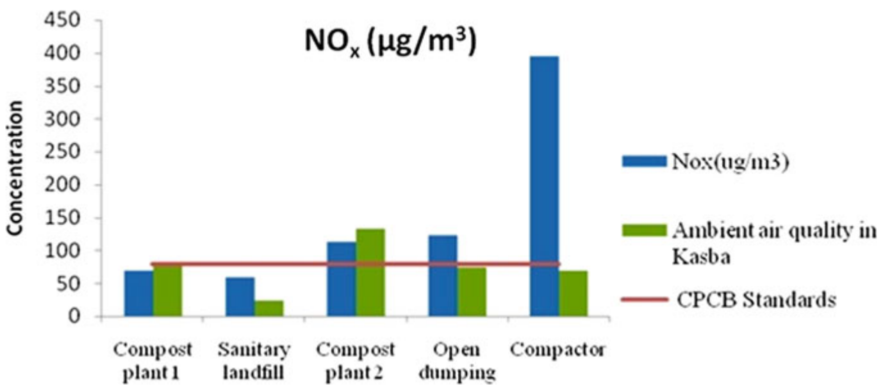

Fig. 5 Concentration of NO_x in various municipal dumping sites under KMA

sanitary landfill, i.e. 58.5 µg/m^3. As per 2009 report notification of CPCB, the National Ambient Air Quality Standards, concentration of NO_x permissible limit should be under 80 µg/m^3 in urban area.

The NO_x level in air is most likely to be contributed from combustion activity. NO_x level was often found above the CPCB permissible limit may be due to contribution from vehicular emission and other combustion in the neighbouring area. However, more in-depth work is required to understand the variation of NO_x emission if any from different waste disposal techniques.

Figure 6 represents the concentration of ammonia in different municipal dumping sites. The highest concentration of ammonia was found in Baruipur open dumping site, i.e. 270.2 µg/m^3 and the lowest concentration of ammonia was found in Uttarpara compost plant, i.e. 125.25 µg/m^3. NH_3 level in all the waste

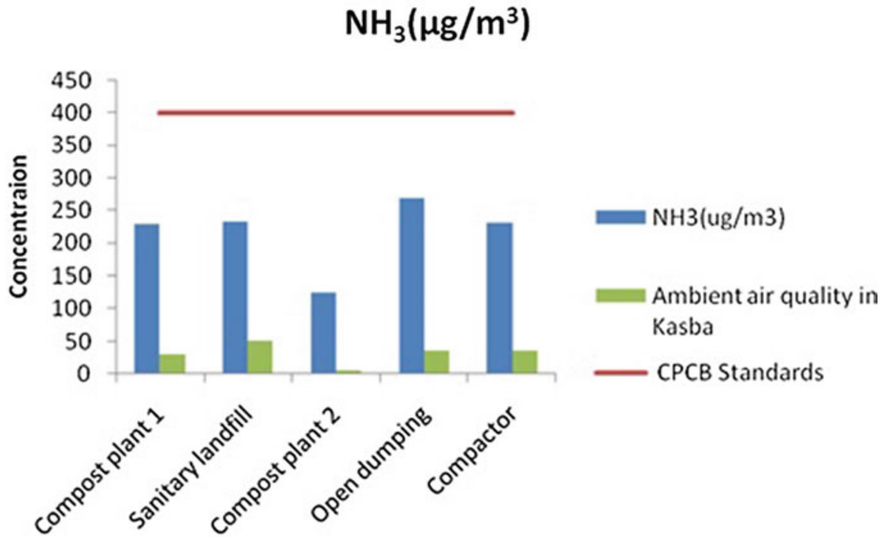

Fig. 6 Concentration of ammonia (NH_3) in various dumping sites under KMA

management sites lies under CPCB permissible limit of 400 µg/m^3. The concentration of NH_3 in municipal dumping site is higher than ambient air in Kasba indicating definite contribution from dumpsite.

Figure 7 representation indicates the ground-level ozone concentration in different municipal waste management sites. The highest concentration of ozone was found in South Dumdum compactor site, i.e. 331.02 µg/m^3, and the lowest

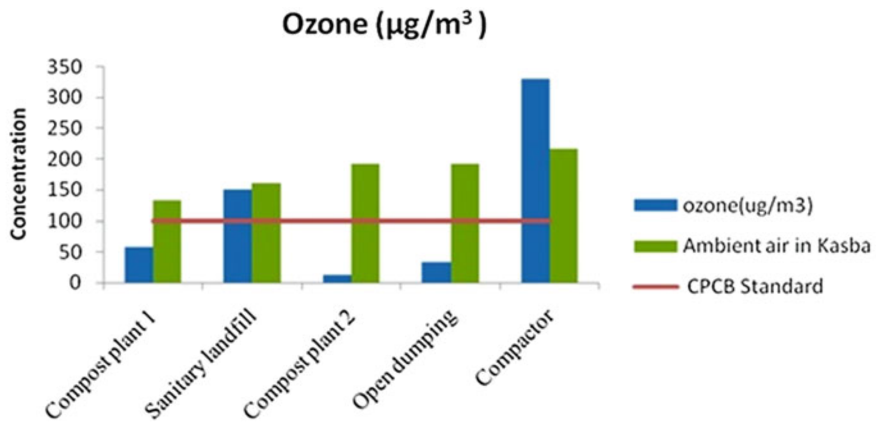

Fig. 7 Concentration of ozone (O_3) in different municipal disposal sites under KMA [5]

concentration of ozone was found in Uttarpara compost plant, i.e. 12.79 μg/m^3. The permissible limit of ozone concentration is 100 μg/m^3 as per CPCB notification 2009. The concentration of ozone in ambient air is exceeding the permissible limit in one or two occasions. Also in most cases the ozone level is lower than the urban ambient level indicating no significant contribution from waste management processes; however, more in-depth study is required to understand the complex nature of ozone level in these sites.

Figure 8 indicates the concentration of Benzene in different disposal sites. The highest amount of benzene was present in Baruipur open dumping sites, i.e. 13.99 μg/m^3, and the lowest amount of benzene was present in Baidyabati compost plant 0.02 μg/m^3. As per CPCB report 2009, the annual permissible limit of benzene is 05 μg/m^3. Figure 8 shows much higher concentration of benzene than the permissible limit in Baruipur open dumping site and south dumdum compactor sites. However, there are many sources in urban atmosphere such as incomplete combustion, vehicular emission, biomass burning. which can contribute to the benzene level in the waste management sites apart from the waste management process. Figure 9 indicates the concentration of toluene in various municipal waste dumping sites. The highest concentration toluene was found in Baruipur open dumping site, i.e. 3.93 μg/m^3, and the lowest concentration of toluene was found in Baidyabati sanitary landfill site, i.e. 0.23 μg/m^3. From Fig. 10, the highest concentration of m-xylene is 9.58 μg/m^3 in South dumdum compactor site and the lowest concentration is 0.69 μg/m^3 in Baidyabati sanitary landfill site. From Fig. 11, the highest concentration of ethylbenzene was found in Baruipur open dumping site, i.e. 3.33 μg/m^3 and the lowest concentration of ethylbenzene was

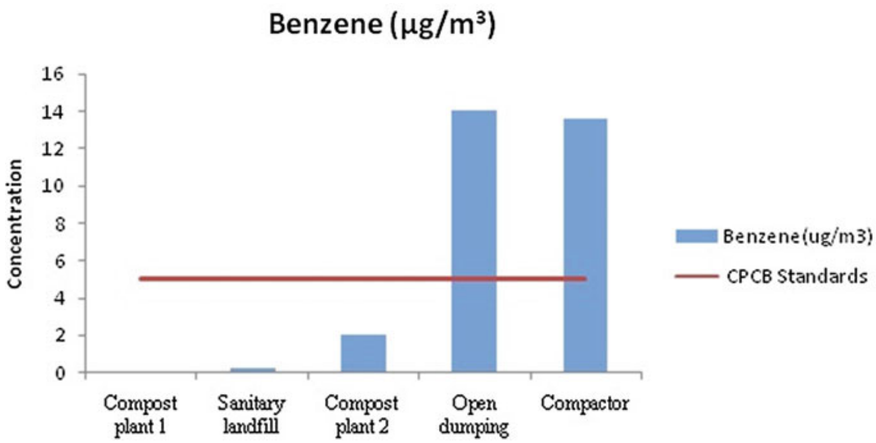

Fig. 8 Concentration of benzene in various municipal dumping sites

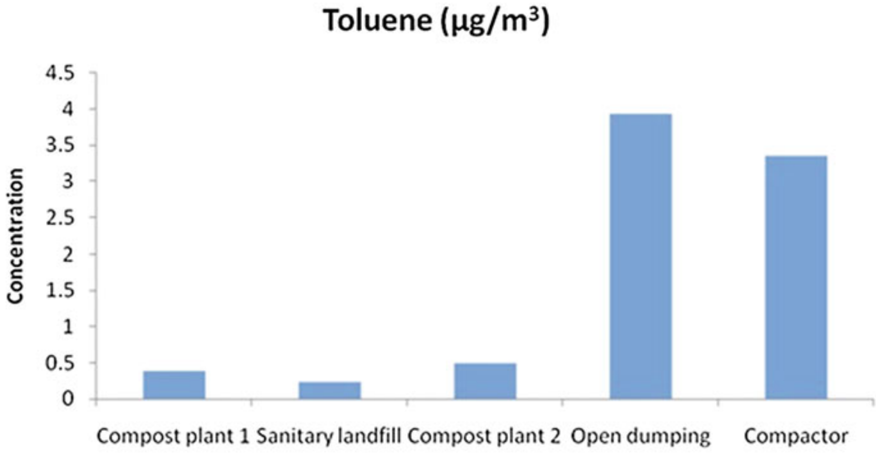

Figure. 9 Concentration of toluene in different municipal dumping sites

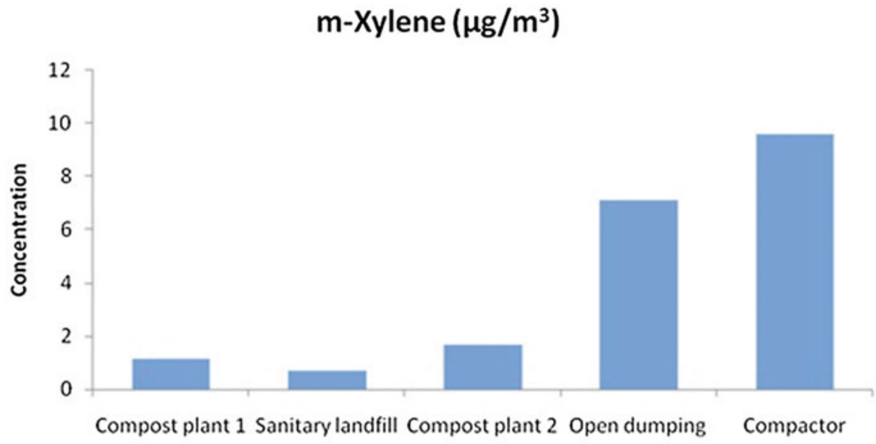

Fig. 10 Concentration of m-xylene in various municipal dumping sites

found in Baidyabati sanitary landfill site, i.e. 0.36 µg/m^3. From Fig. 12, the highest concentration of o-Xylene is 0.07 in Baruipur open dumping site and the lowest concentration of o-Xylene is 0.15 in Baidyabati sanitary landfill site.

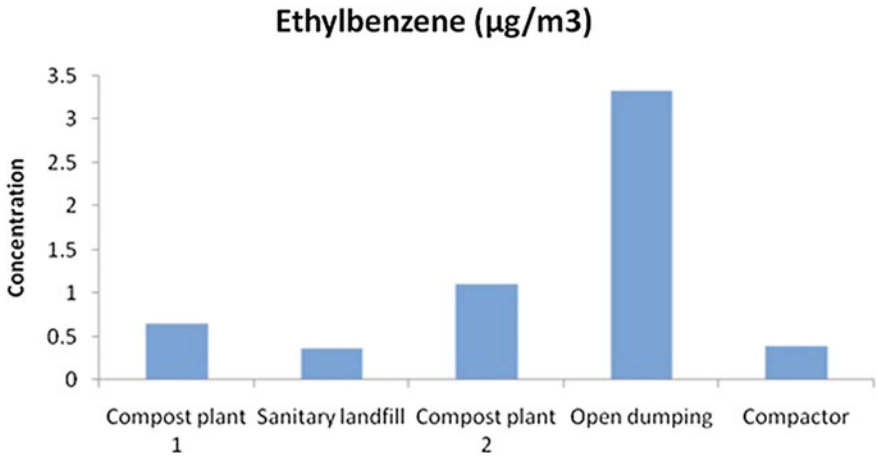

Fig. 11 Concentration of ethylbenzene in various municipal disposal sites

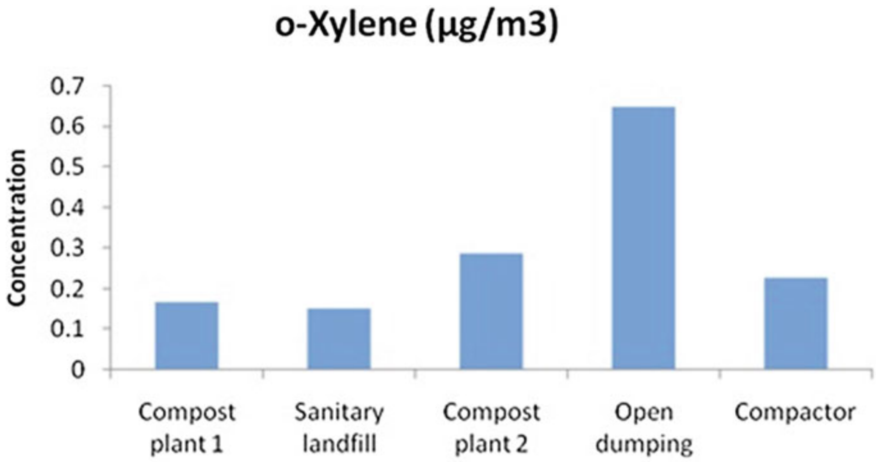

Fig. 12 Concentration of o-xylene in different municipal dumping sites

4 Conclusion

The study suggests that there are variations in pollutant emission across different waste management techniques. However, other local sources such as vehicular emission, residential emission also contribute to ambient level near management sites. Hence, to determine the contribution of the various waste management processes detailed sources apportionment study is required.

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Assessment of Air Contamination Potential from Waste Dumps in Developing Countries

Amit Kumar, Manoj Datta and A. K. Nema

Abstract Odorous and greenhouse gas (GHG) emissions from municipal solid waste (MSW) dumps result in air contamination. This study first applies two existing rating systems, JENV and NPC, to determine the air contamination hazard potential of municipal waste sites with continuously varying site characteristics. The performance of these two existing systems is analysed in terms of the range of hazard ratings obtained and the clustering indices for the ratings. These two rating systems produce scores in narrow ranges with very high clustering indices on account of not taking into account waste height, number of rainy days, waste composition, dispersion scenario and receptor conditions. A new system is proposed, based on combining two other rating systems, OD-HARAS and GH-HARAS, which can determine the hazard potentials from MSW sites for odour emissions and GHG emissions, respectively. The study demonstrates that the new system performs better than JENV and NPC in terms of range of rating scores and clustering index. The new system categorizes seven waste dumps from Indian cities in three different categories for remediation/closure.

Keywords Municipal waste dumps · Rating system · Greenhouse gas
Odours · Air contamination

1 Introduction

In developing counties, municipal waste is mostly disposed in waste dump or uncontrolled landfills. These waste dumps have no scientific or engineered measures to protect surrounding environment from getting contaminated. In absence of any engineered measures, the pollution from these waste dumps continue abated.

These open dumps seriously pose hazard to the surrounding environment through a number of pathways, e.g. groundwater, surface water and air. For air

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contamination, odorous and GHG emissions from a waste site are very important. While landfills are one of the highest sources of global anthropogenic methane emissions [2], a prolonged exposure to odours can generate unpleasant reactions ranging from emotional stresses to physical symptoms [1]. Smoke from landfill fire also causes air contamination. Causes of the landfill fire includes Arson, wastes containing hot embers, sparks from vehicles, equipment fire, waste having low ignition point and heating by biochemical reactions [10].

In developing countries, the waste dumps are generally located in close vicinity of the communities. The close vicinity of human beings and waste dumps further exacerbate the problem for surrounding communities as a result of persistent odour nuisance. To plan for remediation of these waste dumps, it becomes necessary to prioritize these waste dumps for action. The air contamination hazard potential makes a suitable criterion for prioritizing these sites. This study develops and assesses a new system for assessing the air contamination hazard of municipal waste sites.

2 Objective, Scope and Methodology of the Study

The objective of the study is to assess the air contamination hazard potential of MSW dumps. This study considers the Air Contamination caused by the odorous and GHG emissions. As landfill fire and resulting smoke are not a recurring phenomenon, the study neglects air contamination resulting from smoke. The scope of the study encompasses MSW dumps in Indian cities having population more than a million.

The study first investigates the usefulness of the existing rating systems to assess air contamination potential. Afterwards, a new system is proposed by combining two rating systems for assessment of air contamination hazard rating. Three rating systems, i.e. two existing and one proposed, are then applied to the waste dumps from Indian cities.

3 Existing Systems for Air Contamination

A number of rating systems exist which can determine the air contamination hazard potential of waste disposal sites (Table 1). Out of these rating systems, only two, i.e. JENV and NPC, are applicable to MSW sites which can assess the air contamination hazard potential. In addition, two systems, i.e. GH-HARAS [6] and OD-HARAS [7], can be used to assess GHG emissions hazard and odour emissions hazard, respectively.

Table 1 Existing rating systems and their applicability to MSW sites for air contamination hazard

Applicability of rating systems	No. of rating systems	Rating systems
Primarily for hazardous waste	12	Hazard assessment rating methodology; hazard ranking system-1982; defence priority model; hazard ranking system-1990; Washington ranking method; national corrective action prioritization system; relative risk site evaluation (RelRisk) method; environmental repair program hazard ranking system; Indiana scoring model; risk screening system; risk assessment of small closed landfills; and national classification system [3, 12, 13]
For municipal waste but cannot produce a separate score for air contamination hazard	03	Hazard ranking using fuzzy composite programming (HR-FCP) [4]
For MSW and can produce a separate score for air contamination hazard		JENV [5] and NPC system [11]
For MSW waste to assess odour or GHG hazard rating separately	03	OD-HARAS [7] and GH-HARAS [6]

4 Assessment of Two Existing Systems

The foremost difference between JENV and NPC is in terms of parameters used. While site area is used by both the systems, JENV also uses waste height. The fresh waste disposed/day, an important parameter for odours, is employed by JENV but not by NPC. JENV does not take into account any receptor parameters while NPC considers surrounding population density and distance to populated area. JENV employs waste composition, but NPC only differentiates between hazardous and municipal waste and does not consider various levels of biodegradables in municipal waste. Both the systems do not take into account various scenarios of emissions dispersion like valley or hilly topography.

For the purpose of further assessment, both systems were applied to a set of waste sites with continuously varying site characteristics (Table 2). The air contamination potential of these sites increases as one move from HAC-1 to HAC-6. The resulting scores were normalized to 0–1000 scale (Fig. 1).

It is clear from Fig. 1 that the scores from JENV as well as NPC are in narrow ranges of 350–600 and 450–800, respectively. While NPC does not consider the important parameters such as fresh waste disposed/day and waste composition in its formulation, JENV system does not take into account receptor's conditions. Moreover, both the systems do not consider dispersion scenario. Hence, these systems do not respond to change in the value of these parameters and exhibit clustering of scores.

Table 2 Site characteristics for waste sites with continuously varying site conditions

Site	HAC-1	HAC-2	HAC-3	HAC-4	HAC-5	HAC-6
Landfill area (ha)	5	10	15	20	25	30
Waste height (m)	5	10	15	15	20	30
Waste disposed (ton/day)	0.0	300	600	1200	1500	2000
Biodegradable fraction (%)	40	50	60	65	70	75
Hazardous fraction (%)	1	1	5	5	5	5
Rainy days	30	40	50	60	60	100
Annual Precipitation (mm)	500	750	1000	1000	1250	1500
Cover type	None	None	None	None	None	None
Dispersion scenario	Hilly	Hilly	Plain	Valley	Valley	Valley
human density (0–3000 m)	Sparse	Sparse	Medium	Medium	Dense	Dense

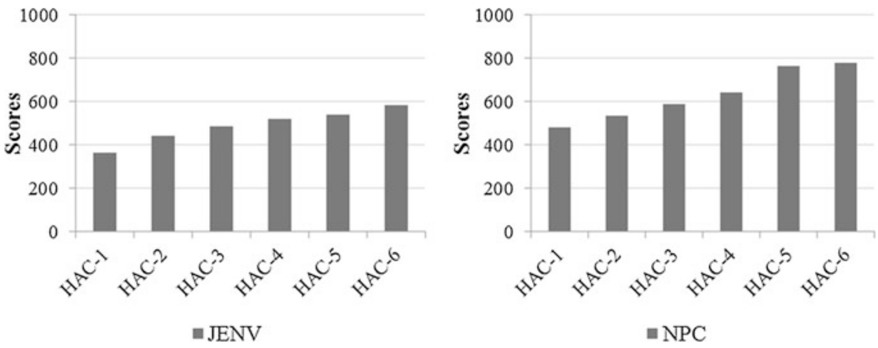

Fig. 1 Air contamination hazard ratings from JENV and NPC for waste sites with continuously varying conditions

The scores obtained from the two systems were also analysed by clustering index [9]. Clustering index is a parameter for measuring uniform spread of scores across a specified scale. The clustering indices of two systems are very high, i.e. 0.70 and 0.78, for NPC and JENV, respectively, indicating the clustering of ratings from two systems.

5 A New System for Determining Air Contamination Hazard Rating

Air contamination from a municipal waste dump consists of GHG emissions and odorous emissions. A rating system for assessment of air contamination would be considering both kinds of emissions from a waste site. Two systems, i.e. GH-HARAS [6] and OD-HARAS [7], can assess hazard potential for GHG emissions and odour emissions, respectively. Both the systems together take into account important parameters relating to air contamination, i.e. area and height of waste, fresh waste disposed/day, waste composition (biodegradable and hazardous fraction), annual rainfall, number of rainy days, dispersion scenario (topography) and surrounding population density.

For the new system, HR_{Air}, air contamination hazard rating of waste disposal site is obtained by the following relationship:

$$HR_{Air} = \left\{ \frac{HR_{GHG}^2 + HR_{odr}^2}{2} \right\}^{1/2}$$

where HR_{GHG}—hazard rating for GHG emissions is calculated by GH-HARAS [6] and HR_{odr}—hazard rating for odour emissions is calculated by OD-HARAS [7]. The aggregation method by root sum square is based on HRS-1990 [14].

6 Comparison of Two Existing Systems with the New System

The new system is applied to the waste sites with continuously varying site characteristics (Table 3). The results from the new system are compared with those from JENV and NPC as applied to. The results are presented in Fig. 2 from which one notes that the ranges of rating scores produced by the new system are in wider range than that of the existing systems. The range of the rating scores from the new system is 150–1000 which is practically the full range of the scale. Moreover, the

Table 3 Site characteristic parameters for MSW dumps from Indian cities (B—biodegradable fraction (%); C&D—construction and demolition waste; hazardous waste assumed to be 5% for all sites; for dumps C, E and G, receptors are present in predominant wind direction; all sites located in plain areas)

Site	Dump A	Dump B	Dump C	Dump D	Dump E	Dump F	Dump G
City	Indore	Nagpur	Chennai	Kolkata	Mumbai	Delhi	Delhi
Landfill area (ha)	8	21.5	81	21.4	120	13	29.8
Waste height (m)	16	5	6.4	24	15	48	32
Waste disposed (ton/day)	0	800	2300	3500	4000	600	3000
B (%)	48	53	46	56	48	50	66
C&D waste (%)	20	20	20	30	20	20	16
Rainy days	70	72	120	115	80	61	61
Annual rainfall (mm)	950	1050	1200	1650	2400	721	721
Population density (0–1500 m) (1500–3000 m)	Sparse Sparse	Med Dense	Dense Dense	Neg. Sparse	Med Med	Med Med	Dense Dense

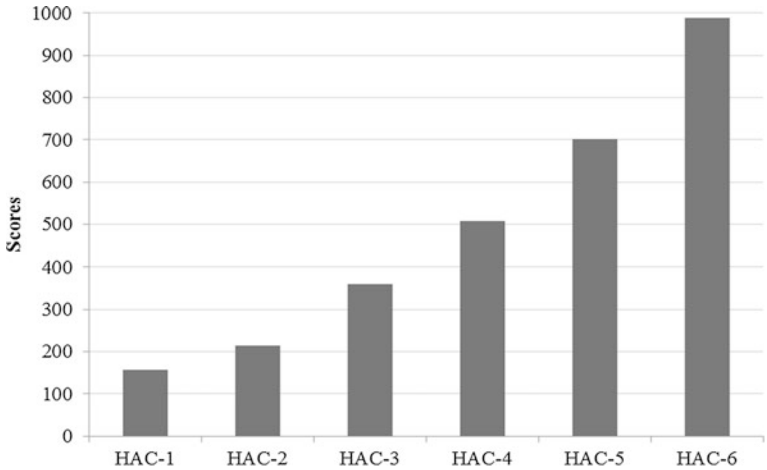

Fig. 2 Air contamination ratings for MSW dumps with continuously varying characteristics from the new system

clustering index of the new system for these scores is 0.18 indicating minimum clustering of the scores. As the new system considers all the parameters relevant to odorous and GHG emissions, it is able to respond to change in these parameters.

7 Case Studies from Indian Cities

For case studies, the data were collected from offices of the municipal corporations. All the cities having population more than one million (fifty-three in total) were contacted with questionnaires regarding the conditions of the dump sites in their jurisdiction [8]. All of these waste dumps are without liners or covers (Table 3). The waste quantity in these waste dumps varies from about 0.8 million to more than 14 million tons. The annual rainfall for these waste dumps lies between 700 and 1700 mm. While Dump A in Indore receives no fresh waste as it is closed, about 4000 tons per day of fresh waste is disposed on Dump E.

The results of applying JENV, NPC and the new system are presented in Figs. 3 and 4. The hazard ratings from existing systems, i.e. JENV and NPC, are in narrow ranges of 450–630 and 610–850, respectively. On the other hand, the new system produces a wider range of 210–820. While the clustering indices of NPC and JENV are 0.78 and 0.85, respectively, the clustering of scores from the new system is reduced with index of 0.41.

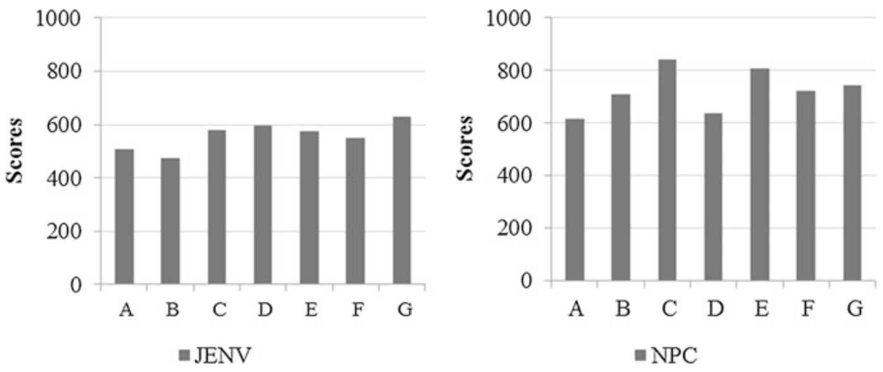

Fig. 3 Air contamination hazard ratings from JENV and NPC for waste dumps from Indian cities

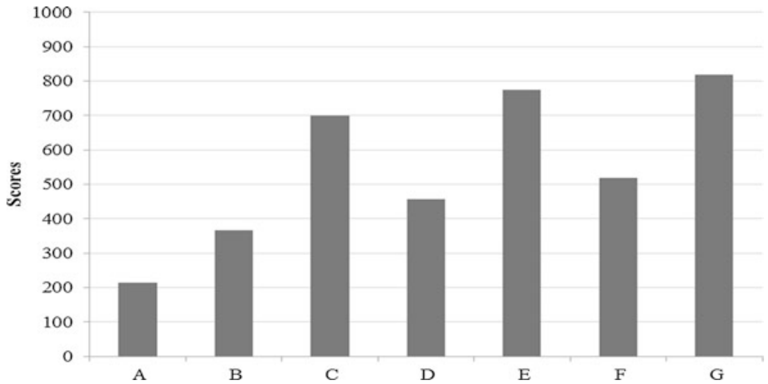

Fig. 4 Air contamination hazard ratings for MSW dumps from Indian cities from the new system

The waste dumps can be put into three categories of hazard: high (rating more than 500), medium (rating between 250 and 500) and low (rating below 250). According to the results from the new system (Fig. 4), while three waste dumps, i.e. Dumps C, E and G, are in high hazard category, two waste dumps B and D are in medium category. Dump F is at the interface of medium and high and can be considered in medium category. Dump A is in low hazard category.

Dumps C, E and G, categorized as having high hazard, are situated in medium to densely populated areas, receive more than 3000 tons of fresh waste every day and receive medium to high rainfall. Dump A, having low hazard, is a smaller and abandoned waste dump site located in a sparsely populated area.

According to the rating scores from JENV, all the waste dumps are in high hazard category except Dump B. Dump A is at the interface of high and medium category and may be considered as medium. NPC system classifies all the seven waste dumps as in high hazard category.

8 Conclusions

The following can be summarized from the study:

- At present, there are two existing rating systems, JENV and NPC, which can be used to estimate the air contamination hazard potential from municipal waste sites. However, these systems do not consider all the relevant parameters, i.e. waste height, waste composition, number of rainy days, fresh waste disposed/ day on the site, dispersion scenario and receptor conditions, necessary to directly estimate the odorous and/or GHG emissions hazard from a waste site.
- A new system for air contamination hazard rating has been proposed based on two rating systems, OD-HARAS and GH-HARAS, intended to assess hazard for odour emissions and GHG emissions. As OD-HARAS and GH-HARAS can estimate the hazard potentials for odorous emissions and GHG emissions from municipal waste sites, the new system can directly estimate the air contamination from waste sites.
- When applied to the waste sites with continuously varying characteristics, the new system gives scores in the widest range, i.e. 150–1000. The scores for the existing systems were confined to the narrow ranges for JENV and NPC. The clustering indices for existing systems ranged from 0.70 to 0.78, which improved to 0.18 for the new system.
- When the existing systems, JENV and NPC, were applied to waste dumps from Indian cities, the resulting hazard ratings were in narrow ranges with very high clustering indices.
- The application of new system shows that from amongst the seven waste dumps studied, three have high hazard potential for air contamination and need immediate attention for closure. Three waste dumps have medium hazard potential and require remediation/closure in short-term. The remaining one dump has low hazard potential and can be taken up for remediation/closure in long-term.

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Part XIX
Modelling in Solid Waste Management

Cost Analysis of Municipal Solid Waste Management Using Waste Compacting Stations: A Case Study

Payel Ghosh and Sadhan Kumar Ghosh

Abstract Under the clean city initiative, one of the biggest challenges is municipal solid waste (MSW) management. The city like Kolkata has a population of 14,112,536 as per 2011 census which is directly related to waste generation. Waste generation which is controlled by the evolution of economic growth, life style, will increase as population will increase. The old concept of dumping in open vat and then transfer into landfill is no more appreciable in this clean city initiative. Open vat produces odor and vector-borne diseases encompassing it. It is easy accessible of birds, animals, and rainwater which scatter wastes in the vicinity of open vat. Moreover, MSW is being carried out for disposal, and the area of disposal site is also limited. To overcome this drawback, municipalities are concentrating on waste compaction. However, the compacted wastes are still transported and dumped into landfill site. Waste compactors help to reduce the volume of MSW which will decrease the number of times the dumpster will be needed to be emptied. As a result, transportation cost will be minimized. The purpose of this study is to analyze cost of MSW management using waste compactor with respect to waste quantity, waste characteristics, number of trip of the compactors, labors requirements. As, increase of population directly influences the MSW generated, the study reveals the future MSW stream in largest municipality of West Bengal and also gives an idea of cost involved due to MSW management.

Keywords Waste management · Compactor · Cost analysis · Municipal solid waste

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1 Introduction

As a developing country, India is producing municipal solid waste (MSW) at an alarming rate due to rapid growth of urban areas and migration of population from rural to urban areas [1]. Statistics shows that nearly 76 million tons of MSW was generated in 2014 which is expected to be 9 billion tons by 2021 [2]. The MSW management is highly neglected in most of the developing countries. Hence, the scenario in India is similar. Present scenario with MSW management in India is basically a combination of primary and secondary collection and open dumping [3–5]. It is seen that about 60% of total generated wastes is collected, 90% of which is openly dumped [6]. With population growth, generation of waste will increase. Thus, present MSW management system in India will not be suitable in near future. The land for waste disposal and agricultural production will become scarce. It is a long procedure to restore landfills, so it becomes crucial to optimize waste before land filling.

The most common techniques in MSW management are collection, land filling, composting, and incineration. Systems and practices of those techniques are outdated and inefficient. No serious efforts and clear plans are there to enhance efficiency in those techniques. Though an ample amount of municipal budget is allotted for MSW management, most of it is spent on the wages of sanitary workers whose productivity is very low [7]. Under clean India initiative, scattering of wastes in the vicinity of open vat and unplanned land filling are restricted. As a result, several municipalities have introduced modern technique of compaction in managing MSW. There are some studies regarding waste management using compactors in metropolitan city like Kolkata [8]. However, cost analysis of this waste compaction procedure at present and near future is rare. The compactors are of two types: mobilizing and static. Mobilizing compactors help in compaction as well as hygienic transportation. Static compactors are placed in a feasible place which is easily reachable from every corner of the corresponding area without any hazards. Compactors are used to reduce the volume of waste; however, the waste weight will remain same. Hence, it can be told that no savings are there with respect to total weight of waste. So the questions arise.

(1) What is the benefit of compaction in front of municipality in terms of cost and environmentally friendly waste management?
(2) What will be the precaution for near future in terms of compaction facility according to the increase of waste which is directly related to the growth of population?

Compactors can reduce up to 80% waste in volume as a result; mobilizing compactors can collect more amounts of wastes in one trip. So, savings will occur in transportation. In case of static compactor, collected MSW are brought to the compaction station and then compaction happens. Here also, as the volume reduces, the number of trips to empty the dumpster in land filling is decreased. That means transportation cost, cost due to energy consumption will be low. The main objective of this paper is the analysis of cost in the whole procedure of MSW management.

2 Define Project Area

However, 70% of India's population lives in rural area according to 2011 census [9], but improving living standard and development in cities are the causes of increased solid waste. Bhatpara municipality is the largest municipality in West Bengal which belongs to the urban part of India. It is situated in North 24 Parganas in West Bengal. Bhatpara municipality is having 34 km^2 of land area and 442,385 populations according to 2011 census. This largest municipality of West Bengal generates 200 ton MSW per day (approx) from 35 wards having 10 marketplaces, 3 railway stations, 1 famous religious space, 3 ferry ghats, 2 burning ghats, 179 educational institutions, 1 hospital along with a huge residential area (Fig. 1).

3 Methodology

This research analyzes the current management of MSW using compactors. After literature survey on present MSW management practices, surveys on 34 wards of Bhatpara municipality have been carried out. Analysis of MSW management cost is an issue that concerns every municipality. Although the costs vary in different municipal areas, composition of cost is roughly same. This study reveals a cost analysis of MSW management using compactor. Due to varying market value, some parameters are taken as interval fuzzy number which allows a range of uncertain value to calculate with.

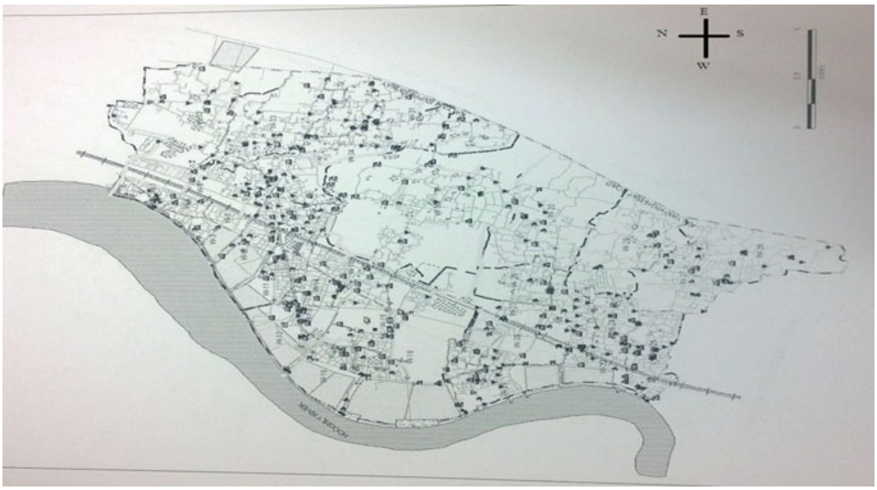

Fig. 1 Map of Bhatpara municipality area

4 Discussion

Most common scenario with MSW is that waste is thrown on the streets. Gradually, storage system has been implemented at source by the concerned personnel or by municipality. Bins, vats for storage of domestic, trade or institutional wastes have been established till collected for its disposal. Then these wastes have been carried off for dumping by open truck. Spilling of garbage, seepage of water from waste is common during transportation by open truck. Bhatpara municipality has two mobile compactors and one stationary compactor as of now. A discussion with respective engineer of the municipality reveals that the major generators of MSW are classified as residential, industrial, commercial, and institutional area. There are total 250 handcarts for door-to-door collection (Fig. 2). After door-to-door collection, they are transferred to a secondary collection point in the form of open vat. Vat is the intermediate storage stations for waste handling, loading, and unloading.

Areas with high density like retail shop, slaughter houses, markets, hotels, and restaurants, open vats regularly overflow due to heavy dumping of wastes. There, tractors are the preferable primary collection point instead of handcarts (Fig. 3). There are total 35 tractors to collect MSW from high density area. Depending on the density of area, the number of handcart varies. A single handcart can carry 100 kg of MSW in one trip. One mobile compactor generally takes wastes from 40 to 70 handcarts, and one stationary compactor takes wastes from 100 to 110 handcarts. It is the discretion of facility personnel to select the type of compactor that will best serve the facility layout since different constraints are there at the time of collection. The mobile compactors (Fig. 4) roam to collect MSW from secondary collection point. The stationary compactor (Fig. 4) is used for the area where mobile compactor can't serve and it is located at a reachable position from each corner of that particular area. The maximum distance from each corner of that area

Fig. 2 Door-to-door collection by handcart

Fig. 3 Storage in VAT and collection by tractor

to the stationary compactor is about 4.5 km. These compactors have a capacity of nearly 10 ton, and volume of waste reduces due to compaction is about 20%. Once it gets filled after compaction, the mobile compactors are carried for dumping in landfill site and the compacted wastes from stationary compactor are again loaded to the truck and carried for dumping. After that, dumped wastes are dispersed in the landfill area using JCB.

5 Cost Generation Factors in MSW Management

Composition of costs in a typical MSW management process from municipality perspective is based on the following factors:

(1) Segregation at source level
(2) Collection of waste materials
(3) Transportation of materials to the storage area or waste to energy plant or composting unit, etc.

The overall MSW management process requires costs due to transportation, handling of wastes, and human resource as major issues. One way of saving in terms of fuel is segregation at source level. It can save up to 3.5 L/tone average fuel consumption of collection vehicle depending on intensity of segregation [10]. Apart from monetary gain, nowadays environmental gain is in highest priority in front of authority. The common practice after segregation was to dump in open vat, and it used to lie for days in some cases two to three days. This unhealthy waste disposal methodology is optimized incorporating waste compactors into MSW management system. Due to waste compaction, transportation cost for landfill will be minimized. On the other hand, a new factor as energy cost due to compaction will be added in composition of costs in MSW management. A case study on Bhatpara municipality involves three major cost components for MSW management using compactor. The cost components are shown below:

Fig. 4 Mobile compactor and stationary compactor

l_c = Labor cost in Rs./day
f_c = Fuel charge in Rs./L
E_c = Electricity cost in Rs./kWh

These costs are dependent on several factors like number of handcart for door-to-door collection, distance to be covered in one trip, power consumption, compaction time. Some of those factors are dependent on total generated waste which is not same each and every day. The data collected by some questionnaire with municipality personal provide us an upper bound and lower bound. We therefore consider those data as interval number.

6 Some Arithmetic Operations of Interval Number [11]

Interval Number: An interval number is a closed and bounded set of real numbers.

$$[a, b] = \{x : a \leq x \leq b \forall a, b, x \in \mathbb{R}\}$$

Addition: The addition of two interval numbers $A = [a_1, a_2]$ and $B = [b_1, b_2]$ is denoted by $A(+)B$ and is defined by

$$A(+)B = [a_1 + b_1, a_2 + b_2]$$

Scalar Multiplication: The scalar multiplication of one interval number $A = [a_1, a_2]$ is denoted by kA and is defined by

$$kA = k[a_1, a_2] = \begin{cases} [ka_1, ka_2] \text{if } k \geq 0 \\ [ka_2, ka_1] \text{if } k < 0 \end{cases}$$

Subtraction: The subtraction of two interval numbers $A = [a_1, a_2]$, and $B = [b_1, b_2]$ is denoted by $A(-)B$ and is defined by

$$A(-)B = A(+)(-1)B = [a_1, a_2](+)[-b_1, -b_2] = [a_1 - b_1, a_2 - b_2]$$

Product: The product of two interval numbers $A = [a_1, a_2]$, and $B = [b_1, b_2]$ is denoted by $A(\cdot)B$ and is defined by

$$A(\cdot)B = [a_1, a_2](\cdot)[b_1, b_2] = [p, q]$$

where p = minimum $(a_1b_1, a_1b_2, a_2b_1, a_2b_2)$ and q = maximum $(a_1b_1, a_1b_2, a_2b_1, a_2b_2)$.

Division: The division of two interval numbers $A = [a_1, a_2]$ and $B = [b_1, b_2]$ is denoted by $A(:)B$ and is defined by

$$\begin{aligned} A(:)B &= [a_1, a_2](\cdot)\left[\frac{1}{b_2}, \frac{1}{b_1}\right] \text{if } 0 \notin [b_1, b_2] \\ &= \text{empty interval if } b_1 = b_2 = 0 \\ &= [a_1, a_2](\cdot)\left[\frac{1}{b_2}, \infty\right) \text{if } b_1 = 0, b_2 \neq 0 \\ &= [a_1, a_2](\cdot)\left(\infty, \frac{1}{b_1}\right] \text{if } b_1 \neq 0, b_2 = 0 \end{aligned}$$

7 Waste Cost Analysis

The supply chain of waste management practice in Bhatpara municipality includes MSW collection, transportation, compaction, landfill. The MSW is collected from every household by 240–250 hand carts (h_i). From high density area like marketplace, hospital area, institutional area, MSW is collected by 20–30 tractors (t_i) and two mobilizing compactors. There is only labor charge associated with each handcart whereas fuel charge is there with the tractors along with labor cost. Average mileage of tractors (m_t) and mobilizing compactors (m_c) are 8–10 L per km and 3–4 L per km, respectively, and fuel charge in West Bengal recently varies from (f_c) 50 Rs. to 60 Rs. per L. The collected wastes are compacted using two mobilizing compactors and one stationary compactor. The man power is distributed as one for each handcart, two for tractor and mobilizing compactor and stationary compactor. There are some temporary workers whose daily pay is around 197 Rs. where some permanent staffs on monthly salary basis are also there. The monthly salary is calculated on the basis of 280 Rs. per day. Hence, as per the information of municipality personal, the labor cost (l_c) is varying from 197 Rs. to 280 Rs. per day. Once the compactors get filled, the compaction process starts and it takes around 45 s. For compaction, the mobilizing compactors' fuel consumption (f_{com}) is 1.2–2.3 L per mt^3 and for stationary compactor the power consumption is 1.1 kW. In West Bengal suburban area, the electricity cost (E_c) is 6.5 Rs. to 7 Rs. per kWh.

The waste when compacted produces water and other liquids, which are drained into sewage via pipeline incorporated in the compactor. Rest part is brought to the landfill area traversing (l_f) 7–10 km for dumping then a JCB is used to spread the dumped waste for land filling. The previous scenario regarding pickup before the introduction of waste compaction process it was 23–27 trips per day. It is to see that waste compaction saves number of trips.

Since most of the data collected are not appropriate, there are ranges of some data, that's why those data are taken as interval number. To analyze costs related to MSW management using compactor, some arithmetic operations of interval number are used here.

Costs at several sections	Parameters
Cost at collection time $h_i \times l_c + t_i \times \frac{d_t}{m_t} \times f_c \times \text{Number of trip} + t_c \times \frac{d_c}{m_c} \times f_c \times \text{Number of trip} + (t_i + t_c) \times \text{Number of labour} \times l_c = [240, 250] \times [197, 280] + [20, 30] \times \frac{[4.5, 5.5]}{[8, 10]} \times [50, 60] \times [22, 28] + 2 \times 2 \times \frac{[7, 10]}{[3, 4]} \times [50, 60] \times [5, 7] + ([20, 30] + 2) \times 2 \times [197, 280]$ Rs./day $= [675,98, 128164.4]$Rs./day	Number of handcart (h_i) = [240, 250] Number of tractors (t_i) = [20, 30] Fuel charge (f_c) = [50, 60] Rs./km Mileage of tractor (m_t) = [8, 10] km/L Number of mobile compactor (t_c) = 2 Mileage of compactor (m_c) = [3, 4] km/L Labor cost (l_c) = [197, 280] Distance to be covered in one trip by tractor (d_t) = [4.5, 5.5] km Distance to be covered in one trip by mobile compactor (d_c) = [7, 10] km Volume of tractor (v_t) = [16, 18] mt^3, Volume of compactor (v_c) = [19, 24] mt^3 Number of trip for tractor = [22, 28] Number of trip for compactor = [5, 7]
Energy usage cost Total fuel cost for mobile compactors during compaction $t_c \times f_{com} \times v_c \times c_p \times o_{tc} \times f_c$ Rs./day = $2 \times [1.2, 2.3] \times [19, 24] \times 5 \times [30, 45] \times [50, 60]$ Rs./day = [750, 3268.62] Rs./day Total electricity cost for compactors during compaction $\frac{E_{elec} \times c_p \times o_{tc}}{360} \times E_c$ Rs./day = $\frac{1.1 \times 5 \times [30,45]}{360} \times [6.5, 7]$ Rs./day = [29.7765, 48.1257] Rs./day Total energy usage cost [779.7765, 3316.7457] Rs./day	Fuel consumption of mobile compactor during compaction (f_{com}) = [1.2, 2.3] L/mt^3 Operation time of compactor for one compaction (o_{tc}) = [30, 45] seconds Number of compaction performed per day (c_p) = 5 times Power consumption of stationary compactor (E_{elec}) = 1.1 kW Electricity cost (E_c) = [6.5, 7] Rs. per kWh
Economic cost analysis Number of pickups if compaction happened will be (N_{ac}) = $N_c(1 - v_r)$ = [23, 27] (1–20/100) ≈ [18, 22] Transport cost after compaction to landfill $\frac{l_f \times N_{ac} \times f_c}{m_t}$ Rs. = $\frac{[7,10] \times [18,22] \times [50,60]}{[8,10]}$ Rs./day = [630, 1650] Rs./day	Volume of wastes reduces (v_r) = 20% Number of pickups without compaction (N_c) = [23, 27] Distance to cover for landfill in one trip (l_f) = [7, 10] km

8 Forecasting of MSW Generation in Bhatpara Municipality Area

The future amounts of waste are closely related to economic growth, and waste generation rate is directly proportional to the rate of change of population (1). A mathematical calculation tells the estimation of future population based on the average increase in population of last two decades. Then the future amount of MSW generation is also calculated to get an idea of expense regarding MSW management using presently provided facility.

$$\text{Future population}(P_{\mathrm{f}}) = P_o(1 + R/100)^y \tag{1}$$

Here, P_o = Initial population, R = Percentage of growth rate = are population increasing percentage of last two decades and y = years.

The rate of change of population [12] in the suburban area in 1991–2001 is 44.93% and in 2001–2011 [13] is −13.3%. Then, the population in 2021 will be 448,961 (Approx)

Future amount of MSW generation per day (1) $(W_t) = w_r \times P_{\mathrm{f}}/1000$ ton/day. Here, w_r is the waste generation rate 0.54 kg/capita/day. Hence, the amounts of MSW in 2021 will 242.439 (Approx) ton/day which will increase by 42.439 (Approx) ton/day.

9 Conclusion

The case study over a population of 383,762 people provides an idea of possible expense of MSW management through waste compactor. Though this procedure of MSW management process doesn't imply any revenue or large saving toward municipality but from environmental point of view the initiative is truly making the municipality area clean. There is a need to increase facility of compaction as waste generation rate is directly proportional to the rate of change of population. The facility includes a sanitized landfill site, segregation of waste at the point of waste generation and collecting them separately and compacting them separately using more number of mobile or stationary compactors.

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Fuzzy Logic Modelling to Predict Residential Solid Waste Generation: A Case Study of Baranagar

K. A. Kolekar, B. Bardhan, T. Hazra and S. N. Chakrabarty

Abstract Accurate prediction of waste generation plays a key role in planning of Municipal Solid Waste Management (MSWM) system. Traditional statistical forecasting models require large continuous crisp data and cannot incorporate new data. Hence, development of advanced prediction method is necessary. Fuzzy logic handles dynamic and linguistic data set successfully on limited database. A mathematical model was developed in this research work for predicting Residential Solid Waste (RSW) generation using fuzzy logic considering Baranagar Municipality (BM), Kolkata, India, as a case study. Household population, annual income and building area of households were considered as independent variables for predicting RSW generation. Triangular- and trapezoidal-shaped membership functions were used to describe the dependent and independent variables, and centroid method was applied for defuzzification. Initially, two input variables were taken at a time to identify the correlation with RSW generation. Finally, all three input variables were considered. Model results were found to follow similar trends with actual RSW generation. Average waste generation per household was obtained between 0.5 and 1.0 kg/day. Statistical analysis shows that household population–annual income model is the best-fitted model. However, building area–annual income model shows least R^2 value. Surface diagram represents that building area has not much effect on RSW generation and household population is the dominating variable for waste generation.

Keywords Residential solid waste · Generation prediction · Fuzzy logic Modelling

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1 Introduction

Developing countries like India face keen issues of Municipal Solid Waste Management (MSWM) system due to population growth, fast-growing urbanization, land scarcity and wide variety of waste generated from residential area. Indian population is second largest population in the world. In India, 423 cities having population greater than 0.1 million produces 72.5% Municipal Solid Waste (MSW) and other 3955 cities produce only 17.5% of total waste. It indicates MSW depends on population and its density [27]. Researchers state that 90% of MSW is disposed of unscientifically in open dumps [15, 19, 20], and such landfills create an adverse effect on environment and human health. Hence, it is essential to plan properly the MSWM system to control the deterioration of environment of the locality. For proper MSW management, accurate prediction of MSW generation is must. However, very few attempts have been made on forecasting of Residential Solid Waste (RSW) generation in India.

This prediction is based on several independent variables [18]. Researchers identified several socio-economic and demographic independent variables for waste generation [9, 14, 16, 23]. Beigl et al. [4] reviewed modelling methods based on independent variables as bivariate analysis models and multivariate analysis models. Household size, income and education level variables were generally used for modelling purpose. However, each variable shows different relations at different locations. For example, household size has strong relation to waste generation in one location, while it has weak relation in another location. Thanh et al. [23] revealed weak correlation in household size and per capita per day waste generation. Traditional statistical forecasting models such as multiple regression models, the geometry average method, saturation curve method and the curve extension method cannot incorporate new data. These models required large continuous crisp data. However, these models have universal approximation and poor precision for inaccurate data [22, 26]. Hence, development of advanced prediction method is necessary which should handle the prediction analysis with reasonable accuracy in spite of limited input database. Fuzzy logic handles dynamic and linguistic data set successfully. This model is now being applied in various fields like system controls, business, electronics and traffic engineering. Developing countries face problems of incomplete or vague data due to insufficient fund, manpower, etc., in forecasting of MSW generation [5]. Expert opinions regarding MSW generation are generally in linguistic terms. Hence, fuzzy logic may be the best solution for such situations.

Chen and Chang [5] applied grey fuzzy model to predict urban solid waste generation of city Tainan in Taiwan on limited sample numbers. They revealed greater accuracy in prediction than the grey dynamic modelling. Karadimas et al. [11] considered residential and commercial waste for forecasting MSW using fuzzy logic. The observed results interpret accuracy in forecasting of MSW generation. Oumarou et al. [17] predicted waste generation of residential campus of University of Maiduguri and the two housing estates in Maiduguri, Nigeria, using fuzzy logic. Lozano-Olvera et al. [14] used fuzzy logic for profiling of waste packaging like plastic paper, metal and glass waste. To select the site of landfilling for disposal of MSW, Al-Jarrah and Abu-Qdais [1] effectively used fuzzy logic by considering attributes such as Topography and Geology, Natural resources, Sociocultural effects, Economy and Safety of landfill site.

Forecasting of RSW generation is a challenging task to understand the exact relation between forecasting variables and its utilities on exact field generation data. Various forecasting models fail due to many practical uncertainties in RSW generation. Present paper aims to identify the correlation between household population (HP), annual family income, building area (BA) and RSW generation which help the decision makers in predicting of future RSW generation. This paper introduces a mathematical model for predicting RSW generation using fuzzy logic considering Baranagar Municipality (BM), Kolkata, India, as a case study.

2 Study Area

Baranagar Municipality (BM) is located at north side of Kolkata in West Bengal state and at east side of River Hooghly. It lies between latitude 22° 38′ 45.15″ north and longitudes 88° 22′ 17.17″ east. The population of BM is 0.245 million. (As per census [10] total area is 7.12 km^2.) The location map of BM is shown in Fig. 1. It has population density around 34 thousand per km^2 [2]. BM consists of 63,387 houses with wide variety as per annual income level. In year 2013–14, 138 ton per day of MSW is generated in BM area [6].

In BM area, RSW collected from door-to-door and street sweeping are first stored in roadside bins and then transferred to disposal site by truck. The collection and transfer are not well equipped and highly labour-intensive. The containers for storage are less than requirement and are not properly designed. The frequency of collection and transfer is not based on daily RSW generation causing municipal solid waste left uncollected. That causes excessive health hazard, aesthetic torture and environmental problems.

3 Methodology

3.1 Fuzzy Logic

Fuzzy logic deals with reasoning that is approximate rather than fixed and exact. Fuzzy logic has unconstrained boundary between true and false. Zadeh [25] in the mid-1960s developed fuzzy logic with imprecise data. In fuzzy logic, four steps are performed: fuzzification, fuzzy rules, fuzzy inference and defuzzification. Fuzzification comprises the process of transforming crisp values into grades of membership for linguistic terms of fuzzy sets. A *Membership Function* (μ) is a

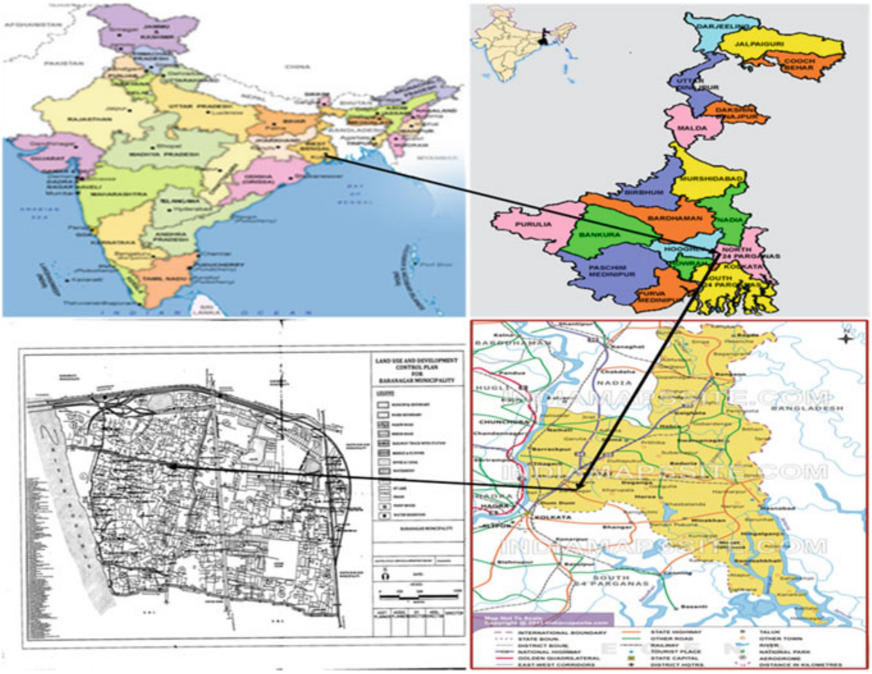

Fig. 1 Location map of study area *Source* Bardhan [3]

curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1 in the universe of discourse. In fuzzy logic, the membership function represents the degree of truth as an extension of valuation. This research work advantageously used triangular- and trapezoidal-shaped membership functions to describe the dependent and independent variables using MATLAB (R2013b). Triangular membership function is a collection of three vertex points (a, b, c) forming a triangle. The *trapezoidal* membership function has a flat top and in reality is just a truncated triangle curve. These straight line membership functions have the advantage of simplicity. Degree of membership for set A is expressed as:

(a) For triangular membership function:

$$\mu A(x) = \begin{cases} 0 & x \leq a \\ \frac{x-a}{b-a} & a < x \leq b \\ \frac{c-a}{c-b} & b < x < c \\ 0 & x \geq c \end{cases}$$

(b) For trapezoidal membership function:

$$\mu A(x) = \begin{cases} 0 & (x < a) \text{ or } (x > d) \\ \frac{x-a}{b-a} & a \le x \le b \\ 1 & b \le x \le c \\ \frac{d-x}{d-c} & c \le x \le d \end{cases}$$

where

A is set of object
x is an individual value of database
a, b, c, d are the vertex of shape of membership $(a < b < c < d)$

Fuzzy rule links the input to the output variables using IF-THEN format. These rules provide facility for all possible relationship between input and output variables. Intuition, inductive reasoning or expert opinions are used for making rules when no database is available. Antecedent part is in between IF-THEN and consequent is coming after then. If multiple variables consist in the rules then AND or OR operators are used to get the single value in between 0 and 1. In this work, intuition method was used for IF-THEN rule formation with AND operator and equal weightage were given to every rule. After formulation of rules, the next step is fuzzy inference. Fuzzy inference consists of two types: Mamdani and Sugeno. Here, Mamdani fuzzy inference system was applied for prediction of RSW generation prediction. This process is widely applied in various applications. Inference gives output in the form of linguistic terms for each rule. This linguistic output is converted into crisp value by defuzzification. Seven methods are available for defuzzification; out of these methods, centroid method is most popular. Centroid method was found most appropriate method for this work.

3.2 Design of Survey Instrument

Survey instruments were designed for collecting data regarding respondent's socio-economic characteristics, amount of RSW generated per household and existing MSWM system provided in their locality. A questionnaire consisting of three parts was prepared for collecting respondent's socio-economic characteristics, amount of SW generated per household and existing MSWM system of the study area.

3.3 Data Collection and Database Development

In BM area, primary data were collected with the help of questionnaire survey. There are 63,387 households in BM area. These households were first clustered into different types depending on annual family income and living standard of the residents. Since household census data are not available and normally household data are collected by survey method and personal interviews [4], paper–pencil-based face-to-face interviews were carried out at various locations in the months of September and October 2014 to get household data.

Respondents were approached randomly. Each respondent was requested to provide information related to his/her socio-economic characteristics. All the randomly selected 200 households were given plastic bags to store their daily waste during the survey period. The weights of solid waste from the households were measured by portable electronic machine before disposal to the handcarts daily to get actual data regarding solid waste generation. Sixty-eight households were selected randomly for modelling from 200 data sets. The sample size was administered to be representative of the total population of the municipality in terms of annual family income. Summary statistics of the information about socio-economic characteristics of respondents was presented in Table 1.

Table 1 Summary statistics of data set

Variables	Description	Values
Observations		200
Gender	Male	51.28%
	Female	48.72%
Age	Below 18 years	15.94%
	19–30 years	21.59%
	31–45 years	26.44%
	46–60 years	21.90%
	More than 60 years	14.13%
Education	Up to secondary	36.93%
	Up to higher secondary	22.30%
	Graduate and above	40.77%
Occupation	Service	31.28%
	Business	13.22%
	Student	22.60%
	Others (housewife, retired person, etc.)	32.90%
House details	Flat (own/rented)	24.5%
	Single home (own/rented)	75.5%
	Area in ft^2	978.97 (mean)
Population per household members		4.70 (mean)
		2.05 (std.dev.)
Annual income per household		3.02 ₹ $\times 10^5$ (mean)
		1.90 ₹ $\times 10^5$ (std. dev.)
RSW generation per household		1.05 kg (mean)
		0.41 kg (std. dev.)

3.4 Model Development

The collected data were analysed by developing a fuzzy inference-based model using MATLAB (R2013b) toolbox. Three input variables were considered for modelling purpose, namely household population (HP), annual family income and available building area (BA). Municipal Solid Waste (MSW) generation depends on socio-economic and demographic factors like income, expenditure, consumption pattern, education, household size, population density. Income is widely utilized for predicting MSW generation for households [8, 14, 16, 21, 23, 24]. Consumption pattern can be related with available building area per house since more the building area represents more potential consumption and more waste generation. A number of previous research studies have significantly and positively hypothesized household population with MSW generation [7, 8, 13, 14, 16, 18, 21, 24]. Initially, two input variables were considered at a time to identify the correlation between the input variables and the output variable "RSW generation". Finally, all three variables were considered in single model to predict RSW generation.

3.4.1 Development of Membership Function

The collected data were fuzzified with the combined triangular and trapezoidal membership functions. The crisp value of variables, household population (HP), income and BA was divided into three linguistic subsets: low, medium and high. The output variable of the model, RSW generation, was also divided into three subsets: low, medium and high. Details of Membership functions of input and output variables are listed in Table 2.

3.4.2 Fuzzy Rules

During analysis, the relationships amongst the input and output variables were formulated considering collected data. "AND" operator was used for combining the input data. When two input variables consist of three membership functions were considered in the antecedent part, 3^2 rules were formulated [12] like "If household population is low and income is low then residential solid waste generation is low".

Table 2 Details of linguistic values and their ranges

Variables	Subset		
	Low	Medium	High
HP (in numbers)	(0, 0, 2, 4)	(3, 5, 8)	(6, 8, 12, 12)
Income (in ₹ $\times 10^5$)	(0, 0, 1, 2.5)	(2, 5, 10)	(8, 10, 13)
BA (in ft^2)	(0, 0, 400, 600)	(400, 800, 1200)	(1000, 1400, 2500, 2500)
RSW(in kg/day)	(0.2, 0.4, 0.7)	(0.5 1, 1.5)	(1.3, 2, 2.6, 2.6)

In case of combination of all variables in a single model, twenty-seven rules were developed.

3.4.3 Fuzzy Inference

In fuzzy inference system (FIS), Mamdani method was used since it is most commonly used. FIS considered all fuzzy rules and gave results. Here, minimization implication was used with equal weightage given to each rule, and maximization was applied for aggregation process.

3.4.4 Defuzzification

The outputs of the model were also obtained in the form of fuzzy set. To convert these outputs into crisp value, defuzzification process is required. Centroid method was used for defuzzification of greater accuracy. The schematic diagram of proposed model is shown in Fig. 2.

4 Results and Discussions

The actual collected data and outputs obtained from developed models were graphically presented in Fig. 3.

From Fig. 3, it is clear that RSW generation obtained from developed model followed same trend as actual generations. Average waste generation per household was obtained between 0.5 and 1.0 kg/day. The performance of developed fuzzy logic models was accessed based on coefficient of determination (R^2) values. Correlation coefficient (R), coefficient of determination (R^2), adjusted (R^2) and root

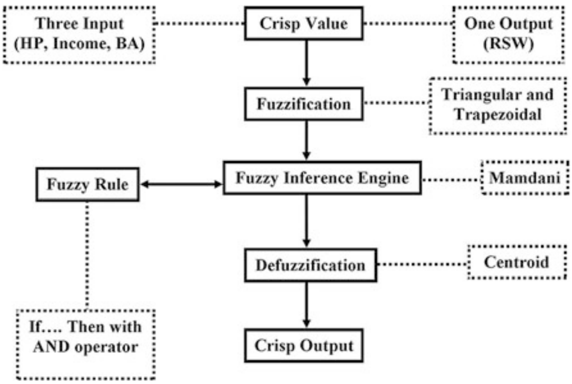

Fig. 2 Schematic diagram of fuzzy proposed model

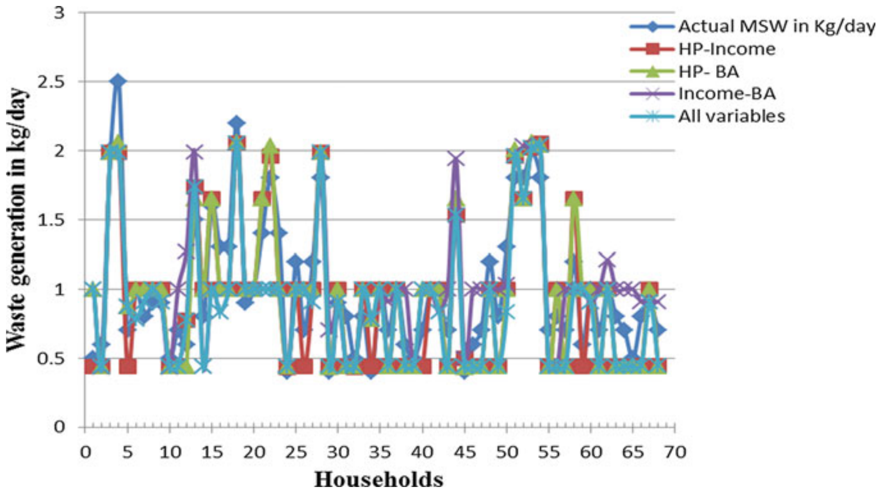

Fig. 3 Graphical representation of actual versus model results

mean square error (RMSE) values of various models obtained in SPSS (20) were shown in Table 3.

From Table 3, it is clear that, R^2 value lies in the range of 0.631–0.861 for various combinations of input variables with output variable. HP-income model gives highest value "0.861". Hence, it revealed that HP-income model was best-fitted model for prediction of RSW generation. However, income-BA model shows lowest R^2 value. Hence, it can be concluded that when input variable BA was introduced in the fuzzy logic model, lesser accuracy in prediction was obtained. Three-dimensional surface diagrams show effectively the relationship between input variables and RSW generation in Fig. 4.

From the surface diagram of HP-BA model, it is clear that up to 6 HP with increasing BA, there is no change in RSW generation, where in income-BA surface diagram, high RSW generation is seen for high income and high BA up to a greater extent. HP-income models show RSW generation increases with increasing in population of household and family income. Since every time, with increasing household population RSW generation increases, it can be said that household population is dominating variable for RSW generation.

Table 3 Results of statistical analysis for evaluating model performances

Model	Correlation coefficient (R)	Coefficient of determination (R^2)	Adjusted (R^2)	Root mean square error (RMSE)
HP-income	0.928	**0.861**	0.859	**0.201**
HP-BA	0.902	0.813	0.811	0.229
Income-BA	0.794	0.631	0.625	0.273
HP-income-BA	0.864	0.747	0.743	0.245

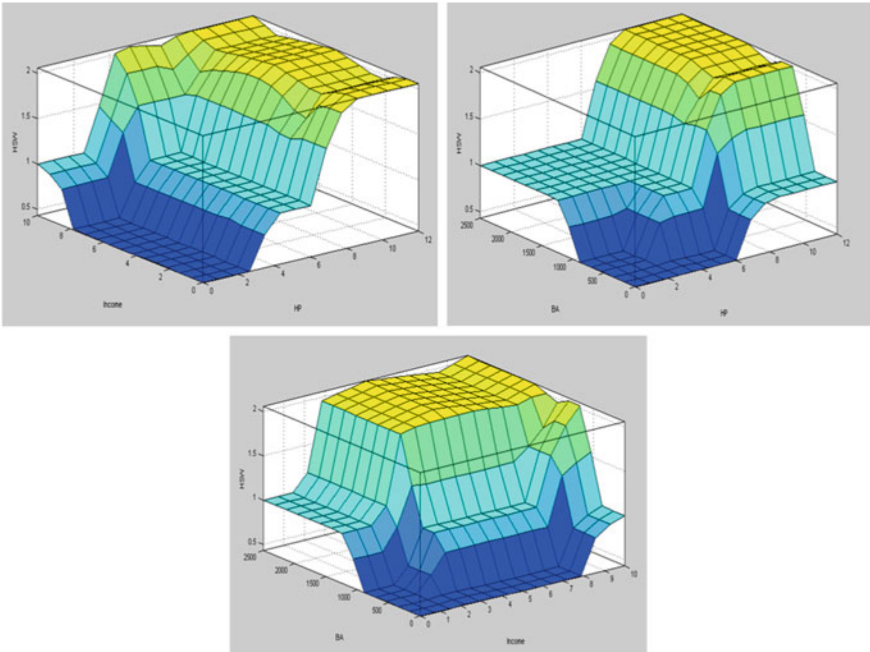

Fig. 4 Surface diagram of models

5 Conclusion

In this study, prediction of RSW generation capability of fuzzy logic model was evaluated. Input variables considered for model development were household population, income and building area. First two input variables were considered at a time to find the correlation between the RSW generation and input variables. After then, combination of all three variables was applied for waste generation prediction. Based on this research, following conclusions can be made.

Fuzzy logic models can be used to predict the RSW generation very effectively. The RSW generation has a strong relationship with the household population and household annual income. However, building area has direct relation with RSW generation though R^2 value obtained is the lowest for the models with building area. HP was obtained as the governing factor in RSW generation. Fuzzy logic models are user friendly; hence, it can be applied for prediction of RSW generation for any municipality. Solid waste is heterogeneous in nature, and its generation depends on number of variables. Hence, considering more variables may give more reliable simulation.

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A Study to Establish an Energy-Efficient Sustainable Business Model in Virtual ERP

Ipsita Saha, Amit Kundu and Sadhan Kumar Ghosh

Abstract The present research is aimed at to do research on energy utilization by SMEs of virtual ERPs. Economic performances of the SME sector have proved its contribution to nation building through the increased contribution to GDP, huge employment generation, equitable allocation resources and facilitate inclusive growth. Based upon the backbone of SMEs, virtual ERP is rising rapidly. The business strategy that virtual ERP follows incorporates the production of huge amount of data. Hence, an attempt has been made in this research to identify the broad parameters which are indicative of the success of the virtual ERP implementation in the Indian context. The identified parameters of adoption of Enterprise Systems (ES) in the Indian organizations are needed to put as factors in developing generic model. The construct of the theoretical model would help us to develop the optimization model in terms of cost, energy efficiency and resource utilization. Loss of huge amount of energy in order to manage 'Big data' produced by the cloud ERPs is becoming a challenge towards the establishment of sustainable business model.

Keywords Sustainable business model · Virtual ERP · Cloud ERP SME · Big data · Cloud federation · Cloud broker

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1 Introduction

Business model is a representation of successful business plan identifying sources of revenue with all customers' satisfaction. It is all about logical interconnection between customers identifying key resources to be circulated over internetwork. It is all about a logical correlation among customers and how they can make profit giving the value for those. The concept of sustainability of business models comes by the implementation of any framework of ERP systems. Sustainable business model describes how dynamic models based on technology, organization and environment (TOE) framework can be built providing a strategic advantage in research gap analysis, implementation, change management and process management for ERP projects. Initially, ERP packages were built to complement the necessity of the manufacturing industries especially to serve the finance sectors. ERP offers support towards purchasing, order tracking, quality management, product distribution and logistics management sectors of all arena of manufacturing and service sectors. ERP has benefits including inventory reduction, inventory carrying-cost reduction, cash management improvements, improved resource utilization, transportation/logistics cost reduction, maintenance reduction, and on-time delivery improvements, customer responsiveness, improved supplier performance, improved decision-making capability, globalization of the organization, better business performance, supply chain integration and the use of the latest technology. ERP incorporates modern technology to decrease more manpower, much cycle time, lead time, procurement cost. This overall IT cost reduction reflects economic growth of world business.

Cloud ERP is a structured approach of enterprise resource planning (ERP) to optimize company's value chain with more flexible business process transformation that makes use of cloud computing platforms and services. Cloud ERP ensures multi-tenant community which can easily be integrated as cloud providers. The SaaS layer can ensure all critical ERP application with huge data. But most importantly, cloud ERP emphasizes on the security of the databases including different modules of ERP projects like Supply Chain Management (SCM), Product Data Management (PDM), Customer Relationship Management (CRM), Product Life cycle Management (PLM), Business Intelligence (BI). The success of the BM can only be possible by the integration of all business activities such as operations, finance, marketing and human resource, and this integration can only be possible by the adoption of ERP modules as per the requirement of the organization. Virtual Enterprise System (ES) implementing sustainable business model includes all socio-ecological aspects of manufacturing hubs.

Virtual ERPs generate plenty of queries from users' perspective which can be treated as structured and unstructured data. When these petabyte of information are stored in a cloud environment, it takes huge amount of consumption of energy. Top management should encourage SMEs to adopt environmentally friendly activities to rate the activities of virtual ERPs as green computing.

2 Literature Review

2.1 Business Model

Though experts and scholars [1] describe business models have been discussed, there is still confusion that how they can be used [2]. This study has used to identify factors for success or failure while implementing enterprise systems in micro-, small- and medium-scale enterprises in developing economies. Those few found were inapplicable to the context of organizational politics and enterprise system success factors. According to Beaubouef [3], optimized business model, the reflection of cloud ES can be regarded as utility computing as fee will be charged based on usage.

2.2 Cloud Deployment Model

It was mentioned that cloud services as SaaS (Software as a Services), PaaS (Platform as a Services) and IaaS (Infrastructure as a Services) in the form of public, private and hybrid cloud. According to Hwang et al. [4], the huge initial investment is the barrier for SMEs to start developing their individual Information System (IS). For a better solution, cloud computing can be chosen as it provides 'pay and use service'. In this respect, Ahmed et al. [5] have identified 12 reasons that why the adoption of enterprise systems is required for Indian organizations. The study revealed that only organizational change factor was closely related with the size of the organization. Considering all the advantages, it can be interpreted as massive hype of cloud ES in the market a generic model can be developed that includes data security, assurance for SaaS applications and transactions. Cloud deployment model includes PaaS layer which is most hyped terms on client calls but the generic model to be proposed based on SaaS layer due to chaotic market of PaaS.

3 Sustainable Business Model

Sustainable business model means providing ultimate satisfaction to producer or distributor and consumer enforcing social and environmental needs. The sustainable borrow-use-return by William Donough and Michael Braungart highlighted on the closed-loop production technique where waste from production should be reused. In virtual ERP, SMEs can replace goods with services even they can lease products instead of selling them. When the product is obsolete to a particular customer, virtual ERP provider takes it back through its supply chain mechanism and the responsible SME will remanufacture the returned one.

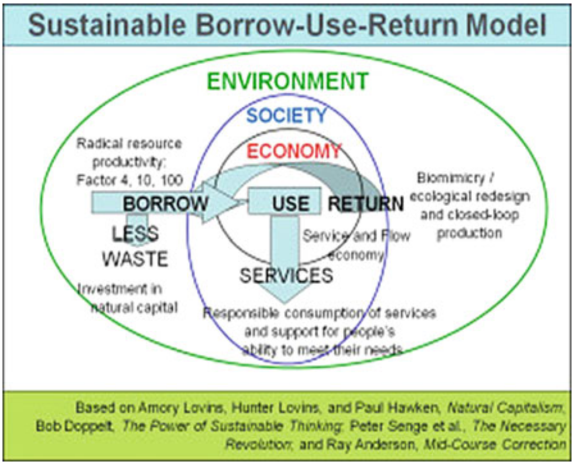

Fig. 1 Diagram of sustainable borrow-use-model

Not only that the model suggests that each virtual ERP should be responsible to share a message over the network regarding the ingredients production companies can use the packaging technology and any other added eco-friendly criteria.

Figure 1 describes how a business model can be tested through 'Borrow-Use-Return Model' to generate high profit with less waste.

4 Cloud ERP and Cloud Federation

Cloud ERP enables a company's finance, business management and reporting to run in the cloud. Private and governmental business organization and agencies mostly follow any of the deployment model, such as Public, Private, Hybrid and Community. Actually, virtual ERPs maintain the supply chain within customers and relevant SMEs for which bulk amount of data is produced that can be stored into the cloud. For this, if organization has its own cloud (like IBM, Amazon), it can store its data over there otherwise any portion of any cloud should be taken as lease. Cloud ERP describes service model as Infrastructure as a Service (IaaS) (e.g. Amazon EC2), Platform as a Service (PaaS) (e.g. Google AppEngine), Software as a Service (SaaS) (e.g. Salesforce). Among these virtual ERP lies on SaaS.

It is clear that how end-users can purchase through cloud ERP. Now the question is how to make both the customers and the providers happy. This is maintained by cloud service broker who has responsibility to select suitable service provider i.e. price versus quality of services, to manage on demand supply, to monitor resource utilization. From the shared pool of resources the way computing, storage and software resources are delivered as on demand service is called cloud federation.

5 Research Gap

The main challenges are regarding the efficiency of business strategies of virtual ERPs and the storage of huge data produced as a result of different operations done by these cloud ERPs. An attempt has been made in this research to build the efficiency of SME using ERP modules. We have identified the reasons of adoption of Enterprise Systems (ES) in the Indian organizations, namely operational improvements (cost, employee, cycle time reductions), business growth, compliance issues, organizational change, standardization and integration of best practices, globalization support, the intimacy between customer and supplier, healthy competition with external bodies, legacy system replacement for better globalization support.

The present research has attempted to address the following research problems:

(1) To what extent, the degree of increase of the performance of the firms by the adoption of ES can be achieved?
(2) What is the need of adoption of ES by SME firms considering the requirements as well as resource constraints of the firm?
(3) SME sector, being the only major contributor of the economic development and catalyst for the inclusive growth, whether the presence of business model using advanced technology like ERP leading them to sustainability?
(4) How can we conserve energy in generic model?

6 Objectives

- To identify the broad parameters which are indicative of the success of the ERP implementation in the technology perspectives, organizational perspectives and environmental perspectives in the Indian context.
- To design a generic model using cloud ERP for SME sectors after identifying the critical success factors for IS implementation.
- To measure the need of customization of on demand ERP.
- To justify the cost effectiveness and challenges faced due to on demand ERP with on premises solution.
- To examine empirically the success rate of ERP implementation.
- To develop a sustainable business model using customized ERP to enhance the competitiveness of the organizations.

7 Proposed Work

Extending the virtual ERP out of network periphery is actually integrating the business process to customers, suppliers or any other enterprise outside the organization. By integration means an organization can adapt any change made in commercial environment [6, 7]. Virtual ERP can be implemented with the concept of the technology, organization and environment (TOE) framework. This paper uses past literature and theoretical and conceptual framework development to introduce a business model for successful ERP implementation [8, 9]. The proposed work consists of the comparative analysis of ERP module and their challenges. Challenges include the managers who worked with similar kind of packages with same client and consultant. The proposed business model is formed based on survey and questionnaire methods. Questionnaire method will be adopted for collection of data, relevant for the study. The study will use factor analysis to find out the degree of importance of all the identified parameters/variables. Discriminate analysis will be used to measure the indices of all the dimensions. Relationship between firm performance and observable adoption parameters will be established by using econometric tools.

Parameters:

The underlying parameters to bridge the gap between ERP implementation and Critical Success Factors (CSFs) are: capability maturity model (CMM), strategic choice theory, contingency theory, social capital theory resource and knowledge-based view. Considering all the limitations, the business model which is going to be developed should possess customer satisfaction. For these prototypes, different business models have to be tested. If we use spiral model of SDLC, every quadrant has a facility to possess all the necessary steps. Not only that risk analysis and security for huge data must be considered. The major benefits that cloud ES provides are the infrastructure and platforms. But the challenges are like to compromise realistic expectations due to technical difficulties and low bandwidth. If the Internet bandwidth is low or is technically departed, cloud ES users have to face difficulty. Therefore, it is prudent to potential users to consider all possibilities at the time of designing, implementation, selecting a cloud provider and negotiating the service-level agreement [10].

The generic business model will be based on spiral model of software development life cycle model. Hence, the model possesses through planning, risk analysis, engineering, evaluation phases. The reason to choose this model is it supports high amount of risk analysis and good for critical business model. But it has some limitations like risk analysis requires highly specific expertise, and it is not well for smaller projects. Hence, another model can be proposed to be incorporated, namely prototyping model. Prototype Model is that where 'Planning' and 'Design' phase are followed by build prototype, customers' evaluation and redefine prototype that actually ensures utmost understanding of developers and clients.

For a certain e-commerce company like Flipkart has digiflip section where digital products are displayed to be sold out. Under the category of mobile phones, visitors can search mobiles of brands like Samsung, Lenovo, Motorola, Apple, Asus, Mi and many more. Buyers can buy any one from these varieties of products. Prior to that visitors can search the website of Flipkart for price, design, colour, features repetitively. After purchasing the product should be delivered to the customer by the specified SME (suppose here Mi of Mobile companies). Next to that customer may go for after.

Sales service operations. The entire process generates huge amount of structured and unstructured data, namely 'Big data'. SMEs are indirectly also responsible for the generation of these huge amounts of data by virtual ERPs (here Flipkart). Cloud computing gives a platform to store these data by the technique of virtualization whose establishment emits huge amount of energy. Based upon case studies, analysis is going on by which we can filter the unstructured data to make it structured and it results highest CPU utilization. As a market survey, the ratio between capacity of production by SMEs and demand of customer should be at par.

8 Conclusion

In a nut shell, it can be said that awareness for eco-friendliness is almost nil [11]. In the way of building well-structured sustainable business model, environmental regulations should be thought of. In software development, the prototype of the design should be verified by managers of virtual ERPs and environment and sustainability cell as the implemented modules consume with less cost, less space which in a broader sense reduce energy consumption. To strengthen this module, feedback can be taken from different levels of social hierarchy and can be implemented as per requirement.

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Part XX
Waste Water Treatment

Performance Study of Jute-Fabricated Filter Media for the Treatment of Faecal Sludge-Induced Wastewater

M. H. Mishuk, S. M. T. Islam and M. Alamgir

Abstract The study focuses on the performance of local jute-fabricated filter media for faecal sludge (FS)-induced wastewater treatment. The study area is in KUET campus, and samples were collected in the month of May of 2015. Samples were prepared with mixing and without mixing of polymer filtering through three types of jute-made bags, named as 'single jute bag', 'double jute bag' and 'jute with cotton bag'. Chemical parameters like DO, BOD, COD, pH, PO_4^{3-}, NO_3^- have been analysed along with some other parameters to observe the performance of treatment of wastewater by these filtering media. In comparison with used jute bags, 'double jute bag' has shown comparatively better performance for the treatment of wastewater. Moreover, use of polymer has noticeably influenced the treatment efficiency.

Keyword Faecal sludge · Wastewater · Jute bag · Polymer

1 Introduction

Faecal sludge management (FSM) is a major challenging issue in the present world. It is also very difficult to improve the quality of sludge-separated wastewater. Because of the lack of effective management of FS, wastewater has been implicated in the transmission of many infectious diseases including cholera, typhoid, hepatitis, polio, cryptosporidiosis, ascariasis and schistosomiasis [5].

In Bangladesh, FSM is also a major challenge in Bangladesh. Only 20% of the population of Dhaka is served by a highly expensive sewerage network; the rest use septic tanks, pit latrines, unhygienic latrines, or none at all [4]. Only a small

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percentage of faecal sludge is managed and treated appropriately [3]. At present, there is no formal or environmentally sound faecal sludge collection and disposal system in Bangladesh [3].

Khulna is the third largest city of Bangladesh situated in the south-western part of the country and lies in the delta of the River Ganges [2]. The city has an estimated population of 1.6 million, and total number of household is 66,257 [7]. But, there is no sewerage system in Khulna City [1]. Besides, currently Khulna has no designated dumping sites or treatment facilities for faecal sludge and wastewater [7]. Generally, wastewater is discharged into the public drains. These drains are connected with either ponds or river. Many city dwellers use these pond and river mainly for washing and bathing purposes. Using the pond or river water, many people are suffering from many infectious diseases daily. On the other hand, faecal sludge is dumped into an open field without proper management. This improper dumping creates nuisance very badly. During tidal flow and rainy season, dumped faecal sludge is then diluted with either the tidal water or rainwater and then mixed with the pond or river water.

This research study was on faecal sludge management where comparison of filtration capability of locally made ‘jute bag’ was performed. Considering the availability of local material, three types of jute-made bags such as single jute bag, double jute bag and jute with cotton bag are used in this research study for dewatering faecal sludge with filtering. The study area is KUET campus, and samples were collected in the month of May. Samples were filtered through three filter media after mixing and without mixing of polymer. Aquaestrol 6370 polymer is used to collect the samples. Some selected parameters were also analysed to observe the performance of treatment of the filter media. In this study, faecal sludge is tried to manage with filtering before dumping it or discharging of wastewater into public sewer.

2 Objectives

The research work is carried out to attain the following key objectives

(1) To characterize the faecal sludge-separated wastewater.
(2) To prepare different filters by using local jute fabrics and evaluate their performance.

3 Materials and Methods

3.1 Study Area

A septic tank was selected which is located in the premises of Khulna University of Engineering & Technology (KUET) which lies at 22″ 50′ north latitude and 89″ 50′ east longitudes (Google Earth). Then, samples were collected from this tank (Fig. 1).

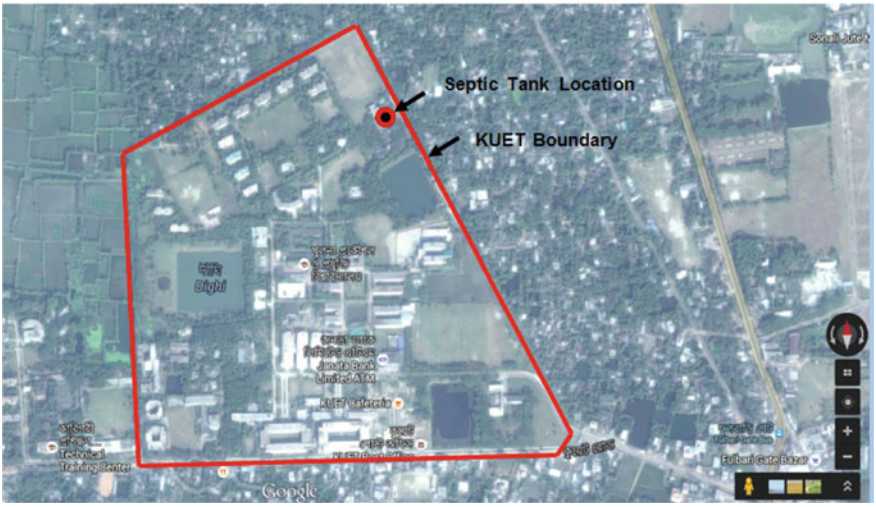


Fig. 1 Location of the study area

3.2 *Preparation of Jute Bags*

The jute material is selected for preparing dewatering bag. Because the jute is locally available material. The another main reason is that the potentiality of absorption capacity of heavy metal ions by jute-fibred materials is assessed satisfactorily [6]. Total three types of jute bags of one cubic feet in size were prepared in this research study. These bags are single jute-made bag, double jute-made bag and jute with cotton made bag shown in Fig. 2.

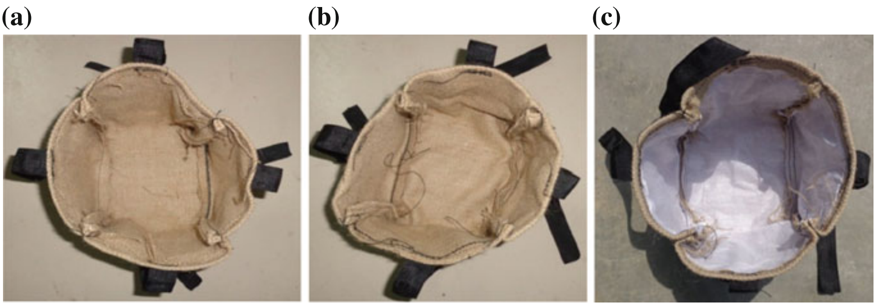


Fig. 2 **a** Single jute bag, **b** double jute bag and **c** jute with cotton bag

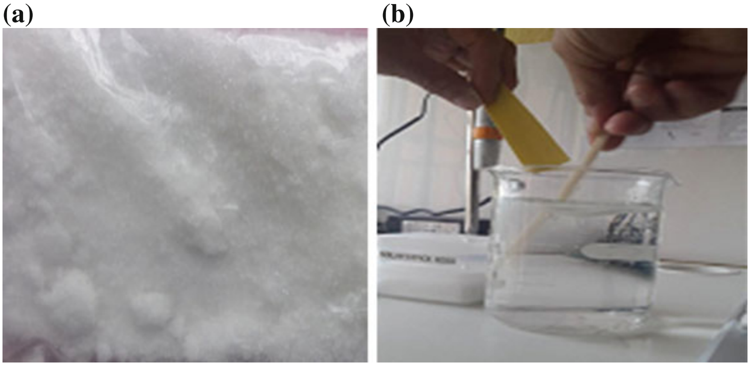


Fig. 3 **a** Polymer and **b** polymer is mixing with sample solution

3.3 Collection of Polymer

In this research study, for dewatering faecal sludge and treatment of wastewater, Aquaestrol 6370 polymer has been used to coagulate suspended solids and produce large curds of solid materials (floc). This polymer is manufactured by Tianrun Chemical Company in China, of which Charisbrent Pte. Ltd. has technical, developmental and production collaborations. This polymer was collected from Water and Sanitation for the Urban Poor (WSUP). The polymer is required 2 gm per 1 L solution of wastewater (Fig. 3).

3.4 Arrangement of Dewatering as Well as Filtering Media

For the collection of faecal sludge with wastewater, three bowls, one bucket, one mug and eight empty drinking water bottles were used to collect the samples from septic tank and after filtering. Hand gloves and masks were used in the time of both collection of sample and laboratory analysis. A weighting measure was used to

Fig. 4 Arrangement of dewatering as well as filtering media

weight the samples. A measuring cylinder was also used to measure the volume. Before collecting the sample, the dewatering and filtering bags were suspended with bamboo supports and bowls that were placed beneath the bags. The whole arrangement was shown in Fig. 4.

3.5 *Procedure of Collection of Samples*

The sample was collected on 10 May 2015. At first, one bucket of wastewater containing faecal sludge was collected from the first compartment of the septic tank. After collecting, raw samples were stirred sometimes for homogeneous mix and no polymer was mixed with the sample. 1.5 kg equivalent sample was poured into every filtering media, and after filtering, one sample was taken in water bottles from each media. One raw water sample was also taken in a bottle. In the second time, polymer was mixed with a bucket of raw samples collected from the same compartment of the septic tank and stirred for homogenous mixed for sometimes

Fig. 5 Collection of samples

and finally, kept 1 h. After that, like previous 1.5 kg equivalent polymer-mixed samples were filtered through each media and single sample was taken against each media in water bottles including raw samples. Some pictorial view of collection of samples has given in Fig. 5.

3.6 Laboratory Analysis

In the laboratory, a total of 14 parameters were determined in each sample. The value of dissolved oxygen (DO) and pH of the samples were determined by HACH125 multimeter immediately after collection of samples. The dilution factor (DF) was 60 for DO measurement. For BOD_5 determination, 300 mL from each diluted sample was taken into stopper-fitted bottles and kept into oven for 5 days. After that, again, DO of these samples at 5 days was measured and the difference of Do_1 and DO_5 was recorded as the BOD_5 value. For determining the chemical oxygen demand of each sample, two dilution factors were used in titration method. Dilution factor 50 and 100 were used for samples without mixing polymer and with mixing polymer. Potassium dichromate ($K_2Cr_2O_7$), sulphuric acid (H_2SO_4), ferrous aluminium sulphates (FAS) and ferion were used as chemical reagents.

Again HACHDR 2500 multimeter was used to determine the value of phosphate (PO_4^{3+}) and nitrate (NO^{3-}) where fosver 3 and nitrover 5 reagents were used respectfully. DF was 100 and 50 for raw water and filtrated water, respectively, in the determination of PO_4^{3+} and NO^{3-} (Fig. 6).

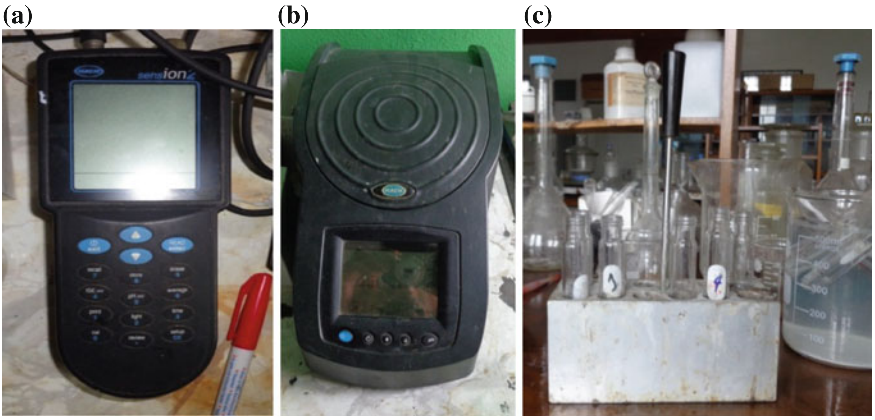


Fig. 6 **a** HACH125 multimeter, **b** HACHDR 2500 multimeter and **c** experimental setup for COD test

4 Results and Discussions

The concentrations of different water quality parameters of raw and filtered samples with and without mixing polymer are presented in Table 1.

4.1 *Dissolved Oxygen (DO)*

Each sample has two DO values—one is determined from polymer-mixed sample and another is from non-polymer-mixed sample. The DO values of non-polymer-mixed wastewater samples filtrated through single jute bag, double jute bag and jute with cotton bag are 0.20, 0.21, 0.23 and 0.26 mg/L, respectively. Again, the DO values of polymer-mixed samples are 3.60, 5.41, 6.02 and 5.74 mg/L, respectively. The DO values of the polymer and non-polymer-mixed samples are presented in Fig. 7.

Table 1 Concentration of different parameters due to filtrate with and without mixing polymer

Parameter	Without mixing polymer				With mixing polymer				BS
	Raw water	Jute-made bag			Raw water	Jute-made bag			
		Single	Double	With cotton		Single	Double	With cotton	
DO (mg/L)	0.20	0.21	0.23	0.26	3.6	5.41	6.02	4.5	4–8.5
BOD (mg/L)	180	180	168	160.2	62.4	15.6	15	18	250
COD (mg/L)	12,800	12,800	9600	9600	12,800	9600	9600	9600	400
pH	5.27	5.38	5.6	5.49	7.12	7.44	7.46	7.45	6.5–8.5
PO_4^{3-} (mg/L)	278.3	137.15	141	184.5	51.6	39.4	47.7	48.6	8
NO_3^- (mg/L)	430	170	135	180	30	3	5	5	–

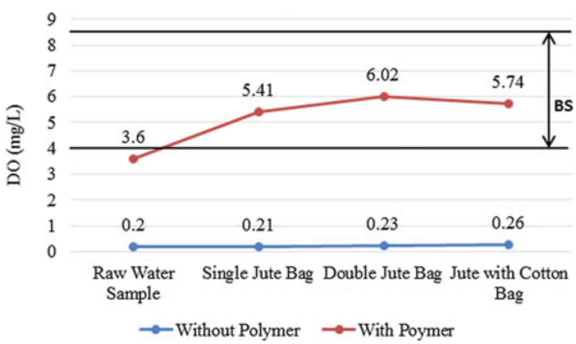


Fig. 7 DO values of the samples with and without mixing polymer

It has been observed from Fig. 7 that the DO value of raw water with mixing polymer has increased in large amount than the raw water without mixing polymer. On the other hand, after filtration of polymer-mixed raw water with different bags, the increasing of DO is considerable and that has varied around 50–70% by concentration. According to the Guideline, 2008 of Department of Environment (DoE), Bangladesh, the standard value of DO for public sewer is 4.5–8 mg/L. The DO values of the polymer-mixed raw sample that were filtrated through hall jute-made bags are within the DoE standard limit, whereas in case of non-polymer-mixed samples, the DO values are excessively below the standard limit. In comparison with different bags, it has been found that double jute-made bag has shown the best results.

4.2 Biochemical Oxygen Demand (BOD)

For BOD values, only diluted samples were kept in incubator for five days. After five days, the diluted DO values of all the samples were recorded. The values of DO_5 for non-polymer-mixed raw water, single jute bag, jute with cotton bag and double jute bag samples are 2.46, 2.80, 3.06 and 3.25 mg/L, respectively. BOD values have been calculated by the multiplication of DF with the difference of initial DO and DO after five days. The BOD values of non-polymer-mixed raw water, single jute bag, jute with cotton bag and double jute bag samples are 180, 180, 168 and 160.20 mg/L, respectively. While mixing polymer with the samples, the BOD values are 62.4, 15.6, 15 and 18 mg/L, respectively. The BOD values of the samples with and without mixing polymer are shown in Fig. 8.

It has been shown from Fig. 8 that the BOD values of raw water and filtrated samples with mixing polymer have decreased in a large amount than those of samples without mixing polymer. The reduction in BOD of polymer-mixed samples is approximately 70–75% by concentration than the non-polymer-mixed samples. According to DoE, Bangladesh, the standard value of BOD for public sewer is 250 mg/L. In case of both polymer and non-polymer-mixed raw water, the BOD

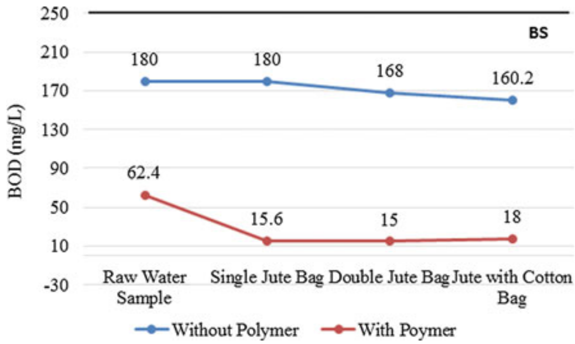


Fig. 8 BOD values of the samples with and without mixing polymer

values of the samples that were filtrated through all jute-made bags are within the DoE standard limit. In comparison with different bags, it has been found that double jute-made bag has shown the best results for BOD reduction.

4.3 Chemical Oxygen Demand (COD)

Without mixing polymer, the COD values of raw water and the samples filtrated through single jute bag, double jute bag and jute with cotton bag are 12,800, 12,800, 9600 and 9600 mg/L, respectively. Again the COD values due to mixing polymer are 12,800, 9600, 9600 and 9600 mg/L, respectively. These values are presented in Fig. 9.

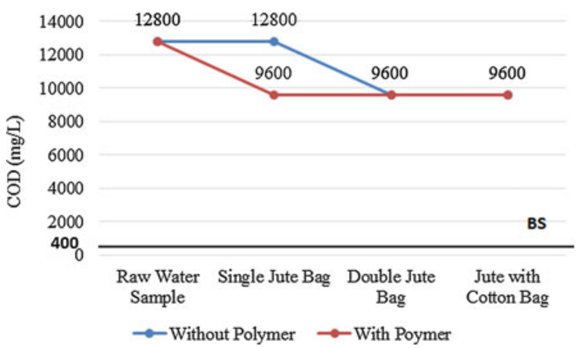
According to DoE, Bangladesh, the standard value of COD for public sewer is 400 mg/L. The COD values of the samples with and without mixing polymer are approximately close to each other. The COD value of the polymer-mixed sample filtrated with single jute bag has decreased to 9600 mg/L from the value 12,800 mg/L of corresponding non-polymer-mixed samples. Rest of the samples has remained same.

4.4 pH

pH is the indicator of acidic or alkaline condition of water. The standard for any purpose in terms of pH is 6.5–8.5. Due to mixing polymer, the values of pH of the raw samples and filtrated samples through single jute bag, double jute bag and jute with cotton bag are 7.12, 7.44, 7.46 and 7.45, respectively. The consecutive pH values of the samples without mixing polymer are 5.27, 5.38, 5.60 and 5.49, respectively. The two sets of pH values are presented in a bar chart in Fig. 10.

Figure 10 shows that the pH values of the samples without mixing polymer are acidic and have not lain between the standard limit. On the contrary, the values of

Fig. 9 COD values of the samples with and without mixing polymer



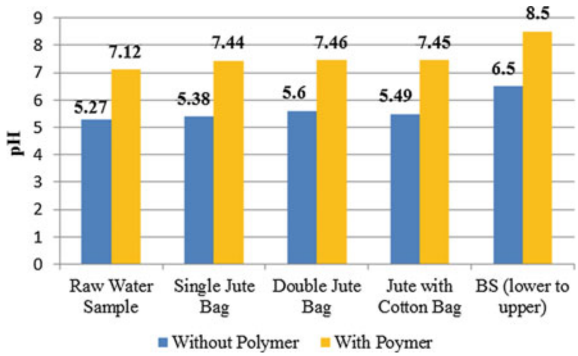


Fig. 10 COD values of the samples with and without mixing polymer

the samples with mixing polymer have lain between the standard limit. However, it is positive sign that all filtering media have shown better results than the raw water sample values. With mixing polymer, all types of jute bags have shown very close results to each other. Without mixing polymer, double jute bag has shown best results and it is approximately equal.

4.5 Phosphate (PO_4^{3-})

Without mixing polymer, the phosphate concentrations in the sample of raw water and after filtering through single jute bag, double jute bag and jute with cotton bag are 278.30, 137.15, 141.05 and 184.50 mg/L, respectively. On the contrary, with mixing polymer, these values are 51.6, 39.4, 47.7 and 48.60 mg/L, respectively. The comparison of these values with BS limit for public sewer is shown in Fig. 11.

It has been observed from Fig. 11, all the samples in both cases have not shown better results compared with the standard limit. If the samples are compared with each other, the polymer-mixed samples have shown the best results. Among

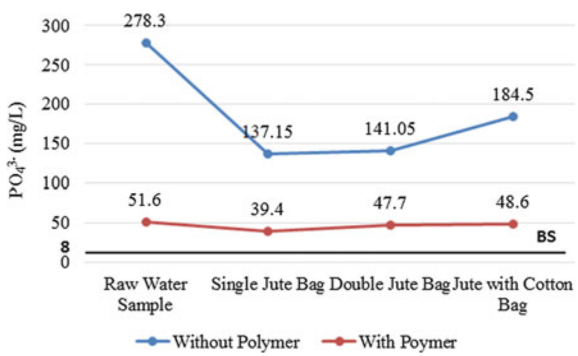


Fig. 11 PO_4^{3+} values of the samples with and without mixing polymer

polymer-mixed samples, the best result comes from single jute bag. For the samples with mixing polymer, the filtering media have reduced the concentration of PO_4^{3-} about 81–86% from their corresponding non-polymer-mixed samples.

4.6 Nitrate (NO_3^-)

In this research, the nitrate values have been found for the samples of raw water, single jute bag, double jute bag and jute with cotton bag are 430, 170, 135 and 180 mg/L, respectively, in case of non-mixing polymer and are 30, 5, 3 and 5 mg/L, respectively, in case of mixing polymer. These values are shown in Fig. 12.

The standard value of nitrate for public sewer is undetermined. So it cannot be recognized the worst NO_3^- values among all samples. However, in both cases, all filtering media have done better jobs than their corresponding raw samples. Double jute bag has shown the best results in both cases. With mixing polymer, the samples of double jute bag have reduced the concentration of nitrate around 70% from their corresponding samples without mixing polymer.

4.7 Cost of Filtering Media and Polymer

One-cubic metre single jute bag, jute double bag and jute bag with cotton cost around 450, 750 and 520 BDT, respectively. The cost of polymer per kg is 350–390 BDT. For example, the total treatment cost of 1.0 m^3 faecal sludge with mixing polymer is approximately 800–1150 BDT.

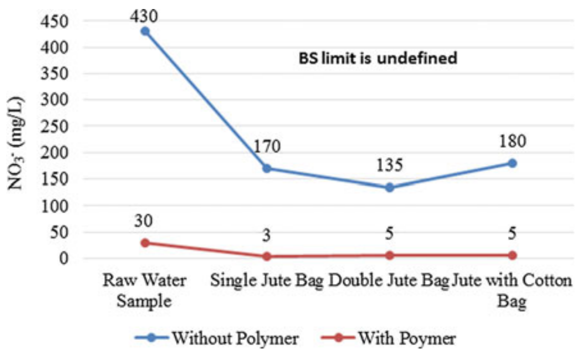


Fig. 12 NO_3^- values of the samples with and without mixing polymer

5 Conclusions

This study is mainly carried out to evaluate the filtration capability of locally made jute bag for the treatment of faecal sludge comparing different categories. From the obtained results, some conclusions can be drawn. 'Double jute bag' has the maximum efficiency of filtering compared to other counterparts. The results show that all the treatment options 'with polymer' are found considerably better for all the samples compared with its 'without polymer' counterparts. The DO value has increased significantly, and the BOD has decreased considerably of the samples 'with polymer' compared to 'without polymer'. The pH value has found within the standard limit due to mixing polymer with the samples. The COD and PO_4^{3-} concentrations are found reasonably well after filtering both the 'with' and 'without' polymer; however, the concentrations have not reached within the DoE standard of Bangladesh. Nitrate concentration has been reduced to a maximum value of 90% by mixing polymer with the samples and after filtering through double jute bag.

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Deployment of Hydrometallurgical System for Heavy Metals Recovery from Wastewater at Industrial Scale

Chilin Cheng and Shu-Yuan Pan

Abstract In this study, a patented hydrometallurgical system was deployed in electroplating industries for recovering heavy metals (e.g., nickel) to establish a sustainable waste-to-resource supply chain. The environmental benefits of the hydrometallurgical system were evaluated by life cycle assessment. The hydrometallurgical system includes three main processes: (1) front-end process: Equalys^{TM} for selected adsorption of targeted heavy metals using ion-exchange resins; (2) core process: regeneration of ion-exchange resin and generate stripped solution with various heavy metals in high concentration; and (3) production process: multi-stage crystallization of metal precipitation. For instance, in the case of nickel recovery, the concentration of nickel in stream was reduced from 20–400 mg/L to less than 1.0 mg/L after ion-exchange adsorption. After that, the nickel will be further concentrated to more than 50,000 mg/L, associated with the regeneration of resins. In the multi-stage production process, both nickel sulfate hexahydrate ($NiSO_4 \cdot 6H_2O$) and nickel sulfate ($NiSO_4$) can be produced with purities of 22 and 99%, respectively. It was concluded that numerous environmental benefits, such as zero generation of hazardous sludge, detoxification of wastewater discharge, and generation of high-value precipitate product, could be achieved by the developed hydrometallurgical system.

Keywords Nickel · Stripper · Ion exchange · Business model
Circular economy

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1 Introduction

Figure 1 shows the conventional wastewater treatment process in wastewater treatment plant. Conventional treatment consists of several unit processes such as coagulation, flocculation, clarification, and filtration, and is typically followed by disinfection at full scale. Water quality parameters such as pH, temperature, and alkalinity may dictate effectiveness of the coagulation–filtration process. The pH of solution during coagulation has a profound influence on the effectiveness during the destabilization process. However, the heavy metal on wastewater was commonly not easily to recover from the treatment process. A hydrometallurgical process is the treatment of primary raw materials (minerals or mineral concentrates) or secondary raw materials (end-of-life products) by aqueous solutions, in order to achieve the dissolution of the metals to be recovered. The feed aqueous solution to purify or concentrate is put in contact with a suitable organic solvent, i.e., so-called extraction step. Afterward, the loaded organic phase is contacted with an adequate aqueous solution to revert the equilibrium, and then the metal ions are transferred to a new aqueous phase, i.e., so-called stripping step.

Various hydrometallurgical techniques have been proposed with the heavy metals in aqueous solution to reduce the complicated nature of pyrometallurgical process. Procedures for the separation and recovery of different heavy metals, such as antimony [1], arsenic [2], nickel [3], manganese [4], and yttrium [5], from a complex concentrate have been evaluated. In addition, the environmental impacts and benefits of the hydrometallurgical treatment have been critically evaluated via the life cycle assessment [6, 7]. However, the difficulty of realizing industrial production and other insurmountable barriers is hindering the establishment of an efficient hydrometallurgical process at the industrial scale [1]. From an industrial implication point of view, addition of either sodium carbonate or oxalic acid/oxalate salt in 1:1 stoichiometric ratio with respect to Ca at 80 °C is suggested to mitigate calcium sulfate scale formation in hydrometallurgical processes [8].

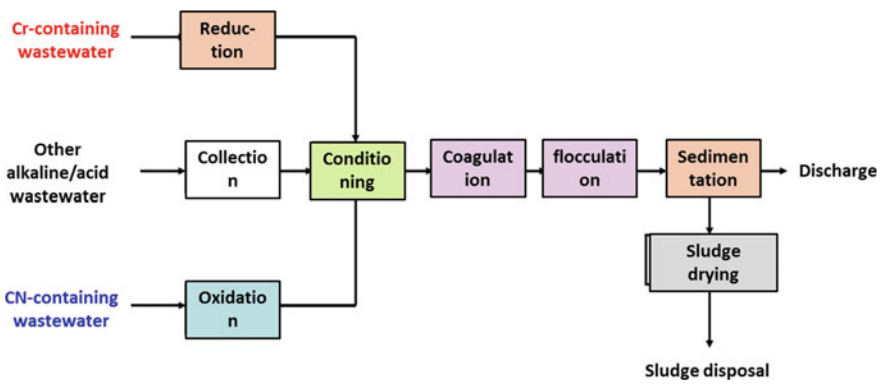

Fig. 1 Conventional wastewater treatment process in wastewater treatment plant

In this study, a patented hydrometallurgical system was developed and deployed in electroplating industries for recovering heavy metals (e.g., nickel) to establish a sustainable waste-to-resource supply chain. The environmental benefits of the hydrometallurgical system were evaluated by life cycle assessment. The hydrometallurgical system includes three main processes: (1) front-end process, (2) core process, and (3) production process. No hazardous sludge results in any long-term liability; passive process with minimal chemical use virtually eliminates workplace liability. Treated wastewater can be recycled directly into production stream; no sewage discharge fees. In addition, metals are recovered, separated, purified, and sold as high value-added chemicals.

2 Materials and Methods

Figure 2 shows the schematic diagram of the hydrometallurgical system [9]. The hydrometallurgical system includes three main processes: (1) a front-end process: Equalys^{TM} for selected adsorption of targeted heavy metals using ion-exchange resins, (2) a core process: regeneration of ion-exchange resin and generate stripped solution with various heavy metals in high concentration, and (3) a production process: multi-stage crystallization of metal precipitation.

Figure 3 shows the treatment procedure at client side (in situ) using the Equalys system. The process includes the suspended solids (SS) removal, oxidation, and

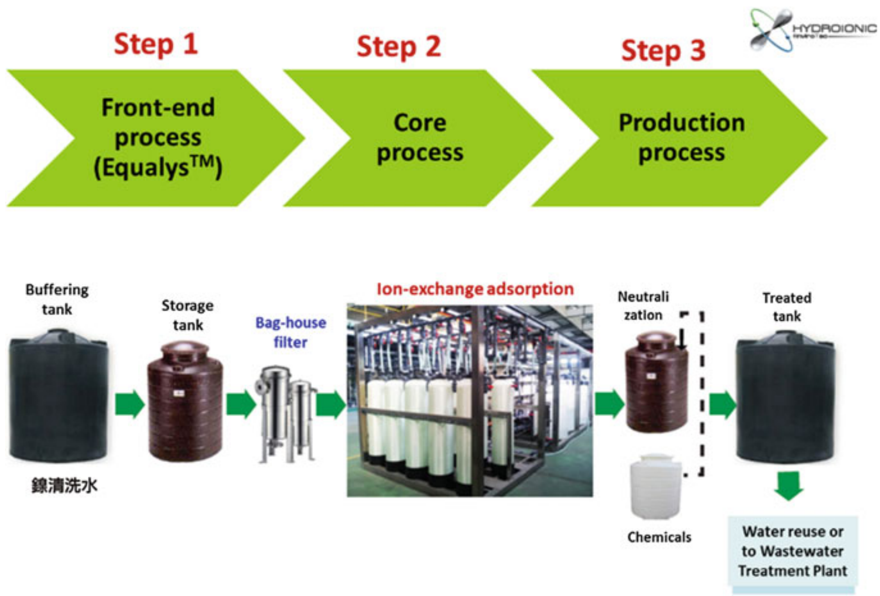

Fig. 2 Schematic diagram of hydrometallurgical system used in this study [9]

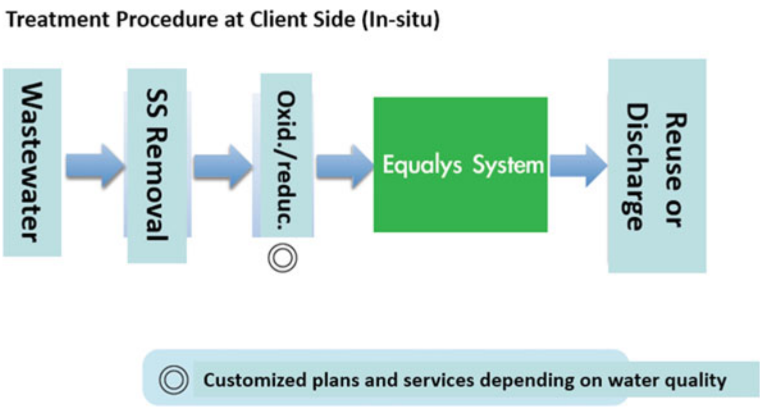

Fig. 3 Treatment procedure at client side (in situ) using the Equalys system

reduction. After treatment, the effluent could be reused or directly discharged. Depending on the wastewater quality, the customized plans and services can be provided.

Figure 4 shows the core process of ion-exchange resin to extract heavy metals from the solution. The concentrated ion-exchange resin was regenerated by using chemicals to produce stripped solution for the subsequent crystallization. After that, the regenerated resin column was back to the client plant.

Figure 5 shows the production process by a patented crystallization procedure using the stripped solution. The stripped solution contained the high concentration of a single heavy metal. The produced solid particles were dried and then packaged for further uses.

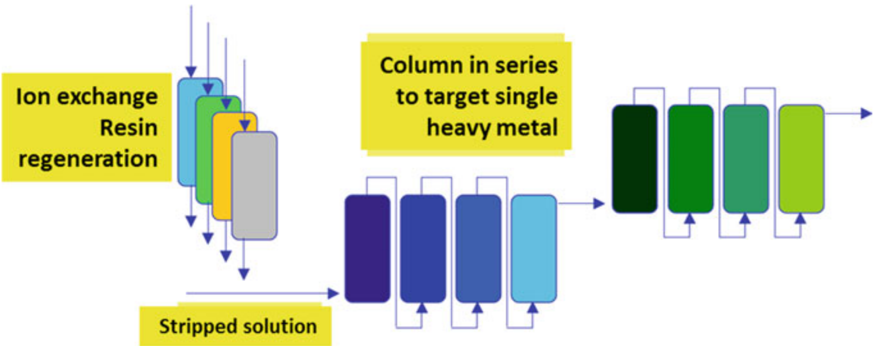

Fig. 4 Core process of ion-exchange resin to extract heavy metals from the solution

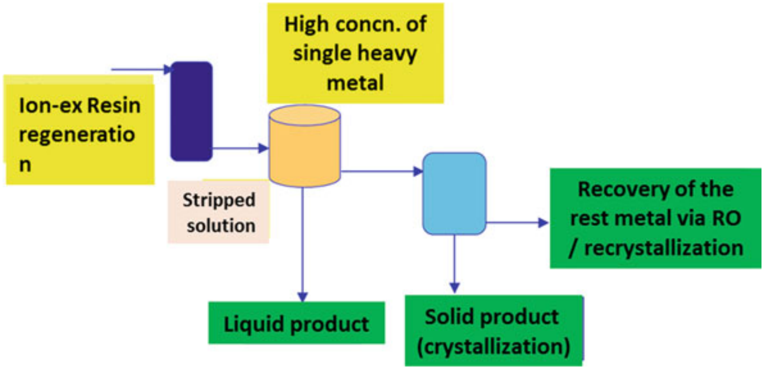

Fig. 5 Production process by crystallization using the stripped solution

3 Results and Discussion

Figure 6 shows the business service modulus of hydrometallurgical system for heavy metals recovery from industrial wastewater in Hydroionic EnviroTec Co. Different types of clients with various types of wastewater can be customized and treated in situ. The saturated resin columns were then sent back to Hydroionic EnviroTec Co. for regeneration. The regenerated resin columns were put back into each client for continuous wastewater treatment.

In the case of nickel recovery as shown in Fig. 7, the concentration of nickel in stream was reduced from 20–400 mg/L to less than 1.0 mg/L after ion-exchange adsorption. After that, the nickel will be further concentrated to more than 50,000 mg/L, associated with the regeneration of resins. In the multi-stage

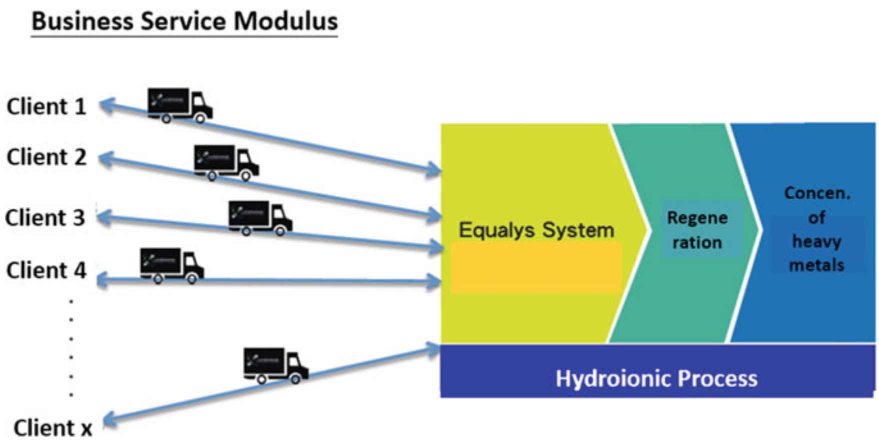

Fig. 6 Business service modulus of hydrometallurgical system in Hydroionic EnviroTec Co

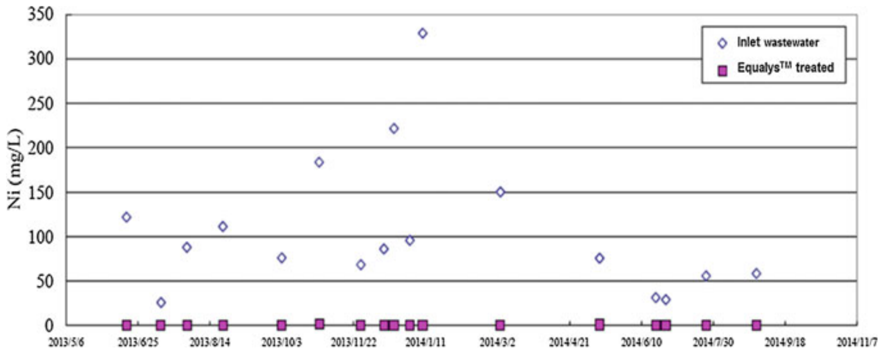

Fig. 7 Performance of nickel recovery via the hydrometallurgical system

production process, both nickel sulfate hexahydrate ($NiSO_4{\cdot}6H_2O$) and nickel sulfate ($NiSO_4$) can be produced with purities of 22 and 99%, respectively.

It is noted that fluctuations in metal concentrations are automatically absorbed by the Equalys system; automated system alerts to capture capacity exhaustion. Throughput capacity is easily scalable by increasing column regeneration frequency or addition of ion-exchange columns. Furthermore, treated wastewater (less loss due to evaporation) is recycled because of no cost for raw water. Figure 8 shows the replacement ratio of the original resin. The results indicated that a continuous and stable operation for more than 15 months can be achieved. The resin replacement per month was approximately 60%.

Table 1 presents the comparison of conventional precipitation process and hydroionic process, in terms of various types of criteria such as capital and operating costs. In conventional precipitation process, active additive process requires correct dosing of chemicals, resulting in regulatory non-compliance, overdosing increases costs and sludge production. In contrast, the passive process in the hydroionic

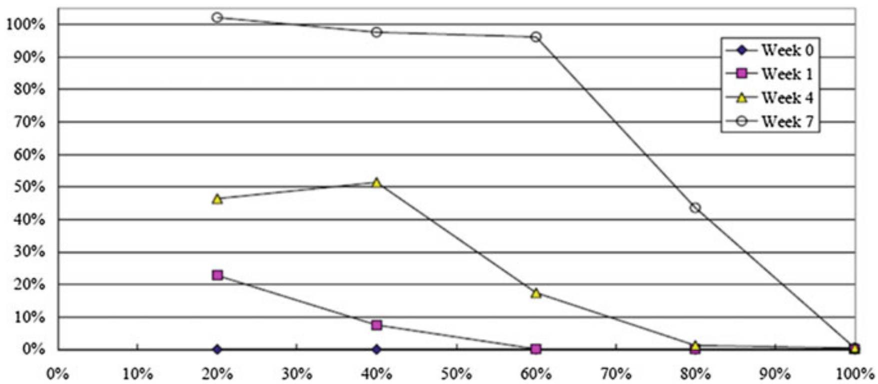

Fig. 8 Replacement ratio of original resin

Table 1 Comparison of conventional precipitation process and hydroionic process

Items	Precipitation process	Hydroionic process
Capital equipment cost	US$125,000 for 40 m^3/day capacity	Up to 60% less
Operating cost	US$3.30–US$6.00 per m^3	Up to 70% less
Sewage cost	Treated wastewater must be discharged (assuming regulatory compliance) and is subject to sewage fees (US$0.25–US$0.70/m^3)	Treated wastewater can be recycled directly into production stream; no sewage discharge fees
Recycling of water (water cost)	No recycling possible raw water cost ~US$0.35/$m^3$	Treated wastewater (less loss due to evaporation) is recycled; $0 raw water cost
Recovery of metals	None	Metals are recovered, separated, purified, and sold as high value-added chemicals
Hazardous sludges	Generates large volumes of hazardous sludges requiring permanent off-site disposal	No hazardous sludges
Insurance and liability	"Cradle to grave liability" requires insurance/set asides for hazardous sludge; heavy use of chemicals and process requires workplace insurance	No hazardous sludges result in no long-term liability; passive process with minimal chemical use virtually eliminates workplace liability
Active/passive process	Active additive process requires correct dosing of chemicals. Underdosing results in regulatory non-compliance, overdosing increases costs and sludge production	Passive process requires minimal operator and chemical input
Client labor cost	Labor required for process monitoring, sludge handling, and chemical handling	No labor input from client
Automation	Semi-automated process requires monitoring	Automated system requires no labor input from client
Scalability	Requires additional capital equipment and floor space	Throughput capacity easily scalable by increasing column regeneration frequency OR addition of IX columns
Metal concentration fluctuation tolerance	Fluctuations in metal concentrations not properly monitored and offset with chemical dosage result in regulatory incompliant water	Fluctuations in metal concentrations are automatically absorbed by Equalys system; automated system alerts to capture capacity exhaustion
Footprint	Large space requirement	Compact, modular design

process requires minimal operator and chemical input. Furthermore, in the conventional precipitation process, fluctuations in metal concentrations were not properly monitored and offset with chemical dosage result in regulatory incompliant water. By the hydroionic process of Equalys system, fluctuations in metal concentrations are automatically absorbed; automated system alerts to capture capacity exhaustion.

4 Conclusions

In this study, a hydrometallurgical system was developed and deployed in electroplating industries for recovering heavy metals (e.g., nickel) to establish a sustainable waste-to-resource supply chain. The results indicated that the concentration of nickel in stream was reduced from 20 to 400 mg/L to less than 1.0 mg/L after ion-exchange adsorption. After that, the nickel will be further concentrated to more than 50,000 mg/L, associated with the regeneration of resins. It was concluded that numerous environmental benefits, such as zero generation of hazardous sludge, detoxification of wastewater discharge and generation of high-value precipitate product, could be achieved by the developed hydrometallurgical system.

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Study of Ammonia Removal from Simulated Coke Oven Wastewater Using Commercial Charcoal Activated Carbon

Uttarini Pathak, Papita Das, Dalia Dasgupta Mandal, Siddhartha Datta, Tarkeshwar Kumar and Tamal Mandal

Abstract Organic pollutants from iron steel, coke, petroleum and other chemical process industries are basically responsible for releasing phenols, cyanides, ammonical and phenolic compounds, biphenyls, thiocyanates and various complex hydrocarbons that pose a threat to the existing flora and fauna of the ecosystem. Individual as well as combined treatment for phenol and cyanide using commercial and low-cost adsorbents has been investigated. But inadequate focus on removal of ammonical compounds leads to algal growth due to conversion into nitrites and nitrates. Thus, elimination of ammonia from simulated wastewater was studied using commercial grade charcoal activated carbon and acid-modified charcoal activated carbon from a mixture of phenol, cyanide and ammonia. The nature of the uptake was investigated and was observed that phenol removal showed a wide range of variation in percentage removal in terms of effect of initial concentration, pH and adsorbent dosage while the removal was enhanced for modified activated carbon. This has been found similar with the literature as reported earlier. But for ammonia, the removal was quite satisfactory irrespective of the variation of mentioned parameters. Also, it was found that modified activated carbon could bring about better removal in case of phenol, but ammonia removal was unaltered.

Keywords Ammonia · Phenol · Cyanide · Activated carbon · Chemical oxygen demand

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1 Introduction

With the ever-increasing demand for metallurgical grade coke in steel industries, production of coke and coke by-products is getting enhanced as a result of pyrolysis of different grades of coal. It has been surveyed that 1000 tons of coke is manufactured by the consumption of approximately 4000 m^3 of freshwater. About 1000 m^3 of perilous virulent wastewater is generated as a result [17]. This coke oven wastewater originates from operations like quenching of torrid coke, scrubbing of ammonia units and coke-oven gases, processing and refining of the by-products. Thus, all these processes devour extensive amount of freshwater at the cost elimination of wastewater containing a wide range of precarious toxicants like phenol, cyanide, ammonia as major compounds along with thiocyanates, oil and grease in trace amount, etc. [11, 14, 19, 24, 28]. Different pollutants from iron steel, coke, petroleum and other chemical process industries are basically responsible for releasing phenols, cyanides, ammonical and phenolic compounds, biphenyls, thiocyanates and various complex hydrocarbons that pose a threat to the existing flora and fauna of the ecosystem. The average pollutant concentration found in coke oven wastewater has been tabulated in Table 1. Out of these, phenol and cyanide complexes are especially carcinogenic as these aromatic hydroxyl compounds are highly stable in nature and soluble in water. Ammonia is related to problems like increased amount of nutrients in water bodies causing eutrophication and fouling, and corrosion of functional units [21]. Also, elevated levels of ammonia in industrial discharge or consumable water lead to formation of chloramines, a potential threat to the human and aquatic life. Thus for environmental preservation, discharge standards are imposed by different regulatory bodies like WHO, EPA, USEPA which indicates that the maximum permissible limit for phenol can vary up to 1 mg/L depending on the type of discharge (potable water or surface water) while for cyanide and nitrogen compounds the value stands up to less than 0.2 mg/L and 30 mg/L, respectively [9].

Table 1 Major pollutants in coke oven wastewater

Parameter	Concentration (average/approximate)
COD	In the range of 500–6000
BOD_5 (mg per Litre)	Up to 2500 approx.
TSS (mg L^{-1})	Less than 50
Phenolic matter (mg L^{-1})	**Up to 1300 approx**.
TKN (mg L^{-1}) (including NH_4^+ –N)	**Up to 1200 approx**.
SCN^- (mg L^{-1})	**In the range of 100–500; but usually absent in Indian origin**
CN^- (mg L^{-1})	**Less than 100**
Other anions	Trace amount/variable
Inorganic matter	Trace amounts

Various conventional physicochemical treatment methods have been investigated which include coagulation and precipitation [12], oxidation [13] (chemical/wet air/electrolytic oxidation), ozonation, steam stripping (applied for ammonia), sedimentation and flocculation, electrolysis and membrane-based techniques [14] which aims at removing particulate matter like suspended solids, colloidal particles, floating matters, colours including these toxic compounds (phenol, cyanide and ammonia). But all these methods suffer limitations from the fact that they require high capital investment in terms of operational costs [20, 27]. Activated sludge processes commonly practised as biological treatment for ammonia removal results in sludge generation and its handling faces a major challenge [19]. Recently, researches present adsorption as the most acceptable technique over several methods because of simple design, involvement of low initial cost investment and reduced space requirements. In addition to this fact, the potential of activated carbon as adsorbent is characterised by its extended surface area, porous constitution and pore volume, great adsorption uptake capacity, convenient and effective regeneration, and chemical nature of surface [3, 6, 10, 15, 26]. Thus, adsorption using activated carbon makes a great combination to be efficiently used in chemical processes entailing purification and recovery operations [25].

Researches and literature indicate the treatment of individual components of coke oven wastewater has been explored successfully but not as a original coke oven wastewater which there is a mixture of pollutants like phenol, cyanide, ammonia from coke oven wastewater. Literature study reports adsorption-based component removal by Balomajumder et al. [1] showing binary adsorption of phenol and cyanide from simulated solution using commercial activated carbon. Ammonia removal using organic acid-modified activated carbon and pristine activated carbon (AC) was investigated by Halim et al. [7]. Other adsorbents for removal of ammonia include clay, zeolites or carbon zeolite composites, limestone [4, 21, 30]. When phenol and cyanide are present in combination, they exhibit a negative hindrance to recovery of other pollutants as observed in rotating biological contactor (RBC) performed by Wang et al. [29]. Again impediment influence of phenol and cyanide on thiocyanate degradation in the nitrification-inactivated sludge process (ASP) is reported by Shivraman et al. [23] and Pandey et al. [18]. Though biological denitrification is one of the most supported and environmentally adopted technologies, it fails to achieve high removal efficiency at low concentration of pollutants like cyanide, phenol and ammonia. Another technological hindrance faced while designing a treatment method is the composition of coke oven wastewater—the combination of toxic elements like cyanide, thio-cyanide and phenol. Due to presence of numerous different toxic and hazardous constituents, complication in coke oven wastewater treatment arises where the presence of one contaminant influences heavily the removal of the other.

In this investigative study, charcoal-based activated carbon has been used for the deportation of ammonia from a mixture of simulated coke oven wastewater containing phenol, ammonia and cyanide. This kind of attempt has not been found in the literature where single or binary component removal has been investigated. But the removal of ammonia using activated carbon from a simulated mixture is a more practical approach.

2 Materials and Methods

All the chemicals involved in the experiment were of analytical reagent grades and used as received, without further purifications. The experimental studies were done in a glass-stoppered Erlenmeyer flasks having a volume of 250 mL with fixed amount of the adsorbent. The adsorbent used was commercial charcoal activated carbon which was further rinsed with distilled water several times to discard the adhered impurities. A known amount of adsorbent was added to samples and was agitated at 140 rpm agitation speed in shaker at room temperature (308–310 K) allowing sufficient time for adsorption. Then, the mixtures were filtered through filter paper to separate the activated carbon particles and the final concentrations of the filtrate were determined using UV/VIS spectrophotometer. Solution pH was altered using sodium hydroxide and hydrochloric acid reagents and measured using a digital pH meter. Phenol concentrations were determined using 4 amino-antipyrene method [2] and ammonia by modified Nessler method [8].

2.1 Preparation of Simulated Wastewater

The wastewater was synthetically prepared by utilising individual solutions of phenol, cyanide and ammonia having their respective concentrations. This was further mixed in equivalent ratio to form a single mixture from where samples were derived for batch process. The concentrations thus obtained after mixing were simultaneously taken into consideration for calculations.

2.2 Preparation of Acid-Modified Activated Carbon

The commercial grade activated carbon was scoured with distilled water to remove the adhered impurities followed by soaking it in 0.5 M sulphuric acid for 24 h in 2:1 ratio of liquid to solid to enhance the surface area and pore volume of the adsorbent. This was further washed with distilled several times and dried in hot air oven at 105–110 °C for more than 1 h. The final adsorbent was prepared by cooling it and preserving in airtight bags for further use.

3 Results and Discussions

3.1 Removal at Lower Concentration

The synthetic wastewater was prepared using phenol, ammonia and cyanide with initial concentrations of 1000, 500 and 50 ppm, respectively. But when they were mixed their concentrations were diluted to 334, 167 ppm for phenol and ammonia, respectively. The activated carbon dosage was varied between 0.5 and 40 g/L. The samples were agitated at 140 rpm for 1 h for allowing sufficient time of contact without any variation in temperature and pH. It was found that the phenolic removal was enhanced with increase in adsorbent dosage due to the inflation in adsorbent sites [22]. The removal of ammonia was found to be initially more than 90% representing a constant profile without being affected by the dosage variation. This observation has been represented in Fig. 1.

3.2 Removal at Higher Concentration

The concentrations of phenol, cyanide and ammonia were initially taken at 2000, 2000 and 1000 ppm, respectively. After varying the dosage for time = 30 min and time = 1 h, it was found that the ammonia removal was not affected but the phenolic removal was increased from 54 to 70%. This was mainly due to enlarged availability of the binding sites at the initial stage; the uptake was more on the adsorbent surface [5]. The graphical interpretation has been represented in Figs. 2 and 3.

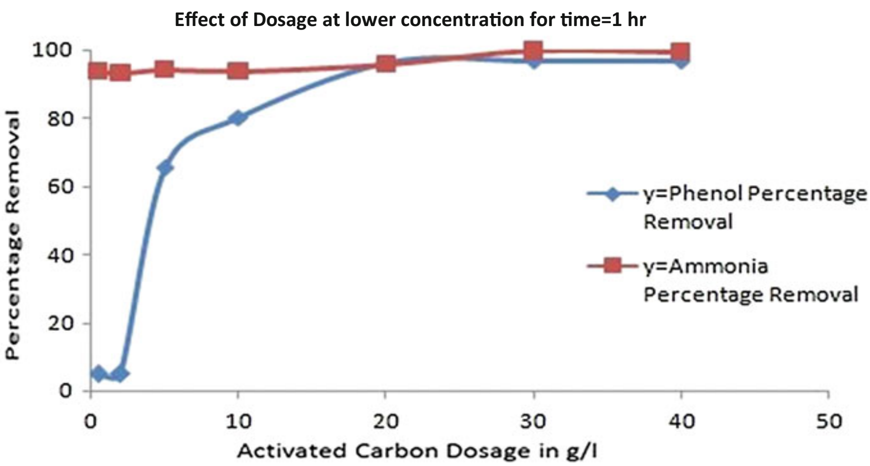

Fig. 1 Removal of phenol and ammonia at lower concentration with variation in AC dosage for contact time = 1 h

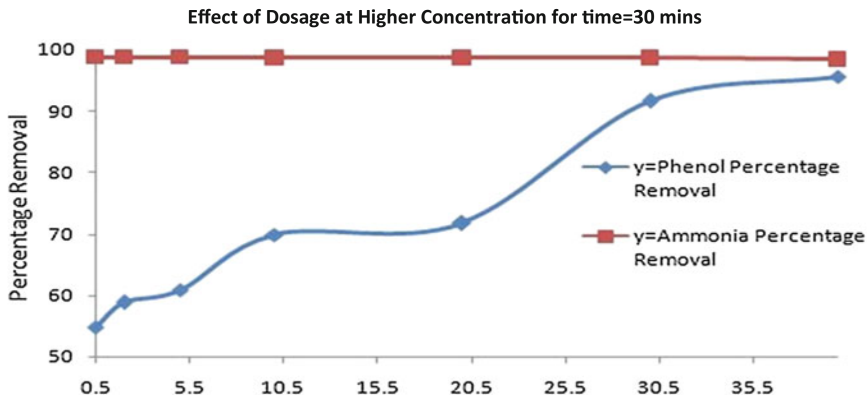

Fig. 2 Removal of phenol and ammonia at higher concentration with variation in AC dosage for contact time = 30 min

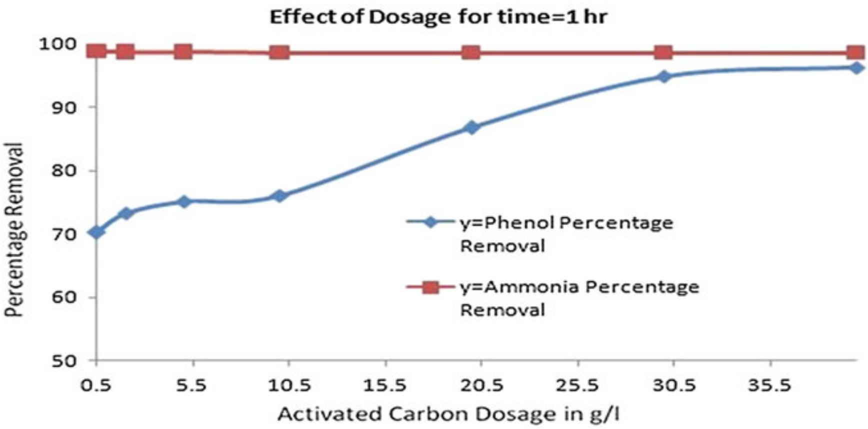

Fig. 3 Removal of phenol and ammonia at higher concentration with variation in AC dosage for contact time = 1 h

3.3 Influence of Solution pH

The solution pH is responsible for surface charge of the adsorbent, degree of ionisation and dissociation of adsorbate. Thus, the removal was studied at extreme acidic and basic conditions with an activated carbon dosage of 30 g/L. The phenolic removal showed similar characteristics where the maximum removal was noticed at pH 2 which decreased with increase in pH value. This may be contributed to the fact that phenol remains undissociated in lower pH conditions, and thus, its uptake was supported by dispersion interactions, whereas repulsion between the phenolate and predominating hydroxyl ions resulted in reduced removal [16]. On the other hand,

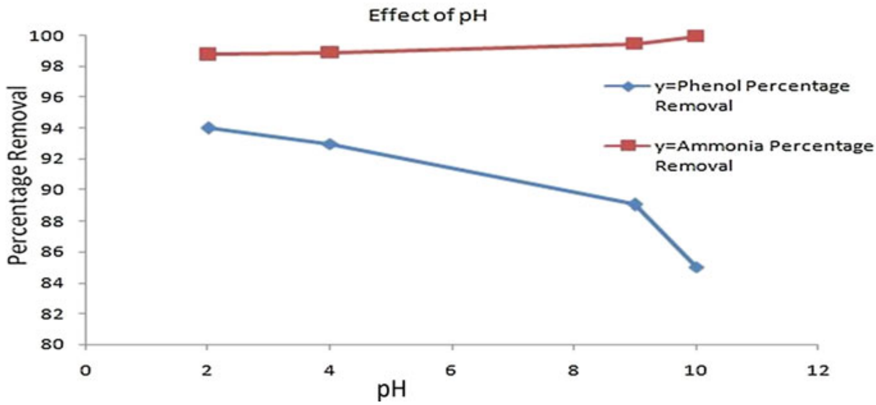

Fig. 4 Removal of phenol and ammonia at higher concentration with variation in pH

ammonia removal was relatively lower at acidic pH due to the dominance of H^+ ions [7]. The effect of pH has been demonstrated in Fig. 4.

3.4 Removal with Acid-Modified Activated Carbon

To develop some modifications in the surface constitution of the commercial grade charcoal activated carbon, it was treated with acid. The concentration of phenol, ammonia and cyanide was taken at 2000, 2000 and 1000 ppm, respectively, with the same variation of adsorbent dosage at constant pH and room temperature. The samples were rotated at an agitation speed of 140 rpm for a contact time of 1 h. It

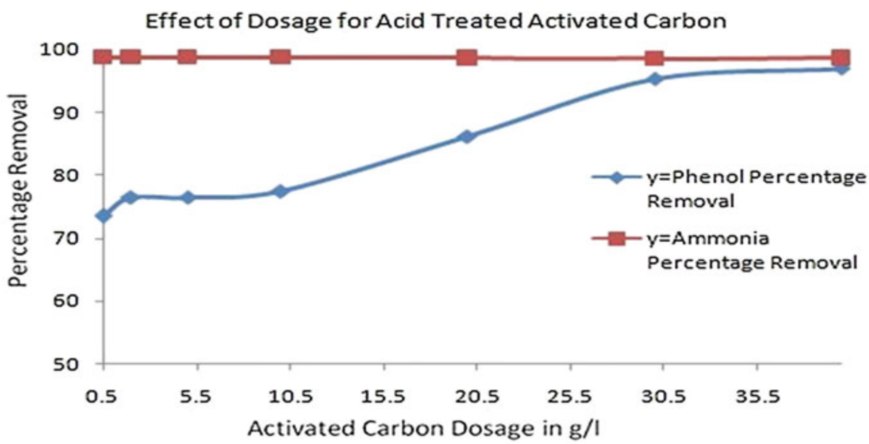

Fig. 5 Removal of phenol and ammonia at higher concentration with variation in AC dosage for acid-treated activated carbon and contact time = 1 h

was obtained that phenol removal was enhanced by a small margin but ammonia removal was almost similar as before. The observation thus obtained was shown in Fig. 5.

4 Conclusion

This work is a preliminary attempt to find how ammonia could be removed from a simulated coke oven wastewater containing phenol, ammonia and cyanide. The percentage removal of ammonia was found to be quite satisfactory irrespective of variation of adsorbent dosage of both charcoal activated carbon and acid-modified activated carbon. But variation of pH could bring a little increase in removal of ammonia. This work can be a slight deviation from the conventional methods used for ammonia removal. Phenol removal was found to be similar as reported in the previous literature. Thus, adsorption can be way to treat bulk concentrations of coke oven wastewater though further studies have to be explored for the hindrance caused by the other toxic compounds present in it.

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Adsorption of Hexavalent Chromium from Wastewater by Using Sweetlime and Lemon Peel Powder by Batch Studies

N. M. Rane, S. V. Admane and R. S. Sapkal

Abstract The continuous increase in population and industrialization the degradation of water ecosystem is happened which may be caused due to untreated industrial and municipal wastewater. Hexavalent chromium is one such toxic heavy metal which is considered to be a major pollutant in wastewater. The Cr(VI) adsorptions are checked by varying the parameters like temperature, contact time, pH, and initial adsorbate concentration. It can be concluded that with the increase of agitation speed up to 180 rpm and increase of particle size from 75 to 180, the percentage of adsorption increases with increased uptake and this is due to increased surface area of the adsorbent. As the pH increases, it is observed that a sharp decrease in percentage of adsorption and maximum adsorption capacity is observed at pH 1.25. For the process of removal of toxic heavy metals from aquatic environment, the kinetic models are used. The equilibrium adsorption isotherms are also analyzed by studying Langmuir and Freundlich adsorption isotherms. The pseudo-first- and second-order kinetic models are used for finding best results for experimentation. And pseudo-second-order kinetic model is found to be best-fitted curve for these results. From error analysis and correlation coefficients (R^2), the statistical errors such as sum of the square of the error (SSE), sum of the absolute error (SAE), average relative error (ARE) are calculated. The SEM and FTIR analysis are also done to study the physical parameters of adsorbents like morphology and functional group of adsorbents. From the result, it is seen that sweetlime peel powder gives good result for adsorption of removal of Cr(VI) from wastewater as compared to lemon peel powder.

Keywords Adsorbate concentration · Adsorbent capacity · Freundlich
Kinetic model · Physical parameters

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1 Introduction

The degradation of water ecosystem is occurred due to continuous increase in population growth and industrialization, which is due to untreated industrial and municipal wastewater. For every living being, water is one of the most important things needed for its survival. Water is required for agriculture, commercial, domestic, and industrial activities which result in water pollution [1]. Due to increase in water requirement, improper waste management increases and all the water resources become unfit. To overcome these problems, the innovative techniques are found out which should be available at low cost, require low maintenance, and should be energy efficient [2] (Figs. 1 and 2).

The effluents from various industries like electroplating, leather tanning, dye cement, and photography industries contain large quantities of heavy metals. Trivalent chromium and hexavalent chromium both the isotopes of chromium are found in wastewater. Due to carcinogenic and mutagenic effects of hexavalent chromium, its removal from wastewater is the problem faced by the world in today's technology [3].

Fig. 1 % Cr removal for variation in pH

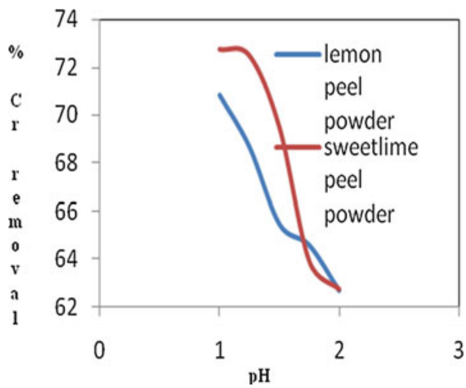
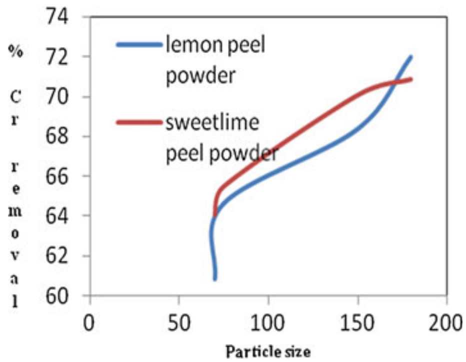


Fig. 2 % Cr removal for particle size



Before discharging of wastewater containing Cr(VI) into the environment, it should be treated by any available methods such as chemical, biological, and adsorption methods. By comparing these methods, adsorption method is generally used for treating the water containing metal ions [4].

For batch experimentation, the sweetlime and lemon peel powder is used. The experimentation is performed by varying the parameters such as particle size, initial Cr(VI) concentration, and adsorbent dosage [5]. It is found that sweetlime peel powder shows good result than lemon peel powder.

2 Selection of Materials and Methods

2.1 Preparation of Materials

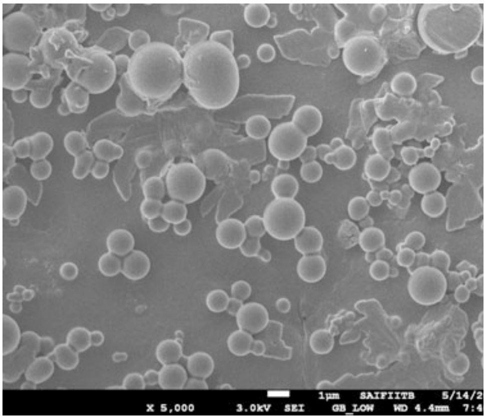
The adsorbent sweetlime peel (A) and lemon peel (B) powder used in this study is collected from the nearby area of Alandi, Pune, Maharashtra. The collected sample is drying washed and sundried [6]. The dried material was ground into fine powder. Then grinded material was separated in sieve shaker into four different particle sizes.

2.2 Adsorbent Characterization

2.2.1 SEM (Scanning Electron Microscope) Images for Adsorbent A and B Before and After Adsorption

A comparison of the SEM images before (Figs. 3 and 5) and after (Figs. 4 and 6) adsorption showed change of morphology and the grain size increase due to

Fig. 3 Before adsorption



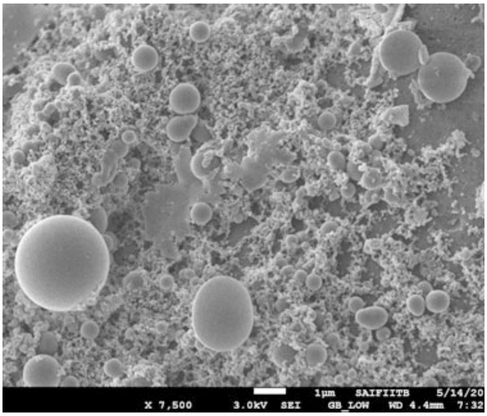


Fig. 4 After adsorption

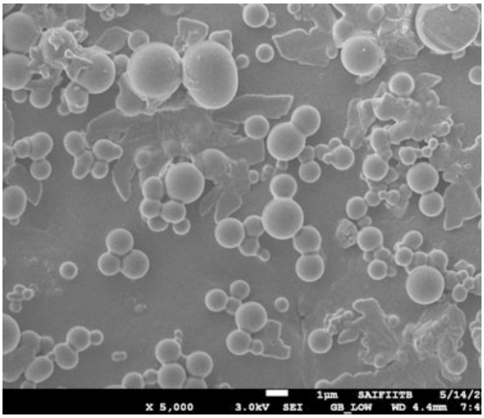


Fig. 5 Before adsorption

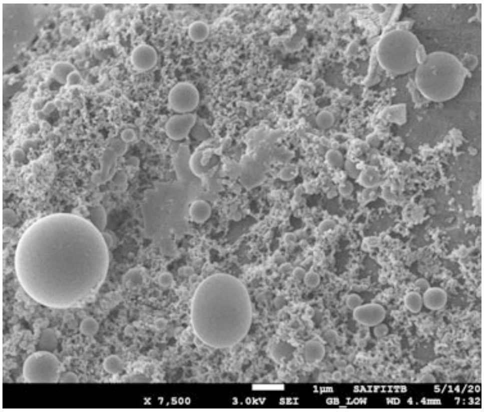


Fig. 6 After adsorption

adsorption on the surface for adsorbents A and B. The increase of Cr count after adsorption on adsorbents A and B unequivocally proved the adsorption of the said ion on the adsorbent.

2.2.2 FTIR (Fourier-Transform Infrared) Images for Adsorbent a and B Before and After Adsorption

Complexes in the adsorbents are formed during the adsorption apart from electrostatic forces of attraction. The peaks shown by adsorbent at 1035, 2920, 3450, 1670 cm^{-1} correspond to bonded C–C stretching aliphatic C–H group, OH group, and C=O stretching, respectively. The shift or reduction in adsorption peaks shows the importance of functional group (Figs. 7, 8,9, and 10).

2.3 Adsorption Study

By dissolving known amount of $K_2Cr_2O_7$ (analytical grade) with distilled water, a stock solution of Cr(VI) (1000 mg/L) is prepared and the pH is maintained by known concentration of sodium hydroxide (NaOH) and hydrochloric acid (HCl). The experiment is performed by varying different particle mesh sizes (>75, 75, 150 and 180), solid loading (1, 2, 3, 4, 5 g) per 250 mL of Cr(VI) solution, and different concentration (100, 200, 300, 400, 500 ppm) of solution for continuous 6 h. The samples are analyzed spectrophotometrically by using (Thermofischer 840-210800)

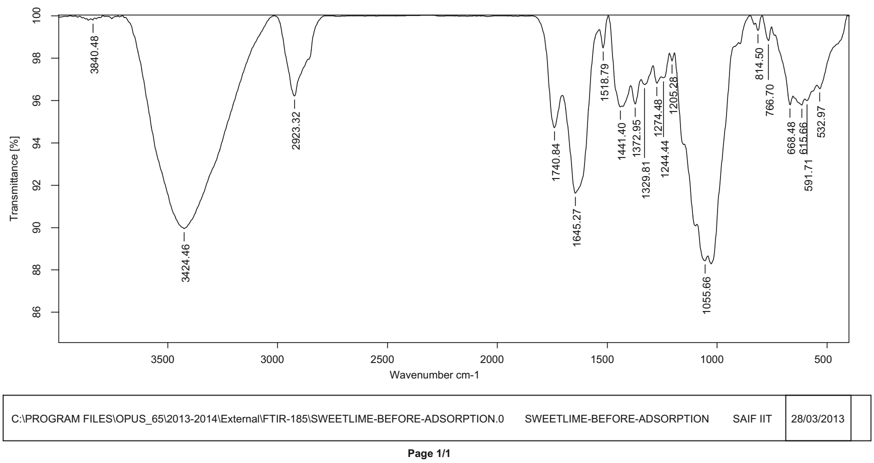


Fig. 7 Before adsorption

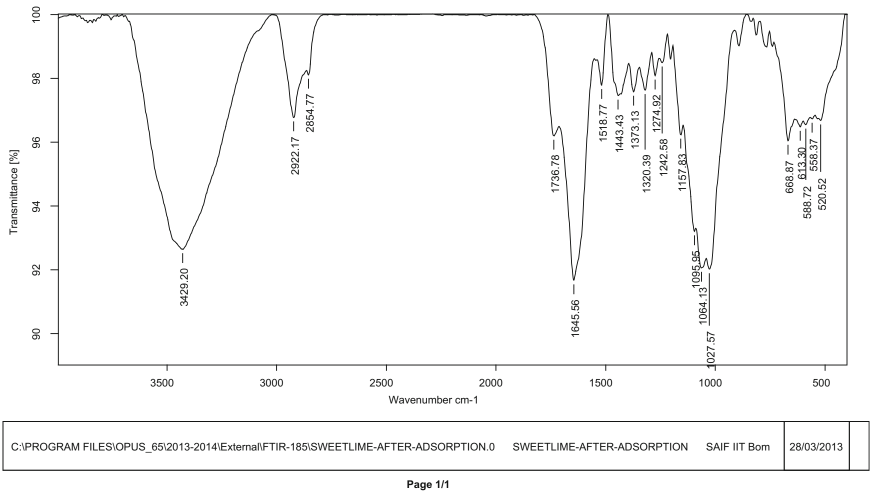


Fig. 8 After adsorption

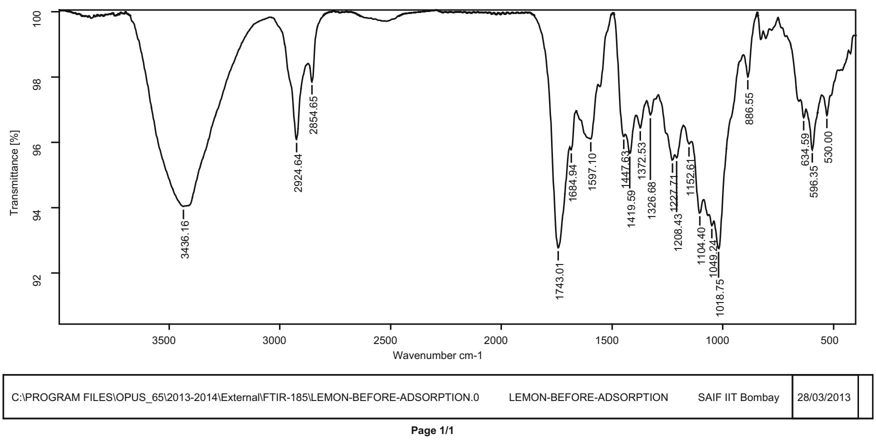


Fig. 9 Before adsorption

UV-VIS spectrophotometer [7]. At pH 1.25 and agitation speed 180, the highest adsorption of Cr(VI) takes place, and it is optimized by pseudo-second-order kinetic equation.

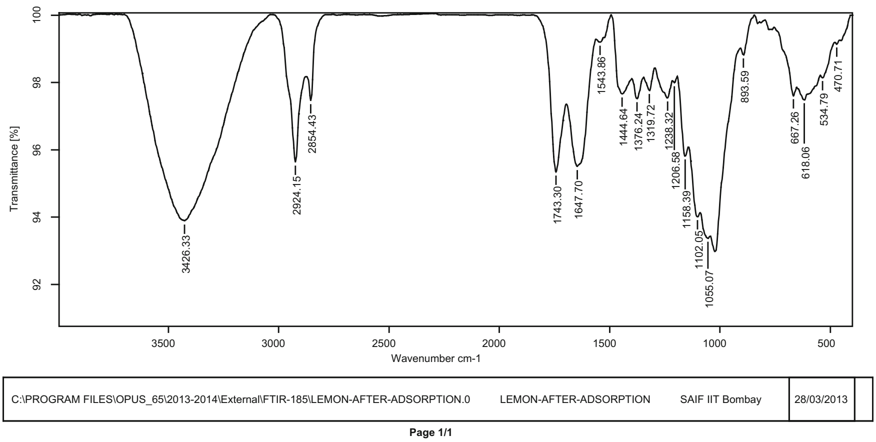


Fig. 10 After adsorption

3 Results and Discussions

3.1 Effect of Particle Size

This parameter is studied by varying particle mesh size from 75 to 180 in order to find out maximum removal of Cr(VI) at constant agitation speed 180 rpm, pH 1.25, and concentration 100 ppm. The graph (Figs. 11 and 12) shows that, with increasing particle size, the percentage removal of Cr(VI) and uptake increase. This is due to adsorbents' increasing surface area.

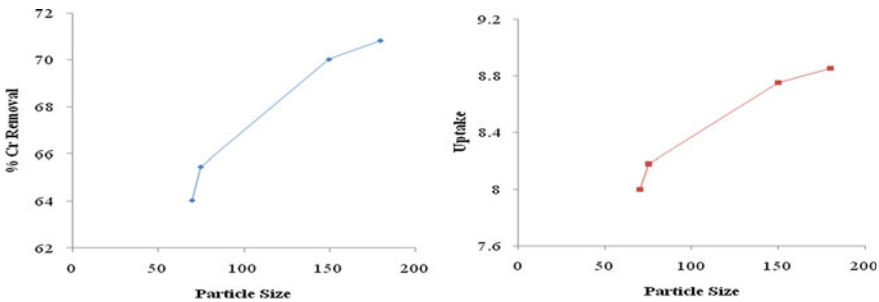


Fig. 11 Uptake and Cr removal for adsorbent A for different particle size (>75, 75, 150, and 180)

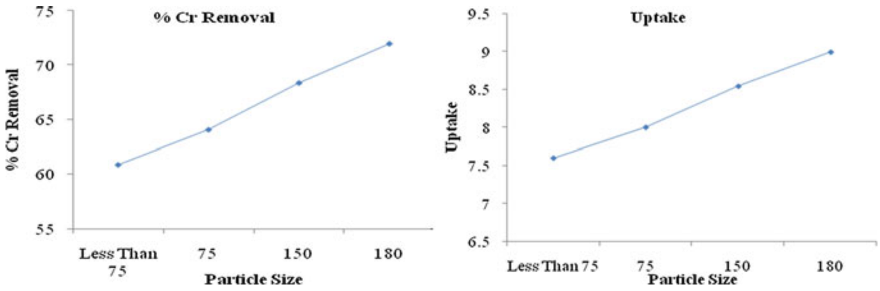


Fig. 12 Uptake and Cr removal for adsorbent B for particle size (>75, 75, 150, and 180)

3.2 *Effect of Initial Concentration of Hexavalent Chromium Cr(VI)*

The percentage removal of hexavalent chromium Cr(VI) with different adsorbate concentrations is studied. The concentration is varied from 100 to 500 ppm, keeping adsorbent dose at (2 g/250 mL), stirring speed (180 rpm), pH (1.25), and particle mesh size 180. From the graph (Figs. 13 and 14), it has been shown that by increasing adsorbent concentration, percentage removal of Cr(VI) decreases and uptake capacity increases. This is happened because of fixed adsorption doses where number of active adsorption sites remains unchanged and at higher adsorbate concentration adsorbent ions' accommodation increases.

3.3 *Effect of Adsorbent Dosage*

By varying the adsorbent dose from 1–5 g at initial concentration of Cr(VI) 100 ppm, the percentage removal of Cr(VI) is studied. The graph (Figs. 15 and 16)

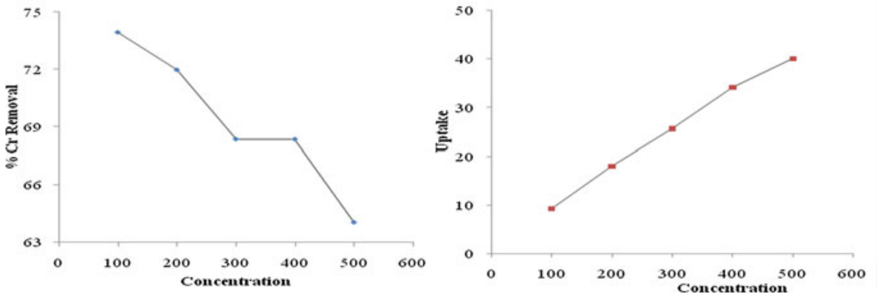


Fig. 13 Uptake and Cr removal for adsorbent A for different initial concentration

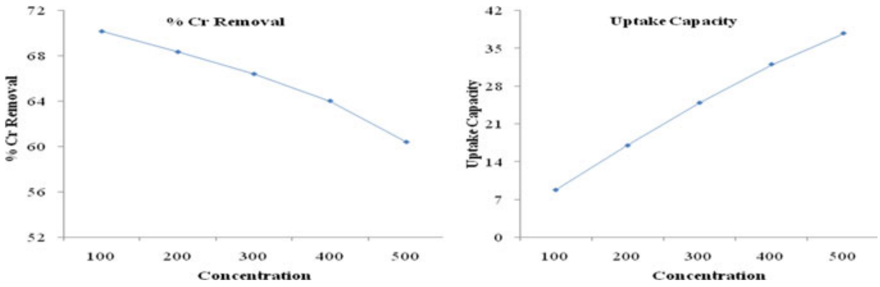


Fig. 14 Uptake and Cr removal for adsorbent B for different initial concentration

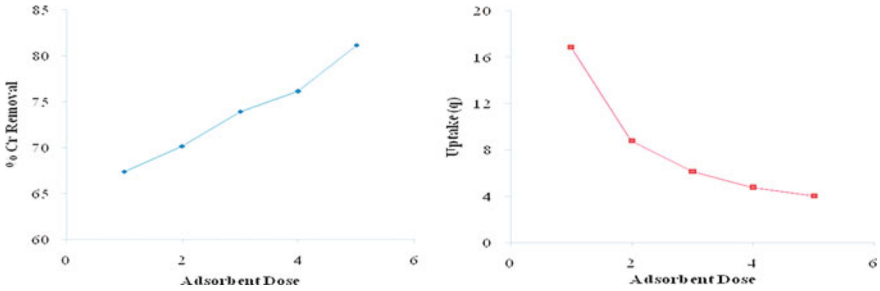


Fig. 15 Uptake and Cr removal for adsorbent A for different adsorbent dosage

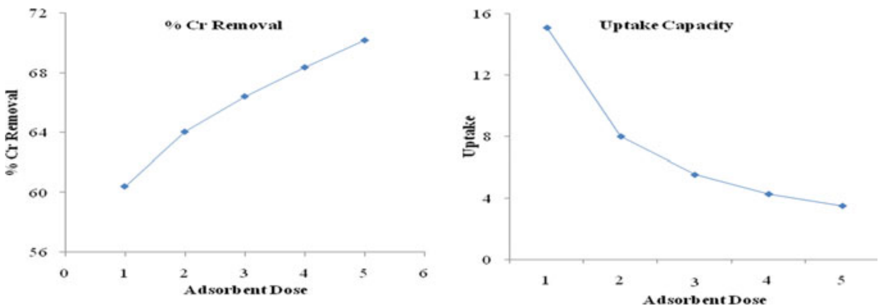


Fig. 16 Uptake and Cr removal for adsorbent B for different adsorbent dose

shows that with the increasing surface area and availability of more bonding sites percentage removal of adsorption of Cr(VI) is more while with the increasing adsorbent dose, uptake decreases because of overlapping of adsorption sites.

Kinetic Studies

3.4 Kinetic Model

The kinetic modeling study is done for the studying the effect of initial and final concentrations at different time interval. From this study, it can be concluded that the driving force for adsorption is the difference between the average solid phase concentration and equilibrium concentration [5].

3.4.1 Pseudo-First-Order Kinetic Model

This equation is used for finding sorption of a solute from a liquid solution. It can be written as:

$$\mathrm{d}q_e/\mathrm{d}t = k(q_e - q) \tag{1}$$

where 'q_e'—the amount of solute adsorbed at equilibrium per unit mass of adsorbent (mg/g),

'q'—the amount of solute adsorbed at any given time 't',

k—rate constant (refer Table 1).

3.4.2 Pseudo-Second-Order Kinetic Model

This equation is used for finding kinetics of sorption, and it can be written as:

$$\mathrm{d}p/\mathrm{d}t = k(q_e - q)^2 \tag{2}$$

The graph between t/q versus 't' shows linear relationship which is used for finding q_e and k (refer Table 1)

Table 1 Summary of error analysis for pseudo-first-order for sweetlime powder

S. No.	Parameter	Rate constant (K_{avg})	Error analysis for pseudo-first-order			
			SSE	SAE	ARE	ARS
1	Agitation speed	0.043	63.037	15.061	0.379	0.495
2	pH	0.032	33.372	11.191	0.271	0.354
3	Particle size	0.012	155.005	18.551	0.540	0.720
4	Adsorbent dosage	0.012	67.051	14.281	0.383	0.514
5	Adsorbate concentration	0.006	158.611	257.00	0.951	24.351

3.5 Equation of Error Analysis

The error analysis is used for finding best model from experimental values. So the number of error analysis methods such as the sum of the square of the error (SSE), the sum of the absolute error (SAE), average relative error (ARE), and the average relative standard error (ARS) is used for finding error between experimental values. The expression can be written as: [8–11]:

$$\mathrm{SSE} = \sum_{i=1} (y_c - y_\mathrm{e})_i^2 \tag{3}$$

$$\mathrm{SSE} = \sum_{i=1} |y_c - y_\mathrm{e}|_i \tag{4}$$

$$\mathrm{ARE} = \frac{1}{n}\sum_{i=1}^{n} \frac{|y_c - y_\mathrm{e}|}{y_\mathrm{e}} \tag{5}$$

$$\mathrm{ARS} = \sqrt{\frac{\sum_{i=1}^{n} \left|\frac{y_c - y_\mathrm{e}}{y_\mathrm{e}}\right|^2}{n-1}} \tag{6}$$

3.6 Isotherm Study

To study the desorption mechanism related with interaction between the adsorbent and adsorbate molecules, and to find the efficiency of an industrial adsorbent as well as to predict the relative performance of different types of adsorbents, the isotherms are used [12].

3.6.1 Langmuir Isotherm

The equilibrium conditions for sorption behavior are described by using Langmuir equation; this equation can be written as:

$$c_\mathrm{e}/q_\mathrm{e} = 1/Q_0 b + c_\mathrm{e}/Q_0 \tag{7}$$

where 'c_e'—the equilibrium concentration,

'q_e'—the amount of adsorbate adsorbed per gram of adsorbent at equilibrium (mg/g),

'Q_0' and 'b'—Langmuir constants related to the sorption capacity and intensity, respectively.

3.6.2 Freundlich Isotherm

The equation is expressed as:

$$x/m = q_e = k \cdot c_e^{1/n} \tag{8}$$

where

q_e equilibrium adsorption capacity (mg/g),
c_e the equilibrium concentration of the adsorbate in solution,
K_f and n constants related to the adsorption process such as adsorption capacity and intensity, respectively (Tables 2, 3, 4, 5, and 6).

Table 2 Summary of error analysis for pseudo-second-order for sweetlime peel powder

S. No.	Parameter	Rate constant (K_{avg})	Error analysis for pseudo-second-order			
			SSE	SAE	ARE	ARS
1	Agitation speed	0.006	0.344	1.162	0.029	0.038
2	pH	0.0028	0.704	1.784	0.043	0.050
3	Particle size	0.013	0.513	1.151	0.033	0.047
4	Adsorbent dosage	0.011	8.619	3.341	0.076	0.167
5	Adsorbate concentration	0.001	54.555	10.820	0.035	0.051

Table 3 Freundlich and Langmuir constant for sweetlime peel powder

S. No.	Parameter	Freundlich isotherm constant			Langmuir isotherm constant		
		n	K_f	R^2	Q_0	b	R^2
1	Agitation speed	−0.578	7.088	0.992	0.204	0.389	0.995
2	pH	−2.114	3.744	0.997	5.714	−0.104	0.999
3	Particle size	−2.074	3.776	0.999	0.176	0.570	0.999
4	Adsorbent dosage	0.418	−5.641	0.845	−0.245	−0.104	0.779
5	Adsorbate concentration	0.225	−11.771	0.893	−5.681	−0.027	0.727

Table 4 Summary of error analysis for pseudo-first-order for lemon peel powder

S. No.	Parameter	Rate constant (K_{avg})	Error analysis for pseudo-first-order			
			SSE	SAE	ARE	ARS
1	Agitation speed	0.048	313.21	39.44	0.83	0.93
2	pH	0.032	332.63	40.75	0.84	0.94
3	Particle size	0.006	268.08	32.70	0.86	0.99
4	Adsorbent dosage	0.008	378.68	37.12	0.79	0.89
5	Adsorbate concentration	0.010	4054.08	124.36	0.89	1.00

Table 5 Summary of error analysis for pseudo-second-order for lemon peel powder

S. No.	Parameter	Rate constant (K_{avg})	Error analysis for pseudo-second-order			
			SSE	SAE	ARE	ARS
1	Agitation speed	0.012	0.64	1.51	0.032	0.042
2	pH	0.009	0.51	1.57	0.023	0.036
3	Particle size	0.010	0.37	1.45	0.029	0.036
4	Adsorbent dosage	0.063	0.37	1.21	0.026	0.029
5	Adsorbate concentration	0.005	7.19	4.71	0.030	0.036

Table 6 Freundlich and Langmuir constant for lemon peel powder

S. No.	Parameter	Freundlich isotherm constant			Langmuir isotherm constant		
		n	K_f	R^2	Q_0	b	R^2
1	Agitation speed	−3.17	3.23	0.999	7.25	−0.19	0.999
2	pH	−3.42	3.16	0.996	7.56	−0.22	0.997
3	Particle size	3.44	3.16	0.994	7.46	−0.21	0.998
4	Adsorbent dosage	0.64	−2.24	0.917	3.76	−0.22	0.776
5	Adsorbate concentration	0.26	−8.46	0.947	−7.82	−0.03	0.770

4 Conclusion

The experiment is performed by varying parameters like particle size, adsorbent dose, initial Cr(VI) concentration at constant pH 1.25, and agitation speed 180 rpm. From the graphs, it is clear that increasing particle size, percentage removal and uptake capacity both increase. It is also concluded that with increasing adsorbent concentration, percentage removal of Cr(VI) decreases and uptake will increase. With the increasing adsorbent dosage from 1 to 5 g, percentage removal of Cr(VI) increases from 70 to 90% while uptake decreases due to overlapping of adsorption sites. The error analysis and regression coefficients are calculated from experimental values. Pseudo-second-order kinetic model is best model for this experimentation. Isotherms are also studied for finding best curve for adsorption process. From the experimental results, it is concluded that Langmuir isotherms show best result. Also the sweetlime shows good result than lemon peel powder.

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Significance of Constructed Wetlands for Enhancing Reuse of Treated Sewages in Rural India

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Abstract Constructed wetland (CW) is an eco-centric technology. It is gaining attention due to its extensive applicability all over the world owing to the distinguishing characteristics such as eco-friendly, simple construction, easy operation and maintenance along with process stability as well as its cost-effectiveness (both, capital and O&M costs). CWs employ the natural processes including wetland vegetation, soils and their accompanying microbial populations for treatment of wastewaters of all kinds—especially sewages. The principal purposes for development of CWs includes improvement of water quality, creation of food (constructed aquaculture wetlands) and establishment of habitats to augment the natural wetlands which are contaminated by disposing urban sewages. Based on our earlier research, an assessment of energy consumption for the wastewater treatment in small cities, towns and villages (approximately population of 85–95 Crores and 35,000 MLD wastewater) has been performed for activated sludge process and contrasted with CW. The parameters selected during assessment of the above-mentioned technologies include electrical energy consumed during operation of treatment facility, corresponding coal required for generation of electricity as well as assessment of the long-term impacts on environment in terms of global warming potential, acidification potential and abiotic resource depletion potential. The CWs in the towns of rural India clearly demonstrate the reuse of treated water by the local community for animals and irrigation purposes as well as achieves reduction of health problems (improved sanitation, absence of mosquito breeding, foul smell, etc.). Thus, the CWs fulfil social, economic and environmental goals. It is hoped that engineered CWs will play important role in rural India. Our research as well as the work of other groups in India has demonstrated that the CWs could be considered as viable and promising alternative for the treatment as well as reuse of sewages and sullages in rural and peri-urban communities.

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Keywords Constructed wetland · Natural treatment system · Phyto-remediation Sanitation · Sewages · Sullages · Wastewater treatment · Water reuse

1 Introduction

In India, the wastewater generation is increasing with the improvement of water supply to urban areas. The 500 Class I cities (including the 35 metros) generate 35,000 MLD sewage as reported by CPCB [5, 6]. In addition, the sewage generation from small cities, towns and villages accounts to approximately 35,000 MLD. It clearly indicates that the huge percentage of wastewater remains untreated and which is directly discharged into the watercourses without any treatment. The wastewater should be collected, treated as well as disposed appropriately in order to circumvent the degenerative effects on health of public as well as on ecosystem. Currently, there are several methods available that may be used for the wastewater treatment. The most widely practiced technologies for wastewater treatments include activated sludge process (ASP), trickling filter, sequential batch reactor, membrane reactors and engineered natural treatment systems (NTSs) [6].

Among the several available technologies, ASP is the most commonly practiced method for the wastewater treatment worldwide [9, 15]. The major key limitation of ASP-based facilities is its high-energy consumption [15]. For operating the ASP-based the wastewater facilities, the electricity consumption creates the huge burden in terms of O&M costs. Analysing on a global scale, among the various wastewater treatment facilities, the electricity costs are generally between 5 and 30% of total operating costs. Moreover, in developing countries like India, Bangladesh, these costs may rise to 40% or more [17]. In ASP-based treatment processes, aeration and sludge treatment and associated processes account for 45–75% of wastewater treatment costs [9]. Further, Zhang and Wilson [21] have reported 46.9 and 22.3% energy consumption for aeration and sludge treatment, respectively, for large-scale wastewater treatment plants. About 3% of total electrical energy is used for wastewater treatment in the USA which is equivalent to 9.6 million households annual electricity use (approximately 110 terawatt hours per year) [9]. In India, for the entire untreated wastewater treatment, if ASP is adopted, then huge amount of electrical energy will be required. This will lead to a huge burden on coal production as major share of electricity production in India is due to coal—which will further aggravate the pollution scenario in India.

Therefore, the future wastewater installations should be an integrated system, which should be less energy-intensive and can recover the resources during the course of wastewater treatment. Thus, energy efficiency is one of the significant factors for the wastewater treatment which will ultimately supplement cost-saving process in the country. Hence, in the view of energy requirement as well as the wastewater treatment, instead of conventional methods such as ASP, the NTSs seem to be much more effective, which are able to meet the discharge standards prescribed by regulatory agencies. In recent years, the NTSs have been acknowledged to be installed as distinctive treatment devices, in particular, constructed wetlands [1, 2, 11, 12, 14]. In India, the water availability per capita will reduce in coming years along with rise in population owing to the increased wastewater generation rate. Therefore, NTSs appear to be the promising way for the improvement of water quality considering all the aforementioned aspects. The most commonly practiced NTSs across India include duckweed pond, oxidation pond, constructed wetlands, waste stabilisation ponds [3].

The primary objective of this paper is to estimate the amount of coal required to produce the desired capacity of electricity for wastewater treatment. Further, assessment of the long-term impacts on the environment in terms of eutrophication potential, global warming potential, acidification potential and abiotic resource depletion potential has been done for the ASP and CW. The scope of this research is limited to the only operation of ASP with diffused aeration followed by anaerobic digestion. However, the primary treatment process before ASP and CW as well as tertiary treatment is not considered in this study. It is to be noted that the impact indicators (eutrophication potential, global warming potential, acidification potential and abiotic resource depletion potential) are estimated based on the life cycle assessment (LCA) of both ASP and CW.

2 Materials and Methods

During the wastewater treatment in ASP, the electrical energy consumed for the operation was estimated as per the guidelines given by USEPA [16]. During estimation of energy consumed, the primary treatment was not considered as these are the common unit operations of the ASP and NTSs. Further, eutrophication potential, global warming potential, acidification potential and abiotic resource depletion potential were estimated using the data from life cycle assessment study of different wastewater treatment technologies [10].

3 Results and Discussion

3.1 Electrical Energy Consumption for ASP

During the operation of ASP-based facility, the electrical energy consumed after primary treatment unit operations accounts to 65–75% of total energy used. In India, the 35,000 MLD sewage is generated by the 500 Class I cities including the 35 metros [5, 6]. The 7,500 Class II and Class III towns having the population of 250 million generate approximately 20,000 MLD sewage with the 80 LPCD. Additionally, the sewage generation from the 0.5 million Indian villages having the population of approximately 700 million amounts to 15,000 MLD considering the

Table 1 Electrical energy consumption for untreated wastewater in India as per USEPA [16]

S. No.	Parameter	kwh required for 1 MLD	kwh required for 35,000 MLD
1	Recirculation pumping	11.88	416,116
2	Diffused air aeration	140.55	4,919,419
3	Final sedimentation	8.08	282,959
4	Sludge pumping	0.71	24,967
5	Air flotation thickening	18.49	647,292
6	Anaerobic digestion	32.65	1,142,933
7	Vacuum filtration	15.45	540,951
8	Incineration	17.17	601,057
9	Light and miscellaneous power	15.05	527,081
Total electrical energy consumption			9,102,774

25 LPCD. Hence, the total sewage generation is approximately 35,000 MLD from the small cities, towns and villages. In order to prevent the untreated wastewater discharge into the watercourses, higher installations for wastewater treatment is required.

USEPA [16] has reported the electrical energy consumption for operation of wastewater treatment processes using the activated sludge process. In activated sludge plants, the electrical energy consumption in supplying diffused air is about 57% and approximately 20% of electricity is required during pumping the influent and return streams. Another 6% of electricity is essential for mixing and heating the anaerobic digester. Thus, these three processes account for 83% of the total electrical energy consumption during the wastewater treatment. The chain of process that consumes the electricity in ASP-based anaerobic digestion facilities includes pumping required for recirculation, diffused aeration, mechanical aeration, final sedimentation, chlorination, sludge pumping, gravity thickening, air flotation thickening, anaerobic digestion, vacuum filtration, incineration and light and also miscellaneous power. Considering all these operations for 35,000 MLD wastewater, the electrical energy consumption in the activated sludge process with anaerobic digestion found to be 9,102,774 kwh which is shown in Table 1 [16]. While, in CWs, energy is not required for the operation of facility. Clearly, it shows the economic importance of the CWs as compared to ASP.

3.2 Coal Consumption

In India, the primary fuel used for the electricity generation is coal, which accounts approximately 58% of total electricity produced [7]. Since the production of 1 kwh of electricity requires 0.4989 kg coal, for the above-required 9,102,774 kwh electricity for treating the remaining wastewater (35,000 MLD), approximately

4,541,374 kg of coal will be required every day [18]. Further, the coal consumption as well as its transportation would additionally impact the environment by the generation of air pollutants. Hence, for further installations of wastewater treatment systems, the natural treatment process may be an appropriate technological solution, as they require negligible energy during its O&M.

3.3 Comparison of Impact Indicators for APS and NTS-Based Facility

Using the life cycle assessment methodology, the comparison of wastewater treatment technologies comprising of activated sludge process and NTS-based facility, namely constructed wetland, has been reported [10]. Considering the data from the available literature, the calculations were done in terms of the population equivalent (p.e.). Therefore, if the 35,000 MLD of wastewater (≈900 million p.e.) is treated in ASP and CW, the eutrophication potential was found to be 3,384 tonnes PO_4^{3-}-Eq/p.e.-year and 3,060 tonnes PO_4^{3-}-Eq/p.e.-year, respectively (depicted in Fig. 1). As shown in Fig. 2, the estimated global warming potential of ASP and CW was 16,380,000 tonnes CO_2-Eq/p.e.-year and -3,474,000 tonnes CO_2-Eq/p.e.-year, respectively.

During the wastewater treatment in CW-based facilities, huge quantity of CO_2 is being sequestered by the plants used in the CW-bed and has negative CO_2 emissions, which attributes to negative global warming potential [10]. Further, the estimated acidification potential for ASP and CW was 171,000 and 27,000 tonnes SO_2-Eq/p.e.-year, respectively (depicted in Fig. 3). As shown in Fig. 4, the abiotic resource depletion potential for ASP and CW was found to be 135,000 and 18,000 tonnes antimony-Eq/p.e.-year, respectively.

From the results, it was clear that the CW-based wastewater treatment facilities had quite lower global warming potential, acidification potential as well as abiotic resource depletion potential than ASP-based facilities. Additionally, CWs require

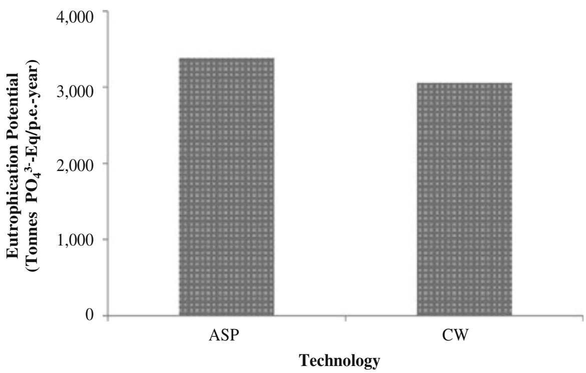

Fig. 1 Comparison of ASP and CW for eutrophication potential

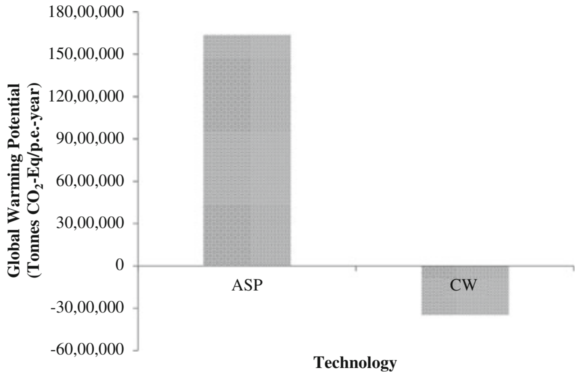

Fig. 2 Comparison of ASP and CW for global warming potential

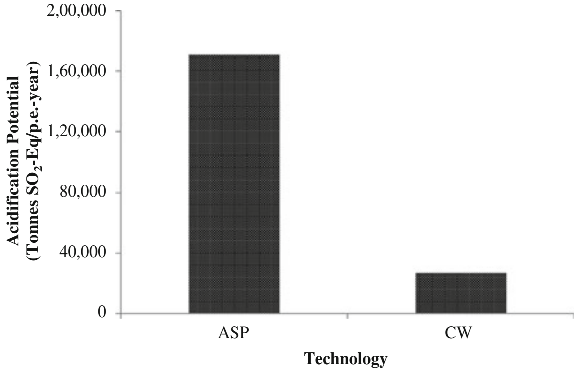

Fig. 3 Comparison of ASP and CW for acidification potential

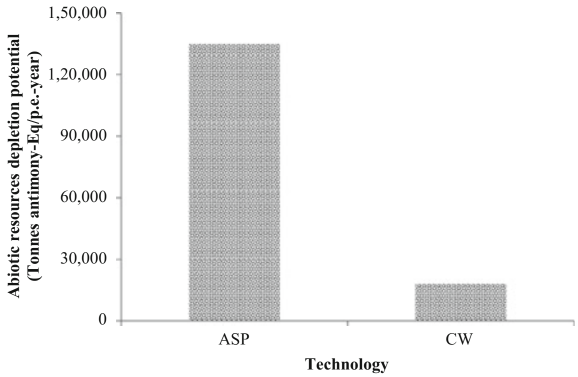

Fig. 4 Comparison of ASP and CW for abiotic resource depletion potential

energy only for pumping (but lower than conventional centralised sewage treatment), and for the operation purposes, no energy is required as like in ASP. Also, the CW-based wastewater treatment facilities attract technocrats for its potential for better quality of treated effluent and producing valuable wildlife habitat (Bassi et al. [4]. The CW-based wastewater treatment facilities possess several advantages including easy management, inexpensive than alternative methods for treatment of various wastewaters, consistent and high level of treatment for hydrocarbons, pathogens and nutrients along with acting as long-term carbon stores, aesthetically pleasing, retain a great ecological value with improving habitat and biodiversity. [8, 20].

Kumar and Asolekar [13] reported the use of horizontal subsurface flow constructed wetland (HSSF-CW) for the reuse of sewage in Kachpura slum in Agra, state of Uttar Pradesh, India which was established by the Crosscutting Agra Program (CAP) with financial assistance from the Water Trust UK and London Metropolitan University and technical support from the Vijay Vigyan Foundation for the low-income community at Kachpura slum. The domestic wastewater (approximately 50 m^3/d) from the five clusters of Kachpura slum is treated in this CW which is further used for the irrigation purposes by surrounding communities. This has led to the improvement in the sanitation due to avoidance of mosquito breeding and foul odour. Hence, with the help of urban local bodies (ULBs) and community participation, the technologies like CW can bring the so-called integrated development. This technology could play a noteworthy role in strengthening the India's agricultural economy as the production of useful water by treating sewages will be typically used for agricultural irrigation along with catering to the skills of rural peoples. Also, the vegetation generated from the wetland bed could be valuable to the rural community as it can be used for the dairy animals as a fodder. Hence, the overall growth of the community can be strengthened with such kind of technology. Considering the future perspective of energy, the cost is expected to increase more promptly than inflation due to several reasons such as future difficulties in searching and recovering new energy sources, higher cost of alternative energy sources, complications in setting new power plants and the anticipated future higher cost of meeting air emission standards [19]. Therefore, CW-based wastewater treatment facilities appear to be energy-efficient technology. Additionally, the CW-based treatment systems may be a more preferred technological alternative for wastewater treatment especially in Indian subcontinent where favourable climatic conditions prevail. Hence, for the resource conservations and higher efficiency of treatment at lower costs, CW possesses an attractive candidature for the wastewater treatment.

4 Conclusions

In this study, the comparison of ASP- and CW-based wastewater treatment facilities has been performed based on energy consumption, eutrophication potential, global warming potential, acidification potential as well as abiotic resource depletion potential. The study reveals that the use of natural treatment systems, in particular CWs, possesses a significant candidature for wastewater treatment as these systems require comparatively less energy. The O&M costs involved are also minimal in these natural treatment systems. Thus, the implementation of constructed wetland-like natural treatment systems could provide economic solutions for the wastewater treatment in small peri-urban, rural as well as remote tribal and rural locations.

In a developing economy like India, the CWs are of greater significance from the spectacles of community ownership and applications of technology for social benefit. In strengthening the India's agricultural economy, this technology could a play significant role through production of useful water by treating sewages which are typically used for agricultural irrigation, along with catering to the skills of rural peoples which will ultimately strengthen the overall growth of the community and thereby facilitate rural development. The vegetation generated from the wetland bed could also be beneficial to the rural community. Additionally, the so-called integrated development could be achieved by the application of CW technology with the help of urban local bodies and community participation. Among the several wastewater treatment technologies, CWs seems to be sustainable and eco-friendly substitute in a developing country like India. Thus, for the treatment as well as reuse of sewages and sullages in rural and peri-urban communities, CWs could be considered as viable and promising alternative.

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Use of *Moringa oleifera* Seeds as a Primary Coagulant in Textile Wastewater Treatment

Varun Agarwal, Divya Dixit and Mansi Jayeshbhai Bhatt

Abstract Recently, development of organic coagulants derived from microorganisms, animal, and plant tissues has been an area of interest of researchers. The present study conducts the performance of natural (*M. oleifera* seeds) coagulant for turbidity and organic constituent removal from textile wastewater. Impact of dose and pH on efficiency of *M. oleifera* in textile wastewater was also studied. *M. oleifera* seeds were extracted and used in powdered form, 2 g of *M. oleifera* powder mixed with 100 mL water. 95% degradation of textile wastewater sample was achieved when *M. oleifera* seeds (dose=16 mg/L, pH = 8) were used. Mechanism of *M. oleifera* coagulation consists of neutralization and adsorption of colloidal positive charge that attract negative charge impurities. Moringa seeds consist of proteins (cationic and dimeric) which help in neutralizing and absorbing colloidal charges in water containing suspended solids. These suspended impurities combine and form heavy clumps which results in easy settling of suspended particles. Natural coagulant produced less voluminous sludge and readily biodegradable that accounts for only 21–31% that of alum-treated counterpart. Seeds of *M. oleifera* (*M. oleifera*) yielded proteins which can act as effective coagulants in water and wastewater treatment. *M. oleifera* seeds have great turbidity and color removal potential. Use of *M. oleifera* seeds as a primary coagulant would decrease the cost of existing water treatment plants. It is eco-friendly method of purification of water, and consequently, it can be recommended for large-scale water treatment.

Keywords *Moringa oleifera* · Coagulant · Turbidity

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1 Introduction

Treatment of textile industry effluent has been a major challenge for environmental engineers. Conventional treatment technologies include a combination of chemical, physical, and biological methods and operations to remove organic matter, solids, and nutrients from wastewater. Coagulation–flocculation has been a promising chemical treatment method to treat highly polluted wastewater [1]. However, use of chemicals as coagulants has been a point of concern for environmentalists. Recently, development of organic coagulants derived from microorganisms, animal, and plant tissues has been an area of interest of researchers. A multipurpose tree called as *Moringa oleifera* Lam (*M. Oleifera*) whose seed contains edible oil (40% weight). Seeds have proteins which act as primary coagulants in wastewater treatment [2]. The effective constituents of seeds of *M. oleifera* are cationic having pH 10 and molecular weight of 6–16 kDa. The by-product of seed pressing to extract oil from Moringa is a seed cake which can be utilized as a filter to obtain drinking water for living beings. Moringa seeds consist of proteins (cationic and dimeric) which help in neutralizing and absorbing colloidal charges in water containing suspended solids. These suspended impurities combine and form heavy clumps which results in easy settling of suspended particles.

Moringa seed cake eradicates the suspended solids from wastewater. Being nontoxic and sustainable as compared to other synthetic materials, it is one of the promising techniques to remove the pollutants from wastewater, particularly in Moringa-growing regions [3, 4]. Use of natural coagulant like

Arachis hypogaea (peanuts), *M. oleifera*, Vigna mungo (urad), Zea mays (corn), and Vigna unguiculata (cowpeas) is now being used for removal of heavy metal. The literature suggests that *M. oleifera* has high absorption capacity compared with other coagulant used. Moringa seeds give high removal efficiency [5, 6]. Copper (90%), cadmium (60%), lead (80%), and chrome and zinc (50%) were removed by the treatment of Moringa seeds. Moringa seeds can be used as coagulants primarily in a clarifier for the wastewater treatment especially in underdeveloped and developing countries as other coagulants have high operating costs for metal removal and are expensive.

It is observed that 64% COD removal from the effluent took place by using combination of *M. oleifera* with alum. This shows that *M. oleifera* can be replaced to commercial coagulant and reduce the use of commercial coagulant [7, 8]

The produced *M. oleifera* extracted by separation of various components from the seed as coagulant gave suspended solids removal of around 97% for the treatment of turbid water. *M. oleifera* used as coagulant alternative to alum which producing very high sludge compared to *M. oleifera* [9]. Jar test is generally used for defining optimum pH, optimum dose of *M. oleifera* and optimum temperature and optimum dose of alum. It has the capability to remove 40% organic constituents [10].

Various studies show that seeds are effective for removal of suspended particles. Moringa seed is not giving any toxic effect. It is eco-friendly.

In this study, the objective of treatment is the performance comparison on natural and commercial coagulant of turbidity and organic constituent removal from textile wastewater.

2 Materials and Methods

Standard methods for pH measurement and COD analysis were followed. The raw effluent was collected from textile industry located near Rajkot. An initial experiment carried out to determine characteristics of textile effluent for further examination. 100 ppm stock solution was prepared for the same standard curve was prepared for the same. 2% solution of alum was used as commercial coagulant, whereas *M. oleifera* seed solution was used as natural coagulant in jar test. Initial COD, pH, and turbidity of the effluent were found out to be 800,6.5, and 265 NTU, respectively, before treatment.

3 Result and Discussion

3.1 Treatment with Alum

(a) **Effect of alum dose**:
Alum is used as commercial coagulant. 100 mL concentrated solution is mixed with 100 ml of water. Different alum doses like 0.10, 0.20, 0.30 mL are mixed to define optimum dose of alum. These coagulants are stirrer for 2 min at rapid speed and 30 min for slow speed. For floc settlement 30 min is providing. After that, absorption is measured by using spectrophotometer. 60% degradation found at 30 mg/L alum dose as shown in Fig. 1. Alum gets hydrolyzed to provide a number of products and cationic species that are neutralized by getting absorbed by negatively charged particles. This helps in destabilization of particles which results in flocculation. Result also indicates that if dosing is increased at some point decreasing occurs in removing capacity [10].

(b) **Effect of pH**:
After optimizing of alum dose, this dose is used to define optimum pH of textile effluent. This fixed dose is mixed with 50:50 solution of textile effluent and water at different pH. At 8 pH, 65% maximum degradation found as shown in Fig. 2. 25% COD can be removed with the help of alum. Maximum

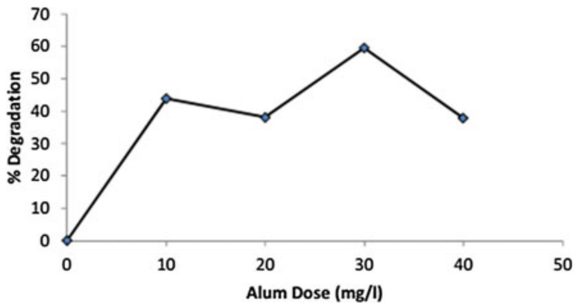

Fig. 1 Effect of alum dose (initial concentration 100 ppm, pH 7.2)

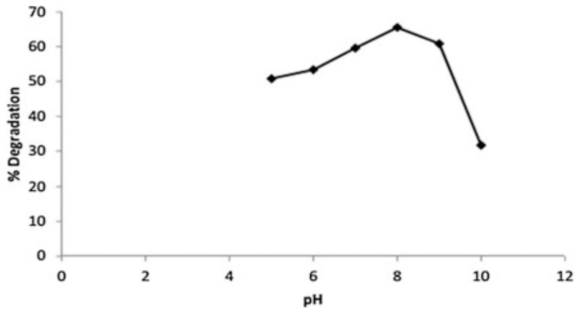

Fig. 2 Effect of pH (initial concentration 100 ppm, pH 7.2, alum dose 30 mg/L)

degradation can be achieved at natural pH, and pH 8 is nearer to natural pH. At natural pH, degradation found maximum. Result also shows that degradation slightly decreases when increasing pH above 9. At 6–7 pH, result is quite similar [11].

4 Treatment with M. *oleifera*

4.1 Effect of Moringa oleifera Seed

M. oleifera is used as natural coagulant. A 2% *M. oleifera* dosage is used to perform in jar test apparatus. In jar test, four beakers are used. 100 mL concentrated solution is mixed with 100 ml of water. Different *M. oleifera* doses like 0.10, 0.20, 0.30 mL are mixed to define optimum dose of *M. oleifera*. These coagulants are stirrer for 2 min at rapid speed and 30 min for slow speed. For floc settlement 30 min is providing. After that, absorption is measured by using spectrophotometer [2]. 95% degradation found at 16 mg/L dose of *M. oleifera* as shown in Fig. 3.

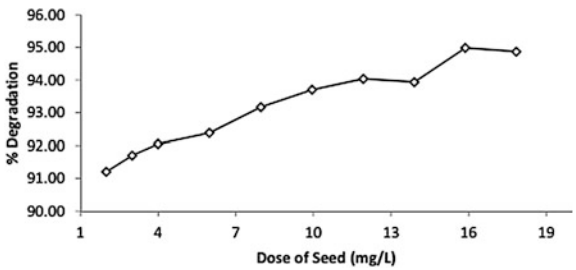

Fig. 3 Effect of *M. oleifera* (initial concentration 100 ppm, natural pH 7.2)

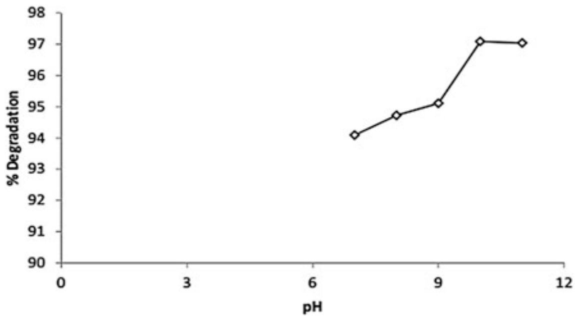

Fig. 4 Effect of pH (initial concentration 100 ppm, natural pH 7.2, optimizing dose 16 mg/L)

4.2 Effect of pH

After optimizing of *M. oleifera*, this dose is used to define optimum pH of textile effluent. This fixed dose is mixed with 50:50 solution of textile effluent and water at different pH. At 10 pH, 97% maximum degradation found as shown in Fig. 4. 75% COD can be removed with the help of *M. oleifera*. Optimum pH lies between 7 and 10, but at 10 pH, floc formation is high compared to other pH. At 10 pH, highest removal efficiency can be achieved [12].

5 Conclusion

The present study shows that alum is used as commercial coagulant and *M. oleifera* is used as natural coagulant to treat the textile wastewater. Result shows that at 10 pH, 16 mg/L optimization dose of *M. oleifera* is used to achieve 95% degradation. Use of *M. oleifera* would decrease the cost of treatment of wastewater. The *M. oleifera* seeds have immense suspended solids and color removal capacity. They reduce COD of textile wastewaters to a great extent. It is a nontoxic and eco-friendly way of treatment of wastewater, and consequently, it is being recommended for large-scale water treatment. So that *M. oleifera* is an alternative coagulant of water treatment plant.

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Chromium (VI) Reduction from Tannery Wastewater and Aqueous Solutions by Adsorption and Biosorption

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Abstract Toxic and harmful metals found in wastewaters are released to the environment, and this affects the living (flora and fauna including beneficial microbes) systems. An efficient and low-cost process facilitating their treatment needs to be established. Bioremediation (metallic biodegradations) is an optimistic scheme due to its low expenditure, high proficiency, and eco-friendly nature. The ability of microbes can be used as a lucrative option for eliminating/reducing chromium from the effluent by bioremediation methods. Recently, much works have been done facilitating the understanding of the interaction between the metal and the microbial communities. Such interaction is further utilized for the detoxification of different metals. Effluent is one of the hazardous pollutants of tannery industry. Higher amounts of chrome powder and chrome liquor are used during the process of tanning. Chromium an important pollutant is famous for mutagenicity, carcinogenicity, and teratogenicity in humans, experimental animals, and plants. The removal of Cr (VI) either by reduction or biosorption can significantly reduce the dangers to human body. Bio-adsorption refers to an uptake mechanism of the constituents in the wastewater by employing the living organisms. The findings of the present study demonstrated that the bacterial strain could efficiently reduce the toxic and chromium form aerobically. Strain 1 has shown a maximum capacity (98.77%) to biosorb the chromium from 100 ppm chromium aqueous solution. As the isolated bacterial strain is an excellent reduction potential of chromium, it can be exploited at the commercial level for bioremediation of chromium-contaminated environments. The tannery wastewater was analyzed and physicochemical parameters such as alkalinity, total solids (TS), total dissolved solids (TDS), total suspended solids (TSS), chloride, dissolved solids(DO), biological oxygen demand (BOD), chemical oxygen demand (COD), phosphate, sulfate, silicate, nitrite, nitrate, hardness, calcium, magnesium, iron, and chromium (Cr). The values are when compared with Indian standard. In this work, focus was made on the removal of cations and anions by using low-cost adsorbent, namely coir pith activated

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carbon. This treatment has resulted in the reduction of COD, Chloride, TS, TDS, TSS, Calcium, and chromium in 1, 10, 50, and 100% diluted tannery effluent. The results indicate that the bacterial strains have exhibited the capacity for the detoxification mechanism of chromium at low at the same time, higher adsorption capacity under a wide range of environmental circumstances. The possibility of the use of these bacterial strains for the reduction of the toxic metal in the industrial wastewater has been assessed. The identified organisms can be further employed for eco-friendly cleanup processes.

Keywords Chromium · Tannery effluent · Biosorption · Coir pith Physicochemical

1 Introduction

Water pollution is a major environmental issue related to the economic/industrial development of several countries [1]. Over the last few decades, uncontrolled metropolitanize industrialization and urbanization have caused a severe contamination due to the disposal of sewage and industrial effluents to water sources [2]. The increase of population at the same time increasing requirement of leather and its products led to the establishment of high levels of profit-making tanneries [3]. Indian tannery is one of the foremost in the world. It is also one of the highly polluting industries in the State [4]. Tannery effluent contains bulky amounts of Cr, variety of microbes and toxic metals, which leads to contamination of the water bodies [5]. In this present century, heavy metal pollution is a major environmental problem. The sources of different kind of pollutants such as industrial overflow of water containing heavy metals pose a hazard to the flora and fauna. Consequently, metal scrubbing, electroplating, washing, mining, paper and pulp manufacture, paint, fabric and leather trades, slaughter debris result in the wastewater of complicated nature [6].

The process of tanning is one of the main divisions in leather manufacture. Huge volumes of chrome residue and chrome liquid are used during the progression of tannery. Regarding 20–40% of applied chromium usually remains un-reacted and discharges directly into the sewage system without treatment. Above 170, 000 tons of unwanted Cr are ejected to the lands and water bodies annually from the industrial operations [7, 8]. Its ability to undergo oxidation makes the ion to enter into the biological films and leads to health impairment [9]. In general, potential microorganism particularly bacterial species can reduce the concentration of heavy metals ions from contaminated source by biosorption methods [10]. In order to fill up the lacuna of the low-cost materials of coir pith, the present work was aimed to check the reduction of cations and anions from tannery effluent by using low–cost materials such as coir pith activated carbon (Adsorption) and bacterial strains isolated from the tannery effluent (Biosorbent). Activated carbon with their large shell area, small porous, and chemical nature of their surface have made them potential adsorbents for the elimination of heavy metals from industrial wastewater.

2 Materials and Methods

2.1 Sample Collection

Tannery waste overflow was collected from a tannery located in Sembattu area in Tiruchirappalli districts of Tamil Nadu (India). The samples were taken in pre-cleaned polyethylene bottles. Samples were collected using plastic bottles of 5 L capacity.

2.2 Reagents and Chemicals

All reagents used were of analytical grade from Merck, loba-chemie and activated coir pith carbon was prepared manually.

2.3 Analytical Method

2.3.1 Physicochemical Parameters

The values of pH of the sampled water samples were determined using pH meter (Model-CyberScan, EUTECH Instruments). The electrical conductivity of the water samples were analyzed using electrical conductivity meter (Model: INOLAB). Alkalinity, TS, TDS, TSS, chloride, DO, BOD, COD, hardness, calcium, magnesium, chloride, Cr were also estimated [11]. The amount of phosphate, sulfate, silicate, nitrite nitrate were further estimated using the Spectrophotometer (Systronics Double Beam Spectrophotometer model-2202).

2.3.2 Identification of Organisms from Bacterial Strain from Tannery Effluent Samples

The microorganisms isolated from the samples were identified by employing the following schematic procedure (Buchanan and Gibbons 1974) [12]. The biochemical test like Indole, Catalase, Voges–Proskauer, Methyl Red, Citrate, Triple Sugar Iron, and Urease Test were conducted.

2.3.3 Determination of Cr (VI) Reduction by Bacterial Strains (Biosorption)

Spread plate technique was used to isolate and identify the microorganisms from the tannery effluent. The bacterial population was selected and isolated based on their resistance to chromium ions. Accurately, 1 mL of effluent sample was diluted in 9 mL of sterile distilled water and serially diluted ten folds. 0.1 mL aliquots from the serially diluted samples were plated on nutrient agar plates that contained 100, 500 and 1000 ppm $K_2Cr_2O_7$. Similar plating was done in control plates that were devoid of metal salts. All plates were duplicated. The plates were allowed to be incubated at 30 °C for 10 days, and the total count was determined at the end of tenth day. To measure the Cr (VI) reduction, 5–1000 ppm Cr resistant bacterial isolates were cultured in nutrient broth at 37 °C overnight. The optical density (OD) was measured at 610 nm for all the isolates. 2 mL of culture was taken from each isolate and was freshly inoculated in nutrient broth with 32 mg/L Cr (VI). The OD was measured at different time intervals which include 30, 60, 120, 240, 360, and 480 min. Similar method was adopted using 1 mL of culture. After the stipulated time interval, the cells were collected by centrifuging at 8000 rpm for 15 min at 4 °C. The estimation of chromium was done for the collected supernatant. The aforesaid Cr (VI)-containing media was also included for estimation of chromium at same intervals. 1,5-diphenylcarbaide (DPC) reagent was used to measure Cr (VI) in the supernatant [11]. Acid digestion of the sample was done, and the total chromium was measured using atomic absorbtion spectrophotometer.

2.3.4 Determination of Maximum Tolerance Concentration (MTC) of Bacterial Strains to Chromium

The MTC of the bacterial isolates from the effluent were assessed to check their metal resistance. The isolates were separately streaked on the media of varying concentrations of chromium salts ranging from 100 to 1000 ppm dissolved in sterile distilled water. The isolates were cultured in metal-containing medium at 30 °C overnight. The plates were incubated at 30 °C for 24–72 h. The least metal concentration which inhibited the bacterial growth was considered as the MTC of that particular isolate.

2.3.5 Antibiotic Sensitivity

Petri plates containing Mueller Hinton Agar Medium (10 mL) were seeded with 24-h-old culture of particular bacterial strain. The zone of inhibition exhibited by the selected isolate on the three different disks (6 mm) Ampicillin, Erythromycin, Tetracycline was calculated based on the zone of inhibition. Succeeding, the plates were incubated for 24 h at 37 °C. The zone of inhibition formed nearby the disk was measured for antibiotic sensitivity.

2.3.6 Removal of Ions by Using Activated Carbon (Adsorption)

The anions and cations present in tannery effluent could affect the soil, water, and atmosphere and could pollute the flora and fauna. Removal of these ions was performed using low-cost absorbent coir pith activated carbon. About two liters of diluted tannery effluent was prepared and about 1 g of coir pith activated carbon was added up to 10 days. The physicochemical parameters were analyzed every day for 11 day which includes initial and final day. The parameters checked were pH, Calcium, Chloride, Chromium, TS, TDS, TSS, COD, DO.

3 Results

3.1 Characterization of Tannery Effluent

The effluent sample was characterized by analyzing the physicochemical parameters such as pH, EC, Alkanity, TS, TDS, TSS, Chloride, DO, BOD, COD, Phosphate, Sulfate, Silicate, Chloride, Nitrite, Nitrate, Hardness, Calcium, Magnesium, Iron, Chromium. The values are tabulated in Table 1. The effluent was subjected to different dilutions such as 1, 10, 50, and 100%.

The removal of the cations and anions was done by using activated carbon prepared with coir pith. The physicochemical parameters from all the diluted samples l (1, 10, 50, and 100%) were done as per the standard procedure given by APHA [11]. Initial experiments were conducted with the addition of 1 g of activated carbon to all the dilutions followed by shaking for 10 days. As the reduction in the physicochemical characters were not pronounced, 1 g of activated carbon was added every day and the removal was continually monitored up to 10 days. The initial and final readings were taken and are tabulated in Table 2 and the figures are presented in Figs. 1, 2, 3, 4, 5, 6, and 7.

Figures 1, 2, 3, 4, 5, 6, and 7: The percentage of cations and anion removal by using coir pith activated carbon.

The effluent sample has been subjected to the identification of heterotrophic bacterial genus. The bacterial strains present in the tannery effluent include

Table 1 Physicochemical characteristics of diluted tannery effluent

S. No.	Parameter	1%	10%	50%	100%
1	pH	6.67	7.26	7.37	7.26
2	EC (µs/cm)	0.961	1.6587	7.2819	14.337
3	Alkalinity	491.2	495.5	566	607.2
4	Acidity	22.2	24.5	28	32.7
5	TS	0.0159	0.0263	0.0397	0.0849
6	TDS	0.0033	0.0054	0.0625	0.0765
7	TSS	0.126	0.266	0.0445	0.0775
8	DO	1.2	1.6	1.9	2.1
9	BOD	1.26	1.82	3.24	6.08
10	COD	8.76	11.73	18.53	26.133
11	Phosphate	0.083	0.128	0.339	0.5609
12	Sulfate	0.263	0.282	0.348	0.556
13	Slicate	0.140	1.822	1.35	1.417
14	Chloride	62.48	77.95	81.45	83.63
15	Nitrite	396	542	967	1682
16	Iron	0.003	0.015	0.055	0.139
17	Calcium	15	17	20	25
18	Chromium	0.570	0.648	1.66	1.79
19	Nitrate	699	761	836	1008
20	Magnesium	132.62	426.50	566	699.70
21	Acidity	22.3	24.5	28	32.7

*Values are expressed in mg/L except for pH and EC

Bacillus sp., and the results were tabulated in Table 3. Many of the organisms have shown a positive result for Catalase test and negative results for the indole test.

The percentage reduction of chromium using bacterial isolates was calculated and is presented in Table 4, Fig. 8 and Plate 1. The percentage was measured from antibacterial activity plate. The strains (Strain 1—57.89%, Strain 2—92.3%, Strain 3—85.71%, Strain 4—66.66%) showed resistance to tetracycline when compared to ampicillin. The strains (Strain 1—68.42%, Strain 2—92.3%, Strain 3—85.71%, Strain 4—80%) showed resistance to erythromycin when compared to ampicillin. Strain 5 has showed no zone formation. Resistance is not valid for the fifth strain alone (Table 5).

Table 4 has highlighted the reduction of Cr by bacterial strains for a time period of 8 h (Figs. 8 and 9; Plate 1).

Table 2 Removal of cations and anions by using coir pith activated carbon

S. No.	Parameter (mg/L)	Percentage	Removal of Cr by low cost such as activated carbon												
			Day initial	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day final	% removal
1	pH	1	6.68	6.59	6.78	6.42	6.69	7.02	7.69	8.23	8.21	7.3	7.1	6.9	3.12
		10	7.48	7.31	7.65	6.9	6.8	7.9	8.3	8.2	7.3	7.6	7.9	7.4	1.06
		50	7.56	7.6	7.9	7.3	7.8	7.1	7.2	7.6	8.1	8.9	7.6	7.8	3.17
		100	7.81	8.4	8.3	8.6	8.4	8.1	7.9	7.3	7.4	7.5	7.6	7.6	2.7
2	Ca	1	47	39	37	35	26	29	27	24	28	21	20	15	68.08
		10	49	48	45	41	41	40	36	31	29	27	26	21	57.14
		50	51	49	43	41	40	39	37	29	24	21	19	14	72.52
		100	55	54	50	48	41	36	35	35	34	31	29	27	50.90
3	Cl_2	1	62.48	63.4	61.3	59.1	54.7	51.6	48.9	48.1	49.7	47.1	45.3	44	29.57
		10	107.4	108.9	92.4	93.1	77.0	70.1	64.9	62.1	61.0	60	54	54	49.72
		50	149.9	150.2	149	139	126	121	116	114	110	109	104	98	72.54
		100	152.6	156.6	152	149	146	143	139	135	131	129	124	119	22.01
4	Cr	1	0.44	0.44	0.32	0.3	0.3	0.24	0.24	0.21	0.2	0.19	0.14	0.13	70.45
		10	1.56	1.5	1.4	1.4	1.2	1.3	1	0.6	0.5	0.4	0.4	0.4	74.35
		50	1.62	1.4	1.3	1.2	1.2	1.2	1	1	0.9	0.7	0.8	0.6	62.69
		100	1.83	1.3	1.29	1.11	1.08	1.06	1.05	1.03	1.02	1.01	1	0.8	57.28
5	TS	1	6.526	6.25	6.23	6.20	6.19	6.14	6.15	6.11	6.0	5.7	5.7	5.4	17.17
		10	10.01	9.1	9.4	9.42	9.12	9.0	9.0	8.16	8.12	8.06	8.02	7.9	21.07
		50	15.02	14.6	14.3	14.1	13.5	13.5	12.4	12	11.9	11.5	11.2	10.1	32.75
		100	17.31	16.5	15.2	15.0	14.3	14.6	14	13.1	13	13.1	12.9	12.5	27.78
6	TDS	1	5.84	4.91	4.90	4.90	4.90	3.50	3.45	3.06	3.01	3.12	2.6	2.51	57.02
		10	9.146	9.12	9.10	9.00	9.12	8.79	8.48	8.35	8.12	8.10	8.09	8.01	12.42

(continued)

Table 2 (continued)

S. No.	Parameter (mg/L)	Percentage	Removal of Cr by low cost such as activated carbon											
			Day initial	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day final	% removal
		50		9.40	9.95	9.30	9.26	9.24	9.20	9.15	9.05	9.06	9.00	9.01	55.15
		100	13.14	12.9	12.8	12.4	11.0	11.1	10.9	10.5	10.6	10.5	10.4	10.1	23.13
7	TSS	1	5.01	5.04	4.81	4.82	4.77	4.65	4.75	4.54	4.44	4.2	4.14	4.10	18.16
		10	8.496	8.48	8.45	8.4	8.36	8.35	8.31	8.00	8.15	8.0	7.4	7.4	12.25
		50	8.261	8.25	8.24	8.21	8.19	8.15	8.14	8.13	8.12	8.11	8.0	8.0	35.15
		100	12.32	11.8	11.6	11.5	11.4	11.4	11.0	11.0	10.9	10.8	10.4	10.1	0.17
8	COD	1	8.53	–	–	–	–	–	–	–	–	–	–	7.12	16.52
		10	10.66	–	–	–	–	–	–	–	–	–	–	8.64	18.94
		50	11.26	–	–	–	–	–	–	–	–	–	–	9.44	16.16
		100	21.23											19.3	9.09

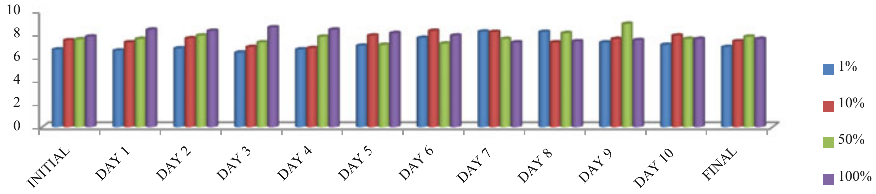


Fig. 1 ph

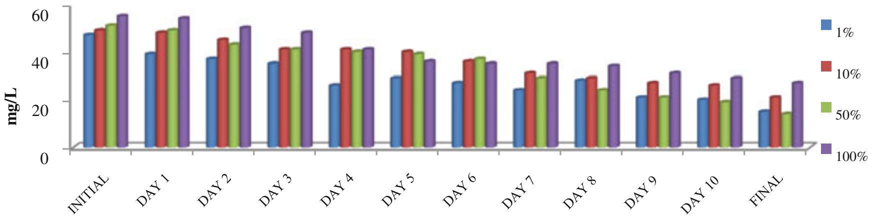


Fig. 2 Calcium

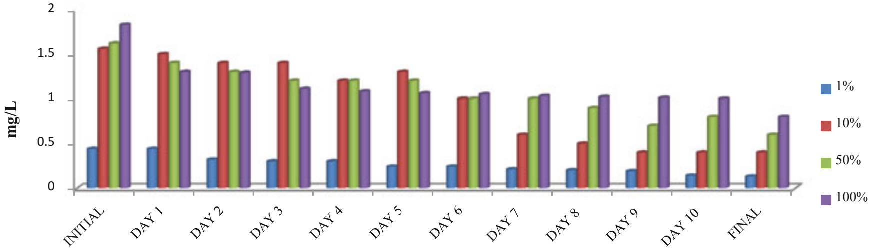


Fig. 3 Chromium

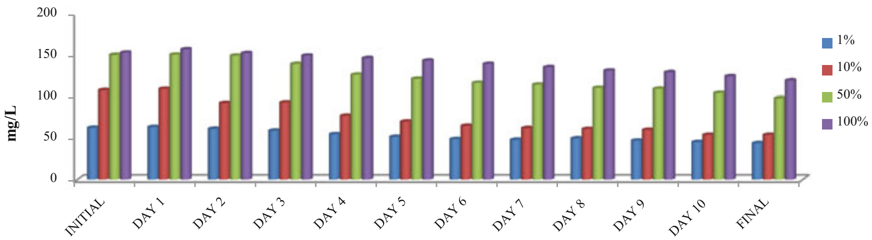


Fig. 4 Chloride

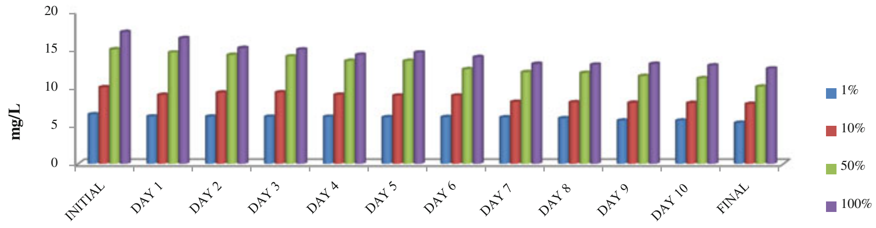


Fig. 5 Total solids

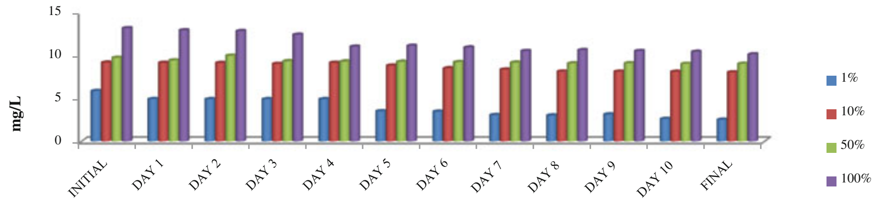


Fig. 6 Total dissolved solids

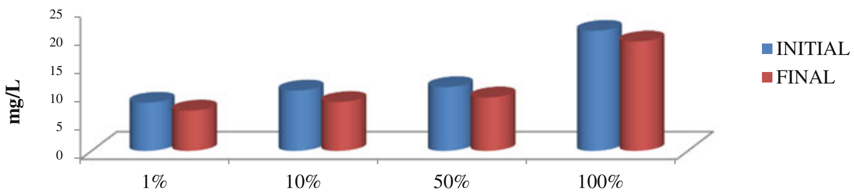


Fig. 7 COD

Table 3 Identification of heterotrophic bacteria isolated from tannery effluent

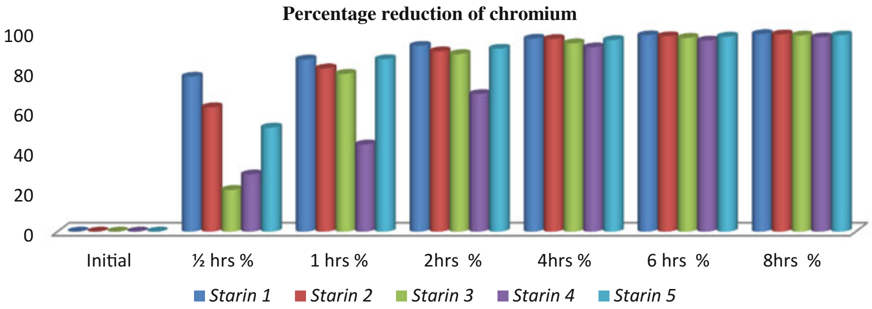
S. No.	Isolated colonies	Indole	MR	VP	TSI	Citrate	Catalase	Urease
1	S_1	−ve	+ve	−ve	+ve	+ve	+ve	±
2	S_2	−ve	±	−ve	±	±	+ve	±
3	S_3	−ve	±	−ve	±	±	+ve	±
4	S_4	−ve	+ve	−ve	+ve	−ve	+ve	−ve
5	S_5	−ve	+ve	−ve	−ve	−ve	+ve	±

Table 4 Percentage reduction of chromium using bacterial isolates (Biosorption)

Isolated strains	Chromium removal						
	Initial	½ hrs (%)	1 h (%)	2 h (%)	4 h (%)	6 h (%)	8 h (%)
S1	0.012	77.46	86.04	92.89	96.41	98.18	98.77
S2	0.014	62.16	81.57	90.14	96.27	97.70	98.58
S3	0.019	20.83	78.88	88.75	94.17	96.82	98.07
S4	0.035	28.57	43.54	68.75	92.12	95.54	97.12
S5	0.012	52.00	86.20	91.48	95.74	97.51	98.14

Table 5 Antibiotic sensitivity of the bacterial strains

Percentage	Strain 1 (%)	Strain 2 (%)	Strain 3 (%)	Strain 4 (%)	Strain 5 (%)
% increase of resistance to tetracycline compared with ampicillin	57.89	92.3	85.71	66.66	Not valid
% increase of resistance to erythromycin compared with ampicillin	68.42	92.3	85.71	80	Not valid



Strains	5 ppm	10 ppm	20 ppm	30 ppm	40 ppm	50 ppm	75 ppm	150 ppm	300 ppm	500 ppm	700 ppm	800 ppm	900 ppm	1000 ppm
Strains1	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**S**	**S**	**S**	**A**
Strains2	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**S**	**A**	**A**	**A**	**A**
Strains3	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**S**	**A**	**A**	**A**
Strains4	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**S**
Strains5	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**S**	**A**	**A**	**A**

R = Resistance *A = Absence of growth *S = Sensitive

Fig. 8 Percentage reduction of chromium using bacterial isolates

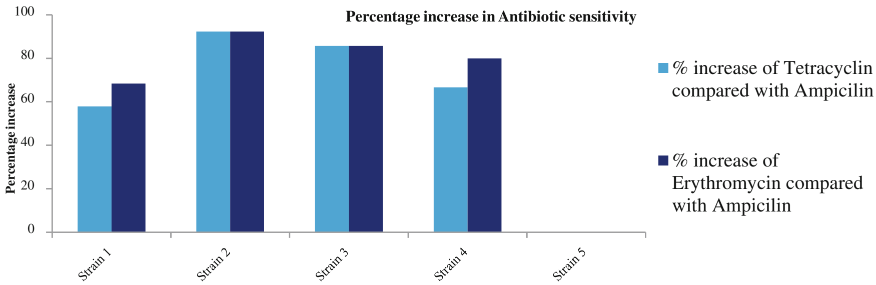


Fig. 9 Percentage of antibiotic sensitivity from isolated bacterial strains

4 Discussion

The effluent from leather industry was subjected to its physic chemical characterization such as pH, EC, Alkanity, TS, TDS, TSS, Chloride, DO, BOD, COD, Phosphate, Sulfate, Silicate, Nitrite, Calcium, Iron, Chromium. The optimum pH range for aerobic processes is always reported to be between 7.0 and 7.5. The pH of the 1% diluted tannery effluent has marginally increased when compared to 10, 50, 100%. The pH has become slightly alkaline for all dilutions except 1% and also alkalinity for 1% was 491.2 mg/L, for 10% it was 495.5, and for 50 and 100% the

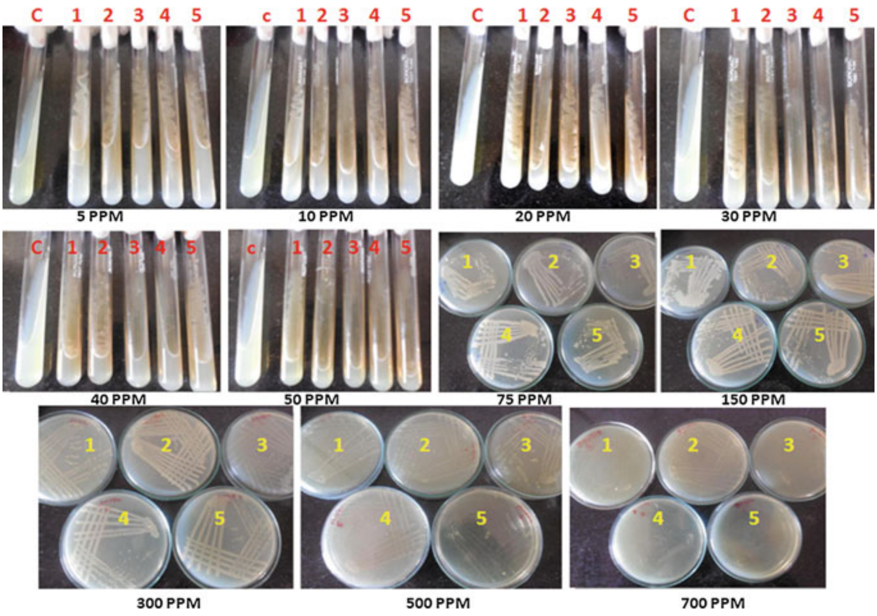


Plate 1 Following plates clearly depict the tolerance of the bacterial strains to different concentrations of chromium (5–700 ppm)

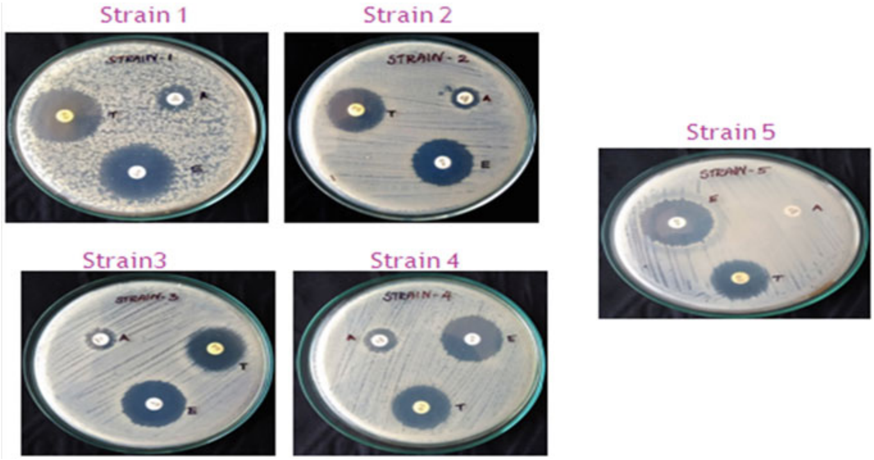


Plate 2 Antibiotic sensitivity from isolated bacterial strains

values were above 500 mg/L. The results of the present study revealed that acidity level from pickling; chrome tanning, and retaining and result were discussed. The acidity was about 32.7 mg/L for 100%. Water containing TDS concentrations below 1000 mg/L is usually acceptable as per WHO standards. The percentage reduction of TDS was 57.02% with 1% dilution and it was 55.15% with 50% dilution. A good reduction of the chloride content was noticed with the dilutions after the adsorption experiments. The percentage reduction of chloride ion was 29.57 with 1% dilution, and it was 49.72% with 50% dilution and 100% dilution for 70.35. The COD was analysis with the dilutions after the adsorption experiments. The percentage reduction of COD ion was 16.52 with 1% dilution, and it was 16.16% with 50% dilution. The percentage reduction of calcium ion was 68.08 with 1% dilution, and it was 72.52% with 50% dilution.

The isolated bacterial strain (Strains 2, 3, 4, and 5) has shown good growth in the 100 ppm chromium containing aqueous solutions. Strain 1 has comparatively shown resistance to chromium solution. This strain has biosorbed the chromium and has resulted in 98.77% reduction of chromium in 8 h with strain 1. This suggests the possibility of utilizing this strain for chromium reduction from the effluent. This needs further investigation. Similarly, Abhipsa and Chandraraj [13] have stated the chromium reduction. From the above analysis, we can confirm the reduction of the cations and anion from the tannery effluent. When the Cr reduction is considered, the higher reduction was obtained using the bacterial strains (98%) than using the low-cost absorbents. However, further research is needed to implement the results for the effective tannery effluent treatment.

5 Conclusion

The tannery wastewater was analyzed for its physicochemical parameters. The values were higher when compared with the prescribed Indian standard. In this work, the focus was made on the removal of cations and anions by using low-cost adsorbent, namely coir pith activated carbon. The findings of the present study demonstrated that the indigenous bacterial strain could efficiently reduce the toxic and soluble chromium and insoluble chromium form aerobically. Strain 1 has shown a maximum capacity (98.77%) to biosorb the chromium from 100 ppm chromium aqueous solution. The results revealed that the bacterial strains were a promising candidate that can be employed in detoxification of chromium. Still, a more extensive understanding of the mechanism behind the chromium reduction in large-scale field is required. Furthermore, successful implementation of eco-friendly bioremediation in the contaminated site applying a more suitable technology integrated with the microbial strain is also needed.

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Removal of Ranitidine from Pharmaceutical Waste Water Using Graphene Oxide (GO)

Suparna Bhattacharyya

Abstract Nowadays, Pharmaceutical drugs has become the major pollutants for aquatic life. It is degrading the quality of water, causing serious health issues and destroying underwater ecosystem. So different engineering and environmental friendly methods has been found out for removal of these drugs from pharmaceutical waste water. Out of which the low cost techniques are quite popular and sustainable now. In the current study Ranitidine is removed from Pharmaceutical Waste water using Graphene Oxide (GO) as an adsorbent. At 10 ppm concentration, dosage of 100 mg and at 313 K temperature, the maximum percentage removal of Ranitidine is 94.1. The Stirrer Speed and pH is maintained at 140 rpm and pH-6 respectively. The 3D plot of temperature and pH is also shown here. Mainly Percentage Removal is calculated with the absorbance found from UV Spectrophotometer. However, forming kinetic Model of required work can be an efficient future scope for this paper.

Keywords Ranitidine · Graphene oxide (GO) · UV spectrophotometer
Percentage removal

1 Introduction

Over these days, pharmaceuticals are considered as harmful bioactive chemicals. It is polluting our environment drastically. They are polluting water bodies and our ecosystem as till now they cannot be controlled in a proper manner. Several processes are under consideration to regularize these pollutants [1]. These chemical pollutants are continuously introduced in the environment from several pharmaceutical industries, hospital's by-product and domestic wastes, which is degrading the drinking water quality, aqueous eco-system and human health [2]. The therapeutic drugs and xenobotic compounds are mainly causing health related problems.

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Thus several emerging engineering process for removal of these dreadful substances from water is one the major concerning issues nowadays [2].

People these days are more concerned about several removal techniques of these pharmaceutical wastes from waste water. Specially the low cost techniques are gathering much attention, mainly for their cost estimation aspect as well as due to their sustainability [3]. Domestic Runoff contains pharmaceutical and personal care products which act as major pollutant for aquatic life. Chemicals, disinfectants, fragrances and veterinary drugs has detrimental effect on natural sources of water [2]. Thus several studies on removal of these drugs from pharmaceutical waste water is carried out now.

Previously several works has been reviewed where activated carbon from mung bean husk [4], tree leaves [5], apricot shell [6] has been used for removal of Ranitidine from pharmaceutical waste water. Very few paper has been studied where GO is used as an adsorbent for removal of Ranitidine from Waste water.

The main objective of this study is to find the efficiency of adsorbent GO for removal of Ranitidine from pharmaceutical Waste Water and to find the optimum parameters like concentration, Adsorbent dose, temperature, pH and Stirrer Speed at which the percentage removal of Ranitidine will be maximum. Some of the research question that came out during execution of this work are, Is it possible to use GO as adsorbent for removal of Ranitidine from pharmaceutical Waste Water? If yes, What will be the maximum percentage Removal of GO? What are the several possible parameters that can be seen during the process? What can be the optimum parameter for which the percentage removal of Raniidine is maximum?

Present study mainly focuses on removal of harmful pharmaceutical compound Ranitidine from pharmaceutical waste water using Graphene Oxide. Several optimum points at which the removal is maximum is also studied. Correspondingly, effect of different parameters on percentage removal of Ranitidine is also shown and some future scope of this work is also discussed here.

2 Materials and Methods

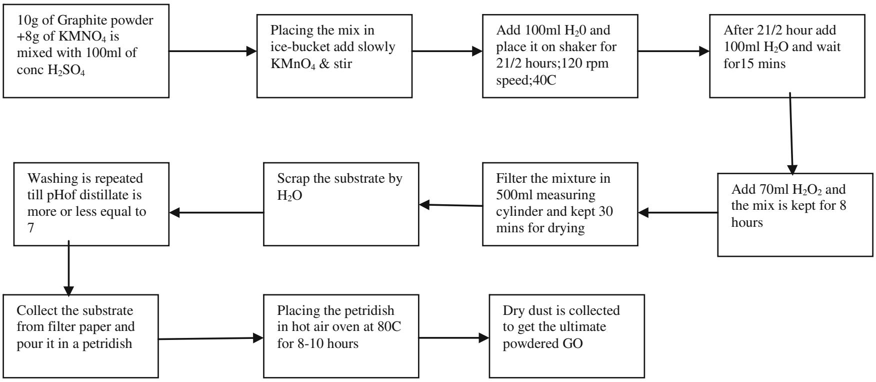
2.1 Material

Ranitidine Solution is synthetically prepared by using Ranitidine chemical from MP Biomedicals Ltd having CAT No: 153563 and IOT No: 9861 K. Graphene Oxide (GO) is also prepared in lab using Modified Hummer's Process from Graphite Powder present in the lab.

2.2 Methods

Preparation of GO using Modified Hummer's Process:

GO is prepared in lab by Modified Hummer's Process by following methods.



2.3 Experimental

Batch Adsorption Study

2.3.1 Preparation of Standard Curve

From 100 ppm Ranitidine solution prepared earlier 6 sample solution of 5, 10, 25, 50, 75 and 100 ppm concentration of the chemical is prepared. Using this sample a standard curve of the solution is formed with the help of UV Spectrophotometer giving its highest peak at wavelengths 227.9 and 313.9 nm respectively. The R^2 value are R^2 (227.9 nm) = 0.997 and R^2 (313.9 nm) = 0.996 respectively [7–9].

2.3.2 Batch Study

5 sets of Sample is examined optimising concentration, Adsorbent doses, pH, temperature and Stirrer speed. Every sample solution contains 100 mL of Ranitidine solution. Sample is incubated and stirred for 1 h and sample is collected after every 15 min [9, 10]. All the sample is centrifuged properly and its absorbence is tested using UV Spectrophotometer.

3 Results and Discussion

3.1 Plot Showing Change in Percentage Removal of Ranitidine Using Graphene Oxide (GO) as Adsorbent at Different Concentrations

In Fig. 1 the graph is plotted with Time (in minutes) in *X*-axis and % Removal of Ranitidine in *Y*-axis at different concentrations of ranitidine like 5, 10, 20 and 50 ppm. Among which the best result is for 10 ppm concentration of ranitidine keeping all other parameters constant. So 10 ppm is selected as optimum concentration for removal of Ranitidine from pharmaceutical waste water, where the maximum percentage removal of Ranitidine is 94.063.

From the graph it can also be seen that 5 ppm concentration also gives quite efficient % removal, but it cannot be selected as an optimum as so less concentration of Rantidine is very rarely found in the waste water coming out from pharmaceutical industries or domestic sewage.

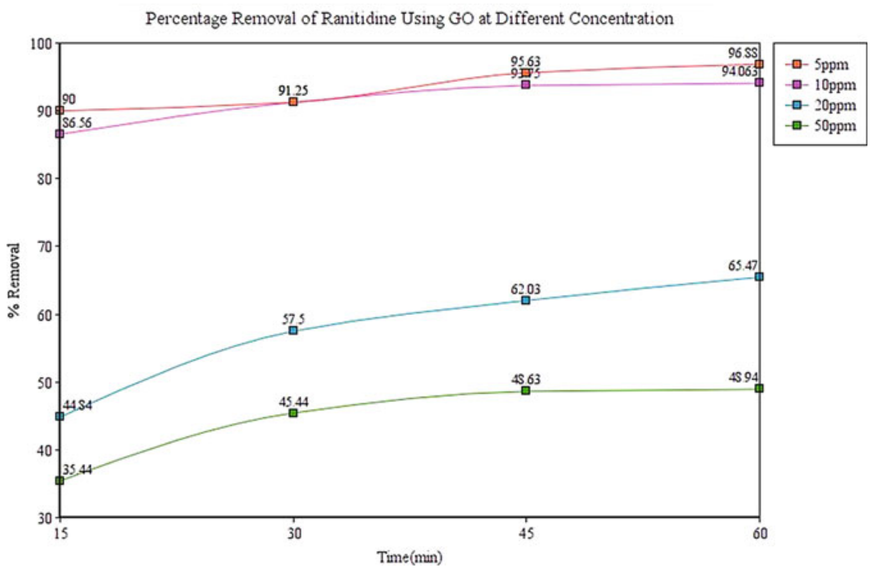


Fig. 1 Percentage removal of ranitidine using GO at different concentration

3.2 Plot Showing Change in Percentage Removal of Ranitidine Using GO at Different Adsorbent Doses

In Fig. 2 the graph is plotted with Time(in minutes) in *X*-axis and % Removal of Ranitidine in *Y*-axis at different adsorbent doses of ranitidine like 50, 75, 100 and 200 mg. Among which the best result is for 100 mg dosage of GO. So, it is selected as optimum Adsorbent Dose for removal of Ranitidine from pharmaceutical waste water, for which the maximum percentage removal of Ranitidine is 90.06.

From the graph it can also be seen that 200 mg dosage of GO yields quite good % removal, but it is not selected as optimum, as it will be more costly than that of 100 mg dosage and the efficiency given does not differs much from 100 mg.

3.3 Plot Showing Change in Percentage Removal of Ranitidine Using GO at Different Temperatures

In Fig. 3 the graph is plotted with Time (in minutes) in *X*-axis and % Removal of Ranitidine in *Y*-axis at different temperatures 298, 303, 308 and 313 K. Among which the best result is at 313 K fixing other parameters which is 94.063. So 313 K is taken as optimum temperature for the removal process.

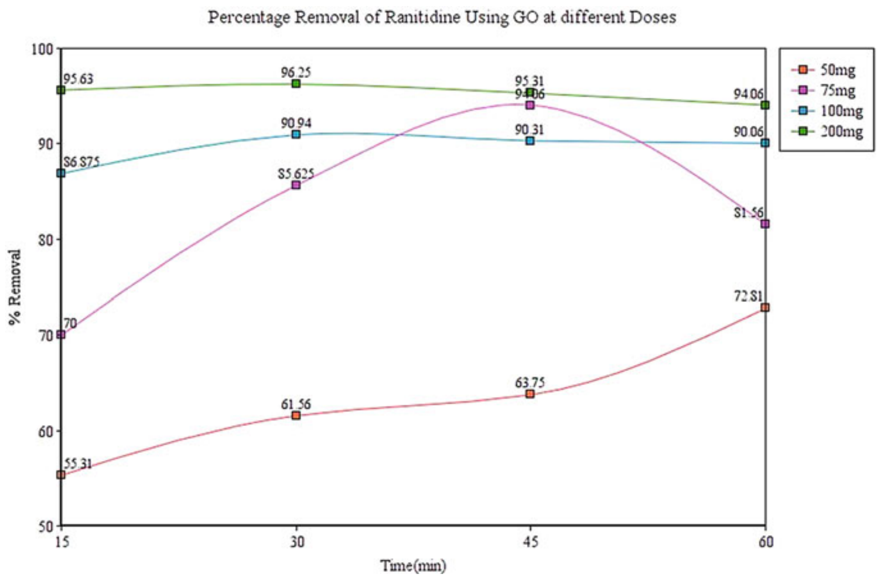


Fig. 2 Percentage removal of ranitidine using GO at different doses

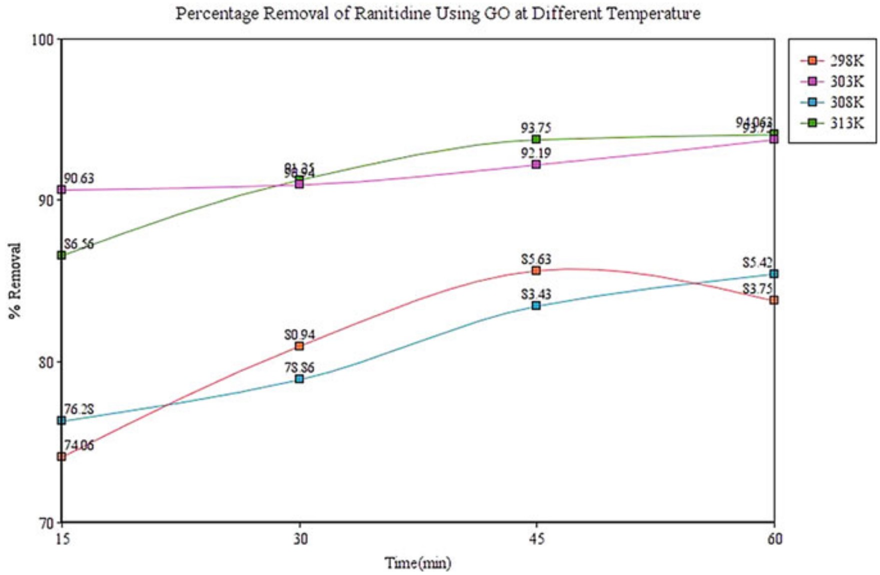


Fig. 3 Percentage removal of ranitidine using GO at different temperature

3.4 Plot Showing Change in Percentage Removal of Ranitidine Using GO at Different pH

In Fig. 4 graph plotted % Removal against Time at different pH. Among which pH-6 gives the maximum yield about 90.94. So, it is taken as optimum pH for removal of the drug.

3.5 Plot Showing Change in Percentage Removal of Ranitidine Using GO at Different Stirrer Speed (in rpm)

Figure 5 plotted % Removal against Time at different stirrer speed. Among which the best result is seen at 140 rpm which is 90.94. So, 140 rpm is taken as optimum stirrer speed for removal of ranitidine from waste water.

Figure 6 shows a contour plot of percentage removal of pollutant with respect to time and pH.

It is observed that maximum removal is obtained within the pH range of 4–7 and 40–60 min time. However, 35–50 min of time may be considered as the optimum time where irrespective of the pH the removal is $\sim$83% which is almost the

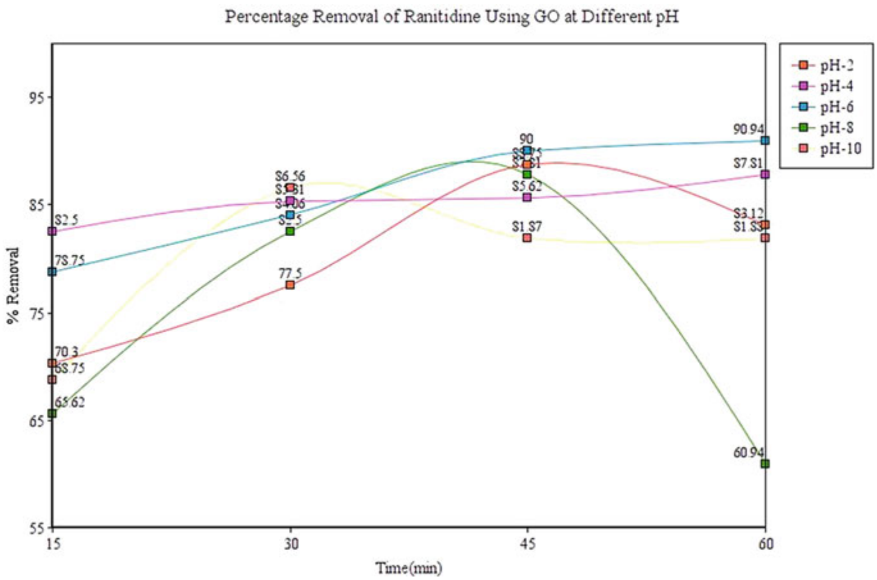


Fig. 4 Percentage removal of ranitidine using GO at different pH

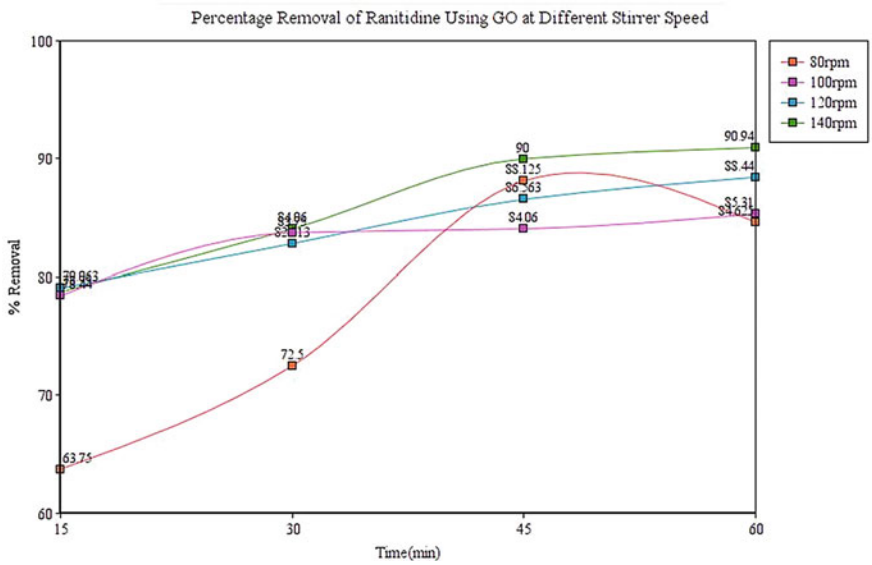


Fig. 5 Percentage removal of ranitidine using GO at different stirrer speed

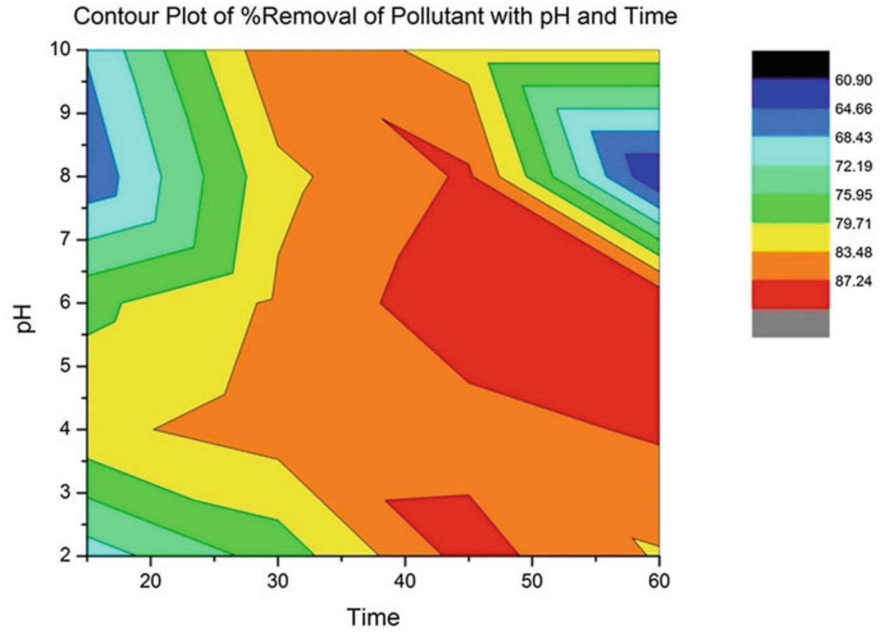


Fig. 6 Contour plot of % removal of pollutant with pH and time

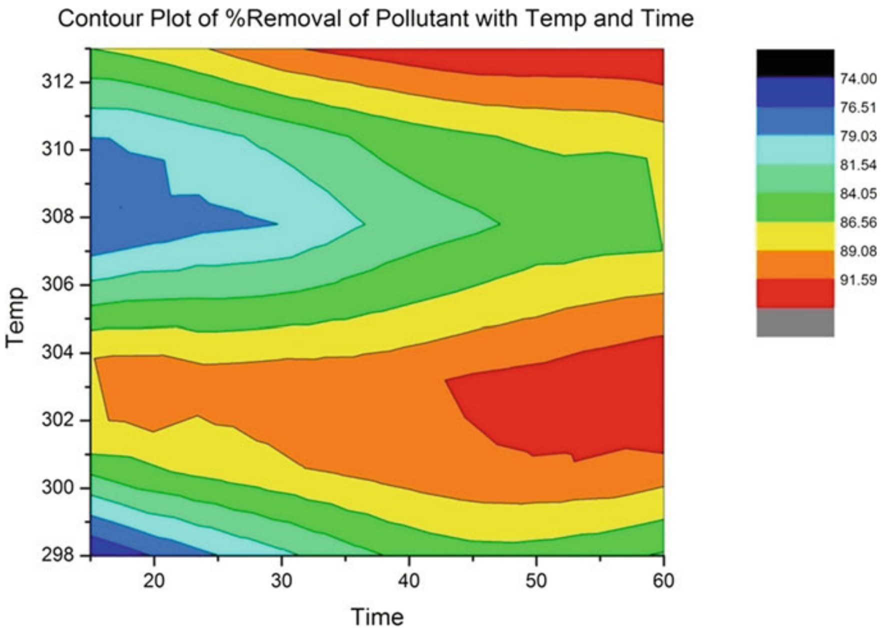


Fig. 7 Contour plot of % removal of pollutant with temp and time

maximum removal. This implies that at certain point of the adsorption process pH has no effect on the overall process. This is an important finding.

The Fig. 7 shows a contour plot of percentage removal of pollutant with respect to time and Temperature. It is observed that maximum removal is obtained within the temperature range of 301–305 K and 45–60 min time. However, over the whole time 300–305 K has showed optimum removal efficiency. Hence, the adsorption process is best when operated within that temperature range.

4 Conclusion

It is found from this study that for an optimum concentration of 10 ppm for 100 mg adsorbent dose at 313 K temperature,at optimum pH-6 and at 140 rpm stirrer speed the maximum percentage removal of ranitidine is about 94.1. As the optimum values at which the removal of ranitidine is maximum, is already found we can further focus on forming Kinetic model for removal of the drug from industrial and domestic waste water. Different types of treated GO can also be used for removal of Ranitidine as a future scope of the work.

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Dye-Containing Wastewater Treatment Using Treated Jute

Suvendu Manna, Papita Das and Debasis Roy

Abstract Natural fiber (cotton, jute, coir, sisal, and ramie)-based textile industries produced copious amount of solid waste mainly comprised of lignocellulosic matters. These waste materials could be an excellent adsorbent for wastewater treatment due to their low cost, biodegradability, eco-friendliness, and high stable nature to most organic solvents. Furthermore, these types of lignocellulosic waste have high density of hydroxyl groups and easy to modify with specific functional groups for removal of specific pollutants from water. The study undertaken in this research used lignocellulosic solid waste from jute industry and modified it with plant-based reagents. Then the treated jute fibers were used to remove safranin from water. For modification, the lignocellulosic waste was first treated with alkali-steam treatment followed by grafting with neem oil-phenolic resin. Safranin was used for demonstrating the removal efficacy of the treated lignocellulosic biomatters. Effect of adsorbent dose, pH, time, and temperature on safranin removal efficiency was also monitored. The study indicated that safranin removal efficacy of jute increased from 166 mg/g to 250 mg/g after the modification. The removal efficiency of the treated jute was less affected by pH changes between 2 and 8. This treated lignocellulosic biomatter-based process was also found to be comparable or better than their available alternatives.

Keywords Lignocellulose · Safranin · Neem oil-phenolic resin
Dye · Adsorption

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1 Introduction

More than 7105 tons of 10,000 different types of dyes and pigments are known to be produced worldwide [1]. Dyeing process releases 1–15% of the initial dyes in the effluents and eventually contaminates the surface and groundwater resources. The effluent discharged from the textile industry not only contains dye but also contains high concentrations of salts and exhibits high biological oxygen demand/chemical oxygen demand values. Thus, the dye containing discharge of the dyeing industries should be treated efficiently before release it to the environment.

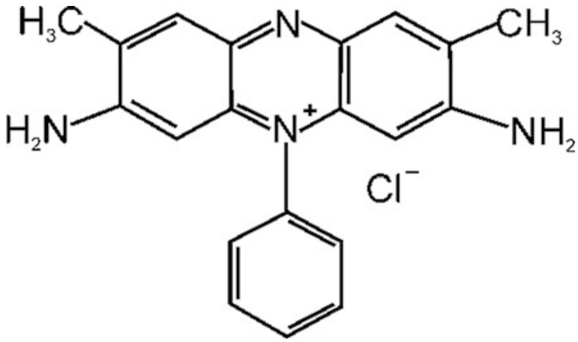
Natural fiber (jute, cotton, sisal, coir, and ramie)-based textile industries produced huge amount of solid waste mainly comprised of lignocellulosic matters. These types of waste are either dump in a landfill or used as a combusting materials for heat generation. However, these waste materials could be an exceptional adsorbent for wastewater treatment as they are inexpensive, biodegradable, eco-friendly, and highly stable to most organic solvents. In addition, these types of lignocellulosic waste have high density of hydroxyl groups which easily can be modified with other functional groups, e.g., carboxyl, sulfo, and cyclodextrin groups for removal of specific pollutants. The study reported here in this paper used lignocellulosic solid waste from the jute industry and modified it with alkali-steam and plant-based reagents. Then the treated solid waste has been investigated for dye removal from water. Safranin has been used as model dye for this study.

2 Experimetals

2.1 Biomass Treatment

Lignocellulosic waste of local jute mills nearby Kolkata, India, was collected for this study. The waste was then thoroughly washed with distilled water to remove the dust and other water-soluble impurities followed by drying at 85 ± 2 °C. The dried materials were then chopped mechanically with a mixer grinder and termed UWL hereafter. The UWL were then treated with alkali-steam treatment by immersing them within 0.5% (w/v) NaOH (Merck) solution for 30 min at 30 ± 2 °C followed by steaming under 103 kPa for 30 min at 121 °C. These alkali-steam-treated lignocellulosic (AWL) materials were thoroughly washed with distilled water to bring down its pH to 7. The AWL was then chemically altered with an emulsion prepared by mixing sodium hydroxide, cashew nut shell liquid, resorcinol, neem (*Azadirachta indica*) oil, and formaldehyde in 0.5:1:2:5:2 proportion by weight. For details of the emulsion preparation and chemical modification are elaborated in elsewhere [2]. The matters were then washed thoroughly with ethanol followed by distilled water and dried at 70 ± 2 °C for 24 h and termed NWL hereafter.

Fig. 1 Structure of safranin



2.2 Estimation of Safranin in Water

Concentration of safranin (CAS no 477-73-6) (Fig. 1) presents in water was estimated by measuring the optical density of aqueous solution at 516 nm in a UV–visible spectrophotometer (PerkinElmer Lambda 950) and comparing the optical density with safranin standard curve following [3].

2.3 Removal of Safranin in Batch Process

A series of batch experiments were done for understanding the influence of biomass amount, pH, and time on safranin removal efficiency. For this aqueous solution of safranin was prepared by mixing 50 mg of safranin in 1 L of distilled water. The pH adjustment of this solution, within the range between 2 and 8, was done by adding appropriate amounts of 0.1 N of HCl and 0.1 N NaOH solutions. For batch study, the powdered lignocellulosic matter was shaken with 50 ml of safranin solutions within Orbitek LE shaker incubator operated at 120 rpm until equilibrium was achieved. Water sample was tested periodically for testing residual safranin and equilibrium time. The removal efficiency, *RE* (%), was calculated using

$$\mathrm{RE}(\%) = (C_i - C_t)/C_i \times 100 \quad (1)$$

where C_i and C_t are the safranin concentrations at the beginning of an experiment and that at time t, respectively.

3 Results and Discussions

3.1 Parametric Influence in Safranin Removal Efficiency

3.1.1 Biomass Amount

Safranin removal efficiency was found to increase with UWL and NWL (Fig. 2a). From the figure, it is evident that initially the efficiency was sharp possibly due to presence of higher dye capturing sites with increased amount of bioadsorbent. The subsequent modest increase indicated relative lack of availability of safranin vis-à-vis bioadsorbent amount. Apparently, Fig. 2a also showed NWL matters are more efficient in safranin removal then their untreated counterparts. This was possibly due to grafting of lignocellulosic matter with neem oil-phenolic resin which enhances the amount of active sites on bioadsorbent for safranin capture. Similar effects of sorbent dose on safranin removal were reported for activated corncob carbon [3] and pineapple peels [4].

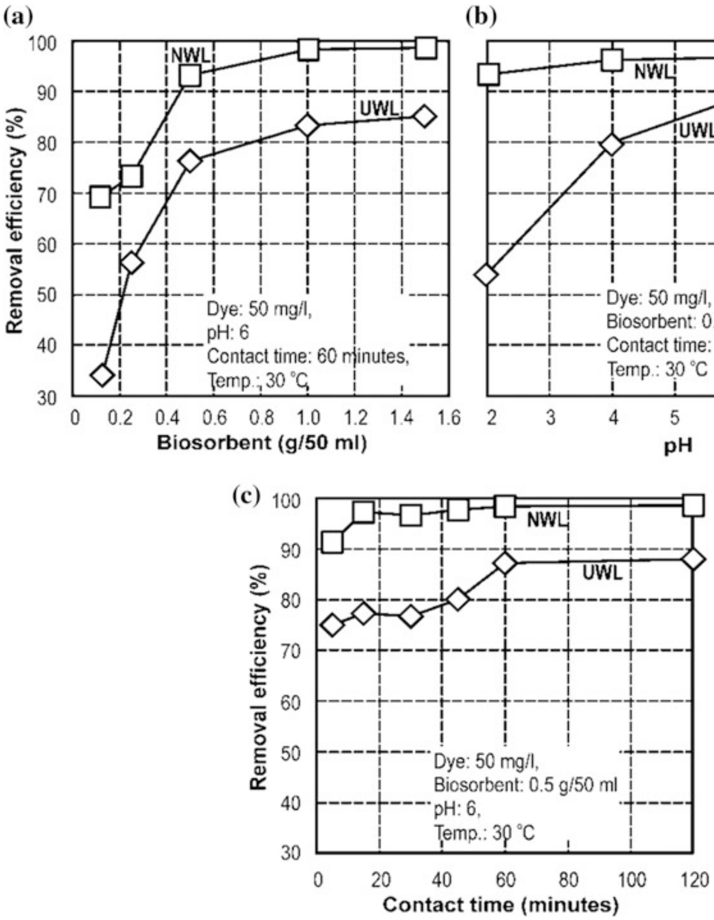


Fig. 2 Influence of **a** biosorbent amount, **b** pH, and **c** contact time on safranin sorption by untreated (UWL) and treated (NWL) lignocellulosic matter

3.1.2 pH

With increasing, pH safranin removal efficiency of UWL and NWL was found to increase (Fig. 2b). Figure indicated that safranin removal for both the bioadsorbents was smaller at acidic pH. These observations possibly indicate that protonation of hydroxyl and carbonyl groups plays a major role on safranin removal by both the bioadsorbents. The surface groups of the biosorbents might be protonated with the H^+ and repel positively charged safranin and adversely affect the removal efficiency. However, from the figure it is also evident that even in acidic pH the treated biosorbents showed considerable amount of safranin removal efficiency. This pointed that not only electrostatic interaction but also other mechanisms such as hydrogen bonding, Van der Waals force, and chemical bonding might have significant contributions in safranin capture. Similar influence of pH on safranin removal was also observed by Preethi et al. [3] and Mohammed et al. [4] during safranin removal from water.

3.1.3 Contact Time

Removal efficiency of UWL found to increase sharply over the initial 60 min of contact (Fig. 1c). Afterward, the increase in removal efficiency was steady possibly due to saturation of available active sites on the biosorbent surface. Instead, the safranin removal efficiency of NWL noticed to be increased more rapidly than their untreated counterparts. More than 90% of the initial safranin was captured by NWL within less than 10 min of contact. This was due to modification of the biosorbent surface with neem oil-phenolic resin.

3.2 Sorption Particulars

3.2.1 Isotherms

The biomass–dye interaction was understood by fitting the batch study data to the following forms of Langmuir (Eq. 2) Freundlich (Eq. 3) isotherm,

$$1/q_e = 1/(k_a \times q_m \times C_e) + 1/q_m \quad (2)$$

$$\log q_e = \log k_f + (\log C_e)/n \quad (3)$$

where q_e is the amount of solute sorbed at steady state, k_a is a constant that measures the net enthalpy, q_m is the estimated amount of solute that saturates a unit dry mass of sorbent, and C_e is the residual concentration of the solute at steady state. The k_f and n are related to sorption capacity and sorption intensity, respectively. The goodness of fit (measured by the correlation coefficients, r^2) for the

Table 1 Isotherm, kinetic, and thermodynamic parameters

Sorption particulars	Parameters	UL	NL
Langmuir isotherm	k_a (L mg^{-1})	0.171	0.222
	q_m (mg g^{-1})	166	250
	r^2	0.95	0.98
Freundlich isotherm	k_f (mg g^{-1})	10.72	42.1
	n	1.362	1.733
	r^2	0.60	0.94
Pseudo-first-order kinetic	k_1 (min^{-1})	0.1	0.057
	q_e (mg g^{-1})	6.8	5.31
	$q_{e,Cal}$	41.64	48.83
	r^2	0.79	0.98
Pseudo-second-order kinetic	k_2 (g mg^{-1} min^{-1})	0.007	0.05
	q_e (mg g^{-1})	45.46	50.0
	r^2	0.99	1.00

Langmuir equation was higher than the Freundlich isotherm which indicated that the data were fitted well with Langmuir isotherm (Table 1).

Therefore, surface process appears to play a significant role in safranin removal by UWL and NWL. Estimated q_m for NWL was found to be higher than that for the untreated biosorbent (Table 1). These data also pointing to the fact that modification of lignocellulosic biomatters with alklai-steam and neam oil phenolic resin had positive impact on the removal efficacy. This is possible due to presense of more active sites on the surface of the modified biomatters than thier untreated counterparts.

3.2.2 Sorption Rate

The rate for safranin adsorption was determined by fitting the batch study data to pseudo-first-order (Eq. 4) and pseudo-second-order (Eq. 5) rate kinetics, respectively:

$$\text{In}(q_e - q_t) = \text{In } q_\text{e} - k_1 t \tag{4}$$

$$t/q_t = 1/\left(k_2 q_e^2\right) + t/q_e \tag{5}$$

where q_t is the amount of dye captured at time, t, and k_1 and k_2(minute-1) are pseudo-first- and pseudo-second-order rate constants, respectively. From Table 1, it has been noticed that the estimated removal efficacy (q_e) (45.46 mg/g for UWL and 50 mg/g for NWL) of the biomatters estimated from Eq. 5 were closely matched with the experimental values (41.64 mg/g for UWL and 48.83 mg/g for NWL). These observations indicated that safranin removal by UWL and NWL biomatters were appeared to follow pseudo-second-order kinetics. The goodness of fit

Table 2 Comparative assessment of safranin adsorption processes

Biosorbent	qm (mg g^{-1})	References
Alkali-treated rice husk	9.77	Chowdhury et al. [5]
Alkali-treated mango seed	31	Malekbala et al. [6]
Corncob activated carbon	1428.57	Preethi et al. [3]
NaOH-teated rice husk	37.97	Chowdhury et al. [7]
Pretreated rice husk	45.58	Chowdhury and Das [8]
Pineapple peels	21.7	Mohammed et al. [4]
Kaolinite clay	16.23	Adebowale et al. [9]
Fly ash	1.76	Dwivedi et al. [10]
Natural palygorskite clay	200	Taha et al. [11]
Treated mango seed	43.47	Mohammed et al. [4]
Coffee spent grounds	3.76	Lakshmi et al. [12]
Untreated (UL)	166	This study
Neem oil-phenolic resin treated (NL)	250	This study

(measured by the correlation coefficients, r2) was also higher for the pseudo-second-order kinetic equation than the pseudo-first-order kinetic equation indicating that data were fitted well with pseudo-second-order kinetics.

4 Comparison with Available Biosorbents

Safranin removal efficacy of NWL was found to be comparable or better than those reported by others (Table 2). The process developed during this study appears to be advantageous as it works over a relatively wider range of pH and could capture safranin within few minutes compared to the available alternatives.

5 Conclusions

Lignocellulosic waste materials were processed through alkali-steam and neem oil-phenolic resin to enhance their dye removal efficiency. The results obtained from this study indicated that the removal efficacy of the lignocellulosic waste increased from 166 to 250 mg/g upon treated with alkali-steam and neem oil-phenolic resin. The treated materials were also can capture safranin over a wide range of pH. Efficacy of the treated biomatters was found to be higher and/or comparable with the available alternatives.

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Part XXI
Nano Technology

Application of Carbon Nanotubes in Fluidic Waste treatment and Energy Harvesting

Abhirup Basu and Biswajit Debnath

Abstract In the recent world, carbon nanotubes (CNT) have attracted the attention of researchers because of their unique physical and chemical properties, small dimensions and strength. After the discovery of carbon nanotubes by Iijima in the year 1991, they have found extensive use in different fields. CNTs are widely used in electronics such as field emission display, nano-electronic devices, sensors and in electrochemical devices such as electrodes for electrochemical double-layer capacitors, rechargeable batteries. Other important applications of carbon nanotubes are in fluidic waste treatment and energy harvesting. Wastewater treatment such as removal of dyes and heavy metals, flue gas treatment like carbon dioxide capture or adsorption of other toxic gases are few wide areas of uses of CNTs. CNTs are also widely applied in energy storage and as energy conversion devices. Though their applications are wide and promising, a few questions still remain. Considering the global concerns, such as climate change, water and energy nexus, whether these CNTs will be sustainable? How the CNTs will be able to meet the requirements of the COP21 treaty? In this paper, a review on the applications of CNT in fluidic waste treatment and energy harvesting has been presented discussing the sustainability of the CNTs in the light of global issues. The findings will help the stakeholders, policy makers and will set the future direction of research.

Keywords Carbon nanotubes · Applications · Fluidic waste treatment
Carbon dioxide capture · Energy storage · Sustainability

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1 Introduction

Carbon has a large variety of allotropes, both natural and artificial like graphite, fullerene, diamond, nanotubes etc. Among these allotropes, carbon nanotubes have emerged as one of the important discoveries in the field of nanotechnology. The most striking feature of the CNTs is their high aspect ratio, i.e. length-to-diameter ratio of about 132,000,000:1 [1, 2]. Carbon nanotubes are sp^2 hybridized and held together by means of van der Walls forces [3]. The in-plane graphitic C–C bonds make them exceptionally strong and stiff against axial strains. They have a low weight and high elastic modulus and therefore considered as the strongest fibres [4] and are widely used in the polymer industry. They also have excellent electrical properties.

CNTs are basically characterized by a pair of indices (m, n) called chirality, which is used to specify the way the carbon nanotubes are wrapped as shown in Fig. 1a. The chiral vector is represented as

$$C_h = m * a_1 + n * a_2$$

where a_1 and a_2 are the unit vectors along two directions in the crystal lattice. If $m = 0$, then it is armchair; if $m = n$, then it is zigzag, else it is chiral (Fig. 1 b) [5].

The process of synthesis of carbon nanotubes involves bringing a carbonaceous feedstock in the vapour phase which leads to the formation of a tube-like structure from the evaporated species [6]. The oldest method of synthesis was arc discharge method developed by Iijima in 1991 where two thin electrodes were placed vertically at the centre of the chamber which acted as the source of carbon for the CNTs [7, 8]. The arc was generated by passing a DC current of 200 A and 25 V between the electrodes, as a result of which some carbon materials were evaporated from the anode. These were transported through the plasma state which got deposited on the negative electrode. But this process had many-fold disadvantages.

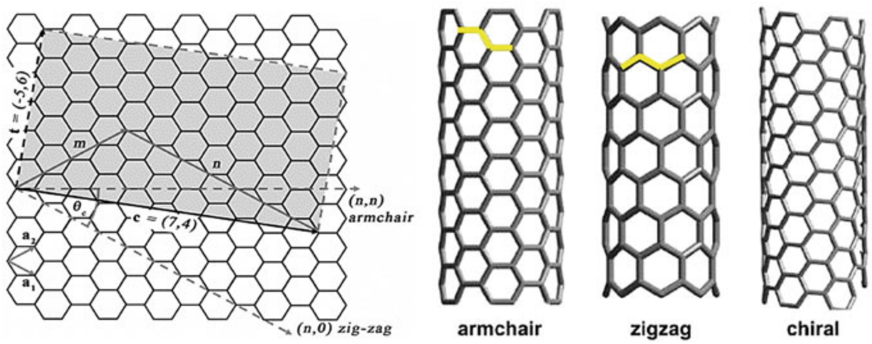

Fig. 1 **a** Hexagonal lattice of graphene sheet including base vectors and **b** Armchair CNTs, zigzag CNTs, chiral CNTs

Lee et al. [9] felt that this process was a discontinuous and an unstable process. Since the spacing between the electrodes was not constant, it might lead to non-uniformity in current flow, as a result of which there was a change in density and chirality within the nanotubes and hence could not be used in nano-electronic devices. Chemical vapour decomposition (CVD) is presently used for large-scale synthesis of CNTs to meet the high demand of CNTs. This process involves the growth of carbon nanotubes on a heated metal substrate in the presence of a catalyst. This process has become widespread because of its low cost, high purity and controlled growth [10]. There are various other techniques of producing CNTs like laser ablation [11, 12], shape-controlled MWNTs via electro-deposition [13] spring-like multi-walled CNTs (MWCNTs) via mechanothermal method [4], producing CNTs via CoMoCAT process [14], solar synthesis of single-walled CNTs (SWCNTs) [15] etc.

In this paper, we have broadly focussed on the application of carbon nanotubes. One of the important uses of carbon nanotubes is in wastewater treatment. Demand of freshwater is increasing day by day. The main pollutants that pollute water are coming from chemical and biological sources, i.e. from anthropogenic activities, heavy metals in the effluent streams from industries, microcystins and antibiotics [16], etc. Besides, there are some synthetic dyes which contain stable aromatic structures and are carcinogenic in nature. Some of these pollutants cannot be removed by traditional water treatment methods like membrane separation, flocculation, coagulation. In recent years, with the progress in the field of nanotechnology, carbon nanotubes are being used for purification of water. The high aspect ratio and hydrophobic nature of the tubes help in efficient transport of water through the tubes [17]. They can be used as an effective absorbent, and therefore, they are able to remove biological and chemical contaminants like Cr^{3+}, Zn^{2+}, Pb^{2+} and arsenic compounds. In recent times, application of multi-wall CNTs in mixed matrix membranes for gas separation has also been explored by the researchers [18]. Carbon nanotubes are also used in energy harvesting, which has also been highlighted in this review. Hydrogen has attracted much attention as a promising energy resource and is expected to be applied to fuel cell systems. Hydrogen storage in carbon nanotubes has been vigorously explored in the past decade. CNT is also used for physical adsorption of carbon dioxide and other gases [19, 20]. Energy harvesting using CNT is an emerging field where CNT is used to manufacture thermoelectric devices, and it is a very promising zone [21].

2 Carbon Nanotubes in Waste Water Treatment

Adsorption is an efficient process of removing organic and inorganic pollutants from wastewater. Treatment of water using adsorption by CNTs was reported much later, after its discovery in 1997 [22]. The morphology of CNTs, nanoscale curvature and chirality of the graphene layers play an important role in the adsorption process. There are four main spaces of CNTs which act as the adsorption sites [23]

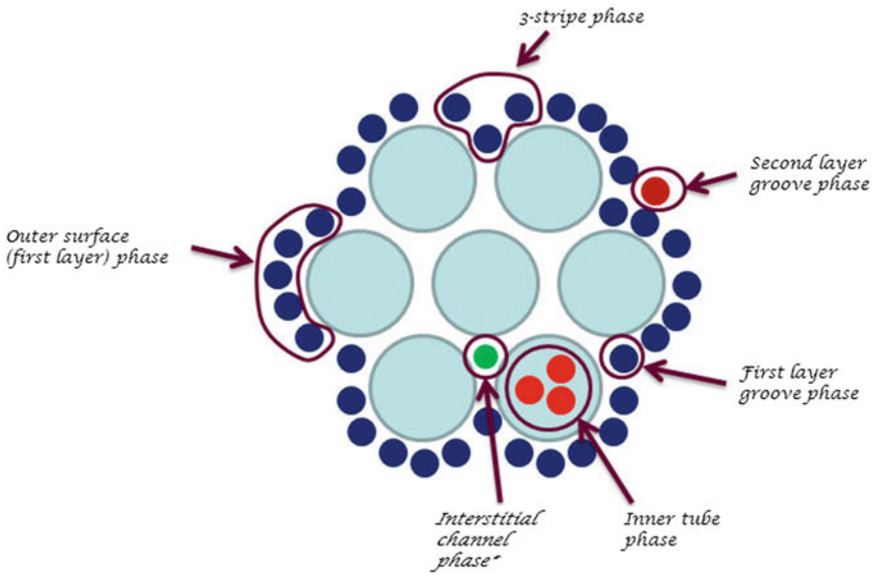

Fig. 2 Sites of CNTs available for adsorption

as shown in the Fig. 2. The internal sites found in the hollow tubular structure of CNTs are available for adsorption when the tubes are open [24–26]. But adsorption is very limited in these sites because of the small diameter of CNTs. Interstitial channels are the gaps present between the nanotubes, which are produced because of entanglement of hundreds of nanotubes to each other. These pores have the dimensions of mesopores and have enough surface area so as to entrap even bacteria and viruses. External grooves are present on the outer surface of the CNTs when two parallel tubes meet. The exposed surface site is the outside curved surface of the CNTs and is easily accessible. The last two sites provide the maximum area for adsorption because they are accessible easily. This large surface area and π–π electrostatic interaction provide extensive adsorption. However, CNTs are poorly dispersed in solvents because of the strong intermolecular van der Waals interaction between tubes leading to the formation of aggregates [27].

There are different types of synthetic dyes whose complex aromatic nature makes them very stable and difficult to biodegrade. Removal of these dyes is very important because it can cause direct destruction of aquatic organisms. Adsorption of dyes from aqueous solution using CNTs is investigated by the scholars in recent years. An idea of the current research on the application of different hybrid CNTs used for removal of different dyes is shown in Table 1.

Removal of toxic metals like chromium, cadmium, lead, zinc, arsenic from water is another important use of carbon nanotubes. There are different techniques involved in the adsorption of metals from water. A few of them are discussed in this paper. Hamza et al. [34] studied the adsorption of aqueous Pb^{2+} using sugarcane

Table 1 Role of different types of CNTs in removal of dyes

Hybrid CNTs	Dye	Comments	Reference
CNT/TiO_2	Azo dye	Enhancement of adsorption of dye; Inhibition of charge recombination	Yu et al. [28]
CNT/TiO_2 nanowire film and CNT/P25 film	Methyl orange	CNT/TiO2 nanowire film more suitable for photocatalytic filtration application owing to its less pore blockage	Daranyi et al. [29]
SWCNT/TiO_2	Congo red	The addition of silica promoted the coating of TiO2 on CNT. Imitate contact between CNT and TiO2 needed to achieve enhanced photocatalytic activity	Jafry et al. [30]
CNT/ZnS	Methylene blue	Post-refluxing treatment played a key role in the improvement of the interaction between ZnS nanocrystals and CNTs	Feng et al. [31]
CNT/CdS	Azo dye	CNTs hampered the photocorrosion of CdS	Ma et al. [32]
MWCNT	Direct blue 53 dye	Electrostatic force of attraction between the charged dye and MWCNTs separates the dye from aqueous solution	Prola et al. [33]
MWCNT/TiO_2	2,6-Dinitro-p-cresol	No obvious decline in efficiency of the composite photocatalysts was observed after five repeated cycles	Wang et al. [1, 2]

bagasse and multi-walled CNT composites. The composite adsorbed 56.6 mg of Pb^{2+} per gram of composite at 28 °C while the bagasse adsorbed only 23.8 mg g^{-1}. Thus, this composite can be used as a good adsorbent for removal of Pb^{2+} from wastewater and control environmental pollution. Luo et al. [35, 36] used manganese dioxide/iron oxide/acid oxidized MWCNTs for enhanced removal of chromium from water. The introduction of the functional groups in MWCNTSs increased the adsorption capacity. The introduction of metal oxides like iron oxide dispersed on the surface of CNTs could also be used for magnetic removal of many compounds. The maximum adsorptive capacity was found to be 186.9 mg g^{-1}. Luo et al. [35, 36] again studied adsorptive capacity and behaviour of manganese modified MWNT for the removal of cadmium. Thallium which is a very toxic element is also being adsorbed by MWNTs as shown by Rehman et al. [23]. Kuo [37] investigated equilibrium and thermodynamics of adsorption of Cu^{2+} using CNTs whose surface is modified by H_2SO_4 and $H_2SO_4/KMnO_4$.

Although CNTs can be used for purification, CNTs removal from aqueous solution is quite difficult because of its nanosize and aggregation property [38]. So nowadays composites with CNTs like CNT-chitosan, CNT-ACF, CNT-cellulose, phosphorylated multi-walled carbon nanotube-cyclodextrin polymer [39], b-cyclodextrin/N-doped carbon nanotube polyurethane nanocomposites [40] are used which have increased surface area and are better adsorbents.

3 Carbon Nanotubes in Gas Purification

Gas purification is a very interesting area where CNTs find their application having impact on both waste management and energy sector. CNTs can be used to treat flue gases, carbon dioxide capture, gas separation (embedded in mixed matrix membranes), etc. CNTs embedded in a mixed matrix membrane used for gas separation is an emerging field of research. Incorporation of the CNTs into the polymer matrix of membranes has certain advantages over the conventional ones. However, there are many engineering challenges incorporated with the preparation of CNT-embedded membranes. CNTs having length below 100 nm is quite difficult to produce, which is basically the first thing to be taken care of [41]. Dispersing the CNTs in proper alignment inside the membrane matrix is a very big challenge [42]. According to Baker and Lokhandwala [43] "*The ideal membrane structure can be obtained by filling the spaces between the CNTs with a continuous polymer film and etching open the closed end of the nanotubes*". Despite the challenges, there are some molecular transport properties whose proper tuning and control can be done in order to get best possible output. There are many studies regarding gas separation using CNT-embedded membranes. Nour et al. [18] evaluated the gas separating properties of a polydimethylsiloxane (PDMS) composite membrane featured with different amounts of MWCNTs. Mixtures of hydrogen and methane gas was used to carry the study. Ismail et al. [44] have presented a comprehensive review on the carbon nanotube mixed matrix membranes in detail which unveils insights to the subject.

Another important area is carbon dioxide capture from flue gas stream. CNTs are preferred for carbon capture due to their promising physical and chemical properties, high thermal and electrical conductivity, along with the possibility to modify their surfaces chemically by adding a chemical function group, yielding high adsorption storage capacity [19]. A comprehensive idea about the current trend of research on carbon capture using CNT is presented in Table 2.

4 Carbon Nanotubes for Energy Harvesting

Carbon nanotubes find its application in the energy harvesting sector too. This sector is developing widely because of the high energy demand and international policies such as COP21. Hydrogen is a clean fuel, and researchers are struggling a lot to find efficient ways to produce hydrogen from different virgin and waste sources. However, the real difficulty lies in the suitable storage of hydrogen for

Table 2 Carbon capture using CNT

Type of CNT	Gas mixture	Process	Uptake		References
Layered double hydroxides/oxidized carbon nanotube Nanocomposites (LDH/OCNT)	Pure CO_2	Adsorption at 473 K	LDH-NS-NO3/OCNT	0.43 mmol/g	Wang et al. [45]
			LDH-NO3/OCNT	0.43 mmol/g	
			LDH-CO3/OCNT	0.43 mmol/g	
MWCNT/PEI	15% CO_2 and 85% N_2	Chemisorption	94 mg/g at 298 K		Lee et al. [46]
Amine-loaded CNT	15% CO_2 and 85% N_2	A dual-column temperature/vacuum swing adsorption (TVSA)	67% at 298 K		Su et al. [47]
CNTs modified by 3-aminopropyl-triethoxysilane (APTS)	15% CO_2	29% physisorption and 79% chemisorption at 293 K	55.1 mg/g at 293 K		Su et al. [48]
	50% CO_2		114 mg/g at 293 K		

Table 3 Different types of CNT and their storage capacity

Type of CNT	Purity	H_2 storage (wt%)	References
CNT	–	11.26	Chambers et al. [52]
K-CNT	Purified	14	Chen et al. [53]
Li-CNT	Purified	2.5	Yang [54]
Li-CNT	Purified	0.7–4.2	Pinkerton et al. [55]
K-CNT	Purified	1.8	Yang [54]
CNT	–	0.5	Adu et al. [56]
V-CNT	Purified	0.66	Zacharia et al. [57]
Pd-CNT	Purified	0.69	Zacharia et al. [57]
Ni-MWCNT	–	2.8	Kim et al. [58]
CNT@MOF-5 hybrid composite	–	0.61	Yang et al. [59]
Pd-CNT (polyol method)	Purified	0.7	Banerjee et al. [60]
Pd-CNT (wet impregnation route)	Purified	0.4	Banerjee et al. [60]
Hexagonal boron nitride MWCNT	Acid treated	2.3	Muthu et al. [61]

future use. CNT is one of the materials that have been explored for storage of hydrogen. A huge number of works have been reported in the last 15 years on this topic. Lee and Lee [49] reported that SWCNTs can be used for hydrogen storage based on density function calculations and the preferred sites are to be interior and exterior of the CNT walls. They predicted that the space inside the CNT is useful and the molecules of hydrogen can exist in them. The maximum storage capacity of hydrogen linearly increases with the diameter of the CNT. It was predicted that the storage capacity of hydrogen can exceed 160 kg/m^3 in an armchair configuration of SWCNT. The storage mechanism hydrogen in a SWCNT was explored and reported [50]. Züttel et al. [51] presented a study on hydrogen storage in different nanostructures. They presented a model that assumes the monolayer condensation of hydrogen at the CNT surface as well as condensation in bulk in the tube cavity. The model predicted that 3.3 mass% was absorbed at the surface considering monolayer absorption. Different types of pure and modified CNT have been employed by the researchers for studying hydrogen storage. A summary is presented in Table 3.

5 Discussions and Analysis

Purification of water is a serious topic to be dealt with, since the scarcity of water will be a major problem that will affect the entire world by 2025. Water is generally purified by desalination, but they are costly monetarily and energy expensive. Even the most efficient process till date such as reverse osmosis requires a great deal of energy input daily, which generally comes from non-renewable sources like fossil fuels and nuclear energy. Also, these processes are not environmentally friendly because they can change the salt concentration thus affecting the life of marine organisms. While the global freshwater availability is choking up, the demand for cheaper, more efficient and eco-friendly desalination technology exists and CNTs could be a viable option for further intervention. CNTs require less energy than reverse osmosis for production of same amount of fresh due to their desalination capacity and frictionless water interactions. There are a few difficulties that must be overcome before real CNT desalination plants can be set up though. A method for large-scale synthesis of CNTs is needed that ensures consistent shape, size and function. Besides, the methods of the increase in adsorption of metals should also be looked further.

CNTs are also useful for energy harvesting and gas purification. Flue gas cleaning, acid gas removal, methane enrichment, etc., are achievable using CNT-embedded mixed matrix membrane (CNT-MMM). These CNT-MMM are advantageous over conventional ones. However, there are certain engineering challenges which need to be dealt with—maintaining certain diameter, adsorption capacity of CNTs, correct alignment of CNTs, proper dispersion into the membrane matrix, etc. Incorporation of CNTs certainly influences the efficiency of removal of pollutants as well as it becomes much more resilient technology to combat climate change issues. Hybridization with the conventional techniques could be another solution where this technology will play a key role. Storage of hydrogen is a very big problem which is offering resistance towards commercialization of use of hydrogen as a mainstream clean fuel. The capability of CNT to store hydrogen is a groundbreaking discovery. However, the efficiency, desorption method, amount of storage, scale up, etc., are the issues that need to be addressed before commercialization. CNTs can be prepared from waste oil and plastic waste which is environmentally friendly as well as socially acceptable. However, the economical viability is still questionable. From the preparation of CNT to applications discussed here reveals its feasibility as a technology and strong contendership to be sustainable. Further research on this will pave a path towards an open challenge to resist climate change and subsequently a clean and sustainable future.

6 Conclusion

In this paper, a review on the applications of carbon nanotubes has been presented focusing on water treatment, flue gas treatment and energy harvesting. The present situation reveals that application of CNTs in the field of water purification, gas separation and energy harvesting has got enough potential. However, a number of engineering challenges are associated with them and addressing them will certainly pave the commercial implementation of these technologies. The discussed applications are both environmentally and socially sustainable, though economic feasibility is still a bit fuzzy. These processes are potent enough to face the challenges to resist the strict guidelines of withstanding climate change so as to comply with treaties like COP21. More investigations will help these technologies to be mature and sustainable enough which will lead to a greener future ensuring circular economy.

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