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Ajay S. Kalamdhad *Editor*

Recent Developments in Waste Management

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Preface

Increasing the world population has put enormous pressure on the planet when it comes to the amount of wastes generated. Such is the case that in a few more years, with this alarmingly increasing rate of waste production, the earth would reach its assimilative capacity. This calls for efficient measures of waste treatment and disposal. Financially developing countries of the world have limited access to vital resources such as funding and human resources for overcoming the problems of waste management. Therefore, it becomes highly essential to develop new strategies and economically viable technologies for the effective management of wastes. This book presents various new concepts and strategies of waste management, coupled with treatment technologies and recycling of waste products. This book also focuses on the treatment of wastewaters and groundwater and the application of GIS techniques for waste management. A special focus has also been made to the recycling of waste products and converting them to useful products or services. Various treatment technologies such as composting, anaerobic digestion and conversion of waste to energy like the use of microbial fuel cells have been inducted in this book. This book is intended to be of substantial help to the students, researchers, industrialists and academicians working in the field of environmental engineering and sciences. This can also be of use to many universities/institutes worldwide which have developed new prospectuses and offer specialized courses on environmental and sustainable development. Finally, this book will also be of use to all the policy makers and government or private organizations for proper design and operation of solid waste management programs.

Guwahati, India Ajay S. Kalamdhad

Aim and Scope of the Proposed Book

In the developing countries, pollution through solid waste, sludge from water and wastewater treatment plants and pollution of natural water resources have become one of the grave issues, the root cause being population explosion, industrialization, urbanization and other anthropogenic activities. The increase rate of solid waste has become a major challenge for the sustainable development of the environment. Poor management of solid waste and sludge from water and wastewater treatment plants may be the cause of health hazards and environmental problems. This book presents new methods and technologies to combat the aforementioned problems and focuses on welfares of using the recycled products. The technologies related to waste and sludge treatment are economical and eco-friendly, bring economic returns and can be applied to most of the developing countries. As such, waste treatment technologies, viz. composting, anaerobic digestion, recycling of plastic and agricultural waste, in construction can be used. The aim of this book is to support everyone who is involved in academics, teaching, research related to solid waste management and water and wastewater treatment study in the leading academic and research organizations globally. This book will be of prodigious value to upcoming researchers, scholars, scientists and professionals in environmental science and engineering fields, and global and local authorities and policy makers responsible for the management of solid wastes and sludge. Globally, universities can develop new prospectuses on the sustainable and eco-friendly waste and sludge management, which are relating to this book's theme. This book can also be of a great source for designing and operation of waste reuse and recycling programs.

Contents

About the Editor

Dr. Ajay S. Kalamdhad is currently working as an Associate Professor in Department of Civil Engineering, Indian Institute of Technology (IIT) Guwahati. He obtained his Bachelors, Masters and PhD in Civil and Environmental Engineering from GEC Jabalpur, VNIT Nagpur and IIT Roorkee respectively. Prior to joining IIT Guwahati in 2009, He was an Assistant Professor at VNIT Nagpur and worked in various projects at RRL, Bhopal (Now AMPRI, Bhopal) and NEERI, Nagpur. In addition to his book on rotary drum composting, Dr Kalamdhad has published more than 100 research papers in acclaimed journals and has presented his work in more than 150 national and international conferences/workshops. He is associated with Indian Public Health Engineers, India, International Solid Waste Association Italy and National Solid Waste Association of India; and serves as a reviewer for 20 international journals. He is a recipient of ISTE- GSITS national award for best research by young teachers) of engineering colleges for the year 2012 and IEI Young Engineers Award 2011-2012 in Environmental Engineering discipline from Institute of Engineers India.

Effective Utilisation of Kitchen Waste to Biogas by Anaerobic Co-digestion

Amar Kumar Das and Achyut Kumar Panda

Abstract The main objective of the experiment is to produce biogas from kitchen waste by co-digestion with cow dung by an anaerobic fermentation process. An anaerobic floating-type digester was used for this purpose in mesospheric condition by maintaining a temperature of 32–38 °C and pH of 6.9–7.2 inside the reactor for optimum biogas production. Three types of feedstock consisting of mixture of food waste, cow dung, left out slurry of the reactor along with water in different proportions are used for biogas generation. Slurry prepared by mixing kitchen waste with water in 1:1 ratio is used as feed. The gas production is recorded for a span of 22 days. A significant yield of biogas having high methane content of about 68% was obtained. This process which involves conversion of organic food waste to biogas not only is source of energy but also caters the management of environmental pollution.

Keywords Kitchen waste · Anaerobic fermentation · pH value · Floating digester · Mesospheric

1 Introduction

In the era of energy crisis, renewable and green energy sources are highly awaited for the next few years for its sustainability and stability to meet the future challenges. Biogas is one such source of renewable and eco-friendly energy and the process of producing it by the anaerobic fermentation of organic matter is a

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technology gaining popularity and is more widely adopted for use. The major component of biogas being methane (CH_4) and carbon dioxide (CO_2), with traces of other gases like nitrogen (N_2), hydrogen (H_2) and hydrogen sulphide (H_2S) gases and impurities [1]. The gas is highly combustible and burns with blue flame. The calorific value of biogas depends on methane percentage that usually varies from 25.9 to 30 J/m^3. The compositions of biogas again are specific to the plant design and feed type. Many factors such as feed type, temperature, hydrogen ion concentration, slurry concentration, carbon to nitrogen ratio, retention time, total volatile acids, chemical oxygen demand (COD) determines the rate of production of biogas. Even though a biogas may be a clean fuel, an upgraded biogas proves to be better than the untreated one. Continuous innovation explains that biogas production has increased by an average of almost 10% every year on a global basis since 1982 [2].

The most common raw material being used for the production of biogas is cow dung. However, biodegradable waste materials that are readily and locally available may be used, in addition, to cow dung would be extremely beneficial and lower the production cost. It includes kitchen waste in the form of vegetable peel offs, decayed food, used tea leaf/ powder, excreta from poultry farm and fish farm, waste dairy products, wastes from mushroom culture, etc. In addition, India being a agriculture-based country, cultivating different types of crops and vegetables, thus generating huge amounts of such wastes due to improper transportation and preservation facilities, may also be a source of biogas. Although composting of all such biodegradable wastes would provide a organic fertiliser or compost; however, energy resource that is locked up in waste could not be captured in this process and rather lost as a greenhouse gas causing air pollution. So, the production of biogas from these all these wastes by anaerobic digestion will be most profitable and environmental friendly that not only produce energy source but also an organic fertiliser. As the efficiency of this process depends on the amount and specific type of the material added to the system, nowadays, the anaerobic digestion process has been carried out in different ways such as single-phase digestion, two-phase digestion, dry fermentation and co-digestion [3].

Co-digestion of different putrescible wastes with the main substrate are reported to improve the biogas yields due to positive synergism established in the digestion media and the provide missing nutrients to microorganisms [4]. Again, the co-digestion process could be operated at lower mesophilic temperature against thermophilic condition to reduce the heating cost without affecting much the efficiency of the process.

This work presents the experimental results of co-digestion of kitchen wastes with cow dung to biogas by anaerobic process using a batch floating drum biodigester with an objective to optimise the process condition for the production of better quality and quantity of biogas.

2 Experimental Investigation

2.1 Materials

Kitchen refuses which include vegetables, fruits and other items of the college hostel mess were used as raw materials in the experiment. The digester was fed with cow dung initially as a starter material to facilitate the microorganism fermentation in absence of oxygen. Slurry free from indispensable chops and fragile items obtained by grinding food waste with water of ratio 1:1 is used afterwards in the digester as a feed for biogas production. Cow dung used in the present study was collected from the nearby localities of a college campus (Fig. 1).

2.2 Anaerobic Digester

In this work, a floating drum digester (Fig. 2) of specification summarised in Table 1 is used in the experiment. It is quite leak proof, easy to handle and less skill is required for operating the process.

Fig. 1 Sample preparation of slurry from kitchen wastes

Fig. 2 Biogas plant set up for experiment

Table 1 Specification of biogas plant

Sl No	Make	Type/Size
1	Floating-type biogas plant	1 m^3
2	Materials of constructions	HDPE/LDPE
3	Biogas digester	3 feet 7 in.
4	Biogas dome	3 feet 4 in.
5	Inlet connection	110 mm HDPE flanged connection
6	Gas outlet connection	1/2″ PVC pipe with check nut and gasket length as to reach the gas bank (approx. 10 m)

2.3 Methods

Experiments are conducted with the floating drum-type bioreactor shown in Fig. 2. The cow dung was used as a starter in this work. It was first mixed with water and fed to the digester and retained for 7 days. The natural process of acidogenesis and methanogenesis initiated during the retention time. After the seventh day, the raw biogas produced from cow dung containing moisture and less methane content was completely released and the fresh slurry prepared with kitchen waste was fed to the digester. In the first experiment, the feed consisting of kitchen waste collected from the college canteen was mixed with water by 1:1 proportion. A total of 10 kg kitchen waste was mixed with water manually and fed to the digester in the lot in every alternate 3 days. In the second experiment, mixture of kitchen waste, cow dung and water was used in 4:1:5 proportions. And in the third experiment, food waste, water and the slurry remained after complete digestion of food waste in the first experiment was used in 5:1:4 proportions.

The experiments were conducted at ambient temperature in the mesophilic range of 27–31 °C, and the temperature and moisture were monitored daily using thermo hygrometer. A gas collector was provided for collection and determination of volume of biogas production. The production of biogas containing methane was monitored daily.

The chemical analysis of the slurry prepared to feed was analysed using IS methods and the biogas produced is analysed using Nucon 5700 Gas Chromatograph.

All experimental data have been collected for a period of a month under normal atmospheric conditions. The volume of gas produced was measured by the rising height of the floating drum with time and resulted a substantial rise in volume on 22nd day of charging of slurry.

A difficulty encountered during the experiment about the solid blockage in the path of gas collection due to the formation of unwanted scum. To eliminate such problem, the digester was turned clockwise and anticlockwise direction thoroughly.

3 Experimental Results and Discussion

3.1 Waste Characterization

Waste analysis is an important anaerobic digestion process and is reported in Table 2. The feed was found to possess high moisture contents, which usually facilitate the anaerobic digestion; however, it was difficult to maintain the same availability of water throughout the digestion cycle. So, the slurry was prepared to feed to the digester maintaining the moisture content about half of the volume of kitchen waste. It was observed that the feed with 1:1 ratio with water provided best result. The C/N ratio, another important parameter, of the feed was found to be 37.74, which was maintained within the desired value of 34–40 and thus, it is found suitable for gas production.

3.2 Effect of PH and Temperature

The production of biogas from kitchen waste was found to be affected by the temperature. Figure 3 shows the effect of temperature on digestion process and was found optimum at mesospheric condition of temperature range of 25–38 °C. Similarly, pH value of slurry was fed to the digester, which also imparts a substantial role for the yield of biogas and is found maximum at a range of 6.9–7.2, as shown in Fig. 4. This condition of temperature and pH must be effective for growth of the microorganisms in the anaerobic cycle leading to high productivity.

3.3 Biogas Production

The biogas was produced at the optimum condition of temperature, retention time and pH. The gas obtained from the biodegradation of cow dung, which was used as starter was released on the seventh day and volume of gas produced was measured at an interval of 3 days of addition of feedstock. Table 3 shows the amount of the feedstock used and gas produced per 3 days of interval. In the beginning, the gas production was

Table 2 Analysis of feedstock to digester

Parameters	Values
Moisture content (%)	46.45
Nitrogen (%)	0.58
Organic carbon (%)	22.27
Phosphorus (m/kg)	523.03
Calorific value (cal/g)	4418.22
C/N ratio	37.74

Fig. 3 Effect of temperature on biogas production

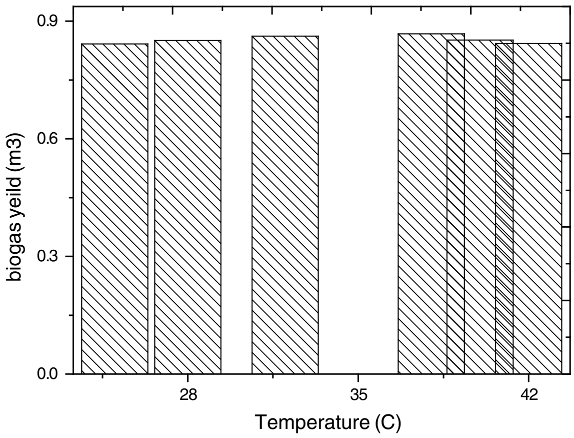

Fig. 4 Effect of pH value on biogas production

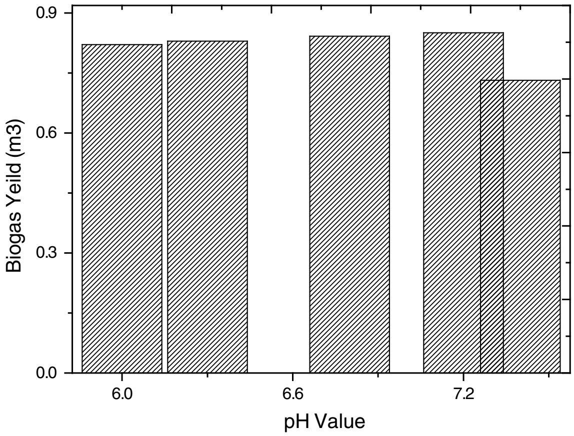

Table 3 Biogas production

Days	Amount of feedstock (kg)	Amount of biogas production (m^3)
10	10	0.852
13	10	0.854
16	10	0.857
19	10	0.864
22	10	0.868
25	10	0.861
28	10	0.858
31	10	0.843

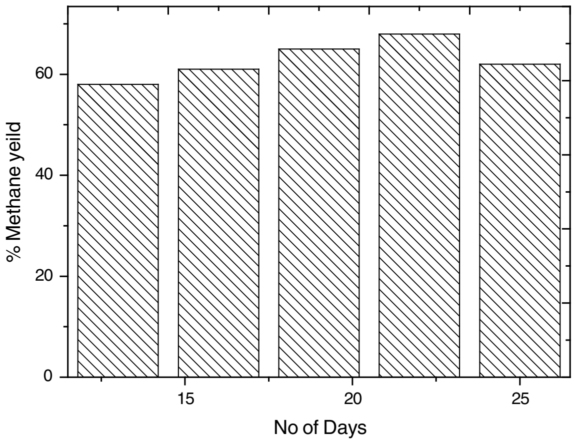

Fig. 5 Concentration of methane in biogas productions

low and gradually increased with time. This may be attributed to the higher bacterial growth after 13 days of the process as higher the bacteria, the higher the methane gas production. The volume of gas obtained measured in 3 days interval is approximately the same for each feed. The concentration of methane gas produced was measured over the length of digestion period and is summarised in Fig. 5. Highest concentration of methane in the biogas was obtained during 19th–22nd day of retention time of loading in the digester. This may be due to optimum microbial action during that period. The biogas generated was tested for its combustibility using a modified LPG burner giving a sustained flame as expected from combustion of the gas.

3.4 Composition of Biogas

The gas chromatography composition of gas obtained at different conditions is summarised in Table 4. From the table, it is clear that the concentration of methane in biogas was found different with different feedstocks and is found higher with residual slurry. This must be due to the availability of preexisting microorganisms in the slurry that facilitates the formation of methane in the process. The H_2S concentration in all the three experiments were highern which might be due to the presence of eggshell, meat leftover, citric fruit and larger size food component in the feedstock.

Table 4 Composition of biogas

Sample type with proportion	CH_4 %	CO_2 %	H_2S %	Other %
Foodwaste + water (1:1)	68.63	20.31	10.97	0.09
Foodwaste + cow dung + water (4:1:5)	71.08	21.32	7.59	0.01
Food waste + slurry + water (5:1:4)	74.52	17.66	7.70	0.12

3.5 Purification of Biogas

The raw biogas contains traces of moisture and considerable hydrogen sulphide (H_2S) that would cause corrosion to metal parts like gas regulators, gas metres, valves, mountings, burners associated with biogas plant. In addition, biogas containing H_2S upon combustion would produce sulphur dioxide (SO_2) and cause environment pollution. Carbon dioxide (CO_2) is also another impurity found in raw biogas declining its efficiency. The calorific value of the gas increases by reducing such impurities from the gas. Excess carbon dioxide in biogas is undesirable for different applications as it can cause freezing problems at valves and metering points. Thus, it is essential to separate biogas from carbon dioxide to enhance the use of biogas for wider range of applications. In the present study, biogas is purified by chemical scrubbing where in the raw gas, it is passed through three columns filled with oxidised steel wool, NaOH and Ca $(OH)_2$ connected in series for the removal of H_2S and CO_2 (Fig. 6).

Hydrogen sulphide is converted into elemental sulphur when it comes into contact with oxidised steel wool in the first column as per the following reactions 1 and 2:

$$Fe_2O_3 + 3H_2S = Fe_2S_3 + 3H_2O \tag{1}$$

$$2Fe_2S3 + 3O_2 = 2Fe_2O_3 + 6S \tag{2}$$

Remaining H_2S in biogas is further removed using sodium hydroxide solution forming sodium hydrosulphide as described by reaction 3

$$2NaOH + H_2S = NaHS + 2H_2S \tag{3}$$

Sodium hydroxide solution also helps the removal of CO_2 in addition to calcium hydroxide as per the following reactions 4 and 5:

$$2NaOH + CO_2 = Na_2CO_3 + H_2O \tag{4}$$

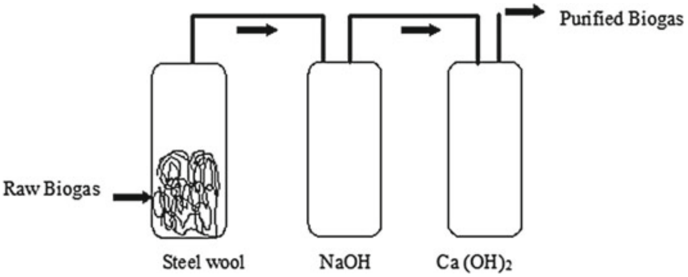

Fig. 6 Purification set up of biogas

Table 5 Composition of biogas element after purification

Sample type with proportion	CH_4 %	CO_2 %	H_2S %	Others
Foodwaste + water (1:1)	80.62	16.34	1.85	1.19
Foodwaste + cow dung + water (4:1:5)	86.30	11.4	1.1	1.20
Food waste + slurry + water (5:1:4)	83.59	13.64	1.67	1.10

Table 6 N-P-K composition of residue

Sample type with proportion	Nitrogen (N)	Phosphorous (P)	Potassium (K)
Foodwaste + water (1:1)	1.2	0.8	0.6
Foodwaste + cow dung + water (4:1:5)	1.8	0.5	0.8
Food waste + slurry + water (5:1:4)	1.3	0.7	0.9

$$\mathrm{Ca\ (OH)_2 + CO_2 = CaCO_3 + H_2O} \tag{5}$$

Significant decrease in the percentage of CO_2 and H_2S and increase in the percentage of CH_4 is observed after passing through the different scrubbing materials as is reported in Table 5.

3.6 Characterisation of the Post-digestion Residue

The residue collected after digestion from the plant contains some nutrients and may be regarded as a source of organic fertiliser or compost. The residues also contain some microbes that are very much helpful for firming. Soil amendment and aeration can be done very effectively using this biogas plant residual due to their valuable nutrient availability as reported in Table 6.

4 Conclusion

Anaerobic fermentation is a floating-type biogas plant using food waste as an appropriate technology for handling waste food for generation of biogas. The waste characterization shows it is more suitable to be treated more anaerobically than other treatments such as methanogenesis. The co-digestion of kitchen waste with cow dung as stator is becoming a beneficiary technique producing methane up to 74%. Further research may be carried out using different biodegradable wastes to optimise the production of gas. Co-digestion of vegetable wastes with protein-rich substrates provide good buffering capacity for better utilisation of food wastes for energy production.

Statement on consent for publication: The authors agrees to publish this study that include human images (fig no. ‘1’ and ‘2’) in the chapter.

References

1. Gupta, P., Singh, S.R., Sachan, A., Vidyaarthi, A.S., Gupta, A.: A reappraisal on intensification of biogas production. Renew. Sustain. Energy Rev. **16**(7), 4908–4916 (2012)
2. Rathod, V., Bhale, P.V.: Experiment investigation on biogas reforming for syngas production over an alumina based nickel catalyst. Energy Procedia. Elsevier **54**, 236–245 (2014)
3. Chanakya, H.N., Ramachandra, T.V., Vijagachamundeeswari, M.: Anaerobic digestion and reuse of digested products of selected products of urban solid waste (2006)
4. Rungvichaniwat, J.: Msc thesis, Mahidol University (2003)

Geotechnical Characterization of Expansive Soil and Utilization of Waste to Control Its Swelling and Shrinkage Behaviour

Aishwarya Gayatri and Akshaya K. Verma

Abstract In the present study, expansive soil from outskirts of Bhubaneswar city (20°11′06.7″N 85°47′23.7″E) was characterized for its index properties. Grain size distribution revealed a 40 and 52% fraction of silt and clay, respectively. Soil was highly plastic with plasticity index of 22% and activity of 0.42. Maximum dry density (MDD) and optimum moisture content (OMC) of soil were appeared to be 16.4 kgN/m^3 and 19.6%, respectively, with a very high degree of expansion. This soil can be considered problematic at present condition and therefore investigations are made to reduce its swelling potential and shrinkage ratio using dross (alumina refining waste) for the reduction of swelling potential of expansive soil. Highest reduction of swelling potential was appeared to be 92% with shrinkage ratio of 1.17, when equal amount of soil and dross were mixed. This study not only revealed the stabilization of expansive soil but also thrust on the management of industrial waste.

Keywords Expansive soil · Dross · Compaction characteristics · Soil stabilization

1 Introduction

For any construction, first, all engineer requires data about soil classification and characteristics. The behaviour of soil at different conditions is also important to assess and this becomes even more necessary in case of expansive soil. Expansive soil is rich with montmorillonite clay. It has shrink and swell behaviour towards different weather conditions. It shrinks when it is dry and swells when wet; because of high percentage of montmorillonite minerals. Expansive soil covers a larger area of India, basically, the central and western parts approximately 25% of our country. An expansive soil is identified as clayey soil, which undergoes shrink–swell

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behaviour with alteration of the moisture content. The swelling in expansive soil occurs due to reduction of soil suction resulting from the increase in the moisture content of clays [1]. Swelling occurs when pressure is induced to resist the internal pressure of expansive soil. Intrinsic expansiveness, heave and suction are some of the important properties to understand the behaviour of expansive soils [2].

There are a number of problems that can be linked to the structures which are developed on these soils. It has been detected that generally, lightweight structures are more susceptible to the unusual (swell–shrink) behaviour of expansive soil [2]. Although the soils possess high water holding capacity, yet water is not available to the plants because of their very fine texture. Permeability of these soils is low which result in extreme surface tension. Any type of construction over these soils is a major challenge, as vertical movement takes place in soil mass causing failure during wetting and drying condition. It results in depression, cracks, unevenness, therefore visual identification is very important at field site. The main objective is to gain enough information about the history of site, which helps in understanding the behaviour of soil. The cracks form due to shrinkage are the good symbol of activity of expansive soil. Figure 1a, b depicts the desiccation cracks in the soil caused by drying on the surface and deep down as well during the summer. The vegetation on the soil can be an indicator of expansiveness. Local knowledge usually reveal that certain type of plants tends to occur more frequently on soil having low or high expansion potential.

The most common component of expandable properties is montmorillonite (Na, Ca) × $(Al,Mg)_2$ (Si_4O_{10}) $(OH)_2 \cdot nH_2O$). The term smectite (generally used to refer montmorillonite) represents a family of expansible 2:1 phyllosilicate clay minerals with a lattice structure containing two tetrahedral sheets that are separated by a layer of octahedral sheet [3, 4].

Due to vast industrialization, many types of waste are generated. It requires large storage area to dispose the waste and the disposal of industrial wastes create negative impact or adverse effect on environment, causing different types of environmental, loss of soil property, etc. It disturbs the ecosystem. Modification of these

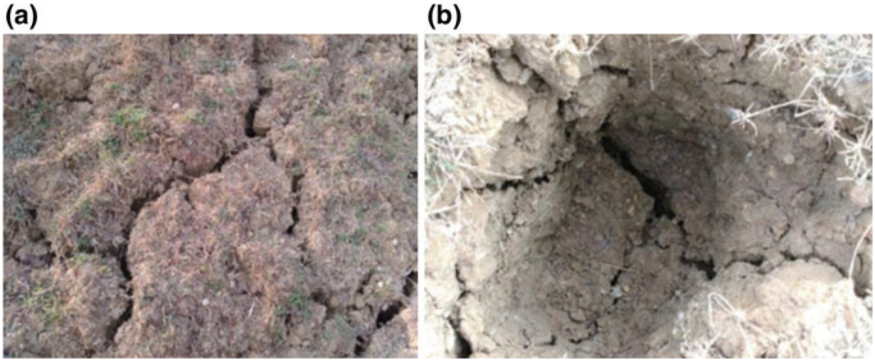


Fig. 1 Appearance of expansive soil at the location

soil using industrial waste products have been used successfully as it improves the geotechnical properties of expansive soil and makes it suitable for construction [5]. Researchers investigated the effect of different waste materials such as quarry dust, fly ash, etc. on the geoengineering properties of expansive soils.

Aluminium dross is a by-product of aluminium production, which is formed during refining and oxidation of the liquid metal during the course of various operations. It consists of a complex conglomerate, including metallic oxides, nitrides, chlorides, fluorides, carbides, sulphides, phosphides, dirt and impurities apart from metallic aluminium (between 20 and 80%). The influence of different industrial wastes on the geoengineering characteristics of expansive soil has been comprehensively examined by different investigators. Mishra et al. [6] characterized the black cotton soil of Odisha and reported the soil with high coefficient of expansion and contraction leading to the steady churning process within the soil. Researcher suggested the use of these soils for growing rice, jowar, bajra, maize, bengal gram, safflower, mustard and cotton. Kiran and Kiran [7] described the properties of black cotton soil obtained from Harihara, Davanagere districts, Karnataka. Different geotechnical experiments [specific gravity (2.46), Atterberg's limits, maximum dry density (15.16%) and optimum moisture content (21.96%)] were carried out to determine its properties, resulting highly expansive. Similarly, many researchers like Sridharan et al. [8], Phanikumar and Sharma [9], Saeid et al. [10], Bhavsar and Patel [11], Hardaha et al. [12], Cokca [13], Pokale et al. [14], Venkateswarlu et al. [15], Chansoria and Yadav [16], Mohanty et al. [5] and many others have reported the enhancement of different geoengineering properties of expansive soil on addition of different waste materials. In the present study, aluminium dross has tried to assess its effectiveness for improving the geoengineering properties of expansive soil.

2 Materials and Methods

The expansive soil from the outskirts of Bhubaneswar city (20°11′06.7″N 85°47′ 23.7″E) was collected. Dross used in this study was brought from NALCO Angul, Odisha. Expansive soil and dross were characterized on the basis of particle size analysis and XRD. Different geoengineering properties such as liquid limit, plastic limit, differential free swell test, compaction, maximum dry density, optimum moisture content, shrinkage limit, Atterberg's limit, unconfined compressive stress, specific gravity was measured on the dross-blended expansive soil samples. All the tests have been carried out as per the Indian Specification.

3 Results and Discussion

3.1 Materials and Their Characteristics

The virgin soil was sampled by excavating the ground up to 0.5 m depth, thus removing the topsoil. The obtained soil was categorized as extremely compressible clay (CH) as per IS:1498. Different tests were conducted on the sampled soil (expansive soil) and industrial wastes (dross) and blended samples (soil–dross) for their characterization. The properties of expansive soil and additive (dross) are reported in Table 1.

Grain size analysis (Table 1 and Fig. 2) depicts that the utilized expansive soil for the experimentation is the fine grained. The clay content of the soil is 52%, possessing a large specific surface area and is highly plastic in nature. The considerable magnitude (60%) of differential free swell index (*dfs*) of the soil indicates its high degree of expansiveness (Table 1). Therefore, the soil under investigation can be catagorized as fine grained, highly plastic (plasticity = 22%), extremely expansive and possessing a high water holding capacity. On the other hand, dross is non-clayey with specific gravity of 2.9. The behaviour of dross was appeared as non-plastic with no swelling. The OMC and MDD of the dross is 12.6% and 2.25 g/cc, respectively.

The mineralogical analysis for expansive soil and dross using X-ray diffraction tests were reported in Figs. 3 and 4. The soil grains are subangular in nature as the angularity falls between 1.051 and 1.23. The mineralogical analysis of dross using revealed the presence of metallic aluminium (Al), aluminium oxide (α-Al_2O_3), spinel ($MgAl_2O_4$) along with defect spinel, diaoyudaoite ($NaAl_{11}O_{17}$) and aluminium nitride (AlN). Minor traces of quartz were also observed.

Table 1 Properties of expansive soil and dross

S.No.	Particulars	Expansive soil	Dross
1.	Soil classification (USCS)	CH	–
2.	Liquid limit (%)	47	28
3.	Plastic limit (%)	25	–
4.	Plasticity index (%)	22	Non-plastic
5.	Activity	0.42	Non-plastic
6.	pH	6.5	8.9
7.	Optimum moisture content (%)	19.6	12.6
8.	Maximum dry density (g/cc)	1.68	2.25
9.	Differential free swell (%)	60	0
10.	Specific gravity	2.56	2.9
11.	Unconfined compressive strength (kN/m^2)	207	–
12.	*Grain size distribution* Gravel (>2000 μm), % Sand (75–2000 μm), % Silt (2–75 μm), % Clay (<2 μm), %	0 8 40 52	13 65 22 0

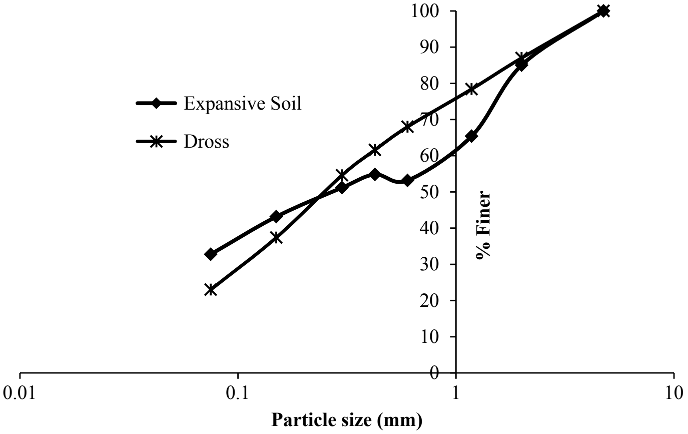


Fig. 2 Grain size distribution curve for expansive soil and dross

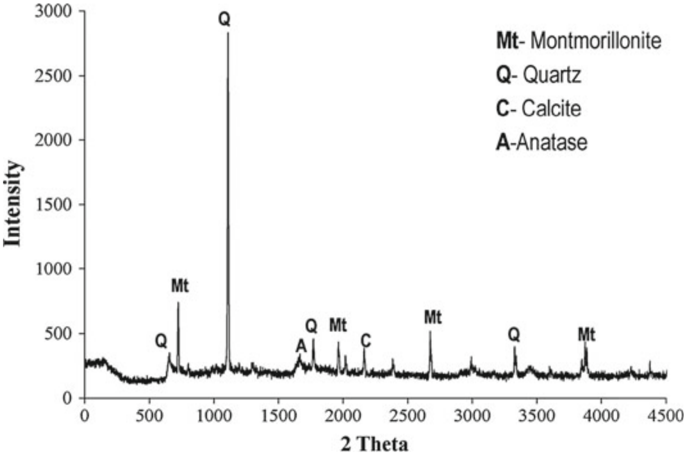


Fig. 3 X-ray diffraction spectra of expansive soil

3.2 *Determination of Index Properties of Dross Blended Expansive Soil*

Dross was added to the virgin soils samples in different percentage (w/w) at 10% increment up to 50%. The index properties such as specific gravity, Atterberg's limits, swelling, OMC and MDD of the intermingled trials were determined according to BIS methods.

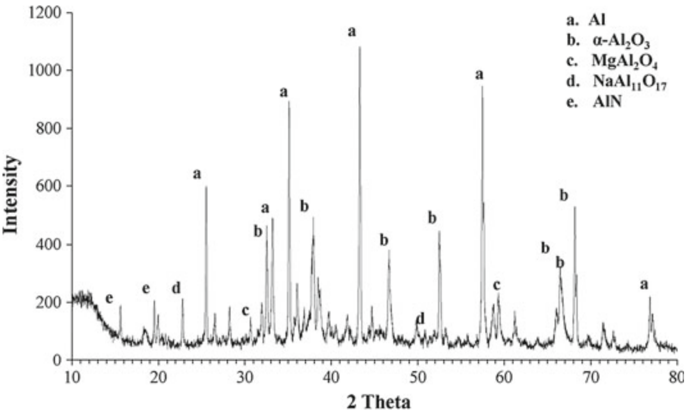


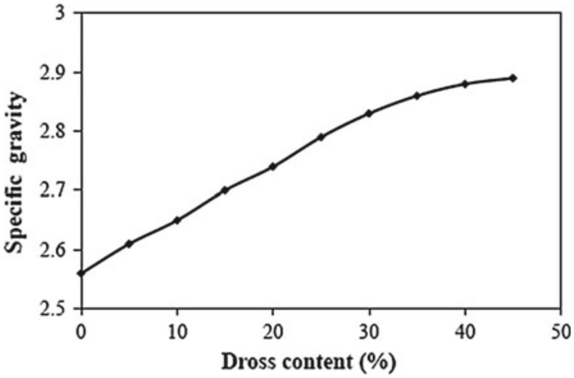
Fig. 4 X-ray diffraction spectra of dross

3.3 Index Properties

3.3.1 Specific Gravity

The specific gravity of virgin soil and dross were determined to be 2.56 and 2.9, respectively. Specific gravity of mixed soil samples was observed to be increased with increase in the dross content (Fig. 5). The observed trend may be explained due to the replacement of expansive soil (lighter grains, specific gravity 2.56) by same fraction of dross (heavier grains, specific gravity 2.9).

Fig. 5 Specific gravity of dross-blended expansive soil samples



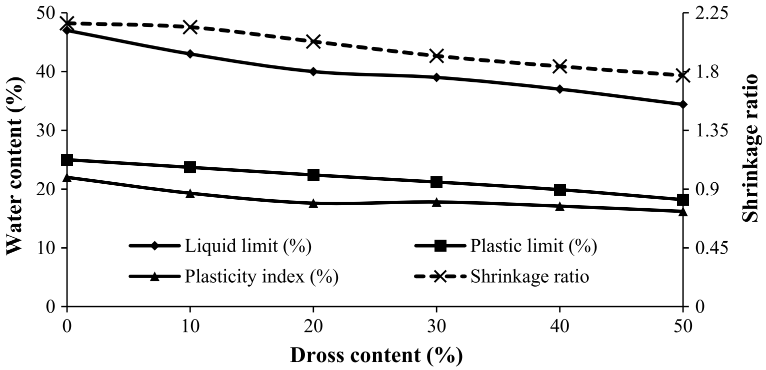


Fig. 6 Consistency characteristcs of dross blended expansive soil

3.3.2 Consistency Features

The consistency features of expansive soil mixed with dross at different percentages are represented in Fig. 6. It can be observed that the studied consistency properties such as liquid limits, plastic limit, plasticity index and shrinkage limit steadily decreased with the rise of dross fraction in expansive soil.

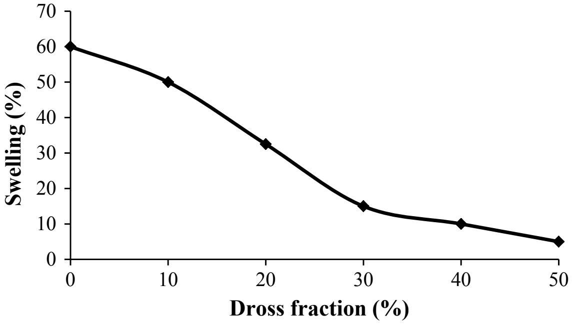
The maximum decrease of 27, 37, 26 and 18% in liquid limits, plastic limit, plasticity index and shrinkage limit, respectively was obtained when an equal amount of dross and expansive soil was mixed. Dross being a non-plastic material (Table 1) having lesser water holding capacity as compared to expansive soil, produce blended samples with reduced water holding capacity with the increase in dross content. The plastic limit and plasticity index of blended samples also reduced progressively with increase in the dross content.

3.3.3 Expansive Characteristics

Differential free swell (*dfs*) test was performed to study the expansive characteristics of expansive soil mixed with dross at different percentages depicted in Fig. 7.

The differential free swell (*dfs*) of virgin soil was determined to be 60%, which depicts that the soil is very expansive in nature, while the dross has *dfs* value of was 0%, indicating it was not expansive. With addition of dross in expansive soil, the swelling was continuously decreased, which is revealed from Fig. 7. A maximum decrease of 91% in swelling was obtained when an equal amount of dross and expansive soil was mixed.

Fig. 7 Differential free swell of dross-blended samples



3.3.4 Compaction Characteristics

A sequence of experiments was performed using standard proctor compaction method with virgin expansive soil and soil mixed with dross at varying fractions as per IS: 2720 (Part-8). With this test, OMC and MDD for each blended sample were calculated and represented in Fig. 8. The observation showed that OMC and MDD of soil sample are found to be 19.6% and 1.68 gm/cc, respectively, whereas a 12.6% and 2.25 gm/cc, respectively for dross. When dross content is increased in mixed samples by reducing the same fraction of soil, the OMC of soil sample decreased while MDD is increased. As OMC of dross (12.6) is lesser than that of soil (19.6), the OMC of blended samples are reduced with rise in the dross content. At 50% of dross, the OMC is 12.9% and MDD is 2.1 g/cc. Reduction in OMC and rise in MDD with rise in dross proportion may be related to introduction of the heavier dross particles in the expansive soil.

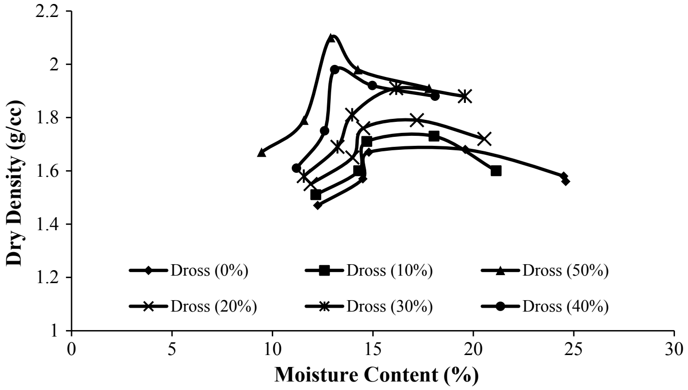


Fig. 8 Compaction test results of expansive soil and dross-blended samples

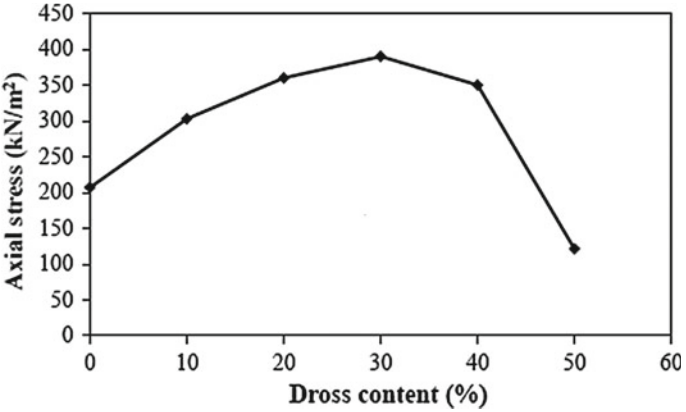


Fig. 9 Test results of unconfined compressive strength of virgin expansive soil and dross blended sample

3.3.5 Unconfined Compressive Strength (UCS) Test

According to the ASTM standard, the unconfined compressive strength is defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test. UCS is the most widely used laboratory tests in pavement and soil stabilization application, which is robust test for soil stabilization. All the specimens were prepared and compacted at their respective MDD and OMC according to standard proctor compaction energy (ASTM standards). The specimens for the test have a diameter of 38 mm and height of 76 mm. The variation of unconfined compressive strength with the addition of dross content is given in Fig. 9.

An increase in the unconfined compressive strength was observed by increasing the dross content from 0 to 30% for the uncured samples. Further addition of dross resulted in the reduction of unconfined compressive strength. This indicates that the quantity of dross up to optimum content can induce pozzolanic reaction and cemented materials effectively contributing to the increase in shear strength, while the additional quantity of dross acts as unbounded silt particles, which has neither appreciable friction nor cohesion, causing a decrease in strength [17].

4 Practical Implications

During the past few decades, the attention of waste management has been highlighted, especially in view of the increase in economic development which has resulted in an increase in different types of wastes. It is found that initially only waste disposal was regulated, but over time, in addition to disposal, other aspects were also regulated in terms of different fragments of environmental legislation.

On the view of this, aluminium dross was investigated for the use of stabilization of expansive soil. From the above tests, it is clear that dross is a good filler material as it resulted in the increase in dry density when added to expansive soil in different proportions. In addition to this, it reduces plasticity and liquid limit. Therefore, it can be used practically for enhancing the strength properties, controlling shrink–swell properties and drying agent to reduce soil moisture contents and permit compaction. The use of dross in soil stabilization and modification may be subjected to the local environmental necessities relating to leaching and potential interaction with groundwater and adjacent water resources.

5 Conclusion

In this study, the influence of dross as industrial waste was assessed for stabilization of expansive soil. Most of the geoengineering characteristics of expansive soil were improved significantly on the addition of aluminium dross at different percentages. Dross was mixed up to 50% at an increment of 10% by dry weight of expansive soil as per prevailing practice. On the basis of experimental outcomes, the major inferences may be deduced as follows. Investigated expansive soil was highly plastic and showed a high degree of swelling potential while aluminium dross was non-plastic and showed zero swelling potential. Atterberg's limit steadily reduced with rise in dross proportion. The maximum reduction of 27, 37, 26 and 18% in liquid limits, plastic limit, plasticity index and shrinkage limit, respectively, was obtained when equal amount of dross and expansive soil was mixed. Specific gravity of dross mixed soil samples was improved with increase in the dross content and a maximum specific gravity of 2.9 was obtained at 45% dross proportion. Swelling potential progressively diminished with addition of dross to selected expansive soil. The diminution was approximately 92% when equal amount of dross and expansive soil was mixed.

References

1. Sherwood, P.: Soil Stabilization with Cement and Lime. State of the Art Review. Transport Research Laboratory, HMSO, London (1993)
2. Jones, L.D.: Chapter C5, Expansive Soils. Institution of Civil Engineers Manuals series (2015)
3. Laird, D.A., Barak, P., Nater, E.A., Dowdy, R.H.: Chemistry of smectitic and illitic phases in interstratified soil smectite. Soil Sci. Soc. Am. J. **55**, 1499–1504 (1991)
4. Diaz, C.I., Laguna, A.H., Dove, M.T.: Modeling of dioctahedral 2:1 phyllosilicates by means of transferable empirical potentials. Phys. Chem. Miner. **28**(2), 130–141 (2001)
5. Mohanty, S.K., Pradhan, P.K., Mohanty, C.R.: Consolidation and drainage characteristics of expansive soil stabilized with fly ash and dolochar. Geotech. Geol. Eng. **34**(5), 1435–1451 (2016)

6. Mishra, A., Dash, B.B., Das, D.: Black soils of Orissa and their management. Orissa Rev. **67**, 24–26 (2011)
7. Kiran, R.G., Kiran, L.: Analysis of strength characteristics of black cotton soil using bagasse ash and additives as stabilizer. Int. J. Eng. Res. Technol. **2**(7), 240–246 (2013)
8. Sridharan, A., Prashanth, J.P., Sivapullaiah, P.V.: Effect of fly ash on the unconfined strength of black cotton soil. Ground Improv. **1**, 169–175 (1997)
9. Phanikumar, B.R., Sharma, R.S.: Effect of fly ash on engineering properties of expansive soil. J. Geotech. Geoenviron. **130**(7), 764–767 (2004)
10. Saeid, A., Amin, C., Hamid N.: Laboratory investigation on the effect of fly ash on the compressibility of soil. In: International Conference on Civil and Architectural applications (ICCAA'2012), Phuket (Thailand), pp. 84–88 (2012)
11. Bhavsar, S.N., Patel, A.J.: Effect of waste material on swelling and shrinkage properties of clayey soil. Int. J. Appl. Innov. Eng. Manage. **3**(11), 200–205 (2014)
12. Hardaha, R.P., Agrawal, M.L., Agrawal, A.: Study about swelling behaviour of black cotton soil with fly ash. Int. J. Sci. Res. **4**(12), 1514–1517 (2015)
13. Cokca, E.: Use of class C fly ashes for the stabilization of an expansive soil. J. Geotech. Geoenviron. Eng. **127**, 568–573 (2001)
14. Pokale, K.R., Borkar, Y.R., Jichkar, R.R.: Experimental investigation for stabilization of black cotton soil by using waste material—brick dust. Int. Res. J. Eng. Technol. **2**(5), 726–728 (2015)
15. Venkateswarlu, H., Prasad, A.C.S.V., Prasad, D.S.V., Raju, G.V.R.P.: Study on behavior of expansive soil treated with quarry dust. Int. J. Eng. Innov. Technol. **4**(10), 193–196 (2015)
16. Chansoria, A., Yadav, R.K.: Effect of quarry dust on engineering properties of black cotton soil. Int. J. Innov. Res. Sci. Technol. **2**(11), 715–718 (2016)
17. Kate, J.M.: Strength and volume change behavior of expansive soils treated with fly ash. GeoFrontiers Congress ASCE, Austin, Texas, United States (2005); IS: 2720 (Part V) (1985) —Determination of liquid & plastic limits; IS: 2720 (Part VI) (1972)—Determination of shrinkage ratio; IS: 2720 (Part III) (1980)—Determination of specific gravity; IS: 2720 (Part VII) (1980)—Determination of moisture content & dry density; IS: 2720 (Part IV) (1975) —Determination of grain size; IS: 2720 (Part X) (1973)—Determination of unconfined compressive strength

Recovery of Manganese from Low-Grade Ferromanganese Ores Using *Bacillus Safensis*

Bhubaneswari Bal and Alok Prasad Das

Abstract The present investigation aims for the betterment of an environmental friendly procedure to extract Mn from mining desecrates using native microorganism. A single bacterial strain viewing noticeable growth on Mn-supplemented agar plate was isolated from the collected ore samples from Mn mining deposits of Joda Barbil districts of Odisha state of India. Molecular characterization of selected isolates conducted by the 16S rRNA sequencing method and the selected strain was taxonomically characterized as *Bacillus safensis* with genebank accession number (MF409013). Bioleaching experiment was conducted in 250 ml flask with optimum process conditions and *Bacillus safensis* as inoculum. Manganese extraction of 80% was monitored in the period of 20 days. The acknowledged bacterial strain exposed an eminent tolerance and solubilizing capability. The existing study brings light on the greener substitute for the extraction and recycling of manganese from the waste materials.

Keywords Manganese · Waste · Bioleaching · Recovery · Recycling · *Bacillus safenesis*

1 Introduction

Manganese is the fourth most strategically used metal in industries as well as in human life. The foremost consumption of manganese (Mn) in ferroalloys form is made by steel manufacturing. Usually, ferromanganese or Mn nodules found on the bottom of ocean contains approximately 30–35% of Mn [3, 6] which could give an additional resource of Mn. Ferromanganese contains approximately above 75% Mn which can be formed either in a electric furnace or in a blast [23]. Worldwide manufacturers of both silicomanganese and ferromanganese increased by around

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9% every year as compared to previous year [6, 7, 14]. In present years, globally, Mn demand has been increased by elevated steel manufacture and its iron making properties, which accounted for the largest part of Mn consumption. Extensive mining and indiscriminately deposition of mining waste are the main cause of ecological contamination. It was projected that the quantity of solid waste liberated in the form of lean grade ore, waste resource, and disposed mineral is approximately 6–8 million tons [9, 17]. The deliverance of noxious element into the environment all the way through industrial waste is the leading matter of distress. Toward the reduction of metal resources and enormously wastage of metals from various mining and any other manufacturing sector, the industries are in the search of new, eco–friendly, and competent substitute for metal recovery [10].

The world's quickly rising requirement of manganese has made it even more significant to build up routes for profitable revival of Mn from the low-grade ferromanganese ore and additional resource [2, 5]. The configuration of the current investigation mainly focuses on the development of novel techniques of manganese recovery from ferromanganese ore is embedded in the growing worldwide requirement [17, 19]. In recent times, investigation has been made to build up a viable bioleaching method to extract Mn from low-grade Mn ore by using the inherent capacity of native microbes, which allows them to change insolvable conjugated metals into the soluble form [13, 15]. There are many investigations carried out on bioleaching of manganese through different microbes but there is a limitation on utilizing known microbial strains [8, 18]. However, the characterization of native microorganism from various mining areas has become a crucial footstep for recovery of manganese because of their tolerance and solubilization capacity of Mn.

Taking into consideration the Mn solubilization by bacterial strain, our current experiment aims: (1) To isolate manganese-soublilizing bacteria; (2) to screen the isolates for their manganese tolerance; (3) molecular identification and phylogenetic analysis of selected bacterial strain; and (4) investigation of Mn bioleaching efficiency using the bacterial strain *Bacillus safensis*.

2 Methodology

2.1 Collection of Sample

The Joda-Barbil, area of Odisha, India having longitude and latitude of 85° 29' East and 21° 9' North is the eminent amount of manganese ore reserves, selected as a suitable sampling site for low-grade ferromanganese ore. A total of 2 kg ferromanganese ore were collected in a sterile container. After reaching, it was finely grounded and sieved for further leaching experiments. Mineralogical analysis was carried out by acid digestion with aqua regia. After the digestion process, the amount of manganese present in the sample was estimated through titration process.

To analyze the elemental composition and morphology, SEM-EDX was carried out. They were preserved at 4 ºC for native bacterial isolation for Mn bioleaching experiment.

2.2 Isolation of Manganese-Solubilizing Bacteria

Isolation of Mn-solubilizing microbial strains was conducted through spread plate method. 50 mM of MnO_2 supplemented nutrient agar plate was used for isolation of Mn-solubilizing bacteria. 10M HCl and 10M NaOH were taken for optimizing the pH of the growth media. Serial dilution of the representative samples were carried out in 10 ml deionized water from 10^{-1} to 10^{-10} and 0.2 ml from that concluding tube was spread over the manganese supplemented nutrient agar. The Mn-supplemented plates were further taken for incubation for 72 h at 37 °C and examined for the formation of morphological dissimilar colonies. The colonies viewing noticeable growth were taken by streaking method in same media for further screening.

2.3 Screening of Isolates for Manganese Tolerance

The bacterial strains were examined for their Mn tolerance capability. This investigation was carried out by using Mn supplemented agar plate of concentration ranging from 50 to 500 mM. Representative strains were diluted from 10^{-1} to 10^{-10} times in double distilled water and 0.1 ml from these diluted samples were utilized for spreading onto the plates and soon after it is incubated at 37 °C for about 48 h. Throughout the incubation, the plates were examined and the isolates producing visible growth in the occurrence of particular Mn concentrations show that the selective bacterial strains are tolerant to Mn.

2.4 Molecular Identification and Phylogenetic Analysis

With the aim of identifying the native isolated bacterial strains, molecular characterization was carried out. 1 ml of bacterial samples was grown in Luria broth medium for 24 h, and it was exposed to DNA extraction through phenol–chloroform DNA extraction technique [20]. Isolated DNA samples were preserved at −20 °C for further experiments. The 16S rRNA is amplified DNA using these primers: 1492R and 8F by using the a definite PCR condition: at 94 °C meant for

3 min, 94 °C for 1 min, at 55 °C for the time of 45 s, at 72 °C for 1 min, and the extension period at 72 °C for 10 min. The total process were completed by 35 cycles. The amplified products were checked on 1.5% agarose gel with 100 bp DNA marker for the visualization of occurrence of amplified fragment of DNA. Resulting sequences were cut from both low-quality 5' and 3' ends and checked for chimeras [12]. The trimmed sequences were investigated and taxonomical identification was carried out using BLAST analysis [21] against 16S rRNA gene sequences database. Phylogenetic trees were created on the basis of Neighbor-Joining algorithm by using 10 near by sequences to investigate the evolutionary relationship with the familiarly linked species.

2.5 Bioleaching of Mn

Manganese bioleaching investigation was carried out for a period of 20 days using the selected bacterial strain. The experiment was conducted in a 250 mL conical flask containing 100 mL of K medium with pH value maintained to 6.5 and 15 mL of selected bacterial culture shaking with 200 RPM at 37 °C. Flask filled with only sterilized media without bacterial inoculums is considered as control. At the end of the experiment, the samples were separated through centrifugation and then filtered with Whatman's filter paper. The solubilized manganese in the form of residues filtrate residues were quantified through titration process. The residues of the ore particle were dried and examined for their metal constituent by means of EDX and XRD study. EDX and XRD testing of the low-grade ferromanganese ore sample before the Mn solubilization was also conducted and the results acquired were linked to authenticate the Mn solubilization using isolated bacterial strains.

3 Results and Discussion

3.1 Physicochemical Characterization of Ore Sample

The samples collected from mining location represented in Fig. 1 was examined for their physical and chemical factors like conductivity, pH, total suspended, and dissolved solids [10, 15, 19]. It was studied that the collected ore sample was alkaline and contains both dissolved and suspended solids. The grounded samples provided in Fig. 2 were further subjected to XRD analysis reported in Fig. 3 and acid digestion and examine the manganese percentage in the ore sample. The Mn content was approximately 21%.

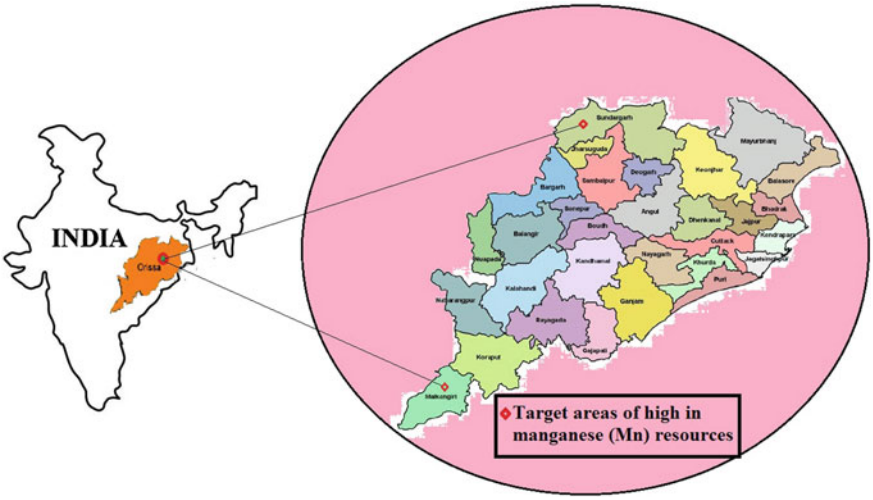

Fig. 1 Geographical location of different mining sites

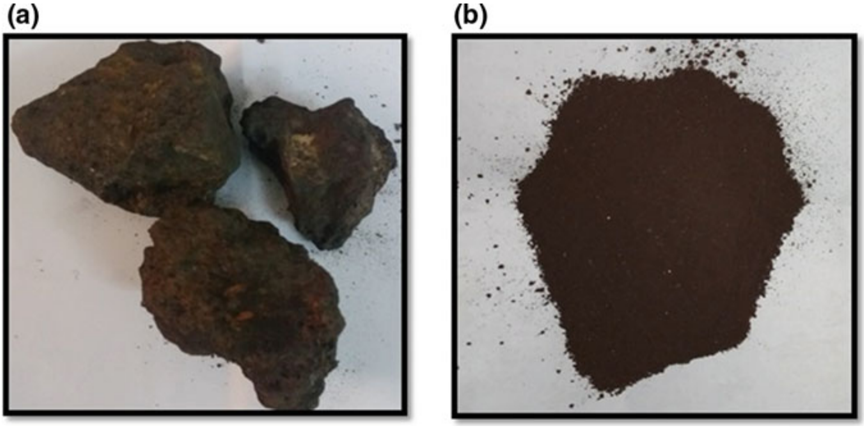

Fig. 2 (a) Collected ore sample. (b) Grounded sample

3.2 Isolation of Mn-Solubilizing Bacteria

A total of three bacterial colonies were isolated in manganese-supplemented plates, which contains 50 mM of MnO_2 after 72 h of incubation at 37 °C [16]. Colonies visible on the plates were round, smooth, white, and approximately 0.5–1.0 mm in size. These bacterial strains were utilized for further manganese tolerance studies.

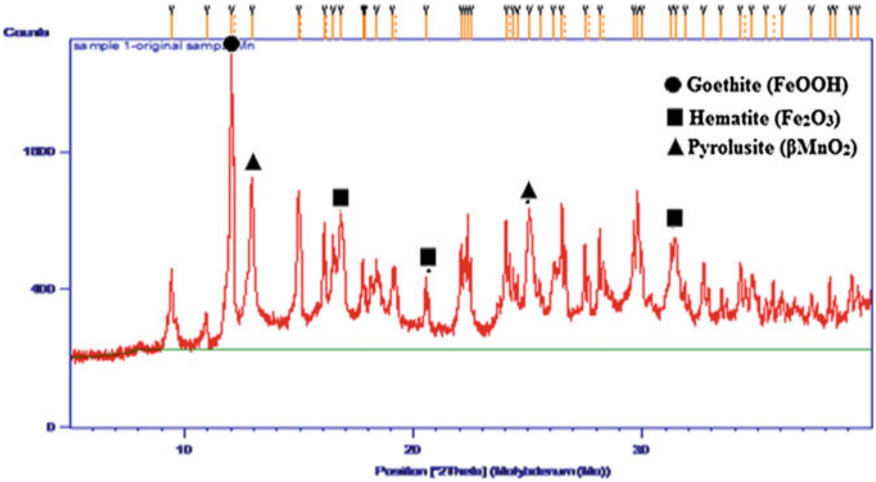

Fig. 3 XRD analysis of grounded sample

3.3 Screening for Manganese Tolerance

Manganese-solubilising capacity of the selected bacteria was measured by lightening the media in the region of the selected colonies [4, 21]. Out of these three bacterial strains, Mn_2 strain is found suitable for further leaching study as it showed optimum growth at pH 6.5 and 37 °C. The selected bacterial culture colonies were grown on agar pates as represented in Fig. 4 for further studies.

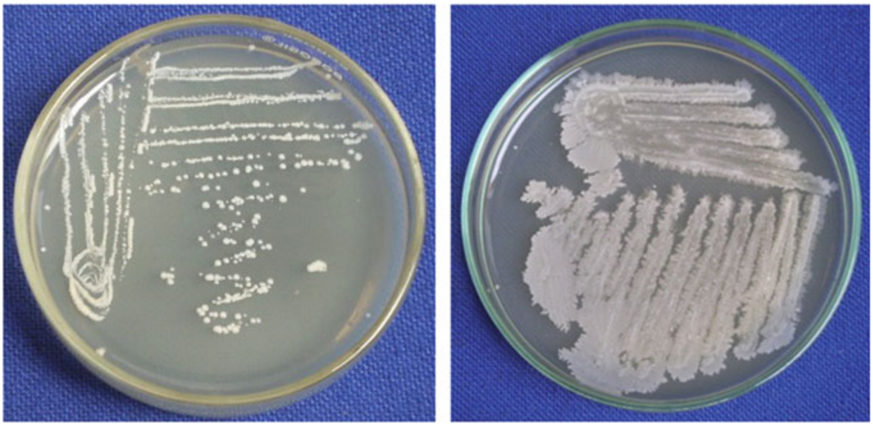

Fig. 4 Selected bacterial strain Mn_2 for further leaching study

3.4 16S RRNA Sequencing of Manganese-Solubilizing Bacteria

Molecular characterization was done for the isolated bacterial strain through 16s rRNA method and after the agarose gel electrophoresis, the DNA bands obtained through PCR were verified on agarose gel as represented in Fig. 5 under ultraviolet (UV) light. It was identified that Mn_2 bacterial strains as *Bacillus safensis.* The obtained sequences is deposited to GenBank and the accession number MF409013 was acquired.

3.5 Phylogenetic Analysis of Selective Bacteria

Evolutionary studies of partial 16s rRNA is used to provide evidence about the convergence/divergence of the microorganism from its descendants. The 16S rDNA analysis of Mn_2 strain of 750 bp in length presented that the isolated bacteria belongs to the *Basillus* group with the sequence similarity of 98%, and its other phylogenetically related species are *Bacillus safensis Rm S8* strain, *Bacillus safensis PR-2* with 97%, *Bacillus safensis Ant Cr 90* with 87%, *Bacillus safensis Ant Cr 81* with 88%, and *Bacillus safensis* H4.9/8 with 89% sequence similarity Fig. 6.

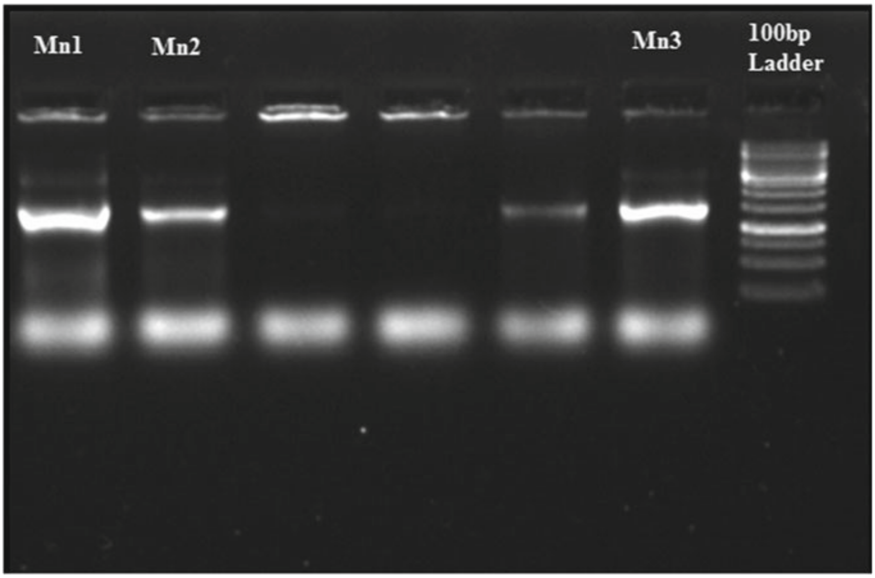

Fig. 5 DNA bands observed after undergoing agarose gel electrophoresis

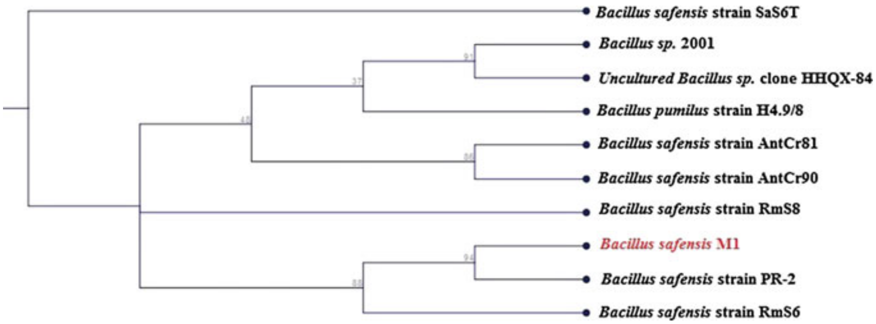

Fig. 6 Phylogenetic tree of *Bacillus safensis* generated by Neighbor-Joining method

3.6 Manganese Bioleaching

For the investigatation of Mn-solubilizing strains, bacterial strains were isolated and screened of their solubilization competence. The utmost recovery of Mn at a certain optimized parameter temperature 37 °C and pH 6.5, was noticed to be 80% in the period of 20 days Fig. 7. The outstanding capability of isolates to tolerate higher concentration has been previously described [10, 12, 22]. The microbial strain Mn_2 exhibited a maximum solubilization efficiency 80%. Investigational outcomes propose that biogenerated production acid by the isolated strain throughout the solubilization process is the probable mechanism and has enormous potential for future application [11, 15, 21] as compared to other reductive leachings [1, 9]. To achieve the current industrial requirement for Mn, it is essential to build up a substitute procedure of Mn recovery from low-grade ferromanganese ore, having less than 30% Mn.

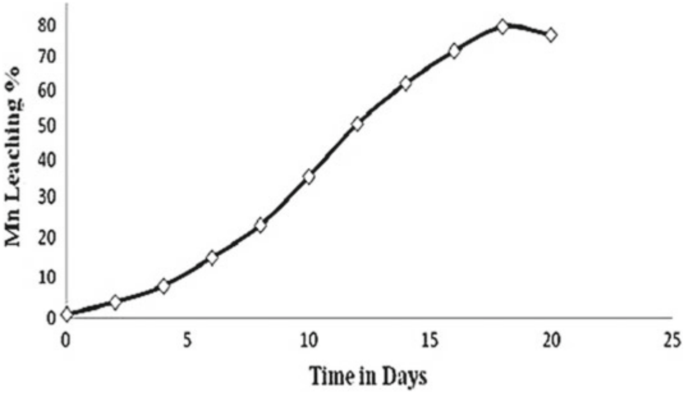

Fig. 7 Mn leaching kinetics by *Bacillus safensis*

4 Conclusion

The current study consequences exposed that the ferromanganese ore had various manganese-solubilizing bacterial communities of *Bacillus* sp. The selected bacterias showed a highest Mn tolerance ability. The solubilizing ability and Mn tolerance of bacterial isolate directly depends on the primary Mn concentration, signifying that they had a capability for the Mn solubilization. Mn biorecovery using bioleaching method has a huge prospective and playing an outstanding role in changing the state of ore. Hence, microorganism having Mn-solubilizing capacity has more interest because of their role in the conversion of insoluble Mn in the surroundings. Molecular method was employed for the identification of native bacterial isolates, and is confirmed to be a competent implementation for bacterial identification. Collectively with the superior molecular technique, it will permit for in-depth study of huge quantities of samples thereby leading to the betterment of metal resources. The current interpretation noticeably says that the bacterial strains indigenous to manganese overload could discover function in the Mn recovery from different mining deposit sites all the way through the progression of appropriate microbial methodology.

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References

1. Acharya, C., Kar, R.N., Sukla, L.B.: Studies on reaction mechanism of bioleaching of manganese ore. Miner. Eng. **16**, 1027–1030 (2003)
2. Akcil, A., Veglio, F., Ferella, F., Okudan, M.D., Tuncuk, A.: A review of metal recovery from spent petroleum catalysts and ash. Waste Manage. **45**, 420–433 (2015)
3. Bal, B., Ghosh, S., Das, A.P.: Microbial recovery and recycling of Manganese waste and their future application: a review. Geomicrobiol. J. **36**(1), 85–96 (2018)
4. Cahyani, V.R., Murase, J., Ishibashi, E., Asakawa, S., et al.: Phylogenetic positions of Mn$_2$þ-oxidizing bacteria and fungi isolated from Mn nodules in rice field subsoils. Biol. Fertil. Soils **45**, 337–346 (2009)
5. Chen, S.Y., Lin, P.L.: Optimization of operating parameters for the metal bioleaching process of contaminated soil. Sep. Purif. Technol. **17**, 178–185 (2010)
6. Corathers, L.A.: U.S. Geological Survey (USGS) Minerals Yearbook: Manganese-2004. http://minerals.usgs.Gov (2004). Date accessed 21 June 2007
7. Corathers, L.A.: U.S. Geological Survey (USGS) Minerals Yearbook: Manganese-2005. http://minerals.usgs.Gov (2005). Date accessed 21 June 2007
8. Das, A.P., Ghosh, S., Mohanty, S., Sukla, L.B.: Consequences of manganese compounds: a review. Toxicol. Environ. Chem. **96**, 981–997 (2015)
9. Das, A.P., Ghosh, S., Mohanty, S., Sukla, L.B.: Consequences of manganese compounds: a review. Toxicol. Environ. Chem. **96**, 981–997 (2014)
10. Das, A.P., Mishra, S.: Biodegradation of the metallic carcinogen hexavalent chromium Cr(VI) by an indigenously isolated bacterial strain. J. Carcinog. **9**, 6 (2010)

11. Das, A.P., Sukla, L.B., Pradhan, N., Nayaka, S.: Manganese biomining: a review. Bioresour. Technol. **102**, 7381–7387 (2011)
12. Dowd, S.E., Zaragoza, J., Rodriguez, J.R., Oliver, M.J., et al.: Windows .NET network distributed basic local alignment search toolkit (W. ND-BLAST). BMC Bioinform. **6**, 93 (2005)
13. Ghosh, S., Kumar, M.S., Bal, B., Das, A.P.: Application of bioengineering in revamping human health. In: Synthetic Biology: Omics Tools and Their Application. Springer Nature, Singapore (2018)
14. Ghosh, S., Das, A.P.: Metagenomic insights into the microbial diversity in manganese-contaminated mine tailings and their role in biogeochemical cycling of manganese. Nat. Sci. Rep. J. **8**, 8257 (2018)
15. Ghosh, S., Mohanty, S., Nayak, S., Sukla, L., Das, A.P.: Molecular identification of indigenous manganese solubilising bacterial biodiversity from manganese mining deposits. J. Basic Microbiol. **56**, 254–262 (2015)
16. Hasan, H.A., Abdullah, S.R.S., Kofli, N.T., Kamarudin, S.K.: Effective microbes for simultaneous bio-oxidation of ammonia and Mn in biological aerated filter system. Biores. Technol. **124**, 355–363 (2012)
17. Mohanty, S., Ghosh, S., Bal, B., Das, A.P.: A review of biotechnology processes applied for manganese recovery from wastes. Rev. Environ. Sci. and Bio/Technol. **17**(4), 791–811 (2018)
18. Mohanty, S., Ghosh, S., Nayak, S., Das, A.P.: Bioleaching of manganese by Aspergillums oryzae isolated from mining deposits. Chemosphere **172**, 302–309 (2016)
19. Sanket, A.S., Ghosh, S., Sahoo, R., Nayak, S., Das, A.P.: Molecular identification of acidophilic Manganese (Mn) solubilizing bacteria from mining effluents and their application in mineral beneficiation. Geomicrobiol. J. **34**(1), 71–80 (2016)
20. Sambrook, J., Fritsch, E.F., Maniatis, T.: Molecular Cloning: A Laboratory Manual, 2nd edn. Cold Spring Harbor Laboratory, Cold Spring Harbor, NY (1989)
21. Wei, Z., Hillier, S., Gadd, G.M.: Biotransformation of manganese oxides by fungi: solubilization and production of manganese oxalate biominerals. Environ. Microbiol. **14**, 1744–1752 (2012)
22. Xin, B., Chen, B., Duan, N., Zhou, C.: Extraction of manganese from electrolytic manganese residue by bioleaching. Bioresour. Technol. **102**, 1683–1687 (2011)
23. Yucel, O., Ari, M.E.: Carbothermic smelting of Tavas manganese ore, Turkey. High Temp. Mater. Processes **20**, 345–351 (2001)

Briquette Making Using Waste Biomass and Analysis of Its Properties

Anjali Narzary, Raghvendra Chauhan and Amarendra Kumar Das

Abstract Dry leaves, grass, agricultural waste such as straw, rice husk, plant stalks are the types of biomass that are widely available in the rural areas. They have low bulk density and cannot give controlled flame while burning, so they cannot be used as fuel. This loose biomass gives handling problems while transporting them elsewhere and this biomass, if not composted properly, is nothing but a waste. Therefore, they are mostly burnt in the open fields creating unnecessary pollution. Briquetting can be seen as a viable method to solve this issue as it is a simple and cost-effective technology. This paper presents a technique of preparing a raw biomass into a usable biomass briquette fuel. Briquettes were made from Eleusine indica grass and sawdust bonded with gelatinized taro tubers. Briquette samples were prepared using low-power screw press machine. The first sample consisted of 3:1 grass and sawdust ratio; the second sample consisted of 1:1 grass and sawdust ratio. In both the samples, 40% of taro (Colocasia esculenta) tuber in weight basis was gelatinized and added. Both the prepared samples were tested for their physical and thermal properties. The result showed that the test sample 1 showed a higher calorific value of 15.539 MJ/Kg compared to sample 2 having a calorific value of 14.683 MJ/Kg. The bulk density was found to be 0.234gm/cm^3 and 0.233gm/cm^3 for sample 1 and 2, respectively.

Keywords Briquette · Colocasia esculenta (Taro) · Thermal properties · Physical properties

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1 Introduction

Over 12 crore household in India does not have access to clean fuel [1]. Almost two-thirds of the Indian population still depends on firewood, cow dung cakes and other freely available biomass for cooking purposes. About one million deaths are reported annually in India due to household air pollution. According to reports, 67% of the rural household still depends on firewood and woodchips for cooking [2]. The dependence on firewood also leads to deforestation and release of CO_2 and other harmful gases to the environment. Direct combustion of loose biomass such as dry leaves, grass, straw, plant stalks is not a viable way to utilize them, as they have low density, low calorific value and they produce unwanted smoke when burnt directly [3]. Also, direct burning of biomass produces low heat and cannot give controlled flame. The use of agricultural waste, grass, leaves and other biomass with the help of appropriate technology can solve the problem of fuel requirement in rural areas. Rural areas are abounding with such wastes but most of them are wasted due to lack of good technology. Many researchers have reported various techniques and methods for energy generation from agricultural waste [4–9]. Among the many reported techniques such as gasification, biogas production, hydrogen production, pyrolysis, torrefaction, biomass briquetting is one of the most important techniques that have a promising future to solve the problem of cooking fuel in rural areas. The briquetting process is used to give higher density to the loose biomass, higher calorific value, better handling, transportation and storage properties [3]. While briquetting due to high pressure applied, the particles come close together. The natural binding agents within the feedstock are forced out of the cell making a solid bridge between the particles [10]. Some of the reported densification processes are baling, pelleting, extrusion and briquetting. Briquetting and pelleting are the most common type of densification process, which is carried out using screw press, piston press and roller press [11–18]. A very high-quality briquette can be produced using high-power-operated screw press machine [12, 19], but this technology is not feasible in rural areas where the supply of electricity is irregular. Piston press, on the other hand, can be manually operated but it has low productivity. Low-power screw press machine also exits but due to lack of high pressure and temperature, a binding agent is required [20]. Starch is the most common binder that is used as reported in many papers; other than that cassava starch, cow dung, wheat flour, coffee husk, gum Arabic, paper pulp, municipal waste, waste from paper industries have been used as a binder [3, 21–24]. A binder should be easily available, not difficult to isolate from the plant matter, should not be from the human food chain and should have good adhesive properties and also an addition of such binding agent should not degrade the thermal properties of the briquettes made.

Colocasia esculenta (Taro) is a perennial tropical plant grown widely for consumption purpose. Assam is one of the major taro producing states of India, and these plants grow widely in the swamps and is widely available in the villages [25]. The tuber is reported to have 70–80% starch content [26, 27]. The tender leaf, stem and tuber are edible, but the tuber of wild taro plant is not edible. Therefore, they do not have any use. These tubers were used as a binder for briquette in the present research. Taro is easily available in the villages and due to its high starch content, it has a potential of being used as a binder for briquetting which is being tested in this research.

The objectives of the present research described in this paper can be listed as follows:

- To evaluate the performance of Taro tuber as a binder for briquetting using a low power screw press briquetting machine.
- To prepare samples by varying the ratio of sawdust and Eleusine indica grass by keeping the tuber percentage constant at 40% by weight.
- To analyze the physical and thermal properties of the briquettes obtained.

Preparation of the briquettes

The grass was dried in the sun for 6 h and then converted to a smaller size (Fig. 1) manually using cleaver knife as the large material particles when pressed in the screw press machine without cutting choked the machine. The grounded particle was then mixed in a particular ratio with sawdust obtained from a nearby small firewood shop in line with the work of Birwatkal et al. [10]. After mixing with the binder and water, mixture was ready to be put in the screw press machine.

Preparation of the Binder

The taro tubers were collected manually in the college campus itself (Fig. 2). The tubers were cut out from the plant and then washed to clear off all the stuck soil. It was then stored for use for a week.

For preparation of the binder, the taro was first peeled and weighed (weight by weight basis) for 40% ratio with the biomass. It was then cut into smaller pieces and

Fig. 1 Sun dried and grounded grass

Fig. 2 Taro tubers collected manually in the college campus

grounded using a mixer grinder by adding 100 ml of water. The paste obtained is then added with measured volume of water to obtain 50% water content in the total mixture of the feed for the machine. The mixture is then boiled to gelatinize it to bring out its pasting property (Fig. 3) as described in the paper [28]. Even though the taro tuber is rich in starch content, still the extraction of starch from the tuber is very difficult as the starch takes long time to settle down unlike other starches, which result in microbial contamination and effects the quality of the starch [29]. Therefore, we have tried to directly use the tuber as a binder for the briquettes that were prepared in this research. Wild taro also consists of higher amount of oxalic acid, which causes itching [30] so the work had to be carried out wearing gloves and taking precautions, so that it does not come into contact with the body.

Fig. 3 Gelatinized mixture

Analysis of the briquettes

The briquettes (sample1 and sample 2) (Figs. 4 and 5) were oven-dried at 100 °C for 3 h and stored for analysis that was to be performed. Sun drying was not possible due to the rainy season and while drying inside the room, the briquettes remained damp even after 3 days of drying. Therefore, analysis of the briquettes was performed on the oven-dried samples according to the methods given by Birwatkar et al. [10].

The physical properties of the briquettes determined were moisture content, bulk density, shatter resistance, degree of densification. The thermal properties determined were calorific value, volatile matter content, ash content and fixed carbon content.

Fig. 4 Oven-dried briquettes of sample 1

Fig. 5 Oven-dried briquettes of sample 2

Moisture Content

Oven-drying method is used to find out the total moisture present on the sample. The sample was placed in the oven at 105 °C for 16 h. The loss in weight was calculated by using the following formula:

$$\text{M.C. } (\%\ \text{wb}) = \frac{W2 - W3}{W2 - W1} \times 100$$

Here, $W1$ denotes the weight of the empty crucible, $W2$ denotes weight of crucible with the sample and $W3$ denotes $W2$ after drying, all units in gram.

Bulk density

The bulk density of material was found out by using by weighing the mass of the sample and measuring its volume and then using the formulae:

$$\text{Bulk density } \left(\frac{\text{Kg}}{\text{m}^3}\right) = \frac{\text{mass of the sample (kg)}}{\text{volume of the sample } (\text{m}^3)}$$

Shatter resistance test

This test was performed to see the strength of the briquettes against external forces. A piece of briquette would be dropped three times on a hard floor from a known height and the previous and later weight minus the initial weight would give the shatter resistance of the sample:

$$\text{Percent weight loss} = \frac{W1 - W2}{W1}$$

% shatter resistance = 100 – % weight loss

Here, $W1$ is the weight of briquette before shattering and $W2$ is the weight of briquette after shattering in grams.

Degree of Densification

Degree of densification shows us numerically, how much we could compact using our method of densification. We have to measure the density of the biomass before briquetting and after briquetting and put in the given formulae to find the degree of densification:

$$\text{Degree of densification} = \frac{\text{Density of briquette} - \text{Density of rawmaterial}}{\text{Density of the raw material}}$$

Energy Density Ratio

This particular ratio shows us how much of energy one unit volume of the briquetted sample can contain or produce when burned. This could simply be found using the following formulae:

$$\text{Energy density ratio} = \frac{\text{Energy content of briquetted fuel } \left(\frac{\text{Kcal}}{\text{m}^3}\right)}{\text{Energy content of raw biomass } \left(\frac{\text{Kcal}}{\text{m}^3}\right)}$$

Thermal properties analysis of the briquette samples

The most important among the thermal analysis test of briquettes are the calorific value, ash content, volatile matter and fixed carbon.

Calorific Value, kcal/kg

The calorific value of the sample can be found using an instrument called a bomb calorimeter. Where a small amount of sample is burnt with 25 atmospheric pressure of oxygen. Once the combustion starts, the change in the temperature is noted until a peak value is obtained and the reading gradually decreases. The following formulae is used to determine the calorific value:

$$\text{Calorific value } \left(\frac{\text{Kcal}}{\text{kg}}\right) = \frac{(W + W) \times (T2 - T1)}{X}$$

where

W is the mass of water used in the calorimeter (2000 g),

w is the water equivalent of the apparatus (455 g),

$T1$ = Initial temperature of the water inside the calorimeter (°C),

$T2$ = Final temperature of the water in the calorimeter (°C), X = Mass of fuel sample taken in the crucible (g).

Volatile Matter

The sample after drying is weighed and placed in a crucible with a lid. The covered crucible was then placed in a muffle furnace whose temperature is set to 950 ± 20 for 7 min. Once the sample cools down, the weight is measured and the difference of the weight was reported as volatile matter on percentage basis

$$\text{Volatile Matter } (\%) = \frac{W3 - W4}{W2 - W1}$$

where

$W1$ denotes weight of the crucible, $W2$ denotes weight of crucible with the sample taken,

$W3$ denotes weight of crucible with sample after moisture removal and $W4$ denotes weight of crucible with the sample after heating in a muffle furnace, all units in grams.

Ash Content

For this analysis, the sample is placed in a closed crucible which was then heated in a muffle furnace at 700 ± 50 °C for one and a half hours. After cooling the sample in a desiccator, the sample is weighed for every half an hour for the weight loss until a constant weight is obtained. Weight of ash divided by the initial weight of the sample is the ash content of the sample:

$$\text{A.C.}\,(\%) = \frac{W3 - W1}{W2 - W1} \times 100$$

where

$W1$ = weight of the empty crucible, g
$W2$ = weight of crucible + sample taken from the second stage
$W3$ = weight of crucible + ash left in crucible, g.

Fixed Carbon

The mass balance formula was used for the calculation given below.

$$\text{Fixed Carbon }(\%\ ) = 100 - \ \%\ \text{of}(MC + VM + AC)$$

where

FC = Fixed carbon, MC = Moisture content, VM = Volatile matter and AC = Ash content, all in percentage value.

Techno-economic Analysis

For making the briquettes reported in this paper, we require a low-power screw press briquetting machine of rating 0.7 Kwatt to continuously produce the briquettes. A heating vessel could be used to gelatinize the taro tuber. Cutting and cleaning of the tubers can be done using any cutting tools like knife as they are soft, but gloves are required for the job as the oxalic acid content may cause itching in the body part that came into contact with the tuber. The raw material used for the study was grass, which is being cut and disposed as waste in the campus and the sawdust was procured from a nearby shop. The cleaver's knife used in the study was also obtained from a nearby blacksmith shop. So, the capital cost of the machine can be a sum of the briquetting machine which cost INR 8000, the cost of locally made cleaver's knife is INR 300, any heating vessel cost is around INR 150. So, the capital cost amounts to INR 8450.

For the operational cost, the grass was brought from the field to the working site in a cart manually pulled by a labour. The labour cost charged for it was INR 100 per cart, which was used throughout the study to make almost 3–4 kg of briquettes. The cost of the sawdust was INR 90 for one bag (1.5 m × .5 m) dimension. INR 100 for bringing it to the destination. The time required for preparation of the grass is 2 h and taro preparation takes just 20 min and preparing the mixture and putting in the briquetting machine to get the output will take another 1 h. Therefore, the total labour cost will be according to labour wage chart by Wikipedia, i.e. 70 INR per hour, equals to 280 INR (approx.) per labour [31]. Electricity cost for 0.7 unit equals 65 INR (approx.) including fixed charge, metre rent and energy charge [32]. Therefore, the total operational cost to produce 3–4 kg of briquettes two labourers costing 560 INR plus 200 INR transportation and 45 INR(for half bag) raw material accounting to an amount of 870 INR.

2 Results and Discussion

The briquettes (samples 1 and 2) (Figs. 4 and 5) obtained from the machine used were cylindrical. The average length of the briquettes measure during the analysis period was found to vary from 4 cm to 9 cm and radius is 1.25 cm.

Physical properties

Sl no.	Sample	Composition	Bulk density (g/cm^3)	Shatter resistance (%)	Degree of densification
1	1	Grass: Sawdust::75:25	0.234	73.52	0.054
2	2	Grass: Sawdust::50:50	0.233	83.55	0.078

Thermal properties

Sl no.	Sample	Composition	Moisture	Ash	Calorific	Volatile	Fixed	
		Grass:SawDust	Content	Content	Value	Mater	Carbon (%)	
			(%)	(%)	(MJ/kg)	(%)	Dry	Wet
1	1	75:25	0.38	4.08	15.539	86.71	9.20	8.83
2	2	50:50	0.54	4.618	14.683	88.93	6.45	5.91

3 Conclusion

Two briquette samples were successfully prepared using grass and sawdust in different proportions and analysed. The following conclusions were made

Taro tuber could not bind at a proportion less than 40% by weight of the biomass taken. 100% grass sample could not be prepared in the machine used in the study. The process of chopping the grass to a smaller size using cleaver knife was very time consuming and less efficient, so in future, a grass chopping machine could be designed in order to optimize the time required to process higher amount of biomass. Oven-drying gives good result but this facility cannot be availed by the rural people, so the test can be performed by sun drying in the future work. The compaction density was low when compared to other works reported in the literatures cited. Sample 2 showed better physical characteristics and sample 1 had better thermal properties.

References

1. http://niti.gov.in/content/electricity-and-clean-cooking-strategy-india. Accessed 16 Oct 2017
2. https://scroll.in/article/747551/67-of-indias-rural-households-still-use-firewood. Accessed 16 Oct 2017
3. Quereshi, S., Ahmad, E., Pant, K.K., Dutta, S.: Recent advances in production of biofuel and commodity chemicals from algal biomass. In: Algal Biofuels, pp. 393–419. Springer International Publishing, Cham (2017)
4. Chandra, R., Takeuchi, H., Hasegawa, T.: Methane production from lignocellulosic agricultural crop wastes: a review in context to second generation of biofuel production. Renew. Sustain. Energy Rev. **16**(3), 1462–1476 (2012)
5. Guo, X.M., Trably, E., Latrille, E., Carrere, H., Steyer, J.P.: Hydrogen production from agricultural waste by dark fermentation: a review. Int. J. Hydrogen Energy **35**(19), 10660–10673 (2010)
6. Sarkar, N., Ghosh, S.K., Bannerjee, S., Aikat, K.: Bioethanol production from agricultural wastes: an overview. Renew Energy **37**(1), 19–27 (2012)
7. Hobson, P.N.: Biogas production-agricultural wastes. Rep, Watt Comm Energy **5**, 37–44 (1979)
8. Sansaniwal, S.K., Pal, K., Rosen, M.A., Tyagi, S.K.: Recent advances in the development of biomass gasification technology: a comprehensive review. Renew. Sustain. Energy Rev. **72**, 363–384 (2017)
9. Bhattacharya, S.C., Sett, S., Shrestha, R.M.: State of the art for biomass densification. Energy Sources **11**(3), 161–182 (1989)
10. Birwatkar, V.R., Khandetod, Y.P., Mohod, A.G., Dhande, K.G., Source, O.E., Dapoli, T.: Physical and thermal properties of biomass briquetted fuel. Ind. J. Sci. Res. Tech **2**(4), 55–62 (2014)
11. Kaliyan, N., Morey, R.V., White, M.D., Doering, A.: Roll press briquetting and pelleting of corn stover and switchgrass. Transactions of the ASABE **52**(2), 543–555 (2009)
12. Florentino-Madiedo, L., Díaz-Faes, E., Barriocanal, C., Castro-Díaz, M., Snape, C.E.: Importance of biomass and binder selection for coking briquette preparation. Their effect on coal thermoplastic properties. Energy & Fuels **32**(10), 10727–10736 (2018)
13. Muazu, R.I., Stegemann, J.A.: Biosolids and microalgae as alternative binders for biomass fuel briquetting. Fuel **194**, 339–347 (2017)
14. Wu, S., Zhang, S., Wang, C., Mu, C., Huang, X.: High-strength charcoal briquette preparation from hydrothermal pretreated biomass wastes. Fuel Process. Technol. **171**, 293–300 (2018)
15. Rahaman, S.A., Salam, P.A.: Characterization of cold densified rice straw briquettes and the potential use of sawdust as binder. Fuel Process. Technol. **158**, 9–19 (2017)
16. Emadi, B., Iroba, K.L., Tabil, L.G.: Effect of polymer plastic binder on mechanical, storage and combustion characteristics of torrefied and pelletized herbaceous biomass. Appl. Energy **198**, 312–319 (2017)
17. Xue, Z., Liu, Q., Emmanuel, P., Qin, J., Liu, D., Gao, W., Bai, X.: Analysis on the effects of pre-heating temperature on mechanical properties of pellets made from corn stalk powder. Int. J. Heat Technol. **35**(2), 421–425 (2017)
18. Shahapur, A., Desai, N.M., Kader, M.A.: Biomass briquette as an alternate source of energy-an economic feasibility analysis. J. S. Pac. Agric. **20**, 25–33 (2018)
19. Tumuluru, J.S., Wright, C.T., Kenney, K.L., Hess, R.J.: A technical review on biomass processing: densification, preprocessing, modeling and optimization. In: 2010 ASABE Annual International Meeting, June 2010
20. Bhatkar, O.P., Patil, S.S., Tambe, S.P., Wafelkar, N.N., Manjarekar, P.P.: Design and fabrication of densified biomass briquette maker machine. Int. J. Environ. Agric. Biotechnol. **2**(2), 0805–0807

21. Karunanithy, C., Wang, Y., Muthukumarappan, K., Pugalendhi, S.: Physiochemical characterization of briquettes made from different feedstocks. Biotechnol. Res. Int. **2012**, 12 (2012)
22. Beker, Ü.G.: Briquetting of Afşin-Elbistan lignite of Turkey using different waste materials. Fuel Process. Technol. **51**(1–2), 137–144 (1997)
23. Sotannde, O.A., Oluyege, A.O., Abah, G.B.: Physical and combustion properties of briquettes from sawdust of Azadirachta indica. J. For. Res. **21**(1), 63–67 (2010)
24. Kishan, B.S., Kumar, K., Santhosh, T.J., Gangadhar, A.D.: Design and fabrication of low cost briquetting machine and estimation of calorific values of biomass briquettes. Int. J. Innov. Res. Sci. **5**(7), 12454–12461 (2016)
25. Zhanbin, C.: Normal temperature briquetting technology for biomass with original moisture content. In: International Conference on Bioenergy Utilisation and Environmental Protection, 6th LAMNET Workshop-Dalian, China, pp. 1–6
26. http://www.agrifarming.in/taro-root-farming/. Accessed 17 Oct 2017
27. Jane, J., Shen, L., Chen, J., Lim, S., Kasemsuwan, T., Nip, W.: Physical and chemical studies of taro starches and flours1 2. Cereal Chem. **69**(5), 528–535 (1992)
28. Agama-Acevedo, E., Garcia-Suarez, F.J., Gutierrez-Meraz, F., Sanchez- Rivera, M.M., San Martin, E., Bello- Pérez, L.A.: Isolation and partial characterization of Mexican taro (Colocasia esculenta L.) starch. Starch-Stärke **63**(3), 139–146 (2011)
29. Lu, T.J., Lin, J.H., Chen, J.C., Chang, Y.H.: Characteristics of taro (Colocasia esculenta) starches planted in different seasons and their relations to the molecular structure of starch. J. Agric. Food Chem. **56**(6), 2208–2215 (2008)
30. Moorthy, S.N.: Extraction of starches from tuber crops using ammonia. Carbohyd. Polym. **16** (4), 391–398 (1991)
31. https://en.wikipedia.org/wiki/List_of_minimum_wages_by_country. Accessed 1 Dec 2018
32. https://www.bijlibachao.com/electricity-bill/online-electricity-bill-calculator-for-all-states-in-india.html. Accessed 1 Dec 2018

Indigenous Household Groundwater Filter Unit of North Guwahati (Assam) for Iron and Fluoride Removals

Ankit Soni and Mohammad Jawed

Abstract The rural population of Amingaon, North Guwahati (Assam) relies heavily on groundwater for their domestic needs. But groundwater is reported to be contaminated with excessive amounts of iron and fluoride. The population uses indigenous household groundwater filter units for iron removals. These units are fabricated using reinforced cement concrete (RCC) circular pipes, tin containers, and plastic buckets with river sand, wooden charcoal (in some cases), and gravel serving as filtering media either in layered or mixed form. The present work aims to review and document the different types of indigenous household groundwater filter units being used in this area. In addition, efforts are also made to evaluate the performance of a selected filter unit for iron and fluoride removal from the groundwater. The iron concentration in groundwater of Amingaon, North Guwahati varies from 0 to 11.03 mg/L exceeding the permissible limit for drinking water (0.3 mg/L), whereas fluoride concentration varies from 0.10 to 0.68 mg/L—always meeting the permissible limit 1.5 mg/L. A selected indigenous household groundwater filter unit is monitored to assess its performance over a period of 86 days. The filter unit is found to be highly effective in iron removal of 99% or more from an initial concentration of 1.33–2.08 mg/L down to 0–0.2 mg/L meeting the limit of drinking water quality. The iron removal is mainly due to increase in DO levels which precipitates out the iron and the precipitated iron is filtered out through the filter unit. The concentration of fluoride in the groundwater is not exceeding the permissible limit of 1.5 mg/L. Fortunately, the filter unit is not reducing the fluoride concentration present in the groundwater.

Keywords Indigenous household groundwater filter unit · Drinking water · Iron · Fluoride · Groundwater · North Guwahati

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1 Introduction

Groundwater is the major source of freshwater, which contributes 29% of total available freshwater on the earth. Roughly, 2 billion people in the world are dependent on groundwater for their daily needs and irrigation purposes. Groundwater fulfills 50% of agricultural needs and 80% of total drinking and cooking water requirements in rural India [12]. But groundwater is generally contaminated with iron, fluoride, arsenic, and nitrate. Assam, a northeastern state of India is facing the problem of fluoride and iron contamination in groundwater. Karbi Anglong and Nagaon districts are severely affected by the fluorosis problem [4]. Fluoride concentration varies from 0.2 to 18.1 mg/L in groundwater of Assam [12]. In and around Guwahati city, fluoride and iron concentration in groundwater varies from 0.2 to 6.9 mg/L [5] and from 1 to 10 mg/L [1], respectively. Iron does not cause any harmful effect on human health but this is unacceptable due to its visual appearance and taste. Excessive concentration of fluoride in drinking water severely affects human health. Fluoride concentration more than 1.5 mg/L causes dental and skeletal fluorosis [17]. The prescribed limits of iron and fluoride in drinking water are 0.3 mg/L and 1.5 mg/L, respectively [9].

Many treatment techniques have been developed all over the world for iron [2, 6, 7, 13, 18]; Polasky [15] and fluoride removal [19, 8, 10, 11, 14, 16] from groundwater. But these techniques are not widely used in rural and semi-urban areas due to its high capital and operational cost, and unavailability of raw materials in rural areas. The rural population of Assam is using indigenous household groundwater filter units to remove excessive iron concentration from groundwater [1]. Fluoride remains in dissolved form in groundwater and does not give any visual appearance, in contrast to iron, thereby escaping the attention. The design and operation of indigenous household groundwater filter is based on traditional knowledge and experiences of rural people. Sand, gravel, and charcoal are generally used as a filter media as these materials are cheap and locally available to rural community.

Rural population of Amingaon—a village located in the North Guwahati area of Assam is heavily dependent on groundwater for their daily needs. However, no attempts have been made to assess iron and fluoride contaminations in groundwater of Amingaon. The people of Amingaon are using different types of indigenous household groundwater filter units to remove excessive iron contamination from groundwater. Unfortunately, the detailed scientific studies are lacking to document the fabrication and operation of different types of filter units in use, to assess the capability of the filter units for contaminant (iron and fluoride) removal. Hence, this research work is focused to understand the fabrication and operation of different types of filter units in use, to assess iron and fluoride contaminations in groundwater of Amingaon (North Guwahati) and to monitor the performance of a selected indigenous household groundwater filter unit.

2 Materials and Methods

2.1 Field Survey

In order to understand the fabrication and operation of different types of filter units in use and to assess iron and fluoride contaminations in groundwater of Amingaon (North Guwahati), a field survey was carried out during mid-June 2017–mid-July 2017 in and around rural areas located just outside the boundary of IIT Guwahati. During the course of field survey, the location of filter units was obtained by GPS. The information related to fabrication and operation of the filter units were obtained through personal interactions with the houseowner (or the landlady). Photographs were also collected for the filter units. In addition, groundwater samples were also collected to assess iron and fluoride levels in the groundwater.

2.2 Monitoring of Selected Indigenous Household Groundwater Filter Unit

The filter unit in the House-B (GPS location: 26° 11′ 01.7″ N and 91° 41′ 38.7″ E) was selected for continuous monitoring. The reasons for selecting this filter unit were: (a) the source of groundwater was located at a distance from the bank of river Brahmaputra with possibly minimum infiltration of river water and (b) filter location was close to the Environmental Engineering Laboratory of the Department of Civil Engineering, IIT Guwahati (at a distance of 400–500 m), which shall facilitate in quick transportation of the collected water samples and its analysis.

The household of the selected house collects the water from the groundwater source, stores it and then filters the stored water according to their needs. Hence, it was deemed essential to collect three samples at a time—the first sample was collected directly from the tube well (i.e., source groundwater), the second was collected from the stored water, and the third one was collected from the filtered water. The collected samples were analyzed for temperature, pH, DO, iron and fluoride—taken as important water quality parameters for monitoring of filter performance. The water samples were collected once in 3 days and analyzed since July 2017.

2.3 Methods

Temperature, pH, dissolved oxygen (DO), iron, and fluoride were selected as water quality parameters and were thus analyzed during the research work. Temperature and pH were determined by the digital pH meter (Model: LT-49, M/S Labtronics Pvt. Ltd., India). DO was determined by the Azide Modification method [3]. Iron concentration in water was analyzed by Phenanthroline method [3] using spectrophotometer (Model: Spectro V-11D, M/S MRC Ltd., UK). Residual fluoride was analyzed by SPADNS method [3] using spectrophotometer. GPS locations were obtained using a smart mobile phone (Model: P5 W, M/S Gionee, India).

3 Results and Discussion

3.1 Field Survey

A field survey was carried out in Amingaon, North Guwahati area of indigenous household groundwater filter units in use in the households located outside the boundary of IIT Guwahati. During the survey, the households having groundwater filter unit in use were selected for gathering information with respect to: (i) procedure followed for fabrication of filter unit type, (ii) operation and maintenance of the filter units, and (iii) quality of groundwater with special attention on iron and fluoride concentrations. The relevant information was obtained through personal face-to-face interaction with the houseowner (or the landlady). In addition, the obtained information was further supplemented with photographic evidences collected for the filter unit in use. The groundwater samples were also collected from the surveyed household for the assessment of concentrations of iron and fluoride. A brief summary of the representative filter units in use as observed during field survey is presented in Table 1. The filter units were generally fabricated using plastic buckets, reinforced cement concrete (RCC) rings, and tin containers depending upon economic condition of respective households. Sand, gravel, and wooden charcoal (in some locations) were used as filtering media either in separate layer form or as a mixture of two or three mediums. Sand and wooden charcoal both were procured from the village market of Amingaon. Some of the filter units also used plastic net to prevent passage of sand to filtered water. The ranges of iron and fluoride concentration in the groundwater of the surveyed locations are 0–11.03 mg/L and 0.10–0.68 mg/L, respectively.

3.2 Monitoring of Selected Indigenous Household Groundwater Filter Unit

Usually, the female members of the family of the selected house (House-B) draws the groundwater from a nearby tube well, store it for a few minutes to hours, and then filter it according to their requirement of drinking and cooking water. On an average, everyday 20 L water is filtered out to meet the requirement of drinking and cooking purposes. After operation of the filter unit for a few days, black color coating is formed on the top layer of filter media (i.e., on sand particles), and

Table 1 Summary of indigenous household groundwater filter unit types in use in Amingaon, North Guwahati

Location details	Description of filter unit type in use and source groundwater quality		
House-A at Ghoramara (400 m from IIT boundary) GPS Coordinates: 26° 11′ 11.6″ N, 91° 42′ 08.2″ E	Filter unit fabricated using a plastic bucket of 29 cm internal diameter and 37 cm height. Filter media comprises of mixture of sand, gravel and a little amount of charcoal. Source groundwater contained 0.22 and 0.45 mg/L of iron and fluoride, respectively	 Front view	 Top view
House-B at Lothia Bagisa (300–400 m from IIT boundary) GPS Coordinates: 26° 11′ 01.7″ N, 91° 41′ 38.7″ E	Filter media placed in a circular plastic bucket of 38 cm internal diameter and 30 cm height in layered form of 13 cm each—sand (on top) and gravel (at bottom). Plastic net placed at the bottom of filter bed to prevent sand particles from passing to filtered water. Source groundwater contained 1.13 and 0.64 mg/L of iron and fluoride, respectively	 Front view	 Top view
House-C at Ghoramara (50 m from IIT boundary). GPS Coordinates: 26° 11′ 10.6″ N, 91° 42′ 02.4″ E	Two circular RCC pipes used for filter unit—top pipe holds filter media in layered form (14 cm sand layer above 7 cm of gravel bed) and bottom pipe stores filtered water. Plastic net placed below sand bed to prevent washing of sand to filtered water. Source groundwater contained 11.03 and 0.68 mg/L of iron and fluoride, respectively	 Front view	 Top view

(continued)

Table 1 (continued)

Location details	Description of filter unit type in use and source groundwater quality		
	Filtered water from the unit used for washing purposes. Constructed using single circular RCC pipe. Sand and gravel mixed to form filter bed of 60 cm depth. Bricks placed on top to prevent disturbing sand bed during pouring of water into the filter. Source groundwater contained 11.03 and 0.68 mg/L of iron and fluoride, respectively	 Front view	 Top view
House-B at Lothia Bagisa (300–400 m from IIT boundary) GPS Coordinates: 26° 11′ 01.7″ N, 91° 41′ 38.7″ E	Household filter unit constructed using two circular RCC pipes with internal diameter 43 cm and height 86 cm. Top RCC pipe holds filter media in layered form—on top 13–17 cm sand, in middle 10–13 cm charcoal and at bottom 10–13 cm gravel and the bottom RCC pipe stores filtered water. Source groundwater only contained 0.10 mg/L of fluoride (but no iron)	 front view	 Top view
House-C at Ghoramara (50 m from IIT boundary). GPS Coordinates: 26° 11′ 11.2″ N, 91° 42′ 02.6″ E	Tin container used to fabricate the filter unit. Filter bed of 24 cm depth prepared by mixing sand and charcoal and placed into the container. Plastic net placed at bottom of the container to prevent sand from passing to the filtered water. Source groundwater contained 3.73 and 0.63 mg/L of iron and fluoride, respectively	 Front View	 Bottom View

clogging problem appears in the filter unit. Filter unit needs dismantling and reinstallation after every 45–60 days of continuous operation to eliminate the problem of clogging and black color coating on sand particles.

As a part of continuous monitoring for assessment of the performance of filter unit operating at the House-B, it was decided to collect three samples at a time every third day—the first is collected directly from the tube well (i.e., source groundwater), the second is collected from the stored water, and the third one i collected from the filtered water. Water quality parameters, namely temperature, pH, DO, iron, and fluoride concentrations were considered relevant for performance monitoring and analyzed for the collected samples. The variations in concentrations of iron and fluoride are shown in Fig. 1, pH and temperature in Fig. 2, and DO in Fig. 3. In groundwater (source) samples, temperature varied from 25.8 to 29.9 °C, pH from 6.37 to 6.69, DO from 0 to 0.5 mg/L, iron from 1.33 to 2.08 mg/L, and fluoride from 0.56 to 0.67 mg/L. In stored groundwater sample, the range of variation in temperature, pH, DO, iron, and fluoride were 26.1–30.3 °C, 6.49–7.03, 3.6–6.6 mg/L, 0.05–1.63 mg/L, and 0.55–0.65 mg/L, respectively. It is important to note that upon storage of fresh groundwater, there was an increase in DO levels from 0 to 0.5 mg/L to 3.6 to 6.6 mg/L leading to reduction of dissolved iron concentration from 1.33 to 2.08 mg/L to 0.05 to 1.63 mg/L. However, there was no impact on fluoride concentration upon storage. The stored groundwater with reduced dissolved iron served as the input for the filter unit. Filtered water samples showed the variation in temperature from 26.6 to 30.6 °C, pH from 6.75 to 7.54, iron from 0 to 0.2 mg/L, and fluoride from 0.48 to 0.64 mg/L. DO was not estimated for filtered water samples. The filter unit consistently produced filtered water with iron concentration less than 0.3 mg/L—the regulatory limits for drinking purposes during the monitoring period. Fluoride concentration of all three samples (groundwater, stored water and filtered water) did not show any significant changes during the monitoring period. pH always remained in the following order: groundwater pH $\leq$ stored water pH $\leq$ filtered water pH. DO was measured only

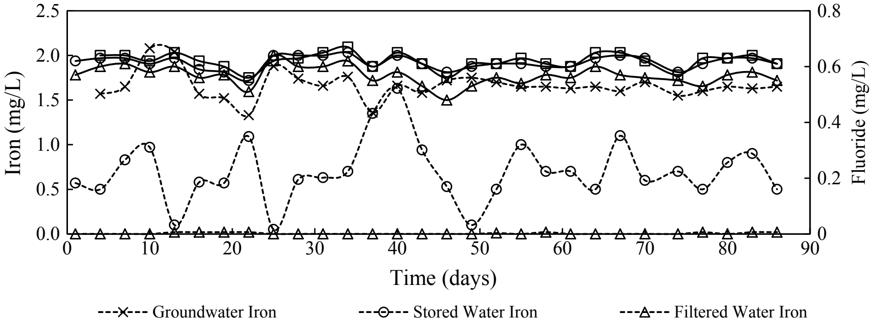

Fig. 1 Variation in iron and fluoride concentrations during the monitoring period of the filter unit

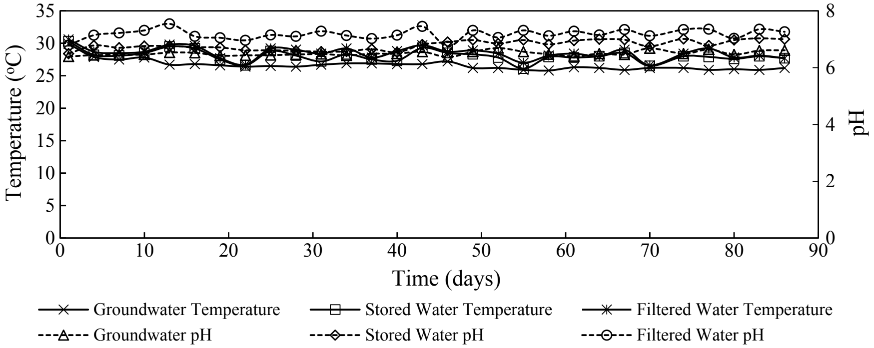

Fig. 2 Variation in temperature and pH levels during the monitoring period of the filter unit

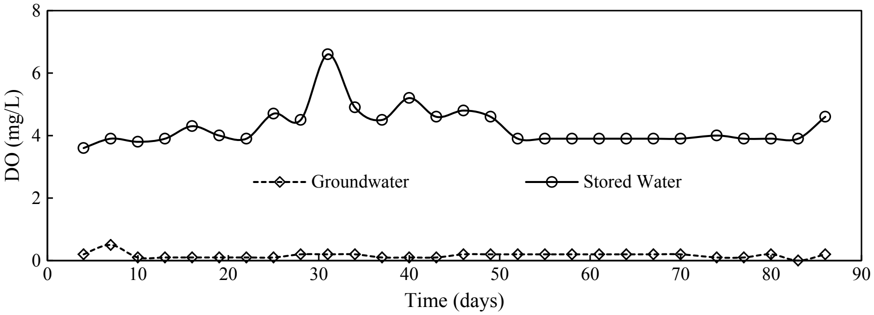

Fig. 3 Variation in DO concentrations during the monitoring period of the filter unit

for the groundwater and stored water (input). Groundwater showed very less DO level, whereas stored water showed variations in DO level; it changed according to the weather condition and storage time of water. Table 2 presents the summary of the performance parameters of filter unit during 3 months of monitoring.

The monitoring works clearly indicated that the iron concentration was the highest in the source groundwater which reduced by more than 50% upon storage for a few hours. During storage, DO levels increase led to precipitation of iron. The filter unit consistently indicated iron removal of 99% and more possibly the sand bed acted as a filter to remove the unsettled iron precipitate. The filter unit was not able to remove fluoride contamination from groundwater. The pH always remained in its permissible limit for drinking water (6.5–8.5). After operation of the filter unit for a few days, black color coating on sand particles was formed. The black coating looked bad esthetically and possibly led to clogging of the filter.

Table 2 Summary of performance parameter of the selected filter unit during 1–86 d of monitoring

Monitored water Quality parameters		Monitoring days		
		1–31	34–61	64–86
Iron (mg/L)	Ground water	1.07 ± 0.24 (10)	1.65 ± 0.48 (10)	1.63 ± 0.15 (8)
	Stored water	0.59 ± 0.32 (11)	0.82 ± 0.44 (10)	0.70 ± 0.22 (8)
	Filtered water	0.01 ± 0.01 (11)	0.00 ± 0.01 (10)	0.01 ± 0.01 (8)
Fluoride (mg/L)	Ground water	0.62 ± 0.03 (10)	0.61 ± 0.03 (11)	0.62 ± 0.03 (8)
	Stored water	0.61 ± 0.03 (11)	0.61 ± 0.02 (10)	0.62 ± 0.02 (8)
	Filtered water	0.59 ± 0.03 (11)	0.55 ± 0.04 (10)	0.56 ± 0.02 (8)
Temperature (°C)	Ground water	27.2 ± 1.04 (11)	26.5 ± 0.48 (10)	26.6 ± 0.15 (8)
	Stored water	28.3 ± 1.06 (11)	27.8 ± 0.84 (10)	27.8 ± 0.58 (8)
	Filtered water	28.8 ± 1.05 (11)	28.1 ± 0.76 (10)	28.1 ± 0.81 (8)
pH	Ground water	6.46 ± 0.04 (11)	6.50 ± 0.09 (10)	6.55 ± 0.09 (8)
	Stored water	6.66 ± 0.10 (11)	6.80 ± 0.16 (10)	6.94 ± 0.11 (8)
	Filtered water	7.14 ± 0.20 (11)	7.16 ± 0.20 (10)	7.24 ± 0.13 (8)
DO (mg/L)	Ground water	0.17 ± 0.13 (10)	0.17 ± 0.05 (10)	0.15 ± 0.08 (8)
	Stored water	4.32 ± 0.87 (10)	4.42 ± 0.49 (10)	4 ± 0.24 (8)

[The data is presented in aa ± bb (cc) format where aa is the average value, bb is the standard deviation, and cc is the number of data points considered for obtaining average and standard deviation]

4 Conclusion

The iron concentration in groundwater of Amingaon, North Guwahati varies from 0 to 11.03 mg/L exceeding the permissible limit for drinking water (0.3 mg/L), whereas fluoride concentration varies from 0.10 to 0.68 mg/L—always meeting the permissible limit 1.5 mg/L. The population is using different types of indigenous household groundwater filter units to remove excessive iron concentration from groundwater to make it suitable for potable purposes. The filter units are fabricated using locally available materials such as plastic bucket, tin container, or circular reinforced cement concrete pipes for filter body. The sand, gravel, and charcoal (in some cases) either in layered form or a mixture of two and three media is used filter media. A selected indigenous household groundwater filter unit is monitored to assess its performance over a period of 86 days. The filter unit is found to be highly effective in iron removal of 99% or more from an initial concentration of 1.33–2.08 mg/L down to 0–0.2 mg/L meeting the limit of drinking water quality. The iron removal is mainly due to increase in DO levels, which precipitates out the iron and the precipitated iron is filtered out through the filter unit. The concentration of fluoride in the groundwater is not exceeding the permissible limit of 1.5 mg/L. Fortunately, the filter unit is not reducing the fluoride concentration present in the groundwater.

References

1. Ahamad, K. U.: Batch and Column Adsorption Studies for Simultaneous Removal of Iron, Arsenic and Fluoride by Wooden Charcoal and River Sand Used as Filter Media in Indigenous Household Iron Filter Units of Rural and Semi-Urban Assam (India). Doctor of Philosophy Thesis, Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati, Assam, India (2010)
2. Andersson, H., Johansson, J.: Iron Removal from Groundwater in Rakai District, Uganda: A Minor Field Study. Master of Technology Thesis, Lulela University of Technology, Lulela, Sweden. (http://www.diva-portal.org/smash/get/diva2:1027702/FULLTEXT01.pdf (2002). Website last accessed on 21 Nov 2017
3. APHA: Standard Methods for the Examination of Water and Wastewater, 20th edn. American Public Health Association, American Water Works Association and Water Environment Federation, Washington, DC, USA (2012)
4. Chakraborti, D., Chanda, C.R., Samanta, G., Chowdhury, U.K., Mukherjee, S.C., Pal, A.B., Sing, B.: Fluorosis in Assam, India. Curr. Sci. **78**(12), 1421–1423 (2000)
5. Das, B., Talukdar, J., Sarma, S., Gohain, B., Dutta, R.K., Das, H.B., Das, S.C.: Fluoride and other inorganic constituents in groundwater of Guwahati, Assam, India. Curr. Sci. **85**(5), 657–661 (2003)
6. Dhadge, V.L., Medhi, C.R., Changmai, M., Purkait, M.K.: House hold unit for the treatment of fluoride, iron, arsenic and microorganism contaminated drinking water. Chemosphere **199**, 728–736 (2018)
7. Feizi, M., Jalali, M.: Removal of heavy metals from aqueous solutions using sunflower, potato, canola and walnut shell residues. Journal of the Taiwan Institute of Chemical Engineers **54**, 125–136 (2015)
8. Hallagodage, J.L., Jayapadma, J.M.M.U., Chaminda, G.T., Kawakami, T. Removal of heavy metals and fluoride from contaminated groundwater using locally available materials. In Proceedings at the Undergraduate Research Symposium on Recent Advances in Civil Engineering (2016)
9. IS 10500: Specification for Drinking Water. Bureau of Indian Standards, New Delhi (1991)
10. Kofa, G.P., Gomdje, V.H., Telegang, C., Koungou, S.: Removal of fluoride from water by adsorption onto fired clay pots: Kinetics and equilibrium studies. J. Appl. Chem. **2017**, 1–7 (2017)
11. Korir, H., Mueller, K., Korir, L., Kubai, J., Wanja, E., Wanjiku, N., Johnson, C.: The development of bone char based filters for the removal of fluoride from drinking water. In Proceedings at 34th WEDC International Conference, Addis Ababa, Ethiopia (2009)
12. Maheshwari, R.C.: Fluoride in drinking water and its removal. J. Hazard. Mater. **137**(1), 456–463 (2006)
13. NEERI: *Handbook on Drinking Water Treatment Technologies*. Government of India. http://www.indiawater.gov.in/misc/Docs/ProvenTech.pdf (2013). Website last accessed on 18 Oct 2017
14. Phantumvanit, P., Songpaisan, Y., Moller, I.J.: A defluoridator for individual households. World Health Forum **9**, 555–558 (1988)
15. Polasky, R.A.: Apparatus for removal of iron from drinking water. U.S. Patent No. 5,180, 491 (1993)
16. Sajidu, S., Kayira, C., Masamba, W., Mwatseteza, J.: Defluoridation of groundwater using raw bauxite: rural domestic defluoridation technology. Environment and Natural Resources Research **2**(3), 1–9 (2012)

17. Sawyer, C.N., McCarty, P.L., Parkin, G.F.: Chemistry for environmental engineering and science, 4th edn. Tata Mc Graw-Hill, New Delhi, India (2003)
18. Siwila, S., Chota, C., Yambani, K., Sampa, D., Siangalichi, A., Ndawa, N., Tambwe, G.: Design of a small scale iron and manganese removal system for Copperbelt University's borehole water. J. Environ. Geology **1**(1), 24–30 (2017)
19. Tirkey, P., Bhattacharya, T., Chakraborty, S.: Optimization of fluoride removal from aqueous solution using Jamun (Syzygium cumini) leaf ash. Process Saf. Environ. Prot. **115**, 125–138 (2018)

Biohydrogen Production Through Dark Fermentation of Food Wastes by Anaerobic Digester Sludge Mixed Microbial Consortium

Adiba Fatima, Bikram Basak, Amit Ganguly, Pradip K. Chatterjee and Apurba Dey

Abstract Food waste is a promising renewable feedstock, which contains a significant amount of fermentable carbohydrate for biohydrogen production. The present research was conducted to investigate the effects of pH (5–7), chemical oxygen demand (COD) in food waste (8–10.8 g/L), and different substrate pretreatment methods on biohydrogen production from food waste. Inoculum enrichment was done by treating anaerobic digester sludge with 2-bromoethanesulfonate (BES) to inhibit methanogenic microorganisms. Dark fermentation was carried out at an initial pH of 7 for 48 h at 37 °C. Total protein before and after fermentation is estimated to be 646.5 µg/mL and 0.1 µg/mL, respectively while total carbohydrate is found to be 5.38 mg/mL and 3.885 mg/mL, respectively. Volatile fatty acids and ethanol production accompanied biohydrogen production which was detected through HPLC. Under optimized conditions of pH 7, temperature 37 °C for 48 h and without any substrate pretreatment around maximum 52% H_2 was obtained in the produced biogas.

Keywords Biohydrogen · Food wastes · Dark fermentation · Pretreatment

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1 Introduction

The world is facing a major climate change caused due to the exploitation of fossil fuels by man. Combustion of fossil fuels results in the release of carbon, nitrogen, and sulfur oxides with trace amounts of soot, ash, tar droplets, and other organic compounds that contribute to the greenhouse effect. Therefore, the development of eco-accommodating fuel is the need of the hour. This is essentially important for the conservation of biodiversity and self-preservation of human life [1, 2]. Global warming and depletion of nonrenewable fuels are no longer a new issue to mankind and ceaseless efforts are being made to mitigate it [3]. This has driven researchers worldwide to develop renewable bioenergy technologies which on combustion does not endanger the environment. Biohydrogen (bioH_2), biomethane, bioethanol, and biodiesel contribute to energy-efficient biofuels produced by various chemical and biological processes but considering the present scenario which among the above can be used in the long run as a sustainable energy, fuel is still a question that is yet to be addressed by researchers [4, 5].

Hydrogen (H_2) is a fascinating alternative as it is clean, nonpolluting, easily recyclable, lighter than air, and has a high heating value (142 kJ/g) which is 2.75 times greater than hydrocarbon fuels [6]. It has the highest gravimetric energy density of 141 MJ/kg and low volumetric energy density at only 12 MJ/m^3 (under normal temperature and pressure) [7]. High gravimetric and low volumetric energy density are the two critical factors which facilitate it being used as a transportation fuel [8]. Its combustion produces high amounts of energy and water as the only reaction product and leaves no net carbon footprint. If bioH_2 technology as a sustainable fuel is to be realized relatively in the long term, further advances have to be made so that it can be called a versatile fuel both from technological and economical points of view [9–11].

Commercially hydrogen is being produced from fossil fuels, biomass, and water by steam reforming of natural gas, biomass gasification, water electrolysis, etc., which are driven by high energy input and subsequent increase in carbon dioxide emissions. This has drastically affected our greenhouse layer of the atmosphere. Biological hydrogen production methods stand out among a plethora of other processes because it is economical, an eco-friendly process in which microorganisms produce hydrogen from renewable biomass or wastewater through dark fermentation [12]. Among the various processes employed for biological hydrogen production, dark fermentation serves as the most promising and judicious technology than photofermentation due to its high production rate, yield, the utilization efficiency of various organic wastes and feedstock as substrate and its ability to catalyze the reaction without the presence of light. Thereby, manifesting no external energy input making it reliable and cost-effective [13, 14].

The magnitude of waste generated depends on lifestyle, the extent of commercialization, eating habits, and season. According to the United Nations Food and Agriculture Organization, approximately one-third of the total global food produced is wasted, costing the world economy about $750 billion. Globally, India currently ranks seventh in terms of overall food wastage of agricultural produce, poultry, and milk. It has been evaluated that around 67 million tonnes of food is wasted from India amounting to 92,000 crores; which is capable enough to feed all of an Indian state of Bihar for a year. Food waste generated by Mumbai alone amounts to 9,400 metric tonnes of solid waste per day of which 73% is food, vegetable, and fruit waste, while only 3% is plastic [15]. With numbers such as these current systems in the country are unable to cope up with this burden, subsequently leading to a negative impact on the environment and public health. Open landfills release various harmful gases such as methane which is an add-on to global warming. It also causes the formation of toxins and/or black leachate which oozes from the waste and is absorbed by the soil leading to groundwater contamination. These brim-full landfills have become the root cause of gridlocked drains, soil, and water pollution [15].

In view of economic consideration, bioH_2 production from waste is constructive as it reduces the cost to manage waste thereby increasing revenue from agricultural produce via its waste to energy conversion route. This has led to mitigating CO_2 emissions owing to the utilization of renewable biomass which has efficiently superseded fossil fuels. In the quest for the development of bioH_2 production, a major challenge that needs to be conquered is the increasing cost of feedstock if the substrates for hydrogen dark fermentation typically employ sucrose or starches which are not practically possible on an economic scale and also edible crops which will ultimately lead to food shortages. Biomass particularly waste and/or wastewater containing high concentrations of carbohydrates, discarded from textile and food processing industries, agricultural processes, municipal solid waste, and restaurant food waste are preferred for pecuniary reasons.

Food wastes are copious in nature and profusely dominated by carbon skeleton. It is a waste comprising of underdone and prepared food removed before or during food preparation from various domestic sources like a restaurant, canteens, etc. It has a high energy content and easily biodegradable because it comprises 85–95% of volatile solids and 75–85% of moisture favoring microbial fermentation. If managed properly it will thwart the leaching of pollutants into the groundwater [16]. Therefore, the biotransformation of food waste to bioenergy is a topic pursued by many scholars worldwide. Enhanced bioH_2 capability by anaerobic digestion of food waste is favored due to high moisture content, substrate concentration and carbon to nitrogen ratio [17]. pH, temperature, partial pressure of hydrogen, pretreatment of substrates, and inoculum enrichment are important physicochemical parameters that need to be monitored in order to uplift bioH_2 production [14]. To stimulate the degradation rate of food wastes, they have coalesced with water. Higher the degradation of food waste higher is the rate of hydrogen liberation [11–13]. Food waste is chemically composed of carbohydrate, protein, triglycerides, and polysaccharides such as starch, cellulose, and hemicelluloses. The major limiting step is the rate of hydrolysis of different components of food waste for energy inception. By far carbohydrate is considered to be a supreme substrate; however, fats and protein can also be exploited for energy liberation. It has been reported that there is a 20-fold increase in bioH_2 production rate utilizing carbohydrate-rich substrate compared to protein and lipid-rich substrates [15]. This paper envisages bioH_2 production by dark fermentation of food wastes utilizing mixed microbial consortia.

2 Materials and Methods

2.1 Enrichment of Mesophilic Hydrogen-Producing Microorganism

Anaerobic digester sludge was collected from biomethanation plant located in CSIR-CMERI colony, Durgapur, India. Prior to its usage, it was pretreated with 200 mM of 2-bromoethane sulfonic acid (2-BES) to inhibit the hydrogen consumers like methanogens and enrich hydrogen-producing bacteria.

2.2 Preparation of Food Waste

The collected food waste used as substrate was comprised of rice 40% (w/w), vegetable 35% (w/w), and lentils 25% (w/w). Renewable food waste was obtained from two cafeterias in and around NIT Durgapur, India. The food wastes were milled in an electric blender without the addition of water in order to make a homogeneous sample and stored in a sealed glass bottle at 4 °C until used.

2.3 Pretreatment of Substrate

Combination of enzymatic and heat treatment 80μL of amylase was added to the milled substrate and subjected to heating in a water bath at 90 °C for 1 h. After pretreatment, the substrate was cooled down and added to serum bottles along with mixed microbial consortia, 2-BES, and phosphate buffer. The mixed solution was adjusted to pH 7 by the addition of NaOH. This was kept in incubation at 37 °C for 72 h.

Combination of enzymatic, heat, and sparging of nitrogen gas 80μL of amylase was added to the milled substrate and subjected to heating in a water bath at 90 °C for an hour. After pretreatment, the substrate was cooled down and added to serum bottles along with mixed microbial consortia, 2-BES, and phosphate buffer. A swarm of nitrogen gas was sparged for 2–3 min to create anaerobic environment in the reactor. This was kept in incubation at 37 °C for 48 h.

Combination of physical and enzymatic treatment The food wastes were subjected to microwave heating for 10 min at 400 W followed by sonication for 20 min at 40 °C and 80 μL of glucoamylase was added and heated at 40 °C for 2 h.

2.4 *Batch Acidogenic Fermentation of Food Waste*

Pretest experiments were performed in 125 mL serum bottle as batch reactors with a working volume of 80 mL comprising the mixed microbial consortium and pretreated food waste. In the latter part of this study bioreactor with 2.5L working volume operating in batch mode was used in order to scale-up the process. The temperature and mixing of the system were maintained at 37 °C and 150 rpm, respectively, using a magnetic stirrer with heater. The pH of the system was adjusted to 7 prior to fermentation. The volume of biogas produced was measured in a wet gas meter using the water displacement method (Fig. 1).

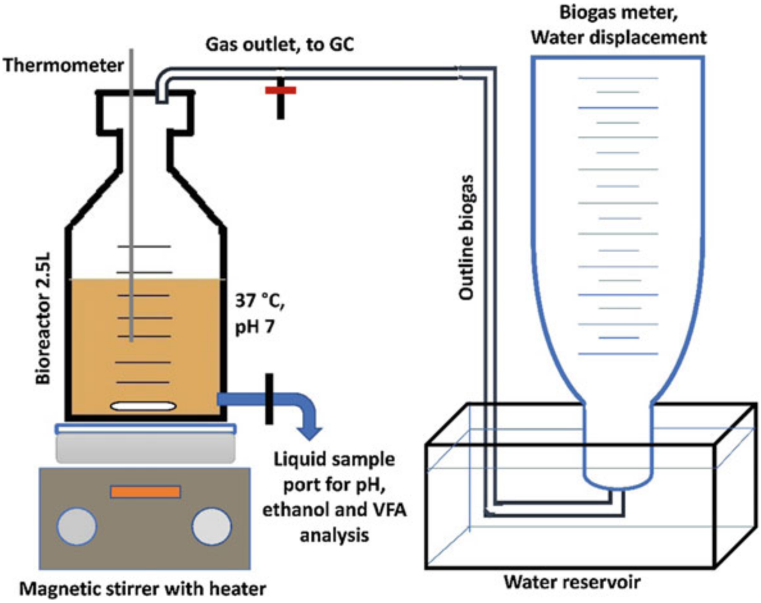


Fig. 1 Schematic representation of batch fermentation set up for bioH_2 production from food waste

2.5 Analytical Methods

Cumulative H_2 production was plotted against fermentation time over the course of fermentation and is analyzed using the modified Gompertz equation

$$H(t) = H_{\max}\, exp\left[-exp\left\{\frac{R_m \times e}{H_{\max}}(\lambda - t) + 1\right\}\right] \quad (1)$$

where H defines cumulative hydrogen production (mL) at time t, $H_{\max}$ is the H_2 production potential (mL), R_m (mL/Lh) stands for the maximum H_2 production rate (mL H_2/Lh), λ is the lag phase time (h), and e is 2.718 [12]. The percentage of H_2 in biogas was measured using a gas chromatograph (Chemito GC 1000, Chemito Instruments Pvt. Ltd., India) equipped with Thermal Conductivity Detector (TCD) and stainless steel packed molecular sieve column. The injector, oven, and detector of the GC were set at an operational temperature of 130 °C, 50 °C, and 150 °C respectively at a voltage of 5 V. Argon was used as a carrier gas. For the determination of volatile fatty acids (VFAs) in the liquid sample, they were first centrifuged at 10,000 rpm for 10 min and the supernatant was subjected to filtration through a 0.22 µM cellulose acetate membrane before being analyzed by HPLC. The concentrations of VFAs (acetate, butyrate, and propionate) and ethanol were analyzed by HPLC (Waters™600, Milford USA) equipped with Cosmosil 5 NH_2-MS column and UV/Visible and Refractive Index detector. Sulphuric acid (0.005N) served as the mobile phase at a flow rate of 0.5 mL/min.

The pH and Chemical Oxygen Demand (COD) were determined using standard methods. Phenol-sulfuric acid method was used to determine the total carbohydrate,

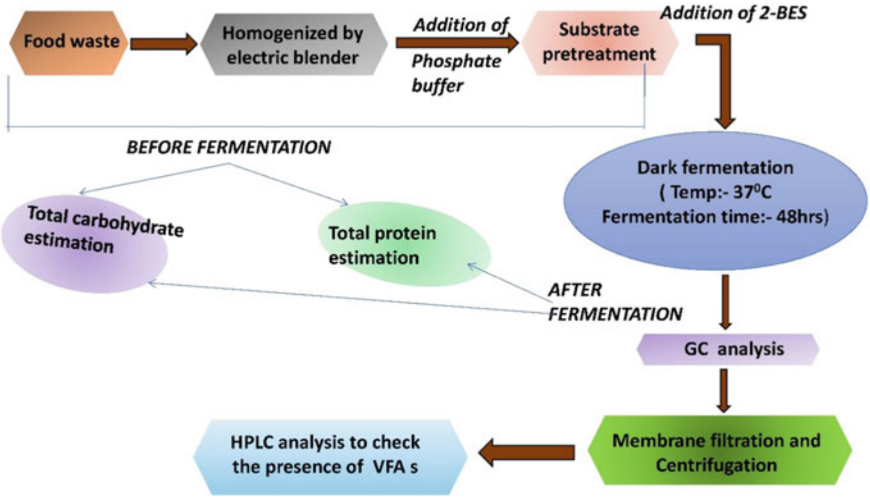


Fig. 2 Schematic representation of experiments performed

while soluble protein was measured by the Lowry's assay using a UV/Visible spectrophotometer (Thermo Scientific™ UV 10, USA). The overall steps of all experiments performed are summarized in Fig. 2.

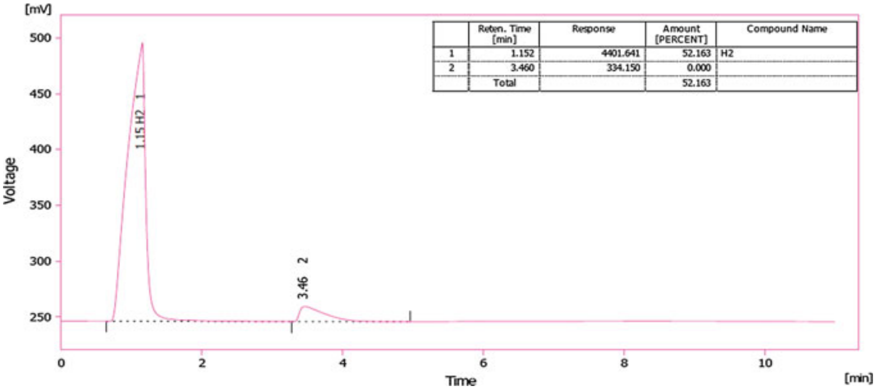
3 Results and Discussion

3.1 Amount of BioH$_2$ in the Produced Biogas

The amount of hydrogen in the produced biogas was measured with respect to standard hydrogen (100% pure) using gas chromatography equipped with TCD. The retention time for the standard was 1 min. Chromatogram of the gas produced from the fermentation of food waste shows hydrogen content to be around maximum 52.2% with no detectable methane because 2-BES is an efficient suppressor for methanogens. 2-BES functions by inhibiting the activity of coenzyme M reductase which is a key enzyme involved in methanogenesis. The other 47.8% comprises traces of nitrogen, carbon dioxide, and water vapor (Fig. 3). The mixture of H_2 and CO_2 can be stripped off from the gas stream with 30% potassium hydroxide (KOH) solution.

3.2 Effect of PH on Kinetic Parameters for BioH$_2$ Production by Dark Fermentation of Food Waste

The regulation of pH is critical to the dark fermentative bioH$_2$ production as it directly affects the activity of enzyme hydrogenase and metabolic pathways. It has been found that when the pH of the fermentation media is below the optimum pH



	Reten. Time [min]	Response	Amount [PERCENT]	Compound Name
1	1.152	4401.641	52.163	H2
2	3.460	334.150	0.000	
	Total		52.163	

Fig. 3 Chromatogram showing a maximum content of 52.2% bioH$_2$ from fermentation of food wastes

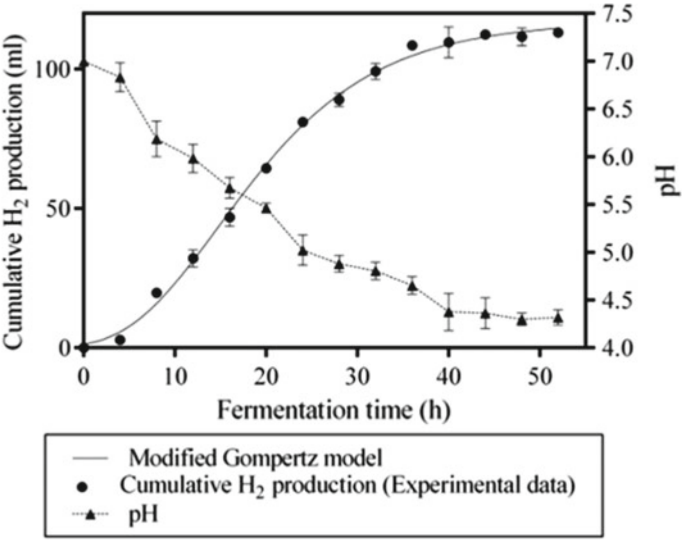


Fig. 4 Kinetic parameters for bioH_2 production are hydrogen production potential (H_{max}) 117.2 mMol/L; maximum hydrogen production rate (R_{max} 4.44 mMol/L/h); and lag phase time (λ) 4.99 h

for bioH_2 production either of the two consequences arose, first, the metabolic activity of hydrogen favoring microorganisms was stalled and second, a shift in the metabolic activity of hydrogen producers would occur resulting in cessation of bioH_2 generation. In this study, the effect of different initial pH and fermentation time on cumulative bioH_2 production during anaerobic fermentation of food wastes in the mesophilic batch reactor was evaluated (Fig. 4). It is observed that with a decrease in pH and increase in the duration of fermentation the cumulative hydrogen production decreases [12]. Experimental results showed that a relatively insignificant amount of bioH_2 was detected in the biogas with an initial pH of 5 or 6, while an initial pH of 7 substantially augmented bioH_2 generation from food waste. This could be possibly due to a swap in the metabolic pathway of microorganisms resulting in the production of organic acids such as acetate, butyrate, and propionate thereby hindering the hydrogenase activity, which contributes to enhancing bioH_2 yield. At pH beyond 7, the cumulative hydrogen accumulation in the biogas declines due to the generation of a little amount of methane. This suggests that pH should be kept between 6 and 7 during the acidogenic fermentation process. Similar findings have been carried out by other researchers [6]. The lag phase for mixed microflora persisted for 4.99 h after which they entered the exponential growth phase. The maximum hydrogen production potential (H_{max} = 117.2 mMol/L) and maximum hydrogen production rate (R_{max} = 4.44 mMol/L/h) is achieved at pH 7 when the reactor is operated for 50 h in batch mode.

3.3 Effect of Different Pretreatment Methods on the Hydrogen Content of Produced Biogas

Pretreatment is a biochemical process employed to ensure complete hydrolysis of complex carbohydrate polymers to simple fermentable sugars which can be readily consumed by the mixed microbial consortia. An ideal pretreatment process should bear the following salient features: (a) improve saccharification by hydrolysis; (b) inhibit the degradation of carbohydrate whilst the formation of inhibitory products; (c) lucrative. If biomass is the choice of the substrate to be used in dark fermentation, the cellulose, and hemicellulose that obstruct enzymatic attack and crystallinity of cellulose needs to be decreased by appropriate pretreatment processes. The number of pretreatment steps is dependent on the type of feedstock being used. Biomass pretreatment is carried out by physical, chemical and/or biological processes. Physical treatment is associated with a decrease in size or involvement of physical forces to degrade and/or alter the cellulose structure in such a form that the enzymes that breakdown cellulose into fermentable sugars have an easy access. Chemical treatment is carried out under high temperature and severe alkali/alkaline conditions. Conversely, biological or enzymatic pretreatment can be achieved at ambient conditions with lower conversion rates. The main principle underlying all the pretreatment steps is to facilitate the access of microorganisms to fermentable sugars within the biomass.

In the present study, food wastes underwent enzymatic and physical treatment while inoculum was enriched by a 2-bromoethane sulfonic acid (2-BES). In the first case, amylase followed by heat treatment was done at 90 °C for an hour to alter the cellulose structure associated with the food waste. The maximum hydrogen content in biogas was found to be 40.1% when compared to the untreated food waste having 52% hydrogen (Fig. 5). The reason behind a decrease in bioH_2 production

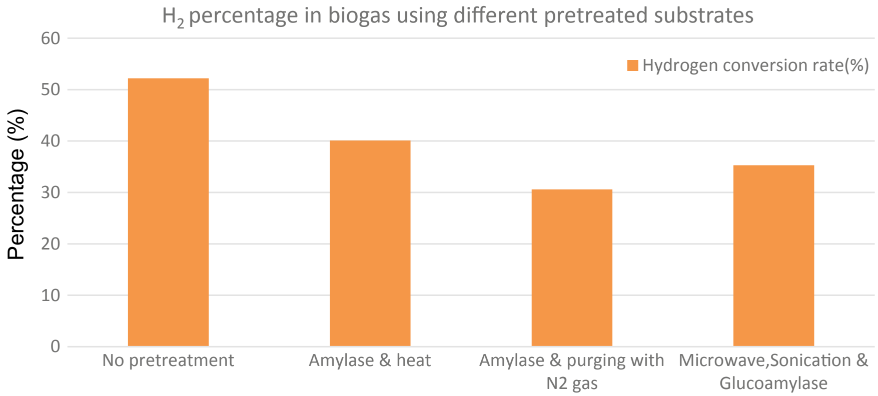


Fig. 5 Different substrate pretreatment and their corresponding H_2 content (%) in produced biogas

could possibly be due to the formation of fermentation inhibitors associated with heat treatment. In order to enhance bioH_2 production, the formation of furfural and 5-hydroxymethyl furfural associated with carbohydrate degradation of pentoses (C_5) and hexoses (C_6) should be prevented by keeping the process temperature and residence time as low and as petite as possible.

In the second case, amylase treatment followed by 2–3 min of sparging with nitrogen gas was performed. The production of bioH_2 via the dark fermentation route are extremely sensitive to the partial pressure of hydrogen, which is a rate-limiting parameter, particularly due to its inhibitory effect on the enzyme hydrogenase, which is involved in the transfer of an electron from an intracellular carrier to H^+. The decrease in enzyme activity is particularly because of feedback inhibition. Hence, sparging with inert gases such as nitrogen, argon in the reactor headspace will lower the hydrogen partial pressure whilst increasing the hydrogen yield. In combination with partial pressure-lowering post-amylase treatment, hydrogen conversion rate subsequently lowered to 30.6%. The probable reason behind this could be lower conversion rate of feedstock into fermentable sugars as reported by Chen et al. that pretreatment of wheat straw by fungi for a continuous period of 10 days resulted in high amounts of fermentable sugars and diminution in fermentation inhibitors [16]. Although enzymatic pretreatment is highly enthralling, the rate of hydrolysis is too slow and is practically not feasible on an industrial scale. In order to make enzymatic pretreatment at par with other pretreatment, a combination of either physical or chemical pretreatment should be followed post enzyme treatment. This has been reported in various studies such as that of Wang et al. (2012), he combined biological with liquid hot water treatment for enhanced saccharification of *Populustormentosa*. This combination resulted in maximum hemicellulose removal leading to an increase in glucose yield by 2.66-fold compared to pretreatment carried out with liquid hot water alone [17].

Structural disruption of organic matter present in food waste can be achieved with microwave irradiation and ultrasonication. When organic material is subjected to microwaves, the organic molecules and water within the cells grasp this wave energy resulting in tremendous heat generation and consequently cell wall is degraded. Conversely, when biomass is subjected to ultrasonication, a prodigy known as bubble collapse occurs by a method involving cavitation which causes an increase in pressure and heat formation resulting in the collapse of the cell wall structure.

As is observed in the third case of the present study where food wastes were subjected first to microwave heating for 10 min at 400 W followed by sonication for 20 min at 40 °C and subsequent addition of glucoamylase followed by heated at 40 °C for 2 h. It was found that only 35.2% of hydrogen is liberated. This study demonstrates that the power, duration of sonication, and time of heating should be kept as low as possible. High sonication power is known to adversely affect the pretreatment process with the formation of bubbles near the tip of the ultrasound transducer, which thwarts the transfer of energy to liquid medium [18]. Similar studies were carried out by Chen et al. (2006) with poplar wood cellulose powder suspension, which turned viscous on treatment with a high-power of 1200 W [19].

It was found that when no substrate pretreatment is carried out hydrogen conversion rate in the biogas is around maximum 52.2% as shown in Fig. 5, which could be possibly due to the presence of cellulose-degrading microorganisms in the mixed microbial consortia. Nevertheless, an imperative analysis of the aforementioned pretreatment methods brings us to an inference that pretreatment step is a "custom-made" process for every individual biomass which requires scrupulous selection and plan based on the characteristic features that are solely associated with that biomass. A comparison of different pretreatment methods on bioH_2 content (%) in the produced biogas is shown in Table 1.

Table 1 A comparison of different pretreatment methods and respective biohydrogen content (%) in the produced biogas

Substrate	Pretreatment method	Inoculum	Hydrogen content in biogas (%)	References
Food waste	–	Anaerobic sludge treated with 2-BES	52.2	This study
Glucose	–	Digested sludge boiled at 100 °C for 15 min	44.5	[20]
Glucose	–	Anaerobic sludge baked at 104 °C for 2 h	24.2	[21]
Food waste	Amylase and heat treatment at 90 °C for 1 h	Anaerobic sludge treated with 2-BES	40.1	This study
Food waste	Amylase treatment followed by purging with nitrogen gas	Anaerobic sludge treated with 2-BES	30.6	This study
Food waste	Microwave heating for 10 min at 400 W followed by Sonication for 20 min at 40 °C and Glucoamylase treatment at 40 °C for 2 h	Anaerobic sludge treated with 2-BES and incubated for 1 h	35.3	This study
Co-digestion of cow manure and waste milk	Waste milk was treated with cefazolin	–	48.7	[22]
Co-digestion of pig manure with fruit and vegetable waste	–	The initial inoculum was formulated by digesting glucose and fruit wastes	42 ± 0.5	[23]

*2-BES = 2-bromoethanesulphonic acid

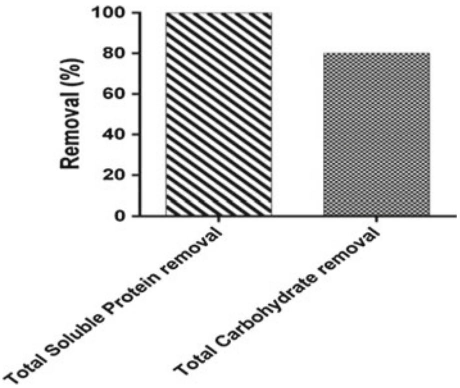


Fig. 6 Total carbohydrate and soluble protein removal (%)

3.4 Evaluation of Nutrients Utilized by the Microflora

The food wastes upon hydrolysis release carbohydrate and protein as the main carbon and nitrogen source for bacteria to readily utilize it and release bioH_2 as the major reaction product. Total carbohydrate and soluble protein were determined before and after fermentation to calculate removal (%). It is clearly observed that total carbohydrate removal is 80.05% while total soluble protein removal is 99.98% respectively. Thus, it can be inferred that the microbial population present in the pretreated anaerobic sludge has efficiently utilized protein and carbohydrate (Fig. 6).

3.5 Volatile Fatty Acids (VFAs) and Ethanol Production

The production of BioH_2 is accompanied by VFAs and ethanol production, thereby lowering the pH of the system. VFAs mainly include acetate and butyrate with acetate being the major by-product. The overall equation of bioH_2 production from food wastes is as follows:

$$C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 2CO_2 + 4H_2 \tag{2}$$

This gives a clear notion that pretreatment procedure such as heat, chemical, or pH shock of the seed culture is a prerequisite to reduce the inhibitory effects of lactic acid-producing bacteria and other hydrogen consumers during dark fermentation [12]. The choice of formation of organic acids depends exclusively on the dominance of respective bacteria favoring their production.

4 Conclusion

The most economical and viable process for producing renewable energy is the utilization of organic waste. H_2 production employing acidogenic dark fermentation represents an exciting new arena of technology for bioenergy production. The lower yield of H_2 obtained with acidogenic fermentation compared to other production methods of hydrogen remains the main issue to be addressed before the process can be commercialized. There is an effort to find ways to enhance both the production rates of hydrogen and its ultimate yield. In this study, if no substrate pretreatment is done, we obtained a high bioH_2 content (52%) in the biogas produced by the rich H_2-producing microflora obtained from anaerobic digester sludge with subsequent consumption of carbohydrate and protein.

References

1. Kim, D.-H., Kim, S.-H., Shin, H.-S.: Hydrogen fermentation of food waste without inoculum addition. Enzyme Microb. Technol. **45**, 181–187 (2009)
2. Kim, S.-H., Shin, H.-S.: Effects of base-pretreatment on continuous enriched culture for hydrogen production from food waste. Int. J. Hydrogen Energy **33**, 5266–5274 (2008)
3. Lee, Y.-W., Chung, J.: Bioproduction of hydrogen from food waste by pilot-scale combined hydrogen/methane fermentation. Int. J. Hydrogen Energy **35**, 11746–11755 (2010)
4. Nazlina, H., Aini, A.N., Ismail, F., Yusof, M., Hassan, M.: Effect of different temperature, initial pH and substrate composition on biohydrogen production from food waste in batch fermentation. Asian J. Biotechnol. **1**, 42–50 (2009)
5. Mohd Yasin, N.H., Rahman, N.A.A., Man, H.C., Mohd Yusoff, M.Z., Hassan, M.A.: Microbial characterization of hydrogen-producing bacteria in fermented food waste at different pH values. Int. J. Hydrogen Energy **36**, 9571–9580 (2011)
6. Das, D., Veziroğlu, T.N.: Hydrogen production by biological processes: a survey of literature. Int. J. Hydrogen Energy **26**, 13–28 (2001)
7. Suzuki, Y.: On hydrogen as fuel gas. Int. J. Hydrogen Energy **7**, 227–230 (1982)
8. Das, D., Veziroglu, T.N.: Advances in biological hydrogen production processes. Int. J. Hydrogen Energy **33**, 6046–6057 (2008)
9. Kim, S.-H., Han, S.-K., Shin, H.-S.: Feasibility of biohydrogen production by anaerobic co-digestion of food waste and sewage sludge. Int. J. Hydrogen Energy **29**, 1607–1616 (2004)
10. Zhu, H., Parker, W., Basnar, R., Proracki, A., Falletta, P., Béland, M., Seto, P.: Biohydrogen production by anaerobic co-digestion of municipal food waste and sewage sludges. Int. J. Hydrogen Energy **33**, 3651–3659 (2008)
11. Hwang, J.-H., Choi, J.-A., Abou-Shanab, R.A.I., Min, B., Song, H., Kim, Y., Lee, E.S., Jeon, B.-H.: Feasibility of hydrogen production from ripened fruits by a combined two-stage (dark/dark) fermentation system. Bioresour. Technol. **102**, 1051–1058 (2011)
12. Basak, B., Fatima, A., Jeon, B.-H., Ganguly, A., Chatterjee, P.K., Dey, A.: Process kinetic studies of biohydrogen production by co-fermentation of fruit-vegetable wastes and cottage cheese whey. Energy Sustain. Dev. **47**, 39–52 (2018)
13. Kim, D.-H., Kim, S.-H., Ko, I.-B., Lee, C.-Y., Shin, H.-S.: Start-up strategy for continuous fermentative hydrogen production: early switchover from batch to continuous operation. Int. J. Hydrogen Energy **33**, 1532–1541 (2008)

14. Sreela-or, C., Imai, T., Plangklang, P., Reungsang, A.: Optimization of key factors affecting hydrogen production from food waste by anaerobic mixed cultures. Int. J. Hydrogen Energy **36**, 14120–14133 (2011)
15. Goswami, A.: Food wastage crisis in India. In: Journal, C.I. (ed.), Clean India Journal. India (2018)
16. Chen, X., Sun, Y., Xiu, Z., Li, X., Zhang, D.: Stoichiometric analysis of biological hydrogen production by fermentative bacteria. Int. J. Hydrogen Energy **31**, 539–549 (2006)
17. Wang, W., Yuan, T., Wang, K., Cui, B., Dai, Y.: Combination of biological pretreatment with liquid hot water pretreatment to enhance enzymatic hydrolysis of *Populus tomentosa*. Bioresour. Technol. **107**, 282–286 (2012)
18. Imai, M., Ikari, K., Suzuki, I.: High-performance hydrolysis of cellulose using mixed cellulase species and ultrasonication pretreatment. Biochem. Eng. J. **17**, 79–83 (2004)
19. Chen, W.-H., Chen, S.-Y., Khanal, S.K., Sung, S.: Kinetic study of biological hydrogen production by anaerobic fermentation. Int. J. Hydrogen Energy **31**, 2170–2178 (2006)
20. Wang, J., Wan, W.: Comparison of different pretreatment methods for enriching hydrogen-producing bacteria from digested sludge. Int. J. Hydrogen Energy **33**, 2934–2941 (2008)
21. Oh, S.-E., Van Ginkel, S., Logan, B.E.: The relative effectiveness of pH control and heat treatment for enhancing biohydrogen gas production. Environ. Sci. Technol. **37**, 5186–5190 (2003)
22. Lateef, S.A., Beneragama, N., Yamashiro, T., Iwasaki, M., Ying, C., Umetsu, K.: Biohydrogen production from co-digestion of cow manure and waste milk under thermophilic temperature. Bioresour. Technol. **110**, 251–257 (2012)
23. Tenca, A., Schievano, A., Perazzolo, F., Adani, F., Oberti, R.: Biohydrogen from thermophilic co-fermentation of swine manure with fruit and vegetable waste: maximizing stable production without pH control. Bioresour. Technol. **102**, 8582–8588 (2011)

Identifying Issues in Assessing Environmental Implications of Solar PVs-Related Waste

Preeti Nain and Arun Kumar

Abstract Hazardous elements like lead, cadmium are growingly being used in solar photovoltaics (PV). The major distress is the risk related to the potential release of these constituents in the environment. This paper reviews the leaching behaviour of various metallic constituents in soil and water, and compiles the latest literature on PVs. The analysis shows that there is substantial release of various metallic components in the environment and exist data gaps in (1) lack of information for solar PV disposal, (2) standardized leaching tests representing actual landfill conditions (e.g. studies with actual landfill waste and leachate), (3) Life Cycle Inventories from cradle to grave, (4) kinetics data for metal leaching, and (5) PV wastewater characterization. These identified data gaps need to be filled by conducting more research in this direction, so that exposure to toxic metals can be estimated with more confidence and efforts for protecting them can be made.

Keywords Photovoltaic · Solar panel · Leaching · Toxic · Metal · End of life

1 Introduction

Owing to the rapid demand for energy production, photovoltaic (PV) is the most promising and sustainable source for inexhaustible electricity production worldwide [1]. PV is growing at the exponential rate because of minimum greenhouse gas emissions and low energy payback time; low emission of pollutants such as sulphur dioxide (SO2), nitrogen oxides (NOx) and carbon monoxide (CO) [2, 3]. According to the European Photovoltaic Industry Association (EPIA), the collective solar modules installed volume worldwide comprises 402 GW in 2017 with China, US

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and India as top PV deplorers [4]. This gigantic PV deployment will generate an enormous amount of PV waste once their operational life is over. The expected operational life of a module is 30 years and then these have to be decommissioned and disposed or recycled or reused [5]. Based on the newest existing information, the solar PV waste volumes will be 70 million tons by 2050 [6]. Silicon-based PVs, the most commonly used solar modules has the least human health and environmental risk as compared to potentially growing thin-film PVs because of well known toxicity of cadmium and tellurium [7]. The negative environmental impact of PV systems is associated with the usage of various toxic elements like lead (Pb), cadmium (Cd), tellurium (Te) and other substances like selenium (Se), silver (Ag), zinc (Zn), gallium (Ga), indium (In), aluminium (Al), molybdenum (Mo), nickel (Ni) and copper (Cu) irrespective of the low concentration as compared to process industries. Cadmium Telluride (CdTe) PV can pose serious environmental risk as semiconductor layer itself has around 50% Cd [8]. As compared to coal-fired energy plants, burning of coal emits approximately 300 times more Cd than cradle to grave PV Cd emissions [7]. Also, as per the various previous analysis done by individual researchers, the solar PV operational cycle is safest than conventional sources of energy [9, 10]. Sill after end of life of solar modules, they have to dispose of suitably to avoid potential environmental or human health risk. However, some manufacturers claim to have prefunded collection and recycling programme to collect the spent modules after their operational life (end-of-life PV, then what?).

Spent solar PVs can end up in the below-mentioned end-of-life scenarios leading to potential leaching of PV components:

1. Improper dumping via accidental open fire, uncontrolled land filling and distribution from land filling into soil and aquatic system [11].
2. Stockpiling in warehouses, renewing panels that have minor repairs.
3. Domestic recycling sent to metal/electronics recyclers and recovery of glass and valuable elements.
4. Proper disposal and energy recovery via incineration, controlled land filling and collection until an efficient recycling process is established.

If not recycled or improperly disposed of out in the open, PVs are exposed to severe outdoor environmental conditions, which will subsequently result in weathering of the material and release of various metals in the environment components [12]. The major reason for not having proper central facility at large scale can be less numbers of EoL panels, lack of PV waste-specific regulations, lack of financial support and subsidies by government for recycling and recovery of rare metals.

This study aims to give an overview of the fate of various hazardous elements in the environment if used-up modules are improperly disposed and to identify current knowledge gaps. This paper studies the fate and environmental implications of end-of-life PV and understanding the leaching behaviour of various metallic constituents of PV modules into the environment by reviewing various research studies (i.e. journal papers, reports, conference articles, and reports). Findings of this study will be useful in policymaking for proper disposal and recycling of spent PVs and at hazard identification stage of the human health risk assessment framework.

2 Fate and Environmental Impacts of Solar PV Modules

PV is exposed to extreme environmental conditions during their lifetime. Human mishandling or weather conditions or irregular maintenance can cause physical damage to modules during operation. Though unusual, damaged or broken modules exposed to rainfall may subsequently lead to the release of hazardous/ bioaccumulative materials like Cd, Pb, Se in the water or soil [13]. Accidental fires in a municipal solid waste containing spent solar panels could supposedly release gases or vapours into the nearby atmosphere and inhalation of which can affect the surrounding population [14]. In particular, physical damage to PV can result in augmented release of these metals. Biota inhabiting the nearby leaching areas could be exposed to high levels of toxic compounds through various exposure pathways such as dermal contact and direct ingestion of contaminated soil, ingestion of contaminated groundwater and effected surface water via runoff and inhalation of polluted air (Fig. 1). Figure 2 shows a schematic of various factors responsible for degradation of PVs leading to release of potentially hazardous compounds into the environment and their partition in various biotas.

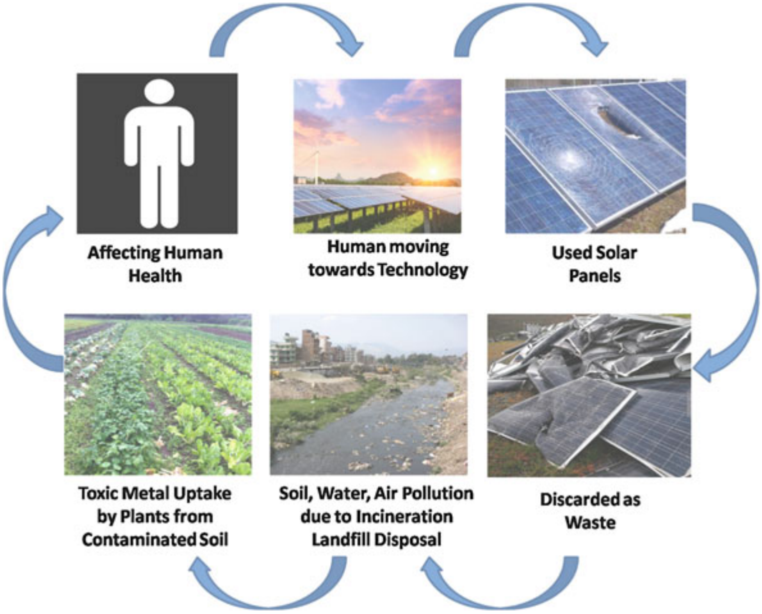

Fig. 1 Impact of solar PVs on human and environment

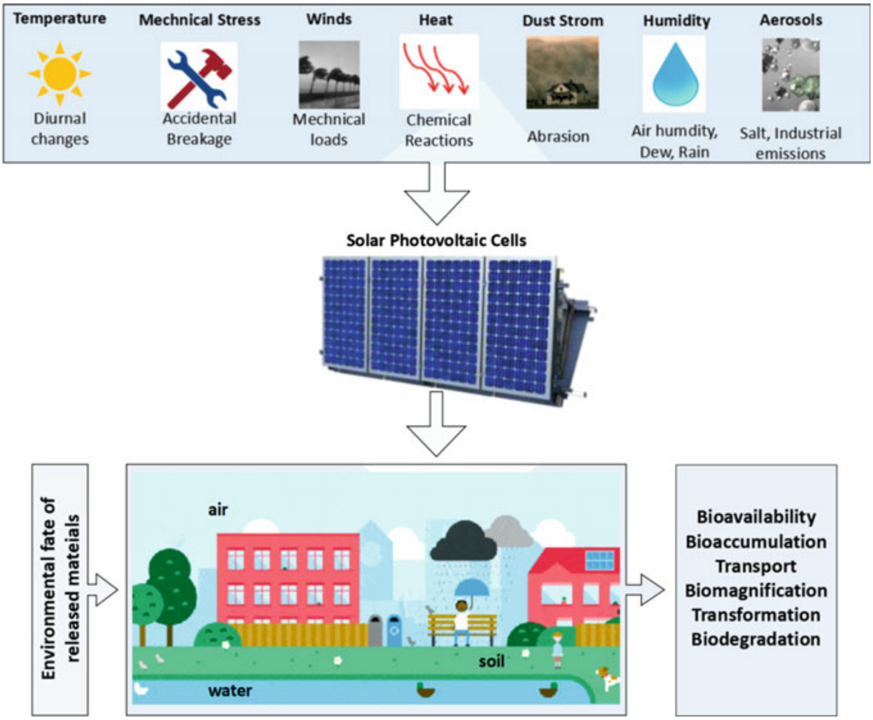

Fig. 2 Factors responsible for the degradation of PVs leading to release of toxic elements in the environment and fate and ecotoxicological impacts of these compounds on different biota

Global Cd emissions to air and water due to CdTe PVs are 0.8 and 2 kg/year, respectively, in 2008 [7]. Toxicological impacts of CIS, CdTe and CIGS on rats were reported by the National Institute of Environmental Health Studies (NIEHS). Studies on ecotoxicological impact on CIGS and OPV suggests that metals leached from damaged CIGS cells under rainwater condition may cause serious environmental risk [15]. Babayigit et al., 2016 studied the ecotoxicological effect of perovskites (lead and tin) solar cells on zebrafish and showed that elevated mortal rate was observed in the fish embryos grown in solutions of tin (II) iodide than lead (II) iodide at same concentration for both elements [16]. Until now, the quantitative assessment of human health risk and environment risk has not been systematically investigated. There is knowledge gap for the quantification of potential negative impact of PVs. Thus, field studies measuring the metal release quantitatively with physical damage needs to be done.

3 Toxic Metals Released from Solar PV

The use of Cd, Te, Pb, Ag, Se and various other hazardous compounds in the semiconductor layer of PVs panels is of special concern. Due to the usage of hazardous compounds present in solar modules, there exists a serious hazard to the environment or public health, especially, to local habitats if not handled or properly disposed of upon decommissioning [17, 18]. Metal toxicity of crystalline and thin-film technologies is discussed in the following section.

3.1 Crystalline Silicon PV Modules

Silicon accounts for the maximum content in crystalline silicon-based PV. The outer frame of a module is mostly made of aluminium, whereas electrical contacts are made out of silver and sometimes cadmium oxide metal compounds. As silicon and aluminium is the second and third most abundant element in earth's crust, so their use in PV does not pose any risk, only the use of silver may pose problems. Lead is used in ribbons, solder and cell metallization layer and can pose serious health risk such as memory loss, high blood pressure, damage to central nervous system [19]. Exposing lead to acidic conditions prevailing in young municipal waste landfills can leach out toxic metals from damaged solar PV modules [20]. Some of the toxic compounds used in solar PVs and their impact on human health are explained in Table 1.

3.2 Thin-Film PV Systems

In contrast to crystalline silicon PV modules, in thin-film PVs, toxic substances and rare elements are used. Cd and Cr can be carcinogenic if exceeds their limit, as would As and Zn up to a minor level. Crystalline based solar panels do not use Cd-related compounds but is of potential concern as have application in other thin-film modules, though in small amount in the latter two types of PV. Organic PV modules (OPV) and Si-based PV release minor metals in various water-based leaching solutions as compared to other thin-film modules [21–28]. The percentage of Cd is about 0.04%, which is lower than the limit of hazardous waste of 0.1% and CdTe acute toxicity is significantly lower than the parent compounds (Cd, Te) [8]. Though they are present in much smaller amount, but there is always a potential risk. During operational period of a PV, the probability of fluid or chemicals or materials of concern release is minimal since they are sealed different various layers of PV module.

Table 1 Impact of toxic elements used in solar PVs on human health

Toxic element	Purpose	USEPA water reuse limits (mg/L)		Health impact
		Long-term use	Short-term use	
Arsenic (As)	Used in GaAs (gallium arsenide) crystals	0.10	2.0	Skin reddening and darkening, nausea, coughing, vomiting and throat infection, reduction in RBCs and heartbeat problems, lung cancer
Cadmium (Cd)	Used in CdTe and CdS solar PV cells	0.01	0.05	Cd dust and vapours causes lung issues, prostate, diarrhoea and chest tightening
Chromium (Cr)	Used in coating layer screw industries	0.10	1.0	Cr can cause instance skin rashes. High uptake can lead to itai-itai disease
Copper (Cu)	Used in wiring	0.20	5.0	Cu cause's headaches, dizziness, vomiting. High concentration causes liver/ kidney damage, Wilson's disease
Manganese (Mn)	Used in doping to achieve low contact resistance	0.20	10	Mn poisoning can cause hallucinations, forgetfulness and nerve damage. It causes Parkinson's, lung
Molybdenum (Mo)	Used in electrode for high conductivity	0.01	0.05	Mo can cause pain in joint, feet, hands, erythematic and articular deformities
Nickel (Ni)	Used in wiring to resist corrosion	0.20	2.0	Ni can cause allergic reactions such as skin rashes. Also, it can cause asthma, heart disorders and chronic bronchitis
Lead (Pb)	Electrical connections, ribbons, solder components, wire	5.0	10	Memory loss, damage to central nervous system, bone weakness, high blood pressure
Silicon (Si)	Used in semiconductor layer of Si-based PV	2.0	7.0	Respiratory problems, skin and eyes irritation and issues in lung and mucus
Vanadium (V)	Used for doping	0.10	1.00	V causes irritation of lungs, throat, eyes and nasal cavities

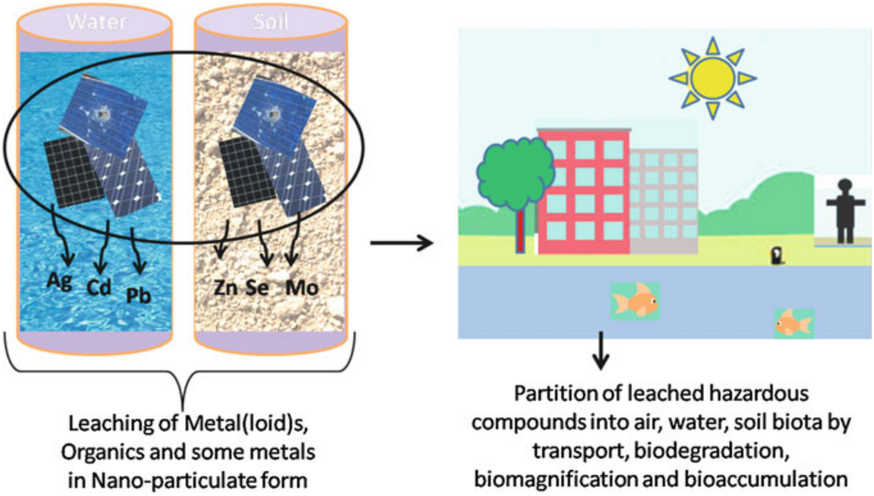

Fig. 3 Leaching of various hazardous compounds into the environment

Release of these metals during operational phase of a module is not a distress, given the sealed nature of the devices [29]. Cd is associated with several human illnesses like bone and kidney damage. Cd leached from landfills bio-accumulates in the various life forms via various exposure pathways [10]. Tests using standard leaching tests like TCLP and Swiss Leach Test show high leaching potential of cadmium from crushed CdTe modules [30]. Recent study on CdTe modules shows that Cd concentrations are 650 times than the US-EPA drinking water standard. Experimental investigations are in progress in order to reduce the concentration of Cd in thin-film cells by replacing the doped elements with non-hazardous metals [31]. Figure 3 shows the fate of spent PVs if dumped in soil and aquatic environment and distribution of various compounds in various biota.

Solar PV waste may possess nanotoxicity risk to the environment. The total content of relevant elements quantified in various studies doesn't differentiate between metal ion and nanoparticulate species interaction with the environment. One of the studies shows nanoparticulate species for Zn and Mo leaching in seawater for CIGS modules, however, neutral pH conditions leached of zinc and silver nanoparticles from CIGS and OPV, respectively [32]. It raises the nanotoxicity concern which needs to be studied. Some of the selected studies on leaching of hazardous compounds from various PV modules are summarized in Table 2.

Table 2 Highlights of selected studies on leaching of hazardous compounds from PV modules

Sr.	Author	Elements measured	Panel size and shape	Experimental conditions	Main findings	Knowledge Gap
1	Nover et al. [21]	Al, In, Ga, Zn, Cu, Pb, Ag, Te, Cd, Se, Mo, Ni	5 × 5 cm^2 without any metallic frame and cables; milled two module pieces having particle size 0.2 mm	Study type: batch; Temp.: RT; Container: HDPE bottles; Leaching Solution: Water-based solutions having pH 3, 7, 11 (1 L); Leached metals form: Ionic Agitation: No; Analysis: ICP-MS; Sampling Rate: 15 ml samples were taken periodically from bottles for analysis. Leaching period: 360 days	**Crystalline silicon PV**: **pH 3** (mg/l, %): Al (72 ± 5, 22), Cu (0.27 ± 0.1, 0.1), Pb (0.45 ± 0.3, 1.4); **pH 7** (mg/l, %): Cu (0.37 ± 0.1, 0.1); **pH 11** (mg/l, %): Al(8.49 ± 0.42, 2.1), Pb (0.07 ± 0.04, 0.1) **Amorphous thin-film PV**: **pH 3** (mg/l, %): Cu (16.1 ± 0.96, 8), Ni 1.02 ± 0.16, 70); **pH 7** (mg/l, %): Cu (0.52 ± 0.05, 0.1), Ni (0.07 ± 0.02, 4); **pH 11** (mg/l, %): Nil **Copper Indium Gallium Deselenide PV**: **pH 3** (mg/l, %): Cd (0.08 ± 0.01, 20), In (0.21 ± 0.05, 0.6), Ga (0.05 ± 0.01, 1.2), Mo (1.44 ± 0.36, 20), Zn (13.20 ± 0.5, 43), Cu (8.93 ± 4.5, 30); **pH 7** (mg/l, %): Cd (0.006 ± 0.003, 1.8), Ga (0.02 ± 0.001, 0.8), Se (0.02 ± 0.015, 0.1), Mo (1.39 ± 0.13, 19), Zn (0.58 ± 0.07, 2), Cu (0.25 ± 0.04, 0.8); **pH 11** (mg/l, %): Ga (0.01 ± 0.001, 3), Mo (1.09 ± 0.36, 12), Se (0.10 ± 0.05, 0.8) **Cadmium Telluride PV**: **pH 3** (mg/l, %): Cd (18.61 ± 0.94,62), Cu (4.59 ± 0.69, 20), Te (2.92 ± 0.91, 9), Mo (18.62 ± 2.58, 70); **pH 7** (mg/l, %): Cd(1.25 ± 0.90, 4), Cu (0.53 ± 0.06, 2), Te (2.75 ± 2.58, 7), Mo (4.98 ± 2.92, 19); **pH 11** (mg/l, %): Te(0.10 ± 0.06, 0.03), Mo (7.69 ± 4.95, 29)	Effect of agitation or module with bigger particle size can be considered

(continued)

Table 2 (continued)

Sr.	Author	Elements measured	Panel size and shape	Experimental conditions	Main findings	Knowledge Gap
2	Zapf-Gottwick et al. [22]	Pb and Ag	7 × 7 cm^2 without any metallic frame and cables, sample 0.2 mm size	Study type: batch; Temp.: RT; Leaching Solution: Water-based solutions having pH 3, 7.8, 8.4 (2 L); Agitation: Yes Analysis: ICP-OES, AAS; Sampling Rate: Samples for analysing are taken at the interval of 5 days Leaching period: 28–56 days	**Crystalline silicon PV**: **pH 3** (%): Pb(40), Ag(1), **pH 7.8**: Not measured **pH 8.4** (%): Pb(0.1), Ag(0.5) **Amorphous thin-film PV**: Not detected **Copper Indium Gallium Deselenide PV**: **pH 3** (%): Cd(50), Te(40), **pH 7.8**: (%): Cd(0.5), Te(50), **pH 8.4** (%): Cd(3), Te(40) **Cadmium Telluride PV**: **pH 3** (%): Cd(50), Te(40), **pH 7.8**: Cd(< 1), Te(40), **pH 8.4** (%): Pb(0.1), Te(35)	Real case scenario with module pieces of bigger size is not considered
3	Tammaro et al. [23]	Al, As, Ba, Cd, Cu, Cr, Mo, Mn, Ni, Sb, Pb, Sn, Se, Zn	0.5–3 cm size solar panel pieces	Test was conducted according to the Italian and European Standard procedure Leaching Solution: pure water with pH 7–8 (18 MΩ resistivity); Container: HDPE bottles; Liquid-to-solid ratio: 10; Study type: batch; Temp: RT; Agitation: Yes; Analysis: ICP-MS; Sampling Rate: At the end of experiment Leaching Period: 24 h	Concentration in µg/L (max) **Crystalline silicon PV**: Al: 1320; Cr: 10.8; Mn: 11.5; Cu: 37.8; Cd: 22; Pb: 61375; Se: 6.2; Sn: 661; Zn: 119; Ag: 693; Ba: 617; Ni: 38.4 **Amorphous thin-film PV**: Al: 491; Cr: 115; Mn: 5.5; Cu: 16.9; Cd: 0.0; Pb: 165.4; Se: 3.6; Sn: 7.9; Zn: 88.3; Ag: 3.75; Ba: 19; Ni: 8.75 **Copper Indium Gallium Deselenide PV**: Al: 63.4; Cu: 673; Cd: 80.9; Pb: 46.9; Se: 1285; Sn: 15; Zn: 703; Te: 6.9; Ga: 399.4; In: 870; Mo: 692; Ni: 47 **Cadmium Telluride PV**: Al: 395.3; Cr: 5.5; Mn: 4.4; Cu: 1.9; Cd: 634.3; Pb: 18.8; Sn: 102; Zn: 20.2; Te: 849; Mo: 626.5; Ba: 8	Effect of other parameters like temp, pH, size is not considered

(continued)

Table 2 (continued)

Sr.	Author	Elements measured	Panel size and shape	Experimental conditions	Main findings	Knowledge Gap
4	Ramos-Ruizet al. [24]	Cd, Te	1.5 g of snipped CdTe film and 300 g crushed glass with 3 mm * 8 mm placed in 2 columns	Study type: Column; Temp.: 25 °C; Leaching Solution: Water-based solutions having pH 3, 7.8, 8.4 (280 ml); Medium: methanogenic anaerobic granular sludge obtained from a WTP; Analysis: ICP-OES, AAS; HRT: 28 h; Panel Size: 60 by 120 cm, and 14 kg; Sampling Rate: Samples from influent and effluent were taken daily for one month study; Leaching period: 30 days	**Acidic column (mg/l, %), pH 4.67:** Cd (3.23, 73), Te (1.1,21) **Methanogenic column (mg/l, %) pH 6.7**: Cd(0.01,0.03), Te (0.02,0.05)	Experiments with MSW as leaching medium can be performed
5	Allan et al. [26]	Cd	25 mm long and 0.5 mm broken by hammer to induce breakage	Study type: batch; Temp.: RT; Container: Mason jar Leaching Solution: Citric acid-based buffer solutions having pH 3, 4, 5 and 6 (150 ml); Agitation: No; Analysis: ICP-ES; Sampling Rate: After 0, 32, 41, 120, 206 days, samples were taken, Leaching period: 206 days	**Cadmium Telluride PV**: **pH 3 (mg/l)**:162 **pH 4 (mg/l)**: 145 **pH 5 (mg/l)**: 122 **pH 6 (mg/l)**: 107 **pH 7 (mg/l)**: 7.28	Effect of other parameters like ionic strength, temp can be seen
6	Zimmermann et al. [27]	Al, As, Ag, Ti, Cu, Ga, Se, Mo, Cd, In, Sn, Sb, Pb and Zn	1.5 cm × 3 cm fragments (two fragments per bottle; 951.1 ± 22.9 mg CIGS)	Study type: batch; Temp.: RT; Container: brown glass flasks; Leaching Solution: Water-based solutions having pH 5, 7.9, 8.6 (40 ml); Agitation: 130 rpm Analysis: TRSP-ICP-MS Best Fit: Sigmodial Sampling Rate: Samples were taken at 0, 13, 29, 48, 70, 95 and 123 days Leaching Period: 123 days	**Copper Indium Gallium Deselenide PV**: **pH 5** (µg/g PV, %): Al (9.2, 9.3), Mo (949.6, 22.3), Zn (27.9; 18.5), Cd (16.7, 8.2), Se (0.9, 0.1) **pH 7.9** (µg/g PV, %): (1661, 38.9), Zn (15.2, 10.1), Cd (9.9, 4.9), Se (2.8, 0.7), Sn (2.6, 0.25), Al (0.9, 0.9) **pH 8.6** (µg/g PV, %): Mo (1150, 27), Cd (55.4, 27.4), Zn (12.7, 8.4), Se (10.7, 0.3), Ag (6.2, 0.3), Cu (3.0, < 0.1), Al (2.2, 2.2), In (1.4, 0.5)	Details about the particle size of modules pieces used in experiment are not given

(continued)

Table 2 (continued)

Sr.	Author	Elements measured	Panel size and shape	Experimental conditions	Main findings	Knowledge Gap
7	Rebecca Brun et al. [15]	Li, Al, As, Ag, Ti, Cu, Ga, Se, Mo, Cd, In, Sn, Sb, Pb and Zn	1.5 cm × 3.0 cm pieces (10 pieces per flask)	Study type: batch; Temp.: RT; Container: brown glass flasks; Leaching Solution: Water-based solutions having pH 4, 7.9, 8.4 (200 ml); Agitation: 130 rpm Analysis: TRSP-ICP-MS Leaching period: 123 days	**Copper Indium Gallium Deselenide PV**: **pH 4** (µg/l): Al(10), Cd(21), Cu(57), Fe (12), Ga(13), Mo(59), Zn(82) **pH 7.9** (µg/l): Ag(50), Cd(61), Cu(122), Fe(7219), Mo(483), se(43), Sn(691) **pH 8.4** (µg/l): Cd(9), Mo(583), Se(11), Zn960)	Real case scenario with module pieces of bigger size is not considered

4 Risk Potential at Landfills with PV Modules

Massive demand and short life span of e-waste have led it to a dreadful state of landfills and as PVs are part of e-waste can nevertheless end up to open landfills [32]. Disposal of used-up or inactive PV modules in large amount in landfills can result in leaching of hazardous compounds such as Cd, Cr, Te, Pb. But risk assessment studies shows no risk to human health if CdTe are disposed to landfill because of less waste volume generation at present rate [33]. Also, fate and transport analysis of Cd from damaged panels installed on a building in rainwater exposure does not pose risk to onsite workers and offsite residents [34]. Human exposure to hazardous compounds due to disposal of solar PV in landfills without pretreatment by various environment routes is shown in Fig. 4.

The standard leaching tests, TCLP, WET are anticipated to over-estimate the pollutant release concentration from solid PVs and are conservative. As mentioned in earlier section, Cd concentration in both CdTe and CIGS modules exceed the standard concentration as per USPA TCLP limit. The fact that PV modules have relatively long life and major installations happened in last two decades; no published literature on the disposal of damaged and spent PVs to landfills and no applicable leachate data is available. Though, considering the demand for thin-film semiconductors, this has increased in the recent years and is expected to garner $22 billion by 2022, registering a CAGR (compound annual growth rate) of 14% during the forecast period 2016–2022 [35]. Therefore, additional research with environmental conditions that stimulate MSW (municipal solid waste) landfills with actual could be done to have a clear understanding of the fate these toxic compounds in the environment.

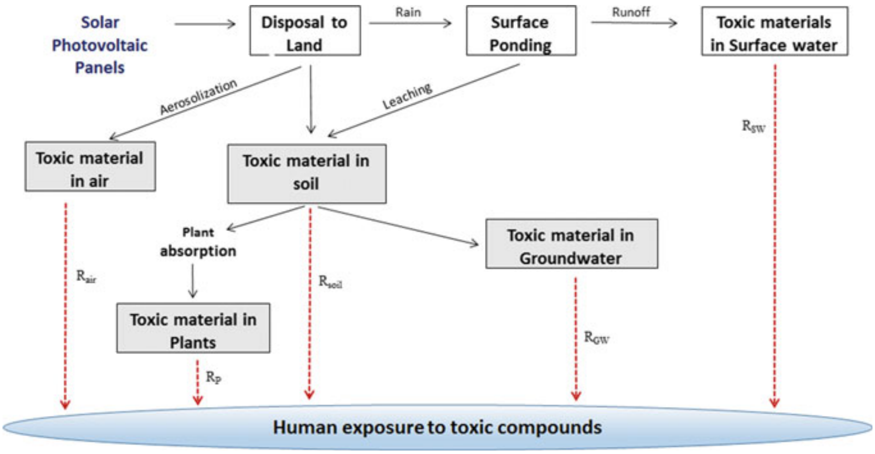

Fig. 4 A theoretical schematic indicating possible human exposure to solar cell-associated components from different environmental components (*Note* Five exposure routes: R_{air} [exposure through air]; R_P [exposure through consumption of edible plants]; R_{soil} [exposure through soil]; R_{GW} [exposure through ingestion of groundwater]; R_{SW} [exposure through surface water])

5 Decommissioning and Recycling of Photovoltaic Modules

Used-up PV modules have some serious health and environmental concerns. Presently, dismantled PV modules are handed over to e-waste recyclers. There is no such published information or data is available on disposing them in landfills. As the growth of PV industry is fast, so, proper planning needs to be done to handle such huge quantity of waste in future. According to an assessment, there is a demand for recyclers especially in developing countries [36]. Therefore, it is essential that local authorities, government, non-profit organizations and manufacturers take responsibility for proper disposal of solar PV modules. Although other policies such as mandated consumer recycling can be followed in order to ensure safe disposal of products containing hazardous materials, in case of solar panels, there is an advantage because government is also encouraging the industry to grow in the energy sector. Research has already been conducted on centralized and decentralized recycling techniques [4, 37]. Irrespective of exponential growth, recycling of EoL PV panels is essential not because of scarceness of various metal used in their manufacturing. It is important to recycle spent modules in order to recover essential metals, reduce cost and resource requirement and have minimal environmental impacts due to disposal. Recycling cost can be improved by enhancing the purity of metal recovered and optimizing the process cost.

Various recycling studies have been done in last 10 years with maximum material recovery and minimum cost and waste generation. At present, major research on solar panel recycling is being done in developing countries like US and Japan [38, 39]. First Solar, Solar World Global and PV Cycle have already voluntarily taken recycling initiatives and continuously optimizing their recycling programmes [40]. First Solar also developed a recycling process having chemical and mechanical processes to recycle CdTe solar PVs [41]. Third-generation PVs are still under development stage. In 2003, Deutsche Solar, established a recycling method for c-Si PV which includes placing of waste PVs in furnace followed by manual dismantling and chemical treatment [42]. In the same year, Solar World presented pyrolytic method to eliminate the organic fraction followed by chemical treatment of waste Si modules and established its own collection system of PV waste. Electrostatic separation can separate 95% of metallic fraction from crystalline-Si PV Modules [43]. Acid treatment and chemical bath deposition can be used to recover material from CdS waste and reused to fabricate new recycled glass/FTO/CdS electrodes [44]. Economically and environmentally meaningful recycling is required.

6 Regulatory Legislation of PV Panel Waste

In most of the countries around the world, PV panel waste still mostly comes under the e-waste or hazardous waste. Currently, EU has established explicit solar PV waste legislation. In developed nations, such as in Japan or the US, toxicity characterization of EoL PV modules, preparation and banning of PV waste and disposal pathways are governed by general electronic waste guidelines. The EU is the pioneer of PV-specific waste regulations covering the collection, recovery and recycling standards. Under Waste Electrical and Electronic Equipment Directive, PV manufacturers delivering PV panels in European nations (irrespective of location) are required to collect and recycle spent solar PVs based on the extended producer responsibility [45]. Table 3 summarizes such legislation/regulation adopted by various countries for handling of WEEE. It is clear from Table 3 that except EU, other countries do not have specific guidelines/legislations to tackle the issue of PV waste.

Table 3 Legislative framework on waste solar photovoltaic management by individual country/ region

Region/ Country	Regulation/Legislation	Description	Reference
Europe	Under the revised WEEE Directive (2012)	Collecting and recycling photovoltaic panels including setting minimum collection and recovery targets. WEEE does not cover the disposal of solar thermal modules	Ministry of Environment
United States	HR 2284: Responsible electronics recycling act (2011)	Bann on export of things having Be, Cd, Pb, Cr, Hg and other organic solvents but does not cover the solar panel waste specifically	United States Environmental Protection Agency
California	SB 489 in section 25259 of Health and Safety Code, Chapter 6.5, Division 20, Article 17 (2015)	Sanctions the department of toxic substances control to implement guidelines to term EoL PVs as toxic e-waste	California Department of Toxic Substances Control. July, 2016 workshop
India	E-waste Management and Handling Rules (2010)	No specific guidelines to regulate solar PV waste	Ministry of Environment, Forest and Climate Change, 2016
Japan	Waste Management and Public Cleansing Act (2015)	No specific guidelines to regulate solar PV waste	Ministry of Environment

(continued)

Table 3 (continued)

Region/ Country	Regulation/Legislation	Description	Reference
China	Catalogue of restricted imports of solid wastes (2008)	No specific guidelines to regulate solar PV waste	Ministry of Environmental Protection of the People's Republic of China
South Korea	Transboundary movement of hazardous wastes and their disposal (1994)	Control on export of hazardous waste without approval from importing country but doesn't cover the PV waste specific guidelines	Ministry of Environment
Singapore	Environmental Public Health (General Waste Disposal Facility) 2017	No specific guidelines to regulate solar PV waste	National Environment Agency
Vietnam	Environmental Protection (2005)	Restricts the import of hazardous waste but doesn't cover the PV waste under hazardous category	Ministry of Natural Resources and Environment

The extended producer responsibility policy could be effective in handling the future solar PV waste volume [46]. It is proposed that a solar PV waste specific central recycling facility should be established, requiring manufacturers to be liable for recycling. The government should develop appropriate regulatory legislations and policies for monitoring recycling and proper management and disposal of spent PV with consequences for improper handling of waste modules. In addition, measures should be taken by the government to oblige solar manufacturing organizations to release information related to waste volumes, breakage rates, recycling process and waste management actions in order to establish equilibrium between the stakeholders. So, there is need to broaden the responsibilities of the manufacturers not only in producing and selling of PVs but also after end-of-life stage.

7 Identified Knowledge Data Gaps

(a) Most of the studies in literature studied leaching behaviour of CdTe panels. Leaching studies on other technologies like silicon-based solar modules are scarce despite of their large market share and therefore, their pollution potential needs to be studied.

(b) Limited data on dumping of spent PV modules was accessible. Data on fate of decommissioned solar PV modules in MSW landfills is not available. This study is required in order to study the effect of solar PV leachate on MSW characteristics.

(c) Lack of data on leaching tests using standard toxicity protocols for measuring heavy metals and nanoparticles. A preliminary leaching rate assessment for decommissioned PV panels disposed in soil is required to generate data for quantifying its waste-type category for future handling and risk assessment.
(d) Lack of data on the waste generated in PV industry during the production and decommissioning stage. The information on various waste streams and solid waste is required for human health risk assessment and environmental impacts.
(e) Lack of standardized leaching tests representing actual solid MSW conditions. Knowledge on factors affecting leaching is not properly known for different types of SPV in various environmental conditions in order to categorize them under specific waste category and for the formulation of framework, guidelines and regulations in future.
(f) Lack of data on Life Cycle Inventories incorporating the likelihood of module failure in a worst-case scenario and kinetics data for metal leaching.
(g) Lack of specific regulations/legislation/guidelines for the management of PV waste.
(h) Lack of information on the aspect that whether the current waste regulatory methods (TCLP, WET) are appropriate for accessing the toxicity of PV modules currently available to consumers or not. Research is required for examining the suitability of standard tests in predicting leaching under realistic field conditions.
(i) Limited data is available on the toxicity of the various elements used in PVs and the read-across issue, more in-depth research required.
(j) Lack of information on economic and technical bottlenecks for the development of PV recycling programme.

8 Future Outlooks

(a) Most of the leaching studies done so far, considered PV module crushed into cm-scale pieces showing worst-case scenario. Though, no particulars were given about the phenomenon/process used for crushing PV to such a degree of crushing if modules were abandoned in nature. So, leaching studies representing real case scenarios of cracked or broken modules is needed to be done.
(b) Studies related to leaching of thin-film PV modules considering the situations existing in India have not been conducted. As, the environmental setting and regulations concerning waste handling differ in the Indian framework, so India centric study on PV waste disposal options could be done.
(c) As the metals used in PV panels are scarce and volume of waste generation in future is going to increase, the viability of recycling methods with value

creation of PV end of life could be explored. Progressing research is needed to establish standardized methods for recycling PVs.

(d) Provision of strategic policies and PV waste management legislation framework in the course of persistent research and development to ensure feasible recycling method and boosting the local PV recycling industries for PV end-of-life management.

(e) Active cooperation from manufacturers, stakeholders, dealers and distributors, for the disclosure of the record information on materials usage, occupational risk, emissions and waste generated at various steps, which could give more reliability and clearness to perform comprehensive and refined LCAs for the large scale deployment of PV modules and their waste management at the same time.

(f) At present, the efficiency of PV modules is reasonably low as compared to conventional energy sources. Consequently, in the next decade, new fabrication technologies with new materials will be developed. Thus, it is important to fill the gap by considering the fact that new PV solar cells with new material composition will be produced.

(g) Long-term leaching test stimulating field conditions may be carried out in order to get the better perceptive from various aspects such as solubility and leaching of metals from the latest PV modules with new metal composition, state and speciation of the mobilized compounds found in leachate and environmental impact of metal toxicity.

9 Conclusions

Solar PV technology offers enormous environmental benefits as compared to other non-renewable energy technologies and fossil fuels. Usage of PV cells on large scale will bring with it the likelihood of widespread environmental contamination if not handled scientifically. Once released into the environment, the ultimate fate and effects of toxic compounds remain poorly understood and difficult to predict. From literature review, it has been observed that CdTe PV system emits the least environmental greenhouse emissions with mono-Si has the highest. The only issue with CdTe PV system is the presence of hazardous metals in small quantity. Presently, little is known about the environmental and health hazards of solar photovoltaics, though research on the recycling and toxicity of some metals already gives rise to concern. This study suggested the urgent requirement of recycling facilities for the upcoming EoL waste streams. From the review, it was observed that there is significant release of metals and recycling of various components is required and disposing in environment is not recommended. Reducing and step-by-step exclusion of unsafe toxic metals in manufacturing of solar PVs can reduce their environmental footprint. The most favoured handling option for EoL PV modules is recycling, for minimizing the negative impacts on environment and recovering the source metals. Overall, the main aim of this paper is to initiate a discussion on the end-of-life management of PVs and highlighting risk due to leaching of hazardous compounds from PV modules and need for proper recycling processes. Ongoing investigation is required for finding of practicable and profitable solutions for application of toxic substances in manufacturing of solar panels and handling of EoL solar modules.

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References

1. Marwede, M., Berger, W., Schlummer, M., Maurer, A., Reller, A.: Recycling paths for thin-film chalcogenide photovoltaic waste—current feasible processes. Renew. Energ. **55**, 220–229 (2013)
2. Peng, J., Lu, L., Yang, H.: Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems. Renew. Sust. Energ. Rev. **19**, 255–274 (2013)
3. Fthenakis, V.M.: End-of-life management and recycling of PV modules. Energ. Policy. **28**, 1051–1058 (2000)
4. EPIA: Global market outlook for photovoltaics (2018)
5. Giacchetta, G., Leporini, M., Marchetti, B.: Evaluation of the environmental benefits of new high value process for the management of the end of life of thin film photovoltaic modules. J. Clean. Prod. **51**, 214–224 (2013)
6. Weckend, S., Wade, A., Heath, G.: End-of-life management: solar photovoltaic panels (No. NREL/BK-6A20-66178). National Renewable Energy Lab, Golden (2016)
7. Raugei, M., Fthenakis, V.: Cadmium flows and emissions from CdTe PV: future expectations. Energ. Policy. **38**, 5223–5228 (2010)
8. Peter, H., Okkenhaug, G., Sparrevik, M.: Leaching from CdTe PV module material-results from batch, column and availability tests. NGI Report (2010)
9. Koehler, A.: Water use in LCA: managing the planet's freshwater resources. Int. J. Life Cycle Assess. **13**, 451–455 (2008)
10. Fthenakis, V., Wang, W., Kim, H.C.: Life cycle inventory analysis of the production of metals used in photovoltaics. Renew. Sust. Energ. Rev. **13**, 493–517 (2009)
11. Hailegnaw, B., Kirmayer, S., Edri, E., Hodes, G., Cahen, D.: Rain on methylammonium lead iodide based perovskites: possible environmental effects of perovskite solar cells. J. Phys. Chem. Lett. **6**, 1543–1547 (2015)
12. Bakhiyi, B., Labrèche, F., Zayed, J.: The photovoltaic industry on the path to a sustainable future—environmental and occupational health issues. Environ. Int. **73**, 224–234 (2014)
13. Fraas, L.M., Partain, L.D.: Solar cells and their applications. Wiley, Texas (2010)
14. Fthenakis, V.M., Moskowitz, P.D.: Thin-film photovoltaic cells: health and environmental issues in their manufacture use and disposal. Prog. Photovoltaics. **3**, 295–306 (1995)
15. Brun, N.R., Wehrli, B., Fent, K.: Ecotoxicological assessment of solar cell leachates: copper indium gallium selenide (CIGS) cells show higher activity than organic photovoltaic (OPV) cells. Sci. Total Environ. **543**, 703–714 (2016)
16. Babayigit, A., Thanh, D.D., Ethirajan, A., Manca, J., Muller, M., Boyen, H.G., Conings, B.: Assessing the toxicity of Pb-and Sn-based perovskite solar cells in model organism Danio rerio. Sci. Rep. **6**, 18721 (2016)
17. Gagnon, L., Belanger, C., Uchiyama, Y.: Life-cycle assessment of electricity generation options: the status of research in year 2001. Energ. Policy. **30**, 1267–1278 (2002)

18. Ladwig, K., Hope, L.: Potential health and environmental impacts associated with the manufacture and use of photovoltaic cells. Final Report, EPRI (2003)
19. Auer, A.: Photovoltaic module decommissioning and recycling in Europe and Japan. Master's Thesis, Swedish University of Agricultural Sciences (2015)
20. Monier, V., Hestin, M.: Study on photovoltaic panels supplementing the impact assessment for a recast of the WEEE directive. Final Report, ENV (2011)
21. Nover, J., Zapf-Gottwick, R., Feifel, C., Koch, M., Metzger, J.W., Werner, J.H.: Long-term leaching of photovoltaic modules. Jpn. J. Appl. Phys. **56**, 8–2 (2017)
22. Zapf-Gottwick, R., Koch, M., Fischer, K., Schwerdt, F., Hamann, L., Kranert, M., Werner, J. H.: Leaching hazardous substances out of photovoltaic modules. Int. J. Adv. App. Phy. Res. **2**, 7–14 (2015)
23. Tammaro, M., Salluzzo, A., Rimauro, J., Schiavo, S., Manzo, S.: Experimental investigation to evaluate the potential environmental hazards of photovoltaic panels. J. Hazard. Mater. **306**, 395–405 (2016)
24. Ramos-Ruiz, A., Wilkening, J.V., Field, J.A., Sierra-Alvarez, R.: Leaching of cadmium and tellurium from cadmium telluride (CdTe) thin-film solar panels under simulated landfill conditions. J. Hazard. Mater. **336**, 57–64 (2017)
25. Sinha, P., Wade, A.: Assessment of leaching tests for evaluating potential environmental impacts of PV module field breakage. IEEE J. Photovol. **5**, 1710–1714 (2015)
26. Allan, J., Kiss, Z., Annamalai, S., Pegg, I. L., Dutta, B.: Water Solubility of Cadmium Telluride in a Glass-to-Glass Sealed PV Module (2010)
27. Zimmermann, Y.S., Schäffer, A., Corvini, P.F.X., Lenz, M.: Thin-film photovoltaic cells: long-term metal (loid) leaching at their end-of-life. Environ. Sci. Technol. **47**, 13151–13159 (2013)
28. Chakankar, M., Su, C.H., Hocheng, H.: Leaching of metals from end-of-life solar cells. Environ. Sci. Pollut. Res. 1–8 (2018)
29. Steinberger, H.: Health, safety and environmental risks from the operation of CdTe and CIS thin-film modules. Prog. Photovoltaics. **6**, 99–103 (1998)
30. Finke, A., Kriele, A., Thumm, W., Bieniek, D., Kettrup, A.: Leaching tests with thin film solar cells based on copper indium diselenide (CIS). Chemosphere **32**, 1633–1641 (1996)
31. Zeng, C., Ramos-Ruiz, A., Field, J.A., Sierra-Alvarez, R.: Cadmium telluride (CdTe) and cadmium selenide (CdSe) leaching behavior and surface chemistry in response to pH and O_2. J. Environ. Manage. **154**, 78–85 (2015)
32. Pagnanelli, F., Moscardini, E., Granata, G., Atia, T.A., Altimari, P., Havlik, T., Toro, L.: Physical and chemical treatment of end of life panels: an integrated automatic approach viable for different photovoltaic technologies. Waste Manage. **59**, 422–431 (2017)
33. Cyrs, W.D., Avens, H.J., Capshaw, Z.A., Kingsbury, R.A., Sahmel, J., Tvermoes, B.E.: Landfill waste and recycling: use of a screening-level risk assessment tool for end-of-life cadmium telluride (CdTe) thin-film photovoltaic (PV) panels. Energ. Policy. **68**, 524–533 (2014)
34. Sinha, P., Balas, R., Krueger, L., Wade, A.: Fate and transport evaluation of potential leaching risks from cadmium telluride photovoltaics. Environ. Toxicol. Chem. **31**, 1670–1675 (2012)
35. Thin Film Material Market By Type—Global Trends & Forecast (2016)
36. Masoumian, M.: End-of-Life Management of Photovoltaics. Doctoral dissertation, PhD thesis, Vienna University of Technology (2014)
37. McDonald, N.C., Pearce, J.M.: Producer responsibility and recycling solar photovoltaic modules. Energ. Policy. **38**, 7041–7047 (2010)
38. Palitzsch, W., Loser, U.: Economic PV waste recycling solutions—results from R&D and practice. In: 38th IEEE Photovoltaic Specialists Conference (PVSC), pp. 000628–000631. IEEE Press, Austin (2012)
39. Doni, A., Dughiero, F.: Electrothermal heating process applied to c-Si PV recycling. In: Photovoltaic Specialists Conference (PVSC), pp. 000757–000762. IEEE Press, Austin (2012)

40. Rocchetti, L., Beolchini, F.: Recovery of valuable materials from end-of-life thin-film photovoltaic panels: environmental impact assessment of different management options. J. Clean. Prod. **89**, 59–64 (2015)
41. Fthenakis, V.M., Wang, W.: Extraction and separation of Cd and Te from cadmium telluride photovoltaic manufacturing scrap. Prog. Photovoltaics. **14**, 363–371 (2006)
42. Müller, A., Wambach, K., Alsema, E.: Life Cycle Analysis of Solar Module Recycling Process. Paper Presented at the MRS Fall 2005 Meeting, Boston, Opatija (2005)
43. Dias, P., Schmidt, L., Gomes, L.B., Bettanin, A., Veit, H., Bernardes, A.M.: Recycling waste crystalline silicon photovoltaic modules by electrostatic separation. J. Sust. Metallur. **4**, 176–186 (2018)
44. Zyoud, A., Al-Yamani, S., Bsharat, H., Helal, M.H., Kwon, H., Park, D., Hilal, H.S.: Recycled polycrystalline CdS film electrodes with enhanced photo-electrochemical characteristics. Mater. Sci. Semicond. Process. **74**, 277–283 (2018)
45. Nowak, S.: IRENA 2016 AND IEA-PVPS: A Renewable Energy Roadmap. International Renewable Energy Agency, Abu Dhabi (2016)
46. Weckend, S., Wade, A., Heath, G.: End-of-Life Management: Solar Photovoltaic Panels. National Renewable Energy Lab, Golden, CO, USA (2016)

Assessing Iron (II) and Fluoride Removals by Indigenously Fabricated Household Water Filter of North Guwahati

Barun Kanoo and Mohammad Jawed

Abstract Groundwater is the major source of water for domestic purposes in Amingaon, North Guwahati, Assam which is contaminated with high concentrations of iron and fluoride. The household-level treatment for iron removal includes the use of indigenously fabricated water filter units comprising sand, gravel, and wooden charcoal. The filter media are arranged in layered form in RCC rings, tin containers, and plastic buckets. The RCC filter unit is the most commonly used, especially for iron removal. However, the contamination level of groundwater of Amingaon and the effectiveness of indigenously fabricated household filter units in iron and fluoride removal is neither estimated/evaluated by government agencies nor reported in the literature. The present study aims to investigate the level of contamination of groundwater for iron and fluoride as well as efficiency and effectiveness of an RCC filter unit in the removal of iron and fluoride over a period of 6 months. The groundwater in and around the IIT Guwahati campus has a high concentration of iron (0–11.3 mg/L) whereas the concentration of fluoride is in the range 0.13–0.66 mg/L. A set of two samples, one from the tube well and the other from the filtered water, was collected at an interval of 3 days from a selected household RCC filter. Water quality parameters, viz., iron, fluoride, pH, temperature, conductivity, turbidity, and dissolved oxygen were estimated for the collected samples of each set. The selected RCC filter unit is able to produce filtered water containing residual iron concentration of 0–0.08 mg/L from an initial iron concentration of 8.13–11.63 mg/L. The selected filter unit is also able to reduce the fluoride concentration from a value of 0.51–1.17 mg/L to 0.39–0.77 mg/L. The DO level in the groundwater increases as the same is poured into the filter unit thereby converting ferrous iron to ferric form. The ferric form of iron is filtered out as precipitate in the filter unit.

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Keywords Iron removal · Fluoride removal · Groundwater · Indigenously fabricated household water filter · Domestic water use

1 Introduction

More than 80% of the rural population in Assam depends on groundwater resources for drinking and irrigation purposes [1]. However, even for a city like Guwahati, groundwater is the major source of domestic water consumption. The reason being that Guwahati is a fast-growing city with the present population of about a million and with an inadequate supply of municipal water, hence, people have no choice but to extract groundwater for domestic use. Unfortunately, the groundwater contains excessive concentrations of dissolved iron and fluoride. Iron concentration in and around Guwahati is observed to be in the range of 1–10 mg/L [2] and fluoride in the range of 0.3–7 mg/L [3]. Even higher concentrations of fluoride in the range of 0.2–18.1 mg/L have been reported from Karbi Anglong and Nagaon districts [3]. The groundwater concentrations of iron and fluoride in different areas of Guwahati city have increased over the years. This could be due to geological reasons such as dissolution of minerals rich in iron and fluoride [4, 5]. The increasing dependency on the groundwater reserves and hence going for boring at much greater depths with depletion of groundwater can also be attributed to the increase of iron and fluoride. Amingaon is a rural locality in North Guwahati on the outskirts of the Guwahati city across the river Brahmaputra. Though a lot of development is taking place in North Guwahati area due to the establishment of IIT Guwahati, higher secondary schools, many small- and medium-scale industrial units, and other public facilities such as super-specialty hospitals, the population of Amingaon is still deprived of piped municipal water supply. Hence, a large population of Amingaon has no alternatives but to depend on the groundwater for their domestic water needs. However, there are no literature available to indicate the level of fluoride and iron concentrations in the groundwater of Amingaon, North Guwahati [3, 6].

The research of the past has yielded a number of methods to remove iron and fluoride from groundwater. The methods of iron removal basically involve oxidation, precipitate settling, and filtration [7, 8]. The methods of fluoride removal involve coagulation, flocculation, and filtration as well as filtration or adsorption alone [9]. However, these methods not only appear to be sophisticated but also need costly chemicals and adsorbents in some cases. The sophistication of these methods for iron and fluoride removal as well as poor economic conditions of the rural population residing in Amingaon area appears to be the reasons for non-application on the ground. Therefore, the people of Amingaon use different types of indigenous household water filter units fabricated using reinforced cement concrete (RCC) rings, tin containers, and clay pitchers to prepare potable water from groundwater. However, the filtering media used in these filters invariably consisted of sand, gravel, and wooden charcoal arranged either in layered form or a mixture of the two or three media. The filtering material, its percentage in the indigenous filter, and its arrangement vary from place to place and house to house. A mesh or net with small openings is provided below the filtering media to prevent escape of sand from the filter unit. The groundwater is applied to the indigenous filter intermittently as per the requirement of the household for drinking and cooking purposes. These filters are fabricated and operated solely based on the experiences of the local population gained and transferred from the previous generations. However, the performance of these indigenously fabricated household water filters in removing iron and fluoride from groundwater has not been assessed so far.

Hence, the objectives of this study are (a) to obtain first-hand information of 8–10 households using indigenously fabricated household water filter units, (b) to assess the quality of groundwater of Amingaon area in North Guwahati with special attention on iron and fluoride concentrations, (c) to understand the fabrication, operation, and maintenance of a selected filter unit, and (d) to monitor the performance of the selected filter unit for its potential to remove iron and fluoride from the groundwater.

2 Materials and Methods

2.1 Field Survey

A field survey was undertaken up to a distance of 600 m from the boundary of the IIT Guwahati campus. During the field survey, the first step was to identify the households which were having and using indigenously fabricated household water filter unit for its drinking and cooking water requirements. The GPS location of the identified households was noted down. The second step was to have a face-to-face interaction with the house owner to seek information mainly with respect to (i) details of physical location such as prominent landmark near IIT Guwahati, Village, Taluka, (ii) household details such as name of the house owner, his/her age, and education levels; main livelihood; number of people residing, (iii) type of indigenously fabricated household water filter in use, (iv) physical water quality parameters, (v) health status (with special emphasis on teeth color) of residents. In addition, groundwater samples were also collected to assess the levels of iron and fluoride present in the water.

2.2 Monitoring of a Selected Indigenously Fabricated Household Water Filter Unit

The filter unit at House No. 9 (refer Table 1) with GPS location 26° 11′ 11.2″ N and 91° 42′ 02.6″ E was selected for continuous monitoring. The reasons for selecting this filter unit were (a) the source of groundwater was located at a distance

Table 1 Summary of surveyed household characteristics using traditional water units in Amingaon, North Guwahati

Location	Left of Faculty Gate facing Faculty School			Lothia Bagisa, Bodogaon			Near Main Gate	Near ASEB Gate	Right of Faculty Gate facing Faculty school	
Village	Ghoramara, North Guwahati			Lothia Bagisa, Bodogaon			Kating Pahar	Abhaypur Shishugram	Ghoramara, North Guwahati	
Taluka	GMC (North Guwahati circle)			GMC (North Guwahati circle)			GMC (North Guwahati circle)	GMC (North Guwahati circle)	GMC (North Guwahati circle)	
District	Kamrup			Kamrup			Kamrup	Kamrup	Kamrup	
House number	1	2	3	4	5	6	7	8	9	10
Latitude	26° 11′ 11.6″ N	26° 11′ 10.1″ N	26° 11′ 09.6″ N	26° 10′ 59.5″ N	26° 11′ 01.7″ N	26° 10′ 58.6″ N	26° 11′ 49.1″ N	26° 11′ 59.5″ N	26° 11′ 11.2″ N	26° 11′ 11″ N
Longitude	91° 42′ 08.2″ E	91° 42′ 04.3″ E	91° 42′ 04.9″ E	91° 41′ 40.3″ E	91° 41′ 38.7″ E	91° 41′ 40.6″ E	91° 41′ 40.6″ E	91° 42′ 12.8″ E	91° 42′ 02.6″ E	91° 42′ 02.4″ E
Distance from IITG campus (m)	400	100	100	100–200	300–400	100–200	100–200	600	50	50
Main livelihood	Electric maintenance works in IITG	Govt. service (irrigation department)	Agriculture, Rented house	Puffed rice business	IITG mess worker	Pig business	Dairy business	Welding and farming	Rented houses, Conductor in bus, Grass cutter in IITG	Labor
Family size	11	3	9	8	8	1	18	7	3	2
Water for drinking purpose	Double compartment filter and then candle filter	Candle filter and then boil	Direct	Traditional filter	Traditional filter	Direct	Well-Filter-Boil	Direct	Double compartment Filter	Traditional filter
Water for other uses	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct
Odor problem	Slight	Slight	Yes	Yes	Slight	No	No	No	Yes	Slight
Color problem	Slightly muddy	Reddish	Reddish	Slight reddish	Slight reddish	Clean	Clear	Muddy	Reddish	Slightly Reddish
Pale teeth	Yes	No	No	No	No	Slight	No	No	Yes	No
		No	Yes	Yes	No	No	Yes		No	Yes

(continued)

Table 1 (continued)

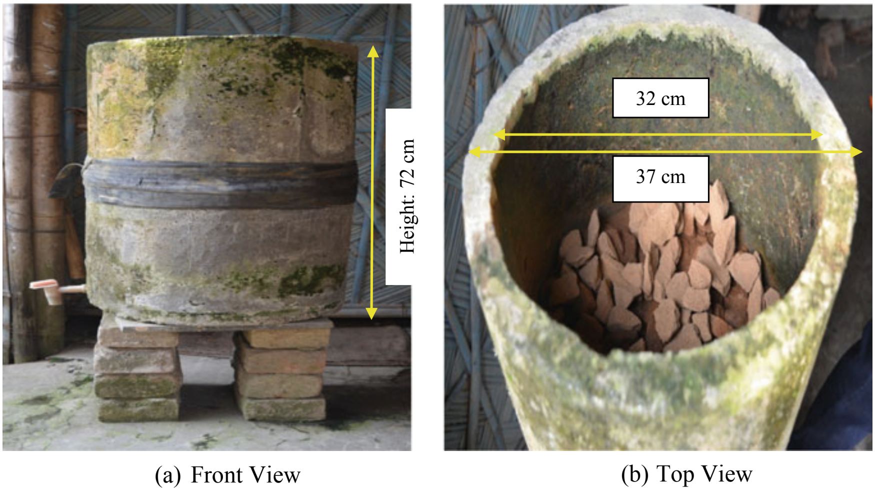
Location	Left of Faculty Gate facing Faculty School			Lothia Bagisa, Bodogaon			Near Main Gate	Near ASEB Gate	Right of Faculty Gate facing Faculty school	
Village	Ghoramara, North Guwahati			Lothia Bagisa, Bodogaon			Kating Pahar	Abhaypur Shishugram	Ghoramara, North Guwahati	
Taluka	GMC (North Guwahati circle)			GMC (North Guwahati circle)			GMC (North Guwahati circle)	GMC (North Guwahati circle)	GMC (North Guwahati circle)	
District	Kamrup			Kamrup			Kamrup	Kamrup	Kamrup	
House number	1	2	3	4	5	6	7	8	9	10
Agriculture water supply system	Yes, in small quantity							Yes (by pond and tube well)		
Cleanliness near the water resource	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
Groundwater iron concentration (mg/L)	0.22	1.21	1.53	2.31	1.11	1.56	0.00	0.52	11.30	3.73
Groundwater Fluoride concentration (mg/L)	0.44	0.51	0.36	0.43	0.59	0.56	0.13	0.35	0.66	0.62

ASEB: Assam State Electricity Board, GMC: Guwahati Metropolitan Corporation from the bank of river Brahmaputra with possibly minimum infiltration of river water, (b) the assessed iron concentration of 11.30 mg/L was the highest in the area, and (c) filter location was close to the Environmental Engineering Laboratory of the Department of Civil Engineering, IIT Guwahati (at a distance of 50 m) which shall facilitate in quick transportation of the collected water samples and its analysis.

The filter unit at House No. 9 collects the water from the groundwater source and then filters the stored water according to their need. Hence, it was deemed essential to collect two samples at a time—the first sample was collected directly from the source groundwater (i.e., tube well), and the second one was collected from the filtered water. The collected samples were analyzed for temperature, pH, conductivity, turbidity, DO, iron, and fluoride—taken as important water quality parameters for monitoring of filter performance. The water samples were collected once in 3–4 days and analyzed since July 2017.

2.3 Fabrication, Operation, and Maintenance of a Selected Filter Unit

The selected indigenously fabricated household water filter unit (commonly known as traditional water filter) is made of two compartments of reinforced cement concrete (RCC) rings (as shown in Fig. 1)—the upper compartment is filled up with the filter materials such as sand, wooden charcoal, and gravel (shown in Fig. 2) while the lower compartment is used for the storage of the filtered water. In the top compartment, a mesh net is put at the bottom and then a sand layer of depth of around 7–8 cm whereas, at the top, there is a layer of gravel with a depth of around



(a) Front View (b) Top View

Fig. 1 Selected indigenously fabricated household water filter unit

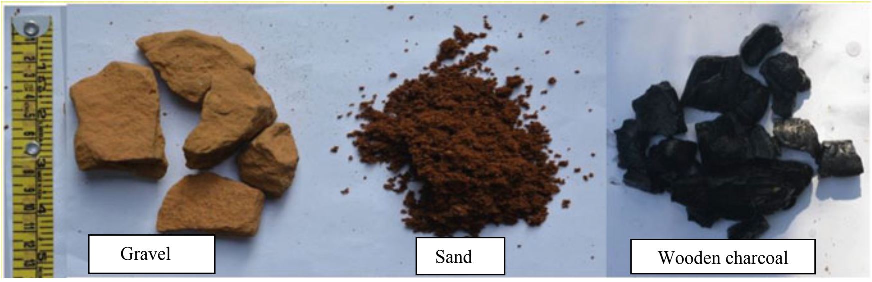


Fig. 2 Gravel, sand, and wooden charcoal used in the selected indigenously fabricated water filter unit

14–16 cm. Also, a layer of wooden charcoal is included as a filtering medium with a depth of 2–4 cm. The internal diameter of the filter unit is 32 cm and external diameter is 37 cm. The total height of the unit is 72 cm with each compartment of height 36 cm.

Approximately 8–10 L of the groundwater collected from the tube well is directly poured into the filter unit in one go for filtration. The filter unit is used to produce approximately 50–60 L of filtered water on a daily basis and the unit is operated for 3–4 months continuously. With use for 2–3 months, the filtration output decreases due to the formation of a reddish cake or a layer of precipitated iron on top of the filter media (as shown in Fig. 3) which indicated clogging of the filter unit. Once the filtration output decreases than the requirement of 50–60 L of filtered water per day, the sand and wooden charcoal are replaced with a fresh lot procured from the local market of Amingaon.

Fig. 3 Reddish layer formed on top of the filter media of the selected filter unit

2.4 Methods

Temperature, pH, conductivity, turbidity, DO, iron, and fluoride were selected as water quality parameters and were thus analyzed during the research work. Temperature and pH were determined by the digital pH meter (Model: µpH System 361, M/S Systronics India Ltd., India). Turbidity was measured using a digital turbidity meter (Model: 123, M/S Systronics India Ltd., India). Conductivity was measured with a digital conductivity meter (Model: LT-51, M/S Labtronics, India). DO was measured by the Azide Modification method [11]. DO level at the outlet was also measured by the micro-Winkler method (required only 1 mL of sample in contrast with 300 mL of sample required in the Modified Winkler's method [10]. Iron concentration in the water was analyzed by 1,10-Phenanthroline method [11] using a spectrophotometer (Model: Spectro V-11D, M/S MRC Ltd., the United Kingdom). The concentration of fluoride was analyzed by the SPADNS method [11] using a spectrophotometer. GPS locations were obtained using a smart mobile phone (Model: PA4C0020IN, M/S Motorola, India).

3 Results and Discussion

3.1 Field Survey

A field survey was carried out in Amingaon, North Guwahati area of 10 households using indigenously fabricated household water filter units in and around the campus of IIT Guwahati. The relevant information was obtained through personal face-to-face interaction with the house owner (or the landlady). The surveyed households were located at a distance of 50–600 m from the campus of IIT Guwahati and the number of members residing in the house varied from a low of 3 to a high of 21 persons. The educational level of the house owners was very diverse —from uneducated, class 5 pass, higher secondary pass to graduation (Bachelor of Arts) degree holder. The livelihood of the house owners was equally diverse—from daily wage workers to self-employed with small business or as welder, private, and government jobs. All of the surveyed households used one or the other type of traditional water filter units for their domestic water needs of drinking and cooking as the groundwater was reported to have odor problems and appeared to contain turbidity. The groundwater samples were also collected from the surveyed households for the assessment of concentrations of iron and fluoride. A brief summary of the surveyed households is presented in Table 1. The ranges of iron and fluoride concentrations in the groundwater of the surveyed locations are in the range of 0–11.30 mg/L and 0.13–0.66 mg/L, respectively. Pale teeth were observed in a few of the surveyed households which might not be attributed to fluoride as its concentration was within the permissible limits [12].

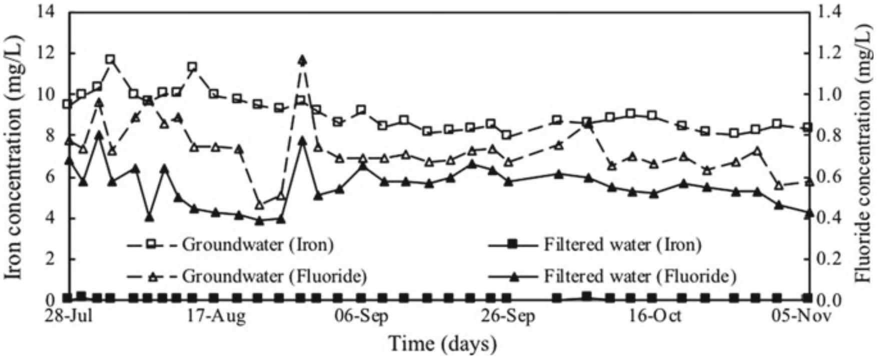


Fig. 4 Variation in iron and fluoride concentration during monitoring period of the selected filter unit

3.2 Performance Monitoring of the Selected Filter Unit

The performance of the selected filter unit was monitored since July 2017. The filter unit performance was assessed by estimating water quality parameters such as iron and fluoride concentrations, pH and temperature, conductivity and turbidity as well as DO levels on regular basis for water samples collected from the source groundwater and filtered water. The variation in iron and fluoride concentrations of groundwater and filtered water is presented in Fig. 4. The iron concentration ranged from 8.13 to 11.63 mg/L whereas fluoride concentration ranged from 0.51 to 1.17 mg/L in the groundwater samples. The groundwater after being filtered through the filter unit has had an iron concentration in the range of 0–0.08 mg/L while fluoride concentration was in the range of 0.39–0.77 mg/L. The concentration of fluoride in the filtered water was always within the permissible limit for drinking and cooking purposes. The removal of iron is taking place possibly due to oxidation of ferrous iron to ferric iron. The ferric iron is forming a reddish color cake which might be able to reduce the concentration of fluoride a bit.

The pH of the groundwater was measured immediately after the sampling to represent the true picture. The pH of the groundwater sample varied in the range of 6.17–6.81. The pH of the filtered water from the unit is in the range 6.82–7.51 which is within the permissible limit of 6.5–8.5 for domestic use [12]. It is observed that the increase in pH is favorable for the precipitation of iron. The temperature keeps on varying and is not constant. It very much depends on the weather conditions for that particular sampling day. The variation in pH and temperature is shown in Fig. 5.

The conductivity of the groundwater samples collected from the tube well and the filtered water did not show major changes and is almost the same ranging from 0.4 to 1.1 mS/cm. The turbidity of the groundwater varied in the range of 0.7–1.5 NTU. It is directly proportional to the time gap between sampling and analysis for turbidity. The main reason is oxidization of Fe^{2+} to Fe^{3+} and the formation of

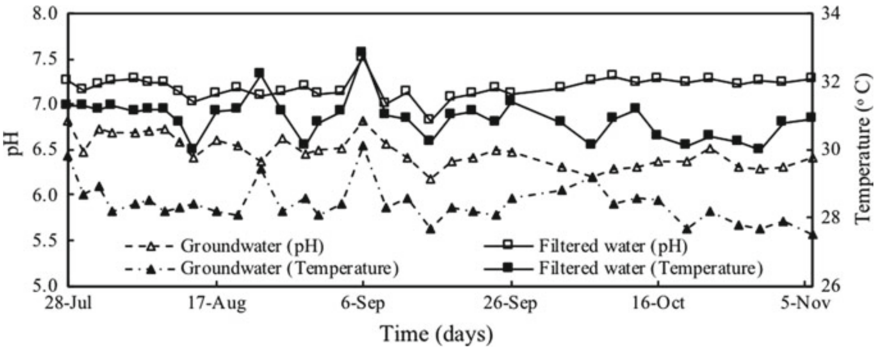


Fig. 5 Variation in pH and temperature during monitoring period of selected filter unit

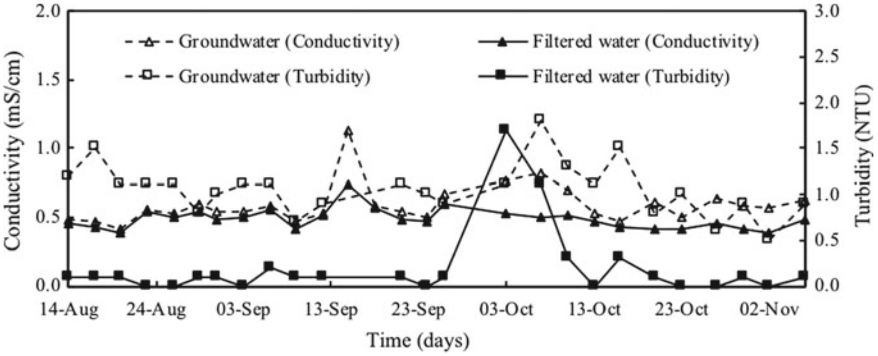


Fig. 6 Variation in conductivity and turbidity during monitoring period of the selected filter unit

precipitates which produces visible turbidity. The turbidity of the filtered water ranged from 0 to 0.2 NTU which is within the permissible limit of less than 1 NTU [12]. The variation in conductivity and turbidity of groundwater and filtered water is shown in Fig. 6.

The collected groundwater samples from the tube well showed no DO. However, when the groundwater is poured into the filter unit, it absorbed oxygen from the air and showed DO in the range of 1.0–2.4 mg/L. This level of DO might have helped in the conversion of ferrous iron into ferric iron and its retention on top of the filter media. Therefore, the mechanism of iron removal from the groundwater is the conversion of ferrous iron to ferric iron and its filtration through the filter media. The filtered water contained DO levels of 5.9–6.7 mg/L. The DO levels in the filtered water were also analyzed using the micro-Winkler method [10] which produced almost similar results with modified Winkler method. The variation in DO levels in groundwater, influent water to the filter, and filtered water is shown in Fig. 7.

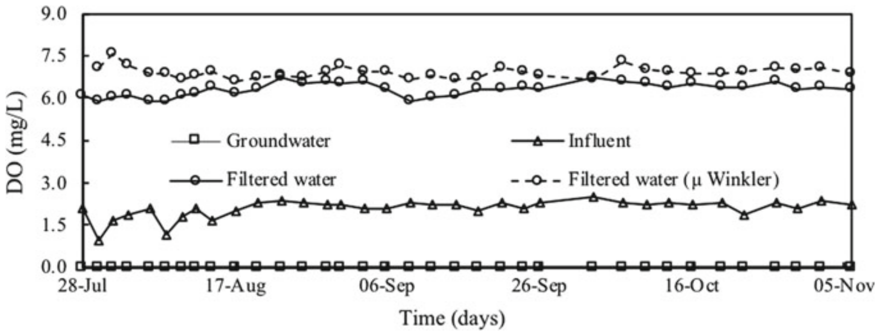


Fig. 7 Variation in dissolved oxygen during monitoring period of the selected filter unit

The monitored performance-related parameters of the selected indigenously fabricated household water filter unit are summarized on a monthly basis and presented in a tabular form in Table 2.

Table 2 Summary of monitored performance parameters for the selected water filter unit

Water quality parameters		Monitoring period		
		July 28, 2017 to August 31, 2017	September 01, 2017 to September 31, 2017	October 01, 2017 to November 06, 2017
Iron (mg/L)	Groundwater	9.94 ± 0.67 (15)	8.43 ± 0.40 (09)	8.50 ± 0.31 (11)
	Filtered water	0.03 ± 0.02 (15)	0.02 ± 0.01 (09)	0.04 ± 0.01 (11)
Fluoride (mg/ L)	Groundwater	0.80 ± 0.18 (15)	0.70 ± 0.02 (09)	0.68 ± 0.08 (11)
	Filtered water	0.55 ± 0.14 (15)	0.60 ± 0.04 (09)	0.53 ± 0.05 (11)
pH	Groundwater	6.59 ± 0.13 (15)	6.47 ± 0.17 (09)	6.33 ± 0.08 (11)
	Filtered water	7.17 ± 0.07 (15)	7.12 ± 0.18 (09)	7.25 ± 0.04 (11)
Temperature (°C)	Groundwater	28.53 ± 0.49 (15)	28.47 ± 0.67 (09)	28.20 ± 0.53 (11)
	Filtered water	31.30 ± 0.52 (15)	31.14 ± 0.7 (09)	30.53 ± 0.40 (11)
Conductivity (mS/cm)	Groundwater	0.51 ± 0.06 (07)	0.61 ± 0.20 (09)	0.62 ± 0.11 (11)
	Filtered water	0.48 ± 0.05 (07)	0.54 ± 0.09 (09)	0.45 ± 0.05 (11)
Turbidity (NTU)	Groundwater	1.11 ± 0.21 (07)	0.97 ± 0.15 (07)	1.05 ± 0.38 (11)
	Filtered water	0.07 ± 0.05 (07)	0.08 ± 0.07 (07)	0.33 ± 0.55 (11)
Dissolved oxygen (mg/L)	Groundwater	0.00 ± 0.00 (15)	0.00 ± 0.00 (09)	0.00 ± 0.00 (11)
	Influent water above filter media	1.93 ± 0.40 (15)	2.18 ± 0.11 (09)	2.25 ± 0.16 (11)
	Filtered water	6.23 ± 0.26 (15)	6.24 ± 0.21 (09)	6.46 ± 0.12 (11)
	Filtered water (by μ Winkler)	6.92 ± 0.25 (14)	6.84 ± 0.15 (09)	6.97 ± 0.17 (11)

[The data is presented in $a \pm b$ (c) format where a is the average value, b is the standard deviation, and c is the number of data points considered for obtaining the average and standard deviation]

4 Summary

The groundwater in and around IIT Guwahati campus has a high concentration of iron (0–11.3 mg/L), often exceeding the acceptable range of 0.3 mg/L whereas the concentration of fluoride in the range of 0.13–0.66 mg/L is within the acceptable limit of 1–1.5 mg/L for domestic purposes. The local population of Amingaon, North Guwahati, irrespective of educational qualification and age, livelihood and occupation, invariably use an indigenously fabricated household water filter units (also known as traditional water filters) fabricated of RCC rings, tin containers, and plastic buckets filled with filtering media comprising sand, gravel, and wooden charcoal in layered form. A selected filter unit is monitored since July 2017 that produced filtered water containing residual iron concentration of 0–0.08 mg/L from an initial iron concentration of 8.13–11.63 mg/L. The selected filter unit is also able to reduce the fluoride concentration from a value of 0.51–1.17 mg/L to 0.39–0.77 mg/L. The DO level in the groundwater increases as the same is poured into the filter unit thereby converting ferrous iron to ferric form. The ferric form of iron is filtered out as precipitate in the filter unit.

References

1. CGWB: Groundwater Year Book 2013–14, Ministry of Water Resources, Government of India, New Delhi (2014)
2. Ahamad, K.U.: Iron (II) Adsorptive capacity evaluation of wooden charcoal and sand media used in indigenous household iron filtration units of rural and semi-urban Assam. Masters Thesis, Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati, India (2005)
3. Das, B., Talukdar, J., Sarma, S., Gohain, B., Dutta, R.K., Das, H.B., Das, S.C.: Fluoride and other inorganic constituents in groundwater of Guwahati, Assam, India. Curr. Sci. **85**(5), 657–661 (2003)
4. Raj, D., Shaji, E.: Fluoride contamination in groundwater resources of Alleppey, Southern India. Geosci. Front. **8**, 117–124 (2017)
5. Singh, R., Maheshwari, R.C.: Defluoridation of drinking water–a review. Indian J. Environ. Prot. **21**(11), 983–991 (2001)
6. NIH: Groundwater water quality monitoring and evaluation in and around greater Guwahati, Assam. National Institute of Hydrology, Roorkee, CS (AR) 10/97-98 (1998)
7. DRDO: “Water Iron Removal Unit”, Technology Focus. Bull. Def. Res. Dev. Organ. **10**(1), ISSN: 0971-4413. https://www.drdo.gov.in/drdo/pub/techfocus/2015/TF_Mar_2015_WEB.pdf (2002). Website last accessed 21 Sept 2017
8. NEERI: Handbook on Drinking Water Treatment Technologies, Ministry of Drinking Water and Sanitation, Government of India, New Delhi (2011)
9. NEERI: Defluoridation technology mission on drinking water in villages and related water management. National Environment Engineering Research Institute, Nagpur, India (1987)
10. Shriwastav, A., Sudarsan, G., Bose, P., Tare, V.: Modification of Winkler’s method for determination of dissolved oxygen concentration in small sample volumes. R. Soc. Chem. **2**, 1618–1622 (2010)

11. APHA: Standard Methods for the Examination of Water and Wastewater, 21st edn. American Public Health Association, American Water Works Association and Water Environment Federation, Washington, DC, USA (2012)
12. IS 10500: Specification for Drinking Water, Bureau of Indian Standards, New Delhi (2012)

Social and Policy Study for Municipal Solid Waste Management Planning for Small Towns in Maharashtra: Case of Mowad

Bhagyashree Patil, Ankita Rathore, Amruta Garud and Bakul Rao

Abstract Municipal Solid Waste Management (MSWM) is a major environmental and social concern for the small towns and growing villages, considering the rapid urbanization and the subsequent changes in the waste generation patterns. Accommodating the small-town characteristics to design feasible and sustainable MSWM plans is one of the biggest challenges faced by the urban local bodies today. This study presents the status of MSWM from the perspective of small towns, in order to establish the causality for the failure in its implementation. Comparisons are drawn between the prescribed, planned and implemented MSWM practices with the help of a case study and a comprehensive methodology. Variations are mapped at each functional step of the MSWM protocol and corrective actions are suggested based on the field surveys. Acknowledging the need for collection system optimization, incorporation of land use in MSWM plans and the inadequacies of small towns in designing those, a simple and robust method is devised to allow efficient and scalable collection plans based on the urban demographic and spatial characteristics. Strategy for regular evaluation of collection system is also provided so that 100% collection can be ensured. It is concluded that the MSWM systems are under designed in small towns and require innovative interventions to sustain within limited resources.

Keywords MSWM policies · System optimization · Small towns · Sustainability · Urban local bodies · Urbanisation

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1 Introduction

Development and growth of economies are primarily driven by urbanization. It is observed that the developing countries are leading the world urbanization process through rapid transition of growing villages and small towns into medium-sized urban areas [1]. India is projected to urbanize from 31% to 65% by 2050, contributed mainly by the growth of such small towns which are characterized by urban nature of employment and consumption, while lacking the capacity and techniques to support the same. India is a rapidly growing economy with a growth rate of around 6.5%–7% [5, 7, 13]. Urbanization is further exacerbating the complexities involved in environmental services, especially Municipal Solid Waste Management (MSWM) with the increase in waste generation, changing consumption patterns, adding more heterogeneity to its character. Waste generation is projected to increase at a rate of 11%–12% per year, leading to increased requirement of resources for its treatment and disposal [6]. The declining availability of these resources, in contrast to the increasing waste generation leads us to further challenges in waste treatment and disposal [7, 11, 12].

In the light of urbanization, the major focus of the Urban Local Bodies (ULB) is managing the municipal solid waste. Being a part of the Public Health and Sanitation System, Solid Waste Management is a state's subject and it is the responsibility of the ULBs and the State together to provide these services in the public domain [3, 4, 8]. Despite being non-hazardous, MSW is critical for the urban as well as rural settlements due to its heterogeneous composition and large-scale generation on daily basis in highly populous developing countries. In the face of the criticality surrounding this municipal service, it is observed that small towns fail to implement efficient MSWM system, causing low level of service standards, leading to problems of health, sanitation and environmental degradation [3, 4, 6].

Figure 1 explains the small-town characteristics and problems impacting each step in the MSWM system. An outcome of various challenges faced by local bodies with small scale of population, lack of funds, infrastructural and institutional inadequacies, lack of education and awareness and inability to provide incentives for public participation, MSWM planning remains a challenge from environmental, economic and sociocultural point of view to ensure total system's sustainability for efficient execution and operation.

The current MSWM practice in India is regulated under the MSWM Rules 2016 and guided by the Central Public Health and Environmental Engineering Organization (CPHEEO)—Swachh Bharat Mission: Compendium of Rules 2016, which delineates the roles and responsibilities for the ULBs with respect to MSWM and also gives a stepwise protocol for documentation, analysis, design, monitoring, assessment and evaluation of the designed MSWM systems. The rules are universal in nature and are unanimously applicable across all the ULBs in India. Hence, they fail to account and accommodate the inadequacies of small towns. This brings forth the understanding that a parallel protocol needs to be developed for MSW planning for small towns which innovates the planning techniques to maximize the coverage in minimum available resources.

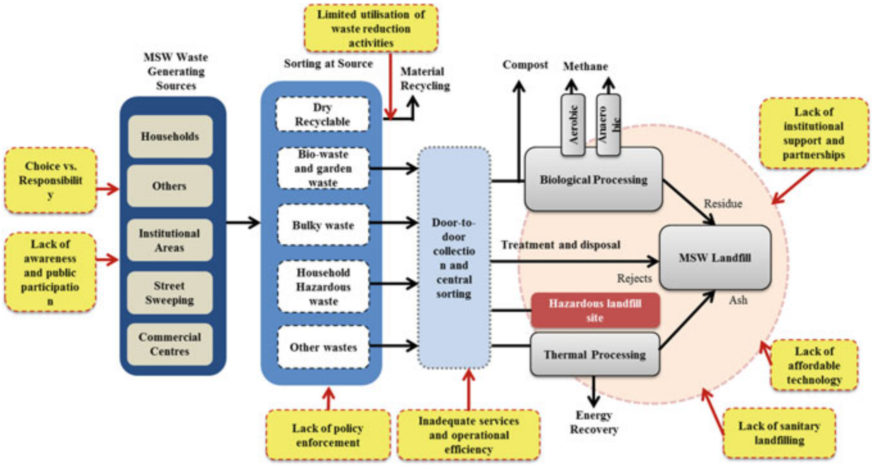


Fig. 1 Small town characteristics impacting the functional steps in MSWM planning

2 Methodology

Figure 2 provides a step wise methodology followed for the paper. A five-step comprehensive methodology has been adopted for the paper using the tools of literature review, secondary data analysis and primary data collection through field visits. Literature review is conducted to study the various challenges faced by small towns with respect to MSWM. An analysis of secondary data is conducted to understand the prescribed practices for MSWM in small towns as per the CPHEEO manual, MSWM Rules 2016 and the Detailed Project Report (DPR). Comparisons are drawn between the two to study the gaps in the adherence of the DPR to the prescribed MSWM rules and guidelines. Case study-based field survey is conducted further to map the differences between the prescribed and actual practices for MSWM and the role of various small-town characteristics causing these differences. Further, the national guidelines and the MSWM DPR for Mowad are compared with the MSWM practice on the field in Mowad to analyse the gaps in its implementation.

A multistage analysis of MSWM processes for quantification, characterization, collection and disposal has been put across to understand the challenges and recommendations required for the rules with respect to small towns. Identifying the need of land use-based planning, the lack of technically sound administrative support and low availability of funds, this paper also tries to devise a simple thumb rule method to allow easy optimization of the collection system.

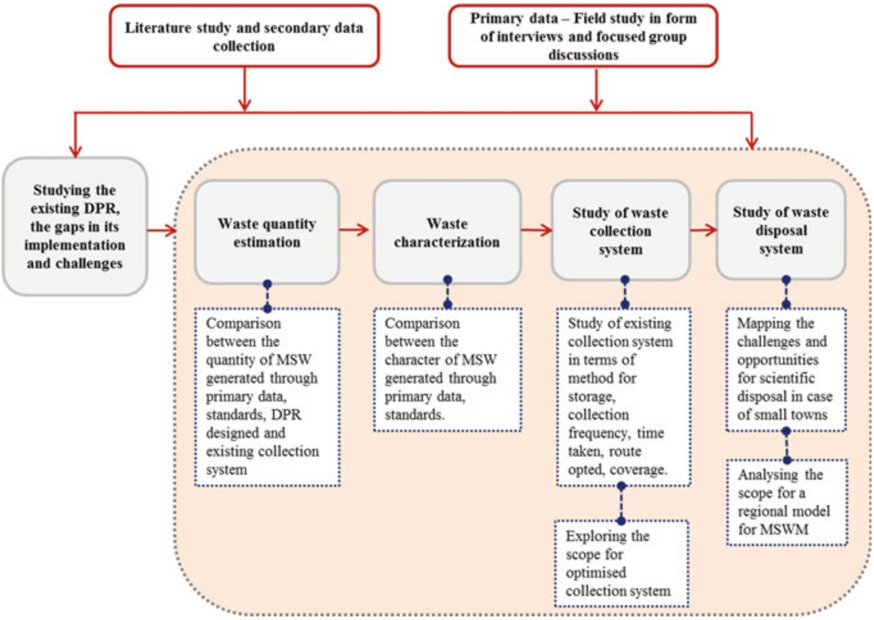


Fig. 2 Methodology adopted for paper

3 Results

3.1 Gaps Observed at Every Functional Stage Between the Prescribed, Planned and Implemented MSWM Practices

The national directives, DPR and practice were compared regarding the aspects of generation, segregation, collection, handling and safety, sorting, treatment, disposal and maintenance, further detailed out as follows.

A. ***Waste generation and segregation***: The national directives for MSWM suggest a two-bin system to be maintained at the source level. The proposed plan suggests a two-bin system for segregation. While the ULB has also provided free bins to the residents, segregation is not practiced at the source for wet and dry. Recyclables are being segregated at household level and sold to the informal sector workers.
B. ***Primary waste collection***: The DPR recommends a community bin system instead of door-to-door collection, whereas door-to-door collection is practiced in Mowad and is also an obligatory service to be provided by ULBs under the MSW Management and Handling Rules—2016.

C. ***Secondary waste collection***: The DPR Proposes a vehicular truck-based collection system from the community bins, whereas pedal operated tricycles are utilized for door-to-door collection. Shifts are suggested to ensure 100% collection but currently, no shifts are followed and the whole town is not covered for door-to-door collection on a daily basis. A 100% door-to-door collection is achieved on an alternate day basis.
D. ***Waste handling and safety***: Field workers handling waste at various stages in MSWM process exposed to health hazards due to no provision of gloves, masks, coats and shoes, unlike as prescribed in the DPR and the Solid Waste Management Rules of 2016.
E. ***Sorting, treatment and disposal***: Although the guidelines and DPR suggest sorting, followed by recycling and landfilling at a site away from habitation, the activity of sorting, treatment and disposal are not executed as observed through field survey. Instead, the waste is dumped along the banks of river Wardha, very close to the water body as well as human habitation.
F. ***Ancillary services***: The maintenance of equipment and vehicles, as well as bin attendance and washing, as mentioned in the national guidelines, have neither been addressed in the DPR nor practiced by the ULB.

Further analysis with the help of interviews bring to our notice the importance of willingness of generators to policy interventions for successful implementation of plans. From Fig. 3, we understand that the residential waste generators in Mowad have low willingness towards community-based disposal system and payment of nominal charges for solid waste services. Whereas, they seem to be positive about reuse of wet waste for composting and segregation at source, awareness camps, use of biogas for cooking and prohibition of plastic bag usage. Figure 4 explains that public space generators and institutional generators are willing to accept interventions for segregation, prohibition of plastic bags, reuse of waste for composting, community level recycling unit and door to door collection, but seem to be reluctant to pay for the nominal charges for MSWM, community-based disposal of wet waste. The commercial establishments have recorded least interest and willingness

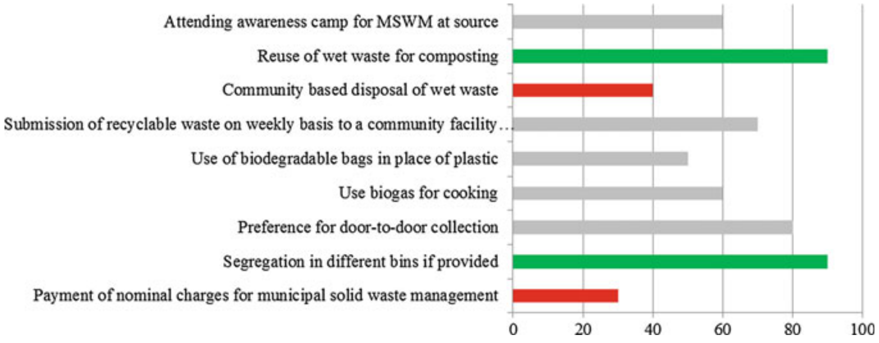


Fig. 3 Percent willingness of households for policy interventions (compiled from primary data)

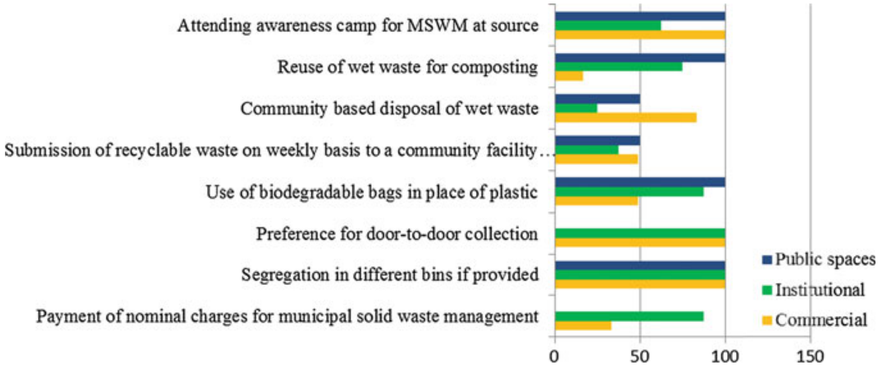


Fig. 4 Percent willingness of other occupancies for policy interventions (compiled from primary data)

towards these aspects of MSWM planning as compared to residential, public use and institutional generators.

3.2 Accurate Estimation of MSW Generation

Accurate waste estimation is essential to proceed with planning for MSWM [6]. Different approaches are followed by ULBs for waste quantity estimation. There are different approaches for quantification of MSWM. The most commonly method used by the ULBs is to calculate total waste generated as '*Total waste generated = total waste collected = capacity of the vehicles X No. of vehicles X no: of trips*' [4]. This method fails to accurately estimate the quantity since 100% collection is not ensured due to undersized vehicles. The short-term planning method looks at representative sampling, carried over a period of 3 days to arrive at quantification and characterization. This is an ideal method but might lead to inaccuracies in case of towns with remarkable seasonal variations in waste generation due to tourism, festivities, migration, etc. The long-term planning method as suggested in the Swachh Bharat Compendium of Rules of 2016 provides a detailed and more accurate estimate with activity class wise generation of waste. For small towns without a well laid spatial plan and lot of organically developed mixed-use areas, this method becomes difficult to execute. It is observed that the current system capacity, as recommended in the DPR, is of 1TPD. But the effective collection achieved is of 0.9 TPD. At the same time, 4.7 TPD waste generation can be estimated based on the primary data collected during focused discussions and interviews of different land use owners across the town. Mowad falls in the smallest range of the urban areas with less than 0.1 million population, as specified in the manual [3]. According to the suggested MSW generation rates for this category, the population size accounts for a 5.5 TPD waste quantity (Table 1).

Table 1 Quantity of waste generation

Method	Quantity of waste generated
Approximation of waste generation by studying the existing vehicular capacity for collection	0.9 TPD (three vehicles of 0.3 tons each)
Waste generation estimates as per the MSWM DPR	1TPD
Waste generation estimation through primary data collection	4.7 TPD
Waste generation estimate calculated by assuming standard generation rates for a ULB for category of <10^6 Population	5.5 TPD

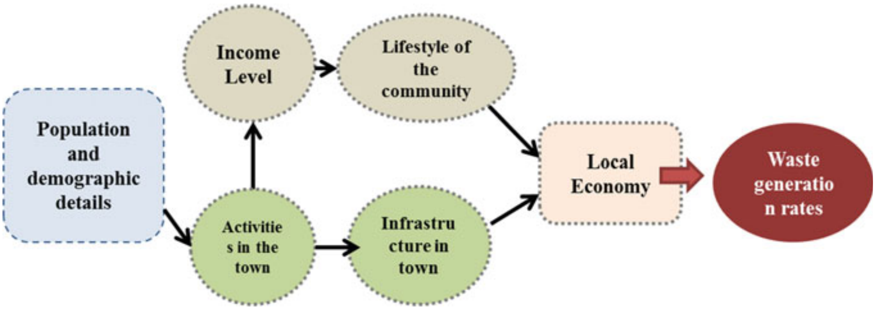


Fig. 5 Interrelationship between town characteristics and generation rates [3, 8, 11]

Thus, the capacity of MSWM system in Mowad is lesser than the MSW generation estimated based on primary data and standard generation rates. Hence, the current system in place is under designed. Furthermore, only 0.9 TPD, i.e. 16% waste is collected out of the total generation of 5.5 TPD, which indicates an inability to achieve 100% collection [4]. There is not much difference between the quantity estimated by using the primary data and the standard generation rates, respectively. Figure 5 shows the interrelationship between demographics, standard of living, local economy and waste generation rates.

Figure 6 shows a stark difference between standard rate and present generation rate of waste from institutional land uses, whereas the quantities calculated by the two methods are comparable in other cases. Figure 7 shows that the major contribution to the MSW in the town is through residential land use. This aligns with the large expanse of land under residential use in the town, which is up to 45% as per the Development Plan of Mowad.

3.3 *Precise Characterization of MSW in Small Towns*

Waste character affects the treatment choices, types of storage containers, handling guidelines, type of collection vehicle and resource recovery. Also, it varies

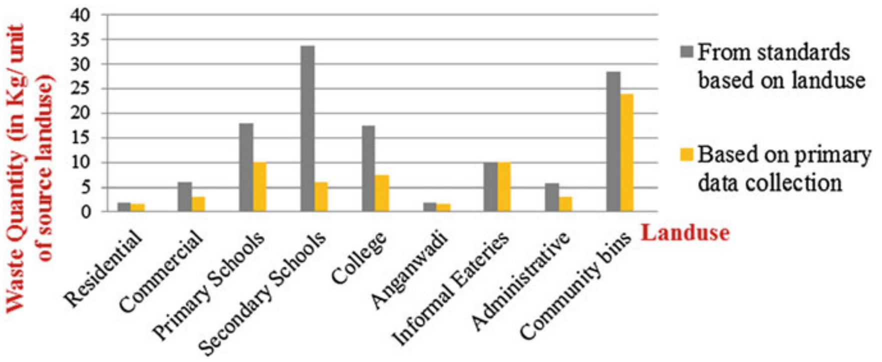


Fig. 6 Land use-based comparison of waste generation (compiled through primary data collection)

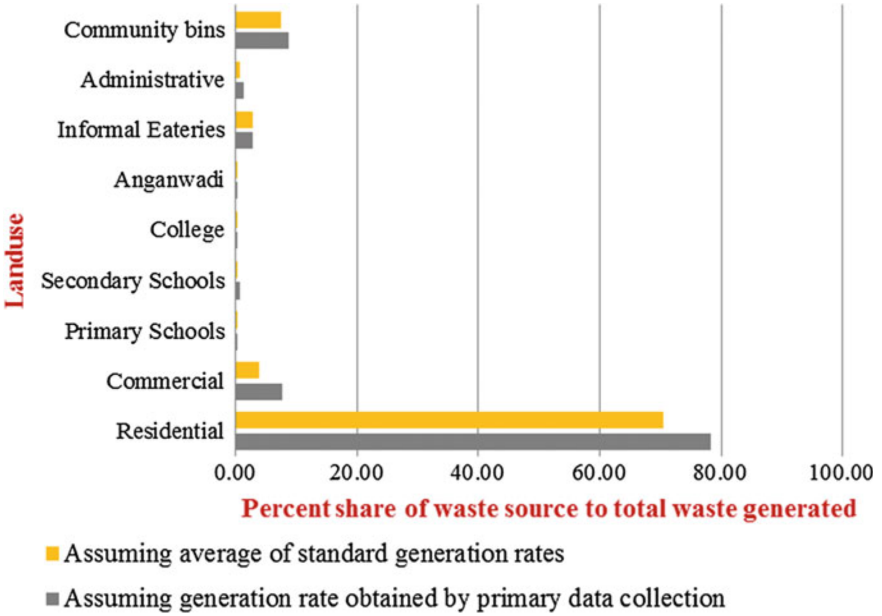


Fig. 7 Land use-based contribution to total waste generation (compiled through primary data collection)

significantly with changing land use and activities in the town [3]. The following table provides a comparison between the physical waste characterization as observed through quartering method and the one projected through standard percentages for a ULB of size less than 0.1 million [4]. While the waste generation estimates by using standard generation rates and those from the primary data do not show much difference, the characteristics differ significantly for the smaller towns.

Table 2 Waste characterization of Mowad with standards [4] (primary data collection)

Waste characteristics (%)	Standards of size (<0.1 million)	Primary data of Mowad	Weight of component in kgs. for 5.5 TPD generation (assumed as the final value arrived at from standards)
Paper	2.91	7.70	426.34
Rubber, leather, synthetic	0.78	4.5	247.55
Glass	0.56	0.8	44.01
Metals	0.33	2.50	138.90
Total compostable	44.57	59	3245.67
Inert	43.59	25.5	1402.79

Table 2 provides the variations in percentages for the waste character for Mowad. The quantity of compostable waste, rubber, leather, synthetics and paper is higher, whereas those for inert materials are very low.

The MSWM rules provide standards for waste characterization based on the population size of the urban area, but fail to provide a land use-based characterization of waste. It is crucial to study to be studied for small towns so that efficient and accurate waste collection and storage can be achieved. The guidelines for waste segregation at source would be based on the varying characteristics of these land uses. Figure 7 provides the varying compositions of waste based on the land use. It is observed that high wet waste is generated through the institutional and residential land uses. The commercial establishments, administrative land use and community bins typically contain higher percentages of dry organic waste. Recyclables are equally contributed at an average of 25% from the community bins, commercial shops and institutional buildings (Fig. 8).

3.4 *Optimized Collection System*

Having proposed methods for accurate estimation and characterization, we identify a need to optimize the collection system. Although maximum amount of waste collection is being ensured nowadays by the ULBs, they fail in implementation of efficient treatment and disposal [2]. If ever any segregation is achieved at source, the collection systems fail to maintain it till the treatment and disposal stage, due to inappropriate vehicles and storage containers. The municipal council of Mowad has adopted stationary container system, which is operated by staff hired by the council on contract basis. The following figure provides us the spatial distribution of the collection routes. The collection system fails to achieve 100% coverage and is time consuming as well due to the peddle driven collection vehicles. The carrying

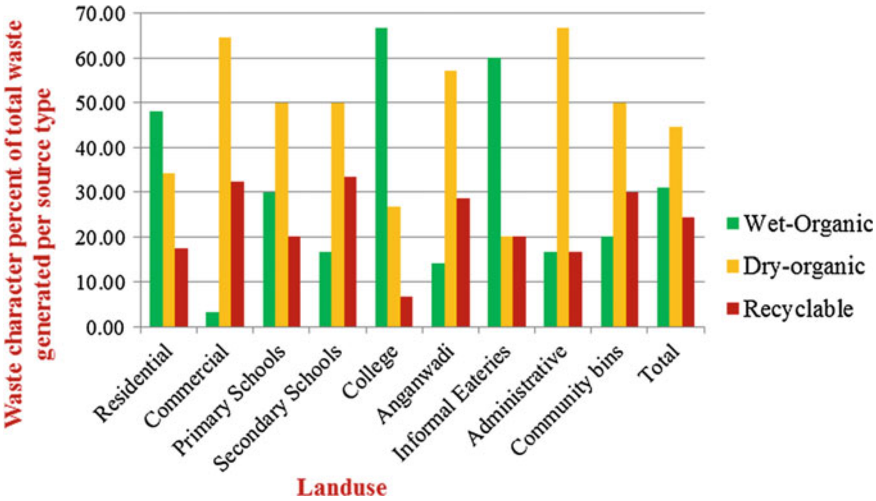


Fig. 8 Land use-based waste characterization (compiled from primary data collection)

Route	Distance	Issues Observed
R 1 🟥	9.13 km	- Multiple overlap in routes - Lack of 100% coverage of route
R 2 🟦	9.62 km	- Designed routes not followed by the collection staff
R 3 🟨	9.96 km	- Total distance covered by 3 routes = 28.71 km
Total	28.71 km	- Additional 4kms for to & fro from end point of routes to dumping site
Time Taken	3X7 hrs. (7.00 am to 2.00)	- 14kms to be manually covered by each collection staff, which is very tiresome

Fig. 9 Collection routes as mapped of the current system (compiled through primary data)

capacity of these vehicles and number of the vehicles in place also do not accommodate 100% collection (Fig. 9).

Based on the above observations, the following methodology is devised to arrive at an optimized collection system for small towns like Mowad. Figure 10 provides a flowchart for the same.

Step 1: Map and study the existing collection system requirements
Studying the existing collection system in practice with respect to the land use, route, time, distance covered, manpower and vehicles. The system is designed for the capacity as per the standard generation rate.

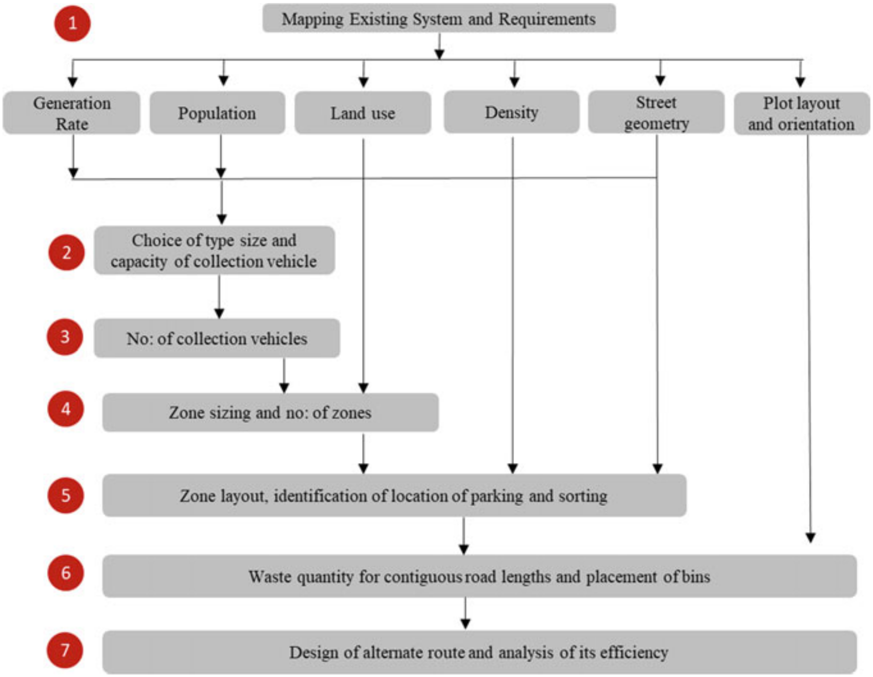


Fig. 10 Proposed method for collection system optimization

Step 2: Choice of collection vehicle

Mowad has small road widths, limited funds, unavailability of a petrol pump in the nearby area and requirement of multiple vehicles to run simultaneously to reduce time. Hence, the choice of an electric autorickshaw as a collection vehicle is made. It comes with a standard capacity of 1.2 tones [9].

Step 3: Zone sizing and number

Based on the capacity of the chosen collection vehicle, five number of vehicles are required to cover the 5.5 TPD waste as per the standard generation rate. A distinct zone for the market area is identified and operated separately due to the different character of waste, which is predominantly wet-organic waste.

Step 4: Zone layout and identifying site for vehicle parking and sorting

Based on land use, density and geometry of plan as per the Development Plan (DP) of the town, crucial zones for waste collection are identified, with similar preferences for timing for collection, required frequency of collection and nature of waste generated based on concentration of activities. Mowad is thus distributed into six zones based on the land use, as illustrated in Fig. 11. Addition of new containers and relocation of the old containers was carried out to cater to a 50 kg requirement of community bin per 24 plots. Parking area for the vehicles and sorting shed site

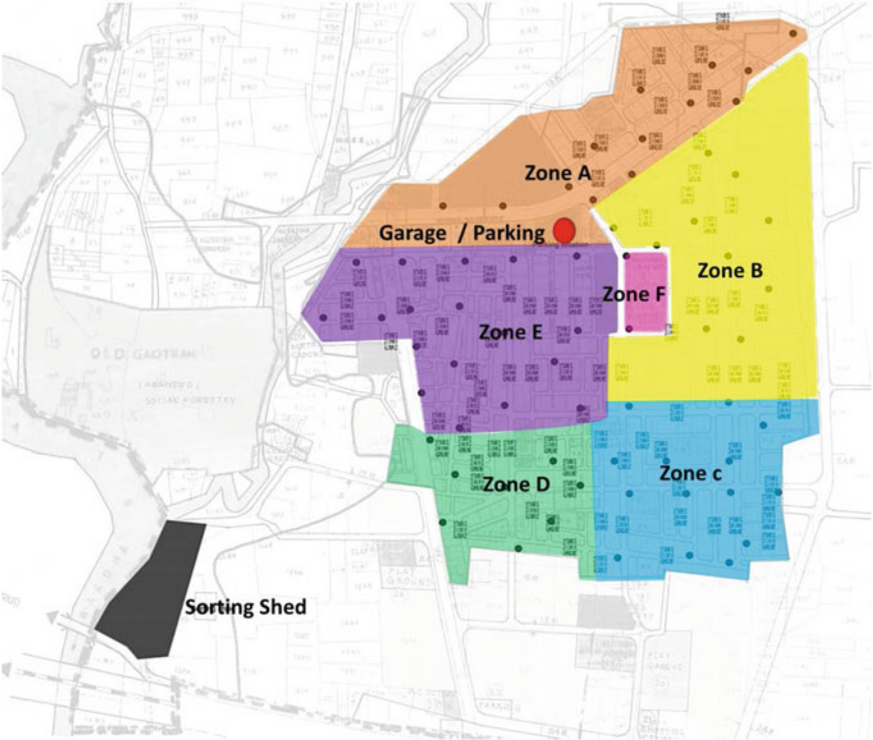


Fig. 11 Zoning

were delineated based on the government land available for the ULB to provide municipal services. The sorting shed at a 2 km distance, outside the main town area and hence poses no hazards to the residential areas. Refer to Table 3 in annexure for the detailed rationale for zoning.

Step 5: Waste quantification for contiguous lengths of roads
This step consists of defining the lengths of roads with contiguous plot areas and deriving the waste collection along the length of each road by plot counting method. This is done by using the standard generation rate to quantify the waste to be collected along each road. The following figure explains the method in detail (Fig. 12).

Step 6: Alternate route design
To design alternate collection routes for the new zones, plot orientations and street geometry are brought under consideration. This process is carried out manually since the current scheme under design is on a small scale. For larger towns, this can be addressed like a classic 'Travelling Sales Person' problem and solved using GIS and route optimization software. But, in case of small towns, this method is more

Fig. 12 Waste quantification along road lengths

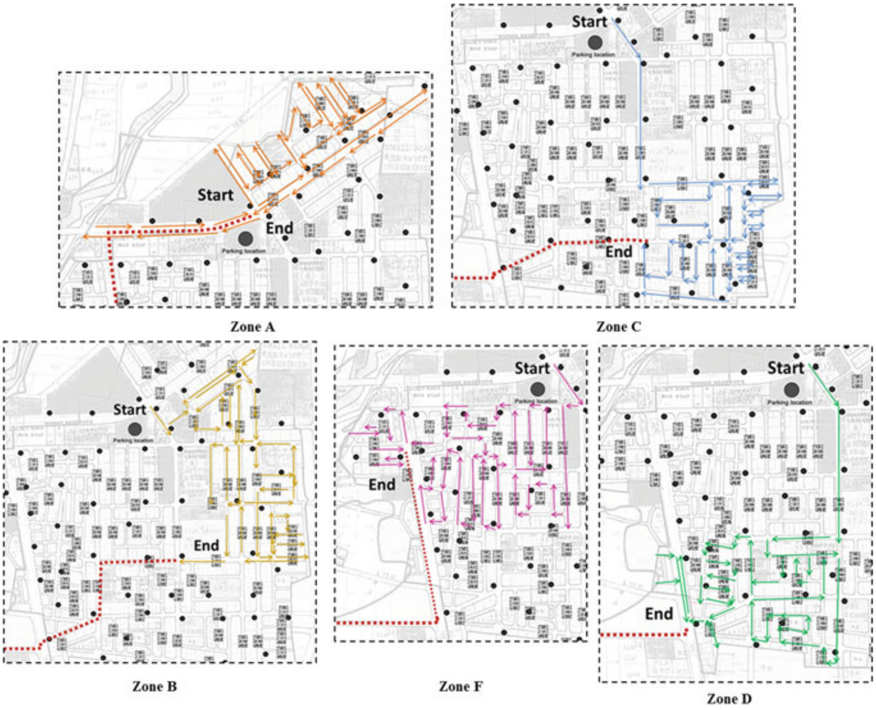


Fig. 13 Zone-wise route designs

effective due to its simplicity and robustness. Figure 13 shows the designed routes for collection for the given zones. Refer to Table 3 in annexure for the route lengths, properties covered and the time required.

Step 7: Analysing the efficiency of the route design

The design is evaluated with respect to the reduction in distance covered for collection, reduction in time and improved coverage, ensuring 100% collection. The distance covered earlier was 28.71 km, whereas the new route designs cover 24.30 km, reducing the distance by 4.3 km. Figure 14 explains the zone-wise distribution of waste collected. Zone F is exclusively designed to cater to the market area. The new routes ensure 100% collection coverage as well as success in maintaining a regular 8–9 h of work shift for the collection workers. Earlier, three workers took about 21 h to collect 20% of the waste. Increasing the efficiency in zoning and route design, we arrive at a 44-h time requirement to complete 100% collection. Employing six workers, this is easily achieved with 8–9 h. of work/person/day. Figure 15 provides zone-wise break up of time required for collection in Mowad. It is also observed that in low-density development like Mowad, the door-to-door system is time and cost-intensive. Thus, further optimization is possible if a door-to-door system is translated into a hauled container system.

Fig. 14 Zone-wise total waste collection

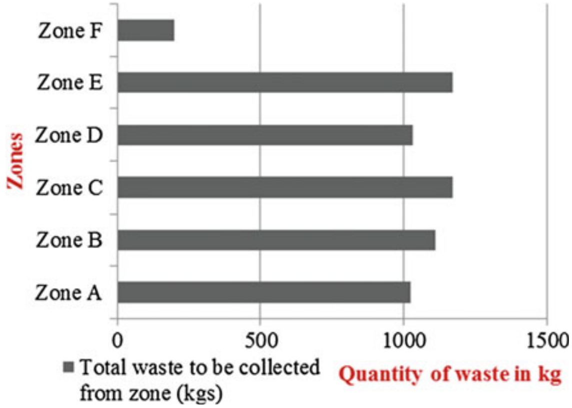
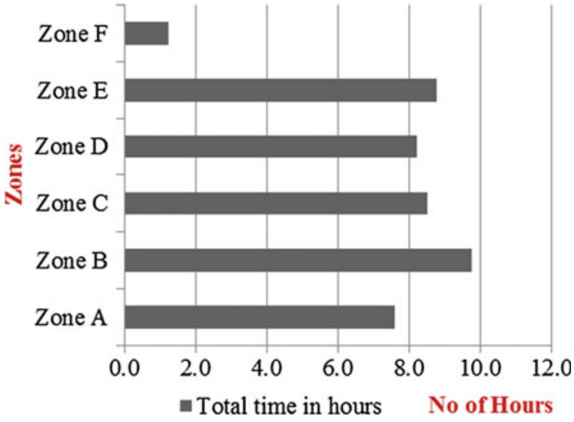


Fig. 15 Zone-wise time for collection



3.5 Challenges for Treatment and Disposal

The most common MSWM strategies after the collection step are waste sorting, waste recycle, waste to compost and waste to energy and waste disposal/sanitary landfill. To set up anyone or more than one strategy from above, any local body requires resources like land, funds and manpower. Besides, the MSW rules 2016 directs all local bodies and census town with a population under 0.5 million, to set up common or regional sanitary landfills within three years from date of notification of rules. Thus, it has become a mandate for ULBs like Mowad to make available necessary resources. From the field discussions with concerned authorities of Mowad, it is evident that the land available with the local body is not sufficient to set up sorting, recycling, composting and landfill units and acquiring more land parcel is difficult and expensive. The regional model for post-collection activities poses to be a promising model to overcome these difficulties (Fig. 16).

3.6 Scope of Developing a Regional MSWM Model

In such scenarios, a regional plan for MSW management for small ULBs like Mowad and nearby town can help in solving issue by combining their resources. Resources like land, cost of establishment of sorting, recycling, composting and landfilling units, cost of operation and maintenance, manpower can be shared by all the towns involved in the regional plan. The first attempt at developing a regional facility in India was by Ahmedabad Urban Development Authority (AUDA), in 2007, to address the SWM requirements of 11 towns in its (then) jurisdiction. The project facility integrated composting facilities for approximately 150 TPD and a scientific landfill site of 50 TPD capacities [10]. Another such example is of project developed in Asansol Urban Agglomeration (AUA) area which includes 5 ULBs. The project developed through JNNURM funding has three treatment plants using composting technology (500, 300 and 200 TPD capacity) and a regional landfill at Mangalpur to accommodate 400,000 MT waste [10]. On similar lines, a regional plan for Mowad and nearby towns can be designed to optimize the resources and develop a complete sustainable MSWM model.

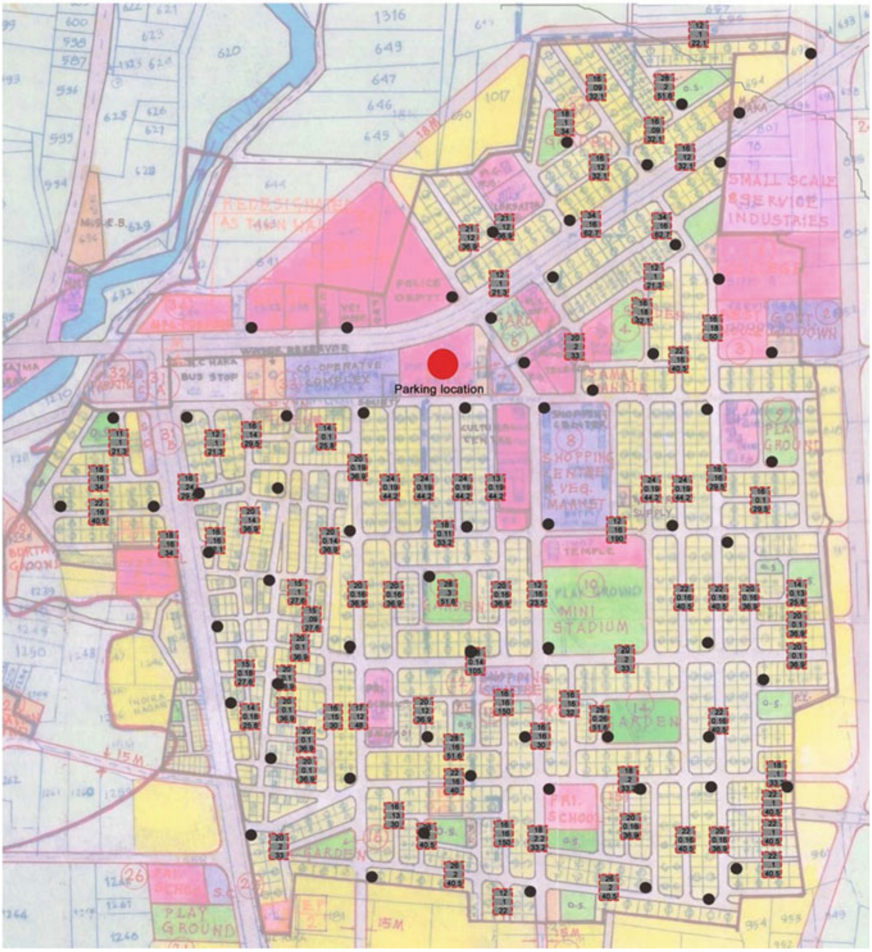


Fig. 16 Waste quantity estimation along the roads for all zones

4 Conclusion

The stepwise analysis of the current MSWM process brings to our notice the nuances involved while planning for MSWM with respect to a small yet rapidly growing urban area. It shows the gaps in the standards, designed project proposals and the implemented proposals. Small towns like Mowad are not completely aligned with the MSWM protocol as mentioned in the CPHEEO compendium of rules. The population-based categorization of the towns needs to be revised and reclassified since the smallest range of '0.1 million and less' is too wide with varying urbanization potentials. These small towns further resort to a makeshift arrangement for MSWM, which fails to sustain the rapid transformation of the town. It can also be concluded that land use-based design of MSWM proves to be more efficient and hence linkages between MSWM aspects and land use planning need to be strengthened in such growing towns. It is also observed that in low density development like Mowad, the door-to-door system is time and cost intensive. Thus, further optimization is possible if a door-to-door system is translated into a hauled container system for such spatial characteristics. A regional perspective with a common post collection facility (sorting, treatment, recycling, disposal) for a cluster of proximate small towns is recommended as it addresses the lack of scale of economies and unavailability of resources. While all these interventions solve the MSWM issues of small towns, we identify the need of a parallel protocol to be developed for small towns to ensure overall sustainability.

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Author Contributions

B.P. developed the data sets, analysed and prepared the complete paper. A.R. and A.G. provided with writing inputs. B.R. supervised the project, discussed findings and commented on the results.

Annexure

See Tables 3, 4, and 5

Table 3 Comparative analysis for waste quantity estimation based on primary data and standards

Land use	Quantity of waste generated (Kg/capita for source)		Quantity of waste generated (Kg/unit source)		Waste types (Kg/category/unit source)			Avg size or occupancy/ unit source	No: of similar units	Aggregate waste generated (Kg/ source)	
	From standards based on activity	Based on primary data collection	From standards based on activity	Based on primary data collection	Wet—Organic	Dry–Organic	Recyclable			From Standards	From primary data
House holds	0.45	0.4	1.845	1.66	0.8	0.57	0.29	4.1	2333	4304.385	3872.78
Shops/ Pharmacies	NA	NA	6	3.1	0.1	2	1	NA	70	420	217
School (1–4)	0.05	0.27	18	10	3	5	2	360	1	18	10
School (5–12)	0.05	0.01	33.75	6	1	3	2	675	1	33.75	6
College	0.05	0.02	17.5	7.5	5	2	0.5	350	1	17.5	7.5
Anganwadi	0.05	0.05	2	1.75	0.25	1	0.5	40	2	4	3.5
Food Stalls	1	1	10	10	6	2	2	10	15	150	150
Offices	0.05	0.03	5.75	3	0.5	2	0.5	115	12	69	36
Road Sides/ Streets	0.05	0.04	28.5	24	6	15	9	570	17	484.5	408
Total					22.65	32.57	17.79			5501.135	4710.78

Table 4 Assumptions for evaluation of the collection system optimization

Time for halting at each house	1.10 min
Time to pick up, load and replace community bin	1.10 min
Time taken from parking to start point	5 min up to 1 km, 10 min up to 4 km range.
Time taken from endpoint to sorting shed	
Volume of waste per property as per standards, volume of waste per bin = 2 bins of 25 kg each for every 24 houses = 50 kg, the community bin locations and the number has been increased as per the standards.	

Table 5 Comparative analysis for waste quantity estimation based on primary data and standards

Zone	Rationale behind zoning	Preferred shift timings	T1 = time req to go to start point from garage	No: of properties in zone	No: of community bin locations	Length of the route (km)	Tl = Total time required to halt at households (Mins)	T2 = Time required to pick, load and replace the community bins (Mins)	T3 = Time req from the end point of the route to the sorting shed	Total time take = T1 + T2 + T3 + T4	VI = Vol. of waste from properties (kgs)	V2 = Vol. of waste from bins (kgs)	Total waste to be collected from zone (kgs)
Zone A	Maximum residential, plus fragmented from the main town due to the highway	Morning	5	393	9	4.5	435.444	9.972	10	455.42	573.9	450	1023.9
Zone B	Mostly composed of institutional properties like schools, offices, etc and hence needs a different time slot	Afternoon	5	507	11	5.5	561.756	12.188	10	583.94	611.0	500	1111
Zone C	Completely residential	Morning	10	440	11	4	487.52	12.188	10	509.71	620.2	550	1170.2
Zone D	Residential with narrow lanes	Morning	10	430	10	4.5	476.44	11.08	5	492.52	529.8	500	1029.8
Zone E	Mixed used with shopping, institutional and residential, with narrow lanes and fragmented due to the highway	Afternoon	5	454	11	5.8	503.032	12.188	10	525.22	670.3	500	1170.3
Zone F	Vegetable market operational just once in a week—needs a separate sendee as segregated wet waste mostly and needs to be catered to separately	once in a week	5	1	NA	2.5	60	NA	10	75	200.0	NA	200
						24.3					3005.2	2500	5505.2

References

1. Cohen, B.: Urban growth in developing countries: a review of current trends and a caution regarding existing forecasts. World Dev. **32**, 23–51 (2004)
2. CPCB: Status Report on Municipal Solid Waste Management 2013–2014. MoEFCC, Govt. of India (2014)
3. CPHEEO: Manual on Municipal Solid Waste Management 2000. Ministry of Urban Development, Govt. of India (2000)
4. CPHEEO: Swachh Bharat Mission: Municipal Solid Waste Management Manual 2016. Ministry of Urban Development, Govt. of India (2016)
5. Department of Economic Affairs: Economic Survey 2016–2017. Ministry of Finance, Govt. of India (2017)
6. Goel, S.: Municipal solid waste management (MSWM) in India: a critical review. Environ. Sci. Eng. **50**, 319–328 (2008)
7. Joshi. R., Ahmed. S.: Status and challenges of municipal solid waste management in India: a review. Cognet Environ. Sci. **2**, 1139434 (2016)
8. MoEFCC: Solid Waste Management Rules 2016. Govt. of India (2016)
9. Mowad Municipal Council: DPR for Municipal Solid Waste Management. Govt. of India (2007)
10. MoUD: Toolkit for Solid Waste Management Jawaharlal Nehru National Urban Renewal Mission. Govt. of India (2012)
11. Peavey, H., Rowe, D.: Environmental Engineering. McGraw-Hill series in water resources and environmental engineering (1985)
12. Planning Commission: Report of the Task Force on Waste to Energy. Govt. of India (2014)
13. United Nations: World Urbanization Prospects. Population Division—Department of Social and Economic Affairs (2014)

Open Dumping of Waste and Its Impact on Our Water Resources and Health—A Case of New Delhi, India

Bini Samal, Shyamala Mani and Omprakash Madguni

Abstract Domestic hazardous waste (DHW) refers to CFL bulbs, broken mercury thermometers, expired medicines, old batteries, used needles, tube lights and syringes and contaminated gauge, etc. as defined by the SWM Rules, 2016, Government of India, generated at the household level. As of today, the above category of waste, along with wet biodegradable and dry recyclable waste is being dumped in unlined landfills in the outskirts of our cities. As per this study, an average home in Delhi generates 0.03 ± 0.01 kg of domestic hazardous waste per day. When improperly disposed of, this waste is a potential risk to people and the environment. In open dumpsites, heavy metals have the potential to leach slowly into soil, groundwater or surface water. This study attempts to study and understand the interaction between such wastes when mixed and the potential impacts of these on the residential colonies located in and around the landfill site. The leachate pollution index (LPI) value of Okhla landfill site indicated that the waste deposited is contaminated since all values calculated during all the three seasons pre-monsoon, monsoon, post-monsoon exceeded the standards [13]. The Water Quality Index (WQI) of the groundwater samples collected from the nearby residential areas proves the poor quality of water and indicates possible contamination of these waters by the landfill site and have been found unsuitable for human consumption. It is also observed that the pollution load is relatively high during the post-monsoon season and the monsoon season. Primary data collection was done through interviews, focus group discussions, direct observations and waste quantity and water quality analyses. This helped to delineate the potential impacts of open dumping on the groundwater of habitations close to the landfill and consequently, the possible health impacts on the individuals residing there.

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1 Introduction

Open dumpsites are the main contamination threats to water resources throughout the world. From the landfill sites, a contaminated liquid, called leachate which varies in chemical characteristics and composition oozes out and percolates through the underlying soils contaminating the groundwater resources. Based on the changing climatic conditions, the leachate flow drastically increases or reduces, i.e. increases during the rainy season and decreases during the dry season [13]. The municipal solid waste (MSW) landfill leachate discharge may cause environmental degradation of soil and water resources especially when the landfills are not scientifically designed and not comply with the specification of liners used in the landfill [10]. Groundwater moves very slowly but is constantly on the move. This groundwater eventually flows to the surface, viz., springs, streams, ponds, swamps or lakes where it vaporizes or is taken into living things. The whole process then starts over again. It is this continuous cycle between surface water and groundwater which spreads water pollution [11].

Domestic hazardous waste (DHW) is the unwanted portions of those products which we throw as part of the trash that contains hazardous ingredients. These products are considered hazardous because they can be flammable, toxic, corrosive or reactive in their nature [2]. This study attempts to quantify and assess the interaction of domestic hazardous waste with other solid waste categories generated in the study area and hypothesize regarding the possible impact of it on the groundwater.

2 Methodology

The present study titled ‘Open dumping of waste and its impact on our water resources and health—a case of New Delhi, India’ was undertaken first to study the solid waste management systems currently operational in South Delhi and its impact on EWS areas. The primary aim of the present study is to explore whether the various hazardous substances perhaps from household wastes in the garbage dumped in open dumpsites, has an impact on the water resources of the study area. To meet the objectives of the study, a site-specific approach was adopted based on various past studies and literature available on the same. Field observations, quantification of domestic hazardous waste, collection of samples such as groundwater, leachate from the existing landfills, interviews with the stakeholders (institutions, households, etc.) have been the source of primary data. Secondary data was also collected from the different organizations, monitoring stations and waste processing units, etc. Leachate and water samples were analysed in the laboratory for pre-decided parameters. The sites given below were selected based on their distance from the landfill site.

Despite the latest solid waste management (SWM) Rules, 2016, promulgated under the Environment Protection Act (EPA), 1986 by the Government of India, only a very small percentage of the population of South Delhi is segregating their domestic hazardous waste, whereas mostly, it is mixed solid waste, along with domestic hazardous waste, that is reaching the landfill as also wet waste and non-recyclable waste; this was confirmed by administering a survey in South Delhi with a sample size of 240. The fresh waste consists of various components, which includes biodegradable vegetable peels, food, etc. (50–55%), non-biodegradable (plastic, paper, cardboard, etc.) (40–43%) and domestic hazardous waste (DHW) (batteries, paints, household health care waste, etc.) about 2–3%. While none of the waste gets segregated, it reaches the *Dalao*, an intermediate storage location within neighbourhoods, where some secondary segregation is carried out by waste pickers and collectors interested in dry recyclables, which they can sell and generate some revenue from. Then it reaches the landfill site in a mixed form, with a high percentage of wet kitchen waste and domestic hazardous waste besides some construction and demolition (C&D) waste, since a lot of the dry recyclable wastes are removed either at the *Dalao* or at the landfill site by waste pickers. All this reaches the dumpsite or the landfill site in a mixed condition. It has been found that at the Landfill site, the percentage of wet waste is nearly 50%, dry waste is 18–20%, C&D waste about 25–27% and DHW about 2–3% [12].

At the landfill site, besides the moisture in the wet waste, if there is rainfall, then the excess moisture interacts with the hazardous waste and leaches out the heavy metals, PAHs, POPs, which further react with acidic or alkaline conditions that develop in the dump and percolate to the lower layers and eventually into the subsoil and groundwater. The hypothesis of this paper is that unsegregated mixed waste being dumped in a dumpsite, will impact the subsoil and groundwater. To test this hypothesis, it was decided to first collect samples of leachate at the Okhla dumpsite and also groundwater samples in and around the dumpsite. The locations selected for the groundwater samples are located where water would migrate easily from the dumpsite to nearby locations. The water has been sampled at the borewells at a depth of 60 m or 120 ft since they are being used by the communities for various household chores and could be possibly contaminated.

To understand this better, quantification of domestic hazardous waste was done, leachate pollution index [8] for the leachate samples and water quality index [14] for the groundwater samples was calculated for the samples, which were collected during the pre-monsoon (June 2016), monsoon (August 2016), post-monsoon (November 2016) periods.

3 Waste Quantification

Solid Waste Management in India is regulated by the Solid Waste Management Rules 2016, a subordinate law under Environment Protection Act 1986. As per the rules, waste has been categorized into three categories namely biodegradable waste, non-biodegradable waste and domestic hazardous waste (DHW) and they have been defined as follows:

3.1 Biodegradable Waste

Organic material that can be degraded by microorganisms into simpler stable compounds.

3.2 Non-biodegradable Waste

Waste that cannot be degraded by microorganisms into simpler stable compounds.

3.3 Domestic Hazardous Waste

Discarded paint drums, pesticide cans, CFL bulbs, tube lights, expired medicines, broken mercury thermometers, used batteries, used needles and syringes and contaminated gauge, etc., generated at the household level [14].

In order to study domestic hazardous waste, a survey was conducted where waste quantification was carried out at 60 households from high, middle and low economic households in South Delhi. The waste was segregated into three components for estimation namely non-biodegradable, biodegradable and domestic hazardous waste and was quantified using a portable weighing scale. The observations were recorded. The sites visited have been listed in Table 1.

Table 1 Sites chosen for waste quantification

S. No.	Name of the site	Geo-coordinates	Category
1.	Defence Colony	28° 34′ 21.48″ N 77° 13′ 57.04″ E	A
2.	Jasola Vihar	28° 32′ 38.5″ N 77° 17′ 34.3″ E	D
3.	Jasola	28° 32′ 50.44″ N 77° 17′ 20.84″ E	G

Note A (High income group), D (Middle income group), G (Low income group)

4 Leachate Pollution Index

The LPI signifies the level of leachate contamination potential of a given landfill. It is a single number which ranges from 5 to 100 like a grade, which articulates the complete leachate contamination potential of a landfill based on many leachate pollution parameters in a given time. As per this index a higher value indicates a poor environmental condition [8].

Seven leachate pollutant variables were selected for inclusion in LPI. They are pH, total dissolved solids (TDS), biochemical oxygen demand (BOD5), chemical oxygen demand (COD), lead, chromium and chlorides.

The weights for these seven parameters were calculated based on the significance levels of the individual pollutants. The weight factor indicates the importance of each pollutant variable to the overall leachate pollution (Table 2).

The averaged sub index curves for each parameter were drawn to establish a relation between the leachate pollution and strength or concentration of the parameter.

The weighted sum linear aggregation function was used to sum up the behaviour of all the leachate pollutant variables.

LPI can be calculated by the following equation:

$$LPI = \frac{\sum_{i=1}^{m} w_i p_i}{\sum w_i}$$

LPI represents the weighted additive leachate pollution index,
W_i represents the weight for the ith pollutant variable,
P_i represents the sub-index value of the ith leachate pollutant variable, m = number of leachate pollutant, variables used in calculating LPI.

Table 2 The weight factor of seven leachate pollutant variables selected for inclusion in LPI

Parameter	Weight factor
Chromium	0.064
TDS	0.050
BOD5	0.061
COD	0.062
Lead	0.063
Chlorides	0.049
pH	0.055

5 Water Quality Index

A water quality index (WQI) helps in understanding the general water quality status of a water source and hence it has been applied for both surface and groundwater quality assessment all around the world [2].

A set of six most commonly used water quality parameters namely pH, electrical conductivity (EC), total dissolved solids (TDS), chloride, biochemical oxygen demand (BOD), chemical oxygen demand (COD) which, together, reflect the overall water quality of the site area were selected for generating the water quality index (WQI).

Calculation of WQI was carried out by the following equation:

$$\mathrm{Q_n} = 100\ (\mathrm{V_n} - \mathrm{V_{io}})/(\mathrm{S_n} - \mathrm{V_{io}})$$

$\mathrm{Q_n}$ represents the Quality rating for the nth water quality parameter,
$\mathrm{V_n}$ represents the estimated value of the nth parameter at a given sampling station,
$\mathrm{S_n}$ represents the Standard permissible value of the nth parameter,
$\mathrm{V_{io}}$ represents the Ideal value of the nth parameter,

$$\mathrm{W_n} = \mathrm{K}/\mathrm{S_n}$$

$\mathrm{W_n}$ represents the unit weight for the nth parameters,
$\mathrm{S_n}$ represents the standard value for the nth parameters,
K represents the Constant for proportionality.

The overall water quality index was calculated by aggregating the quality rating with the unit weight linearly (Table 3).

$$WQI = \sum_{i=1}^{n} Q_i W_i$$

Table 3 Water quality index (WQI) and status of water quality [3]

Water quality index level	Water quality status
0–25	Excellent water quality
26–50	Good water quality
51–75	Poor water quality
76–100	Very poor water quality
>100	Unsuitable for drinking

6 Study Area

The leachate samples were collected from the Okhla landfill site and the groundwater samples were collected from locations lying in the 10 km radius of the dumpsite namely Okhla borewell, Tuglakabad village and Tekhand village. The exact locations from where the water was sampled are listed below (Table 4). Similarly water samples from three sites 11–30 kms away from the dumpsite were collected and analysed as controls.

The leachate and groundwater samples were collected from the following sites (Table 4).

Given below are the brief descriptions of Okhla Dumpsite and the sampled areas around it:

6.1 Okhla Landfill Site

The site is accessed from Maa Anand Mai Marg in Okhla and is close to Okhla Industrial area in the southern part of Delhi. This landfill site is owned and operated by the South Delhi Municipal Corporation. The landfill site has an area of 16.89 hectares and was commissioned in 1994. The landfill site has approximately 5.6 million tonnes of waste in place, and was to be closed in 2008 after reaching a site capacity of 6.3 million tonnes. The landfill currently receives 3000 MT, out of which 1500 MT is from domestic sources, 1000 MT is C&D waste and about 300–500 MT of silt all in mixed form. That this landfill does not receive any waste from industrial sources was confirmed by the SDMC officials at the site as well their office. The existing landfill covers a total of 54 acres, which is almost covered with waste. The waste mass has a height of 20–30 m with steep slide slopes [15].

Table 4 Location of the study site

Sr. No.	Longitude (DD)	Latitude (DD)	Place name	Distance from landfill (zones)
1.	77.2836	28.5116	Okhla landfill	1
2.	77.2836 N	28.5116 E	Okhla bore well	2
3.	77.2822	28.5133	Tuglakabad village	4
4.	77.2822	28.5212	Tekhand village	5
5.	76° 54′ 7.91″ E	28° 31′ 21.44″ N	Raota village	6
6.	77° 7′ 58.97″ E	28° 28′ 19.43″ N	Aya Nagar	6
7.	77° 13′ 39.03″ E	28° 26′ 0.20″ N	Bhati mines	6

where distance (zone); 1—landfill site, 2—less than 50 m (0.05 km) from the landfill, 3—within 1000 m (<1 km) from the landfill, 4—between 1000 and 2000 m (between 1 and 2 km) from the landfill, 5—between 2001 and 4000 m (between 2 and 4 km) from the landfill and 6—more than 4000 m (> 4 km from the landfill site)

Table 5 Sites are falling within 5 km radius of the landfill site

S. No.	Description name	Distance from the periphery of	Distance
1.	Protected Forest	Jahanpanha City Forest	3.5 km in NW
2.	Reserved Forest	Rajokri Protected Forest	15 km in NW
3.	National Park/Wildlife Sanctuary/Biosphere Reserve	Asola Wildlife Sanctuary Okhla Bird Sanctuary National Zoological Park	3.5 km in SW 6 km in NE 10 km in NW
4.	Eco-sensitive Zone	Okhla Bird Sanctuary Eco-Sensitive Zone ESZ Aravalli notification	5 km in NE within 5 km

The following sites are falling within 5 km radius of the landfill site (Table 5):

Tekhand

Tekhand is located at a distance of 2 kms north-east from the Okhla landfill site. Its estimated population is 63,172.[1] The people living in the northern region throw their household waste in an open area and nobody picks up waste from there. The source of water in Tekhand is ground water and DJB Tanker, which contains water from various sources.

Tughlakabad

Tughlakabad village is located at a distance of 4 kms south from the Okhla landfill site. It is a part of Tughlakabad Fort, a ruined fort in Delhi, stretching across 6.5 km. It lends its name to the nearby Tughlakabad residential–commercial area as well as the Tughlaqabad Institutional Area. Its estimated population is about 4768.[2] The source of water in Tughlakabad is groundwater and DJB Tanker, which contains water from different sources. Residents also purchase water bottles for drinking and cooking.

Raota

Raota is a large village located in Najafgarh Tehsil of South-West Delhi district, Delhi and is located approximately 37 kms west from the dumpsite with total of 545

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[1] http://www.elections.in/delhi/mcd-elections/mcd-ward-list-2017.html.

[2] http://www.elections.in/delhi/mcd-elections/mcd-ward-list-2017.html.

Fig. 1 Map showing the location of the control sites

families residing. The Raota village has population of 2933.[3] Groundwater is predominantly being used for various household purposes. This site is acting as a control for the calculations of water quality index.

Aya Nagar

Aya Nagar is located near the Delhi–Haryana border at a distance of 15 Kms south-west from the Okhla landfill site. The population of Aya Nagar is 33,123.[4] Water supply is mainly through borewells and by Delhi Jal Board. There are approximately 80 borewells in the entire area. This site is acting as a control for the calculations of water quality index.

Bhati Mines

Bhati Mines were quartzite mines located in south Delhi at an approximate distance of 11Kms south-west from the Okhla landfill site. These mines are located near the southern ridge and have a population of 50,000[5] with approximately 8,000 households. These mines are located near the Sanjay colony and the Asola Bhati Wildlife sanctuary. Water supply is mainly through borewells and by Delhi Jal Board. This site is acting as a control for the calculations of water quality index (Figs. 1 and 2).

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[3] http://www.census2011.co.in/data/village/64043-raota-delhi.html.

[4] www.census2011.co.in/data/town/64065-aya-nagar-delhi.html.

[5] http://www.rkmdelhi.org/tag/bhati-mines/.

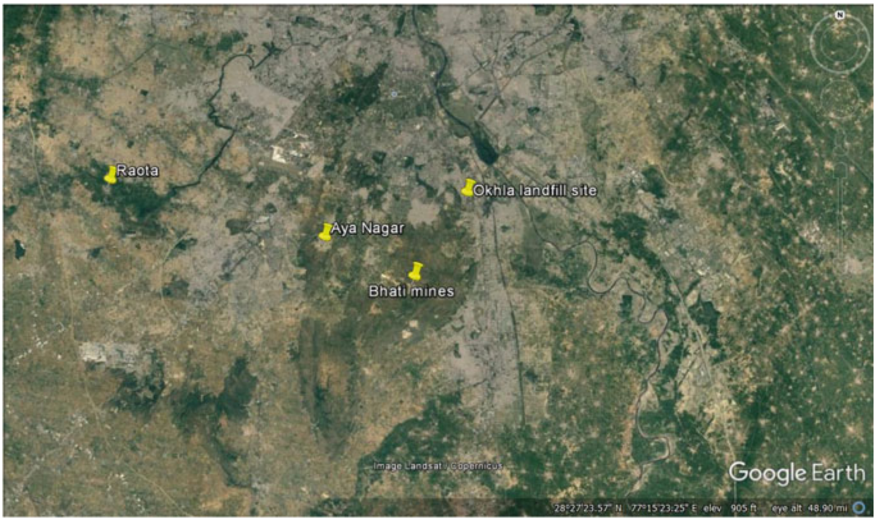


Fig. 2 Map showing the location of the sampled sites

7 Results

7.1 Waste Quantification Results

Waste quantification was carried out at 60 households, 20 each from high-, middle- and low-economic households in South Delhi colonies. The waste was segregated into three components for estimation, namely biodegradable, non-biodegradable and domestic hazardous waste; it was quantified using a portable weighing scale. The results of quantification are given below.

From the table above, it can be corroborated that the average biodegradable waste per household is coming out to be 0.68 ± 0.03 kg, non-biodegradable waste is 0.60 ± 0.04 kg and domestic hazardous waste is 0.03 ± 0.01 kg.

The following graph gives site-wise waste composition (Figs. 3, 4, and 5).

Figure 3 describes the waste generation scenario in Defence colony (high-income group). It can be seen that about 55% (0.62 ± 0.009 kg) of the total waste is biodegradable in nature, 44% (0.5 ± 0.02 kg) of the waste is non-biodegradable in nature and 1% (0.16 ± 0.008 kg) of the waste is domestic hazardous in nature.

Figure 4 describes the waste generation scenario Jasola (middle-income group). It can be seen that about 51% (0.9 ± 0.09 kg) of the total waste is biodegradable in nature, 46% (0.8 ± 0.1 kg) of the waste is non- iodegradable in nature and 3% (0.03 ± 0.01 kg) of the waste is domestic hazardous in nature.

Figure 5 describes the waste generation scenario Jasola EWS (low-income group). It can be seen that about 49% (0.54 ± 0.03 kg) of the total waste is

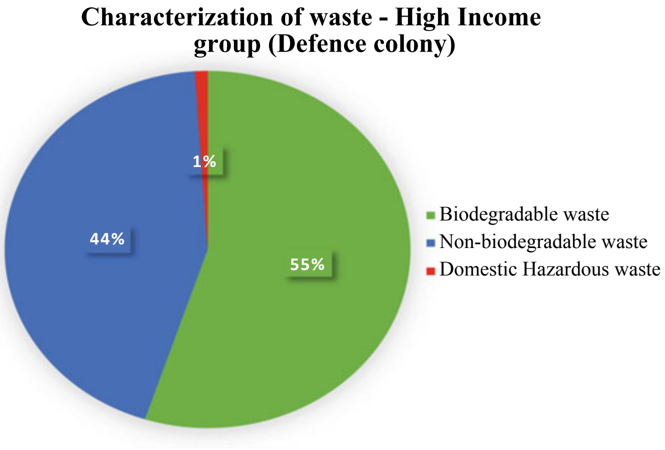


Fig. 3 Characterization of waste—high income group (Defence colony)

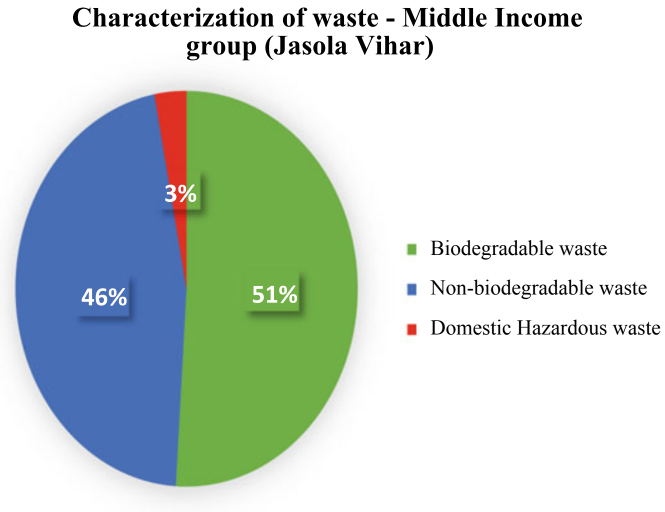


Fig. 4 Characterization of waste—middle-income group (Jasola Vihar)

biodegradable in nature, 46% (0.5 ± 0.03 kg) of the waste is non- biodegradable in nature and 5% (0.04 ± 0.03 kg) of the waste is domestic hazardous in nature.

As per the waste quantification data (Table 6) the quantity of domestic hazardous waste is coming out to be 0.030 ± 0.01 kg. Given below is the list of items that are a part of DHW, key harmful chemicals present in them (Table 10) as per the presence of described items as per SWM Rules 2016.

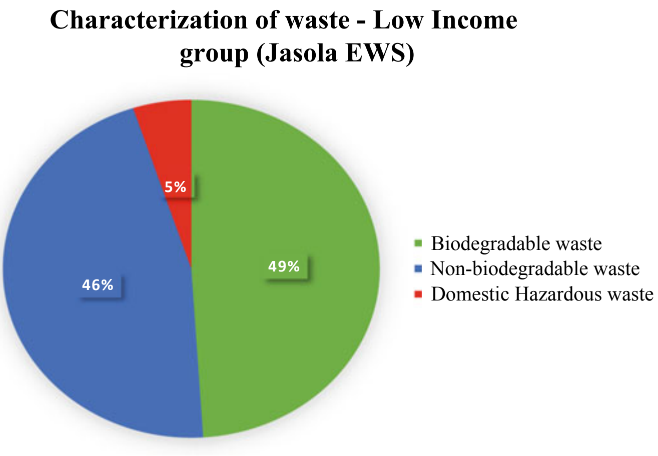


Fig. 5 Characterization of waste—low income group (Jasola EWS)

Table 6 Statistical analysis of the waste quantification data collected (BDW—Biodegradable waste, NBW—Non-biodegradable waste, DHW—Domestic hazardous waste)

		BDW in kg	NBW in kg	DHW in kg
N	Valid	60	60	60
	Missing	0	0	0
Mean		0.688	0.600	0.0342
Std. error of mean		0.0398	0.0401	0.01511
Std. deviation		0.3081	0.3103	0.11702
Variance		0.095	0.096	0.014

As explained earlier, as per the SDMC, 3000 MT waste generated from the households, commercial areas, institutions and offices in South Delhi from the Central, Najafgarh, South and Delhi Cantonment Board (DCB) zone are going to the Okhla dumpsite except 200 tons which goes to the Okhla Compost plant on Mathura Road. As per SDMC, no industrial waste goes to the Okhla Landfill site.

Leachate pollution index (of leachate emerging from Okhla Landfill site) was calculated for three seasons (pre-monsoon, monsoon and post-monsoon) to determine the contamination level of the collected leachate samples. For this estimation, leachate samples were collected from the Okhla landfill site.

The calculated results are given below:

Table 7 describes the levels of various parameters in the leachate collected during the pre-monsoon season. Leachate pollution index was calculated using the formula by [8, 13]. The value of LPI (pre-monsoon) is 27.01.

Table 8 describes the levels of various parameters in the leachate collected during the monsoon season. Leachate pollution index was calculated using the formula by [8, 13]. The value of LPI (monsoon) is 23.8.

Table 7 LPI—Pre-monsoon season

Pre-monsoon						
S. No.	Parameter	Value	Unit	W_i	P_i	P_iW_i
1	pH	8.3	NA	0.055	5	0.275
2	TDS	2.2	mg/l	0.05	5	0.25
3	BOD	119	mg/l	0.061	10	0.61
4	COD	4000	mg/l	0.062	60	3.72
5	Nitrogen	1400	mg/l	0.051	100	5.1
6	Iron	3.76	mg/l	0.044	5	0.22
7	Chromium	0.234	mg/l	0.064	5	0.32
8	Lead	0.256	mg/l	0.063	5	0.315
9	Chloride	2600	mg/l	0.048	55	2.64
LPI						27.01

Table 8 LPI—monsoon

Monsoon						
S. No.	Parameter	Value	Unit	W_i	P_i	P_iW_i
1	Ph	6.8	NA	0.055	5	0.275
2	TDS	17,680	mg/l	0.05	40	2
3	BOD	1450	mg/l	0.061	30	1.83
4	COD	1192	mg/l	0.062	35	2.17
5	Nitrogen	500	mg/l	0.051	55	2.805
6	Iron	2.4	mg/l	0.044	5	0.22
7	Chromium	0.021	mg/l	0.064	5	0.32
8	Lead	0.002	mg/l	0.063	5	0.315
9	Chloride	4930	mg/l	0.048	40	1.92
LPI						23.8

Table 9 describes the levels of various parameters in the leachate collected during the post-monsoon season. Leachate pollution index was calculated using the formula by [8, 13]. The value of LPI (post-monsoon) is 43.13.

Table 10 describes the levels of various parameters in the treated leachate (as per the standards mentioned in the solid waste management rules, 2016) was calculated using the formula by [8, 13]. The value of LPI is 6.8.

The Leachate pollution index (LPI) value of the leachate disposal standards to inland surface water as per Solid Waste (Management and Handling) Rules, 2016, Government of India is 6.8. The LPI value of Okhla landfill site indicated that the waste deposited is contaminated since all values calculated during all the three seasons (i.e. pre-monsoon, monsoon, post-monsoon) has exceeded the standards (Figs. 6 and 7). This is indicating the landfill site is an old and also continued interaction of waste in the landfill site. As per the policy, leachate to be treated and

Table 9 LPI—post-monsoon

Post-monsoon						
S. No.	Parameter	Value	Unit	W_i	P_i	P_iW_i
1	pH	8.3	NA	0.055	5	0.275
2	TDS	67,000	mg/l	0.05	100	5
3	BOD	43,550	mg/l	0.061	75	4.575
4	COD	600	mg/l	0.062	10	0.62
5	Nitrogen	2630	mg/l	0.051	100	5.1
6	Iron	13,000	mg/l	0.044	100	4.4
7	Chromium	0.032	mg/l	0.064	10	0.64
8	Lead	1.5	mg/l	0.063	10	0.63
9	Chloride	0	mg/l	0.048	5	0.24
Total						43.13

Table 10 LPI for standard treated leachate

For standard treated leachate						
S. No.	Parameter	Value	Unit	W_i	P_i	P_iW_i
1	pH	7.25	NA	0.055	5	0.275
2	TDS	1000	mg/l	0.05	5	0.5
3	BOD	30	mg/l	0.061	5	0.305
4	COD	250	mg/l	0.062	10	0.62
5	Nitrogen	50	mg/l	0.051	5	0.255
6	Iron	ND	mg/l	–	–	0
7	Chromium	2	mg/l	0.064	10	0.64
8	Lead	0.1	mg/l	0.063	5	0.315
9	Chloride	1000	mg/l	0.048	10	0.48
Total						6.8

discharged after attaining the standard values for pollutants. But in this case it is above the standard value. Hence, it can be inferred that the leachate not being treated and thus suggest for immediate action in this regard.

7.2 *Physico-chemical Test Results of Groundwater Samples from Different Sites*

For this study, chemical parameters like pH, TDS, turbidity, BOD, COD, iron, ammonia, nitrate, chloride, conductivity, chromium and lead were taken.

Figure 8 describes the levels of pH in the water samples collected from sampling sites during the pre-, monsoon and post-monsoon. The value of pH varied between

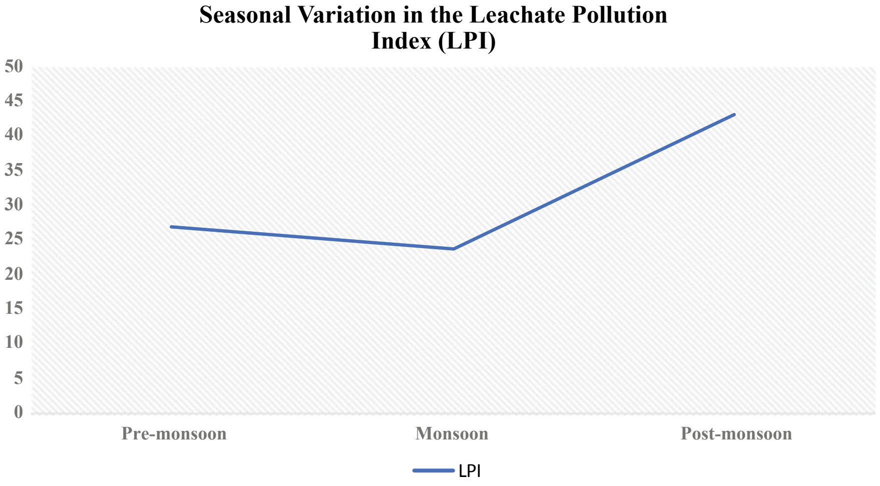
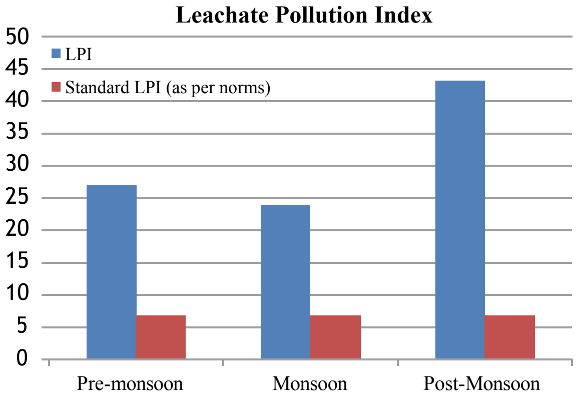


Fig. 6 Seasonal variation in leachate pollution index (LPI)

Fig. 7 Comparison between the LPI of the three seasons with the standard treated leachate (pre-monsoon, monsoon and post-monsoon)



6.8 and 7.8. The pH was near neutral 6.8 in the pre-monsoon but moved towards basic pH 8 in the post-monsoon.

Figure 9 describes the levels of TDS in the water samples collected from sampling sites during the pre-, monsoon and post-monsoon. The value of TDS varied from 200 to 2800 mg/l. TDS was found to be very high during monsoon and post-monsoon in most of the sampled sites.

Figure 10 describes the levels of conductivity in the water samples collected from sampling sites during the pre-, monsoon and post-monsoon. The values of conductivity varied from 250 to 4500 microseimens. The values conductivity was found to be high during the monsoon and post-monsoon in all the sampled sites.

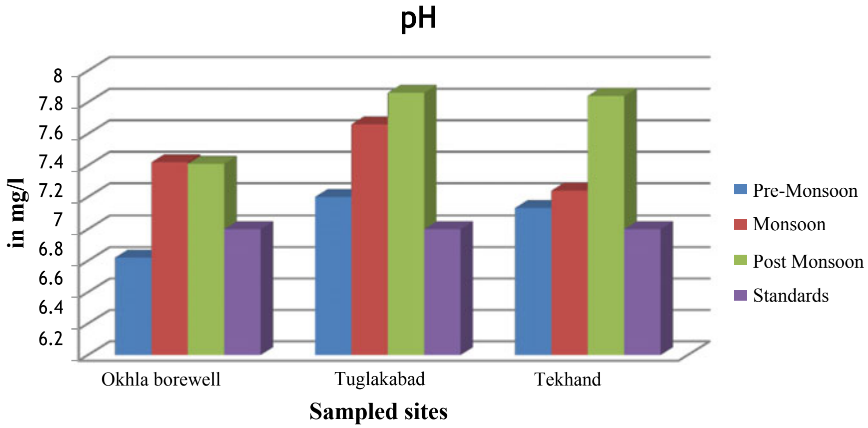


Fig. 8 pH levels in pre monsoon, monsoon and post monsoon seasons

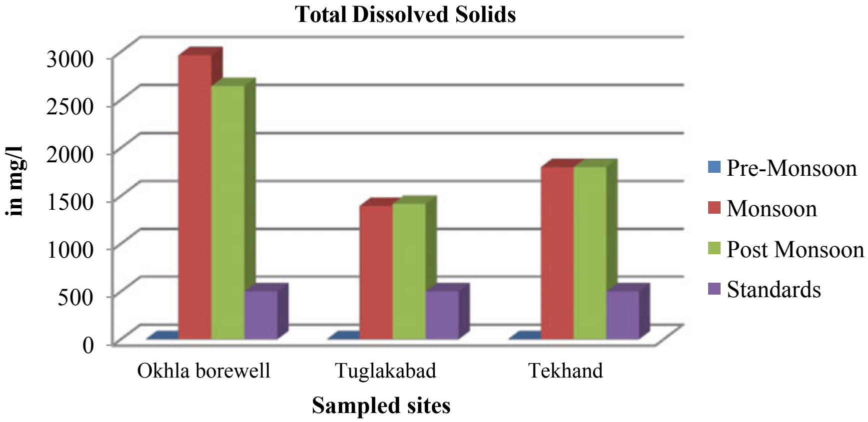


Fig. 9 Levels of TDS in pre monsoon, monsoon and post monsoon seasons

Figure 11 describes the levels of biochemical oxygen demand in the water samples collected from sampling sites during the pre-, monsoon and post-monsoon. The biochemical oxygen demand (BOD) values varied from 3 to 43 mg/l. BOD was high during pre-monsoon at Okhla borewell, Tuglakabad and Tekhand.

Figure 12 describes the levels of iron in the water samples collected from sampling sites during the pre-, monsoon and post-monsoon. The Iron levels varied from 0.05 to 0.8 mg/l. It was found to be high during pre-monsoon in Tekhand and Tuglakabad and high during monsoon at the Okhla borewell.

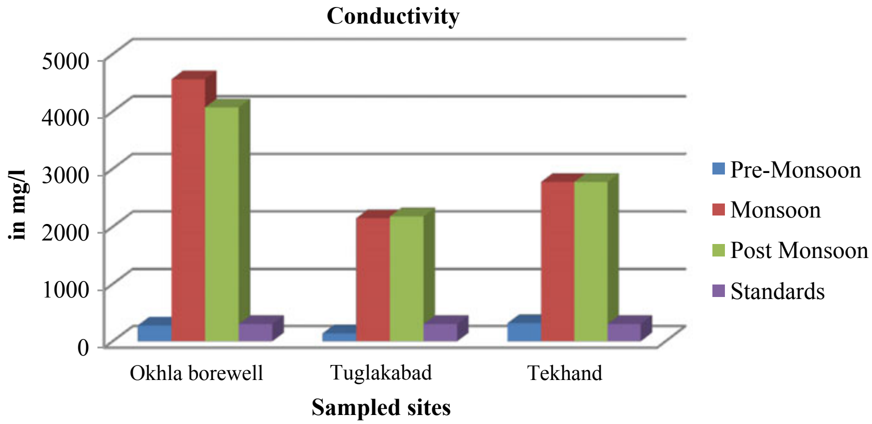


Fig. 10 Levels of conductivity in pre monsoon, monsoon and post monsoon seasons

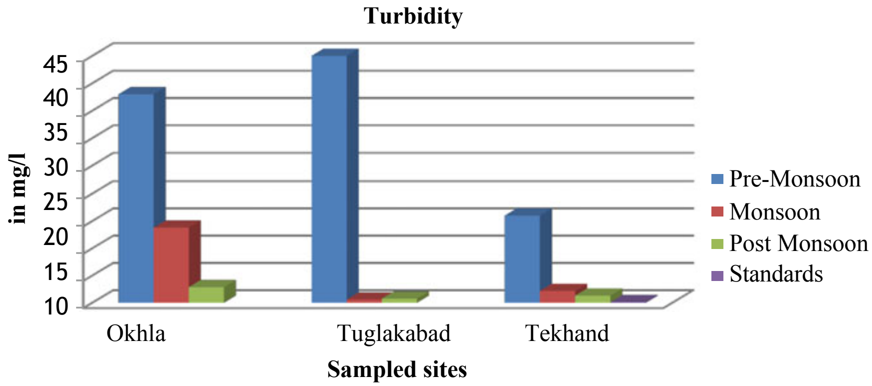


Fig. 11 Levels of turbidity in pre monsoon, monsoon and post monsoon seasons

Figure 13 describes the levels of chloride in the water samples collected from sampling sites during the pre-, monsoon and post-monsoon. The value of chloride varied from 300 to 1100 mg/l. The values of chloride were found to be high during the pre-monsoon, monsoon and post-monsoon in Okhla borewell and in monsoon and post-monsoon in almost of the sampled sites.

Figure 14 describes the levels of ammonia in the water samples collected from sampling sites during the pre-, monsoon and post-monsoon. The values of ammonia varied from 0.01 to 0.8 mg/l. The values were high during monsoon in Tekhand.

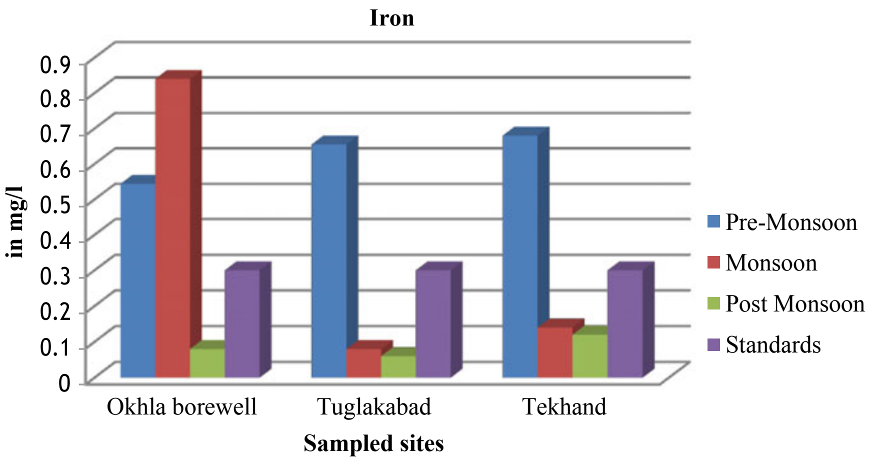


Fig. 12 Iron levels in pre monsoon, monsoon and post monsoon seasons

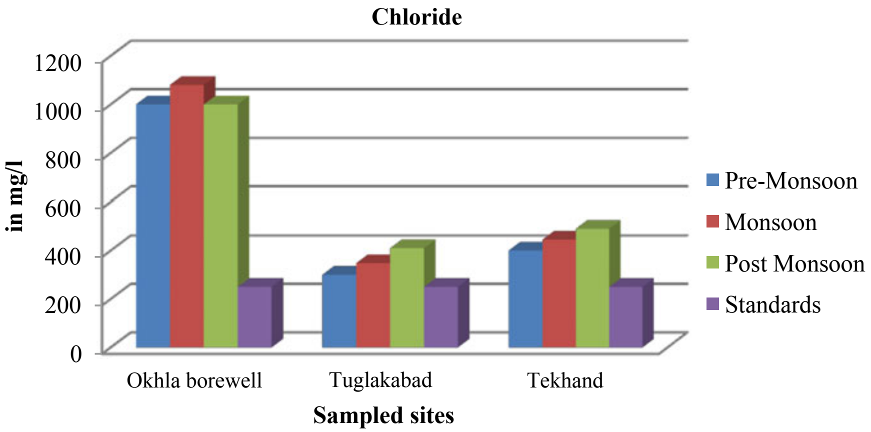


Fig. 13 Chloride levels in pre monsoon, monsoon and post monsoon seasons

Figure 15 describes the levels of nitrate in the water samples collected from sampling sites during the pre-, monsoon and post-monsoon. The values of nitrite varied from 15 to 68 mg/l. The values of nitrate were found to higher than the standards in Tekhand and Tuglakabad during pre-monsoon, monsoon and post-monsoon.

Figure 16 describes the levels of biochemical oxygen demand in the water samples collected from sampling sites during the pre-, monsoon and post-monsoon. The biochemical oxygen demand (BOD) values varied from 3 to 18 mg/l. BOD was high during monsoon at Okhla borewell, Tuglakabad and Tekhand.

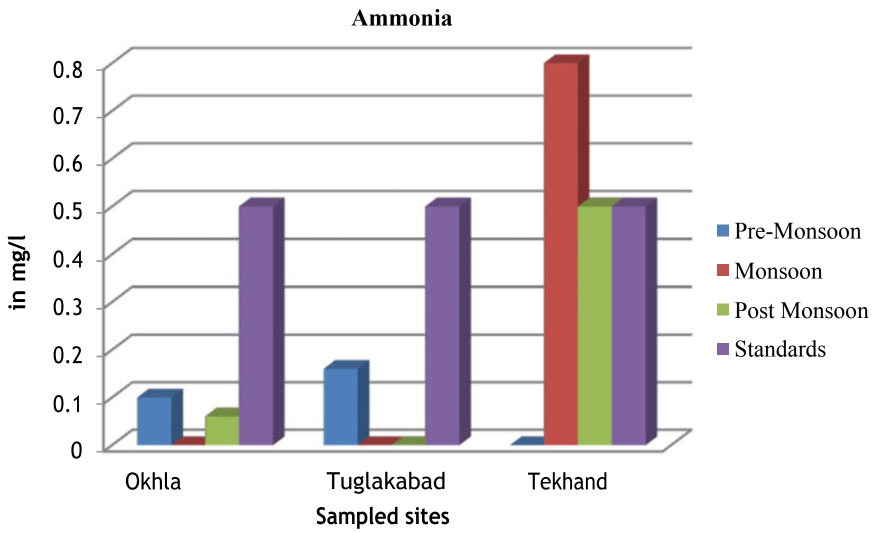


Fig. 14 Levels of ammonia in pre monsoon, monsoon and post monsoon seasons

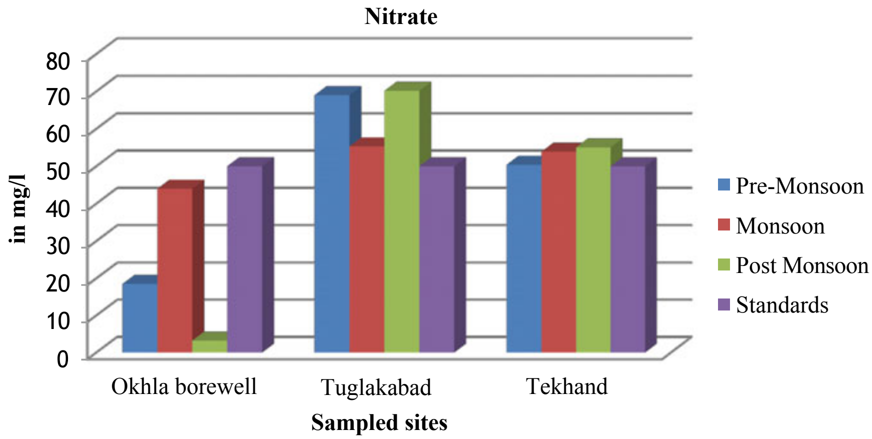


Fig. 15 Levels of nitrate in pre monsoon, monsoon and post monsoon seasons

Figure 17 describes the levels of chemical oxygen demand in the water samples collected from sampling sites. The chemical oxygen demand (BOD) values varied from 3 to 23 mg/l and were exceeding the standard limits.

Figure 18 describes the levels of chromium in the water samples collected from sampling sites during the pre-, monsoon and post-monsoon. The value of chromium varied from 0.07 to 0.12 mg/l. The values of chromium were found to be high during the pre-monsoon in Okhla borewell, Tuglakabad and Tekhand.

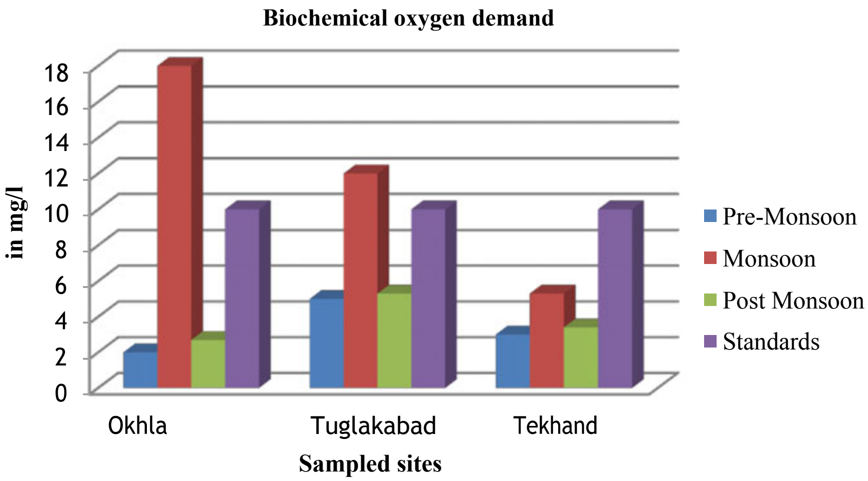


Fig. 16 Biochemical oxygen demand in pre monsoon, monsoon and post monsoon

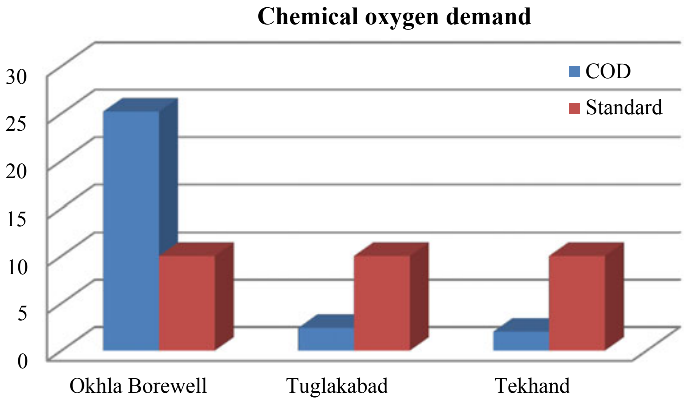


Fig. 17 Chemical oxygen demand in pre monsoon, monsoon and post monsoon

Figure 19 describes the levels of lead in the water samples collected from sampling sites during the pre-, monsoon and post-monsoon. The value of lead varied from 0.01 to 0.35 mg/l. The values of lead were found to be high during the pre-monsoon in Okhla borewell, Tuglakabad and Tekhand.

Using the above parameters, a water quality index was estimated and the results have been listed below in Table 12. The sites were compared with control sites is illustrated in Fig. 19.

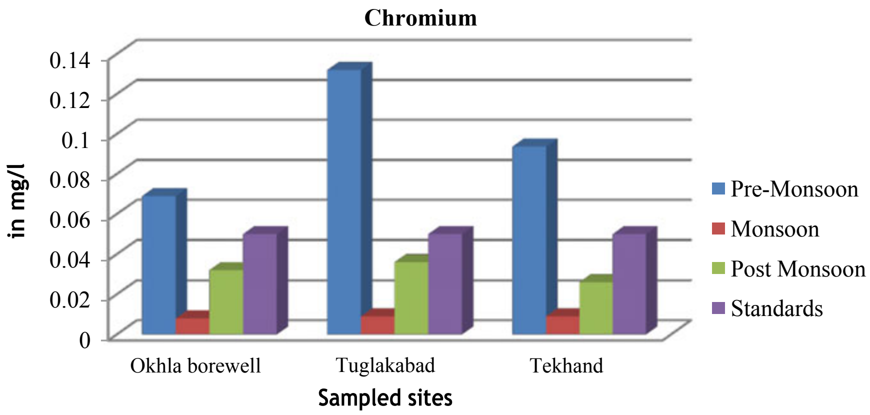


Fig. 18 Chromium in pre monsoon, monsoon and post monsoon

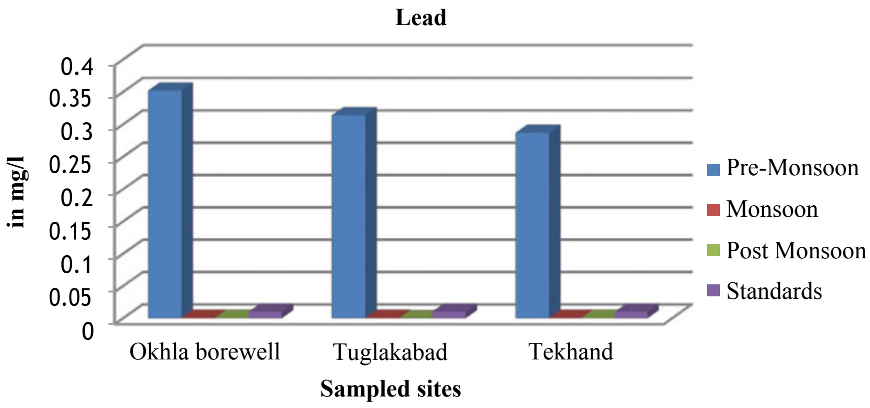


Fig. 19 Lead in pre monsoon, monsoon and post monsoon

The water quality index (WQI) was calculated of the water samples were collected from sampled sites. The values of various physiochemical parameters for calculation are given in Fig. 20 for Pre-monsoon, monsoon and post-monsoon. The results prove the poor quality of water and thus indicates possible contamination of these waters by the landfill site. The water quality index obtained for these water samples have been found unsuitable for human consumption. It is also observed that the pollution load is relatively high during the monsoon season as well as the post-monsoon seasons.

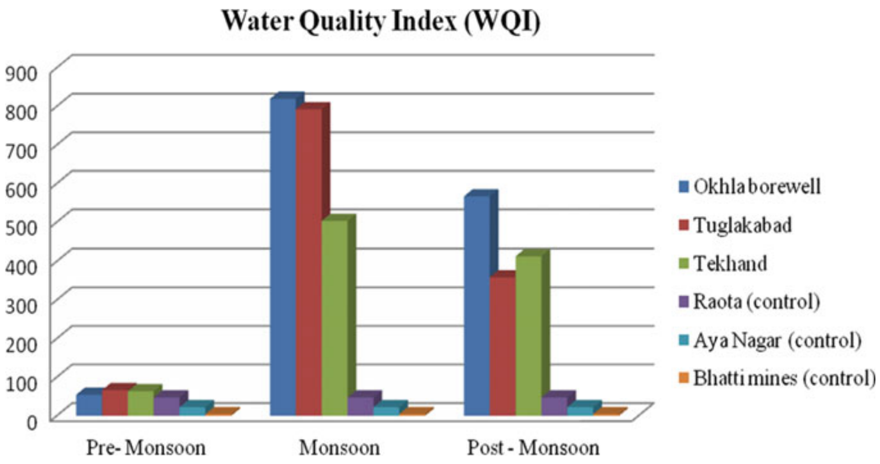
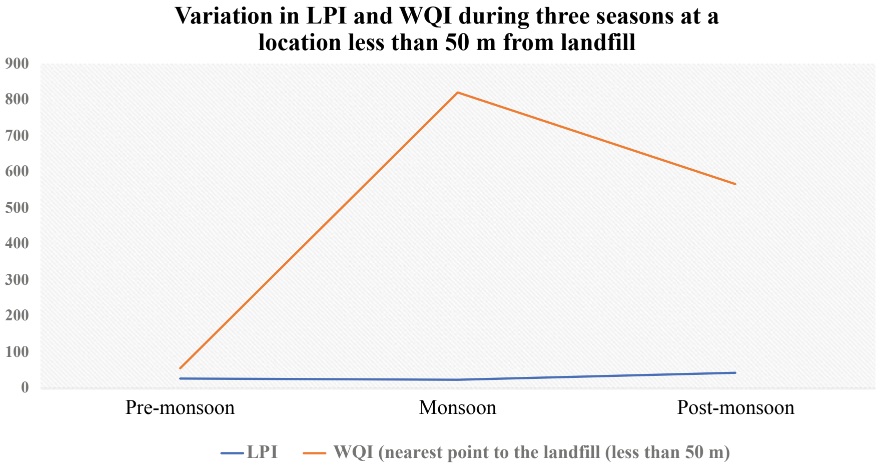


Fig. 20 Water quality index (WQI) of the collected groundwater samples



*LPI – Leachate pollution index – elevated values depict poor leachate quality
*WQI – Water Quality Index – elevated values depict poor water quality

Fig. 21 Variation in LPI and WQI during three seasons at a location less than 50 m from landfill

Figure 21 shows the variation in water quality index (WQI) and leachate pollution index (LPI) for a site which is 50 m away from the landfill in three different (pre-monsoon, monsoon and post-monsoon) seasons.

It can be clearly seen that during the pre-monsoon, the values of both LPI and WQI are low. This shows that the quality of leachate and water are somewhat better. But during monsoon, due to excessive leachate production and enhanced movement, this leachate percolates the ground contaminating the groundwater of the area. This is to be noted that the water quality is the worst during the monsoon season. In the post-monsoon season, there is an increase in the LPI but due to increasing dryness and decreased leachate movement, there is a drop in the WQI indicating enhancement of the water quality during the post-monsoon. Thus, it can be concluded that leachate pollution index influences the water quality of the area.

8 Findings

The physiochemical parameters of groundwater samples from the selected sites for study have been found to be more than the Indian Standards (IS 10500: 2012), especially, in monsoon and post-monsoon season, depicting high levels of environmental pollution in the Okhla borewell, Tekhand and Tuglakabad, which are within 2–5 km from the landfill site. Although, many factors may contribute to the migration of heavy metals and other organic contaminants through groundwater, the fact that high levels of heavy metals like lead and chromium are found in the groundwater in sites close to the landfill site, namely in Tekhand and Tuglakabad shows that the landfill could be a major source of these and this migration of contaminants from the landfill towards the nearby habitation is because of the long-term accumulation of heavy metals from unsegregated household waste being dumped at the landfill site for several years.

The leachate characteristics may demonstrate high variations in which a range of physical, chemical and biological parameters may vary over several orders of magnitude. However, LPI is a good tool to compare the pollution potential of landfill sites. Leachate sample of Okhla landfill site was collected and analysed for nine significant leachate pollutant variables, viz., chromium, lead, pH, TDS, BOD5, COD and chloride (Cl^-), nitrate, iron to estimate its pollution potential. The concentration of all the studied leachate pollutant variables exceeded the permissible limits.

The leachate pollution index (LPI) value of the leachate disposal standards to inland surface water as per Solid Waste (Management and Handling) Rules, 2016, Government of India is 6.8. The LPI value of Okhla landfill site indicated that the waste deposited is contaminated since all values calculated during all the three seasons pre-monsoon, monsoon, post-monsoon have exceeded the standards. The water quality index (WQI) of the water samples were collected from Tekhand, Tuglakabad and Okhla borewells as well as habitations more than 5 km away from landfill site. The values of various physiochemical parameters for calculation depicted in Table 11 for monsoon and post-monsoon indicates towards many of the habitations close to the dumpsite having poor quality water and possible contamination of these waters by the landfill site. The Water Quality Index obtained for these water samples have been found unsuitable for human consumption. It is also observed that the pollution load is relatively high during the monsoon season as well as the post-monsoon season (Table 12). It is also found that although during monsoon and post-monsoon, levels of lead and chromium in ground water is lower

Table 11 List of items that are a part of DHW and key harmful chemicals

Product	Key harmful chemicals
Drain cleaner	Sodium hydroxide
Glass cleaner	Ammonia, Glycol Ether, Phthalates
Toilet cleaner	Hypochlorite, Butyl oleylamine
Mothballs	Para dichlorobenzene
Furniture polish	Nitrobenzene
Perfumes/Deodorants	Phthalates
Ant sprays and baits	Organophosphates
Cockroach bait	Boric acid
Rat baits	Zinc phosphide
Mosquito coils	Benzene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k] fluoranthene
AAA batteries	Potassium hydroxide, lead and chromium
Nickel cadmium batteries	Nickel and Cadmium
Nickel metal hydride batteries	Nickel and metal hydrides
Lithium Ion batteries	Lithium
Small-sealed lead batteries	Lead
Shoe polish	Nitrobenzene
Nail polish remover	Acetone
Automotive batteries	Heavy metals (Cadmium, Chromium, Lead)
Oil or enamel-based paint	Toluene, Methylene chloride, Lead and Chromium
Latex or water-based paint	
Paint thinners and turpentine	Ethyl acetate
Mercury thermometers	Mercury
Expired Medicines	Varies as per composition
Health care waste	Benzyl benzoate

than the allowed safe limits, it's much higher than the allowed safe limits during pre-monsoon probably because of acidic to neutral pH conditions during pre-monsoon, which changes to alkaline during monsoon and post-monsoon periods, where they may be forming colloids with organic matter [1].

This pollution is likely to affect the health of the people residing in these locations. It is also to be noted that these sites are located near the Asola Bhati Wildlife sanctuary and the Okhla bird sanctuary. Illegal dumping of waste has been found in and around the Asola Wildlife sanctuary as well. These are eco-sensitive zones could also be affected in future if the migration of heavy metals is happening in the nearby habitations to the landfill and could, one day, eventually affect these eco-sensitive zones as well. It would then affect wildlife and cause a major loss in biodiversity and irreparable damage to the general ecosystem of Delhi.

Table 12 Water quality index summary for all the collected groundwater samples

Site	Pre-monsoon	Quality	Monsoon	Quality	Post-monsoon	Quality
Okhla borewell	54.34	Poor (Unsuitable for human consumption)	819.5	Poor (Unsuitable for human consumption)	566.58	Poor (Unsuitable for human consumption)
Tuglakabad	66.227	Poor (Unsuitable for human consumption)	792.49	Poor (Unsuitable for human consumption)	358.51	Poor (Unsuitable for human consumption)
Tekhand	63.5	Poor (Unsuitable for human consumption)	503.12	Poor (Unsuitable for human consumption)	413.14	Poor (Unsuitable for human consumption)
Raota (control)	47.19	Good water quality	47.19	Good water quality	47.19	Good water quality
Aya Nagar (control)	22.03	Good water quality	22.03	Good water quality	22.03	Good water quality
Bhati mines (control)	4.22	Excellent water quality	4.22	Excellent water quality	4.22	Excellent water quality

8.1 Chromium Toxicity

Exposure to Cr (VI) and Cr (III) compounds can be associated with allergic responses (e.g. asthma and dermatitis) in sensitive individuals. Chromium eczemas are often observed in the general population, due to exposure to chromium in products used in daily life. In recent scientific studies of laboratory animals, hexavalent chromium has been linked to cancer when ingested and also can cause obstructive respiratory dyspnea at ≥ 0.2 mg chromium(VI)/m3, fibrosis at $\geq$ 0.1 mg chromium(VI)/m3, and hyperplasia (the enlargement of an organ or tissue caused by an increase in the reproduction rate of its cells, often as an initial stage in the development of cancer) at ≥ 0.05 mg chromium(VI)/m3 were found in the lungs of rats exposed to sodium dichromate for 30 or 90 days [9]. The results of the groundwater samples collected in this study have been found to have exceeded the limits of 0.05 mg/l.

8.2 Lead Toxicity

Epidemiological studies have suggested that low-level exposure of the foetus and developing child may lead to reprotoxic effects, i.e. damage to the learning capacity and the neuropsychological development [4]. These studies have also indicated a correlation between lower IQ and higher lead content in the blood, although it must be emphasized that there is no known blood lead level for children without some level of risk for some of the adverse neurological effects of lead in children.

As per a study conducted by [16], lead has also been associated with causing evident signs of acute intoxication, include restlessness, irritability, dullness, headaches, poor attention span, muscle tremor, abdominal cramps, kidney damage, hallucinations, loss of memory and encephalopathy occurring at blood lead levels of 100–120 µg/dl (1–1.2 mg/l) in adults and 80–100 µg/dl (0.8–1 mg/l) in children. Some of signs and symptoms of chronic lead toxicity, include tiredness, sleeplessness, irritability, headaches, joint pain and gastrointestinal symptoms, may appear in adults at blood lead levels of 50–80 µg/dl (0.5–0.8 mg/l). This study also reported that low levels of environmental lead exposure could have adverse health effects; therefore, knowing the degree of lead exposure from household water relative to other sources is important. The results of the groundwater samples collected in this study have been found to have exceeded the limits of 0.3 mg/l [16].

9 Recommendation

One of the major problems of all the surveyed sites in Delhi is improper solid waste management. Despite regular pickup, collection claimed by the SDMC, over 90% of the surveyed population does not segregate their waste into three categories as recommended in the SWM Rules 2016, resulting in mixing and interaction of wet, dry and hazardous waste and this mixed solid waste being dumped as such in landfills, resulting in high levels of contamination not only in the leachate emanating from the landfill but also percolating into the groundwater of habitations nearby, especially during monsoon and post-monsoon periods.

As shown in results above, dumping unsegregated solid waste is against the SWM Rules and especially, dumping those kinds of waste which have the potential to harm the environment and enter the food chain of human beings and become accumulated in blood, muscles and other tissue which will result in severe debility and diseases like cancers is dangerous. Hence, waste should be segregated at source and processed as close to the point of generation, as is possible, e.g. composting wet waste, recycling dry waste and separating the domestic hazardous waste and sending them for safe processing and encapsulation rather than discarding it indiscriminately in the environment [13]. Furthermore, keeping domestic hazardous waste like batteries, paints, bulbs, especially from mixing with wet waste is of utmost importance. Hence, we suggest that all households, educational institutions, commercial organizations, etc., have to follow the segregation of waste at source as suggested in the SWM Rules 2016.

9.1 Recommendation for Future Research

Due to financial and other constraints, this study could not test for all heavy metals. Furthermore, lead and chromium in blood or tissues could not be studied because of various reasons. However, due to presence of these heavy metals in groundwater at levels that can cause exposure and risk of accumulation in blood and tissues, it is recommended that a more detailed study of the accumulation of these pollutants in blood and tissue of children and adults should be undertaken. This could throw greater light on the impact of accumulation of hazardous substances especially heavy metals such as lead and chromium in blood and tissues through water, due to accumulation of domestic hazardous wastes in the city garbage dumpsites, from continuous dumping of unsegregated domestic waste from households, commercial areas and institutions into unlined landfills or dumpsites.

Note: This paper contains parts of my Ph.D. work. The permission to conduct surveys, FGDs, water and waste analysis was taken from the Executive Engineer, South Delhi Municipal Corporation, Delhi before beginning the work.

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References

1. Abbasi, S.A.: Water quality indices, state of the art report, National Institute of Hydrology, scientific contribution no. INCOH/SAR-25/2002, Roorkee: INCOH, p. 73 (2002)
2. Bowen, C.F.: Household Hazardous Products and Hazardous Waste: A Summary for Consumers College of Agricultural Sciences Agricultural Research and Cooperative Extension (1998)
3. Chatterjee, A.A., Raziuddin, M.: Determination of water quality index (WQI) of a degraded river in Asanol Industrial area, Raniganj, West Bengal. Nat. Environ. Pollut. Technol. **1**(2), 181–189 (2002)
4. Goyer, R.A.: Toxic effects of metals. In: Cassarett and Doull's Toxicology. The basic science of poisons. Klaassen, C.D., M.O Amdur, and J.Doull, (eds.), 3rd ed. McGraw-Hill, New York (1986)
5. http://www.elections.in/delhi/mcd-elections/mcd-ward-list-2017.html. Information retrieved on 16.01.2018
6. http://www.census2011.co.in/data/village/64043-raota-delhi.html. Information retrieved on 16.01.2018
7. http://www.rkmdelhi.org/tag/bhati-mines/Information. Retrieved on 15.03.2018
8. Kumar, D., Alappat, B.J.: A technique to quantify landfill leachate pollution. Proceedings of the 9th International Landfill Symposium, Cagliari, 6–10 October 2003, Paper No. 400 (2003)
9. Li H, Shi A, Li M, Zhang X: Effect of pH, temperature, dissolved oxygen, and flow rate of overlying water on heavy metals release from storm sewer sediments. J. Chemistry **2013**, Article ID 434012, 11 pages (2013). https://doi.org/10.1155/2013/434012
10. Naveen, B.P., Sivapullaiah, P.V., Sitharam, T.G.: Characteristics of a municipal solid waste landfill leachate. Indian Geotechnical Conference on Geotechnics for Inclusive Development of India (GEOIND), 18–20 December, Kakinada, pp. 1413–1419 (2014)
11. Naveen, B.P., Sivapullaiah, P.V., Sitharam, T.G.: Influence of leachate migration on ground water quality. 5th Indian Young Geotechnical Engineer's Conference (5IYGEC-2015), Indian Geotechnical Society Baroda Chapter, 14–15 March, pp. 127–128, 2015
12. Planning Commission. Report of the Task Force on Waste to Energy, Vol. I, Planning Commission, New Delhi, May (2014)
13. Samal, B., Madguni, O.: Assessing leachate pollution index and its variability across various seasons—a case of Okhla landfill site. Octa J. Environ. Res. International Peer-Reviewed Journal Oct. Jour. Env. Res. **6**(1), 041–045
14. Solid Waste (Management and Handling) Rules, 2016, Government of India
15. Sun, H., Brocato, J., Costa, M.: Oral chromium exposure and toxicity. Curr. Environ. Health Rep. 2015 Sep; **2**(3), 295–303 (2015). https://doi.org/10.1007/s40572–015-0054-z
16. US Environmental Protection Agency. Air quality criteria for lead. Research Triangle Park, NC, 1986 (Report EPA-600/8-83/028F)
17. www.census2011.co.in/data/town/64065-aya-nagar-delhi.html. Information retrieved on 15.03.2018

Performance Evaluation of Sewage Treatment Plant (STP)—A Case Study

C. F. Rajemahadik and Nikunj Mendapara

Abstract Maintaining STP is a vital assignment in present circumstances to reduce pollution. This paper describes the importance of maintaining STP in small cities. A case of 20 MLD capacity STP units having activated sludge process with sludge thickener and sludge drying beds were monitored for STP performance. A 7-week monitoring was conducted to analyze pH, alkalinity, TDS, TS, TSS, BOD_5, COD, MLVSS, MLSS, and SVI form inlet to outlet. The study indicates STP was inefficient in treating domestic wastewater received through pumping stations. The reasons for inefficient STP performances were identified as improper pumping, insufficient F/M ratio, higher return sludge, greater oxygen dissolved, lower volumetric loading rate, greater recirculation ratio, and long HRT, which is more than required. The solid loading rate and hydraulic loading rate were underloaded. The parameters were evaluated and rectified, which further improved performance, increasing BOD_5 removal, and possibly reducing operational cost.

Keywords Performance · Evaluation · STP · Wastewater · Operational parameters

1 Introduction

Discharging of wastewater into the environment poses serious threats, evolving importance of sewage treatment [1]. For around 80 years until today, activated sludge process (ASP) is widely applied in wastewater treatment [2]. Treatment of municipal wastewater in the current scenario among developing countries in STPs is necessary [3]. ASPs are adopted to convert organic and inorganic pollutants to improve quality of environment through low operation cost and favorable

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performance [4]. The domestic wastewater discharged from community is collected and treated by activated sludge process (ASP) considering its removal efficiency [5]. Despite good pollutant removal, ASP has declining treatment efficiency because of operational problems [6]. The collection of wastewater from all streams is essentially a prerequisite confirming environmental quality [7]. The major source of pollution is discharged from urban settlements to water bodies [8]. These methods cause distress on natural water resources imparting change in the characteristics of water causing disease outbreak. Along with domestic wastewater, industrial wastewater is also discharged from their units and collected from the facilities. Construction of Sewage Treatment Plant (STP) is not the only solution for treating domestic wastewater, but it is a crucial task to maintain them properly [9]. The inappropriate scheduling and maintenance of plant hamper the efficiency and purpose of STP. Hence, the paper describes the aspect of STP maintenance and performance.

2 Study Area

The wastewater treatment plant of 20 MLD is located near Kolhapur in India. STP is designed as a conventional type activated sludge system (ASP) having screen and grit chamber, partial flume, carrousel type aeration tank, primary and secondary clarifier, chlorine contact tank, sludge thickener, and sludge drying beds.

2.1 Problem Identified

After construction, the maintenance of STP is very important. STP plant inspected described certain gaps and uncertainty to follow inventory.

a. Lack of monitoring
b. Improperly operated designed parameters.

3 Materials

The chemicals required for experimentation such as BOD, COD, and alkalinity were purchased from Merck. Instruments for experiments used were pH meter, muffle furnace (1050 °C), oven (250 °C), along with glassware required.

4 Methodology

4.1 Details of STP units

Initially, data is collected from the Technical office, India. The data collected specifies the dimension and capacity of units, electrical and mechanical equipment allocated to STP (Fig. 1). The inlet chamber provided was of 2.55 m × 2.55 m × 4.50 m dimension constructed using RCC M20 grade concrete. The retention time of the chamber is 1 min having 50 MLD of discharge. The screen chamber of size 4 m × 2.1 m × 1.9 m having two numbers was provided according to the design flow. Manually and mechanically operated screens were provided along with inclined screen at 45° angle. A D-gritting mechanism was provided having retention time of 2 min in peak discharge of 8.5 m × 8.5 m × 1 m having 3 scrapper arms. Grit was removed by a rotating screw of 600 mm diameter. A Parshal flume having length of 3787 mm was provided. The inlet and outlet width were 1207 mm and 915 mm, respectively, where width of 601 mm for throat was adopted. The distribution chamber of 50 MLD discharge of size 5.0 m × 4.2 m × 3.65 m with a retention capacity of 1 min of peak flow was constructed. A Corrousel type of aeration tank having size 67 m × 51.0 m × 3.9 m was provided with five fixed surface aerators installed with 75 H.P. motor for each aerator at 1440 rpm. Secondary clarifier having retention time of 4.25 h, 42.55 m of diameter and launders of 700 mm wide were provided. One chlorination tank of size 52.0 m × 6.25 m × 1.95 m with discharge of 20,000 m^3/day with 13 baffles was connected to clarifier. Sludge thickener of size 3.2 × 2.0 × 1.85 m was provided. The last units were sludge drying bed with 11 numbers of beds, each of size 35.7 × 10.45 × 0.9 and were manually operated.

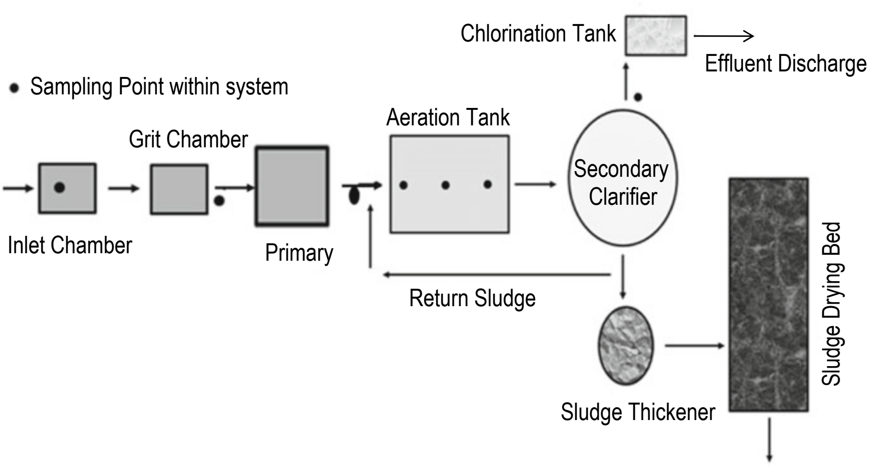


Fig. 1 Flow diagram of STP with sampling points

Table 1 Monitoring Programme for wastewater analysis

Point	Location of station	Frequency of sampling	Parameters analysis
1	Inlet (before screen)	Thrice in a week	pH, alkalinity, TS, TDS, TSS, BOD, and COD
2	Aerator (inlet)		pH, alkalinity, TS, TDS, TSS, BOD, COD, MLSS, MLVSS, and SVL
3	Aerator (middle)		
4	Aerator (outlet)		
5	Recycling (sludge inlet)		
6	Outlet		

4.2 Sampling and Monitoring

The sampling was carried out for 7 weeks during the summer season to assess variation in the parameters of wastewater and to examine the overall performance of STP. The grab sampling was conducted three times in a week at seven sampling points. Sampling points selected were as shown in Fig. 1. The frequency of sampling is elaborated in Table 1. All experimental parameters detected in the laboratory are in agreement with the standard methods [10].

4.3 Calculations

$$\text{Food to microorganism ratio, (F/M)} = \frac{Q\,x\,So}{V\,x\,X} \tag{1}$$

F/M—expressed as kg BOD5/kg MLVSS*day; Q—Discharge of wastewater (m^3/Day); So,—BOD of wastewater (g/m^3); V—Volume of reactor (m^3); X—Reactor Biomass (g/m^3)

$$\text{Volume of reactor, (V)} = \frac{Q\,x\,(\theta c) x Y (So - S)}{X(1 + Kd * \theta c)} \tag{2}$$

θc—mean cell residence time (10 day); k_d—endogenous decay coefficent, (0.05/day); Y—Mass of cell formed to the mass of substrate consumed; So—Influent flow BOD (mg/L); S—Effluent flow BOD (mg/L); Q—flow discharge; X—MLVSS (mixed liquor volatile suspended solid) in reactor mg/L.

$$\text{Quantity of sludge wasted (mg/mg)}, Y_{obs} = Y/(1 + k_d \cdot \theta c) \tag{3}$$

$$\text{Mean cell residence time}, \theta c = (V \cdot X)/(Q_W X_r + (Q_O - Q_W) X_e \tag{4}$$

V—Volume of reactor; X—Reactor Biomass (mg/m^3); Q_w—Flow rate of liquid containing the biological cells to remove from the system; X_r—Microorganism concentration in returned sludge; Q_O— Flow rate of liquid form SST; X_e—Microorganism concentration in effluent from solid separation unit.

$$\text{Volumetric loading rate} \left(\text{kg BOD}/\text{m}^{3*}\text{d}\right), (\text{VLR}) = Q \cdot So/V \tag{5}$$

$$\text{Recirculation ratio} = Q_r/Q = (X/X_r - X) \tag{6}$$

Q_R—Recycle rate; Q—Flow rate of wastewater; X—MLVSS in aeration tank; X_R—VSS concentration in return sludge.

$$\text{Solid loading rate (SLR)} = [(Q + Q_r) \cdot X]/A \tag{7}$$

Q—Influent flow rate m^3/day; Qr—Returned activated sludge flow rate m^3/day; X—MLSS concentration mg/L; A—Clarifier area m^2.

5 Results

The flow from the intake is collected in a sewage treatment plant according to Fig. 1. A performance of wastewater treatment plant observed was based on operational parameters and characteristics of effluent.

The discharge of wastewater in STP system was lower than the designed flow of 20 MLD (Fig. 2). The flow of wastewater from pumping into system ranged from 8 to 13 MLD. Similarly, HRT value observed during monitoring ranged between 1 and 1.6 days (25.25 to 38.81 h). Whereas HRT standard value varies within 4 to 6 h [11]. After observations, STP was having delay of discharging solids from the aeration system.

After analyzing discharge and characteristics of the effluent of wastewater in STP, volumetric loading (Eq. 5) for 7 weeks ranged between 0.098 and 0.169 kg BOD/m^3 (Fig. 3). During the sixth week, it raised to 1.4 kg BOD/m^3. Then, recycling ratio ranged between 1.24 and 0.64. VLR was comparatively good and maintained, but during a single week, it was heavily disturbed. The other parameter, recirculation ratio, is the microorganisms' mass entering in and exiting from the aeration tank. In addition, MLSS concentration is controlled in aeration tank by recirculation of sludge, sludge settling, and thickening in secondary sedimentation tank. The standard value for recirculation ratio is between 0.5 and 1.25 [12]. Similarly, recirculation ratio had great flux within 7 weeks; it ranged from 0.64 to 1.24, which was a little higher than required.

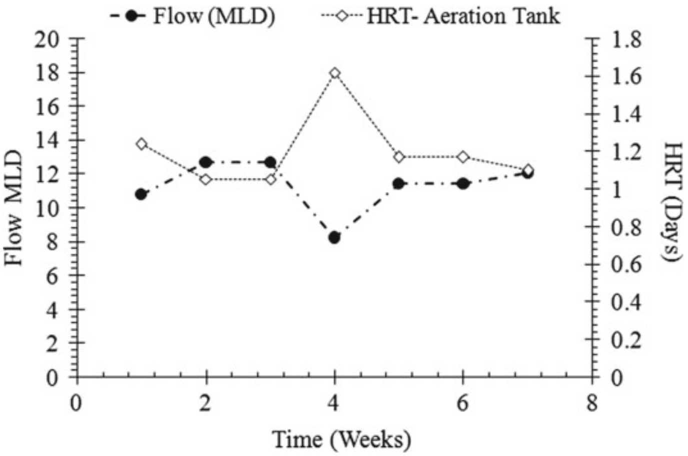
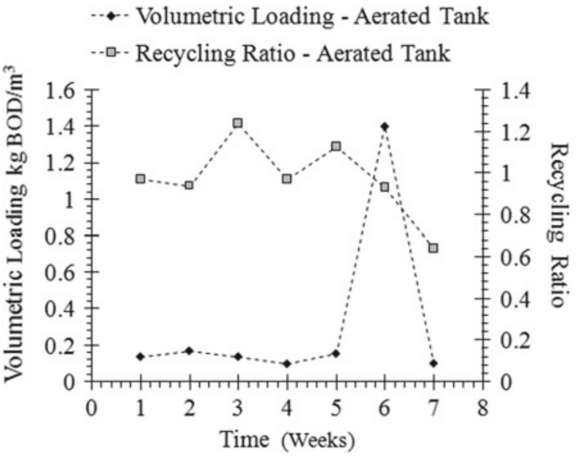


Fig. 2 Discharge into system and HRT of aeration tank

Fig. 3 Volumetric loading and recycling ration of aeration tank



From Fig. 4, inlet BOD_5 was a minimum of 111 mg/L and maximum to 181 mg/L within 7 weeks of observations. Similarly, suspended solids in the aeration tank ranged from 614 to 168 mg/L, showing no correlation in rise or fall in BOD_5. MLSS and MLVSS were having gradual flux, which ranged from 3000 to 5500 mg/L and 2900 to 3200 mg/L, respectively. MLVSS was observed lower compared to an extended type of aeration system [12]. Furthermore, suspended solids from returned sludge ranged from 7600 to 11500 mg/L, which indicate flux in the systems.

In Fig. 5, surface loading (Eq. 7) was in the range of 31–79 kg/m^2/Day and hydraulic loading ranged from 5.0 to 8.9 m^3/m^2/day. There was a little flux with hydraulic loading than the surface loading. Similarly, retention time ranged from 2

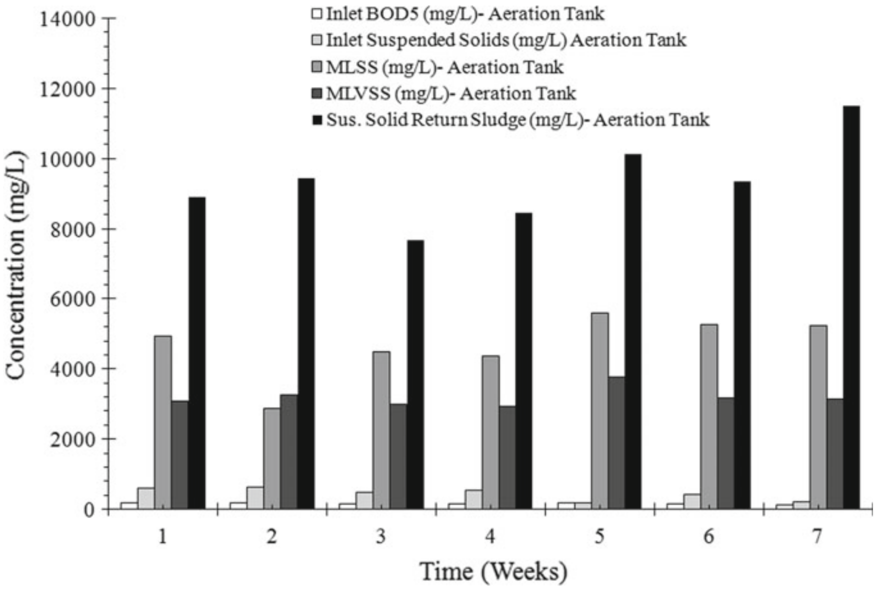


Fig. 4 Concentration of parameters tested for Aeration Tank

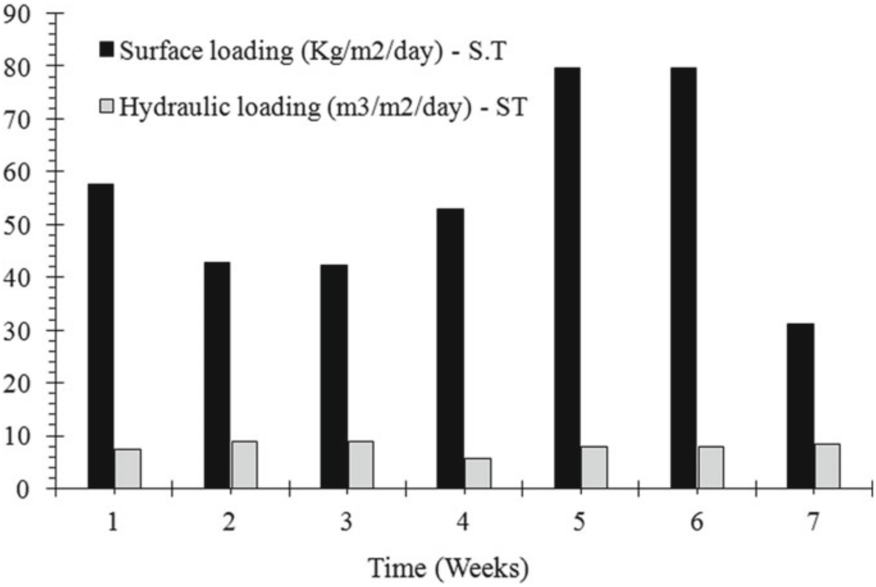


Fig. 5 Compares Surface loading rate and hydraulic loading rate of secondary clarifier

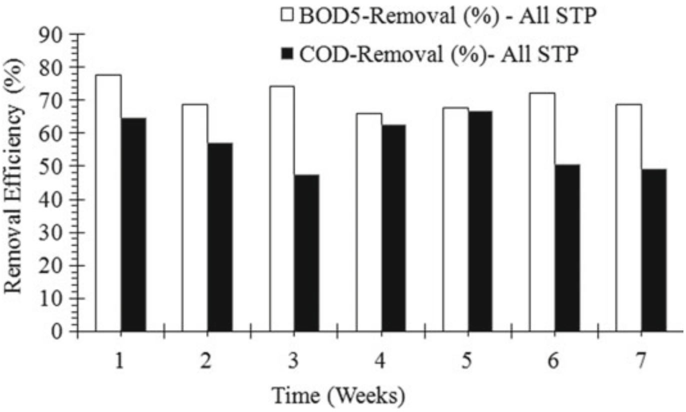


Fig. 6 Overall BOD_5 and COD removal of system

to 3 h. little higher retention time was noted for the third weeks, but not less than 2 for any remaining weeks. pH during treatment observed for inlet flow ranged between 6.5 and 7.0 and for the outlet, it ranged from 7.0 to 7.8. Similarly, alkalinity of the inlet wastewater ranged from 350 to 550 mg/L and for the outlet, it lowered in the range of 220–400 mg/L.

BOD_5 removal percentage ranged from a maximum of 77.74% to a minimum of 65.68%, whereas COD removal ranged between 47.52% and 66.66% (Fig. 6). Major flux in both BOD_5 and COD removal was observed in 7 weeks.

6 Discussion

Food to microorganism ratio (F/M) remains an important parameter to design and control the ASP [13]. The present activated sludge process is considered as an extended type of system. According to Indian conditions, $0.05 < F/M < 0.15$ of value is used for designing parameters. The range of F/M ratio was observed as 0.0326–0.0521 per day, which was comparatively less than the designed value (Eq. 1) [12]. Lower value than the designed leads to uneconomical operation and maintenance of the plant [14]. The existing return sludge quantity was varying in between 295.43 m^3/hr and 359.58 m^3/hr. However, based on F/M ratio, returned sludge was higher than the required discharge. This was required for maintaining appropriate amount of mixed liquor suspended solids (MLSS) [15]. According to the design, 13326 m^3 of aeration tank volume (Eq. 2) is provided. During process of ASP, it was observed that the actual volume accommodated was 1268 m^3 to 2800 m^3 only. Oxygen is introduced in ASP process for oxidizing organic matter in the influent. The BOD_5 of the influent was an average of 160 mg/L and at the outlet of the secondary clarifier $BOD_{5,}$ concentration was 51–55 mg/L. The oxygenation capacity of the surface area ranges between 1.2 and 2.4 kg/O_2/kWh for standard rate. While oxygenation of 903.75 kg/hr was supplied, assume a lower rate of 1.4 kg/O_2/HP*hr. The oxygen supplied to the aeration tank from five pumps was high. Sludge Volume Index parameter is used to measure settling characteristics of returned sludge. The SVI value typically is ranged to be effective between 50 and 150 ml/g [16]. During experimentation, SVI within the system ranged between 66 and 107 ml/g, indicating settling ability of the sludge. Moreover, solid loading rate represents one of the important characteristics. The solid loading ranged from 31.2 kg/m^2/d to 79.68 kg/m^2/d. Whereas recommended values were between 70 and 140 kg/m^2/d, which may be uneconomical [15]. Solid Retention Time (SRT) parameter describes a period where sludge remains in the system. SRT is responsible for nutrient removal depending on the period of retention such as 3–5 days [17]. The recirculation ratio is calculated (Eq. 6), considering microorganisms mass entering in and exiting from the aeration tank. The standard value for recirculation ratio is maintained up to 0.5; during experimentation value it ranged from 0.64 to 1.24, which was greater than required [18]. The hydraulic loading rate is an operational parameter, which is known as the overflow rate. Hydraulic loading of secondary clarifier was varying from 5.79 to 8.91 m^3/m^2/day. Whereas for better performance of secondary clarifier, hydraulic loading rate is limited to 16–32 m^3/m^2/day.

7 Findings and Recommendations

- Regular programmes should be organized on monitoring, surveillance of raw sewage, and effluent quality to implement appropriate, preventive, and corrective measures to achieve prescribed standard effluent.
- Hydraulic measurement units required maintenance and also are suggested with the replacement of gauges for proper measurements.
- The design of the plant is 20 MLD having maximum inflow, but 13 MLD discharge into STP was observed. Suggesting that the plant was underloaded, it affects the performance of the units. To improve the situation, more sewer needs to be connected to total 20 MLDs.
- The pumping system was intermittent; the pumping of sewage to STP was done after required quantity of sewage was collected in the receiving well. Therefore, pumps need to be replaced from 200 Hp to 100 HP to overcome the situation.
- The recirculation ratio ranged from 0.97 to 1.24, which was higher than 0.5 to 1.0. This increases MLSS concentration in the aeration tank requiring control.
- F/M ratio ranged from 0.0326 to 0.521/day which is comparatively lower than F/M ratio needed. Therefore, F/M should be maintained within 0.25–0.3/day. This is achieved by excess pumping of return sludge in the aeration in the tank.
- Variation in MLSS concentration was observed within the aeration tank. This indicated improper mixing of return sludge at the inlet to the aeration tank.

- Sludge removal from the secondary clarifier was varying at intervals and there was not constant for a period of 24 h. The delay in sludge removal leads to scoured suspension.
- The sludge from the secondary clarifier was removed by pumping; this creates a problem in setting of solids. It is recommended construction of a separate tank under gravity to handle disposal.
- O_2 requirement for the treatment was 160 kg/hr, where 703.75 kg/hr was supplied to the reactor, which was higher than designed.
- Frequent power failure and maintenance breakdowns too affect the performance of the treatment units.

8 Conclusions

STPs constructed to treat municipal wastewater require continuous monitoring and maintenance during the process. ASP is the most used technique and is required to run according to the designed operational parameters. From the above investigation, only 70.69% of BOD_5 and 56.61% of COD were removed from the overall system. In addition, excess aeration was a major problem-consuming energy and reducing efficiency of the system. This leads to emission of GHGs and uneconomical aspect of the plant. Operational parameter correction may lead to economical use of the system with increased efficiency of wastewater treatment.

References

1. Choksi, K.N., Sheth, M.A., Mehta, D.: To evaluate the performance of Sewage Treatment Plant: A case study. Int. Res. J. Eng. Tech. **2**, 1076–1080 (2015)
2. Chua, H., Yu, P.H.F., Sin, S.N., Tan, K.N.: Effect of food: microorganism ratio in activated sludge foam control. Appl. Biochem. Biotechnol. **84**, 1127–1135 (2000)
3. Dalzell, D.J.B., Alte, S., Aspichueta, E., de la Sota, A., Etxebarria, J., Gutierrez, M., Hoffmann, C.C., Sales, D., Obst, U., Christofi, N.: A comparison of five rapid direct toxicity assessment methods to determine toxicity of pollutants to activated sludge. Chemosphere **47**, 535–545 (2002)
4. Liu, X.C., Zhang, Y., Yang, M., Wang, Z.Y., Wen-zhou, L.V.: Analysis of bacterial community structures in two sewage treatment plants with different sludge properties and treatment performance by nested PCR-DGGE method. J. Environ. Sci. **19**, 60–66 (2007)
5. Sperling, M.V., Freire, V.H., De Lemos Chernicharo, C.A.: Performance evaluation of a UASB—activated sludge system treating municipal wastewater. Water Sci. Technol. **43**, 323–328 (2001)
6. Graveleau, L., Cotteux, E., Duchene, P.: Bulking and foaming in France: the 1999–2001 survey. Acta Hydrochim. Hydrobiol. **33**, 223–231 (2005)
7. Shijin, R.: Assessing wastewater toxicity to activated sludge: recent research and developments. Environ. Int. **30**, 1151–1164 (2004)

8. Imaia, A., Takehiko, F., Kazuo, M., Yong-H. K., Kwangsoon, C.: Characterization of dissolved organic matter in effluents from wastewater treatment plants. Water Res. **36**, 859–870 (2002)
9. Barberá, C.L., Crespo, A., Viverosb, P., Stegmaier, R.: A case study of GAMM (Graphical Analysis for Maintenance Management) applied to water pumps in a sewage treatment plant. Qual. Reliab. Eng. Int. **30**, 1473–1480 (2014)
10. Iluminada, C.M.: Standard Methods for Examination of Water and Wastewater. 22nd ed. 1360 pp. American Public Health Association, Washington (2012)
11. Muller, E.B., Stouthamer, A.H., Van Verseveld, H.W., Eikelboom, D.H.: Aerobic domestic waste water treatment in a pilot plant with complete sludge retention by cross-flow filtration. Water Res. **29**, 1179–1189 (1995)
12. Vera, I., Sáez, K., Vidal, G.: Performance of 14 full-scale sewage treatment plants: comparison between four aerobic technologies regarding effluent quality, sludge production and energy consumption. Environ. Technol. (2013). https://doi.org/10.1080/09593330.2013.765921
13. Mishoe, G.L.: F/M ratio and the operation of an activated sludge process. Fla. Water Res. J. **X**, 20–29 (1999)
14. Singh, T., Jain, S.: Removal of organics and metal ion nanoparticles from synthetic wastewater by activated sludge process (ASP). PeerJ. PrePrints. (2014). https://doi.org/10.7287/peerj.preprints
15. Guven, H., Ersahin, M.E., Dereli, R.K., Ozgun, H., Sancar, D., Ozturk, I.: Effect of hydraulic retention time on the performance of high-rate activated sludge system: a pilot-scale study. Water Air Soil Pollut. 228–417 (2017). https://doi.org/10.1007/s11270-017-3598-8
16. Hong, C., Peter, H.F., Shirley, N.S., Kok, N.T.: Effect of food: microorganism ratio in activated sludge foam control. Appl. Biochem. Biotechnol. **84–86**, 1127–1135 (2000)
17. Ge, H., Batstone, D.J., Mouiche, M., Hu, S., Keller, J.: Nutrient removal and energy recovery from high-rate activated sludge processes—impact of sludge age. Biores. Technol. **254**, 1155–1161 (2017)
18. Marcos, V.S.: Activated Sludge and Aerobic Biofilm Reactors, Biological Wastewater Treatment Series, vol. 5. IWA Publishing, New Delhi (2007)

Biomining: An Innovative and Practical Solution for Reclamation of Open Dumpsite

S. Mohan and Charles P. Joseph

Abstract Many of the developing nations practice open dumping as a final disposal method for municipal solid waste (MSW) generated. These dumpsites of MSW create the surface water pollution through the leachate discharge from the dumpsite, pollute the groundwater by leaching of heavy metals from the dumped solid waste over the years and also create air pollution in terms of release of CO_2, CH_4, thus contributing to climate change and other toxic gases. Thus, dumpsite becomes an eyesore and it is the need of the hour to find an alternate way of environmentally friendly disposal method of MSW. A feasible solution for the reclamation of these large sites is by biomining in which different groups of materials are extracted from the dumpsite and recycled or reused in a proper way thus resulting in the monetary value and resource flow. Biomining concept is a simple, innovative, economically feasible, practical, quick, and environmentally acceptable measure to remediate the old open dumpsite to achieve zero emission of landfill gases and leachate, and also reclaim the land reusability and zero maintenance. An integrated approach has been incorporated in which the stabilization part in biomining is carried out through bioreactor landfill treatment and then followed by biomining concepts. A conceptual framework for Biomining of the MSW dumpsite at Chennai has been developed and the implementation of the same in a site has been discussed. Also, a detailed framework for future management of open dumpsites has been developed and discussed.

Keywords Municipal solid waste · Open dumpsite · Biomining · Leachate · Sustainable environment

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1 Introduction

Open dumping is the common disposal practiced in most of the developing countries. The quantum of waste load generated is increasing day by day and is sent to the open dumping as an ultimate method for solid waste disposal. According to the Central Pollution Control Board 2012, the total quantum of waste generated in India is 127,486 tons per day (TPD) out of which a total amount of 89,334 TPD (70.07%) is collected and only 15,881 TPD is treated, which accounts to only 12.45% of the total quantum generated. The major problem associated is that in most of the Asian cities, open dumping is being carried out for the last 40–50 years and this had greatly expanded alarmingly, posing major havoc in the near future. Also, the groundwater and surface water have been greatly affected due to dumping practices carried out in the last few decades. Thus, it is the need of the hour for the reclamation of the existing open dumping grounds in many of the Asian cities. Biomining in combination with bioreactor landfill technology will be the most viable solution for the reclamation of the same. Biomining refers to the process of excavating the MSW and reclaiming the previously disposed material fractions like metals, glass, plastic, soil, fine materials, and other combustible materials [1]. The major factors which have contributed to the rising need of biomining concepts are reducing the greenhouse gas emissions, avoiding the surface water and groundwater contamination due to open dumps since it is unlined, reducing the footprint area of landfill, i.e., increasing land value and economic costs associated with it, rising energy demand, improving reuse and recycling concepts especially the variety of metals available which have a market value, and reducing the post-closure operation and maintenance costs.

Biomining concept was first implemented at Hiriya Landfill in 1953 by the Dan Region Authority, next to Tel Aviv, Israel. The waste contains many resources with high resource value and the most notable are the nonferrous metals such as aluminum cans and scrap metal. A study conducted by Zee et al. [2] revealed that the concentration of aluminum in many landfills is higher than the concentration of aluminum in its ore, i.e., from bauxite.

The most practiced or implemented method of waste management in developing and developed countries are landfill biomining [3–6] and this technology is reported in several Indian cities [7]. During 2002–03, the first biomining experiment was adopted at Panchavati in Nashik city, where a 28-acre site with an average 4–7 m depth of garbage was engulfed by expanding the existing facility. The old waste was cleared off in 120 days costing around 6.4 million rupees. To enhance the windrow composting process of old waste, composting bioculture was used at the rate of 250 g/m^3. Understanding the importance and proven benefits of the biomining process of reclaiming the old dumpsite/landfill, the Government of India is now considering funding for dumpsite bioremediation projects [7]. Landfill Biomining is the best approach for landfill reclamation since it is very important to address the contamination of groundwater posed by the old and new wastes, to increase the area of the existing facility for future expansion and to reduce the post-closure operational expenses.

1.1 Biomining Technology

Biomining (also referred to as landfill mining) refers to the process of digging out the previously dumped/disposed materials from a landfill (in our case open dumpsite) to recover metal, plastic, glass, combustibles, soil, and other fine materials [1]. It also refers to clearing the open dumpsites by segregating the prevailing waste into different constituents and converting the biodegradable portion into compost, methane gas or biodiesel and the remaining nonrecyclable plastic as refused derived fuels, which in turn can be used as an alternative fuel in industries. The compostable portion of the waste is removed through sieving and sold for use as soil enriches/fertilizers or for landscaping.

Landfill mining has been adopted at a number of landfill sites throughout the United States and is globally gaining interest [8–12]. The first step for landfill mining is the stabilization of the existing waste in the dumpsite. The mining of unstabilized or insufficiently decomposed wastes would result in an unacceptable generation of nuisances and will have a negative impact with regard to the health and safety of the people operating and also affects the ecosystem. The technology mainly targets to excavate the materials and process in such a way that the target materials can be separated from the excavated mass and further process to meet its required grade for any reuse or recycling operations. Generally, excavation is conducted using technologies used for open-cast mining, usually a front-end loader, a backhoe, a clamshell, a hydraulic excavator, or a combination of these. The excavated material may be directly processed in situ or will be stockpiled for later processing via different methodologies to segregate the components. Based on the extent of resource recovery, the quantum and number of streams of segregation of the excavated material varies. The process starts with the excavation of materials and the excavated materials are discharged into coarse screens and oversize, non-processible wastes are removed. The residual fraction is further sent to relatively smaller screens and the material fraction that passes through the second screen is considered as soil fraction. Further, to segregate the soil fraction from the excavated waste, an efficient unit process named trammel screen is widely used. In order to recover or retrieve the ferrous fraction in the composition, the remaining fraction is exposed to the magnetic field/force. After this, the nonferrous fraction is processed through an air classifier that separates the light organic materials from the heavy organics and commonly, this is used to recover waste-derived fuel (RDF). The processing at the landfill site is typically accomplished by means of equipment mounted on trailers, which usually consists of conveyor belts, a coarse screen, a fine screen, and a magnet. After the recovery of metals, plastics and combustible materials, the processing rejects and the inerts are disposed of as a backfilling material after ensuring the required geophysical properties.

1.2 Bioreactor Landfill Concept into Biomining Process

On average, 70% of solid waste generated throughout the South Asian region is a biodegradable organic mass with high moisture content [13]. Central Pollution Control Board (CPCB) in assistance with National Environmental Research Institute (NEERI) has conducted a survey of solid waste in 59 cities and found that the major fraction (40–60%) of the municipal solid waste is biodegradable [14], which provides an opportunity for composting or energy recovery processes. The excavated biodegradable fraction can be used as a potential resource for the bioreactor landfill technology. Energy conservation is a cornerstone of waste management. In most of the developing countries, the activities like open dumping have led to climatic change through Green House Gas (GHG) Emissions and other health-related impacts. A bioreactor landfill could be any permitted Subtitle D landfill or landfill cell where liquid or air is injected in a controlled fashion into the waste mass in order to accelerate or enhance biostabilization of the organic waste as defined by the Solid Waste Association of North America (SWANA). In order to recover the untapped energy from waste, an effective method of waste management which is environmentally and biologically sound has to be adopted and thus bioreactor landfill (BLF) comes into being.

Bioreactor landfill serves as a sustainable way of solid waste management and has the potential for recovery of methane (CH_4) and other resources. The leachate recirculation and the addition of other supplements into a landfill accelerate waste degradation and enhance gas production by stimulating the microbial activity. Several researchers performed small-scale laboratory tests, pilot-scale and full-scale investigations to study the effects of leachate recirculation in waste and noted the advantages of this concept [15–18]. These bioreactor landfills have several benefits over traditional landfills such as effective management of leachate generated, early waste stabilization, enhanced CH_4 production, and low post-closure monitoring costs. The biodegradation of municipal solid waste (MSW) is considered to be highly crucial as it greatly influences the other processes and in addition dictates the CH_4 production, the landfill settlement, and the stabilization time. BLF can serve in the potential extraction of metals from leachate by some selective adsorption techniques. Most of the developing countries have open dumpsites or uncontrolled dumpsites with no liners or gas collection system which poses an enormous health threat to the neighborhood by fetid, ground and surface water contamination and exacerbates the global climate change. The energy generated from BLF is biogas which in turn can be utilized for the production of electricity or heat or as a biofuel for automobiles or all of these.

The major constraints of the biomining process are as follows:

- During biomining process, methane will escape into the atmosphere resulting in odur problems, health risks, and air emissions. This can be captured by operating the existing dump as a bioreactor in the initial period and then after stabilization leaving it as the former condition.
- In uncontrolled dumpsites, the degradation process is not uniform, hence, recovery of fine fractions is not possible; recovery of fractions like plastics, wood, etc., will be very difficult and those recovered will be contaminated. So in order to remove the contaminated plastic and wood fraction, bioreactor landfill technology helps in removing the same and finally, the leachate has to be pumped out for treatment and the same has to be sent to the open dump and after stabilizing, we need to stop the entire process.
- Typical quantity reduction achievable is between 28 and 32% (based on the study undertaken at Gorai by MCGM in Mumbai). The large quantity of unprocessed biomining rejects will need an area within the site for disposal.

2 Case Study—Hyderabad City

The Municipal Solid Waste Composition of Hyderabad City is as follows (Fig. 1):

Steps carried out are:

- Loosening of waste for drying the material
- Transportation of waste to the trammel site

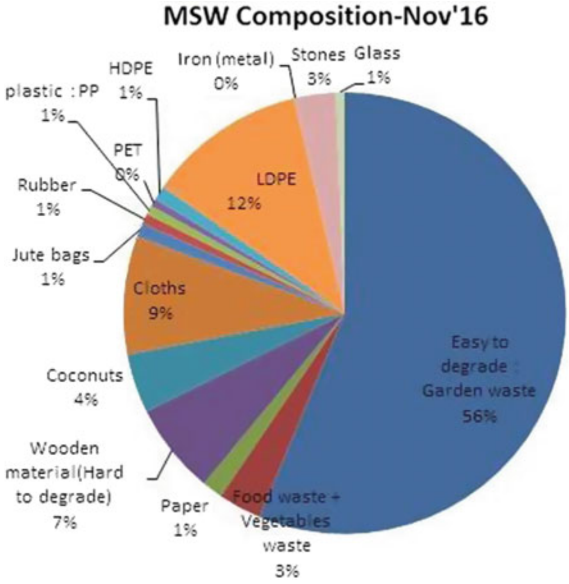

Fig. 1 Municipal solid waste composition in Hyderabad city (*Source* Ramky Enviro Engineers Ltd.)

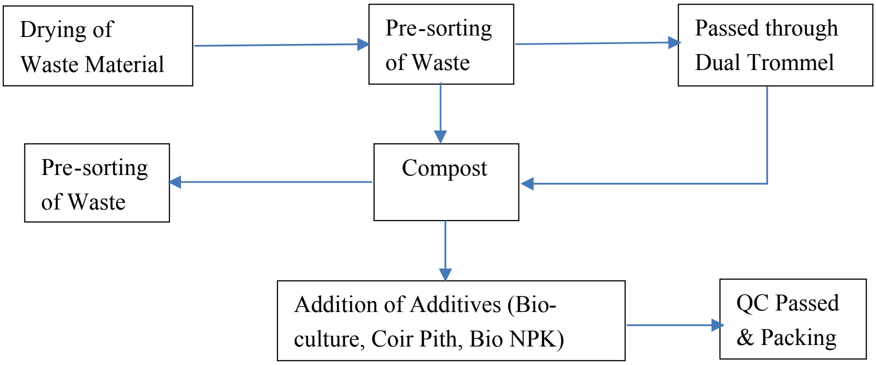

Fig. 2 Process flow diagram of the biomining process operational cost per ton

- Presorting of waste—Removing large size stones, tires, coconut shells, etc.
- Feeding the waste to the DUAL Trammel having sieve size of 35 mm and 3 mm
- Transportation of sieved material (compost) to the packing shed
- Mixing of the compost by adding additives—Bio culture, Rich soil, Coir pith, Tobacco, and Jaggery and maintaining 15 to 25% of moisture
- Before packing, the material should pass the Fertilizer Control Order (FCO) specification
- After passing Quality Control, material is weighed, packed and sent to the market (Fig. 2, Table 1).

Table 1 Operational Cost of Biomining (*Source* Ramky Enviro Engineers Ltd.)

REQUIRE MACHINERY/EQUIPMENT	UNIT COST	QTY.	TOTAL COST		
25 TPD Capacity of Trammel	500000	1	500000		
SHED	1500	1250	1875000		
EXCAVATOR	1300	20	26000	26000	
TIPPER	100	20	2000	2000	
JCB	550	20	11000	11000	
OPERATOR	15000	1	15000	500	
POWER	10	400	4000	150	
			1YR	DAY 39650	
		TRAMMEL	100000	273.9726	
		SHED	187500	513.6986	
		COMPOST	500	40437.67	
			50	808.7534	PER TON

3 Case Study—Kumbakonam Model

The dump yard was an eyesore with no place left to dump the future MSW. The average height of the heaps was 7 m from the ground level. Out of the total area of 10.5 acres, around 7.5 acres of land was dumped indiscriminately with MSW and others being utilized as green cover and other utilities.

The municipality contacted Service Providers for understanding the solutions to clear their dump in the landfills. The Urban Local Body awarded the contract to Zigma Global Environ Solutions Pvt. Ltd. after considered two points: the quantity of the prevailing waste and time required to clear the entire dump yard. Zigma conducted a contour mapping survey before the presentation to assess the quantity of waste dumped. Zigma then assessed the time required to clear the entire dump yard. There was a Questions and Answers session specific to Kumbakonam Dump Yard, among Municipal Employees, Sanitary Inspectors, Pollution Control Board Representatives, and Municipal Health Officers, among others.

The plant is designed to segregate around 14 different aggregates enabling efficient and responsible disposal of all of them. The plant disposes of all its aggregates responsibly to the tune of 100%. The plant has achieved 0% rejects which means none of the aggregates is considered as rejects and dumped back into sanitary landfill [19].

The different ways that it has been used as resources are 17% for cement companies and power plants, 15% for pyrolysis plants, 6% for recyclers, 2% for reclaimers, 3% for recycling companies, 0.5% for steel plants, 5% for pipe-making companies, 6% for soil enricher to sugarcane farmers, and 6.5% consisting of wood cloth and other organic items are shredded and sold as refuse-derived fuel to cement companies and power plants.

Out of 131,250 m^3, more than 100,000 m^3 has been processed and aggregates successfully disposed of. Out of 7.5 acres dumped with garbage, more than 5 acres have been reclaimed. The ULB has built an RCC Compost Plant and a 70 MT per day MSW Processing plant in the 2 acres land reclaimed. As of now, the entire quantity is processed and the dump yard is a site to see.

4 Proposal for the Reclamation of Perungudi Open Dumpsite, Chennai

Chennai Corporation has two major dumping sites; Perungudi and Kodungaiyur located south and north of Chennai. These are open dumpsites, which stink and the surface water percolates through these waste dissolves or release harmful chemicals and heavy metals in the waste contributed to environmental pollution. Human health is very well affected when they consume the groundwater contaminated by heavy metals. Therefore, the bore wells and tube wells near the dumpsite threatens the lives of people living near it.

Perungudi dumpsite extends around 230 acres and the dumping has been carried out for the last 40 years. The average height of the MSW is 5–7 m and the total quantum of waste will be around 2.5 million metric tons. At first, the entire open dumpsite will be operated as anaerobic bioreactor landfill and after the stabilization; biomining concepts have to be incorporated. This, in turn, helps in energy recovery and less GHG emissions, less health hazards, and so on. The aerobic bio-reactor has to be operated in the following method:

a. The entire area has to lessen for reducing the horizontal area. This is in order to reduce the plan area because we have to provide a final covering over the dumpsite. The entire area has to be reduced to lessen the horizontal area of final covering over the dumpsite. Soil parameters like bearing strength, safe bearing capacity, etc., and landfill stability parameters like slope stability, density, etc., have to be ensured while doing so.
b. After this, we have to encapsulate the entire area by providing sheet piles until a hard stratum which does not allow the leachate within the encapsulated zone to move out. The geology of the location has to be studied for determining the depth of the sheet piles.
c. Then the water level inside the encapsulated zone is kept below the water level just outside the encapsulated zone thereby creating a gradient toward the landfill (encapsulated zone). This is to ensure that no water/leachate moves out of the encapsulated zone. This can be achieved by pumping the water/leachate inside the encapsulate zone; for this, there are existing leachate drains from which the leachate can be pumped. This leachate pumped out has to be treated and a part can be sent back for recirculation and some part can be sent to the marshland. The treatment plant can be set next to the dumpsite since there is already a wastewater treatment near it, but for the treatment of leachate, separate treatment methods have to be adopted.
d. For the degradation of different organic and inorganic compounds, oxidation has to be provided. This can be achieved by two different processes: one is by purging the air into the top layers of the landfill. Second is by oxidizing using hydrogen peroxide (H_2O_2) because, at the bottom layers of the landfill where it is saturated by leachate, the air addition will not be having enough pressure to move through the saturated zone and also the oxidation efficiency would be less (Fig. 3).

The quantification and monetization costs and benefits associated with the rehabilitation of a dumpsite in Chennai have been studied by Anna University, Chennai, Asian Institute of Technology and University of Kalmar [20]. The total quantity of waste mass has been analyzed totally and it is estimated to have 3.5 million tones with a density of 700 kg/m^3. About 50% of the waste mass accounts for soil fraction, 10% recyclables, and the remaining 40% requires landfilling. The disposal of residuals in a landfill with a height of 15 m will require about 17.3 ha of land and the remaining land of 82.7 ha could be reclaimed, of which at least 90% of it will be available for future landfilling applications. The project would cost 147

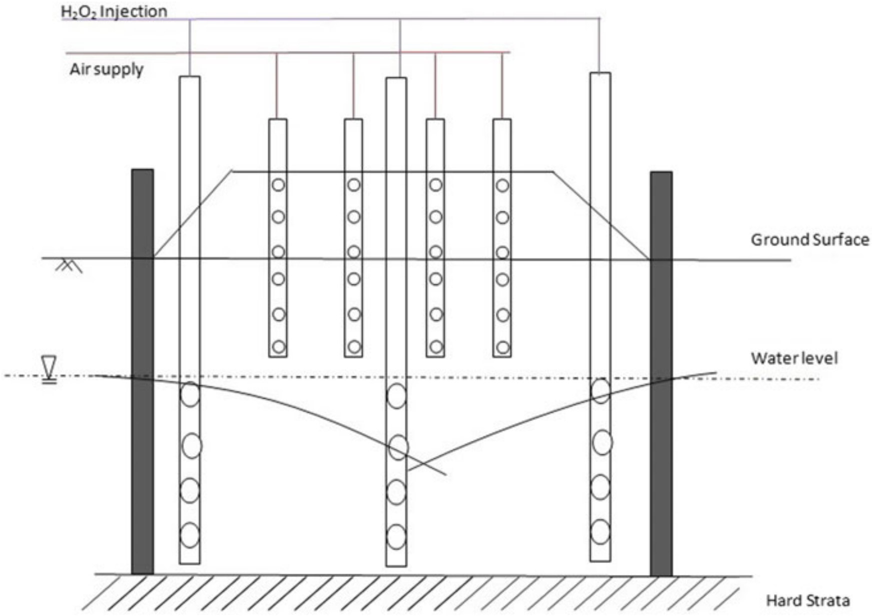

Fig. 3 A conceptual proposal for the remediation of an existing open dumpsite

million rupees as against a benefit of 162 million rupees resulting in a positive benefit to cost ratio of 1.1 and it is economical to take up the project for implementation.

5 Framework for Future Management of the Reclaimed Open Dump

After the reclamation of the open dumpsite, say 70% of the land can be reclaimed. This land has to be utilized in a proper manner for the future MSW practice within the city. A conceptual framework for the utilization of the reclaimed land is being discussed. The fresh unsegregated waste should be processed through a sequence of the process which will be a sustainable solution for MSW management. The incoming fraction of the waste is first spread in windrows with a maximum height of 2 m, where we are providing sufficient aeration for the partial degradation of waste. This is carried out on a concrete surface with channels for collecting the leachate generated from initial hydrolysis. After this, the waste is sent through a conveyer belt where form one side, the hot air is blown to remove the lightweight plastics, paper, and other light materials. Further on the conveyor, the material remaining is then exposed to the magnet to recover the ferrous metals and finally, the remaining is sent to the bioreactor landfill, where energy and compost can be

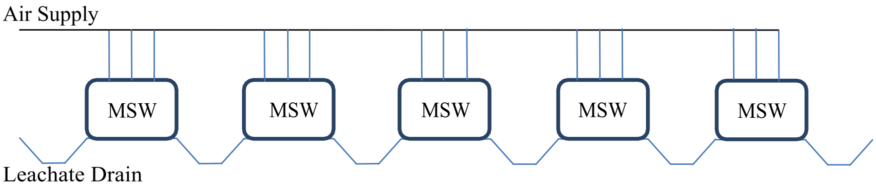

Fig. 4 Windrow operation of MSW in concreted/lined surface with leachate collection system

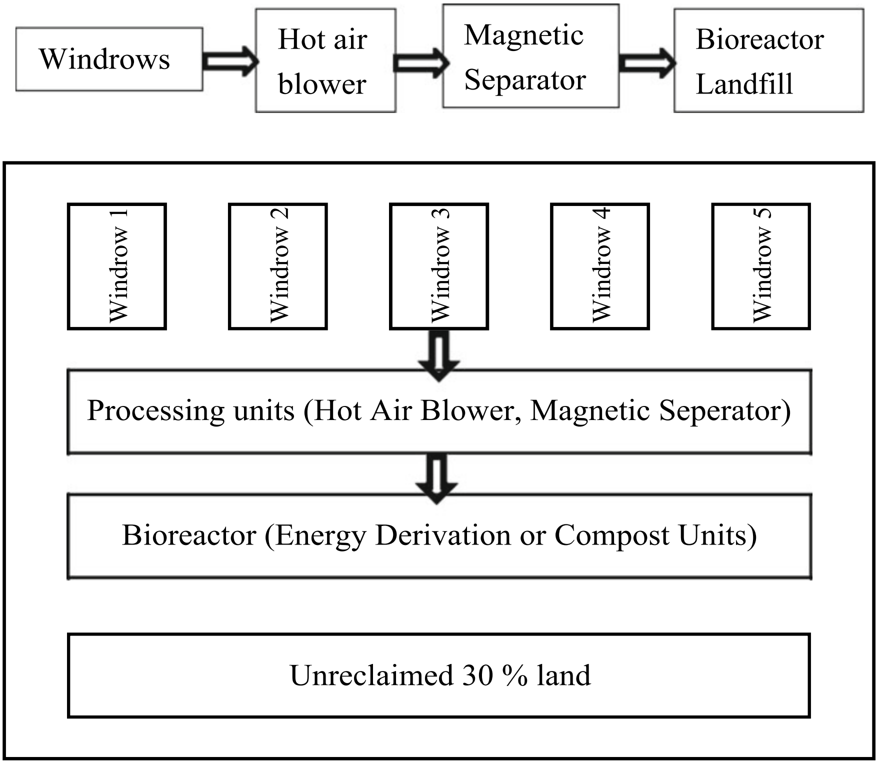

Fig. 5 Framework for future management of reclaimed open dump

produced, thus finding an economic benefit from the waste. The pictorial representation for the same is also shown below (Figs. 4 and 5).

Alternatively, if the waste is segregated at the source into biodegradable and nonbiodegradable; the process can be bypassed and the biodegradable fraction can be directly sent to the bioreactor facility and the nonbiodegradable fraction can be further segregated to different components.

6 Conclusions

Biomining will provide for exhumation that will not only reclaim landfill space but will definitely provide an opportunity to remediate existing public health and environmental quality problems associated with the existing or closed open dumpsite that would otherwise not be addressed until serious surface water or groundwater contamination is broadcasted. Further, it also emphasizes the regulatory bodies for ensuring a proper lining system and design at the bio-mined site so that future processing and MSW activities are undertaken at a manageable risk to the surrounding environs and public health. Biomining and bioreactor concepts have to be adopted in the reclamation of the old dumpsites in most of the Asian cities. We also have to take care of the reclaimed land and adapt facilities for further future management of MSW.

References

1. Morelli, J.: Landfill reuse strategies. Biocycle (April), 60–61 (1990)
2. Zee, D.J., et al.: Assessing the market opportunities of landfill mining. Waste Manag. **24**(8), 795–804 (2004)
3. Murphy, R.J.: Optimization of Landfill Mining. Dept. of Civil Engineering & Mechanics, University of South Florida, Tampa, FL, 33620 (1993)
4. Nelson, H.: Landfill reclamation project on the rise. Biocycle **36**(3), 83–84 (1995)
5. Forster, G.A.: Assessment of Landfill Reclamation and the Effects of Age on the Combustion of Recovered MSW. Municipal Solid Waste Management, Forester Communications Inc., March/April (2001)
6. Hull, R.M., Krogmann, U., Storm, P.F.: Characterization of municipal solid waste reclaimed from a landfill. Proceedings of Eighth International Waste Management and Landfill Symposium, Cagliari, Italy, October, pp. 567–576 (2001)
7. Almitra Patel: Bio-Remediation of old landfills. Proceedings of the International Conference on Sustainable Solid Waste Management, Chennai, India, 5–7 September (2007)
8. Murphy, R.J., Stessel, R.I.: Optimization of landfill mining: interim final report- phase I. Center for Solid and Hazardous Waste Management, Gainesville, FL (1991)
9. NYSERDA: Town of Edinburg landfill reclamation demonstration project. Final report prepared for the New York State Research and Development Authority (1992)
10. US EPA: Landfill reclamation. EPA530-F-97-001 (5305 W), Office of Solid Waste and Emergency Response, Washington, DC (1997)
11. Serpa, L.: Peer-reviewed feature Clovis landfill reclamation project. MSW Manage. (May–June) (2008)
12. Jones, P., Geysen, D., Tielemans, Y., Steven, V., Pontikes, Y., Blanpain, B., Quaghebeur, M., Hoekstra, N.: Enhanced landfill mining in view of multiple resource recovery: a critical review. J. Cleaner Prod. (2012)
13. Government of Australia, AID Programme (2012)
14. Gupta, N., Yadav K., Kumar V.: A review of the current status of municipal solid waste management in India. J. Earth Sci. (2015)
15. Reinhart, D.R., Al-Yousfi, B.A.: The impact of leachate recirculation on municipal solid waste landfill operating characteristics. Waste Manage. Res. **14**, 337–346 (1996)

16. Šan, I., Onay, T.T.: Impact of various leachate recirculation regimes on municipal solid waste degradation. J. Hazard. Mater. **87**, 259–271 (2001)
17. Benbelkacem, H., Bayard, R., Abdelhay, A., Zhang, Y., Gourdon, R.: Effect of leachate injection modes on municipal solid waste degradation in an anaerobic bioreactor. Biores. Technol. **101**, 5206–5212 (2010)
18. Kadambala, R., Powell, J., Singh, K., Townsend, T.G.: Evaluation of a buried vertical well leachate recirculation system for municipal solid waste landfills. Waste Manage. Res. **34**, 1300–1306 (2016)
19. Erstwhile dump yard in Kumbakonam now appears like a football ground. Times of India. June 6, 2018. http://timesofindia.indiatimes.com/articleshow/64479510.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst
20. Kurian, J., Visvanathan, C., William, H.: Dumpsite rehabilitation manual. Research programme on sustainable solid waste landfill management in Asia

The Influence of Ground-Granulated Blast-Furnace Slag on Geotechnical Properties of Jarosite Waste

Chayan Gupta and Arun Prasad

Abstract The rapid growth of industrial development sources the insufficiency of valuable land. Accordingly, it is the vibrant necessity to encourage the Research and Development works to attain ecological, financial, and societal benefits from colossal exploitation of their waste for worldwide benefits. The present work encourages the impact of pozzolanic waste material, i.e., ground-granulated blast-furnace slag (GGBS) in geotechnical characteristics of jarosite waste (zinc industries residual). The strength tests (unconfined compressive (UCS) and indirect tensile strength) were conducted on GGBS stabilized jarosite mixtures (GGBS, 10–30%) with different curing periods such as 7 days, 28 days, and 90 days. The outcomes illustrate that strength properties, increase by increase in GGBS percentage as well as curing periods. This strength improvement behavior of stabilized jarosite is also detected from the microstructural study (SEM), in which, denser agglomeration of GGBS stabilized jarosite particles, proves strength advancement. The durability studies (freeze–thaw (F-T)) of jarosite–GGBS mixtures were performed and it was observed that the loss in the UCS after five sequential F-T phases improved from 61.8% (raw jarosite waste) to 36.89, 26.60 and 17.12% with 10, 20, and 30% GGBS content, curing at 28 days period, respectively. The leachate study of jarosite indicates that jarosite contains hazardous constitutes, which were immobilized after stabilization with GGBS. From this study, it may be summarized that mixing of pozzolanic admixtures (GGBS) along with raw jarosite waste lead to a substantial enhancement in geotechnical properties with economic, social as well as environmental concern.

Keywords Jarosite waste · GGBS · Strength · Durability · Leachate · Microstructural · Cost estimation

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1 Introduction

Presently, industrialization advancement is a symbol of any developing country that tracks the way to becoming a developed country. However, advancement in the industrialization produces the significant level of waste and derivatives. Usually, the wastes can be categorized as solid, liquid, radioactive, and e-waste and it can also be categorized as hazardous or non-hazardous contingent on the basis of their production source. Globally, the total wastes are generated about 20 billion tons, in which 60% are produced from industrial evolution, 20% generated as municipal solid wastes, and residual 20% produced as organic and inorganic waste [1]. The land disposal technique is one of the broadly accepted traditional approaches for the disposal of such wastes. However, due to huge production of wastes, the necessity of supplementary precious land is raised. Thus the land scarcity arises. Today, this land scarcity problem is easily solved by adopting waste management techniques. The waste management technique mainly consists of, controlled production of waste; reduce, reclaim, reuse, and recycling (4-R) the waste; and reclamation of energy and also sustainable disposal of waste. In the previous few decades, for the enchantment in the waste management/utilization, the various industrial wastes such as stone slurry residuals, coal combustions residues, rice husk ash, phosphogypsum, metals slag, blast-furnace slag, cement kiln dust, bagasse ash, waste steel chips, ceramic dust, brick dust, and many more, have been profitably used as a stabilizing agents, with or without the addition of small percentage of cementing agents such as cement, hydrated lime etc. [2–6].

Jarosite is a waste by-product of zinc smelters and is produced during metal extraction processes. Worldwide, a huge amount of jarosite waste produces annually, in which around 0.25 million tons jarosite is produced in India and about and 0.60 million tons in European Union, respectively [2]. Chemically, it is acidic and contains mobilize toxic elements, thus from safety and environmental concern, disposal of jarosite residues is a universal issue [7]. For enhancing the opportunity to reduce, reclaim, reuse, and recycle (4-R) jarosite waste, numerous works done have been accomplished in the recent past. The works reported by Mymrin et al. [8, 9], concluded the chances for producing a new material from blends of jarosite along with dumped ferrous slag, aluminum surface cleaning waste, and the small addition of lime or Portland cement. These obtained blends produce a solidified material which possesses significant strength and water resistance. Chen and Dutrizac [10] advocated the morphological study of jarofix material (resulting from blending of jarosite along with 1% lime and 10% ordinary Portland cement) and observed that the stability of jarofix was directly depended upon the percentage combination of jarosite and Portland cement. Katsioti et al. [11] reported the opportunity to use jarosite as a substitute for gypsum content used in the production of cement. Asokan et al. [1, 2, 12, 13] advocated numerous studies on jarosite waste blends with different compositions of inorganic pozzolanic wastes such as coal combustion residues, and stone slurry residues and reported that hazardous jarosite could be detoxified by making immobilized products.

Sinha et al. [14] described the relative study of jarofix blends with different compositions of bottom ash and local clay and reported the utilization potential of these blends in the field of civil engineering. Similarly, numerous investigators have reported their work done for enhancing the possibilities of huge utilization of the waste materials in civil engineering applications [15–26].

In India, mainly two industries named as Hindustan Zinc Limited (HZL) and Binani Zinc limited have contributed to the production of zinc metal, among which HZL has the largest multi-unit of mining and smelting industry producing about 4 lac metric tons of jarosite waste annually [2, 18, 27]. On concerning environmental factors involves in the safe disposal practice of zinc by-products in HZL, the jarosite waste is mixed with 2% lime and 10% cement and carried to the disposal area as a stabilized and stable material named as jarofix. From the economic factor applied in the production cost of jarofix, the current study attempts to be the focus on the production of more economical, immobilized, and stable material. For this, the jarosite waste is blended with the pozzolanic activator such as ground-granulated blast-furnace slag (GGBS) (by-product of the iron industries) in different proportions to produce a more stabilized, stable, and economical material, which to be used as construction materials in various civil engineering applications.

2 Scope and Objectives

In this work, the author attempts to evaluate the opportunities to reduce, reclaim, reuse, and recycle (4-R) the jarosite waste as well as enrich the opportunity to huge utilization of jarosite waste in the field of civil engineering. In order to find out the feasibility of GGBS stabilized jarosite waste, the various properties were investigated. The main objectives of the study are as follows:

- Evaluate of index properties of jarosite waste such as consistency indexes, specific gravity, and grain size distribution (hydrometer analysis).
- Study the effect of various GGBS content on compaction characteristics (maximum dry density (MDD) and optimum moisture content (OMC)) and examine that the GGBS blend which gives maximum MDD is taken as an optimum blend.
- Study the strength properties (unconfined compressive and split tensile strength) of GGBS-stabilized jarosite waste with the inclusion of the effect of curing times (7, 28, and 90 days).
- Perform morphological studies (SEM).
- Evaluate the durability characteristics (freeze–thaw).
- Evaluate the leachate characteristics.

Thus, the main objectives of the study focused on exploring and evaluating the practical as well as economical ways for safe utilization of hazardous jarosite waste.

3 Materials

3.1 Jarosite

Jarosite is a waste by-product of zinc smelters and produced during zinc metal extraction processes in which, primarily the zinc ore (which contains about 50% zinc) is roasted at temperature 900 °C and afterward send for the leaching process, where jarosite (iron residual) is produced in the form of a waste [8, 9, 28, 29].

In the present study, jarosite is found from the local zinc industry (Hindustan Zinc Limited, Udaipur, Rajasthan (India)). The jarosite found is yellowish in color (Fig. 1a). The grain size distribution test of jarosite was tested, as mentioned in ASTM D6913-04 (sieve analysis) and ASTM D422-63 (hydrometer analysis) [30, 31], in the laboratory and presented in Fig. 2. As per ASTM D2487-11 [32] (soil classification), jarosite is categorized as silt with high plasticity (MH) fine grained material. The physical characteristics and chemical compositions of jarosite and GGBS are tabulated in Tables 1 and 2, respectively.

3.2 Ground-Granulated Blast-Furnace Slag (GGBS)

GGBS is an iron-manufacturing derivative, generated when iron ore, limestone, and raw coke are blended with each other and then roasted up to 1500 °C in a blast furnace. Afterward, due to the application of heating, the blend is melted and converted into two products such as melted iron and melted slag. The melted slag has a very low specific gravity as compared to the melted iron, thereby floating on

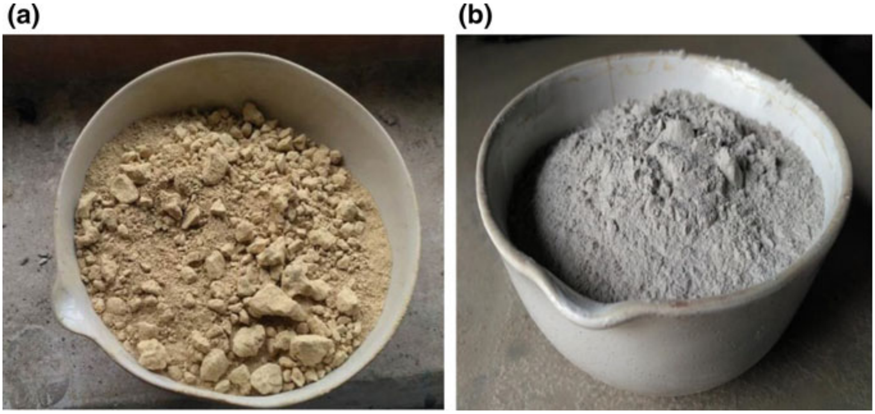


Fig. 1 A picture of raw materials: (**a**) Jarosite; (**b**) GGBS

Fig. 2 Grain size distribution chart of jarosite and GGBS

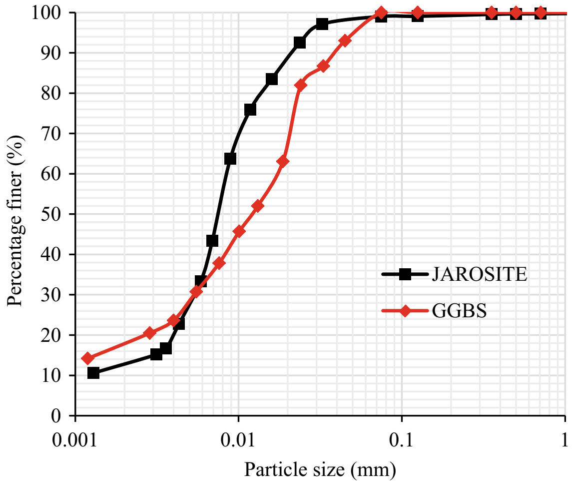


Table 1 Physical properties of jarosite and GGBS

Properties	Values	
	Jarosite	GGBS
Liquid limit (%)	53.78	36
Plastic limit (%)	31.48	NP
Plasticity index (%)	22.30	NP
Specific gravity	2.77	2.74
Specific surface area (cm^2/g)	10,496	4200
Silt (%)	85.42	80
Clay (%)	14.58	20
MDD (Mg/m^3)	1.13	1.38
OMC (%)	42.16	21.44
Hydraulic conductivity (cm/s)	1.76×10^{-3}	–
Texture	Clayey silt	Clayey silt
pH	6.88	9.86
Differential free swell Index (%)	18.21	–

the topmost surface, from where it is extracted easily. As the whole process of slag extraction is continued in a blast furnace, it is designated as blast-furnace slag and its granulated residue is designated as GGBS.

Typically the GGBS contains the silicates of Aluminum and calcium [33, 34]. In the present work, the GGBS (specific gravity of 2.74) is found locally from Krishna Udyog, Burdwan, India (Fig. 1b). The particle size distribution of GGBS and its chemical composition is presented in Fig. 2 and Table 2, respectively.

Table 2 Chemical compositions of jarosite and GGBS

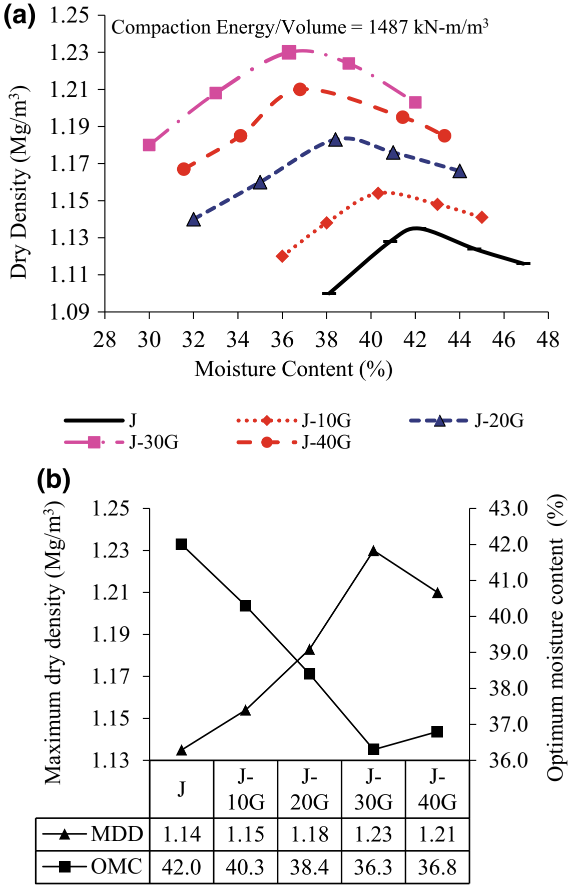
Chemical composition	Value (%)	
	Raw jarosite	GGBS
Silica (SiO_2)	7.73	34.17
Alumina (Al_2O_3)	8.98	18.36
Calcium oxide (CaO)	4.92	33.78
Iron oxide (Fe_2O_3)	32.11	0.80
Potassium oxide (K_2O)	0.76	–
Magnesium oxide (MgO)	1.08	8.82
Zinc oxide (ZnO)	9.07	–
Total sulfer (SO_3)	31.80	2.91
Lead oxide (PbO)	1.91	–
Sodium oxide (Na_2O)	0.63	–
Loss on ignition	1.01	1.16

4 Results and Discussions

4.1 Effect of GGBS on Compaction Characteristics

For conducting the compaction test, The Mini Compaction Mold (developed by Sridharan et al. [35] and permitted by ASTM D698-12e1) is used. Primarily, the compaction parameters (optimum moisture content (OMC) and maximum dry density (MDD)) of jarosite blended with varying percentages of GGBS (10, 20, 30, and 40%) were determined and presented in Fig. 3a.

It was examined from the results that the raw jarosite had 1.13 Mg/m^3 and 42% of MDD and OMC, respectively. Afterward, the addition of GGBS affects these parameters. With increase in the GGBS content, the MDD of blends was increased up to 30% GGBS; beyond this (i.e., at GGBS content 40%), MDD reduces. This happened mainly due to the rearrangement of particles in the blends. Initially, the void pores between the jarosite particles were filled with the GGBS particles. Thus the structure of particles was varied from a flocculated to dispersed, and henceforth the MDD increases with GGBS (up to 30%). However, beyond the optimum limit of GGBS (i.e., 30%), the blend particles separated in the matrix. Thus the reduction in MDD occurred. Similarly, the OMC was decreased up to 30% of GGBS. It happened due to the less specific surface area and glassy nature of GGBS, requiring a lesser amount of moisture content to attain MDD. Afterward, the OMC was increased at 40% of GGBS, because the separation of particles enhanced the OMC. These variations in compaction parameters are presented in Fig. 3b.



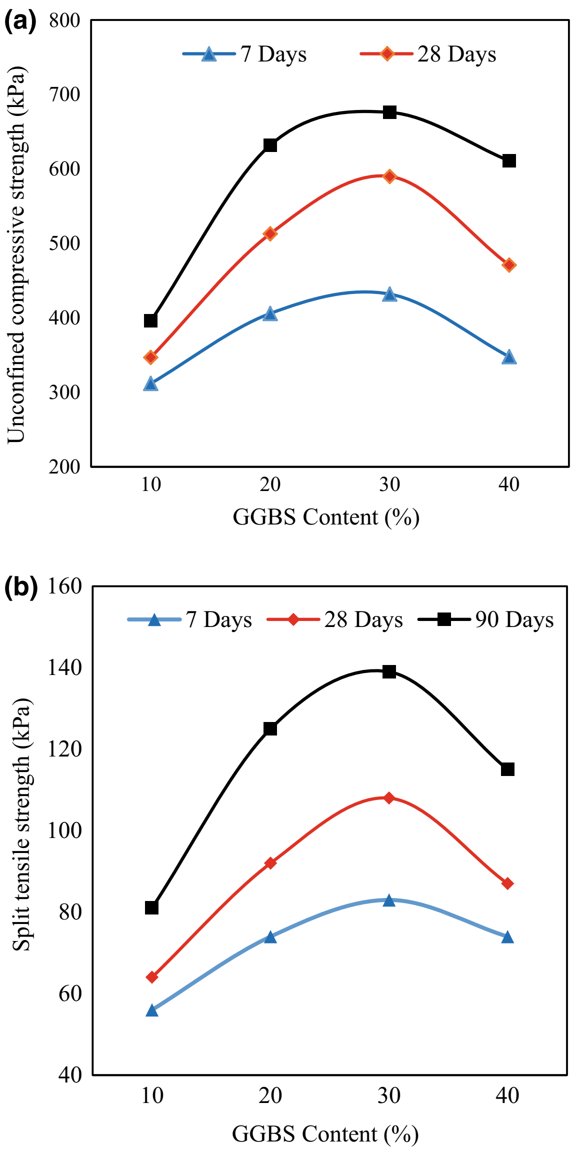
	J	J-10G	J-20G	J-30G	J-40G
▲ MDD	1.14	1.15	1.18	1.23	1.21
■ OMC	42.0	40.3	38.4	36.3	36.8

Fig. 3 Compaction characteristics of jarosite with GGBS: (**a**) Effect of GGBS on dry density and moisture content; (**b**) Variation of MDD and OMC with GGBS

4.2 Effect of GGBS on Strength Characteristics

The unconfined compressive strength (UCS) and split tensile strength test of stabilized jarosite–GGBS blends were conducted in a laboratory by ASTM D2166-06 and ASTM D-3967, respectively [37, 38]. The result of UCS and split tensile strength of jarosite–GGBS blends are presented in Fig. 4a. It was examined from the results that the UCS of jarosite comprising 30% GGBS was increased from 187 kPa (unstabilized jarosite) to 432, 590, and 676 kPa at various curing periods, i.e., 7, 28, and 90 days, respectively. Similarly, in Fig. 4b, it is clear that split tensile strength was increased from 96.32 kPa (unstabilized jarosite) to 83, 108, and 129 at various curing periods, i.e., 7, 28, and 90 days, respectively. After examining the strength test result, it was observed that the increase in both types of strength directly varied increase in the curing periods such as 7, 28, and 90 days.

Fig. 4 Effect of GGBS on strength characteristics with all curing periods: (**a**) UCS, (**b**) split tensile strength



This happened because of the pozzolanic material (GGBS) having time-dependent self-hardening characteristics [34].

It is interesting to note that, after the addition of GGBS content for more than 30%, the segregation of particles happened (MDD reduces), which causes a reduction in both types of strength values. Thus the freeze–thaw study was limited up to 30% jarosite–GGBS blends and GGBS contents up to 30% were considered as a boundary of jarosite–GGBS blends.

4.3 Effect of GGBS on Durability

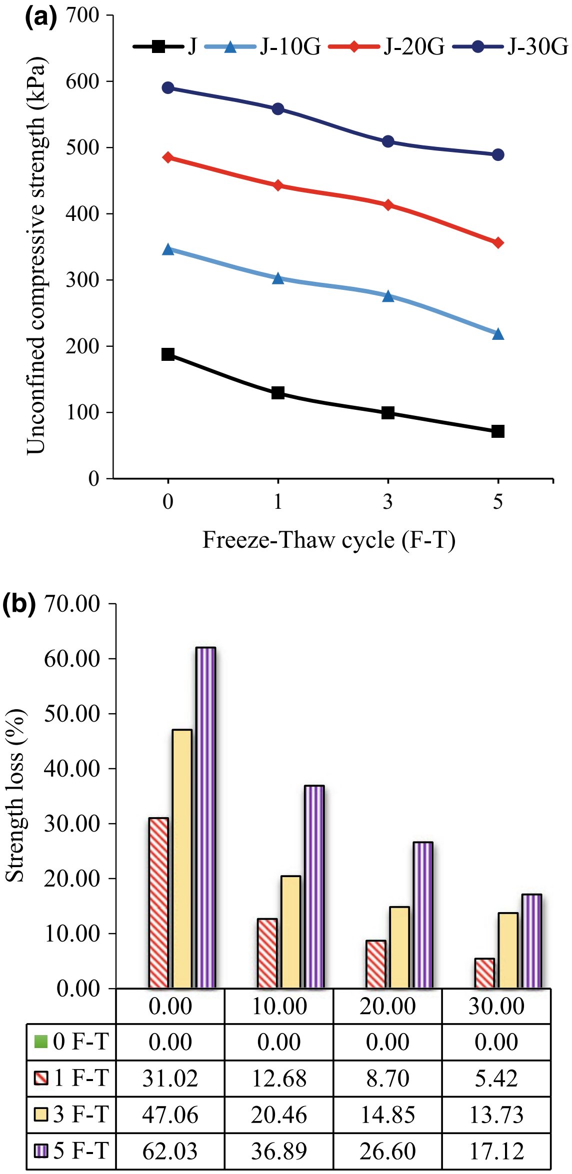
The durability of stabilized jarosite mixtures was examined by performing a freeze–thaw study by ASTM D560 M-15 [36]. In this study, a sealed-system form of freezing was exposed to the mixtures. Also, throughout the study, moisture is inexistent excluding the present at the start in the voids. After the particular curing cycle, the samples experienced alternate freeze–thaw by placing them in a refrigerator at −18 ± 2 °C and openly at room temperature (23 ± 5 °C) for 1 day, respectively. This temperature slots for complete freeze and thaw were designated by following some preceding studies [39, 40], which conclude that if the temperature in the vessel closed to 0 °C, chances of fractional freeze or perhaps no freeze occurs; thus to achieve comprehensive freezing, −18 ± 2 °C temperature for 1 day was desired. In the same way, to accomplish complete thawing, 23 ± 5 °C temperature for 1 day was maintained. Each jarosite–GGBS blend were endangered to continuously zero, one, three, and five freeze–thaw (F-T) cycles. The numeral of successions was selected as per the existing literature works [41–43], which publicized that the lack in the strength typically happens majorly in a few cycles, i.e., up to five cycles.

After the accomplishment of alternative freeze and thaw series, the blends mold were checked for Unconfined Compressive Strength test. The results of the influence of freeze and thaw on the Unconfined Compressive Strength of raw jarosite and treated jarosite–GGBS blends are shown in Fig. 5a, b, correspondingly. It is revealed from Fig. 5 that the blending of GGBS noticeably improves the freeze and thaw resilience resistance as associated with raw jarosite. For example, after five freeze–thaw alternate series, the reduction in UCS values got improved from 62% (natural jarosite waste) to 36.89, 26.60, and 17.12% with 10, 20, and 30% GGBS content, curing at 28 days period respectively.

4.4 Effect of GGBS on Microstructure Study

The fresh samples of the jarosite–GGBS optimum blend (i.e., 30% GGBS) were further studied for their morphological modifications using a scanning electron microscope (SEM). It was examined from the results that by the blending of GGBS, denser packing of particles or agglomeration of particles was achieved as compared to untreated jarosite. This denser packing was achieved due to the pozzolanic reaction of free aluminous and silicious components existing in jarosite by calcium component found in GGBS, which leads to producing cementing gels such as calcium silicate hydrate [C-S-H] and calcium aluminate hydrate [C-A-H]. Similar outcomes have been advocated by many researchers [44–46]. The agglomeration or densification in particles is presented in Fig. 6. Figure 6a, b shows a loosely packed (porous) jarosite and GGBS matrix (uncemented) respectively; Fig. 6c, d shows SEM image of optimum jarosite–GGBS blend (i.e., 30% GGBS content) at 28 days

Fig. 5 Effect of GGBS on durability characteristics with all curing periods: (**a**) UCS, (**b**) Strength loss



	0.00	10.00	20.00	30.00
🟩 0 F-T	0.00	0.00	0.00	0.00
▨ 1 F-T	31.02	12.68	8.70	5.42
🟨 3 F-T	47.06	20.46	14.85	13.73
▥ 5 F-T	62.03	36.89	26.60	17.12

curing period, with and without five freeze–thaw cycles. On comparing Fig. 6c, d, it is observed that some closed and dense matrix (some less agglomeration) are still produced after completion of five freeze–thaw cycles as compared to more closed and dense matrix jarosite–GGBS blends (without F-T cycle).

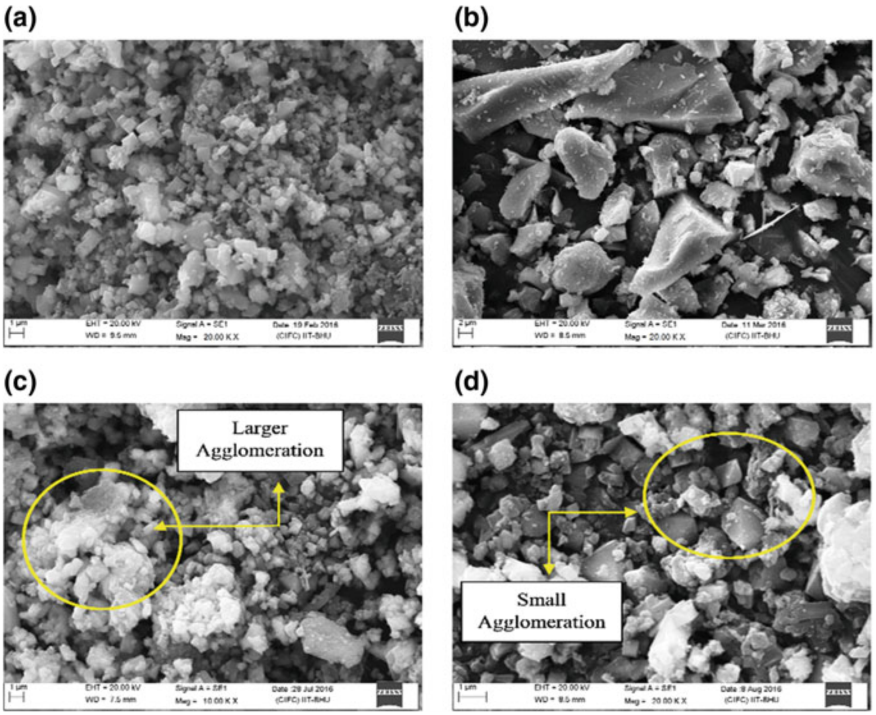


Fig. 6 SEM images (20,000 × magnification) of (**a**) Raw jarosite; (**b**) Raw GGBS; (**c**) Jarosite–GGBS blend (30% GGBS and 28 days curing); (**d**) Jarosite–GGBS blend (30% GGBS 28 days curing and five freeze–thaw cycles)

4.5 Effect of GGBS on Toxicity Leachate Potentials

For evaluation of the degree of hazardous nature of raw waste and its stabilized product, the United States Environmental Protection Agency (USEPA) Toxicity Leachate Characteristics Procedure (TCLP) [47] is widely adopted. In this procedure, the powdered sample of stabilized product is blended with a solution of acetic acid and 1 N NaOH as an extraction liquid (pH 4.93), with a liquid to solid weight ratio of 20:1, and then this solution is agitated in a rotary extractor for a period of 18 h at the speed of 30 RPM and 22 °C. After agitation, the solution is loaded into Zero Head Space Extractor (ZHE) and the extractor is airtight closed. To extract leachate fluid, the 50 psi pressure is applied through the extractor, and up to 50 ml of expelled fluid is collected. The collected fluid is screened through a filter paper having 0.6–0.8 μm filtering capacity. This filtrate fluid is distinct as a TCLP extract, and it is analyzed further for the evaluation of hazardous constituents such as Silver (Ag), Chromium (Cr), Cadmium (Cd), Lead (Pb), and Arsenic (As). In the current

Table 3 Leachate concentrations of heavy metals and toxic elements (TCLP extract)

Heavy metals	Concentration (ppm)		US-EPA limit [47]
	Raw jarosite	J-30G	
Ag	27.951	4.271	5.0
Cd	20.045	0.168	1.0
Cr	24.270	2.699	5.0
Pb	30.876	0.579	5.0
As	2.825	1.679	5.0

study, the Inductively coupled plasma (ICP) Spectrophotometer is used for evaluation of heavy metals and toxic elements. The analysis results of leachate samples are tabulated in Table 3.

From the results presented in Table 3; it is revealed that the leachate concentrations of Ag, Cd, Cr, Pb, and As in raw jarosite waste are 27.95, 20.04 ppm, 24.27 ppm, 30.88 ppm, and 2.82 ppm, respectively. All these leachate concentration ranges are higher in raw jarosite waste than that of the limiting in the USPEA-TCLP standard (Table 3). Therefore the jarosite waste is characterized as a hazardous waste.

Similarly, the leachate concentrations of Ag, Cd, Cr, Pb, and As in GGBS stabilized jarosite products are 4.27, 0.16 ppm, 2.70 ppm, 0.58 ppm, and 1.68 ppm, respectively. Comparing the limiting USEPA ranges of heavy metals concentrations with raw jarosite and GGBS stabilized jarosite waste blends, it was observed that stabilized jarosite was found to be within the permissible limits for exploitation in eco-friendly applications of civil engineering.

The reason for the immobilization of heavy metals that occurred in the presence of higher percentage GGBS content is due to the occurrence of more particle agglomeration, which produces the cemented bonds such as calcium silicate hydrate [C-S-H] and calcium aluminate hydrate [C-A-H] bonds (discussed earlier). Thus the heavy metals were trapped and immobilized along with these cemented bonds.

5 Cost Estimation

Traditionally, the jarosite waste is disposed of by its conversion into a more stable form, i.e., jarofix (jarosite–lime–cement blends). In this study, an attempt is made to equate the economic viability of GGBS-stabilized products with that of lime and cement stabilized products (jarofix). Construction rate of 1 cum of embankment is expected as illustrated in the Schedules of Rates of CPWD, Govt. of India [48] regarding the United State currency $. The cost in Indian currency is changed to the United State currency established on the current exchange rate (December 2017).

The above financial estimation (Table 4) advocates that the utilization of jarosite treated with 10, 20, and 30% GGBS can be reduced by up to 74.18, 73.56, and

Table 4 Estimation of embankment construction cost as per Analysis of Rates of Delhi (CPWD), India [48]

Particulars	Cost estimation ($) per cum of embankment			
	J-10% G	J-20% G	J-30% G	Jarofix
Material cost* *Jarosite and GGBS, both wastes are freely available at zinc and steel plants, respectively.	0	0	0	13.16
Hauling cost** (including uploading, unloading, and stacking) **Assume hauling distance of jarosite, GGBS, lime, and cement are 10, 30, 30, and 30 km, respectively.	2.64	2.75	2.90	2.70
Compaction cost (including filling, rolling/ramming, and watering)	1.96	1.96	1.96	1.96
Total cost($) Currency exchange rate: 1 INR = 0.016 US $	4.60	4.71	4.86	17.82

72.72%, respectively of the rate of making one cum embankment as equalled with lime and cement stabilized jarosite products (jarofix), which is conventionally used by industries of India in order to make jarosite stable.

6 Conclusions

In the universe, nothing is completely waste, whether it is above or below the earth’s surface. For saving the energy, economy, and environment, the potential reduces, reuse, and recycling of all types of wastes becomes a global environmental concern. Thus it is an urgent need to conduct extensive research and development work for optimizing the use of current technology and exploring novel applications for sustainable waste management with social and economic benefits. Stabilization of any waste is a process in which an additive/reagents is employed to reduce the toxic nature by changing its toxic constituents into a more stable form to diminish the contaminant migration rate thus reducing the level of toxicity. In this study, hazardous jarosite waste is treated with GGBS, and the stabilized product is suitable to be used in various applications in an eco-friendly manner. Based on this study, the following conclusions can be drawn:

- The addition of GGBS affects the compaction characteristics of jarosite waste. As the GGBS percentage increases up to 30%, the OMC of blends goes decreased, and the MDD goes increased. Afterward, further addition of GGBS causes a reduction in MDD and an increase in OMC.

- Both types of strength, i.e., unconfined compressive and split tensile strength increase considerably with an increase in the GGBS content and curing period.
- The addition of GGBS increases the durability of jarosite waste. The loss in both types of strength due to alternative F-T cycles decreases with increase in the GGBS content and curing periods. That means the stabilized product is more durable with a higher percentage of GGBS.
- The comparative financial estimation of treated jarosite revealed that GGBS-treated jarosite could be reduced up to 72.72% of the total construction cost of 1 cum embankment as compared to conventional jarosite stabilization (jarofix). Thus, jarosite–GGBS stabilization is a cheaper alternative to jarofix.
- Leachate study of jarosite and its stabilized product advocates that this product can be safely used in the various fields of civil engineering and is also eco-friendly.

References

1. Asokan, P., Saxena, M., Asolekar, S.R.: Waste to wealth-cross sector waste recycling opportunity and challenges. Can. J. Environ. Constr. Civ. Eng. **2**(3) (2011)
2. Asokan, P., Saxena, M., Asolekar, S.R.: Hazardous jarosite use in developing a non-hazardous product for engineering application. J. Hazard. Mater. **137**, 1589–1599 (2006)
3. Havanagi, V.G., Sinha, A.K., Arora, V.K., Mathur, S.: Waste materials for construction of road embankment and pavement layers. Int. J. Environ. Eng. Res. **1**(2), 51–59 (2012)
4. Gupta, C., Prasad, A.: Strength and durability of lime-treated jarosite waste exposed to freeze and thaw. J. Cold Regions Eng. **32**(1), 04017025 (2018a). https://doi.org/10.1061/(ASCE)CR.1943-5495.0000154
5. Gupta, C., Prasad, A.: A parametric strength study of jarosite waste. Proceedings of the Institution of Civil Engineers: Waste and Resource Management, vol. 170, issue 3+4, November 2017, pp. 149–161 (2018b). https://doi.org/10.1680/jwarm.17.00041
6. Gupta, C., Prasad, A.: Variables controlling strength of lime stabilized jarosite waste. Int. J. Geo-Eng. **9**(1) (2018c). https://doi.org/10.1186/s40703-018-0074-2
7. Kerolli-Mustafa, M., Ćurković, L., Fajković, H., Rončević, S.: Ecological risk assessment of jarosite waste disposal. Croat. Chem. Acta. **88**(2), 189–196 (2015)
8. Mymrin, V., Vaamonde, V.A.: New construction materials from Spanish jarosite processing wastes. Miner. Eng. **12**(11) (1999)
9. Mymrin, V.A., Ponte, H.A., Impinnisi, P.R.: Potential application of acid jarosite wastes as the main component of construction materials. Constr. Build. Mater. **19**, 141–146 (2004). https://doi.org/10.1016/j.cemconcomp.2006.12.005
10. Chen, T.T., Dutrizac, J.E.: A mineralogical study of jarosite products for the stabilization of jarosite residues for disposal. TMS, 917–933 (2000)
11. Katsioti, M., Boura, P., Tsakiridis, P.E., Agatzini, S., Oustadakis, P.: Use of jarosite/alunite precipitate as a substitute for gypsum in Portland cement. Cem. Concr. Compos. **27**, 3–9 (2005)
12. Asokan, P., Saxena, M., Asolekar, S.R.: Jarosite characteristics and its utilization potentials. J. Total Environ. **359**, 232–243 (2005)
13. Asokan, P., Saxena, M., Asolekar, S.R.: Recycling hazardous jarosite waste using coal combustion residues. Mater. Charact. **61**, 1342–1355 (2010)

14. Sinha, A.K., Havanagi, V.G., Ranjan, A., Mathur, S., Arora V.K.: Feasibility study of Jarofix waste material for road construction. Indian geotechnical conference, Kochi. Vol. 1, pp. 685–688 (2011)
15. Ding, M., Geusebroek, M., Sloot, H.A.: Self-sealing isolation and immobilization—a geochemical approach to solve the environmental problem of waste acidic jarosite. Appl. Geochem. **17**, 93–103 (2002)
16. Cheilas, A., Katsioti, M.: Impact of hardening conditions on to stabilized/solidified products of cement -sewage sludge -jarosite/alunite. Cem. Concr. Compos. **29**, 263–269 (2007)
17. Vyas, A.K.: Solidification-stabilization technique for metal bearing solid waste from zinc industry—a case study. Proceeding of International Conference on Environmental and Computer Science (IPCBEE). vol. 19, pp. 151–155. BS 5950-3 (2011)
18. Sinha, A.K., Havanagi, V.G., Arora, V.K., Mathur, S.: Design, construction and evaluation of jarofix embankment and sub grade layers. Int. J. Environ. Eng. Res. **1**(3), 97–103 (2012)
19. Sinha, A.K., Havanagi, V.G., Ranjan, A., Mathur, S.: Geotechnical characterization of jarosite waste material for road construction. Proceedings of Indian Geotechnical Conference, 22–24 (2013)
20. Arora, V., Sachdeva, S.N., Agrawal, P.: Effect of use of jarosite on workability and early age strength of concrete. Int. J. Comput. Math. Sci. (IJCMS) **4**, 136–144 (2015)
21. Makhatha, M.E., Ndou, M.O. Nheta, W.: Characterisation of jarosite, fly ash and clay for their possible usage in the construction industry. Proceedings of the World Congress on Mechanical, Chemical, and Material Engineering, Barcelona, Spain, 1–9 (2015)
22. Mehra, P., Chandra, R., Skariah, B.: Assessment of durability characteristics of cement concrete containing jarosite. J. Cleaner Prod. **119**, 59–65 (2016a). https://doi.org/10.1016/j.jclepro.2016.01.055
23. Mehra, P., Chandra, R., Skariah, B.: Properties of concrete containing jarosite as a partial substitute for fine aggregate. J. Cleaner Prod. **120**, 241–248 (2016b). https://doi.org/10.1016/j.jclepro.2016.01.015
24. Yadav, J., Tiwari, S.: Behaviour of cement stabilized treated coir fibre-reinforced clay-pond ash mixtures. J. Building Eng. **8**, 131–140 (2016)
25. Yadav, J., Tiwari, S.: Effect of waste rubber fibres on the geotechnical properties of clay stabilized with cement. Appl. Clay Sci. **149**, 97–110 (2017a)
26. Yadav, J., Tiwari, S.: A study on the potential utilization of crumb rubber in cement treated soft clay. J. Build. Eng. **9**, 177–191 (2017b)
27. Acharya, S., Anand, S., Das, R.P.: Iron rejection through jarosite precipitation during acid pressure leaching of zinc leach residue. Hydrometallurgy **31**, 101–110 (1992)
28. Singh, V.: Technological innovation in the zinc electrolyte purification process of a hydrometallurgical zinc plant through reduction in zinc dust consumption. Hydrometallurgy **40**, 247–262 (1996)
29. Hage, J.L.T., Schuiling, R.D.: Comparative column elution of jarosite waste and its autoclaved product-evidence for the immobilization of deleterious elements in jarosite. Miner Eng. **13**(3), 287–296 (2000)
30. ASTM D6913-04: Standard Test Methods for Particle Size Distribution of Soils. American Society for Testing of Materials, Pennsylvania, PA, USA
31. ASTM D422-6: Standard Test Methods for Hydro Meter Analysis of Soils. American Society for Testing of Materials, Pennsylvania, PA, USA
32. ASTM D2487-11: Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System). American Society for Testing of Materials, Pennsylvania, PA, USA
33. Seggiani, M., Vitolo, S.: Recovery of silica gel from blast furnace slag. Resour. Conserv. Recycl. **40**, 71–80 (2003)
34. Sharma, A.K., Sivapullaiah, P.V.: Ground granulated blast furnace slag amended fly ash as an expansive soil stabilizer. Soils Found. **56**(2), 205–212 (2016)
35. Sridharan, A., Sivapullaiah, P.V.: Mini compaction test apparatus for fine grained soils. Geotech. Testing J. **28**(3) (2005)

36. ASTM D560 M-15: Standard Test Methods for Freezing and Thawing Compacted Soil-Cement Mixtures. American Society for Testing of Materials, Pennsylvania, PA, USA
37. ASTM D2166-06: Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. American Society for Testing of Materials, Pennsylvania, PA, USA
38. ASTM D-3967: Standard Test Method for Splitting Tensile Strength of Intact Rock Core Specimens. American Society for Testing of Materials, Pennsylvania, PA, USA
39. Güllü, H., Khudir, A.: Effect of freeze-thaw cycles on unconfined compressive strength of fine-grained soil treated with jute fiber, steel fiber and lime. Cold Reg. Sci. Technol. **106–107**, 55–65 (2014). https://doi.org/10.1016/j.coldregions.2014.06.008
40. Güllü, H.: Unconfined compressive strength and freeze-thaw resistance of fine-grained soil stabilised with bottom ash, lime and superplasticiser. Road Materials and Pavement Design, pp. 608–634 (2015). https://doi.org/10.1080/14680629.2015.1021369
41. Lee, W., Bohra, N.C., Altschaeffl, A.G., White, T.D.: Resilient modulus of cohesive soils and the effect of freeze-thaw. Can. Geotech. J. **32**, 559–568 (1995)
42. Ghazavi, M., Roustaei M.: The influence of freeze-thaw cycles on the unconfined compressive strength of fiber-reinforced clay. Cold Reg. Sci. Technol. **61**, 125–131 (2010)
43. Roustaei, M., Eslami, A., Ghazavi, M.: Effects of freeze-thaw cycles on a fiber reinforced fine grained soil in relation to geotechnical parameters. Cold Reg. Sci. Technol. **120**, 127–137 (2015). https://doi.org/10.1016/j.coldregions.2015.09.011
44. Eades, J.L., Grim, R.E.: A quick test to determine lime requirements for soil stabilization. Highway Research Record No. 139. Highway Research Board, Washington, DC, 61–72 (1966)
45. Sherwood, P.T.: Soil Stabilisation with Cement and Lime: State of the Art Review. HMSO Publication, London (1993)
46. Kalkan, E., Akbulut, S.: The positive effects of silica fume on the permeability, swelling pressure and compressive strength of natural clay liners. Eng. Geol. **73**(1–2), 145–156 (2004)
47. Toxicity Characteristics Leaching Procedure. Method 1311. United States Environmental Protection Agency (USEPA), USA (1992)
48. Analysis for Rates of Delhi. Central public work department (CPWD), Government of India, New Delhi, Vol. 1 (2016)

Experimental Investigation on Bubble Deck Concrete Using Plastic Waste

A. Dinesh, R. Prasanth Kumar and S. R. Abijith

Abstract Reinforced concrete and steel are the commonly used building materials in which reinforced concrete plays a vital role in the construction of buildings. In the structural components like slab and beam, the concrete below the neutral axis is assumed that it will not take any tensile stresses and will act only as a filler material. Hence, those ineffective concrete can be replaced with other material which in turn reduces the self-weight of the structure. Plastic waste which is nondegradable becomes a great concern to the environment. Such plastic waste must be recycled to create an eco-friendly atmosphere. Hence, plastic waste are recycled in the form of balls and can be used in the slab, such type of slab is called Bubble deck slab. Bubble deck slab replaces ineffective concrete by plastic balls, thereby dramatically reducing the structural self-weight which in turn reduces the magnitude of seismic forces which will be highly useful in seismically active areas. Hence in this paper, spherical balls made of recycled plastic were introduced to replace the ineffective concrete near the neutral axis of the concrete slab. Two slabs are casted with dimensions 0.75 m × 1 m, one with bubbles (Bubble deck slab) and one without bubbles (Conventional slab). It is found that, though ultimate load of Conventional slab is more than the Bubble deck slab, the cracking load of Bubble deck slab is comparatively higher than the Conventional slab due to its flexibility. And also the Bubble deck slab undergoes maximum deflection before failure while compared to the Conventional slab which will give sufficient warning to the users before failure of the structure.

Keywords Bubble deck slab · Cracking load · Deflection · Plastic waste · Ultimate load

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1 Introduction

Concrete is the most commonly used construction material due to its sustainability, durability, versatility etc. It is highly used in the construction of buildings, bridges, and pavements. The various constituents of concrete are cement, fine aggregate, coarse aggregate, and water in which 5% of the world's CO_2 is produced during the manufacture of the cement. In addition, the concrete is heavy, thus in order to reduce the self-weight of the structure, some portion of the concrete needs to be removed. Hence, to achieve this, a new type of concrete is introduced called Bubble deck concrete. Bubble deck concrete is a type of concrete in which some amount of the concrete is replaced by the plastic hollow bubbles, which are made by the waste plastic material that reduces the self-weight of the structure and reduces the CO_2 emission. The main advantage of using Bubble deck slab is that it can be highly used for large-span structures, large overhang areas, and it can be used where only fewer supporting points (like columns and walls) are available for the slab [1–7].

In this project, Bubble deck slab is cast by using hollow balls made by recycled plastic. It is an innovatory method of virtually eliminating the concrete part below the neutral axis of Conventional slab, which does not contribute to the tensile strength of the member. By introducing this recycled plastic in the concrete, there is nearly one-third reduction in the weight of Bubble deck concrete compared to Conventional concrete. This reduction in slab weight reduces the load acting on the beams, walls, and columns, which in turn reduces the size of the beam, column, and other structural components of the building.

In this project, slab of size 0.75 m × 1 m is used, since most of the slab used in the construction of the buildings are rectangular. The depth of the slab is taken as 230 mm, to have sufficient depth below the neutral axis to place the plastic balls. The recycled plastic is made of high-density polyethylene hollow plastic spheres.

The casting of the slab with recycle plastic in the zone below neutral axis is shown in Fig. 1.

Fig. 1 Bubble deck slab

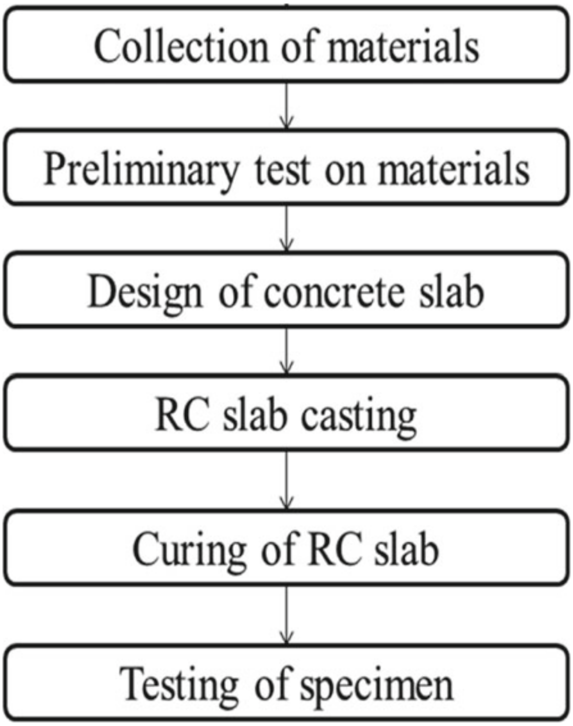
2 Objectives

The main objective of this study is

- To use HDPE—High-density polyethylene balls in the reinforced concrete slab in order to avoid the dumping of plastic, make use of the recycled plastic in concrete and reduce the self-weight of the slab,
- To study the behavior of Conventional slab and Bubble deck slab,
- To present a procedure for comparison of all parameters between solid Conventional slab and Bubble deck slab, and
- To study the deflection and load carrying characteristics of Conventional slab and Bubble deck slab.

3 Methodology

The methodology defines the strategy that shows the way in which this research is carried out. The methodology of the project is as follows.



4 Materials Used

The various materials used for the casting of Bubble deck concrete are

- Cement,
- Aggregates,
- Reinforcement bars,
- Waste Plastic bubbles, and
- Formwork.

5 Preliminary Design of Slab

The preliminary design of the concrete slab is as follows.

5.1 Slab Details

Slab size: 0.75 m × 1 m

(since most of the slabs are rectangular, this size is chosen)

Grade : M20
Steel : Fe 415
Rod diameter : 8 mm
Spacing : 150 mm c/c
Cover : 15 mm
Depth : 150 mm
Clear span : 1 m
Live load : 3000 N/m^2
Concrete : M20
Steel : Fe 415.

5.2 Design of Slab

Depth required = (SPAN/2 X MF)
= 50 mm

Assuming the overall depth of the slab as 150 mm

Dead load of slab = 25 × 150
= 3750 N/m^2
Live load = 3000 N/m^2

Total = 6750 N/m^2
Factored load = 1.5 × 6750
= 10,125 N/m^2
α_X = 0.056
α_Y = 0.056
r = 1
Maximum span BM per meter length, Mu = 0.056 × 10,125 × 1^2
= 567 Nm
Maximum span BM per meter length, Mu = 0.056 × 10125 × 1^2
= 567 Nm

Equating Mu, limit to Mu

0.138Fckbd^2 = 567
d = 45 mm
Percentage of steel = 0.4%
Spacing of 8 mm dia bars, required = 300 mm

Provided 8 mm dia bars at 150 mm c/c.

6 Quantity of Materials Used

The mix design of concrete is done as per IS 10262:2009 and by using IS 456:2000. The mix design is done using the following stipulations for proportioning which is commonly adopted in Coimbatore zone and it is tabulated in Table 1.

The final quantity of materials arrived through mix design is shown in Table 2.

The quantity of the materials per cubic meter is calculated as per IS 10262:2009 and IS 456:2000. This value is ascertained for the volume of 1 m × 0.75 m × 0.23 m for Conventional slab and they are tabulated in Table 3 and the values are again ascertained for the volume of 1 m × 0.75 m × 0.146 m (84 mm is deducted since plastic balls are used) for Bubble deck slab and they are tabulated in Table 4. It is seen that the quantity of materials in Bubble deck slab is reduced compared to Conventional slab because of the usage of recycled plastic.

Table 1 Stipulations for proportioning

1.	Grade designation	M20
2.	Type of cement	OPC 53 grade conforming to IS12269-1987
3.	Maximum nominal aggregate size	20 mm
4.	Coarse aggregate	165 kg
5.	Exposure condition	Normal
6.	Degree of supervision	Good

Table 2 Quantity of materials for M20 grade concrete

Materials	Cement	Fine aggregate	Coarse aggregate	Water
Quantity	319 kg/m^3	478.26 kg/m^3	956 kg/m^3	174 l
Mix ratio	1	1.5	2	0.5

Table 3 Quantity of materials for Conventional slab

Grade of Concrete—M20		
S. No.	Materials	Quantity
1.	Cement	55 kg
2.	Fine aggregate	82.5 kg
3.	Coarse aggregate	165 kg
4.	Water	30 l

Table 4 Quantity of materials for Bubble deck slab

Grade of concrete—M20		
S. No.	Materials	Quantity
1.	Cement	35 kg
2.	Fine aggregate	52.5 kg
3.	Coarse aggregate	105 kg
4.	Water	17.5 l

7 Experimental Investigations

A formwork for Conventional Slab and Bubble deck slab is prepared for the inner dimension of 1 m × 0.75 m × 0.23 m. The slab is provided with a clear cover of 15 mm. A wire mesh is placed over the concrete in both the slabs above the concrete cover. In Conventional concrete slab, concrete is placed over the wire mesh until the depth of the slab becomes 230 mm. In case of Bubble deck slab, a layer of concrete is poured over the wire mesh and plastic balls are placed till it reaches the neutral axis of the slab and again concrete is placed over the balls till the depth of the slab becomes 230 mm. The casting of Conventional slab is shown in Fig. 2.

The completed Conventional slab and Bubble deck slab is shown in Fig. 3. The Conventional slab and Bubble deck slab is kept under curing for 28 days using gunny bags. At the end of 28 days, curing experimental investigations are made. In addition to this, nine cubes are cast to validate the mix design done.

Fig. 2 Casting of Conventional slab

Fig. 3 Casted Conventional and Bubble deck slab

7.1 Rebound Hammer Test

The rebound hammer test, which is one of the nondestructive testings, is conducted to determine the compressive strength of the concrete. The mean values obtained by testing in three different horizontal positions are tabulated in Table 5 for and the mean values obtained by testing in three different vertical positions are tabulated in Table 6.

Table 5 Rebound hammer values for horizontal position

S. No.	Type of slab	Rebound value	Compressive strength (N/mm^2)
1.	Conventional slab	30	20
2.	Bubble deck slab	24	18

Table 6 Rebound hammer values for vertical position

S. No.	Type of slab	Rebound value	Compressive strength (N/mm^2)
1.	Conventional slab	34	22
2.	Bubble deck slab	24	18

Table 7 Characteristic strength of concrete at the age of 7, 14, and 28 days

S. No.	Type of concrete mix	7 days (MPa)	14 days (MPa)	28 days (MPa)
1.	Conventional	17.64	20.27	22.66

7.2 Compression Test

The cubes are cast in order to validate the mix design done as per IS 10262:2009 and IS 456:2000. The cubes are kept in curing for 7 days (=3 cubes), 14 days (=3 cubes), and 28 days (=3 cubes) and its compressive strength is determined by placing it in the compression-testing machine. The mean value of compressive strength is tabulated in Table 7.

8 Results and Discussions

After 28 days, curing the slab is placed in loading frame of 200T. The load is applied through the load cell to the I-girder, which is placed directly on the top surface of the Conventional slab. A dial gauge is placed beneath the slab to indicate the deflection of the slab when the load is applied. The experimental setup for the slab is shown in Fig. 4. The load is applied to the slab and the corresponding deflection values are measured. This process is repeated until a particular point where the load values get reversed. The load corresponding to this point is called yield load and the deflection corresponding to the yield load is noted. Now the dial gauge is removed and the load is continuously applied till the slab breaks and the load corresponding to this point is called as ultimate load. The yield load, corresponding deflection, and ultimate load values are computed for both the Conventional and Bubble deck slabs.

Fig. 4 Experimental setup of the slab

Table 8 Test results of Conventional concrete slab

S. No.	Yield load (kN)	Deflection (mm)	Ultimate load (kN)
1.	340	12	380

8.1 Conventional Concrete Slab

The Conventional concrete slab has been cast and tested for the load carrying capacity and its corresponding deflection. The test results of Conventional concrete slab obtained are shown in Table 8.

8.2 Bubble Deck Concrete

The Bubble deck slab has been cast and tested for the load carrying capacity and its corresponding deflection. The test results of Bubble deck concrete slab obtained are shown in Table 9.

Table 9 Test results of Bubble deck concrete

S. No.	Yield load (kN)	Deflection (mm)	Ultimate load (kN)
1.	280	16	320

9 Conclusions

- The yield load of Conventional slab is 340 kN and for Bubble deck slab is 280 kN, thus the yield load of Bubble deck slab is reduced by 17.64%.
- The deflection of Conventional slab is 12 mm and for Bubble deck slab, it is 16 mm; thus the deflection of Bubble deck slab is increased by 4 mm contributing more ductility to the Bubble deck slab.
- The ultimate load carrying capacity of the Conventional slab is 380 kN and for Bubble deck slab, it is 320 kN; though the load carrying capacity is decreased, the Bubble deck slab exhibits more ductility behavior compared to Conventional slab.
- The flexural capacity of Bubble deck concrete slab is improved (since deflection is higher compared to conventional) compared to Conventional concrete slab even with the usage of the same quantity of reinforcement and the same grade of concrete.
- Since the quantity of concrete materials are reduced in the Bubble deck slab (due to the usage of recycled plastic) compared to Conventional concrete slab, the economy of the structure is reduced.
- By using the hollow elliptical balls, though the load bearing capacity for the Bubble deck slab was reduced, the self-weight of the structure was also reduced which in turn will reduce the size of the other structural components and reduce the overall economy of the structure.

References

1. Shetkarand, A., Hanche, N.: An experimental study on bubble deck slab system with elliptical balls. NCRIET-2015 & Indian J. Sci. Res. **12**(1), 21–27 (2015)
2. Churakov, A.: Biaxial hollow slab with innovative types of voids. Constr. Unique Build. Struct. **6**(21), 70–88 (2014)
4. Bhagat Dr., S., Parikh, K.B.: Comparative study of voided flat plate slab and solid flat plate slab. **3**(3) (March 2014). ISSN 2278-0211
5. Bhagat Dr., S., Parikh Dr., K.B.: Parametric study of R.C.C voided and solid flat plate slab using SAP 2000. IOSR J. Mech. Civ. Eng. **11**(2), 12–16 (2014)
6. Sakin, S.T.: Punching shear in voided slab. Civ. Environ. Res. **6**(10) (2014). ISSN 2224-5790, ISSN 2225-0514
7. Subramanian, K., Bhuvaneshwari, P.: Finite element analysis of voided slab with high density polypropylene void. J. Mech. Civ. Eng. (IOSR-JMCE) **11**(2 Ver.VI), 12–16 (March–April. 2014). e-ISSN: 2278–1684, p-ISSN: 2320-334X

A Study on Total Nitrogen Balance and Alkalinity Balance in a PVA Gel-Based Bioreactor

Ghazal Srivastava and Absar Ahmad Kazmi

Abstract PVA gel beads are proven out to be an effective structure for enrichment of large number of bacteria, providing high nitrification rates at lesser filling percentages. The treatment configuration (oxic–anoxic–oxic along with a settler) has shown a characteristic balance of nitrogen and alkalinity through the nitrification and denitrification phenomenon in the tanks. Ammonia removal rates were >90%, organic matter removal (COD) was 87–96%, and TSS removal was 96–99% at variable HRTs (6, 5, and 4.4 h) and temperatures. Total nitrogen balance was figured out as, average TN was 4.507 g/d in inlet, out of which 0.121–0.526 g/d (2.69–11.67%) get into the waste sludge, 0.191–0.947 g/d (4.25–21.01%) remained in the outlet, and the rest 3.077–4.151 g/d (68.27–92.11%) was removed. Accordingly, alkalinity balance showed that 25% of the inlet alkalinity was consumed in overall nitrification and denitrification process.

Keywords Chemical Oxygen Demand (COD) · Hydraulic Retention Times (HRTs) · Polyvinyl Alcohol (PVA) gel · Total Nitrogen (TN) · Total Suspended Solids (TSS)

1 Introduction

As we know, domestic sewage commonly contains organic contaminants, high suspended solids and numerous pathogens and insects which give rise to eutrophication of lakes, etc., if released to water bodies or groundwater without any treatment. But through appropriate analysis and gaining control over the environment, effective biological treatment of nearly all wastewaters having biodegradable components can be accomplished using proper elementary knowledge of microorganisms [1]. Biological wastewater treatment technology has proceeded

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stupendously since its origin toward the end of 1800s and Conventional Activated Sludge (CAS) systems came into picture in the early 1900s for treating both municipal wastewaters and the effluents discharged from industries. Although CAS process played a very good role in removing these pollutants it still had some issues like disposal of too much sludge produced, low treatment efficiency, i.e., presence of lesser number of microorganisms in each unit volume and a larger area requirement. Eventually the prolonged use of fixed-growth concepts came forth by the introduction of synthetic media into treatment processes during 1950s. Integrated Fixed-Film Activated Sludge (IFAS) is a comparatively advanced technology that delineates any suspended growth system as it integrates an attached growth media inside the suspended growth reactor [2]. It has gained the benefits of both conventional activated sludge and biofilm systems by merging these two technologies together as it allowed two separate biological populations to act in harmony, with the Mixed Liquor Suspended Solids (MLSS) depleting the bulk of organic load (BOD), and the biofilm helping in the oxidation of the nitrogenous load (NH_4^+) by cultivating a dynamic nitrifying community. Recently, Polyvinyl Alcohol (PVA) gel beads are observed as excellent immobilization media, have been proven effective in growth and enrichment of bacteria [3]. The 4 mm spherical shaped PVA gel bead possesses a mesh of 10–20 micron pores crossing through it, which enables growth of bacteria in a shielded mode and minimizes sloughing of biomass. Due to its better fluidity, minimum energy is consumed for mixing and the larger porosity of gel beads favors better supply of oxygen and carbon residing bacteria, resulting in stable treatment under variable loading. Volumetric packing ratios of the beads are typically 5–15%, which is much less compared with other carriers (50–70% usually) [4].

PVA gel displayed better performance as an immobilization medium by providing higher nitrification rates, with less bulk, thereby occupying little space in the reactor [5]. Consequently, even a lesser filling ratio of PVA gel beads in a reactor provides a high treatment potential. PVA gel treatment produces much less surplus sludge in contrast to conventional biological treatment methods; therefore, it requires lesser area to construct their tanks. A certain experiment carried out on MBBR process model provided an outcome that the effective specific surface area for PVA gel beads is around 2500 m^2/m^3 which is about 2.5 times larger in comparison to when only outer specific surface area of beads is taken into account and which is literally responsible for residing large number of bacteria in its pores with a protected atmosphere [4].

The aim of the study was the performance evaluation of this IFAS system containing only 4% PVA gel beads being a biomass carrier targeting the Total Nitrogen (TN) as well as Ammonical Nitrogen (NH_4–N) removal and to draw out TN balance in the entire system and also total alkalinity consumption linked with that removal during nitrification and denitrification processes occurring within the tanks. As worldwide, a multitude of people are feeling an extreme agony due to improper sanitation, dissatisfactory wastewater treatment, and unavailability of utilizable water. The situation is seriously worsened in smaller towns and rustic regions of developing countries [6]. So, this study actually drives our attention toward the decentralized sewage treatment systems especially for the nitrogen removal in rural areas, not much focused in India in past but now India needs their successful implementations for the better future of water bodies.

2 Materials and Methods

2.1 Reactor Configuration and Operational Parameters

Throughout the study, although as per variable conditions prevailing in the reactor regarding changes in Hydraulic Retention Times (6, 5, and 4.4 h), and in temperature (20–33 °C), this Integrated Fixed-film Activated Sludge system has been found capable to provide consistently effective ammonia removal rates >90%. Each of the reaction tanks (oxic–anoxic–oxic) was found to work satisfactorily at optimum maintenance of D.O, ORP, and pH. The three reaction tanks were: (1) media tank (consisting of 4% beads in the 10 L of tank) with aeration (for nitrification) (2) an anoxic tank (denitrification tank) of 10 L, (3) an oxic tank (i.e., secondary aerobic tank), whose reaction volume was 10 L first but was decreased to 5 L and then to 2 L which resulted in changes in HRT from 6 h to 5 h and then to 4.4 h, respectively, and also a 5 L settling tank with rotating scraper was installed at the end of treatment process (Fig. 1). The media used in the first tank was Polyvinyl Alcohol (PVA) gel beads occupying 4% or 0.4 L of reactor volume. Aeration in media tank and oxic tank was provided with diffusers placed at bottom. Continuous mixing was carried out in anoxic tank with the help of rotating shaft. Thus, an effective nitrogen mass balance was figured out using the tank-wise data analysis, nitrification as well as denitrification rate experiments were also conducted during this period and the results were found appreciable. The raw sewage on which the study was performed had COD/TN ratio of about 11.1:1 and Solids Retention Time (SRT) of 8.5 days on average. Performance evaluation showed that organic matter removal (COD) was 87–96% and suspended solids removal was 96–99%.

All the operational parameters were measured timely in which physicochemical parameters were pH, temperature, D.O., and ORP and sludge parameters were MLSS, MLVSS, SVI, and Solids Retention Time (SRT).

Physicochemical Parameters. In each of the three tanks, these parameters were maintained in PVA gel tank (media tank) D.O. values were kept on an average 6.76 mg/l with pH approximately 8.17 and ORP as +42 ± 74 mV; in anoxic tank (denitrification tank), D.O. value was 0.19 mg/l, pH was 7.68, and ORP was −138 mV on an average and in the oxic tank 4.01 mg/l, 7.81 and +66.7 mV, respectively (Figs. 2 and 3). pH of the inlet tank was 7.52 ± 0.3 and of the outlet was 7.9 ± 0.5. Maximum and minimum ambient temperatures at the study location were 33 °C and 20 °C, respectively, as the period of study of the pilot plant was from May 2, 2017 to October 31, 2017.

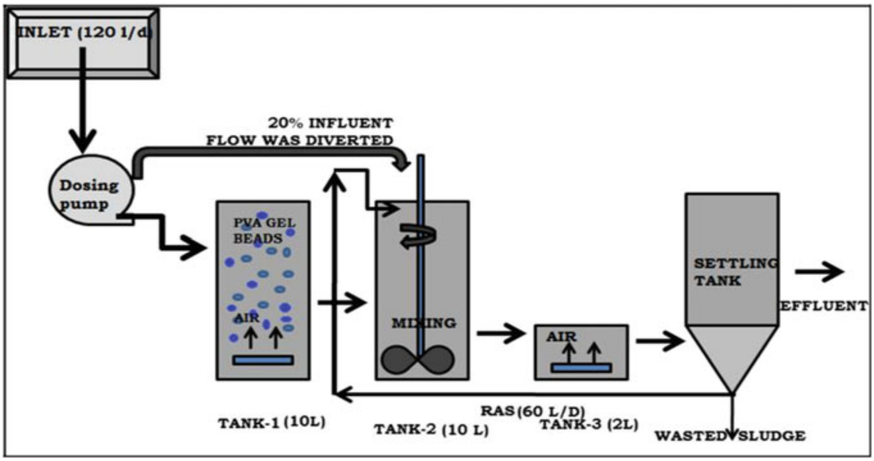

Fig. 1 Current schematic diagram of the pilot plant used in the study

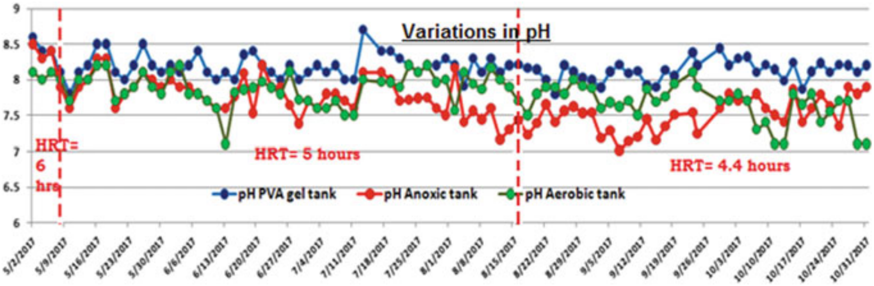

Fig. 2 Graph showing pH values in all the three tanks

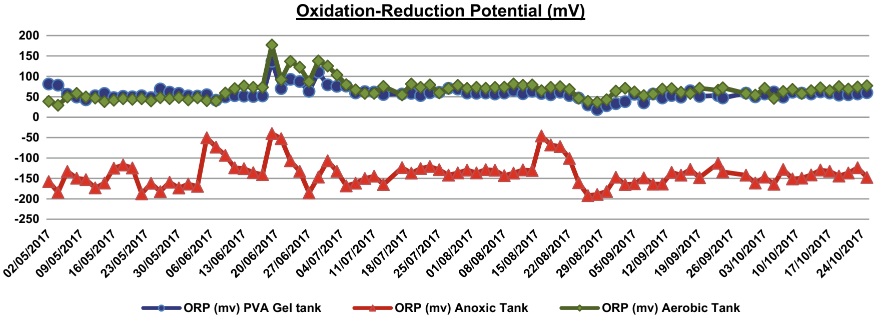

Fig. 3 Variations in ORP in all the three tanks

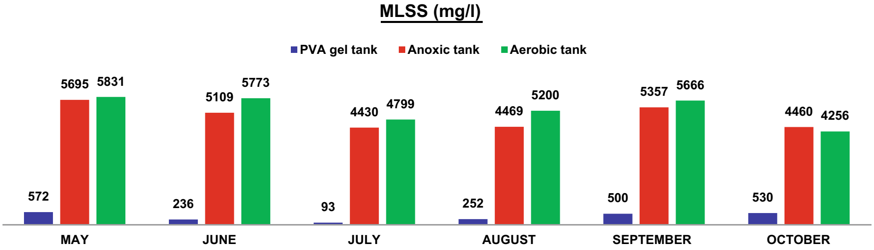

Fig. 4 Month-wise variations of MLSS (only suspended biomass) in all the three tanks

Sludge Parameters. Since May, average MLSS (mg/l) of the PVA Gel tank (except attached biomass) was maintained as 358 ± 247 mg/l, of the anoxic tank was 4942 ± 1001 mg/l and of the aerobic tank was 5336 ± 1074 mg/l and in the same way MLVSS (mg/l) was 179 ± 131 mg/l, 2291 ± 760 mg/l and 2449 ± 584 mg/l, respectively (Fig. 4). And thus, their ratio was approximately maintained as 0.494 ± 0.13 on an average generally in all the tanks with good settling characteristics having SVI 67 ± 16 ml/g and SV30 around 330 ± 60 (ml/l). The average attached biomass (inside the beads) was found to be as 436 mg/l.

The laboratory-scale plant was operating at an average Solids Retention Time (SRT) of 8.5 days. SRT was calculated using the MLSS (suspended) in all the three tanks, the sludge concentration (attached) in the beads (0.4 L of beads in 10 L of first oxic tank), and the daily sludge wasted in g/d.

2.2 *Method and Analysis*

The influent flow rate was maintained as 120 L/d in the inlet (80% in the PVA gel tank and 20% diversion to the anoxic tank just for external BOD loading for denitrification) and it was maintained as 60 L/d for RAS. It was measured regularly by visual measurement with measuring cylinder and timer. A portable DO meter (Hach 110Q multimeter, Hach, USA) was used to measure DO and temperature in the reaction tanks. The pH was measured by a portable pH meter (HQ11d pH Meter, Hach) and ORP by the portable ORP meter. Grab samples of 0.5 L were taken on every alternate day from the raw sewage tank, the three reaction tanks and from the outlet of the sedimentation tank for the analysis of Chemical Oxygen Demand (COD), Bio-chemical Oxygen Demand (BOD), Total and Volatile Suspended Solids (TSS and VSS), Total Nitrogen (TN), ammonia, nitrate, and alkalinity was done in accordance with *Standard Methods* [7].

Mixed Liquor Suspended Solids (MLSS), Mixed Liquor Volatile Suspended Solids (MLVSS) of the wasted sludge, and reaction tanks were investigated as stated in *Standard Methods* [7].

3 Results and Discussions

3.1 Reactor Performance

COD and BOD Removal. This pilot plant was found very effective in the removal of organic matter and suspended solids. During the study of 6 months it was found that the COD removal was on an average 92.3 ± 4.2% (where COD in the influent was 398 ± 162 mg/l and in the effluent was 26 ± 9 mg/l). And in the same way, BOD removal was 96.4 ± 2.15% (having influent BOD as 194 ± 76 mg/l and effluent as 6 ± 2 mg/l) thus, the plant was showing good results in organic matter removal (as according to new effluent standards) (Fig. 5 and Fig.6).

TSS and VSS Removal. This plant was consistently very effective in removing suspended solids as well. The influent and effluent TSS and VSS were found to be as 279, 4, and 169, 2 respectively on average. Thus, the VSS: TSS ratio was maintained as 0.59 and 0.42 of influent and effluent, respectively. And the average removal percentages were 98.39% and 98.89% of TSS and VSS, respectively (Fig. 7 and Fig. 8).

Total Nitrogen (TN) and Ammonical Nitrogen (NH4–N) Removal. As described earlier, nitrification was undergoing in the PVA gel tank and secondary

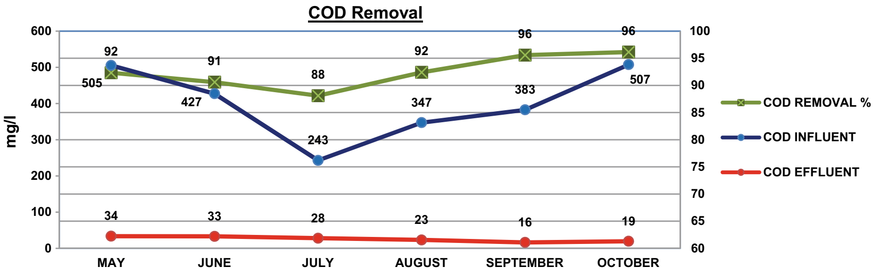

Fig. 5 COD month-wise graph of the pilot plant (values were taken as an average during a full month)

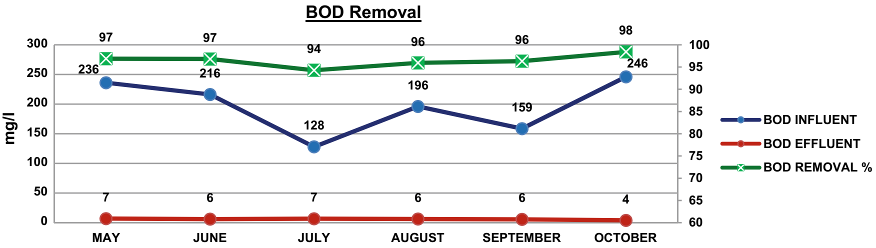

Fig. 6 BOD month-wise graphs of the pilot plant (values were taken as an average during a full month)

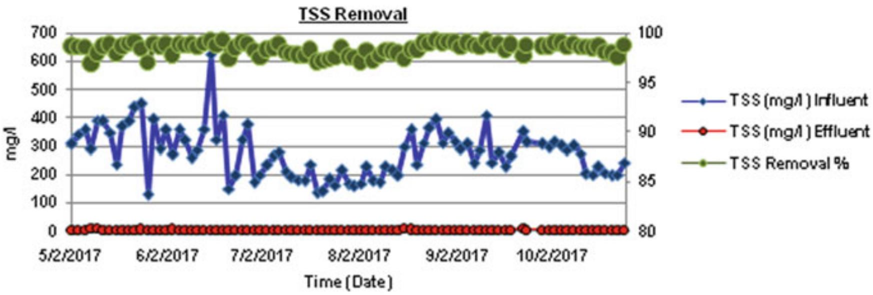

Fig. 7 TSS removal in the pilot-scale plant

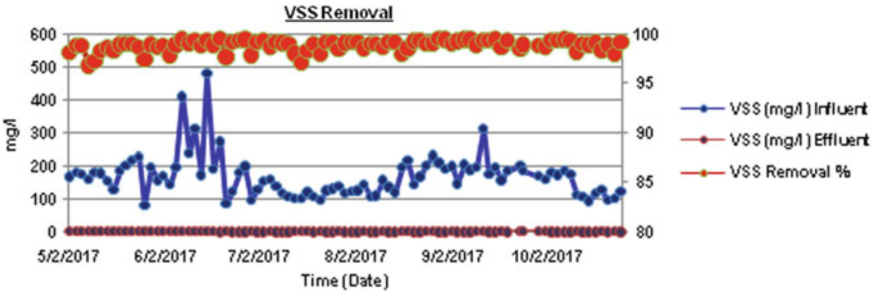

Fig. 8 VSS removal in the pilot scale plant

aerobic tank and denitrification process were being carried out in anoxic tank which brought out the objective of removing TN.

Significance of nitrification in wastewater treatment

1. Hazardous role played by ammonia on water bodies with respect to lowering of DO concentrations and increasing fish toxicity compels us to remove ammonia,
2. Issues related to eutrophication direct us for nitrogen removal and
3. For reusability of water covering groundwater recharge applications, etc., there's an ultimate need for effective nitrogen removal (Metcalf & eddy, Inc.) [1].

Nitrifiers are the dominant bacteria when organic food supplies have been consumed and polyvinyl alcohol gel beads (having diameter of 3–4 mm) are an excellent immobilization media having a network of minute pores about 10–20 microns-meter for enrichment of large number of bacteria in their protective cores [8]. Having advantages of both suspended as well as attached growth processes within a single system leads to simultaneous removal of organic matter (BOD) and nitrogen (Total Nitrogen and Ammonia).

These bars (Fig. 9) show that how deammonification and nitrification is taking place in the PVA gel tank and how at last >90% is getting removed in the effluent (Fig. 10).

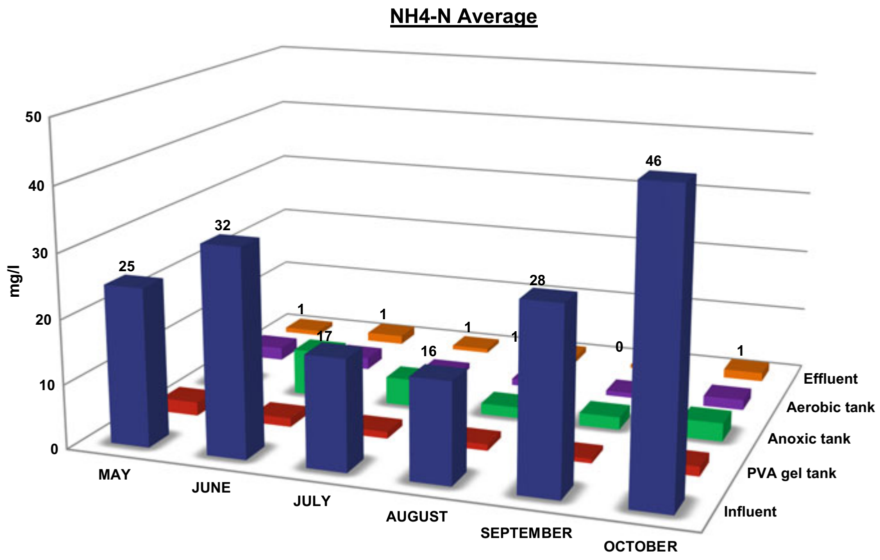

Fig. 9 Bar graph of ammonical nitrogen values in each of the tanks, in influent and in effluent taken an average value for a month

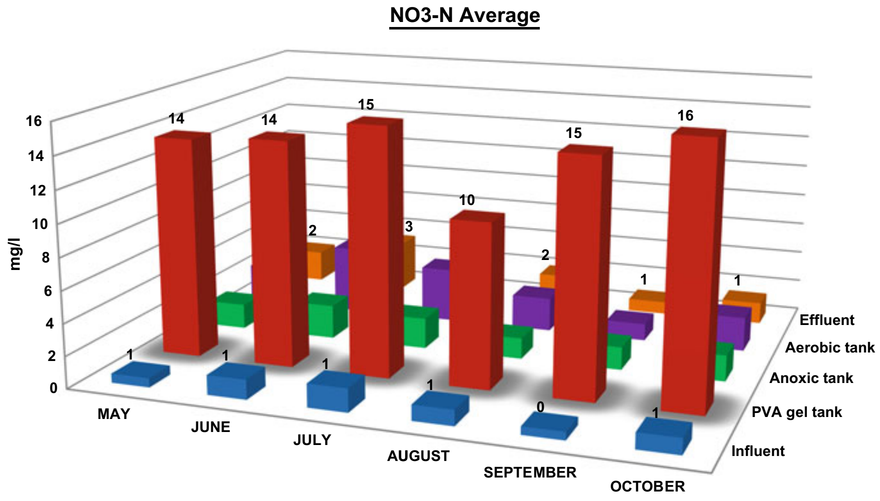

Fig. 10 Bar graph of nitrate values in each of the tanks, in influent and in effluent taken an average value for a month

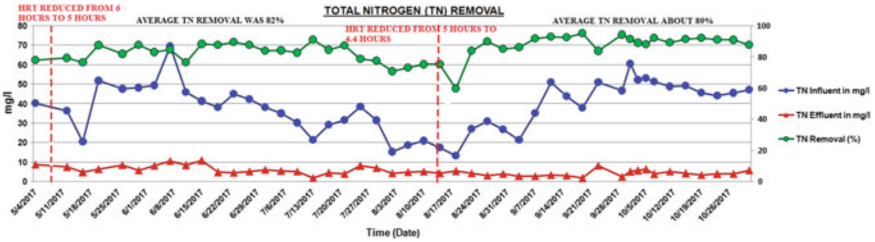

Fig. 11 Total Nitrogen (TN) removal in the pilot scale plant

These bar graphs show that most of the ammonia removal occurred in the PVA gel tank by simultaneous nitrification and denitrification inside the beads. The anoxic tank performed denitrification, i.e., reducing nitrate to nitrogen gas in a very satisfactory manner. Then the oxic tank (i.e., aerobic tank) did further nitrification of the 20% diverted inflow (containing about 2–4 mg/l ammonia) from the anoxic tank. Then, removal of nitrate which was formed in the oxic tank due to 60 L/d Return Activated Sludge (from the sedimentation tank to the anoxic tank) took place. Through this journey, only 0.2–3 mg/l of nitrate remained in the effluent. Total Nitrogen removal is shown in Fig. 11.

3.2 Total Nitrogen Balance

PVA gel tank with combination of anoxic and secondary aerobic tanks, i.e., IFAS configuration (oxic–anoxic–oxic) has shown a characteristic balance of nitrogen through nitrification and denitrification phenomenon in the tanks. Thus, an effective Total Nitrogen Mass Balance was figured out by doing tank-wise total nitrogen content analysis.

This balance used the following equations for the calculation of each part of TN distribution:

$$\text{Mass (Influent TN)} = \text{Q} * \text{TN inf.} \tag{1}$$

Mass of nitrogen in the influent per day (Mass (Influent TN)) was calculated by a product of the influent flow rate (Q) and content of total nitrogen in influent in mg/l (TN inf.) which constitutes each form of nitrogen organic nitrogen, ammonical nitrogen (NH_4–N), and nitrate (NO_3–N) [9, 10].

$$\text{TN (Mass (Influent TN))} = \text{Mass}_{\text{DEN}}\text{TN} + \text{Mass waste TN} + \text{Mass (Effluent TN)} \tag{2}$$

This Eq. (2) is showing balance of TN in the reactor. The influent nitrogen present in the form of ammonia was nitrified in the PVA gel tank. The portion of ammonia which was not nitrified came out of the system in effluent. This nitrate from nitrified ammonia, nitrate already present in influent, and nitrate coming from secondary oxic tank (aerobic tank) to anoxic tank through RAS or due to 20% diversion were denitrified in the anoxic tank denoted here as Mass $_{\mathrm{DEN}}$TN. The remaining amount of nitrate, which was not denitrified came out of the system with the effluent and in wasted sludge.

$$\begin{aligned}\text{Mass waste TN} &= \text{q waste (l/d)} * \text{ MLSS (wasted sludge) (g/l)} \\ &\quad * \text{x \% TN in sludge}/100\end{aligned} \tag{3}$$

This mass of TN in the wasted sludge in g/d was calculated by multiplying daily sludge wasted in l/d (q waste) and MLSS of the sludge wasted in g/l to the fraction “x”, where “x” generally found to be in the range of 1.9–2.4% in the sludge.

$$\text{Mass (Effluent TN)} = \text{Q} * \text{TN eff.} \tag{4}$$

Mass of nitrogen in effluent per day (Mass (Effluent TN)) was calculated in the same way as a product of the flow rate (Q) and content of total nitrogen in effluent in mg/l (TN eff.). So, to calculate denitrified content of TN, an indirect approach was used through subtracting Mass waste TN and Mass (Effluent TN) from the Mass (Influent TN).

“Q” is influent flow rate, i.e., 120L/d, whereas “q waste” is wastage flow rate generally about 1.2 l/d. All masses in g/d and MLSS concentration in g/l. Mass DEN corresponds to the mass of denitrified portion of Total Nitrogen in g/d. In the nutshell, fate of the influent TN is discussed here. Influent TN showed its destination after its overall tank-wise journey in three ways; some part of it went to the wasted sludge, some part remained in the outlet (effluent), and the rest got liberated as Nitrogen gas through denitrification [10]. The results can be expressed through this bar chart (Fig. 12).

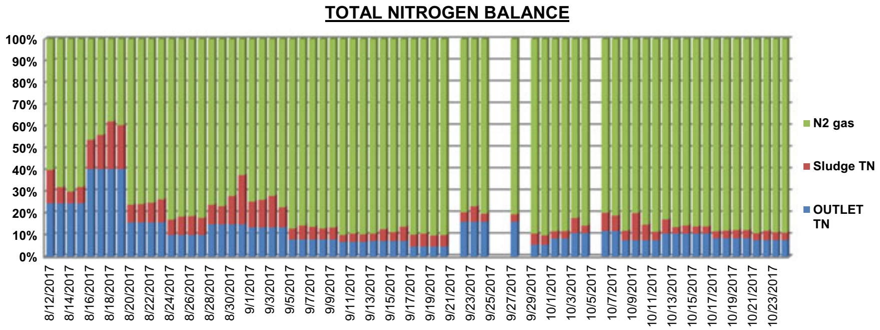

Fig. 12 Comprising the percentage distribution of all the three parts of the Total Nitrogen as described above

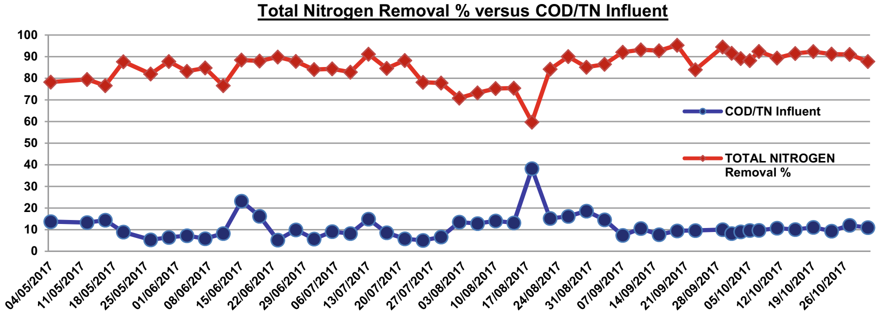

Fig. 13 TN removal % at varying COD/TN influent values

Average Total Nitrogen (TN) was 4.507 g/d in inlet, out of which 7.18 ± 4.5%, i.e., on an average 0.324 g/d got into the waste sludge, 0.569 g/d (12.63 ± 8.4%) remained in the outlet and the rest 3.610 g/d (80.1 ± 11.9%) was removed as N_2 gas. Based on primary effluent, the percent nitrogen removal by assimilation in the treatment of domestic wastewater may range from 8 to 20% and appreciable results were found here. The sludge was of better quality and was exhibiting good settling characteristics with $SVI < 70$. The COD: TN ratio of the raw sewage was approximately 11:1 (as shown in Fig. 13).

3.3 Alkalinity Balance

The alkalinity of water is a measure of its capacity to neutralize acids. For wastewater operations, alkalinity is measured and reported in terms of equivalent calcium carbonate. We know that 7.14 mg of alkalinity as $CaCO_3$ is consumed during nitrification (oxidation of every "mg of ammonium ion") [11]. Lack of carbonate alkalinity will stop nitrification as, $NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$.

So, one mole of NH_4–N liberates two moles of H + ions which corresponds to $2HCO_3$ ions. And thus, after calculations, it was found that 7.14 mg was consumed at 1 mg oxidation of ammonia. In the same way during denitrification, 3.57 mg of alkalinity was released. Inlet alkalinity during this study was about 330 ± 33 mg/l and of outlet about 240 ± 30 mg/l of $CaCO_3$. Here, a balance is obtained between calculated values and observed values (alkalinity of inlet and outlet experimentally obtained) of total alkalinity consumed within the reactor by nitrification and denitrification phenomenon (Fig. 14 and Fig. 15).

This was achieved through the calculations as shown in the Table 1.

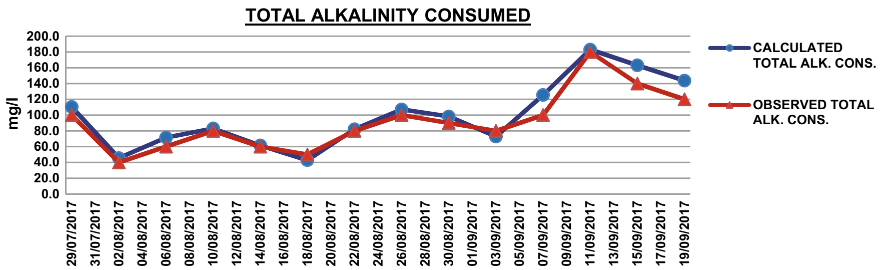

Fig. 14 Graph showing a balance in calculated and observed total alkalinity consumed

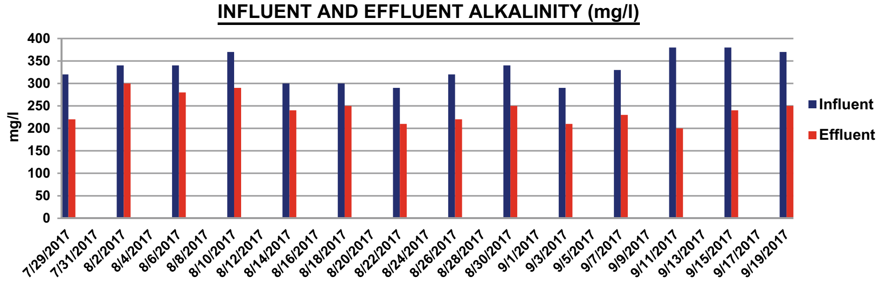

Fig. 15 Influent and effluent alkalinity observed after doing lab experiments

Table 1 Calculated versus observed values of the total alkalinity consumed

(NH_4–Ninf + Org N inf)-(NH_4–Neff-Org N eff)	Alkalinity consumed	TN inf (except TN in wasted sludge)-TN eff	Alkalinity released	Dates	Calculated	Observed
	(NH_4–Ninf + Org N inf-NH_4–Neff-Org N eff) * 7.14		(TN in (except sludge)-TN eff) * 3.57		Total alk. cons.	Total alk. cons.
26.6	189.9	22.30	79.6	7/29/2017	110.3	100
11.3	80.3	9.74	34.8	8/2/2017	45.5	40
16.2	115.7	12.39	44.2	8/6/2017	71.5	60
18.8	134.2	14.33	51.2	8/10/2017	83.1	80
14.6	104.2	11.98	42.8	8/14/2017	61.5	60
9.5	68.0	7.06	25.2	8/18/2017	42.8	50
22.0	157.0	21.00	75.0	8/22/2017	82.1	80
27.9	199.1	25.73	91.9	8/26/2017	107.2	100
24.2	173.0	20.93	74.7	8/30/2017	98.3	90
18.7	133.5	17.00	60.7	9/3/2017	72.8	80
32.5	232.3	29.94	106.9	9/7/2017	125.5	100
47.6	339.9	43.93	156.8	9/11/2017	183.0	180
41.7	297.7	37.72	134.7	9/15/2017	163.1	140
36.9	263.5	33.54	119.7	9/19/2017	143.7	120

4 Conclusion

The outcomes of the study revealed that good TN (Total Nitrogen) balance and alkalinity balance were exhibited by this IFAS system. The nitrification and denitrification processes in the tanks were going on satisfactorily at optimum maintenance of ORP, D.O., and pH and even at variable HRTs and temperature differences and PVA gel beads have come out to be an effective structure for residing numerous of bacteria in its protective cores with good oxygen permeability and thus higher nitrification rates at just 4% filling percentages were obtained. This system was also showing a very good response (according to new effluent standards) in suspended solids removal and organic matter removal. This detailed study during its operation can be helpful in laying out a better performance evaluation of the system and in figuring out many operational problems in future too and maybe implementation of these types of reactors, a considerable and a significant step toward decentralized sewage treatment approaches.

References

1. Metcalf and Eddy: Wastewater Engineering Treatment, Disposal and Reuse, 4th edn. McGraw-Hill, Indian Edition (2003)
2. U.S. EPA: Nutrient control design manual. United States Environmental Protection Agency, Washington, DC (2010)
3. Wang, Y., Liu, Y., Feng, M., and Wang, L.: Study of the treatment of domestic sewage using PVA gel beads as a biomass carrier. J. Water Reuse Desalination **8**(3), 1–10 (2017)
4. Levstek, M., Plazl, I., Rouse, J.D.: Estimation of the specific surface area for a porous carrier. Acta Chimica Slovenica, 45–51 (March 2010)
5. Rostron, W.M., Stuckey, D.C., Young, A.A.: Nitrification of high strength ammonia wastewaters: comparative study of immobilisation media. Water Res. **35**(5), 1169–1178 (2001)
6. Singh, N.K., Kazmi, A.A., Starkl, M.: A review on full-scale decentralized wastewater treatment systems: techno-economical approach. Water Sci. Technol. **71**(4), 468–478 (2015)
7. APHA, AWWA, WPCF: Standard Methods for the Examination of Water and Wastewater, 22nd edn. American Public Health Association, Washington, DC (2005)
8. Onnis-Hayden, A., Dair, D., Johnson, C., Schramm, A., Gu, A.Z.: Kinetics and nitrifying populations in nitrogen removal processes at a full-scale integrated fixed-film activated sludge (IFAS) plant. Water Environ. Fed. 3099–3119 (2007)
9. Gani, K.M., Singh, J., Singh, N.K., Ali, M., Rose, V., Kazmi, A.A.: Nitrogen and carbon removal efficiency of a polyvinyl alcohol gel based moving bed biofilm reactor system. Water Sci. Technol. **73**(7), 1511–1519 (2015)
10. Barker, P.S., Dold, P.L.: COD and nitrogen mass balances in activated sludge systems. Wat. Res. **29**(2), 633–643 (1995)
11. Benninger, R.W., Sherrard J.H.: Nitrification and alkalinity relationships in activated sludge. Water Pollut. Control Fed. **50**(9), Annual Conference Issue, 2132–2142 (September 1978)

Sustainable Energy Potential from Different Types of Waste Products

Jasvir Singh and Harmeet Singh

Abstract Fast depletion of fossil fuels in the world will cause the energy crisis in near future. Due to stringent environmental norms the whole world is focusing on energy from renewable energy sources. Energy from different types of waste in not only renewable but also bring down the cost of disposing the waste from different resources. In this study, five samples of each different types of waste like uneaten food, municipal waste, hospital waste, and cow dung have been focused to recover the energy from these resources. The various samples were tested in laboratory where calorific value and proximate analysis tests were conducted. The study highlighted that cow dung has the highest percentage in terms of mass with approximately 93 and 90% in terms of power that can be recovered. The total energy that can be produced from these wastes amounts to 18.45 MW/day.

Keywords Energy · Power potential · Calorific value · Proximate analysis

1 Introduction

According to United Nations Environment Program, squanders are materials that are not prime items (that is items created for the market) for which the underlying client has no further use as far as his/her own motivations of generation, change or utilization, and of which he/she needs to arrange. Squanders might be created amid the extraction of crude materials, the preparing of crude materials into halfway and last items, the utilization of conclusive items, and other human exercises. Residuals reused or reused at the place of age are prohibited.

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1.1 Types of Waste

- Kitchen Waste—uneaten food.
- Municipal Waste—paper, polythene bag, leaves.
- Cattle Dung—cow dung.
- Hospital Waste—cotton, bandages, plastic syringes, glucose bottles.

1.1.1 Kitchen Waste

The United States Environmental Protection Agency characterizes nourishment squander as "uneaten sustenance and sustenance planning squanders from living arrangements and business foundations, for example, markets, eateries, and create stands, institutional cafeterias and kitchens, and modern sources like representative break rooms". The states stay allowed to characterize nourishment squander distinctively for their motivations; however, many decide not to kitchen squander, till as of late was not being overseen appropriately but rather it was basically arranged off, which results in landfilling. Kitchen squander contains natural and in addition inorganic issue. The dormant vitality present in its natural part can be recouped for productive use through appropriation of reasonable waste processing and treatment advancements. Squander potential estimations were performed by the Stockholm County Administration Board in the County of Stockholm, both in 2009 and in 2030. This investigation extended the examination and considered the alternative where the biogas from the sustenance squander is used to create power to fuel electric vehicles in Stockholm. The most asset and vitality productive use of the biogas from nourishment waste is converting it to power for electric vehicles [6].

1.1.2 Municipal Waste

A wide range of strong waste produced by families and business foundations are gathered as a rule by nearby government bodies. The arrangement of metropolitan waste fluctuates extraordinarily from nation and changes essentially with time. In nations that have created reusing society, the waste stream comprises essentially immovable squanders, for example, plastic film and unrecyclable bundling. Toward the beginning of the twentieth century, the lion's share of waste (53%) in UK comprised coal powder from open flames. The waste accumulation is performed by the district inside a given region. The term "Lingering waste" identifies with waste left from family unit sources containing materials that have not been isolated out, in which the diverse kinds of waste resemble plastic, leaves, papers, and sewage slop, etc. [3].

1.1.3 Cattle Dung

Cow compost, otherwise called dairy animals pat, is the waste result of ox-like creature species. These species incorporate household steers ("dairy animals"), buffalo ("bison"), yak, and water wild ox. Cow excrement is the undigested buildup of plant matter which has gone through the creature's gut. The resultant fecal issue is wealthy in minerals. Shading ranges from greenish to blackish, regularly obscuring not long after introduction to air. It is additionally known in the American southeast and west as "dairy animals pies". If not reused into the dirt by species, for example, night crawlers and waste creepy crawlies, cow manure can dry out and stay on the field, making a region of munching land which is unpalatable to domesticated animals. In numerous parts of the creating scene, and in the past in mountain districts of Europe, hardened and dried cow manure is utilized as fuel. Excrement may likewise be gathered and used to create biogas to produce power and warmth. The gas is wealthy in methane and is utilized in country zones of India/ Pakistan and somewhere else to give an inexhaustible and stable wellspring of power. The capability of vitality recuperation from provincially accessible agro and family unit natural squanders and accordingly, the conceivable effect on enhancing vitality request, diminishing deforestation, and supplanting nonrenewable energy source and also maintained a strategic distance from ozone harming substances. Results demonstrate that co-assimilation of an extensive variety of excrement, edit buildups, and family unit squanders with dairy animals fertilizer was effective to deliver expanded gas yield than what might be if cow compost is processed independently and the vitality esteem from this can enhance 57–79% of the provincial interest contingent upon methane yield from natural waste blends. It has been proposed that execution of co-assimilation in the concentrated plant could be a suitable answer for delivering decentralized vitality for the rustic family units as far as maintainable waste administration, lessening deforestation, and in addition supplanting fossil fuels [5].

1.1.4 Hospital Waste

Doctor's facility squander is characterized as all squanders produced from medicinal services or well-being related offices. It is naturally heterogeneous, comprising objects of a wide range of sizes and made out of various materials. As indicated by World Health Organization (WHO) gauges 85% of doctor's facility squander is really non-dangerous and around 10% is irresistible while the remaining 5% is non-irresistible yet comprises unsafe synthetic concoctions like methyl chloride and formaldehyde [4]. In the aggregate sum of city squander, a city produces just 1–1.5% healing center wastes, of which 10–15% is considered infectious [1].

2 Materials and Methods

The methodology adopted for the study is outlined below:

- Preparation of Questionnaires
- Data Collection
- Collection of Waste Samples
- Testing of Samples
- Result and Conclusion.

2.1 Preparation of Questionnaires

A questionnaire has been designed to assess the overall quantity and quantity of different types of hospital waste in Mullanpur city. Quantitative approach has been used to tape the perception of the individual respondent. The questionnaire contains seven questions related to type and quantity of waste.

2.2 Data Collection

Both primary and secondary data has been used for the study. The data has been collected from the hospital employees in the form of responses to the questionnaire. The data has been collected by personal visits to the hospitals. This includes personal meetings with hospital employees. The data related to municipal waste was obtained from Municipal Council Mullanpur Dakha and Data regarding quantity of cow dung was obtained from Gaushala.

2.3 Collection of Waste Samples

Five samples of each different type of hospital waste like cotton, bandages, plastic syringe, and glucose bottles in different conditions have been taken from hospital. Samples of municipal waste were collected from dumping site and the sample of cow dung was collected from Gaushala. Collected samples in different conditions were collected and taken to laboratory for experiments.

2.4 *Testing of Samples*

Gathered examples have been tried in research facility where calorific esteem and proximate examination tests were directed. Calorific esteem test gives the measure of potential vitality that can be changed over into real warming capacity. It has been found by utilizing device known as Bomb Calorimeter. The proximate examination test gives the four parameters, i.e., dampness content, unstable issue, fiery debris content, and settled carbon.

2.4.1 Proximate Analysis

The proximate analysis is done for the determination of

1. Moisture Content
2. Volatile Matter
3. Ash
4. Fixed Carbon

Moisture Content

The value of moisture content has been obtained by heating the sample at 105 °C in muffle furnace.

Mathematically it is given by

$$\% \text{ moisture} = \frac{X1 - X2}{X1 - X} \times 100 \qquad \text{(eq.1)}$$

X1 = weight of crucible + weight of sample
X2 = weight of crucible + weight of sample after heating
X = weight of empty crucible.

Volatile Matter

The value of volatile matter has been obtained by heating the sample at 915 °C for 7 min. The difference in weights of sample before heating and weight of sample after heating gives net value of volatile matter.

Mathematically it is given by

$$\% \text{ volatile matter} = \frac{X1 - X2}{X1 - X} \times 100 \qquad \text{(eq.2)}$$

Ash

The value of ash content has been obtained by heating the sample at 630 °C for 2–3 h. The difference in weights of sample before heating and weight of sample after heating gives net value of ash content.

Mathematically it is given by

$$\%\ \text{ash} = \frac{X1 - X2}{X1 - X} \times 100 \tag{eq.3}$$

Fixed Carbon

The value of fixed carbon has been obtained by subtracting % age value of all above from 100.

Mathematically it is given by

$$\%\ \text{fixed carbon} = 100 - (\text{eq.1} + \text{eq.2} + \text{eq.3})$$

2.4.2 Calorific Value Test

Calorific esteem is the measure of potential vitality that can be changed over into real warming capacity. This warming capacity gives the estimation of vitality that can be recuperated. The calorific esteem is found by utilizing contraption known as Bomb Calorimeter.

3 Results and Discussion

3.1 Municipal Waste Generation Rates

From Municipal Council Mullanpur Dakha it was observed that generation rate of plastic was highest with 102 kg/day, paper with 73 kg/day, and leaves having 25 kg/day. Municipal waste generation rates are mentioned in Table 1.

Table 1 Municipal waste generation rates

Sr.No.	Type of waste	Quantity of waste/day (kg)
1.	Paper	73
2.	Polythene bag	35
3.	Leaves	25

3.1.1 Classification of Municipal Waste (Mass %)

Quantitative analysis of municipal waste shows that plastic waste has the highest percentage in terms of mass with 51%, paper, the next highest has 37%, and leaves with 12% in terms of mass (Fig. 1).

3.2 Hospital Waste Generation Rates in Surveyed Hospitals

To calculate the generation rate per patient per day, the total waste generated per day of hospital was calculated then divided by number of patients per day [2]. The diagram shows that the medical waste generated from "Deol Hospital" is small and medical waste of "Sant Nursing Home" is large as compared to other hospitals. The average medical waste generated per patient per day is 1.28 kg (Fig. 2).

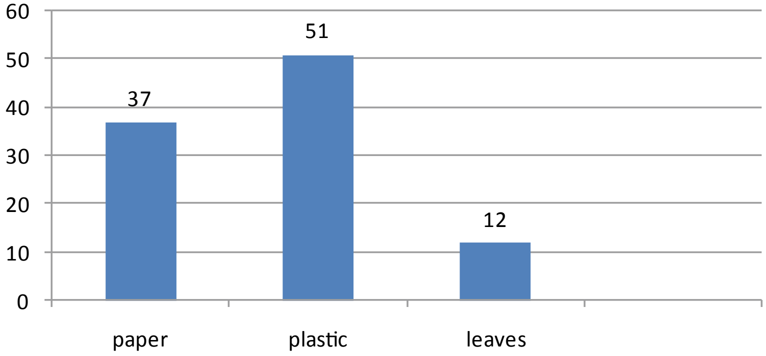

Fig. 1 Municipal waste assessment

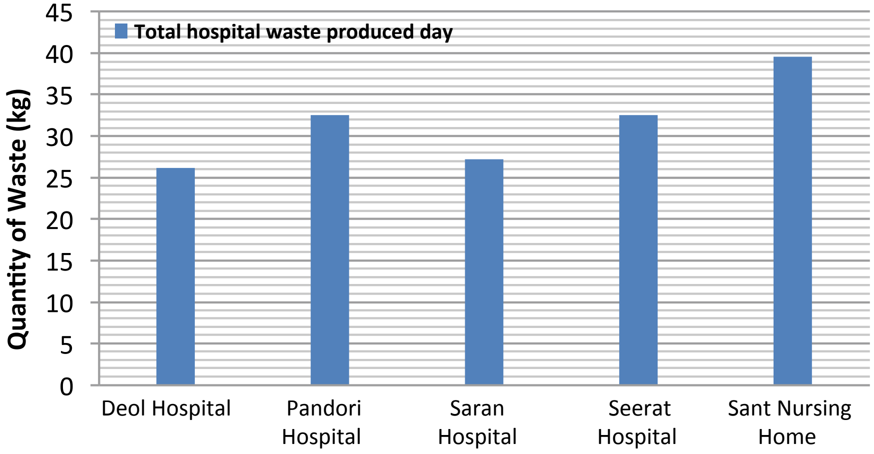

Fig. 2 Hospital waste generations in surveyed hospitals

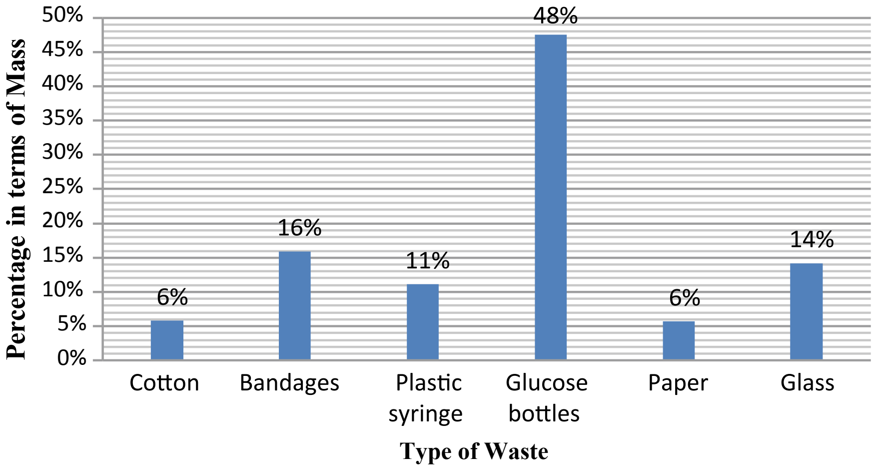

Fig. 3 Classification of hospital waste in surveyed hospitals (mass %)

3.2.1 Classification of General Healthcare Waste (Mass %)

The following diagram shows that total cotton waste of surveyed hospital is 9.2 kg/day, total bandages waste is 25.1 kg/day, total plastic syringe waste is 17.4 kg/day, total glucose bottles waste is 75.0 kg/day, total paper waste is 9.0 kg/day, and total glass waste is 22.3 kg/day. Average generation rate of cotton is 1.8 kg/hospital/day, for bandages 5.0 kg/hospital/day, for plastic syringe 3.5 kg/hospital/day, for glucose bottles 15 kg/hospital/day, for paper 1.8 kg/hospital/day, and for glass 4.5 kg/hospital/day (Fig. 3).

Quantitative and Qualitative analysis of hospital waste shows that glucose bottles have the highest percentage in terms of mass with 47.5%, bandages, the next highest has 15.9%, glass with 14.2%, plastic syringe with 11.1%, cotton with 5.8%, and **region**: On surveying the region it has been found that quantity of uneaten food was 34 kg/day.

3.3 Quantitative Assessment of Cow Dung from Gaushala

On visiting the Gaushala, it has been found there were 350 cows and average dung produced by each cow per day was approximate 11 kg, and hence total Cow dung per day from Gaushala has been obtained (Table 2).

Table 2 Quantitative assessment of cow dung from Gaushala

No. of cows in Gaushala	Average dung obtained/cow/day (kg)	Total dung/day (kg)
350	11	3850

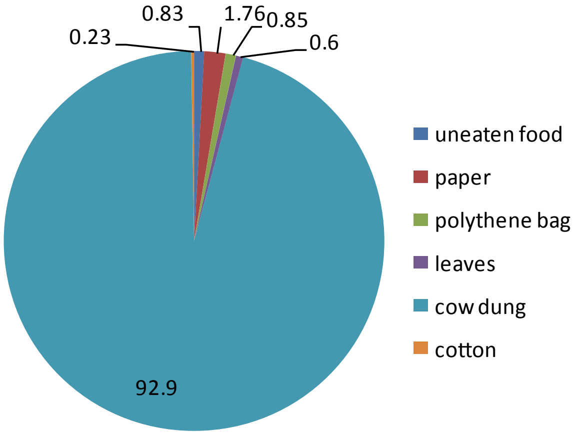

Fig. 4 Quantitative assessment of selected squander in terms of percentage

The generation of cow dung from Gaushala is 3850 kg/day and the average dung obtained is 11 kg/cow/day (Fig. 4).

The cow dung is 92.9% of the overall waste, uneaten is 0.83%, paper is 1.76%, polythene bag is 0.85%, leaves are 0.6%, and cotton is 0.23% of the overall waste.

3.4 Calorific Value Test

3.4.1 Calorific Value Test of Hospital Waste

The experiment of calorific value on selected hospital wastes shows that calorific value of plastic syringe is highest which is 42740 kJ/kg, glucose bottles contain 39840 kJ/kg, bandages have 18030 kJ/kg, and cotton contains 15190 kJ/kg of energy. The calorific value is found by using apparatus known as Bomb Calorimeter (Fig. 5).

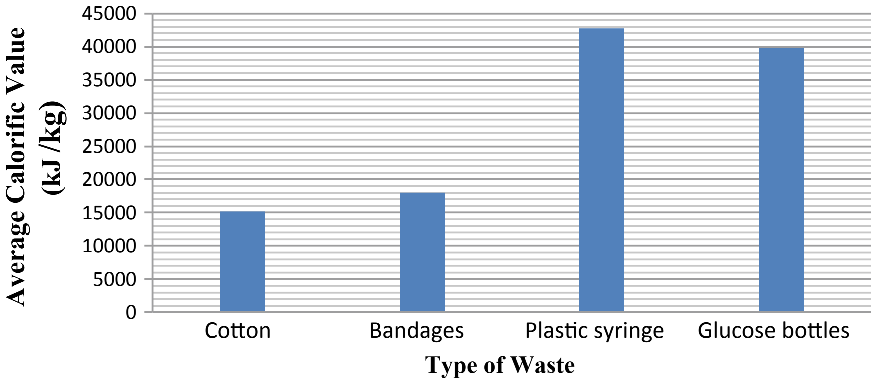

Fig. 5 Average calorific value content in selected hospital wastes

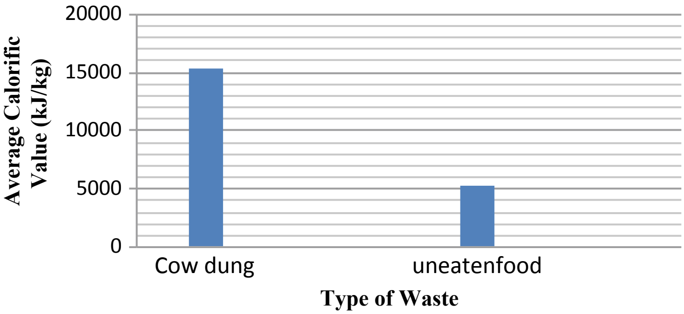

Fig. 6 Average calorific value of uneaten food and cow dung

3.4.2 Calorific Value Test of Kitchen Waste and Cattle Dung

The experiment of calorific value on selected cattle dung shows that calorific value of cow dung is highest which is 15472 kJ/kg and uneaten food contains 5208 kJ/kg of energy. The calorific value is found by using apparatus known as Bomb Calorimeter.

3.4.3 Calorific Value Test of Uneaten Food and Cow Dung

See Fig. 6.

3.4.4 Calorific Value Test of Municipal Waste

The experiment of calorific value on selected municipal waste shows that calorific value of polythene bag is highest which is 27140 kJ/kg, leaves contain 16370 kJ/kg, and paper has 13840 kJ/kg of energy. The calorific value is found by using apparatus known as Bomb Calorimeter (Fig. 7).

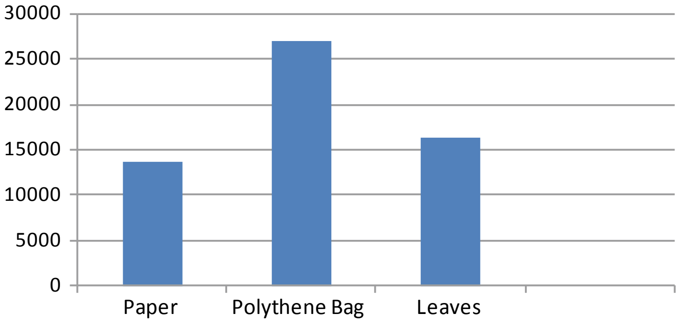

Fig. 7 Average calorific value of municipal waste

Table 3 Energy potential calculations

S. No.	Waste	Generation rate/day (kg)	Average calorific value (MJ/kg)	Energy (MJ)	Power (MW)
1.	Uneaten food	34	5.20	176.8	0.05
2.	Paper	73	13.84	1010.32	0.28
3.	Polythene bag	35	27.14	949.9	0.26
4.	Leaves	25	16.37	409.25	0.11
5.	Cow dung	3850	15.47	59559.5	16.54
6.	Cotton	9.2	15.19	139.74	0.03
7.	Bandages	25.1	18.03	452.55	0.12
8.	Plastic syringe	17.4	42.74	743.67	0.20
9.	Glucose bottles	75	39.84	2988	0.83
	Total			66429.98	18.45

3.5 Calculation of Energy Potential from the Selected Waste

See Table 3.

4 Conclusions

- The ponder featured that amount of waste is expanding quickly, it is smarter to execute a vitality recuperation venture instead of burn or dumping of waste.
- The contribution of cow dung in terms of power was 90% out of total power.

Appendix—I

(Questionnaire)

This questionnaire contains quantitative questions, kindly read carefully the questions and enter your response in the space provided.

This questionnaire contains quantitative questions, kindly read carefully the questions and enter your response in the space provided.

Q1. Name of the hospital. ________________________

Q2. Type of hospital:

a) Speacialist b) Multi-Specialist

Q3. Number of beds in hospital. ________________________

Q4. Number of patients per 24hrs. ________________________

Q5. Total medical waste produced per day in hospital:

a) upto 20kg b) 21-40kg c) more than 40kg

Q6. Total medical waste produced per bed/day in hospital:

a) upto 1kg b) 1-2kg c) more than 2kg

Q7. Quantity of following waste produced per day:

a) cotton ________kg b) bandages ________kg
c) plastic syringe _____kg d) glucose bottles _______kg

References

1. Akter, N., Trankler, J.: An analysis of possible scenarios of medical waste management in Bangladesh. J. Manag. Environ. Qual. **14**(2), 242–255 (2003)
2. Altin, S., Elevli, B.: Determination of hospital waste composition and disposal methods. Pol. J. Environ. Stud. **12**(2), 251–255 (2003)
3. Alamgir, M., Ahsan, A.: Municipal solid waste and recovery potential: Bangladesh perspective. J. Environ. Health. Sci. Eng. **4**(2), 67–76 (2007)
4. Azage, M., Kumie, A.: Healthcare waste generation and its management system: the case of health centres in West Gojjam Zone, Amhara Region, Ethiopia. Ethiop. J. Health Dev. **24**(2), 119–126 (2010)
5. Ashekuzzama, S.M.: Supplementing energy demand of rural households in Bangladesh through appropriate biogas technology. In: International Conference on Environmental Aspects of Bangladesh (2010)
6. Curry, N., Pillay, P.: Biogas prediction and design of a food waste to energy system for the urban environment. J. Renew. Energy **41**, 200–209 (2011)

Effect and Management of Various Terrestrial Weeds—Review

Biswanath Saha, Heena Kauser, Meena Khwairakpam and Ajay S. Kalamdhad

Abstract Terrestrial weeds affect ecosystems like forest, agriculture, and urban areas seriously, which demand proper management of these invasive plants. Due to their fast adaption and morphological advancement, controlling it's expand is challenging. Globally found are the species *Parthenium hysterophorus*, *Lantena camara*, *Saccharam spontaneum, and Azeratum conyzoides.* Though many attempts were made to control the terrestrial weeds either environmental and/or economical drawbacks occurred. This paper presents an alternative way for treatment of terrestrial weeds. Anaerobic digestion and composting are feasible and low-cost options. Anaerobic digestion is the process which breaks down organic compounds in presence of microorganism and in absence of oxygen and at the same time it obtains renewal energy. Methane and carbon dioxide are the products. Composting is also a biological process that breaks down organic compounds in presence of oxygen, fertilizer is the end product. Few studies were conducted on anaerobic digestion and composting of weed.

Keywords Terrestrial weeds · Anaerobic digestion · Composting · Biogas · Fertilizer

Highlights

- Negative effect of terrestrial weed has become a matter of concern globally.
- The terrestrial weeds increase the productivity of cropland.
- Utilization of this weed for anaerobic digestion and composting as a way of control.
- The regarded weeds contain a high amount of lignin.
- Pretreatment is required for efficient degradation.

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1 Introduction

According to various definitions, weed is considered as a plant growing in not desired localities, within competing with native and/or agricultural plants. Features that are responsible for invasive nature of terrestrial weed are (1) prolonged seed life, (2) fast mergence, (3) vigorous early growth, (4) capacity to grow in harsh environment, and (5) ability to survive and prosper under unfavorable condition [10]. Actually, the daily speedy spread of terrestrial weeds is a worldwide dilemma because of its harmful effect toward the soil and the ecosystem it is introduced to as well as to human health. The dominant nature of terrestrial weeds threatens the agricultural sector; once it grows in the farming sector, it does allow the other crops to grow. Environmental factors influence the growth of terrestrial weeds significantly [4]. Terrestrial weeds in India cause heavy destruction in agricultural field, for example, *Parthenium hysterophorus* covers vast area of plantation in urban and rural areas*,* *Lantana camara* in forestlands, and *Ageratum conyzoides* in rice fields. All these three weeds are native in America, later on it spread all over the world. In recent scenarios, these weeds spread almost all over the world, i.e., Australia, Western Africa, Asia, and Caribbean countries. It can grow anywhere like wastelands, roadsides, railway sides, watercourses, and cultivated crops. In India, 40% damages were found in yield of agricultural crops due to *P. hysterophorous* [12]. In Australia, yearly damage of around $16.8 million in the cattle industry was found [5]. Vivek et al. [23] reported that black gram (*P. mungo*) causes significant yield losses after 30–45 days after crop planting.

The adverse effects on ecological, agricultural, environmental, health of cattle, and man demand for a sustainable solution to control terrestrial weed [1]. Utilizing it for methane production and composting are favorable techniques to control weeds within obtaining renewable energy and biofertilizer. Currently, anaerobic digestion has become an established technology which is used for biogas production from the sewage sludge, animal manure, agricultural residue, industrial sludge, and energy crops in various countries [14]. Several researchers all over the world are focusing on renewable sources of energy production regarding the depletion of the oil reserves [3]. The application of chemical fertilization in modern agriculture has a major impact on the environment. The utilization of chemicals over a long period of time may reduce the efficiency of the soil, it continuously increases the productivity of land and cultivation. Biofertilizers produced from the biomass can be mixed with chemical fertilizers and applied on the field. Conversion of terrestrial weed to biogas or compost is one of the sustainable way to control invasive weed in low cost and energy.

2 Allelopathy

Allelopathy is a significant characteristic of terrestrial weeds. It produces phytotoxin that interferes the growth of the other plants. Germination and growth of other plants get affected due to the presence of the phytotoxic that is found in plant tissue or soil; the released phytotoxins are known as allelochemics or allelochemicals. Allelopathy is another harmful mechanism of these weeds. After understanding the biochemical and molecular structure, complex mechanism is used to overcome these challenges [24].

2.1 Terrestrial Weeds

The growth of the terrestrial weeds *Mikania micrantha* kunth*, Parthenium hysterophorus, Lantana camara, and Ageratum conyzoides* is problematic in India and various other countries. These weeds initiate economically and environmentally threats.

2.1.1 Lantana camara

Lantana camara is one of the most harmful terrestrial weed. It comes under the family of Verbenaceae. *L. camara* grows scrambling and horizontal for which reason it is mostly found on the floor of forests and plantations. Its bushy nature obstructs the function and balance of the ecosystem forest [11]. It is native to Central and South America, defined as an evergreen aromatic shrub [18] and now it is spread all over the world (shown in Fig. 1). In India, this weed was used as an ornamental plant in Calcutta [13] and now it is found all over the country. *L. camara* is found to be cytotoxic in nature. Lantadene A and lantadene B which are present in the leaves are responsible for the harmful effect of the plant [15]. Due to the allelopathy nature of *L. camara*, the growth of the other species in the forest started to decline [27, 6]. Ability of high regeneration potential and sexual reproduction it spread in a huge area within a short period of time [1]. To stop the expansion of this weed forest and cultivable lands, the management of this weed is required.

2.1.2 Ageratum conyzoides

Ageratum conyzoides is commonly named as “billy goat weed” or “goat weed”. It is mostly found in tropical and subtropical zones and it grows mainly in cultivated areas. The plant has a harmful effect on almost 36 crops (including plantations) and is found in 46 several countries [10]. It has been considered as 19 worst weeds of

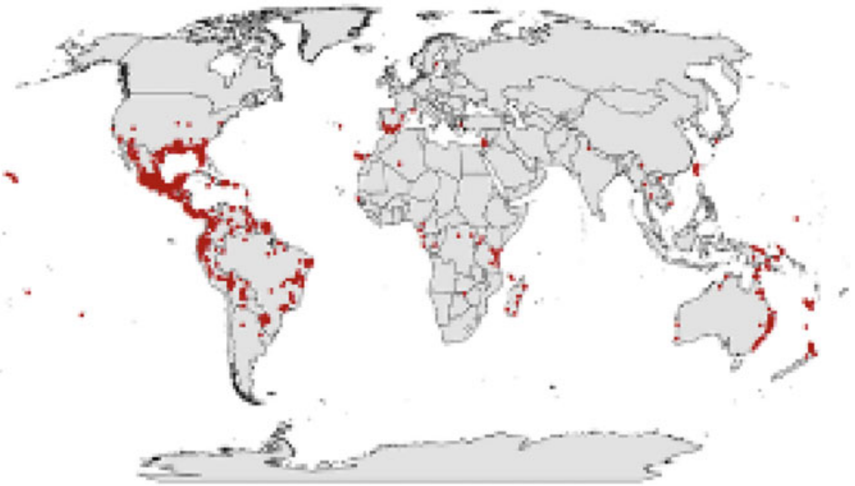

Fig. 1 Redmark represents presence of Lantana camara all over the world [19]

the world [10]. The origin of *A. conyzoides* is in Central America and the Caribbean, now it spread throughout the world [26]. This weed can be easily spread by air, water, and animals. The growth of crops like rice, wheat, corn, etc. has been declined due to the invasion of *A. conyzoides* [19]. The morphological features of this weed facilitate its dispersion as well as its high reproductive capability leading to a successful invasion in absence of natural predators. *A. conyzoides* shows allelopathic effects to a number of cultivated crops, which spread to soil due to volatilizing and leaching. Efforts in maintenence of crops are required to hinder the spread in fieldwork like ploughing. This comes along with increasing maintenence and operation costs.

2.1.3 Parthenium hysterophorus

Parthenium hysterophorus is found among the worst weed worldwide. This weed comes under the family of Asteraceae and it carries the name “Congress Grass”. This weed’s origin is in the southern United States, Mexico, Central and South America. Within the increase of global export and import it spread all over the world. Now, it is found all over the world (shown in Fig. 2). The growth of this weed became a serious issue over agricultural land and rangeland in Australia, Asia, Africa, and the Pacific Islands. The allelopathic nature of this weed reduces the crops production drastically. This weed has some harmful effects on humans that includes allergic reaction, respiratory problems, contact dermatitis, mutagenicity in human, and livestock [17]. *P. hysterophorous* interferes the early growth of surrounding plants [2]. *P. hysterophorous* is a global species [16], it spread in over 20

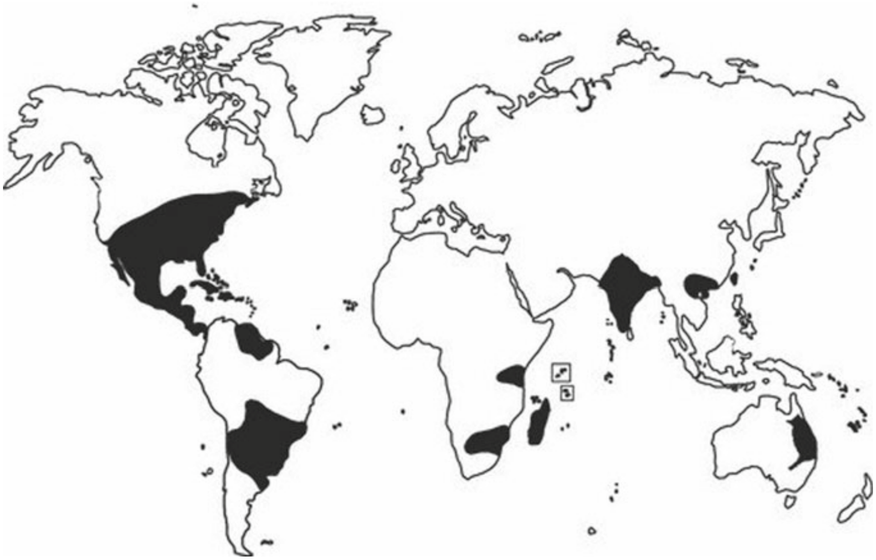

Fig. 2 This figure was reported by [19], 1994. Black color area indicates the distribution of *P. hysterophorous*

countries within Africa, Asia, and Oceania ([7]; Fig. 2). In Africa, this weed arises from South Africa [25, 9]. A Management was installed but an approach is still demanded.

2.1.4 *Mikania micrantha* Kunth

Mikania micrantha is a perennial vine native to subtropical zones of North, Central, and South America (Asia-Pacific Forest Invasive Species Network). The plant is commonly known as “mile a minute” that can grow up to 8–9 cm within 24 h. The main problems associated with *M. micrantha* is that it can smother other plant species inhibiting their photosynthesis process and takes up minerals from the surrounding plants. It has the ability to conquer a vast area once it is established and has huge ability to cope up with the environment. In India, the plant was invaded during 1940s as a ground cover for tea plantation and rubber. But because of its immense growth it has become threat to forest and other ecological system. A number of phytochemicals have been identified in this weed species. A lower level of nitrate and nitrogen was observed in plants grown with *M. micrantha.*

There was prominent reduction in rubber when *M. micrantha* smothers the rubber plant. Various management strategies have been applied to overcome the problems associated with *M. micrantha* but no appropriate outcome was observed because of its rapid growth.

Therefore, biological treatment can be a useful method for the management of this noxious weed.

3 Anaerobic Digestion and Composting, a Possible Way of Control This Weeds

P. hysterophorous is an ideal feedstock for methane production [8]. *P. hysterophorous* shows the potential to produce alcoholic biofuels after pre-treatment [20] Proper study of anaerobic digestion on *P. hysterophorous*, *A. conyzoids, L.camara* has not been done. So systematic anaerobic digestion study is necessary for sustainably control of these weeds. *P.hysterophorous* can be converted into compost [22]. [21] reported that *P. hysterophorous* and neem leaves can utilize for compost. *A.conyzoids and L.camara* can also be converted into compost. Not proper research has been done on compost of these weeds. Few literature review was found that show conversion converts these weeds into biogas and compost. More efficient study is required to convert this weeds into biogas and compost so that it can be utilized for various applications.

4 Conclusion

Although lots of management skills were applied to these noxious weeds that are not sustainable and economically beneficial. Anaerobic digestion and composting are some of the efficient techniques that can be applied for proper utilization of these invasive weeds. This can result in the production of methane gas and compost for agriculture use, respectively. This is one of the sustainable way to control these weeds and at the same time it converts into renewal energy and organic fertilizer, where energy and chemical fertilizer is one of the significant issue. Presence of lignin content in these weeds may cause challenges of anaerobic digestion and composting but pretreatment can overcome these challenges. More research is needful for recovery of biogas and composting technic to increase the efficiency.

References

1. Batish, D.R., Singh, H.P., Kohli, R.K., Johar, V., Yadav, S.: Management of invasive exotic weeds requires community participation. Weed Technol. **18**, 1445–1448 (2004)
2. Belgiri, A., Adkins, S.W.: Allelopathic potential of invasive *Parthenium* weed (*Parthenium hysterophorus L.*) seedlings on grassland species in Australia. Allelopath. J. **36**(1), 1–14 (2015)
3. Calado, J.M.G., Basch G., Carvelh, M.: Weed emerging in autumn under temperature conditions. Print version ISSN 0100-8358 (2011)
4. Chippendale, J.F., Panetta, F.D.: The cost of *parthenium* weed to the Queensland cattle industry. Plant Prot. Quart. **9**, 73–76 (1994)
5. Day, M.D., Neser, S.: Factors influencing the biological control of *Lantana* camara in Australia and South Africa. In: Proceedings of the X International Symposium on Biological Control of Weeds, pp. 897–908 (2000)
6. Day, M.D., Wiley, C.J., Playford, J., Zalucki, M.P.: Lantana: current management, status and future prospects. Aust. Centre Int. Agric. Res. **5**, 1–20 (2003)
7. Dhileepan, K., Strathie, L.: 2009., *Parthenium hysterophorus L.* (Asteraceae). In: Muniappan, R., Reddy, G.V.P., Raman, A. (eds.) Biological Control of Tropical Weeds Using Arthropods, pp. 274–318. Cambridge University Press, Cambridge, UK
8. Gunaseelan, V.N.: Impact of anaerobic digestion on inhibition potential of Parthenium solids. PII: S0961-9534(97)10019-8 (1996)
9. Hilliard, O.M.: Compositae in Natal, 659 pp. University of Natal Press, Pietermaritzburg, South Africa (1977)
10. Holm, L.G., Plucknett, D.L., Pancho, J.V., Herberger, J.P.: The World's Worst Weeds: Distribution and Biology, 609 pp. An East-West Centre Book, University Press of Hawaii, Honolulu, Hawaii (1977)
11. Iyengar, A.V.V.: The problem of the *Lantana*. Curr. Sci. **1**, 266–269 (1933)
12. Khosla, S.N., Sobti, S.N.: Effective control of *Parthenium hysterophorus* L. Pesticides **15**, 18–19 (1981)
13. Kohli, R.K., Batish, D.R., Singh, H.P., Dogra, K.S.: Status, invasiveness and environmental threats of three tropical American invasive weeds (*Parthenium hysterophorus L., Ageratum conyzoides L., Lantana camara L.*) in India. Biol. Invasions **8**, 1501–1510 (2006)
14. Li, Y., Khanal, S.K.: Bioenergy: Principles and Applications. Wiley, Hoboken (2016)
15. Ma, W.J., Xiao, D.J., Deng, S.Z.: Terpenoids constituents of the leaves of *Lantana camara*. Guangzhou Chem. **29**, 14–19 (2004)
16. Navie, S.C., Mcfadyen, R.E., Panetta, F.D., Adkins, S.W.: The biology of Australian weeds 27. *Parthenium hysterophorus* L. Plant Prot. Q. **11**, 76–88 (1996)
17. Patel, S.: Harmful and beneficial aspects of *Parthenium hysterophorus*: an update. Biotech. **1**(1), 1–9 (2011)
18. Raghubanshi, A.S., Rai, L.C., Gaur, J.P., Singh, J.S.: Invasive alien species and biodiversity in India. Curr. Sci. **88**(4), 539–540 (2005)
19. Saha, B., Davi, C., Kalamdhad, S.A., Khwairakpum, M.: Vermicomposting and anaerobic digestion—viable alternative options for terrestrial weed management—a review. Biotechnology Reports (2017). https://doi.org/10.1016/j.btre.2017.11.005
20. Singh, S., Khanna, S., Moholkar, S.V., Goyal, A.: Screening and optimization of pretreatments for Parthenium hysterophorous as a feedstock for alcoholic biofuels. Appl. Energy **129**, 159–206 (2014)
21. Sivakumar, S., Kasthuri, H., Prabha, D., Song, Y.C.: Efficiency of composting Parthenium plant and Neem leaves in the presence and absence of an olligochaete Eisenia fetida. Iran. J. Environ. Health. Sci. Eng. **6**(3), 201–208 (2009)

22. Sivaraj, R., Narendhran, S.: Ruthenium mediated compost versus Parthenium mediated vermicompost: a comparative study of nutrition status. In: International Conference on Chemical, Agricultural and Medical Sciences (CAMS-2013), Kuala Lumpur, Malaysia, Dec. 2930 (2013)
23. Vivek, N.S., Rana, R.S., Tomar, S.S.: Effect of weed interference on weeds and productivity of black gram (Phaseolus mungo). Indian J. Weed Sci. **40**, 65–67 (2008)
24. Weir, T.L., Park, S.W., Vivanco, J.M.: Biochemical and physiological mechanisms mediated by allelochemicals. Curr. Opin. Plant Biol. **7**(4): 472–479 (2004)
25. Wood, J.M.: Report on Natal Botanic Gardens for the Year 1896, 31 pp. Durban Botanical Gardens, Durban, South Africa(1897)
26. Xuan, D., Shinkichi, T., Hong, N.H., Khanh, T.D., Min, C.: Assessment of phototoxic action of *Ageratum conyzoides L.* (billy goat weed) on weeds. Crop. Prot. **23**, 915–922 (2004)
27. Zamalloa, C., Boon, N., Verstraete, W.: Anaerobic digestibility of *Scenedesmus obliquus* and *Phaeodactylum tricornutum* under mesophilic and thermophilic conditions. Appl. Energy **92**, 733–738 (2012)

A Comparative Study on Removal of Ammoniacal Nitrogen by Chemical and Biological Processes

Helly Mehta, Neha Patel, Desai Raj and Mehta Shiv

Abstract Nutrient compound such as ammoniacal nitrogen (NH_4-N), often present in different types of waters and wastewaters, can find their way to lakes, rivers and drinking water reservoirs and are alleviation of environmental problems including eutrophication, corrosion and fouling. Also, the Indian pharmaceutical industry is estimated to grow at 22.4% compound annual growth rate over the next 5 years. Therefore, it is necessary to treat the waste that is being generated from the treatment process to meet the stringent discharge. For this, a comparative study was conducted by performing series of experiments at laboratory scale by chemical process in which one of the most innovative and advanced physicochemical process was used, namely, MAP Process (Struvite crystallization) and its comparative study was made with the biological treatment process which was conducted using microbial growth of bacterial sppi for treating pharmaceutical wastewater. MAP process is also known as struvite formation was used under chemical treatment process which includes precipitation of struvite formation by addition of magnesium source followed by addition of phosphate source and mixed bacterial culture sppi was used under biological treatment process for the treatment of pharma waste mainly for the removal of ammoniacal nitrogen. Different stoichiometric ratios were tested and an optimum ratio was found for the maximum NH_4-N removal for the effluent. And their comparative studies with biological process, in which different mixed bacterial sppi were carried out for removal of NH_4-N. Biological processes are time-consuming but non-polluting. Different concentrations of mixed bacterial

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culture give different percentage removal of ammoniacal nitrogen and their removal efficiencies were compared with MAP process results.

Keywords Pharmaceutical wastewater · Ammoniacal nitrogen · MAP process · Struvite solution · Incubation

1 Introduction

Contamination of water resources through nitrate and its other derivatives are becoming a serious environmental problem worldwide nowadays. Ammoniacal nitrogen (unionized ammonia, NH_3, and ammonium ion, NH^{4+}) has been found to exist in various types of agricultural, municipal (domestic) and many industrial wastewaters [2]. Also it is noticeable that the presence of nitrogen excess in the aquatic environment has caused natural nutrient cycle. Furthermore, it is also observed that high nitrate levels in water can cause methemoglobinemia (a condition found especially in infants of age under 6 months). Not even that, also the animals are affected by nitrates in the same way as human babies. Ammonia is known to be very toxic for fish; concentrations as low as 0.2 mg/l to 0.5 mg/l can be fatal. As far as, ammoniacal nitrogen is considered it also contributes to BOD in water.

Studies indicate that there are many conventional treatment processes for $NH4^+$-N removal which involve biological nitrification, denitrification, air stripping, [6, 18] chemical treatment and selective ion exchange [8]. Also, ammoniacal nitrogen has a contribution to corrosion of certain metals and to reduce the amount of dissolved oxygen in water due to nitrification process. High concentration of ammonium in surface water makes it unsuitable as drinking water; ammonium can reduce disinfection efficiency, conduct to nitrate formation, and cause taste and odour problems.

Struvite formed from the precipitation in wastewater containing high ammoniacal nitrogen is crystalline structure as white orthorhombic crystals [12]. Crystalline structure is formed by struvite precipitation which includes successive addition of magnesium source and phosphate source in equal molar concentrations with ammoniacal nitrogen which is contained by the waste stream itself. Struvite solubility decreases with increasing pH, and on the other hand we also know that ammoniacal nitrogen also has tendency to get evaporated at that pH values or above [6]. As a result of that, it becomes essential to optimize the dosage. This process of MAP is controlled by pH, super saturation, temperature and impurities such as calcium as review from the literature. On the other hand, if specific environment is provided under specific suitable conditions to the bacteria's, biological process for nitrogen removal can be enhanced. There are three steps through which biological treatment of wastewater for removal of nitrogen can be achieved by following the mentioned treatment processes. For bacteria to perform at their optimum range, careful control of process condition is required. For this, understanding of biological treatment process in wastewater treatment plant is required.

This process includes

- Ammonification (In this process breakdown of organic N to NH_3-N occurs);
- Nitrification (Here, oxidation of NH_3-N to NO_3-N will take place) and;
- Denitrification (Final stage includes conversion of NO_3-N to N_2).

The microorganisms involved in denitrification are facultative heterotrophic and are usually abundant in domestic sewage; examples are Pseudomonas, Micrococcus and others (Arceivala, 1981) [1]. The process of denitrification occurs under anoxic conditions. Denitrification is a process in which nitrates are transformed to nitrite, nitric oxide, nitrous oxide and finally molecular nitrogen, which is released into the atmosphere. And on the other hand, nitrifying bacteria require a large amount of dissolved oxygen to convert NH_3 into NO_3^- (4.3 mg of O_2 for every 1.0 mg of NH_3).

The heterotrophic microorganisms that use nitrite or nitrate instead of oxygen as electron acceptors and organic matter as a carbon and energy source oxidizes nitrogen compounds (NO_2^- and NO_3^-) and reduce them to gaseous nitrogen [5, 9]. Also it has been studied that denitrifying bacteria are ubiquitous in nature and numerous researchers cultivated them using mixed cultures taken from wastewater treatment plants as seeds [17].

In context to that, Dong Wei (2013) in his studies has showed biological nitrogen removal (BNR) that is commonly used in wastewater treatment plants involving two processes: NH_4-N is oxidized to NO_3-N during aerobic nitrification process and NO_3^--N to molecular nitrogen during anoxic denitrification (full nitritation, 100% ammonium conversion to nitrite) [19]. For the abovementioned process, bacteria such as Nitrosomonas, Nitrosococcus, Nitrosospira and Nitrosolobus were used. These species are mainly used for the removal of ammoniacal nitrogen under the category of biological treatment of ammoniacal nitrogen removal. Subsequently, nitrite is oxidized to nitrate (NO_3^-), process performed by bacteria Nitro bacter [15]. Schmidt in the year 2003 reviewed those processes that make use of new concepts in microbiology which includes partial nitrification, nitrifier denitrification and anaerobic ammonia oxidation [16].

Research studies indicate that in 2014, one of the researchers named Nur Farehah proposed two conditions of treatment (aerobic as well as anaerobic) environment in SBR and three isolated bacteria from worm tea have been used in the semiconductor wastewater treatment. The isolated bacteria's are, namely, Bacillus pumilus, Micrococcus lutues and Staphylococcus warnaeri. His results showed efficiencies of removal of ammoniacal nitrogen by Staphylococcus warneri is 97.2% which remained NH_3N 30 mg/L from initial NH_3N 1000 mg/L, Bacillus pumilus is 60.7% and Micrococcus lutues is 79.2%, respectively [14]. Therefore, in considerations to all the above literature and detail analysis to what the work has been carried out till now for the removal of ammoniacal nitrogen, our present study was to determine the optimal MAP ratio for the removal of ammoniacal nitrogen and its comparative analysis with biological process using microorganisms which have ended with the conclusion mentioned at the end of the study.

2 Materials and Methods

2.1 Raw Wastewater

The raw wastewater used in this experiment was collected from the outlet of the effluent treatment plant (ETP) of a pharmaceutical company located near Vapi, Gujarat. The sample was stored at 4 °C immediately after collection. Its initial characterization is shown in Table 1.

2.2 Chemicals for Struvite Formation

For the effective removal of ammonia, some phosphate and magnesium salts are required to be added. In this study, MgCl2.6H2O was with 11.8% Mg content was used as a source of magnesium in struvite precipitation. As for the phosphate source, Na2HPO4 was used with 21.8% P content. In addition, MgCl2.6H2O, and Na2HPO4 of analytical grade were used in this study.

2.3 Experimental Procedure for MAP Process

Take 1 L of beaker, in which sample to be tested is taken. In MAP process, during its first step the experiment was carried out using 1 L of Parma wastewater and was allowed to treat with moderate speed agitator (mixer). Before the treatment, all the parameters were estimated and later on some calculative amount, precipitating reagents were added which is shown in Table 2. Also note that for the process of struvite precipitation, pH at this stage should be maintained at about 9 value. Here, in this case, our sample was alkaline so chemical addition was not required to maintain the pH value. $MgCl_2.6H_2O$ (20_3) was added in calculated amount followed by the addition of Na_2HPO_4 according to the stoichiometric calculations,

Table 1 Characteristics of raw wastewater

Sr. no.	Parameter	Method used	Values	Permissible limit
1.	pH	Glass electrode	7.8–8.1	5.5–9
2.	TDS	Gravimetric method	15,248 mg/L	2100 mg/L
3.	TSS	Gravimetric method	22 mg/L	100 mg/L
4.	NH_4-N	Kjeldahl method	1,710 mg/L	50 mg/L
5.	COD	Open reflux	5,747 mg/L	250 mg/L
6.	BOD (3 days at 27 ° C)	–	1170 mg/L	30 mg/L

Table 2 Calculation of precipitating reagent for ratio 1:1:1

NH_4-N present in the wastewater sample	1.050/14 = 0.075 gmol
Mg required to treat the wastewater sample	0.075 × 1 = 0.075 gmol
Mg(24) content in $MgCl_2.6H_2O$ (20_3)	11.82%
Mg required	0.075 × 1 × 24/0.118 = 15.254 g/l
Na_2HPO_4 required	= (0.075 × 1 × 31)/0.218 = 10.66 g/l

which is shown in Table 2. Now the sample is ready for agitation and is allowed to mix for 15 min at moderate speed. Estimate the results after the settlement of struvite complex and collect the supernatant for its characterization. Follow the experiments by varying time as well as pH values for gaining optimum results for the removal of ammoniacal nitrogen.

2.3.1 Stoichiometric Calculation

When the sample was collected, the value of parameter NH4-N was of about 1710 mg/L. But after pretreatment its value was estimated as 1050 mg/L. Also, it is to be noted that the optimum ratio considered for the stoichiometric calculation is 1:1:1. The calculation is shown for one sample and rest is calculated in the same manner.

2.4 Experimental Procedure for Biological Process

Take 100 ml sample in each set of three sterile flasks after washing it with distillate water. Inoculate the sample with Nitrosomonas (10 ml) which was cultivated before and keep them on shaker mechanism for 5 days. Process of nitrification takes place under aerobic conditions only. Now add denitrifying bacteria such as *Pseudomonas, Staphylococcos Warneri* and *Anaerobic* Mixed bacterial Culture into three different samples in anaerobic condition, as the process of denitrification takes place most efficiently in anaerobic condition. Label them properly. Analyse the result after the next 5 days for reduction in NH4-N. For biological nitrogen removal, 10 days were given for simultaneous nitrification and denitrification process to take place.

3 Results and Discussion

To carry out MAP process for struvite formation, pH should be raised up to 8.5. After raising pH, MAP process is carried out keeping the ratio of Mg:N:P = 1:1:1 constant and changing the time period of chemical reaction.

3.1 Reduction by MAP Process

Mg:N:P = 1:1:1, pH-8.5

It is clear from the above table that the above MAP process is not time based and it is moles to moles reaction. It is quick chemical reaction process and the reduction in ammoniacal nitrogen is obtained up to 426 mg/L. Reduction in COD was obtained up to 4748 mg/L (Table 3 and Fig. 1).

3.2 Varying Different Molar Ratios of Mg and P

For maximum removal of NH4-N by varying magnesium chloride and Di-sodium Hydrogen Phosphate ratios, we get the following results for reduction in ammoniacal nitrogen in form of struvite formation. The table below shows the different ratios with mixing time 15 min, the molar ratio range of (a) Mg:N:P = (0.8–1.3:1:1); (b) Mg:N:P = (1:1:0.8–1.3) (Tables 4 and Figs. 2 and 3).

Table 3 Reduction of NH4-N By MAP process

Sr. no.	Time period (min)	pH	NH_4-N after treatment (mg/L)	COD after treatment (mg/L)
1.	0	8.5	1050	5747
2.	15	4.5	426	5017.6
3.	30	4.3	434	4704
4.	60	4.2	420	4704
5.	90	4.2	426	4860.8
6.	120	4.2	426	4547.2

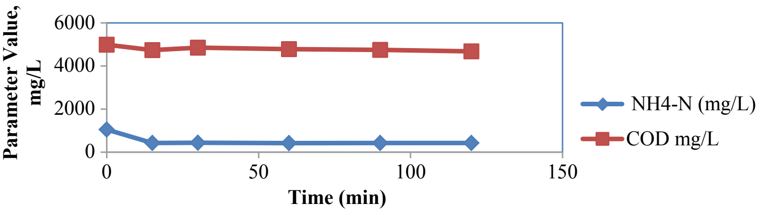

Fig. 1 Graphical presentation of % removal of NH4-N

Table 4 (a) Percentage removal of NH4-N for Mg:N:P = (0.8–1.3:1:1) (pH = 8.01, Initial NH4-N = 1050 mg/L) (b) Percentage removal of NH4-N for Mg:N:P = (01:1:0.8–1.3) (pH = 7.5, NH4-N = 1050 mg/L)

Sr. no.	Ratio Mg:N:P	Final NH_4-N (mg/L)	% removal	Initial COD (mg/L)	Final COD (mg/L)	% removal
1.	0.8:1:1	378	64	4990	3872	22.40
2.	0.9:1:1	364	65.33	4990	3980	20.24
3.	1:1:1	336	68	5747	4990	13.17
4.	1.1:1:1	322	69.3	4990	4489	10
5.	1.2:1:1	322	69.3	4990	4210	15.63
6.	1.3:1:1	329	68.6	4990	3980	20.24

Sr. no	Ratio Mg:N:P	NH_4-N after treatment (mg/L)	% removal of NH_4-N
1.	1:1:0.8	266	74.47
2.	1:1:0.9	308	70.6
3.	1:1:1.0	336	68
4.	1:1:1.1	350	66
5.	1:1:1.2	364	65.33
6.	1:1:1.3	364	65.33

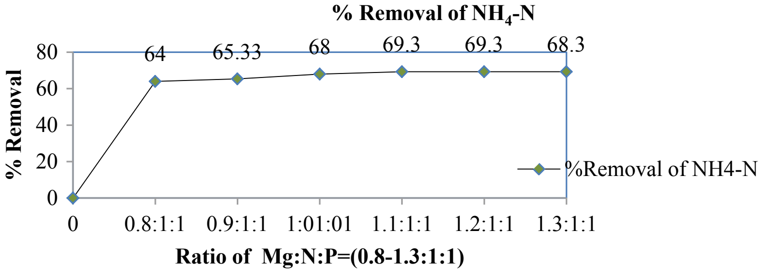

Fig. 2 Graphical representation of % removal of NH4-N

3.3 Graphical Representation of NH4-N Removal for Mg:N:P = (0.8–1.3:1:1)

It is to be noted that after the conduction of experiment at the stoichiometric ratio when Mg:N:P was of the molar ratio 1:1:0.8, removal of NH4-N reached nearly the maximum values. Therefore, we can conclude from the above experiment that the molar ratio of 1:1:0.8 was determined to be optimum for the removal of NH4-N from pharmaceutical wastewater by struvite precipitation.

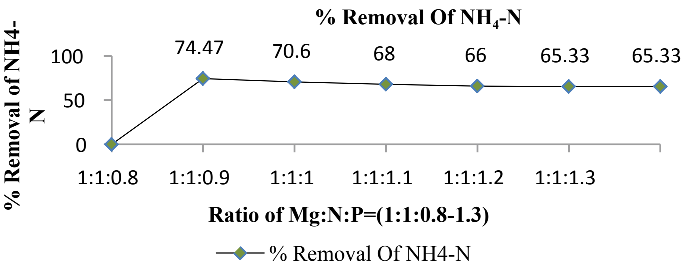

Fig. 3 Graphical representation of NH4-N removal for Mg:N:P = (1:1:0.8–1.3)

3.4 Biological Process Results

As bacteria are easily available and their reduction in ammoniacal nitrogen has also been noticed, different species of bacterial culture along with their mixed combination have been studied. Waste sample is treated by Nitrosomonas bacteria up to 5 days for nitrification and after that the denitrifiers such as *Pseudomonas, Staphylococcus warneri* and *Anaerobic Mixed Culture* are added and again kept in incubator for another 5 days. Their results are shown in Table 5.

From above results, it is clear that *Staphylo coccus Warneri* bacteria gives the maximum reduction in NH4-N from all the other bacterial species. Reduction in NH4-N is obtained up to 88% and along with it reduction in COD is about 10.6% only. *Pseudomonas Species* give maximum COD reduction, i.e. 63% that was checked during experimental work. But for a comparative study against removal of ammoniacal nitrogen using chemical and biological processes, biological process proved to be more effective and efficient. It is non-polluting and does not generate sludge that needs to be discarded. The only problem that exists in biological processes are they take much time to give final results and species used need much favourable condition to grow. Here in this study, chemical process such as MAP process gives maximum reduction up to 73.3%, whereas biological process using *Staphylo coccus Warneri*bacteria gives up to 88% reduction in ammoniacal nitrogen and noticeable reduction in COD up to 21.44% by MAP process and 49.93% by biological process. Also, the sludge in the form of struvite complex formed here can be sold out to fertilizer making industries. So, chemical process can now also be more favourable for most effective removal of NH4-N from waste stream.

Table 5 Percentage removal of NH4-N by bacterial *Species* (Initial NH4-N = 1050 mg/L, Initial COD = 4990 mg/L)

Sr. no.	Bacterial species	Reduction in NH_4-N (mg/L)	% reduction
1.	Pseudomonas	226	78.47
2.	Staphylo coccus Warneri	126	88
3.	Anaerobic Mixed Culture	406	61.3

4 Conclusion

From chemical process, if MAP process is used for NH4-N reduction, depending on the waste parameters, it can not only reduce ammoniacal nitrogen but also the complex formed in this process is in a form of struvite which can be used for many other purposes such as horticulture, agriculture and for recovery of N and P. Thus, using chemical process also is more convenient for any industries to treat their waste, as no industries will be able to consume their time for biological process to take place for more than 1–2 days. And for reduction of NH4-N, there will be at least 10 days given to carry out their biological process.

References

1. Arceivala, S.J.: Wastewater Treatment and Disposal, p. 892. Marcel Dekker, New York (1981)
2. ASCE and AWWA: Water Treatment Plant Design, 2nd edn, p. 197. McGraw-Hill Publishing Company, New York (1990)
3. Ayusho, M., Pascual, J.A., Garcia, A., Hremandez, T.: Evaluation of urban wastes for agricultural use. Soil Sci. Plant Nutr. **42**, 105–111 (1996)
4. Carrera, J., Baeza, J.A., Vicent, T., Lafuente, J.: Biological nitrogen removal of high-strength ammonium industrial wastewater with two-sludge system. Water Res. **37**, 4211 (2003)
5. Cyplik, P., Grajek, W., Marecik, R., Kroliczak, P.: Effect of macro/micro nutrients and carbon source over the denitrification rate of Haloferaxdenitrificans archaeon. Enzym. Microb. Technol. **40**, 212–220 (2007)
6. Daekeun, K., Ryu, H.D., Kim, M.S., Kim, J., Lee, S.: Enhancing struvite precipitation potential for ammonia nitrogen removal in municipal landfill leachate. J. Env. Qual. **30**, 1548–1563 (1996)
7. Jeong, Y.K., Hwang, S.J.: Optimum doses of Mg and P salts for precipitating ammonia into struvite crystals in aerobic composting. Bio. Tech. **96**, 1–6 (2004)
8. Kauspediene, D., Snukiskis, J.: Recovering ammonium nitrate from the waste fertilizer production by sulphonic cation exchangers. Environ. Technol. **28**, 1119 (2007)
9. Kim, J.K., Park, K.J., Cho, K.S.: Aerobic nitrification–denitrification by heterotrophic Bacillus strains. Biores. Technol. **96**, 1897–1906 (2005)
10. Khwairakpam, M., Bhargava, R.: Vermitechnology for sewage sludge recycling. J. Hazard. Mat. **161**, 948–954 (2009)
11. Li, Y.Z., Peng, C.Y., Peng, Y.Z., Wang, P.: Nitrogen removal from pharmaceutical manufacturing wastewater via nitrite and the process optimization with on-line control. Water Sci. Technol. **50**, 25–30 (2004)
12. Metcalf, E.: Advanced Wastewater Treatment in Wastewater Engineering: Treatment, Disposal and Reuse, 3th edn., p. 663. McGraw-Hill, New York (1991)
13. Michalowski, T., Pietrzyk, A.: A thermodynamic study of struvite plus water system. J. Talanta **68**, 594–601 (2006)
14. Miles, A., Ellis, T.G.: Struvite precipitation potential for nutrient recovery from anaerobically treated wastes, vol. 1. Ames, IA, 50011–3232 (1996)
15. NurFarehah, Z.A., Norli, I.: Ammoniacal nitrogen removal in semiconductor wastewater by sequence batch reactor using bacteria inoculum from WormTea. J. Med. Bioeng. **3**(4) (2014)
16. Rodriguez, D.C., Penuela Mesa, G.: Ammoniacal nitrogen removal in wastewater using nitrifying and denitrifying bacteria in a SBR system. New Biotechnol. **25**, S353 (2009)

17. Schmidt, I., Sliekers, O.: New concepts of microbial treatment processes for the nitrogen removal in wastewater. FEMS Microbiol. Rev. **27**, 481–492 (2003)
18. Szekeres, S., Kiss, I., Bejerano, T.T.: Hydrogen-dependent denitrification in a two-reactor bioelectrochemical system. Water Res. **35**, 715–719 (2001)
19. Wei, D., Xue, X.: Effect of influent ammonium concentration on the shift of full nitritation to partial nitrification in a sequencing batch reactor at ambient temperature. Chem. Eng. J. **235**, 19–26 (2014)

Effects of Using Kota Stone as Filler on Mechanical Properties of Asphalt Concrete Mixes

Sarvesh Singh, Jayvant Choudhary, Brind Kumar and Ankit Gupta

Abstract This study utilized waste dimension limestone (viz. Kota stone) dust as a surrogate filler to conventional stone dust in asphalt concrete mixes. Primary characterization of both fillers was done through specific gravities, particle size distribution, German filler values, X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), plasticity index, hydrophilic coefficient and pH value tests. Asphalt mixes were designed and tested as per Marshall test procedure recommended in Indian paving specification. Retained stability values and Marshall Quotient of both mixes were determined at their optimum binder contents. Kota stone mixes displayed superior mechanical properties and rutting resistance, which was attributed to the lower their relatively lower apparent film thickness. Kota stone mixes displayed and improved the resistance against moisture permeation due to the presence of Calcite, which improved aggregate–bitumen adhesion.

Keywords Asphalt concrete · Filler · Kota stone · Marshall properties · Moisture resistance

1 Introduction

India is a developing country having a large road network that primarily consists of flexible pavements which usually adopt asphalt concrete mixes in their surface course. Filler can be termed as the finest part of aggregate, having particle sizes finer

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than 0.075 mm. As per Indian specifications, filler should be devoid of organic particles, active clay content and its plasticity index value should not exceed to four [1]. Filler type and its quantity in asphalt mixes influence the economy as well as the asphalt mix's behaviour against various primary distresses and thus influence pavement's behaviour from the construction stage to the end of its service life [2]. Filler displayed dual behaviour in asphalt mixes, where coarser filler particles behave as non-reactive material which fills voids in between various aggregates in the mix, while finer filler particles become part of asphalt mastic and affect its viscosity as well as consistency [3]. The asphalt mix's performance against primary pavement problems like ageing, cracking, fatigue, ravelling, rutting and moisture susceptibility are dependent on filler's physical properties (particle size, particle shape, particle surface texture, particle gradation and void contents, etc.), chemical properties (quantity of active clay and mineralogy, etc.) and to filler binder interaction [2, 3]. Hence, it is necessary to choose appropriate filler for ensuring optimum performance of asphalt mixes. Today, researchers are showing interest in adopting various wastes and by-products from different sources as fillers in order to counter growing environmental problems and increase of the cost of standard fillers (cement, hydrated lime and stone dust). Various wastes like dimensional stone wastes, sewage sludge ash, rice straw ash, copper tailings, carbide lime, etc., have improved performances of asphalt mix in various aspects when utilized as filler [4–7].

According to ASTM C-119, Dimension stone can be defined as natural stone, which is produced to the specific size and size with or without having one or more mechanically finished surfaces and can be used in building components, pavement surfaces, monuments and various other industrial products [6, 8]. At the global level, dimensional limestone is considered as one of the popularly used dimension stone because of its cheap cost as well as its ability to get polished as good as that to marble [9]. Dimension limestone is usually recognized in India by the name of its place of origin (Kota) as Kota stone [6]. During the cutting and polishing of large slabs of Kota stone, water is utilized as the coolant, which cools the saw blades and removed the powdered dust. The water forms slurry with the suspended dust which travels through drains to the nearby sedimentation tank. This settled slurry is being disposed of to landfills where water gets evaporated, leaving behind fine dust which gets airborne with the wind and causes contamination which leads to the problems regarding the bronchial, skin and vision disorders in the residents of their neighbouring areas [6]. There are several studies which assess the prospect of recycling stone waste in different purposes [9, 10]. However, studies concerning the usage of waste dimension limestone slurry in flexible pavement are very limited. This novelty of this study is that it investigated the possibility of utilizing waste Kota stone dust from dimension stone industry as replacement filler in asphalt mixes. Recycling of slurry waste as filler not only ensures its environmental-friendly disposal but also conserves conventional fillers (hydrated lime, cement and stone dust) as well as ensures economic pavement construction.

2 Material Properties and Experimental Investigations

2.1 Material Properties

Aggregates. This study utilized the aggregates which are crushed, angular and of dolomite origin. All aggregates were obtained from the quarry located in the Sonbhadra region of the Uttar Pradesh state of India. All aggregates were properly washed and sieved over their respective sieve to remove additional fine dust adhered to them. Table 1 displayed the characterization properties of aggregates. The gradation of mix was chosen according to the guidelines specified the Indian specifications [1] and is given in Table 2.

Asphalt. VG 30 (Viscosity Grade 30) asphalt, similar to 60/70 penetration grade asphalt, was locally collected and used. Various properties of asphalt were evaluated according to IS:73 (2013) specification and displayed in Table 1.

Filler. Dolomite stone dust was taken as standard filler and obtained locally. Kota stone dust was taken from the municipal dumping ground situated in the Kota city of the India state of Rajasthan. Both fillers were dried in the moisture oven for overnight and sieved on 0.075 mm sieve. Only the filler portion which is finer than 0.075 mm sieve is used for the analysis. Various physical characterization parameters such as specific gravity, plasticity index, particle size distribution and fractional void content were assessed using specific gravity test [11], plasticity

Table 1 Characteristics of the aggregates and the asphalt

Component	Physical characteristic	Testing specification	Obtained result
Aggregates	Bulk specific gravity of coarse aggregates	ASTM C127	2.795
	Apparent specific gravity of coarse aggregates		2.820
	Water absorption (%)		0.374
	Bulk specific gravity of fine aggregates	ASTM C128	2.702
	Apparent specific gravity of fine aggregates		2.747
	LA Abrasion Value (%)	IS:2386 (Part IV)	13.40
	Aggregate Impact Value (%)		11.10
	Combined Flakiness and Elongation Index (%)	IS: 2386 (Part I)	21.30
Asphalt	Absolute viscosity at 60 °C (poise)	IS: 73(2013)	2692
	Softening Point (°C)		51.5
	Penetration at 25 °C (0.1 mm)		62
	Ductility at 27 °C (cm)		>100
	Specific gravity		0.999

Table 2 Mix Gradation

Sieve size (mm)	Recommended range (Cumulative % passing)	Gradation selected (Cumulative % passing)
19	100	100
13.2	90–100	91
9.5	70–88	78
4.75	53–71	67
2.36	42–58	52
1.18	34–48	45
0.6	26–38	35
0.3	18–28	23
0.15	12–20	13
0.075	4–10	4.0

index test, particle size analysis [12] and German filler test value, respectively. Methylene blue value test [13] was used to calculate the harmful clay present in the filler. Mineralogy and morphology of fillers were studied with the help of X-Ray Diffraction (XRD) and Scanning Electron Microscope (SEM) analysis. Apart from these, pH value and hydrophilic coefficient [14] analysis were performed to determine affinity of both fillers towards asphalt. The results of various tests are stated in Figs. 1, 2, 3 and in Table 3.

2.2 *Design and Experimental Evaluation of Asphalt Concrete Mixes*

Mix design of the asphalt concrete mixes. This study adopted the procedure of the mix design stated in MS-2 [15] specification to calculate the Optimum Binder Content (OBC) of prepared mixes. OBC is defined as binder content of the mix corresponding to the air void content of 4%. According to this procedure, mixes with chosen gradation (Table 1) and different binder contents (5–7% at 0.5% interval) were prepared. All ingredients were heated at the mixing temperature chosen according to the MS-2 specification to achieve uniform binder coating on aggregates. The Marshall specimens of diameter 101.5 mm and 63.5 mm thickness mixes were prepared after the compaction of mixes using standard Marshall Compactor which provided 75 blows on each side. 15 specimens (3 at each binder content), were designed for each filler and various properties like stability, flow value, Voids in Mineral Aggregates (VMA), Voids Filled with Binder (VFB) and air voids (VA) were determined. Apparent Film Thickness (AFT) of every asphalt mix was determined at their OBC according to the procedure suggested by NCHRP Report 567 [16]. AFT was calculated as per the Eq. 1.

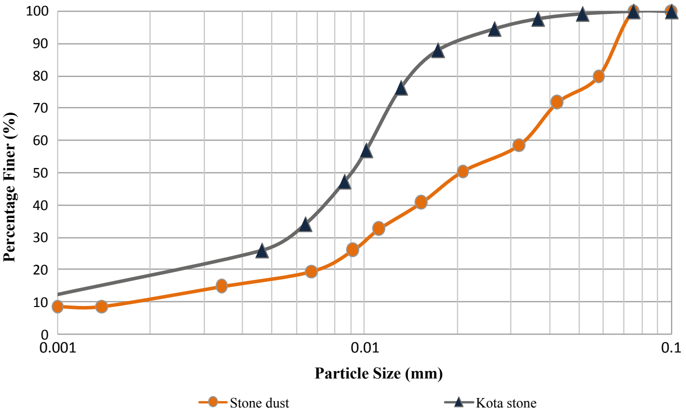


Fig. 1 Gradation of both fillers

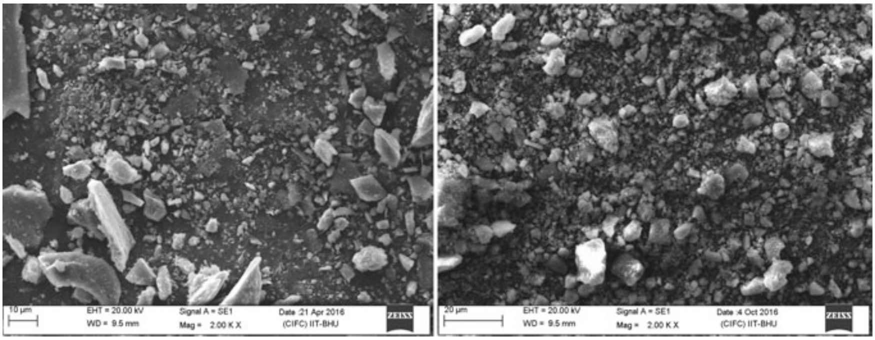


Fig. 2 SEM of stone dust (left) and Kota stone dust (right)

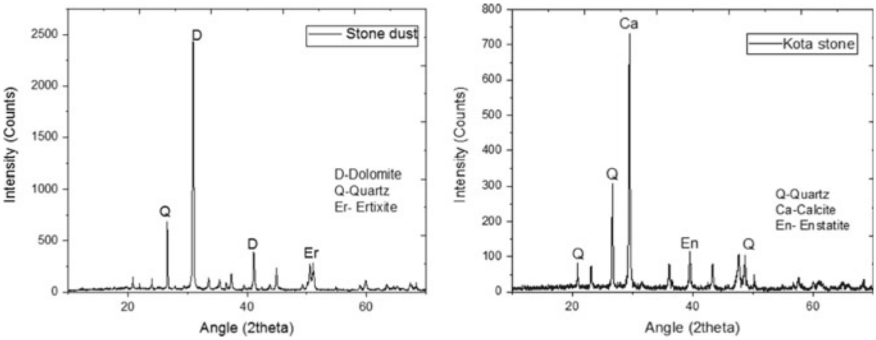


Fig. 3 XRD test results of stone dust (left) and Kota stone dust (right)

Table 3 Various filler characteristics

Property	Kota stone dust	Stone dust	Inferences
Specific gravity	2.65	2.70	Both materials have similar specific gravities and thus both will occupy almost similar volume in asphalt mixes
Plasticity index	4.0	2.3	Both fillers satisfied criteria for plasticity index as per Indian specifications
Methylene Blue Value (MBV) (mg/g)	3.75	3.25	Both materials have low harmful clay contents (<20 mg/g)
German filler test value (g)	97	85	Stone dust have relatively higher fractional voids per unit weight and thus expected to have higher optimum binder content
Fineness modulus	3.03	5.38	Kota stone can be considered as finer filler than stone dust
Shape and texture	Small size, granulous and somewhat subrounded grains having relatively rough texture	Angular grains having texture varying from rough to smooth	Kota stone has relatively small and granular size particles with rough texture. This may led to greater bitumen absorption
Primary Mineralogical Composition (XRD)	Calcite ($CaCO_3$); Quartz (SiO_2); Enstatite ($Mg_2Si_2O_6$)	Ertixite ($Na_2Si_4O_9$); Quartz (SiO_2); Dolomite ($CaMg(CO_3)_2$);	Both fillers constituted calcite and dolomite in their composition which are calcium-based insoluble mineral having good bitumen adhesion. No expansive clay mineral was found in both materials. Thus satisfactory stripping resistance is expected from both
Hydrophilic coefficient	0.80	0.77	Both material displayed hydrophobic nature
pH	8.74	12.58	Both materials displayed alkaline nature and showed decent affinity towards binder

$$AFT = \frac{1000VBE}{S_s P_s G_{mb}} \tag{1}$$

where

VBE (Effective binder content) (% of the total mix volume); S_s (specific surface area of aggregates) (m^2/kg); P_s (percentage of the aggregates) (% of total weight of the mix); G_{mb} (mix's bulk specific gravity)

Rutting resistance. Marshall Quotient (MQ) can be termed as the ratio of Marshall stability (kN) to flow (mm) in the mixed at OBC. MQ is used to determine the stiffness of the mix, which also an indirectly measures the resistance of asphalt mix against rutting. Asphalt mix having higher MQ value usually displayed superior resistance against permanent deformation or rutting.

Moisture susceptibility tests. Retained Marshall Stability (RMS) test was conducted to determine the moisture susceptibility of both mixes. For each type of mix, a total of six Marshall specimens were prepared at OBC which were divided in two groups, each having three specimens. The first group (unconditioned specimen) was placed in water maintained at 60 °C for 30 min. Similarly, the second group (conditioned specimens) was placed submerged in water maintained at 60 °C for 24 h. Both set of specimens were loaded to failure at constant compression rate of 51 mm/min using curved steel loading plates. The RMS was determined by taking mean stability values of each sample group according to the equation

$$RMS = \frac{MS_{cond}}{MS_{uncond}} \times 100 \tag{2}$$

where MS_{uncond} is the average Marshall stability for unconditioned specimens (kN); and MS_{cond} is mean Marshall stability for conditioned specimens (kN).

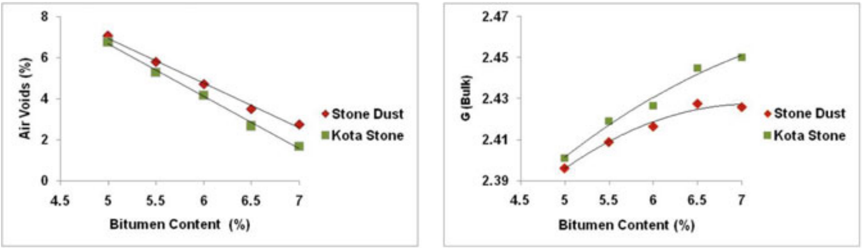
3 Test Results

3.1 Analyses of Marshall and Volumetric Properties

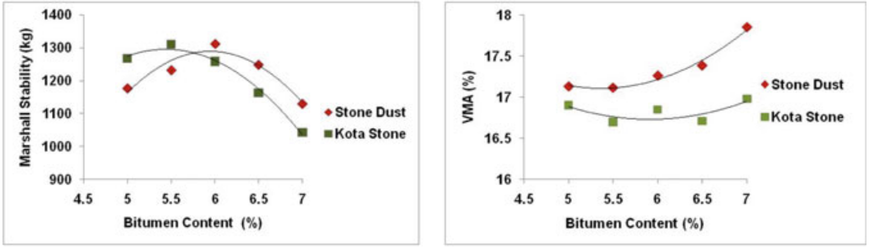
Analysis of mix's properties are given in Table 4 and in Fig. 4a–f. It was observed that Kota stone mix (5.96%) has relatively lower OBC than conventional mix (6.29%) (Fig. 4a). This was attributed to the relatively lower porosity of Kota stone, since it has higher German filler value (97 gm) than stone dust (85 gm) [6]. Because of the lower porosity of Kota stone dust, its mixes seemed to have lower values of VMA as well as air void contents at same binder contents (Fig. 4a and d). This may

Table 4 Various parameters of mixes at OBC

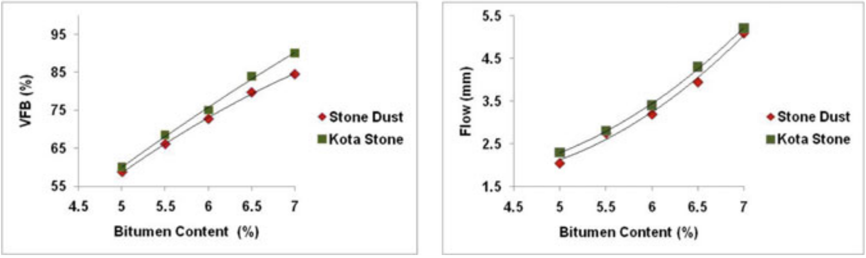
Mix	OBC	Marshall stability	Flow	Bulk specific gravity	VMA	VFB	AFT (μ)
Stone dust	6.29%	12.51 kN	3.51 mm	2.423	17.26%	74.70%	8.14 μ
Kota stone	5.96%	12.44 kN	3.38 mm	2.438	16.7%	74.90%	7.91 μ
Requirements	–	9 kN (minimum)	2–4 mm	–	14% (minimum)	65–75%	–



(a). Air voids versus binder content **(b).** Bulk Specific Gravity versus binder content



(c). Marshall Stability versus binder content **(d).** VMA versus binder content



(e). VFB versus binder content **(f).**Flow versus binder content

Fig. 4 Properties of mixes at different binder contents

justify their lower requirements of binder to reach the air void content of 4%, which may be responsible for their relatively lower OBC than stone dust mixes.

Lower air voids in Kota stone mixes may also lead to their higher bulk specific gravities (Fig. 4b). Marshall stability is defined as the load resisting capability of the asphalt mix and depends on its ingredient as well as on the interaction between them. Kota stone is the finer filler than the stone dust since it has lower fineness modulus (3.03) than the stone dust (5.38). Hence it seemed that Kota stone modifies the binder at a greater extent and produced Marshall stability equivalent to the stone dust mixes at the relatively lower OBC (Fig. 4c). Stone dust and Kota stone mixes have VFB values equal to 74.9% and 73.57%, respectively. Since VFB value of Kota stone mixes is lower than stone dust mixes, Kota stone dust may be preferred especially in the region having hotter ambiance. Average AFT of Kota stone mixes (7.91 µ) was also relatively lower than conventional mixes (8.14 µ), which might be due to the lower OBC of their mixes.

3.2 Analysis of Marshall Quotient

Marshall Quotient (MQ) value of Kota stone mix (3.68 kN/mm) was marginally higher than standard mix (3.56 kN/mm). Lower AFT of an asphalt mix is a responsible factor for its superior performance against rutting [16]. It was stated earlier that the Kota stone mixes has lower AFT than conventional mix, which may be responsible for its higher rutting resistance (Fig. 5).

3.3 Retained Marshall Stability Test

Both mixes fulfilled the minimum requirement of 75% Retained Marshall Stability (RMS) as suggested by Indian specification [7]. Kota stone mixes (96.41%) had slightly higher RMS values than conventional mixes (93.19%), which might be due to the good quantity of water insoluble calcite in the mineralogy of Kota stone dust.

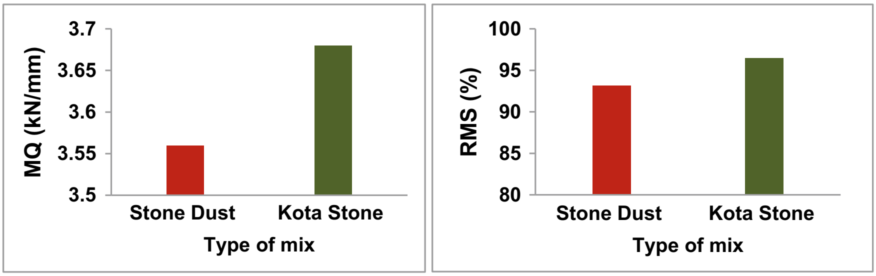


Fig. 5 Marshall Quotient (left) and Retained Marshall Stability (right) of studied mixes

4 Conclusions and Discussions

The following conclusions can be derived.

- Asphalt concrete mixes prepared with Kota stone has fulfilled all Marshall and volumetric criteria specified by Indian paving specification. It also has almost equivalent Marshall stability than stone dust that mixes with lower OBC. The Kota stone mixes have lower OBC due to the lower porosity of the filler.
- Kota stone mixes have higher MQ value which signifies its superior resistance against rutting than standard mix. This may be due to the finer nature of Kota stone and lower AFT of their mixes in comparison to the conventional stone dust mixes.
- Kota stone fulfilled the minimum retained stability requirements, i.e., 75% with a higher margin. This indicated its satisfactory performance against moisture permeation. This might be due to the lower harmful clay content, hydrophobic nature and presence calcite in the mineralogy of Kota stone dust which promotes binder–aggregate adhesion.

References

1. Ministry of Road Transport and Highways (MORTH): Specifications for Road and Bridge Works, Section 500, Fifth Revision. Indian Roads Congress, New Delhi, India (2013)
2. Suhaibani, A., Mudaiheem, J., Fozan, F.: Effect of filler type and content on properties of asphalt concrete. In: Effect of Aggregate and Mineral Fillers on Asphalt Mixture Performance, pp. 107–130. ASTM STP 1147, American Society for Testing and Materials, West Conshohocken, PA (2004)
3. Huang, B., Shu, X., Chen., X.: Effects of mineral fillers on hot-mix asphalt laboratory-measured properties. Int. J. Pavement Eng. **8**(1), pp. 1–9 (2007)
4. Chandra, S., Choudhary, R.: Characterization of fly ash bituminous concrete mixes performance characteristics of bituminous concrete with industrial wastes as filler. J. Mater. Civ. Eng. **25**, 1666–1673 (2013)
5. Choudhary, J., Kumar, B., Gupta, A.: Laboratory evaluation on recycling waste industrial glass powder as mineral filler in hot mix asphalt. In: Proceeding of Civil Engineering Conference—Innovation for Sustainability, Hamirpur, India, pp. 352–359 (2016)
6. Choudhary, J., Kumar, B., Gupta. A.: Use of dimension limestone sludge as filler in asphalt mix. In: Proceedings of the Institution of Civil Engineers-Construction Materials. https://doi.org/10.1680/jcoma.18.00022 (2018)
7. Choudhary, J., Kumar, B., Gupta. A.: Application of waste materials as fillers in bituminous mixes. Waste Manage. **78**, 417–425 (2018)
8. ASTM C119–16: Standard Terminology Relating to Dimension Stone. ASTM International, West Conshohocken, PA (2016)
9. Rana, A., Kalla, P., Csetenyi, L.J.: Recycling of dimension limestone industry waste in concrete. Int. J. Min. Reclam. Environ. **31**(4), 231–250 (2017)
10. Torres, P., Fernandes, H.R., Olhero, S., Ferreira, J.M.F.: Incorporation of wastes from granite rock cutting and polishing industries to produce roof tiles. J. Eur. Ceram. Soc. **29**(1), 23–30 (2009)

11. ASTM D854-14: Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. American Society for Testing and Materials, West Conshohocken, USA (2014)
12. ASTM D422-63: Standard Test Method for Particle-Size Analysis of Soils. American Society for Testing and Materials, West Conshohocken, USA (2007)
13. EN 933: Tests for Geometrical Properties of Aggregates—Part 9—Assessment of Fines Methylene Blue Test. British Standards Institution, London, UK (1999)
14. MTPRC (Ministry of Transport of P.R. China): Test Methods of Aggregate for Highway Engineering (JTG E42–2005). China Communications Press, Beijing (2005)
15. Asphalt Institute: Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types: Manual Series No. 2 (MS-2), 6th edn. Lexington, KY (1999)
16. Christensen, D.W., Bonaquist, R.F.: Volumetric Requirements for Superpave Mix Design, vol. 567, p. 57. Transportation Research Board, National Research Council, Washington DC (2006)

Experimental Investigation of Waste Glass Powder as Filler in Asphalt Concrete Mixes

Gaurang Asthana, Jayvant Choudhary, Brind Kumar and Ankit Gupta

Abstract Glass industry generates a large amount of powdered glass waste during the cutting and polishing processes. Laboratory investigations were conducted to evaluate the feasibility of recycling this waste into asphalt concrete as mineral filler. The primary characterization of both fillers was done through specific gravities, plasticity index, particle size distribution, German filler values, textural analysis, mineralogical analysis, hydrophilic coefficient, and pH value tests. Asphalt mixes were designed as per Marshall test procedure and retained stability values as well as Marshall quotient were determined at their optimum binder contents (OBC). Mixes having waste glass powder have higher Marshall stability and lower bulk density at lower OBC. Glass powder mixes were found to have superior rutting resistance which may be attributed to their lower apparent film thickness. However, inclusion of glass powder impaired the resistance of mixes against moisture permeation due to high amount of silica in glass powder.

Keywords Asphalt concrete · Filler · Glass powder · Marshall properties · Moisture resistance

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1 Introduction

Asphalt mixes primarily consist of aggregates (coarse and fine) along with filler and asphalt binder. Aggregates form a skeleton to resist traffic load imposed upon them and bitumen acts as a binder and lead to adhesion between these aggregates. The filler is the finest part of aggregate which is finer than 75-micron sieve, devoid of organic matter and displayed almost nonplastic behavior [1].

It displays a complex behavior in asphalt mixes: first, it primarily acts as inert material and fills gaps between the aggregates in mixes, second, the finer filler particles also actively modify viscosity of bitumen-filler mastic and alter its behavior. This led to stiffening of mastic and improvement of properties such as density, stability, and load-carrying capacity of mixes [2]. Filler, due to its larger surface area, occupies voids between aggregates particles and influences optimum bitumen content of mix [3]. It also influences the performance of pavement against distresses such as rutting failure, fatigue failure, and moisture susceptibility [4]. Hence, the selection of optimum quality and quantity of filler is vital for design of good hot mix asphalt. Increasing environmental concerns and increase in cost of standard fillers (cement, hydrated lime, and stone dust) motivates investigators to use wastes like dimensional stone wastes, brick powder, sludge ash, etc., as fillers in asphalt mixes [5–8]. All these materials were found to have positive effect over performance of pavements against various distresses.

Glass is a nonmetallic and inorganic material produced by sintering appropriate raw materials. United Nations estimated that glass waste constitutes about 7% of a total 200 million tons annually produced solid wastes [9]. It can be neither be decomposed nor incinerated and is generally dumped into a landfill site. However, landfilling of glass is not an environment-friendly solution due to its non-biodegradable nature. Hence, there is strong need to utilize waste glasses. Since glass is brittle and primarily composed of silicon, so the key technical indices that should be basis of asphalt mixes design are strength and resistance to moisture susceptibility. Recent studies utilized waste crushed glass powder from bottles, window panes, etc., as fillers in asphalt mixes [10, 11]. However, to utilize glass waste from aforesaid sources, large amount of additional energy and cost is consumed in order to reduce glass into suitable filler size. It must be noted that large amount of glass waste is also generated in form of slurry during the cutting and polishing operations in glass industries which cause serious damage to environment. Utilization of glass powder from these sources can decrease environmental waste as well as can save energy. So an attempt was made to assess the usability of glass powder from glass industries as mineral filler by replacing the standard stone dust filler.

2 Material Properties and Methodology

2.1 Materials

Aggregates. This study utilized the aggregates which are crushed, angular, and of dolomite origin. All aggregates were obtained from the quarry located in the Sonbhadra region of the Uttar Pradesh state of India. All aggregates were properly washed and sieved over their respective sieve to remove additional fine dust adhered to them. Table 1 displayed characterization properties of aggregates. The gradation of mix was chosen according to the guidelines specified the Indian specifications [1] and is given in Table 2.

Asphalt. VG 30 (Viscosity Grade 30) asphalt, similar to 60/70 penetration grade asphalt, was locally collected and used. Various properties of asphalt were evaluated according to IS:73 (2013) specification and displayed in Table 1.

Filler. The two filler materials utilized in this study are standard stone dust (SD) and waste glass powder (WGP). The SD was collected locally and WGP was obtained from the dumping yard of Kochar glass industry situated in Bhopal city in Indian state of Madhya Pradesh which was used as alternative filler. Both the fillers were sieved as per MORTH specification and the replacement was made on weight basis. Only the portion finer than 75-micron sieve was chosen for analysis. The fillers are characterized using specific gravity [12], plasticity index, particle

Table 1 Characteristics of the aggregates and the Asphalt

Component	Physical characteristic	Testing specification	Obtained result
Aggregates	Bulk specific gravity of coarse aggregates	ASTM C127	2.795
	Apparent specific gravity of coarse aggregates	ASTM C127	2.820
	Water absorption (%)	ASTM C127	0.374
	Bulk specific gravity of fine aggregates	ASTM C128	2.702
	Apparent specific gravity of fine aggregates	ASTM C128	2.747
	LA abrasion value (%)	IS:2386 (Part IV)	13.40
	Aggregate impact value (%)	IS:2386 (Part IV)	11.10
	Combined Flakiness and Elongation Index (%)	IS: 2386 (Part I)	21.30
Asphalt	Absolute viscosity at 60 °C (poise)	IS: 73(2013)	2692
	Softening Point (°C)		51.5
	Penetration at 25 °C (0.1 mm)		62
	Ductility at 27 °C (cm)		>100
	Specific gravity		0.999

Table 2 Adopted gradation of asphalt concrete (grading II) mix

Sieve size (mm)	Recommended range (cumulative % passing)	Gradation selected (cumulative % passing)
19	100	100
13.2	90–100	91
9.5	70–88	78
4.75	53–71	67
2.36	42–58	52
1.18	34–48	45
0.6	26–38	35
0.3	18–28	23
0.15	12–20	13
0.075	4–10	4.0

gradation [13], active clay content [14], SEM, XRD, hydrophilic coefficient, and PH value tests. The results are collectively stated in Table 3. Particle gradation curves, SEM, and XRD are shown in Figs. 1, 2, and 3.

2.2 *Tests on Asphalt Mixes*

Design of asphalt concrete mix. This study adopted the procedure of the mix design stated in MS-2 [15] specification to calculate the optimum binder content (OBC) of prepared mixes. OBC is defined as binder content of the mix corresponding to the air void content of 4%. According to this procedure, mixes with chosen gradation (Table 1) and different binder contents (5–7% at 0.5% interval) were prepared. All ingredients were heated at the mixing temperature chosen according to the MS-2 specification to achieve uniform binder coating on aggregates. The Marshall specimens of diameter 101.5 mm and 63.5 mm thickness mixes were prepared after the compaction of mixes using standard Marshall compactor which provided 75 blows on each side. 15 specimens (three at each binder content), were designed for each filler and various properties like stability, flow value, voids in mineral aggregates (VMA), voids filled with binder (VFB), and air voids (VA) were determined. Apparent film thickness (AFT) of every asphalt mix was determined at their OBC according to the procedure suggested by NCHRP Report 567 [16]. AFT was calculated as per Eq. 1.

$$AFT = \frac{1000VBE}{S_s P_s G_{mb}} \tag{1}$$

Table 3 Characterization properties of studied fillers

Characteristics	Stone dust	WGP	Inferences
Specific gravity	2.70	2.37	Glass powder has lower specific gravity and thus occupy greater volume in asphalt mix
Plasticity index	2.3	Nonplastic	Both fillers satisfied the criteria for plasticity index as per Indian specifications
Active clay content (mg/g)	3.25	1.25	Glass powder has low harmful clay contents as well as lower absorption
Fineness modulus	5.57	5.38	Both materials have almost equivalent average particle sizes
Coefficient of uniformity (Cu)	17.89	5.00	Glass powder has much uniformly graded particles
Mineralogical composition	Dolomite (CaMg $(CO_3)_2$); Quartz (SiO_2); Ertixite ($Na_2Si_4O_9$)	Quartz (SiO_2)	Glass powder has a predominance of silica which may have negative effect over bitumen-aggregate adhesion whereas Dolomite in stone dust promotes bitumen filler adhesion
Textural details (SEM)	Angular grains having a slightly rough texture	Angular grains having a relatively smooth texture	Smooth texture of glass particles may cause lower absorption of bitumen over surface
pH value	12.57	10.3	Stone dust is expected to have superior bonding with bitumen due to its alkaline nature
Hydrophilic coefficient	0.77	0.81	Both materials displayed hydrophobic nature

where,

VBE (Effective binder content) (% of the total mix volume); S_s (specific surface area of aggregates) (m^2/kg); P_s (percentage of the aggregates) (% of total weight of the mix); and G_{mb} (mix's bulk specific gravity).

Rutting Resistance. Marshall quotient (MQ) can be termed as the ratio of Marshall stability (kN) to flow (mm) in the mixed at OBC. MQ is used to determine the stiffness of the mix, which is also indirectly measures the resistance of asphalt mix against rutting. Asphalt mix having higher MQ value usually displayed superior resistance against rutting.

Moisture susceptibility tests. Retained Marshall stability (RMS) test was conducted to determine the moisture susceptibility of both mixes. For each type of mix, a total of six Marshall specimens were prepared at OBC which were divided into two groups, each having three specimens. The first group (unconditioned specimen)

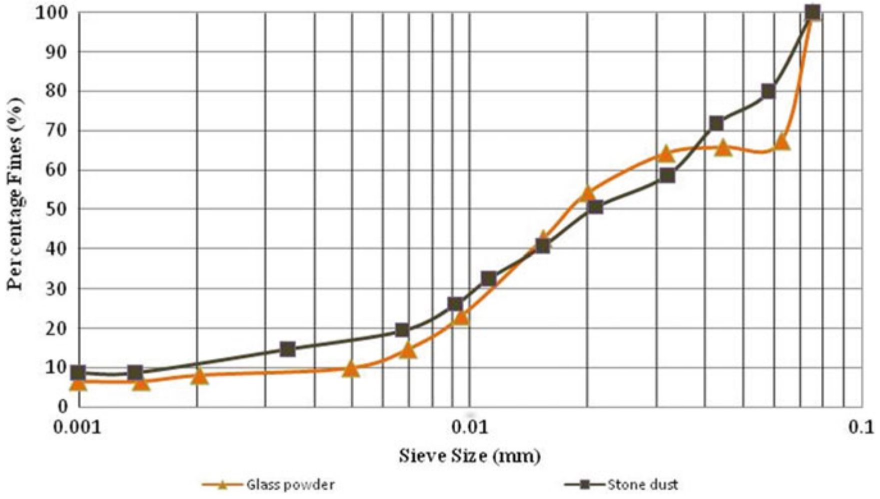


Fig. 1 Particle gradation of both fillers

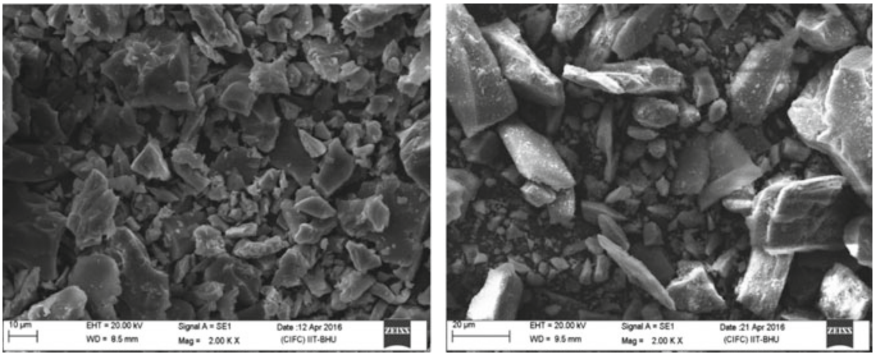


Fig. 2 SEM results of WGP (left) and SD (right)

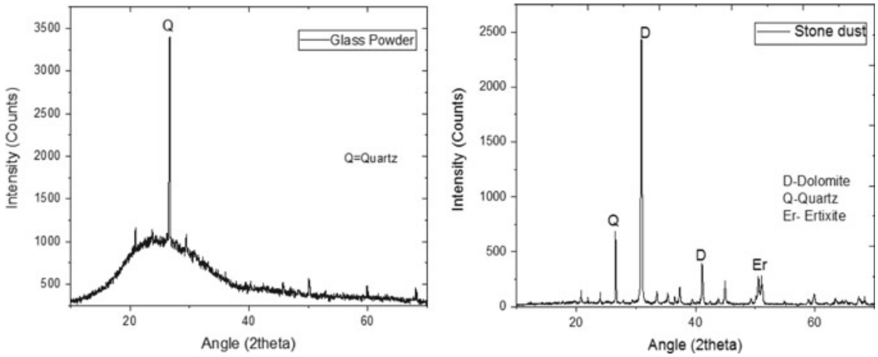


Fig. 3 XRD results of WGP (left) and SD (right)

were placed in water maintained at 60 °C for 30 min. Similarly, the second group (conditioned specimens) were placed submerged in water maintained at 60 °C for 24 h. Both set of specimens were loaded to failure at constant compression rate of 51 mm/min using curved steel loading plates. The RMS was determined by taking mean stability values of each sample group according to the equation

$$RMS = \frac{MS_{cond}}{MS_{uncond}} \times 100 \tag{2}$$

where $\mathrm{MS}_{\mathrm{uncond.}}$ is the average Marshall stability for unconditioned specimens (kN); and $\mathrm{MS}_{\mathrm{cond}}$ is mean Marshall stability for conditioned specimens (kN).

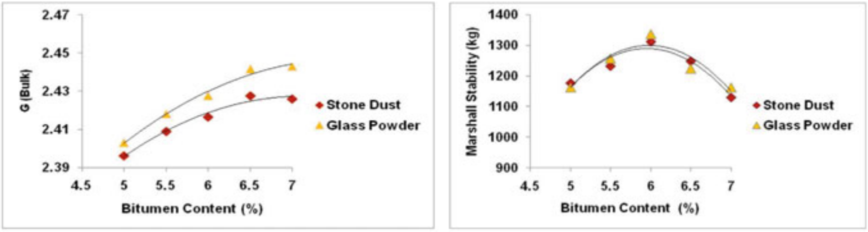
3 Test Results

3.1 Analyses of Marshall and Volumetric Properties

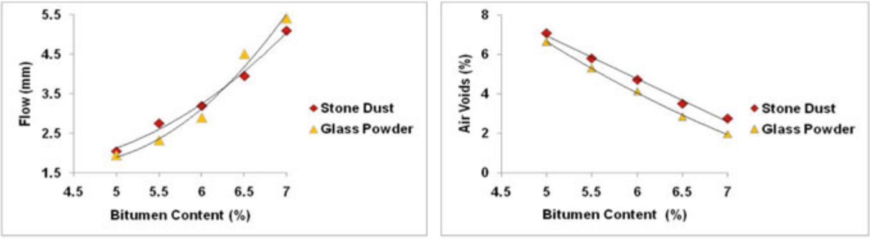
Analysis of the mix's properties is given in Table 4a–f. The OBC of glass powder mix (6.03%) was found to be lower than that of stone dust mixes (6.29%). It may be due lower bitumen absorption of glass powder as observed from lower methylene blue value of glass powder. Larger fineness modulus of glass powder also suggested that it is a coarser filler and hence having a lower absorption than stone dust mix. Glass powder mixes also has lower bulk specific gravity which is due to lower specific gravity of glass powder. Marshall stability values of glass powder mixes are also higher than SD mixes due to higher percentage of silica in glass powder. Both mixes met all design requirements for asphalt concrete mix as per Indian specifications. AFT of glass powder mix (7.75μ) was marginally lower than stone dust mix (8.14μ) due to lower OBC of glass powder mix.

Table 4 Various parameters of mixes at OBC

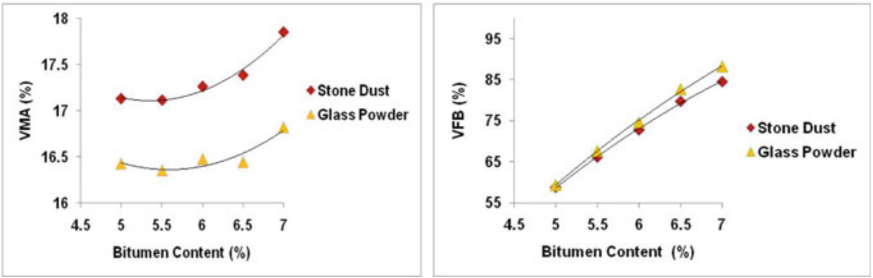
Mix type	OBC (%)	Marshall stability (kN)	Flow (mm)	Bulk specific gravity (gm/cm^3)	VMA (%)	VFB (%)	AFT (Micron)
Stone dust	6.29	12.51	3.51	2.440	17.27	74.70	8.14
Glass powder	6.03	12.82	3.14	2.423	16.38	74.87	7.75
Requirement	5.4 (min)	9 (min)	2–4	–	14 (min)	65–75	–



(a). Bulk specific gravity versus bitumen content **(b).** Marshall stability versus bitumen content



(c). Flow versus bitumen content **(d).** VA versus bitumen content



(e). VMA versus bitumen content **(f).** VFB versus bitumen content

Fig. 4 Properties of mixes at different binder contents

3.2 Marshall Quotient

Marshall quotient (MQ) value of WGP mix (4.08 kN/mm) was higher than SD mixes (3.56 kN/mm). Lower AFT of asphalt mix is somewhat responsible for higher rutting resistance of asphalt mixes [17]. Since glass powder mixes have low AFT than stone dust mix, this may be a responsible factor for its superior MQ value than the stone dust mix (Fig. 5).

3.3 Retained Marshall Stability Test

Both asphalt mixes satisfied the minimum requirement of 75% retained Marshall stability (RMS). However, the glass powder mix barely managed to satisfy the RMS requirements (77.89%). This may be due to high amount of silica in glass and

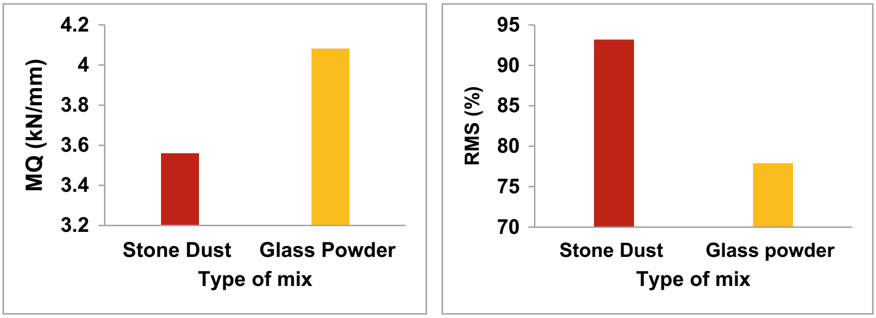


Fig. 5 Marshall quotient (left) and retained Marshall stability (right) of studied mixes

low AFT of mixes, which was found to have negative effects over moisture resistance of asphalt mixes in previous study [17]. SD mixes (93.19%) had superior RMS value, due to high quantity of water-insoluble dolomite mineral in its mineralogical composition.

4 Conclusions and Discussions

The following conclusions can be derived:

- The waste glass powder is a nonplastic material and it fulfills the requirements stated in Indian paving specifications. It doesn't have expansive clay minerals such as montmorillonite in its composition and also has low harmful fine content. It primarily consists of silica in its composition which may have a negative effect over bitumen-aggregate adhesion.
- Glass powder also displayed hydrophobic nature as estimated from its hydrophilic coefficient value. However, stone dust has a comparatively lower hydrophilic coefficient and higher pH value due to the appreciable amount of dolomite in its composition.
- Asphalt mixes prepared with glass powder has satisfied all strength and volumetric requirements specified by Indian paving specification. It also has higher Marshall stability than the conventional stone dust mix.
- OBC of glass powder asphalt mixes (6.03%) was less than SD mixes (6.29%), due to lower absorption of glass powder as stated from its lower active clay content than the stone dust mix.
- Glass powder mixes have superior rutting resistance than stone dust mixes as specified from their higher MQ values. It may be attributed to their lower apparent film thickness than stone dust mixes.
- Asphalt mixes prepared with glass powder have lesser resistance against moisture due to higher silica content in glass powder or due to lower apparent film thickness of glass modified asphalt mixes.

References

1. Ministry of Road Transport and Highways (MORTH): Specifications for Road and Bridge Works, Section 500, Fifth Revision. Indian Roads Congress, New Delhi, India (2013)
2. Buttlar, W., Bozkurt, D., Al-Khateeb, G., Waldhoff, A.: Understanding asphalt mastic behavior through micromechanics. Transportation Research Record: Journal of the Transportation Research Board **1681**, 157–169 (1999)
3. Kandhal, P., Lynn, C., Parker, F.: Characterization tests for mineral fillers related to performance of asphalt paving mixtures. Transportation Research Record: Journal of the Transportation Research Board **1638**, 101–110 (1998)
4. Suhaibani, A., Mudaiheem, J., Fozan, F.: Effect of filler type and content on properties of asphalt concrete: effect of aggregate and mineral fillers on asphalt mixture performance. ASTM STP 1147, pp. 107–130. American Society for Testing and Materials, West Conshohocken, PA (2004)
5. Cardone, F., Frigio, F., Ferrotti, G., Canestrari, F.: Influence of mineral fillers on the rheological response of polymer-modified bitumens and mastics. Journal of Traffic and Transportation Engineering (English Edition) **2**(6), 373–381 (2015)
6. Chandra, S., Choudhary, R.: Characterization of Fly Ash Bituminous Concrete Mixes Performance Characteristics of Bituminous Concrete with Industrial Wastes as Filler. Journal of Materials in Civil Engineering **25**, 1666–1673 (2013)
7. Chen, M.Z., Lin, J.T., Wu, S.P., Liu, C.H.: Utilization of recycled brick powder as alternative filler in asphalt mixture. Construction and Building Materials. **25**(4), 1532–1536 (2011)
8. Tenza-abril, A.J., Saval, J.M., Cuenca, A.: Using Sewage-Sludge Ash as Filler in Bituminous Mixes. Journal of Materials in Civil Engineering **27**(4), 04014141 (2014)
9. Topcu, I.B., Canbaz, M.: Properties of concrete containing waste glass. Cem. Concr. Res. **34** (2), 267–274 (2004)
10. Saltan, M., Öksüz, B., Uz, V.E.: Use of glass waste as mineral filler in hot mix asphalt. Science and Engineering of Composite Materials **22**(3), 271–277 (2015)
11. Arabani, M., Tahami, S.A., Taghipoor, M.: Laboratory investigation of hot mix asphalt containing waste materials. Road Materials and Pavement Design **18**(3), 713–729 (2016)
12. ASTM D854-14: Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. American Society for Testing and Materials, West Conshohocken. USA, (2014)
13. ASTM D422-63: Standard Test Method for Particle-Size Analysis of Soils. American Society for Testing and Materials, West Conshohocken, USA (2007)
14. EN 933: Tests for Geometrical Properties of Aggregates—Part 9—Assessment of Fines Methylene Blue Test. British Standards Institution, London, UK (1999)
15. Asphalt Institute: Mix design methods for asphalt concrete and other hot-mix types: Manual Series No. 2 (MS-2), 6th edn. Lexington, KY (1999)
16. Christensen, D.W., Bonaquist, R.F.: Volumetric requirements for Superpave mix design, vol. 567. Transportation Research Board. National Research Council, Washington, DC, p. 57, (2006)
17. Kuity, A., Jayaprakasan, S., Das, A.: Laboratory investigation on volume proportioning scheme of mineral fillers in asphalt mixture. Constr. Build. Mater. **68**, 637–643 (2014)

Adsorption of Lead Ions from Aqueous Solution by Functionalized Polymer Aniline–Formaldehyde Condensate, Coated on Various Support Materials

Jonali Saikia

Abstract Continuous release of heavy metals such as Cadmium, Chromium, Copper, Lead, Manganese, Nickel, Zinc, etc., from different industrial wastewaters has become one of the most alarming threats all over the world due to their adverse effects on the proper ecosystems functioning. Most of the heavy metals do not degrade or degrade very slowly in the environment. A study was conducted for quantifying the metal removal capacity of a functionalized resinous polymer, i.e., aniline–formaldehyde condensate (AFC), which was coated on eggshell, sand, tea leaves, and fly ash separately as support material and divalent lead (Pb^{+2}) was taken as the model metal ion. The various parameters affecting adsorption, i.e., reaction pH, adsorption time, and initial concentrations of lead were taken into consideration. A pH range of 3.0–6.0 shows a continuous increase in metal adsorption but at pH > 6.0, the lead precipitates as lead hydroxide, i.e., $Pb\ (OH)_2$. The maximum removal of Pb^{+2} by AFC coated tea leaves (91.9%), fly ash (91.4%), eggshell (74.5%), and sand (65.8%) was obtained at optimum solution pH of 6.0. For the AFC coated adsorbents, reaction kinetics followed the Lagergren second-order model. Adsorption of lead by the AFC polymer coated on the above support materials could be better described by Langmuir isotherm model with maximum Langmuir monolayer uptake of 96.15, 46.73, 13.62, and 7.07 mg/g for AFC polymer coated on eggshell, tea leaves, fly ash, and sand, respectively. It can be concluded that AFC polymer coated on the above support materials have the efficiency for the removal of lead from waste discharge.

Keywords Adsorption · Amine group · Functionalized polymer · Heavy metal · Isotherms · Solution pH · Kinetic models

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1 Introduction

Heavy metals in comparison to water have high density and are present in the environment naturally. Sources releasing heavy metals to the environment may be of natural or anthropogenic origin. Natural activities include weathering, volcanic eruptions [3, 7, 11, 21, 24] and man-made sources include various industrial activities, mining activities, foundries and smelters, piping, combustion, traffic, etc. [4, 15, 20, 22, 23]. Industries such as metal processing, mineral-processing, electroplating, metallurgical, and battery manufacturing generate huge quantities of aqueous effluents on a regular basis. If such effluents containing high concentrations of toxic heavy metals, such as Cadmium, Chromium, Copper, Lead, Manganese Nickel, Zinc, etc., are directly released into the soil or any receiving water body like river, lake, etc., without proper treatment, they can cause several environmental issues. Unlike organic pollutants, heavy metals do not degrade into innocuous end products [9]. The presence of toxic heavy metals even in very minute concentrations in industrial effluents can severely affect the ecosystems. Aquatic animals may adsorb the heavy metals present in waste stream and the consumption of such aquatic animals can lead to the direct entry of heavy metals into the human food chain, causing potential health threats to human beings [18].

Lead, which is one of the major ubiquitous toxic heavy metals, can cause adverse effects on human health like retarded physical and mental development. To protect and save the environment from harmful effects of heavy metals, efficient treatment techniques should be adopted that can remove toxic contaminants effectively before the discharge of the industrial effluent into the environment. Various techniques like chemical precipitation, electrodialysis, ion exchange, reverse osmosis, adsorption, etc., are universally employed for efficient removal of heavy metals from industrial wastewater. These techniques have their own inherent merits and demerits as in case of reverse osmosis where presence of particulate and colloidal matter in feed water results in frequent clogging of the membrane, thereby requiring high level of pretreatment of feed water. Similarly, in case of electrodialysis, frequent clogging of membrane occurs due to formation of metal hydroxides. Ion exchange, though efficient in recovering the metals, has the disadvantage of being highly expensive due to higher operational and maintenance costs.

Adsorption technique when combined suitably with proper desorption technique proves to be one of the most effective and versatile methods, for removal of heavy metals, and thus minimizes the sludge disposal problem [2]. Functionalized polymers containing an amine (NH_2) group have an affinity toward heavy metal ions. Previous researches were carried out, using a functionalized polymer aniline–formaldehyde condensate (AFC) coated on silica gel as a support material, for the successful removal of Copper and Chromium from aqueous solution [16, 17]. This polymer can be synthesized by polymerization reaction between aniline and formaldehyde in acidic medium [19]. Since AFC polymer is a resinous material, it was coated separately on various support materials like eggshell, sand, tea leaves, and fly ash, to improve the rigidity of the polymer. The present work was carried out for comparison of lead removal efficiencies of AFC polymer coated on the selected support material that includes eggshell, sand, tea leaves, and fly ash.

2 Materials and Methods

2.1 Materials

The commercially purchased aniline ($C_6H_5NH_2$) of AR grade was in impure form and hence was purified using the distillation method. KOH pellets were added to aniline prior to distillation for 12 h. The other chemicals like Methanol (CH_3OH), formaldehyde (37% HCHO), and conc. HCl were procured from S.D. Fine Chem. Concentrated H_2SO_4 of AR grade and NaOH required for adjusting the sample pH were procured from S.D. Fine Chem and SRL, respectively. For the preparation of stock solution of lead, lead nitrate [$Pb(NO_3)_2$] was selected as the parent salt and working lead solutions of desired concentrations were prepared by accurately diluting the stock lead solution with deionized water.

2.2 Synthesis of Aniline–Formaldehyde Condensate

Synthesis of aniline–formaldehyde condensate was done, as suggested by Liu and Freund [19], by the reaction between formaldehyde (HCHO) and aniline ($C_6H_5NH_2$) in presence of HCl as shown in Fig. 1. The neutralization of the above mixture was done by employing NaOH (30%) solution. The prepared resin was kept in a vacuum desiccator for removal of moisture.

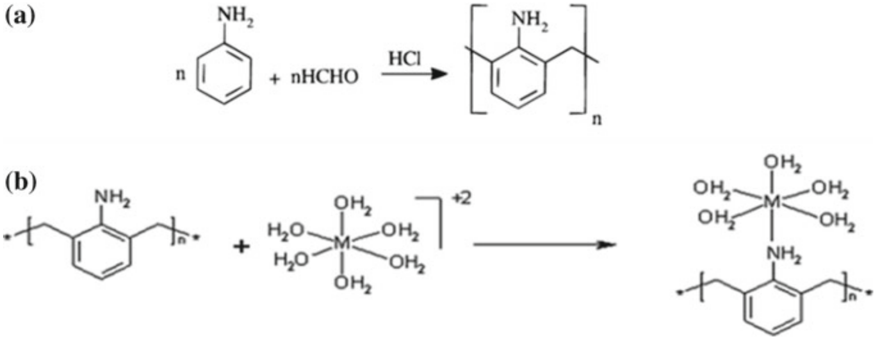

Fig. 1 **a** Synthesis of aniline–formaldehyde condensate (AFC) **b** Schematic of metal ion and aniline–formaldehyde resin interaction

2.3 Coating of AFC on Various Support Materials

The prepared aniline–formaldehyde condensate polymer was resinous in nature, thus in order to form a granular adsorbent, the addition of support material was essential. So, various materials were used as support of AFC polymer, i.e., eggshell, sand, tea leaves, and fly ash.

Eggshell was collected from the kitchen wastes of the canteen of IIT Guwahati, cleaned and oven-dried at low temperature for nearly 6 h and was ground in a mortar and sieved manually. The eggshell was mixed in the prepared methanol-resin solution and dried over filter paper for 6 h and thereafter used as an adsorbent for removal of lead from aqueous solution.

The sand was collected from the banks of river Brahmaputra; the longest river of the state of Assam. Collected sand was properly cleaned with deionized water and was oven-dried at 100–105 °C for 24 h. Oven-dried sand was subsequently sieved through 300 μm sieve for obtaining the finer fraction. The finer fraction of sand thus obtained was mixed uniformly in the prepared methanol-resin solution and was allowed to dry over filter paper for nearly 6 h and thereafter used as an adsorbent for Pb^{+2} removal in the present study.

Waste tea leaves were collected from kitchen wastes of the Canteen of IIT Guwahati and were thoroughly cleaned with deionized water, till the supernatant was free of color and subsequently air-dried at room temperature for 72 h. The aniline–formaldehyde resin was added to the tea leaves, mixed properly and the mixture was allowed to dry over filter papers for nearly 6 h and was subsequently used as an adsorbent for removal of Pb^{+2} in aqueous environments.

Fly ash, a byproduct of thermal power plants, has excellent capacity for the removal of heavy metals. Fly ash was used as received and aniline–formaldehyde resin was coated on it, mixed uniformly and was dried over filter paper for nearly 6 h. Afterward the AFC polymer coated on fly ash was used as an adsorbent for removal of Pb^{+2} ion from aqueous solution, in the present study.

2.4 Adsorption Experiments

Studies were conducted using divalent lead (Pb^{+2}) as the model ion and the effect of various parameters affecting the adsorption process, such as reaction pH and concentrations of lead ion, were investigated in batch mode. The effect of pH on Pb^{+2} adsorption by AFC polymer coated on the selected support materials was studied by conducting batch adsorption experiments in the pH range of 3.0–6.0, employing a fixed adsorbent dose of 2 g/L. The kinetic parameters were estimated using linearized forms of Lagergren first-order and second-order kinetic models. Emphasis was also given on evaluation of isotherm constants using Langmuir and Freundlich isotherm models.

2.5 Analytical Procedure

The concentrations of Pb^{+2} were estimated with the help of an atomic absorption spectrophotometer (Make: Agilent Technologies, Model: 55B). In the atomic absorption spectrophotometer, an oxidizing flame of air with acetylene gas mixture was used, and a hollow cathode lead lamp was used as the light source at a wavelength of 282.3 nm. In order to differentiate between the surface morphology of the AFC polymer coated on the selected support materials, before and after Pb^{+2} adsorption, scanning electron microscopic (SEM) study was done using scanning electron microscope, Make: Carl Zeiss, Germany; MODEL: LEO. 1430 VP. Also, EDX (Energy-dispersive X-ray) analysis was carried out simultaneously along with SEM analysis in order to confirm the Pb^{+2} adsorption by each of the selected adsorbents.

3 Results and Discussion

3.1 Effect of Reaction pH and Kinetic Studies

The effect of pH on Pb^{+2} adsorption by AFC polymer coated on the selected support materials was studied by varying the pH of the lead solution between 3.0–6.0. The working solution of Pb^{+2} of concentrations 50 mg/L was prepared and batch adsorption experiments were conducted separately using fixed adsorbent dose of 2 g/L of each of the selected adsorbents. Lead uptake (mg/g) was estimated by the ratio of the difference between the initial liquid phases lead ion concentration (mg/L) and the final equilibrium liquid phases lead ion concentration after adsorption (mg/L), to the quantity of the adsorbent dose (g/L). The experimental results of effects of reaction pH and kinetics are summarized in Fig. 2a–h.

From Fig. 2a–h, it is clear that for all the AFC coated adsorbents, equilibrium was achieved within 80–100 min. At pH 3.0, Pb^{+2} adsorption was lowest for the selected adsorbents and maximum lead removal (34.94%) was achieved with AFC coated tea leaves. The batch experimental data reveals that when the solution pH was increased within 3.0–6.0, there was increase in the lead removal efficiencies of all the selected adsorbents. The highest lead removal efficiency was achieved at pH 6.0, irrespective of the type of adsorbent. The maximum lead removal efficiency was obtained at solution pH of 6.0, for all the selected adsorbents. Maximum removal (91.9%) was achieved with AFC coated tea leaves and was followed by AFC coated fly ash (91.4%), AFC coated eggshell (74.5%), and AFC coated sand (65.8%).

Lead uptake by AFC coated sand was 15.87 mg/g at a pH of 6.0. AFC coated tea leaves showed relatively higher lead uptake (9.38 mg/g) at solution pH of 3.0, as compared to the other AFC coated adsorbents. With increase in solution pH, lead

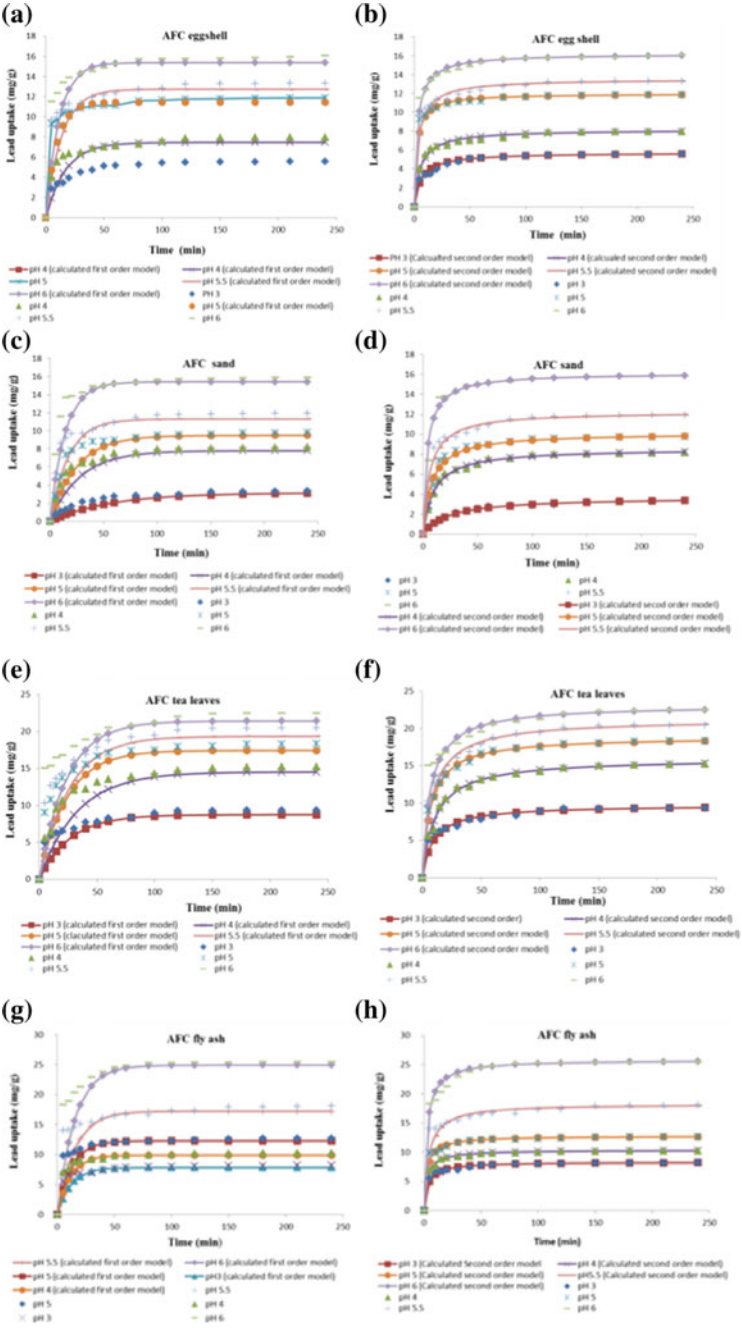

Fig. 2 Kinetics of lead uptake by first and second order kinetic models; (**a**, **b**) AFC eggshell; (**c**, **d**) AFC sand; (**e**, **f**)) AFC tea leaves; (**g**, **h**) AFC fly ash

uptake of AFC coated eggshell and AFC coated sand was relatively less as compared to the other two adsorbents.

The maximum lead uptake of AFC coated eggshell (16.11 mg/g) was similar to AFC coated sand (15.87 mg/g). Among the selected adsorbents, lead uptake was maximum for AFC coated fly ash (25.47 mg/g) at pH 6.0 and this was followed by AFC coated tea leaves (22.51 mg/g), AFC coated eggshell (16.11 mg/g), and AFC coated sand (15.87 mg/g). According to [5], the pH of the aqueous solution determines the surface charge as well as the degree of ionization and speciation of the adsorbate and hence has an important effect on heavy metal uptake by the adsorbent.

For kinetics study, the data obtained from batch adsorption experiments were analyzed using Lagergren first-order kinetic model (Eq. 1a) and second-order kinetic model (Eq. 2a) as suggested by Ho and McKay [12]; Ho [13]. The above two equations can be expressed in linearized forms as given by Eqs. 1b and 2b.

$$q_t = q_e\left(1 - e^{-k_1 t}\right) \tag{1a}$$

or

$$\log(q_e - q_t) = log q_e - \frac{k_1}{2.303} t \tag{1b}$$

$$q_t = q_e \frac{q_e k_2 t}{1 + q_e k_2 t} \tag{2a}$$

or,

$$\frac{t}{q_t} = \frac{1}{K_2 q_e^2} + \frac{t}{q_e} \tag{2b}$$

In the above equations, q_t (mg/g) and q_e (mg/g) denote metal uptake at any time t and at equilibrium, respectively, and k_1(min^{-1}) and k_2(g/mg.min) denote the kinetic rate constants corresponding to Lagergren first-order and second-order kinetic models. The theoretical metal uptake q_e and the kinetic rate constants (i.e., k_1 and k_2), which are calculated using Eqs. (1b) and (2b) for adsorption of Pb^{+2} by AFC coated adsorbents, in the pH range of 3.0–6.0 are shown in Tables 1, 2, 3 and 4 along with the correlation coefficients. Correlation coefficients R^2 of all the adsorbents, for both Lagergren first- and second-order kinetic models were almost comparable. The kinetics of adsorption of Pb^{+2} by all the adsorbents followed Lagergren second-order kinetic models as indicated by higher values of correlation coefficients, i.e., $R^2 > 0.99$.

As suggested by [14], for the selection of suitable kinetic model, the batch experimental data on adsorption of Pb^{+2} by the prepared AFC coated adsorbents in the pH range of 3.0–6.0 were subjected to Chi-square test which is represented by Eq. (2c)

Table 1 First order and second order parameters and correlation coefficients at varying pH calculated from the experimental data using AFC coated eggshell

Solution pH	First order model					Second order model			
	$q_{e\,(exp)}$ (mg/g)	$q_{e(cal)}$ (mg/g)	Rate constant k_1 (min^{-1})	R^2	χ^2	$q_{e(cal)}$ (mg/g)	Rate constant k_2 (g/mg.min)	R^2	χ^2
3.0	5.57	5.37	0.036	0.9739	8.41	5.72	0.027	0.999	0.198
4.0	7.97	7.46	0.059	0.9043	4.86	8.15	0.021	0.9991	0.1193
5.0	11.87	11.45	0.106	0.7937	5.30	11.98	0.032	0.9998	0.2808
5.5	13.34	12.73	0.074	0.8462	11.37	13.55	0.019	0.9996	0.6848
6.0	16.11	15.38	0.087	0.9025	8.67	16.21	0.021	0.9998	0.2376

Initial Pb^{+2} concentration 50 mg/L; adsorbent dose: 2 g/L

Table 2 First order and second order parameters and correlation coefficients at varying pH calculated from the experimental data using AFC coated sand

Solution pH	First order model					Second order model			
	$q_{e(exp)}$ (mg/g)	$q_{e(cal)}$ (mg/g)	Rate constant k_1 (min^{-1})	R^2	χ^2	$q_{e(cal)}$ (mg/g)	Rate constant k_2 (g/mg.min)	R^2	χ^2
3.0	3.36	3.14	0.018	0.949	3.825	3.69	0.011	0.999	0.035
4.0	8.185	7.78	0.036	0.953	5.455	8.55	0.012	0.999	0.129
5.0	9.78	9.47	0.041	0.929	5.505	10.13	0.012	0.999	0.575
5.5	11.925	11.28	0.059	0.887	6.278	12.29	0.013	0.999	0.267
6.0	15.87	15.39	0.071	0.940	5.296	16.16	0.016	0.999	0.391

Initial Pb^{+2} concentration 50 mg/L; adsorbent dose: 2 g/L

Table 3 First order and second order parameters and correlation coefficients at varying pH calculated from the experimental data using AFC coated fly ash

Solution pH	First order model					Second order model			
	$q_{e\,(exp)}$ (mg/g)	$q_{e(cal)}$ (mg/g)	Rate constant k_1 (min^{-1})	R^2	χ^2	$q_{e(cal)}$ (mg/g)	Rate constant k_2 (g/mg.min)	R^2	χ^2
3.0	8.21	7.84	0.083	0.89	4.52	8.31	0.036	0.999	0.14
4.0	10.27	9.89	0.088	0.92	3.56	10.37	0.034	0.999	0.07
5.0	12.67	11.75	0.082	0.90	9.55	12.79	0.029	0.999	0.31
5.5	18.08	17.21	0.065	0.78	23.68	18.28	0.013	0.999	1.95
6.0	25.47	24.90	0.066	0.95	24.66	25.84	0.014	0.999	0.49

Initial Pb^{+2} concentration 50 mg/L; adsorbent dose: 2 g/L

Table 4 First order and second order parameters and correlation coefficients at varying pH calculated from the experimental data using AFC coated tea leaves

Solution pH	First order model					Second order model			
	$q_{e\,(exp)}$ (mg/g)	$q_{e(cal)}$ (mg/g)	Rate constant k_1 (min^{-1})	R^2	χ^2	$q_{e(cal)}$ (mg/g)	Rate constant k_2 (g/mg. min)	R^2	χ^2
3.0	9.38	8.74	0.038	0.92	14.68	9.76	0.011	0.999	1.03
4.0	15.23	14.52	0.031	0.98	16.22	16.0	0.006	0.999	0.29
5.0	18.34	17.44	0.042	0.83	18.89	18.94	0.007	0.999	0.28
5.5	20.49	19.36	0.039	0.95	26.13	21.28	0.006	0.999	0.86
6.0	22.51	21.41	0.043	0.93	44.19	23.20	0.006	0.999	3.32

Initial Pb^{+2} concentration 50 mg/L; adsorbent dose: 2 g/L

$$\chi^2 = \sum \frac{(q_t - q_{tm})^2}{q_{tm}} \tag{2c}$$

where q_t denotes the experimental Pb^{+2} uptake at any time t and q_{tm} denotes the corresponding model predicted Pb^{+2} uptake at time t using either Lagergren first- or second-order kinetic models.

For all the adsorbents, χ^2 values between the experimental and model-predicted lead uptake values were lower for Lagergren second-order kinetic models confirming that the Pb^{+2} adsorption by AFC polymer coated on the selected base material followed Lagergren second-order kinetic model. There is not much deviation between the experimental and second-order model-predicted lead uptake values for all the adsorbents as seen from the graphs (Fig. 2a–h) suggesting that the rate-limiting step was chemisorption [13]. The comparison between the kinetic parameters for Pb^{+2} adsorption by AFC polymer coated on the selected base materials used in the present study, at solution of pH 6.0, is shown in Table 5.

Table 5 Comparison of kinetic parameters for the adsorption of Pb^{+2} onto various AFC coated adsorbents at pH 6.0

Adsorbent	AFC eggshell	AFC sand	AFC fly ash	AFC tea leaves
First order				
$q_{e(exp)}$ (mg/g)	16.11	15.87	25.47	22.51
$q_{e(cal)}$ (mg/g)	15.38	15.39	24.90	21.41
k_1 (min^{-1})	0.087	0.071	0.066	0.043
R^2	0.90	0.94	0.95	0.93
Second order				
$q_{e(exp)}$ (mg/g)	16.21	16.16	25.84	23.20
k_2 (g/mg.min)	0.021	0.016	0.014	0.006
R^2	0.999	0.999	0.999	0.999

Experimental conditions were all carried under initial Pb^{+2} conc. 50 mg/L, adsorbent dose 2 g/L and pH 6.0

3.2 Mechanism of Lead Removal

To understand the lead removal mechanism by AFC coated on the selected base materials, viz., eggshell, sand, tea leaves, and fly ash, the reaction pH of the working solution of lead of concentrations 50 mg/L was varied in the range 3.0–6.0. Initially, control experiments were conducted in the pH range of 3.0–6.0, without any adsorbent and then, similar experiments were performed with AFC polymer coated on the selected base materials as the adsorbents.

Table 6 clearly shows that for AFC polymer coated on the selected base materials as the adsorbents, significantly higher lead removal efficiencies were achieved than in the case of control experiments (without adsorbent). This suggests that even though lead removal by AFC polymer, coated on the selected base materials, was favored at higher solution pH (5.0–6.0), precipitation was less important for Pb^{+2} ion removal up to a pH of 6.0. Adsorption/complexation by NH_2 group present in aniline–formaldehyde resin was the major lead removal mechanism. Amine group present in the AFC polymer probably forms coordination bonds with Pb^{+2} ions utilizing the lone pair of electrons present in sp^3 hybridized amine nitrogen, after replacing one or more water molecules [16]. The lesser lead adsorption at lower solution pH may be probably due to the fact that H^+ ions preferred the available adsorption sites in comparison to the Pb^{+2} ions. However, with increase in solution pH, a reverse trend is followed and Pb^{2+} ion replaces H^+ ion bound to the adsorbent. Interaction of aniline–formaldehyde condensate (AFC) with metal ion in neutral medium is shown in Fig. 1b.

Table 6 Comparison of lead removal efficiencies of AFC coated on various support materials at various pH levels with experimental data of control experiments (without any adsorbent)

Reaction pH	Control[a]	AFC coated on egg shell	AFC coated on sand	AFC coated on tea leaves	AFC coated on fly ash
	Pb^{+2} removals (%)	Pb^{+2} removals (%)	Pb^{+2} removals (%)	Pb^{+2} removals (%)	Pb^{+2} removals (%)
3.0	4.3	26.44	13.54	34.94	33.25
4.0	6.0	33.26	34.19	60.39	41.41
5.0	6.2	49.21	40.28	74.92	58.49
5.5	9.2	57.23	49.12	85.51	70.67
6.0	10.0	74.54	65.79	91.88	91.35

Initial Pb^{+2}: 50 mg/L, Adsorbent dose: 2 g/L; Reaction time: 4 h

[a] Control is without adsorbent

3.3 Adsorption Isotherm

An isotherm signifies the relationship between the amount of adsorbate which is adsorbed on the adsorbent surface and the equilibrium liquid phase adsorbate concentration, at a constant temperature, when equilibrium is reached. In order to elucidate the mechanism of lead adsorption by the AFC coated adsorbents, the equilibrium isothermal data obtained from experimental studies were analyzed using Langmuir and Freundlich isotherm models, since they are extensively used in wastewater treatment. The Langmuir and Freundlich isotherms in linear forms can be expressed as

$$\frac{C_e}{q_e} = \frac{1}{q_m b} + \frac{C_e}{q_m} \tag{3a}$$

$$log q_e = log K_f + \frac{1}{n} log C_e \tag{3b}$$

where q_m (mg/g) denotes Langmuir monolayer capacity of the adsorbent, b(L/mg) denotes equilibrium constant of the Langmuir isotherm (L/mg), C_e (mg/L) denotes the concentration of metal ions in the liquid phase at equilibrium, q_e (mg/g) denotes the concentration of metal ions on the adsorbent at equilibrium, K_f (L/g) denotes Freundlich's uptake factor, and n is dimensionless Freundlich's constant. Smaller the value of n for any adsorbent, stronger is the bond between the adsorbate and the adsorbent, whereas a higher value of K_f expresses higher adsorption rate. For favorable adsorption, $1 < n < 10$.

Hall et al. [10] introduced a unit less equilibrium parameter, R_L, which is indicative of the type of isotherm. R_L can be expressed as

$$R_L = \frac{1}{1 + bC_0} \tag{3b}$$

where C_0 denotes the highest initial concentrations of metal ions used in the isotherm study in the liquid phase, and for favorable adsorption, $0 < R_L < 1$.

For isotherm study, initial concentrations of Pb^{+2} ions selected were 10, 50, 75, 100, 150, 200, 250, 350, and 450 mg/L and the adsorbent dose selected was 2 g/L of each of the selected AFC coated adsorbents. Figure 3a and b shows the linearized plots of Langmuir and Freundlich isotherm models for Pb^{+2} adsorption by the four selected adsorbents at solution pH of 6.0. The isotherm parameters corresponding to Langmuir and Freundlich models for adsorption of Pb^{+2} by the selected AFC coated adsorbents are shown in Table 7. For all the adsorbents, the adsorption processes followed Langmuir isotherm, as indicated by higher values of correlation coefficients ($R^2 > 0.94$). Plots of log q_e versus log C_e for all AFC coated adsorbents resulted in linear correlation, indicating lead adsorption followed Freundlich isotherm also. The regression coefficients (R^2) for all the adsorbents for Freundlich isotherms were much above 0.90, except for AFC polymer coated on sand.

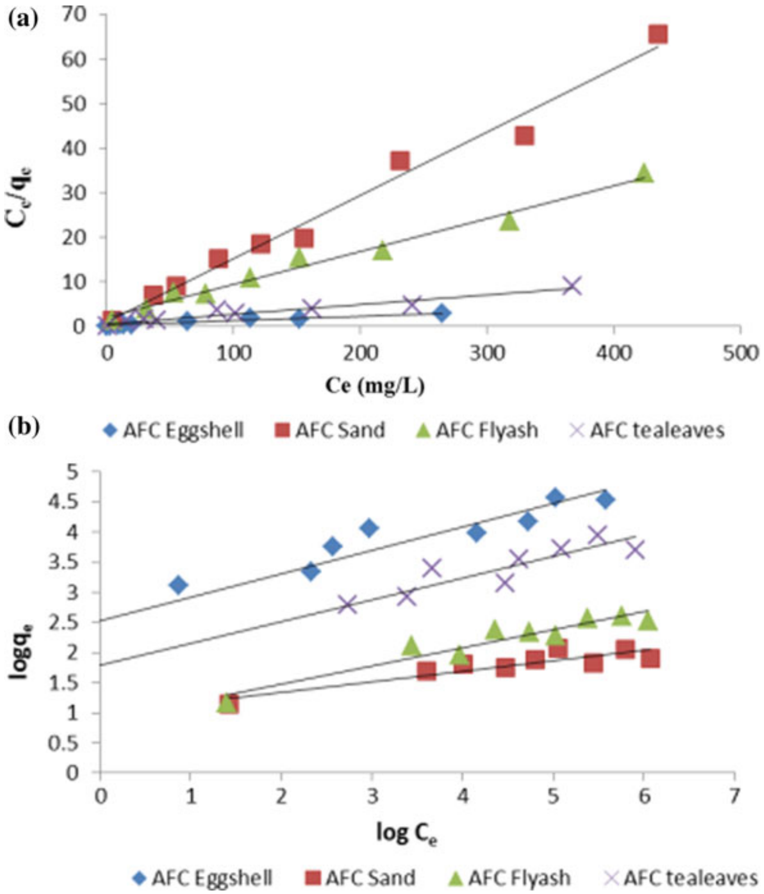

Fig. 3 **a** Langmuir plot for adsorption of Pb^{+2} by AFC coated adsorbents **b** Freundlich plot for adsorption of Pb^{+2} by AFC coated adsorbents (Adsorbent dose: 2 g/L, contact time 4 h and pH 6.0)

Table 7 Langmuir and Freundlich isotherm parameters for adsorption of Pb^{+2} onto various AFC coated adsorbents

Adsorbent	Langmuir isotherm				Freundlich isotherm		
	q_m (mg/g)	b (L/mg)	R^2	R_L	K_f (L/g)	1/n	R^2
AFC egg shell	96.15	0.05	0.96	0.04	12.54	0.39	0.93
AFC sand	7.07	0.13	0.98	0.002	2.72	0.18	0.82
AFC fly ash	13.62	0.04	0.98	0.06	2.41	0.30	0.90
AFC tea leaves	46.73	0.03	0.94	0.06	5.98	0.36	0.94

The results showed that out of the selected adsorbents, AFC tea leaves had the maximum Langmuir monolayer capacity q_m of 96.15 mg/g. Langmuir monolayer capacity (q_m) for the selected adsorbents followed the sequence; AFC eggshell (96.15 mg/g) > AFC tea leaves (46.73 mg/g) > AFC fly ash (13.62 (mg/g) > AFC sand (7.07 mg/g). The Langmuir isotherm constant b, which quantifies the relative affinity between the adsorbent and adsorbate, ranged from 0.03–0.13 for the adsorbents tested. Langmuir's R_L value from 0.002 to 0.06 indicated favorable adsorption of lead by all the AFC coated adsorbents tested.

Curkovic et al. [6] used electric furnace slag as an adsorbent for lead removal and reported Langmuir monolayer capacity q_m in the range of 33.78–37.04 mg/g, for an increase in reaction temperature from 293 to 313 K. Ghoul et al. [8] used silica gel (a) coated with polyethyleneimine and (b) cross-linked with glutaraldehyde, for adsorption of lead and reported Langmuir monolayer capacity of 82.64 and 50.76 mg/g, respectively.

For the AFC polymer coated adsorbents, Freundlich's intensity factor, i.e., n was in the range of 2.56–5.56, indicating that lead adsorption by the above adsorbents is favorable, since $1 < n < 10$. K_f, which denotes adsorption capacity, was maximum for AFC coated on eggshell (12.54 L/g), followed by AFC coated on tea leaves (5.98 L/g). K_f values for AFC polymer coated on sand (2.72 L/g) and AFC coated on fly ash (2.41 L/g) were relatively less in comparison to the other two adsorbents. Curkovic et al. [6] used electric furnace slag as an adsorbent for lead removal, varying the temperature in the range of 293–313 K and reported K_f values in the range of 0.57–1.82 L/g and the corresponding "n" values in the range of 1.78–2.38 [1], used leaves of cypress, cinchona, and pine trees as adsorbents, for lead removal and reported K_f values 0.42, 1.35, and 0.02 L/g and corresponding n values of 0.97, 0.61, and 1.57.

3.4 Surface Characteristics of AFC Coated Adsorbents

(a) Characteristics of AFC coated eggshell

Prior to adsorption, eggshell surfaces showed irregular shape (Fig. 4a), whereas a large amount of pores were observed on the surface of the prepared AFC polymer coated on eggshell (Fig. 4b), indicating a higher possibility for lead ion to be adsorbed. SEM images of AFC coated on eggshell, after lead adsorption (Fig. 4c), revealed the presence of dark spots, suggesting effective lead adsorption on the pores of the adsorbent. EDX spectra, prior to adsorption, revealed presence of carbon, calcium, and oxygen atoms on AFC polymer coated on eggshell, whereas lead peak was present after adsorption (Fig. 4c).

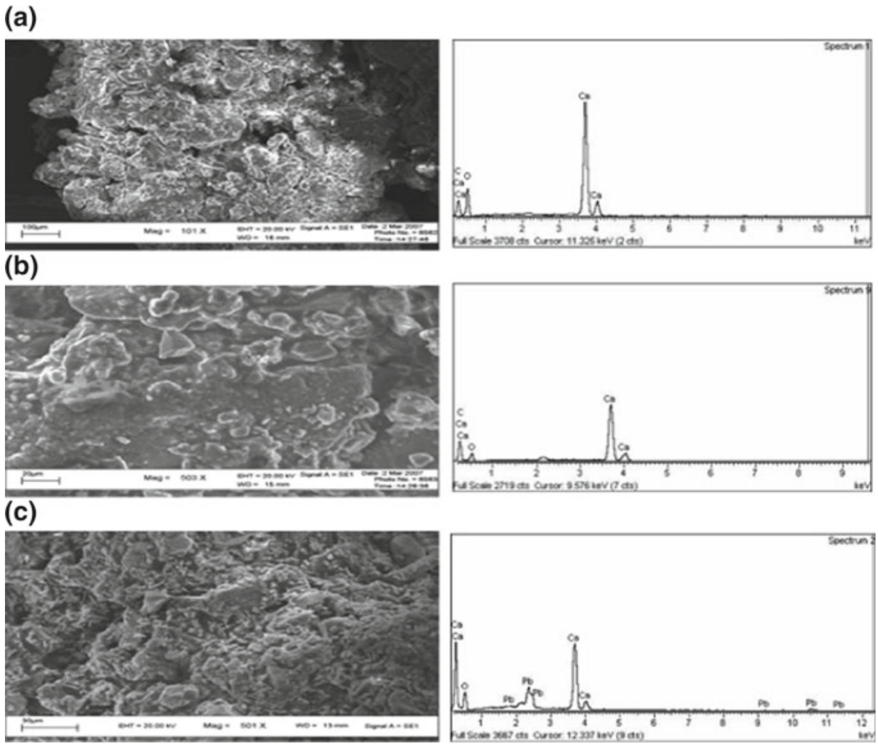

Fig. 4 **a** SEM image and EDX spectra of raw eggshell **b** SEM image and EDX spectra of AFC coated eggshell before lead adsorption **c** SEM image and EDX spectra of AFC eggshell after lead adsorption

(b) Characteristics of AFC coated sand

SEM images revealed that natural sand has loose aggregates with porous structure (Fig. 5a), while after interaction with AFC polymer, there is marked change of the surface morphology of the adsorbent showing disappearance of the pores and resulting in compact aggregates (Fig. 5b). The EDX spectra of AFC coated on sand, before adsorption, showed the presence of carbon, oxygen, sodium, aluminum, and silicon atoms, whereas after adsorption, presence of lead atom was revealed by corresponding EDX spectra (Fig. 5c).

(c) Characteristics of AFC coated tea leaves

When SEM images of raw waste tea leaves (Fig. 6a) and AFC polymer coated on tea leaves before (Fig. 6b) and after Pb^{+2} adsorption (Fig. 6c) were compared it was observed that the pores present on the surfaces of the adsorbent were occupied by the adsorbate, after adsorption. EDX spectra revealed the presence of carbon,

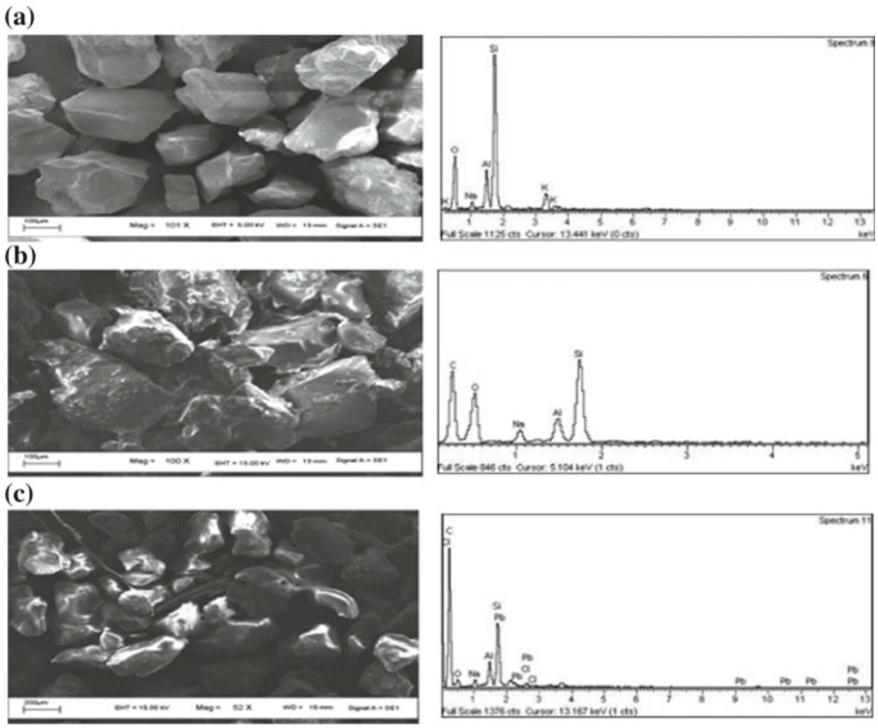

Fig. 5 **a** SEM image and EDX spectra of sand **b** SEM image and EDX spectra of AFC coated sand before lead adsorption **c** SEM image and EDX spectra of AFC sand after lead adsorption

oxygen, and calcium atoms on AFC coated on waste tea leaves before adsorption, while lead atom was observed after adsorption (Fig. 6c).

(d) Characteristics of AFC coated fly ash

The surface morphology of AFC polymer coated fly ash has marked distinction, in comparison to the untreated fly ash, as is evident from SEM images (Fig. 7a and Fig. 7b). The untreated fly ash showed smooth spherical particles, whereas the surfaces after AFC treatment became progressively rougher and broken (Fig. 7b). Before interaction with lead ion, EDX spectra of AFC polymer coated on fly ash, showed the presence of carbon, oxygen, and aluminum atoms, whereas lead peak was observed after adsorption (Fig. 7c).

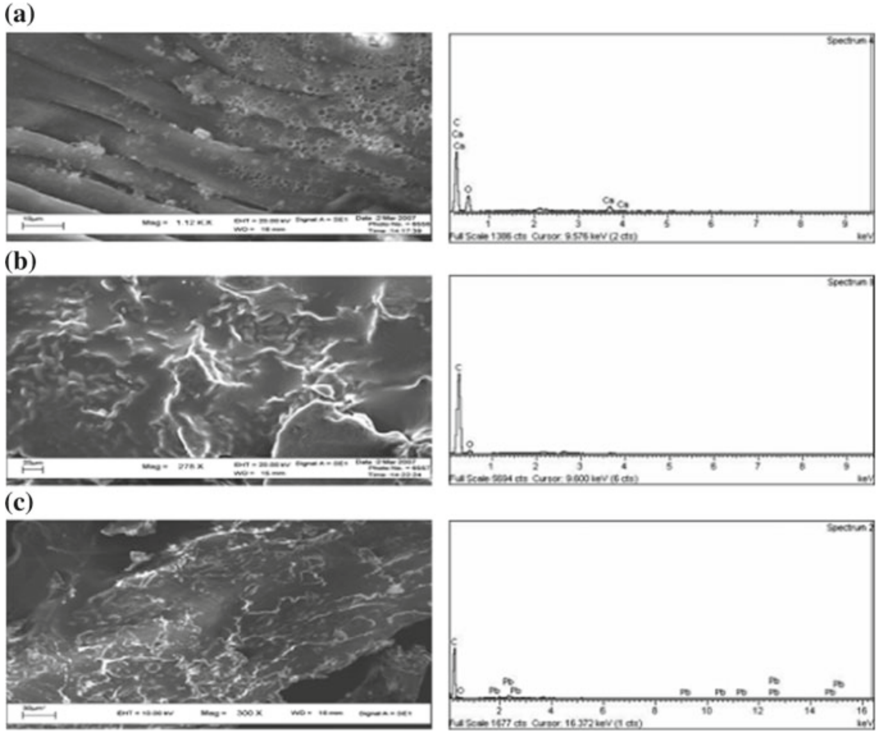

Fig. 6 **a** SEM image and EDX spectra of tea leaves **b** SEM image and EDX spectra of AFC coated tea leaves before lead adsorption **c** SEM image and EDX spectra of AFC tea leaves after lead adsorption

4 Conclusions

Reaction pH is the most critical parameter, which controls the Pb^{+2} ion removals by aniline–formaldehyde condensate polymer coated on the selected support materials. Lead adsorption by the AFC polymer coated on various support materials like eggshell, sand, tea leaves, and fly ash followed Lagergren second-order kinetic models. The advantage of using AFC coated adsorbents includes easy synthesis of the polymer. The above adsorbents can be effectively used as a potential adsorbent for the removal of lead from wastewater.

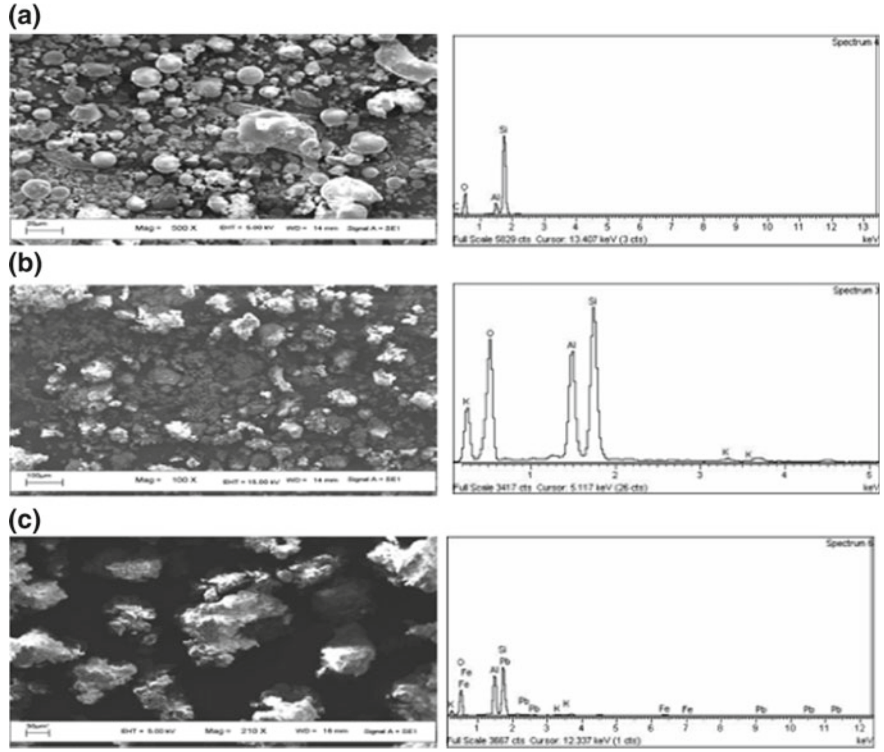

Fig. 7 **a** SEM and EDX spectra of fly ash **b** SEM image and EDX spectra of AFC coated fly ash before lead adsorption **c** SEM image and EDX spectra of AFC fly ash after lead adsorption

References

1. Al-Subu, M.M.: The interaction effects of cypress (*Cupressus sempervirens*), cinchona (*Eucalyptus longifolia*) and pine (*Pinus halepensis*) on their efficiencies for lead removal from aqueous solutions. Adv. Environ. Res. **6**, 569–576 (2002)
2. Bailey, S.E., Olin, T.J., Bricka, R.M., Adrian, D.D.: A review of potentially low-cost sorbents for heavy metals. Water Res. **33**, 2469–2479 (1999)
3. Bradl, H. (ed.): Heavy Metals in the Environment: Origin, Interaction and Remediation, vol. 6. Academic Press, London (2002)
4. Bryan, G.W., Langston, W.J.: Bioavailability, accumulation and effects of heavy metals in sediments with special reference to United Kingdom estuaries: a review. Environ. Pollut. **76**, 89–131 (1992)
5. Cho, H., Oh, D., Kim, K.: A study on removal characteristics of heavy metals from aqueous solution by fly ash. J. Hazard. Mater. **1–3**, 187–195 (2005)
6. Curkovic, L., Cerjan-Stefanovic, S., Rastovean-Mioe, A.: Batch Pb^{+2} and Cu^{+2} removal by electric furnace slag. Water Res. **35**, 3436–3440 (2001)
7. Fergusson, J.E. (ed.): The Heavy Elements: Chemistry, Environmental Impact and Health Effects. Pergamon Press, Oxford (1990)

8. Ghoul, M., Bacquet, M., Morcellet, M.: Uptake of heavy metals from synthetic aqueous solutions using modified PEI-silica gels. Water Res. **37**, 729–734 (2003)
9. Gupta, K.V., Gupta, M., Sharma, S.: Process development for the removal of lead and chromium from aqueous solutions using red mud-an aluminium industry waste. Water Res. **35**, 1125–1134 (2001)
10. Hall, R.K., Eagleton, L.C., Acrivos, A., Vermeulen, T.: Pore and solid diffusion kinetics in fixed bed adsorption under constant pattern conditions. Ind. Eng. Chem. Fundamentals. **5**, 212–223 (1966)
11. He, Z.L., Yang, X.E., Stoffella, P.J.: Trace elements in agro ecosystems and impacts on the environment. J. Trace Elem. Med Biol. **19**(2–3), 125–140 (2005)
12. Ho, Y.S., McKay, G.: The kinetics of sorption of divalent metal ions onto sphagnum moss peat. Water Res. **34**, 735–742 (2000)
13. Ho, Y.S.: Second order kinetic model for the sorption of cadmium onto tree fern: a comparison of linear and non-linear methods. Water Res. **40**, 119–125 (2006)
14. Ho, Y.S., Chiu, W., Wang, C.: Regression analysis for the sorption isotherms of basic dyes on sugarcane dust. Bioresour. Technol. **96**, 1285–1291 (2005)
15. Hyun, S., Lee, C.H., Lee, T., Choi, J.W.: Anthropogenic contributions to heavy metal distributions in the surface sediments of Masan Bay, Korea. Mar. Pollut. Bull. **54**, 1031–1071 (2007)
16. Kumar, G.P., Kumar, P.A., Chakraborty, S., Ray, M.: Uptake and desorption of copper ion using functionalized polymer coated silica gel in aqueous environment. Sep. Purif. Technol. **57**, 47–56 (2007)
17. Kumar, P.A., Ray, M., Chakraborty, S.: Hexavalent chromium removal from wastewater using aniline formaldehyde condensate coated silica gel. J. Hazard. Materials. **143**, 24–32 (2007)
18. Lin, S.H., Lai, S.L., Leu, H.G.: Removal of heavy metals from aqueous solution by chelating resin in a multistage adsorption process. J. Hazar. Mater. **76**, 139–153 (2000)
19. Liu, G., Freund, M.S.: New approach for the controlled cross-linking of polyaniline: synthesis and characterization. Macromolecules **30**, 5660–5665 (1997)
20. Long, E.R.: Degraded sediment quality in US estuaries: a review of magnitude and ecological implications. Ecol. Appl. **10**, 338–349 (2000)
21. Nriagu, J.O.: A global assessment of natural sources of atmospheric trace metals. Nature **338**, 47–49 (1989)
22. National Research Council (NRC) ER: Contaminated marine sediments—assessment and remediation. Washington (DC) Marine Board, National Research Council, National Academy of Science Press (1989)
23. Pekey, H.: The distribution and sources of heavy metals in Izmit Bay surface sediments affected by a polluted stream. Mar. Pollut. Bull. **52**, 1197–1208 (2006)
24. Shallari, S., Schwartz, C., Hasko, A., Morel, J.L.: Heavy metals in soils and plants of serpentine and industrial sites of Albania. Sci. Total Environ. **19209**, 133–142 (1998)

Investigation on the Effect of Planting *Canna Indica* in Two-Stage Vermifilter for Synthetic Dairy Wastewater Treatment

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Abstract Two vermifilters were designed using persplex in which *Canna indica* was planted in one reactor (MAVF) and the other was without any plant (VmF), but earthworm *Eisenia fetida* was inoculated in both the filters. The filter consisted of two units: first vertical flow (VF) unit and second horizontal flow (HF) unit. Hydraulic load of synthetic dairy wastewater was maintained 0.6 md^{-1} in VF unit of the reactor. The average removal efficiencies of BOD_5 and COD in MAVF were found to be 88.4% and 80.7%, respectively, while for VmF, it was 78.3% and 69.1%. Nitrogen is usually removed in nitrification and denitrification process. The combined unit removed 61.7% TN in MAVF and 51.3% in VmF reactor. Average TP removal was observed 77.8% and 73.4% in MAVF and VmF, respectively. The efficiency of MAVF was more than VmF.

Keywords Vermifilter · *Canna indica* · *Eisenia fetida* · Laterite · Nutrients · Organics

Nomenclature

MAVF	Macrophyte Assisted Vermifilter
VmF	Vermifilter
VF	Vertical Flow
HF	Horizontal Flow
TN	Total Nitrogen
TP	Total Phosphorous

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BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
AOB	Ammonium Oxidizing Bacteria
PSM	Phosphorous Solubilizing Microbes

1 Introduction

Due to rapid industrialization and urbanization, a huge amount of wastewater is generated from various industries. The maximum portion of the wastewater is sent back to natural water body or flowing fresh streamline without proper treatment. The majority of wastewater is generated from brewery industry, electroplating, pharmaceutical, chemical, food processing, dairy, oil refining, textile industries, etc. [1–3]. Effluent from dairy industry contains a lot of organic substances which can be degraded easily when mixed with freshwater bodies. The carbohydrate and protein content of dairy wastewater was degraded by microbes and the byproducts are deposited as sludge at the bottom. It affects negatively all the aquatic flora and fauna [4, 5].

Vermifilter (VmF) is an eco-friendly and natural technology for the treatment of organic and nutrient-rich wastewater. It is a natural biofilter in which earthworm is added in a suitable filter bed to improve the treatment process. The bed materials where earthworm is inoculated can be soil, ceramsite, compost, or any organic half decomposed waste. Earthworm stimulates the microbial activity and changes the diversity of decomposing microbes in vermi bed [6–8]. In first stage, earthworm churned the bigger pollutants present in wastewater and converted it to small one, and in second stage, microbes further degraded the same particles (Fig. 1). Earthworm and microbe's symbiotic activity accelerate the degradation process. Macrophyte root system releases oxygen and converts the surrounding to aerobic in nature which favors growth of aerobic microbes. Apart from this, microbes attached to the root surface colonize easily. Overall, planting macrophytes in vermi bed enhances the efficiency of the filter [9]. Most of the previous researches have focused on macrophyte filter and vermifilter separately. Very few preliminary

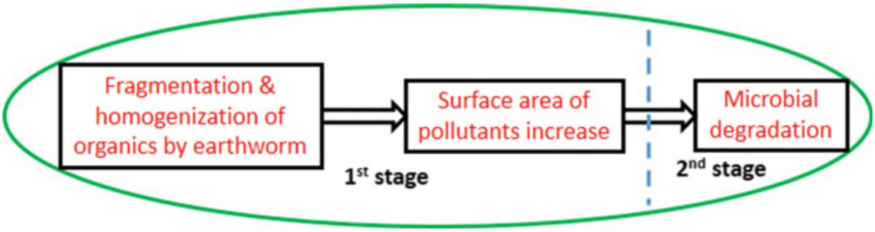

Fig. 1 Symbiotic activity of earthworm and microorganism

reports are available in which both earthworm and macrophyte are combined in a single reactor to treat various wastewater. So, the major objective is to study the effect of *Canna indica* on performance of vermifilter (VmF).

2 Materials and Methodology

2.1 Design of Reactors

Two laboratory-scale VF unit and HF unit were designed using persplex and placed as shown in Fig. 2. VF unit receives wastewater with a hydraulic load of 0.6 m^3 m^{-2} d^{-1} by gravity flow. The working height and diameter of VF unit were 70 cm and 19.8 cm, respectively, and length, width, height of HF unit were 60, 18, and

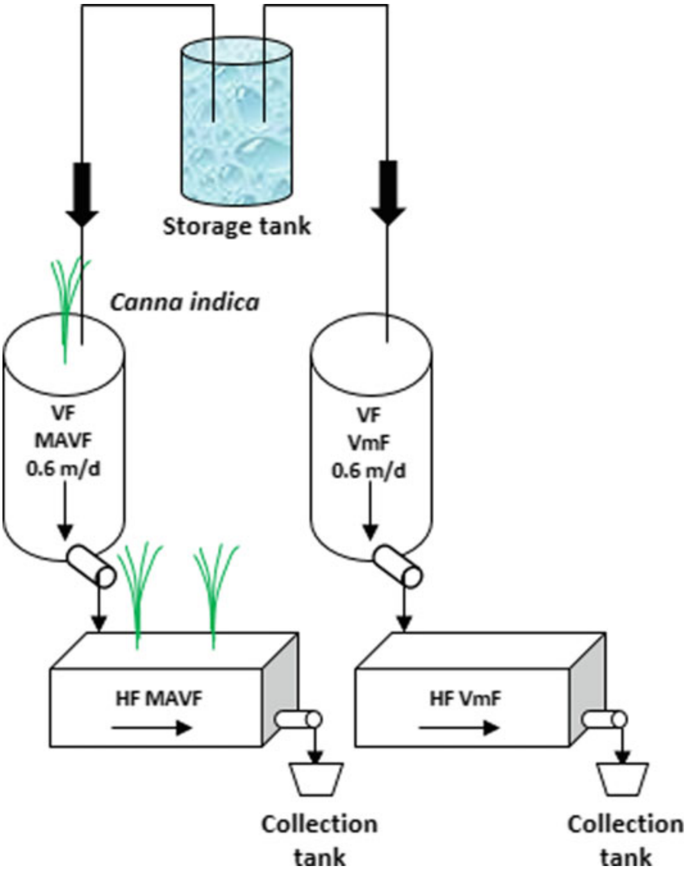

Fig. 2 Schematic diagram of experimental setup

30 cm, respectively. The upper layer (25 cm) of vermi bed was taken a mixture of vermicompost and garden soil in the ratio of 1:3 by volume in VF unit. Washed sand (10 cm thick), 4–6 mm laterite stone (20 cm thick), and 8–10 mm coarse gravel (15 cm thick) were taken as second, third, and fourth layers from top to bottom in VF unit. HF unit was filled with soil and laterite. One set of reactor (both VF and HF) among these two was planted with *Canna indica* to improve the treatment process, which was called macrophyte assisted vermifilter (MAVF). The top layer was called as worm active layer and in this zone, *Eisenia fetida* was inserted at a density of 10,000 worms/m^3 [1]. The duration of the experiment was 90 days and prior to that, 15 days of acclimatization period was given to all the reactor units.

2.2 Wastewater Composition and Characteristics

Influent was prepared daily by the addition of 1500 mg milk powder, 15 mg $FeCl_3.6H_2O$, 70 mg $MgSO_4.7H_2O$, 30 mg $CaCl_2.H_2O$, 15 mg $MnSO_4.7H_2O$, 60 mg KH_2PO_4, 120 mg NH_4Cl, and 1000 mg $NaHCO_3$ in tap water [16]. Wastewater was kept for one before applying to the reactor.

2.3 Analytical Procedure

BOD_5, COD, solids, NH_4^+-N, TN, TP, and pH were analyzed for both influent and effluent. The methods used to determine BOD_5, COD, solids, NH_4^+-N, TN, and TP were azide modification method, potassium dichromate method, gravimetric method, Nessler reagent method, and persulfate digestion method (for TN and TP), respectively [11]. The removal efficiency was calculated using Eq. 1

$$\text{Percentage Reduction} = \frac{C_i - C_o}{C_i} \times 100 \tag{1}$$

where C_i represents influent and C_0 represents effluent value.

3 Results and Discussion

3.1 Organics Removal

The maximum portion of organic pollutants present in wastewater is filtered out and settled in worm active zone of VF unit [10]. Earthworm present in that zone utilized those pollutants as food sources and assimilated in their body. Due to earthworm

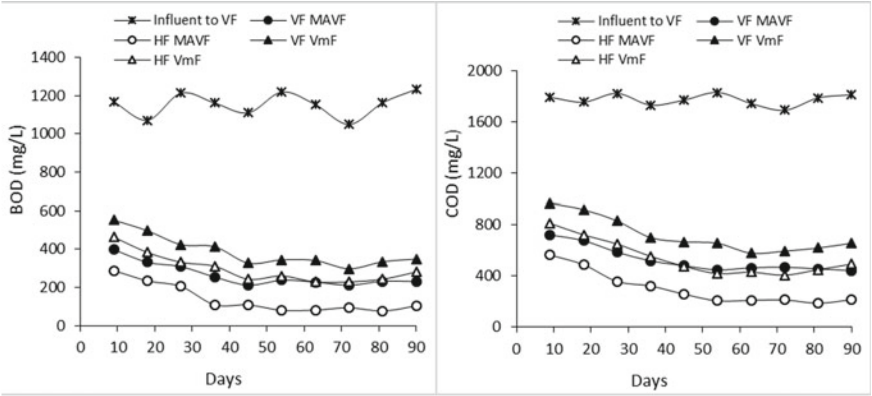

Fig. 3 Organics removal in MAVF and VmF

burrowing activity and oxygen leakage from *Canna indica* root, aerobic conditions maintained in vermi bedfavors the growth of aerobic decomposing microbes [3, 4]. Those microbes break down the remaining organics present in filter bed through aerobic degradation process [12]. The average removal efficiency of BOD was found to be 88.4% for MAVF and 78.3% for VmF at an average influent BOD of 1103.6 ± 82 mg/L. Similarly, average 80.7% COD and 69.1% BOD were observed at an average influent COD of 1734.8 ± 110 mg/L (Fig. 3).

Due to the easy degradation of biodegradable parts of dairy wastewater, BOD reduction was high related to COD. Organic removal was higher in MAVF than VmF due to the presence of *Canna indica.* The root system of macrophyte enhances physical filtration process and provides surface area on root for the colonization of microorganisms [3]. In bio-oxidation process, a large portion of the carbon was released to atmosphere in the form of carbon dioxide and some portion was utilized as energy source by earthworms [13].

3.2 Nitrogen Removal

Nitrogen removal processes in present biofilter are nitrification–denitrification, matrix adsorption, and plant and microbial uptake [14, 15]. Due to the dominance of oxygenation conditions in VF unit, nitrification occurred and HF unit promotes denitrification. Different sources of oxygen in VF unit are diffused atmospheric oxygen, oxygen present in wastewater and biofilm, oxygen leakage from root tip of macrophyte, etc. The macrophyte root system also nourishes plenty of nitrifier and ammonium oxidizing bacteria (AOB). Apart from this, earthworm's intestine supports the growth of nitrifying and denitrifying bacteria too. All these microbes together participate in removal of nitrogen in the present biofilter. Earthworm's burrowing activity creates a lot of micro and macro pores accelerating the diffusion

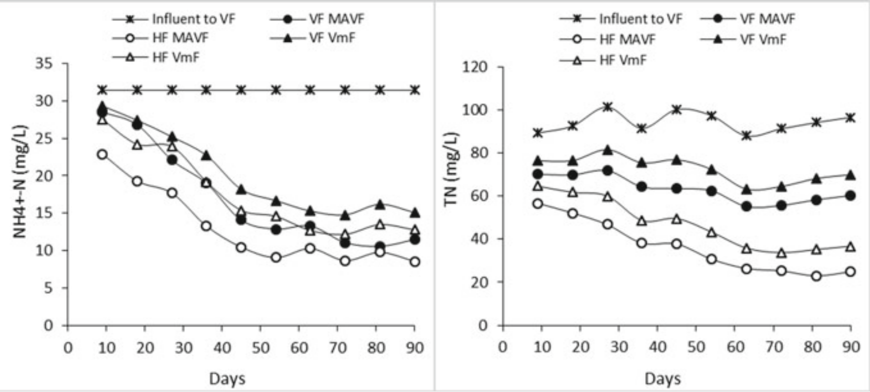

Fig. 4 Nitrogen removal in MAVF and VmF

of oxygen to filter bed [17–19]. NH_4^+-N and TN concentration in influent wastewater were 31.4 mg/L and 92.3 ± 9 mg/L, respectively. MAVF and VmF removed 61.7% and 51.3% TN, respectively, and effluent NH_4^+-N concentration in both the reactors was 8.6–12.8 mg/L. Figure 4 shows the NH_4^+-N and TN variation in reactor.

Figure 5 shows the change in pH in effluent wastewater. According to the literature, earthworms have the capacity of neutralizing pH. Initially, ammonia is deposited in the top layer of the VF unit and it cannot be oxidized due to low establishment of ammonium oxidizing bacteria (AOB). For this reason, initially, influent pH was higher. Gradually deposited nitrogen in filter bed changed to nitrates due to growth of nitrifiers. Various organic acids and CO_2 formation accelerate the pH reduction process. The agglomerate effect of both processes regulates the pH [1, 21].

3.3 *Phosphorous Removal*

In biofilter, phosphorous removal depends upon sorption capacity, particle size, and surface area of filter bed. Apart from this, macrophyte and microbial uptake, precipitation, and complex formation play a major role [4, 23]. Laterite is composed of Fe and Al, which adsorb and form various complexes with phosphorous present in wastewater. In contrast, PSM present in vermicast and phosphatase enzyme released from earthworm's gut stimulate phosphate mineralization in vermifilter bed [14, 24]. Both the processes control phosphorous removal [12, 20, 22]. Influent TP concentration was 29.4 ± 4.9 mg/L. The average removal of phosphorous in MAVF and VmF were 77.8% and 73.4%, respectively (Fig. 6). Phosphorous removal efficiency gradually decreases due to deposition of phosphorous in active site of laterite.

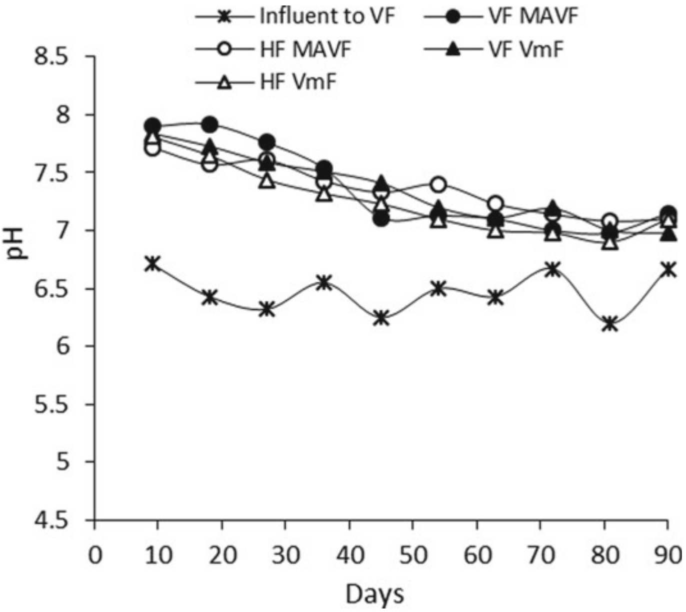

Fig. 5 pH variation in effluent of MAVF and VmF

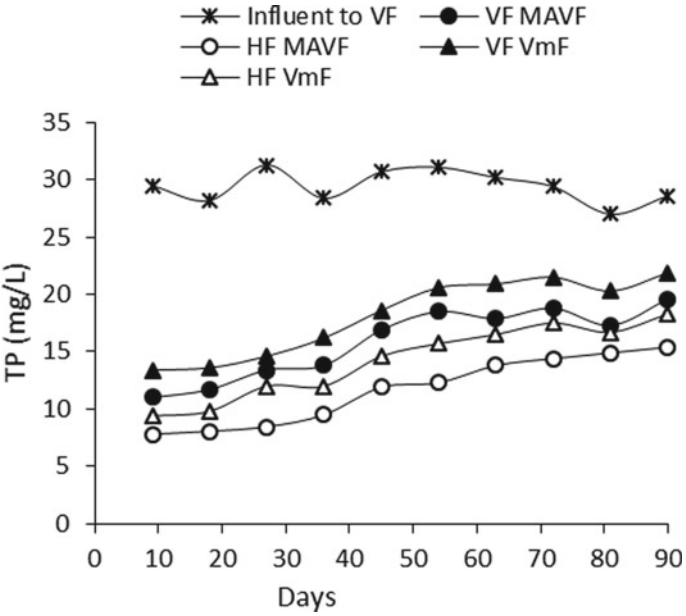

Fig. 6 Phosphorous removal in MAVF and VmF

4 Conclusions

The hybrid biofilter planted with *Canna indica* and inoculated with *Eisenia fetida* effectively reduces organics and nutrients present in dairy wastewater. VF unit removed more pollutants than HF unit and efficiency of MAVF was higher than VmF system. Laterite media has good phosphorous removal capacity. Still a lot of research is necessary in the area of influent feeding mode, microbiological approach, design aspect, and longevity of the filter to make it more convenient.

References

1. Arora, S., Rajpal, A., Kazmi, A.A.: Antimicrobial activity of bacterial community for removal of pathogens during vermifiltration. J. Environ. Eng. **142**, 1–10 (2016)
2. Bhatia, A., Madan, S., Sahoo, J., Ali, M., Pathania, R., Kazmi, A.A.: Diversity of bacterial isolates during full scale rotary drum composting. Waste Manage. **33**, 1595–1601 (2013)
3. Carballeira, T., Ruiz, I., Soto, M.: Aerobic and anaerobic biodegradability of accumulated solids in horizontal subsurface flow constructed wetlands. Int. Biodeter. Biodegra. **119**, 396–404 (2017)
4. Dan, T.H., Quang, L.N., Chiem, N.H., Brix, H.: Treatment of high-strength wastewater in tropical constructed wetlands planted with *Sesbania sesban*: horizontal subsurface flow versus vertical downflow. Ecol. Eng. **37**, 711–720 (2011)
5. Demirel, B., Yenigun, O., Turgut, T.O.: Anaerobic treatment of dairy wastewaters: a review. Pro. Biochem. **40**, 2583–2595 (2005)
6. Domínguez, J., Aira, M., Gómez-Brandón, M.: Vermicomposting: earthworms enhance the work of microbes. In: Microbes at Work. Springer, Heidelberg, Dordrecht, London, New York, pp. 93–114 (2010)
7. Hait, S., Tare, V.: Vermistabilization of primary sewage sludge. Bioresour. Technol. **102**, 2812–2820 (2011)
8. Kantawanichkul, S., Kladprasert, S., Brix, H.: Treatment of high-strength wastewater in tropical vertical flow constructed wetlands planted with *Typha angustifolia* and *Cyperus involucratus*. Ecol. Eng. **35**, 238–247 (2009)
9. Kumar, T., Rajpal, A., Arora, S., Bhargava, R., Hari Prasad, K.S., Kazmi, A.A.: A comparative study on vermifiltration using epigeic earthworm *Eisenia fetida* and *Eudrilus eugeniae*. Desalin. Water Treat. **57**, 6347–6354 (2016)
10. Liu, J., Lu, Z., Yang, J., Xing, M., Yu, F., Guo, M.: Effect of earthworms on the performance and microbial communities of excess sludge treatment process in vermifilter. Bioresour. Technol. **117**, 214–221 (2012)
11. APHA: Standard Methods for the Examinations of Water and Wastewater, 21st edn. APHA and AWWA and WEF, Washington DC (2005)
12. Merlin, G., Cottin, N.: Performance of a compost biofilter containing earthworms to treat cheese whey. Environ. Technol. **30**, 995–1002 (2009)
13. Pramanik, P.: Changes in microbial properties and nutrient dynamics in bagasse and coir during vermicomposting: quantification of fungal biomass through ergosterol estimation in vermicompost. Waste Manage. **30**, 787–791 (2010)
14. Rajpal, A., Arora, S., Bhatia, A., Kumar, T., Bhargava, R., Chopra, A.K., Kazmi, A.A.: Co-treatment of organic fraction of municipal solid waste (OFMSW) and sewage by vermireactor. Ecol. Eng. **73**, 154–161 (2014)

15. Ravindran, B., Wong, W.C., Selvam, A., Sekaran, G.: Influence of microbial diversity and plant growth hormones in compost and vermicompost from fermented tannery waste. Bioresou. Techn. **217**, 200–204 (2016)
16. Rodgers, M., Xiao, L.W., Mulqueen, J.: Synthetic dairy wastewater treatment using a new horizontal-flow biofilm reactor. J. Environ. Sci. Healt A. **41**, 751–761 (2006)
17. Saeed, T., Sun, G.: A review on nitrogen and organics removal mechanisms in subsurface flow constructed wetlands: dependency on environmental parameters, operating conditions and supporting media. J. Environ. Manage. **112**, 429–448 (2012)
18. Samal, K., Dash, R.R., Bhunia, P.: Performance assessment of a *Canna indica* assisted vermifilter for synthetic dairy wastewater treatment. Process Saf. Environ. Prot. **111**, 363–374 (2017)
19. Samal, K., Dash, R.R., Bhunia, P.: Treatment of wastewater by vermifiltration integrated with macrophyte filter: a review. J. Environ. Chem. Eng. **5**, 2274–2289 (2017)
20. Samal, K., Dash, R.R., Bhunia, P.: Effect of hydraulic loading rate and pollutants degradation kinetics in two stage hybrid macrophyte assisted vermifiltration system. Biochem. Eng. J. **132**, 47–59 (2018)
21. Singh, R., Bhunia, P., Dash, R.R.: A mechanistic review on vermifiltration of wastewater: design, operation and performance. J. Environ. Manag. **197**, 656–672 (2017)
22. Sinha, R.K., Bharambe, G., Chaudhari, U.: Sewage treatment by vermifiltration with synchronous treatment of sludge by earthworms: a low-cost sustainable technology over conventional systems with potential for decentralization. Environmentalist **28**, 409–420 (2008)
23. Vymazal, J.: Removal of nutrients in various types of constructed wetlands. Sci. Total Environ. **380**, 48–65 (2007)
24. Wu, H., Fan, J., Zhang, J., Ngo, H.H., Guo, W., Hu, Z., Lv, J.: Optimization of organics and nitrogen removal in intermittently aerated vertical flow constructed wetlands: effects of aeration time and aeration rate. Int Biodeter. Biodegra. **113**, 139–145 (2016)

Removal of Chromium Using Water Treatment Sludge

Toji N. Thomas and M. Mansoor Ahammed

Abstract Aluminium-based water treatment sludge (WTS) was investigated for its potential to remove chromium(VI) from simulated wastewater. Batch sorption tests and column tests were carried out using poly aluminium chloride sludge. Results of the batch study showed that chromium sorption decreased with increase in pH for the pH range studied (2.0–12.0). Long-duration column test with an empty bed contact time of 3 h indicated good Cr(VI) removal capacity of WTS as no chromium was present in the effluent for 115 bed volumes, and a sorption capacity of 1.62 mg/g of dry sludge was obtained which was lower than the sorption capacity reported in the literature. In the presence of other metals such as Co, Cu, Hg and Pb, both percentage Cr(VI) removal and sorption capacity was negatively affected in column tests, and Cr(VI) sorption capacity was only 0.96 mg/g of dry sludge.

Keywords Chromium removal · Column study · Heavy metals · Water treatment sludge · Adsorption

1 Introduction

In recent years, the problems caused due to accumulation of heavy metals in the environment have been receiving increased attention. Heavy metals are still being used in large quantities due to their technological importance in different industries and this has made heavy metals as unavoidable pollutants. Due to low removal efficiency, heavy metals at its lower concentration and higher costs in conventional techniques paved the way for the identification of adsorbents with high sorption capacity for heavy metals, and several adsorbents obtained from low-cost and waste materials have been identified.

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In water treatment facilities all around the world, large quantities of water treatment sludge or residual (WTS) are generated during the coagulation and flocculation process which results from the removal of suspended impurities in the raw surface water. At present, disposal methods for these WTS include (a) discharge into municipal wastewater (b) disposal into inland water bodies and (c) use for soil improvement, with the assumption that these wastes do not cause any harm to the receiving environment [1, 2]. In recent years, with the realization of negative impacts of WTS on the environment, stringent regulations have been implemented in many countries. This resulted in an interest in the reuse of these residuals. Studies have been reported in the literature on the possible reuse of the water treatment sludge in different ways which include its use for soil improvement, as a construction material and in water and wastewater treatment [3, 4].

Coagulation is a common treatment process in water treatment industry which uses iron or aluminium ions, and the resulting sludge namely Fe-WTS and Al-WTS contain iron and aluminium hydroxides, respectively. These sludges also contain humic substances and suspended solids originally present in the raw water [5]. Further, due to their amorphous nature, WTS will add more sorption sites on sorption surface [6]. Thus, this highly reactive nature makes water treatment sludge suitable for several potential applications as sorbents [7]. Two different approaches have been employed in the reuse of WTS for wastewater treatment [3]. In the first approach, aluminium or iron ions are first recovered from the waste material and the recovered chemical is used generally as a coagulant in the treatment of water/wastewater. The raw residual in dry/wet form itself can also be used for the removal of different pollutants present in wastewater. The second approach where wet/dry sludge is utilized is more popular compared to the first approach and has been employed to treat types of wastewaters containing a variety of pollutants such as heavy metals, nutrients and colour [3, 4, 6, 8]. Several studies have been reported in the literature assessing the potential of WTS for removing various heavy metals [7, 9–14]. As heavy metal itself is a major environmental problem in consideration, the reuse of these residuals in the removal and recovery of metals can be considered as an environmentally friendly option for both sludge and metals.

The present study investigated the suitability of water treatment residuals obtained from a treatment plant which uses poly aluminium chloride as a coagulant for removing heavy metals from simulated wastewater. The performance of water treatment sludge was evaluated in batch and long-duration column tests using single metal and multi-metal systems. Heavy metals tested included chromium, copper, mercury, cobalt and lead.

2 Materials and Methods

2.1 Collection and Characterisation of Water Treatment Sludge

In the present study, WTS was collected from the coagulation–flocculation unit of the water treatment plant in Katargram, Surat, India. The plant treats 240 million litres of River Tapi water per day using poly aluminium chloride (PACl) as the coagulant. The collected residual was transported to the laboratory and was dried at 105 °C for 2 days. No pretreatment was given to the sludge before use. The sludge was crushed after drying and passed through 150-micrometre sieve and the retained portion on the sieve was employed in all the tests. A single batch of sludge collected on a particular day was used in all the tests reported in this study.

Scanning electron micrographs of the powdered sludge shown in Fig. 1 indicate that the sludge is of various sizes and shapes and is of highly porous nature. The SEM images do not show classical well-crystalline appearance on WTS surface. Hence, the aluminium present in the WTS may be in the amorphous form.

2.2 Batch Sorption Tests

The batch tests to determine the adsorption capacity of different metal ions was performed at ambient temperature. Five metals, namely lead, cobalt, mercury, copper and chromium were used. Tests were conducted in duplicate at a constant ionic strength using 0.01 M sodium nitrate solution. The desired concentration of metals was prepared by using lead nitrate $Pb(NO_3)_2$, cobalt nitrate $Co(NO_3)_2$, mercuric nitrate $Hg(NO_3)_2$, copper nitrate $Cu(NO_3)_2$ and sodium chromate Na2CrO4. A 50 mL of solution containing equal volume of 0.01 M $NaNO_3$ solution and individual metal solution was taken in a bottle and the calculated

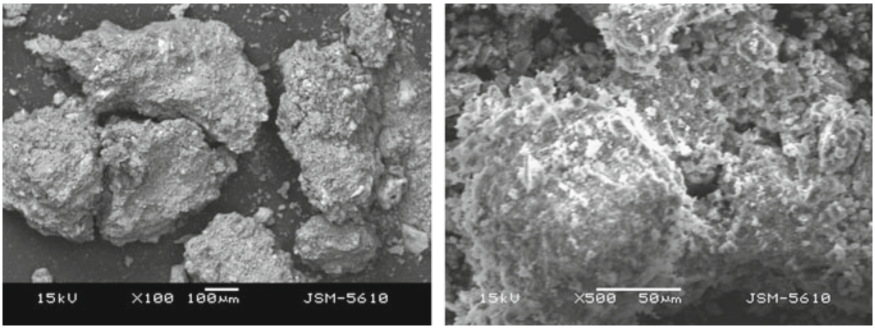

Fig. 1 Scanning electron micrographs of water treatment sludge at different magnifications

quantity of WTS was added to a particular solution. This solution was shaken for the desired period in a shaker at 150 rpm until equilibrium was reached. After the equilibrium period, centrifugation was done (2000 × g) for 10 min and was analyzed for the metal content using ICP-AES/spectrophotometer (ARCOS Spectro, Germany). For the batch adsorption experiments, different variables were considered including contact time, initial concentration of metal, pH and WTS dosage and the optimum conditions for metal adsorption were determined. Effect of each parameter on the extent of adsorption was analyzed by maintaining other variables constant.

2.3 Column Study

Two columns were set up, one for the removal of chromium alone and the other for multi-metal (chromium, copper, mercury, lead and cobalt) removal. Both these columns were made of a cylindrical glass tube of inner diameter 2.4 cm. Sludge was packed between two supporting layers of glass wool for 15 cm height and the upper portion of the bed was covered with pebbles. The synthetic metal solution of 10 mg/L concentration was prepared to feed the column. Column operation was done in upflow mode using a peristaltic pump with a flowthrough time maintained at 1 h for chromium and multi-metal removal studies. The effluent was collected and metal contents were determined. Leaching of aluminium and organic matter from sludge were checked by measuring effluent aluminium and COD, respectively.

3 Results and Discussion

3.1 Characteristics of Water Treatment Residual

Table 1 presents the physical and chemical properties of the sludge employed. The solid content of the sludge was high at 67% while TVS/TS ratio showed a low value of 0.45. The low TVS/TS ratio shows a larger proportion of inorganic materials in the sludge. The elemental spectra analysis using EDS showed that the important contents in the sludge were Al, Si, Ca, and Fe. Aluminium and iron contents were 88.7 and 48.2 mg/g dry sludge, respectively. Scanning electron micrographs indicated that residuals consist of particles with irregular shape and sizes. High silica content in sludge (165.1 mg/g dry sludge) indicated the predominated silica surface sites on the surface of the water treatment sludge that can involve in surface complex reactions of metals with silica oxide.

Table 1 Physico-chemical characteristics of the residual used in the study

Parameter	Value	Parameter	Value
pH	7.16	Mg (mg/g)	9.7
pH_{zpc}	6.9	Al (mg/g)	88.7
CEC (cmol/kg)	4.61	Si (mg/g)	165.1
Moisture content (% of sludge)	33.11	P (mg/g)	5.5
Total solids (% of sludge)	66.89	Cl (mg/g)	6.5
Fixed solids (% of total solids)	55	Ca (mg/g)	19.6
Volatile solids (% of total solids)	45	Fe (mg/g)	48.2
C (mg/g)	146.8	O (mg/g)	509.9

3.2 Batch Tests

In order to determine the suitable contact time for the sorption of metal onto water treatment sludge, the adsorption rate of metal ions was determined as a function of time (Fig. 2). It was observed that equilibrium had occurred at a contact time of 8 h. Adsorption did not seem to increase beyond a contact time of 8 h, and hence, further tests were conducted with a contact time of 8.0 h.

In order to study the effect of pH on heavy metal removal, the solution pH was varied in the range of 2–12 for the metals considered, and the results are shown in Fig. 3. As evident from Fig. 3, for Cr(VI), sorption decreased with increase in

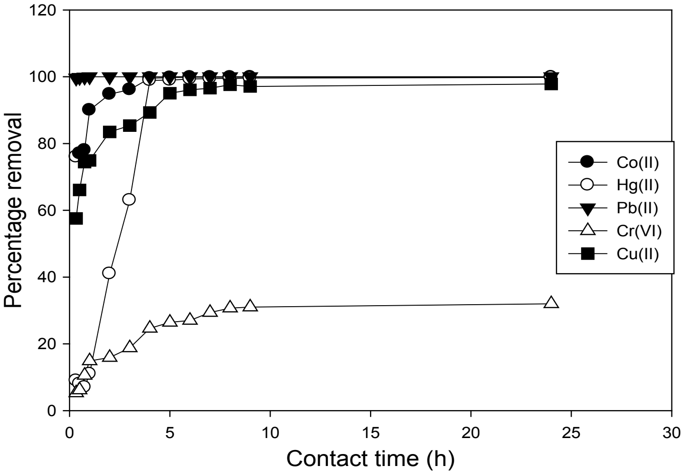

Fig. 2 Metal removal at different contact times (initial concentration of each metal = 10 mg/L, water treatment sludge dose = 10 g/L, pH = 7.3)

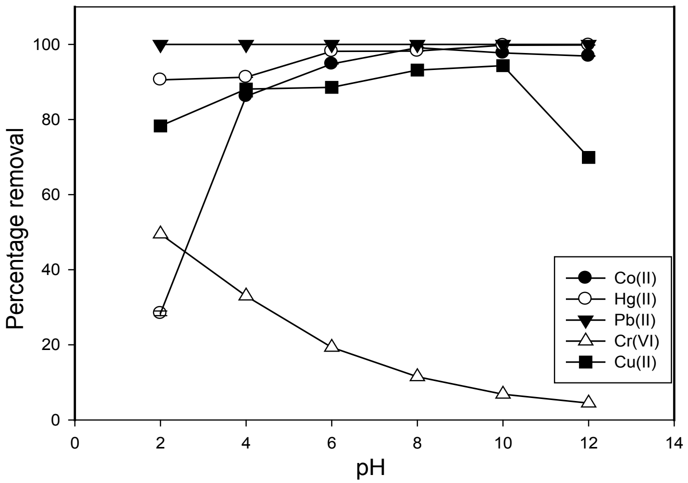

Fig. 3 Metal removal at different initial pH values (initial concentration of each metal = 10 mg/L, water treatment sludge dose = 10 g/L)

initial pH. For Cu(II) removal, increased pH till pH 10 showed a decreased value at pH 12. Co(II) and Hg(II) showed increasing removal with increasing pH, while Pb (II) was unaffected by pH and was completely removed in the pH range studied (2–12). pH is the key parameter that governs surface charge of WTS. The extent of sorption on adsorbent surface depends on the zero point charge (pH_{zpc}) of the sorbent material. In this study, pH_{zpc} of sludge was observed as 6.9. It is known that above pH_{zpc}, the sorbent would be negatively charged and cationic metal adsorption would be favoured. Further, it is reported that increase in pH would result in increased generation of cation hydroxide phase [15] and as a result, higher metal cation removal was observed at higher pH values.

3.3 *Column Tests*

Two column tests were conducted, and in the first test, initial chromium content was maintained around 10 mg/L while the second column test was conducted using a solution containing all the five metals. Bed flowthrough time of 1.0 h was used in the column tests. Both the tests were performed with an initial solution pH of 6.38. Breakthrough time for each of the metals and the corresponding breakthrough concentration were found out.

Breakthrough curve for the first column test is presented in Fig. 4. The Cr(VI) concentration was below detectable limit till 116th bed volume and breakthrough occurred suddenly after that. The column run was continued till 308th bed volume where the removal reached <7.0%. Generally, the breakthrough is said to have

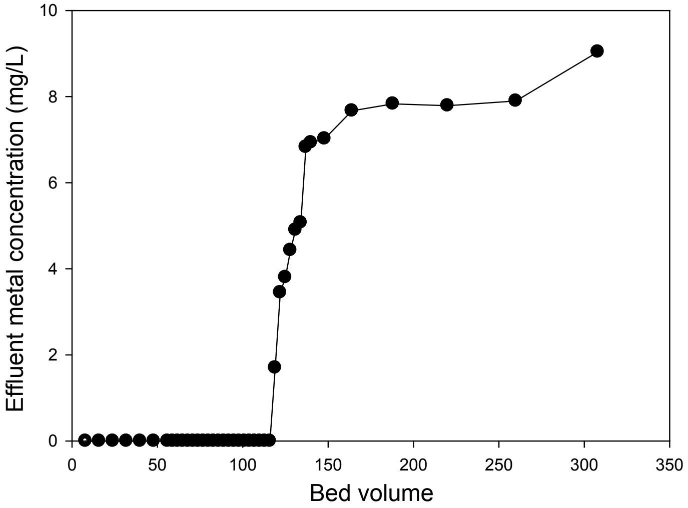

Fig. 4 Breakthrough curve for Cr (VI) (initial pH = 6.5, initial metal concentration = 9.7 mg/L)

occurred when C_e/C_0 value approaches 0.05, and adsorption bed is said to be exhausted when the outlet value reaches 95% of the initial value [16]. Maximum equilibrium capacity of the sludge was given by area behind the breakthrough curve and it was obtained as 1.62 mg/g of sludge. It is much higher than that obtained from batch adsorption study (0.24 mg/g of sludge).

Figure 5 presents the results of the column study with all the five metals. Though the targeted initial concentrations for all the metals were 10.0 mg/L, it resulted in precipitation of some metals. Thus the column was clogged after 1 day operation. It was decided to filter the prepared metal solution which resulted in reduced metal concentration in the influent to the column. The average metal concentrations were Cu(II): 0.732 mg/L, Pb(II): 0.381 mg/L, Co(II): 9.019 mg/L, Cr(VI): 9.5 mg/L and Hg(II): 0.433 mg/L.

Figure 5 clearly shows that the presence of other metals affected Cr(VI) removal. For Cu(II), Pb(II) and Hg(II) breakthrough occurred at 220th, 228th and 200th bed volumes, respectively. For Co(II), no breakthrough occurred even after passage of 228th bed volume in spite of a high influent concentration of 9.019 mg/L. Column effluents were monitored for COD and aluminium also, and the results presented in Table 2 show no evidence for leaching of organic matter or Al from the sludge with effluent showing very low values for these two parameters. Influent and effluent pH were also measured and the values are given in Fig. 6. An increase in pH was observed, and it was expected due to removal of metals from the solution.

Maximum equilibrium sorption potential of the sludge for chromium in the presence of other metals is 0.96 mg/g of sludge. It is less than that from column study done for Cr(VI) alone (1.62 mg/g of sludge). Thus, it is evident that the presence of cationic metals inhibits the removal of anionic metals like Cr(VI).

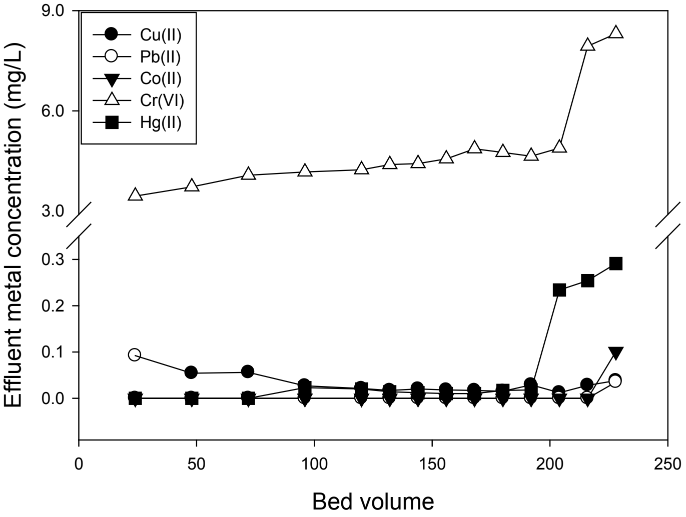

Fig. 5 Breakthrough curve for removal of heavy metals (initial metal concentrations: Cu (II) = 0.732 mg/L, Pb(II) = 0.381 mg/L, Co(II) = 9.019 mg/L, Cr(VI) = 9.5 mg/L and Hg (II) = 0.433 mg/L, pH = 6.38)

Table 2 Effluent quality at different bed volumes

Bed volume	Aluminium (mg/L)	COD (mg/L)
192	0.025	20
204	0.024	10
216	0.028	BDL
228	0.027	BDL

From these studies, it can be concluded that the sludge used in the study has a stronger affinity toward cationic metals compared to anionic metals. In the presence of cationic metals, chromium, which is anionic, shows lower removal efficiency. It might also be due to the higher pH values of solution. Higher pH range favours the removal of cationic metals and at the same time, reduces anionic metal removal [12].

4 Conclusions

The potential of water treatment sludge to treat chromium(VI) containing wastewater was assessed in the present study. Batch adsorption experiments and column tests conducted showed a significant effect of pH on chromium removal with decreased sorption at higher pH values. In long-duration column test, good Cr (VI) removal was obtained and the medium had a Cr(VI) sorption capacity of

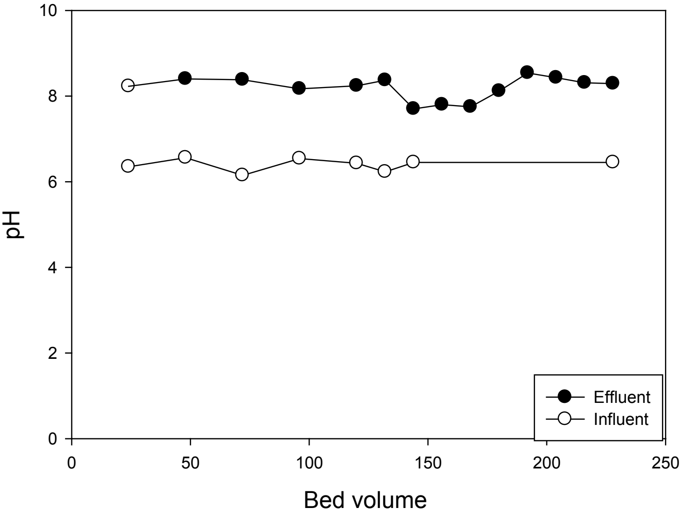

Fig. 6 Variation of effluent and influent pH with bed volume

1.62 mg/g of dry sludge. Presence of other heavy metals Co, Cu, Hg and Pb reduced both percentage chromium removal and sorption capacity, and the maximum chromium sorption capacity was only 0.96 mg/g of dry sludge. No significant leaching of organic content or aluminium from the sorbent occurred with the column effluent showing very low values for these two parameters.

References

1. Babatunde, A.O., Zhao, Y.Q.: Constructive approaches toward water treatment works sludge management: an international review of beneficial re-uses. Crit. Rev. Environ. Sci. Technol. **37**, 129–164 (2007)
2. Makris, K.C., O'Connor, G.A.: Beneficial utilization of drinking-water treatment residuals as contaminant-mitigating agents. In: Sarkar, D., Datta, R., Hannigan, R. (eds.) Developments in Environmental Science, Concepts and Applications in Environmental Geochemistry, vol. 5, pp. 607–636. Elsevier Science, Amsterdam (2007)
3. Nair, A.T., Ahammed, M.M.: Coagulant recovery from water treatment plant sludge and reuse in post-treatment of UASB reactor effluent treating municipal wastewater. Environ. Sci. Pollut. Res. **21**, 10407–10418 (2014)
4. Ahmad, T., Ahmad, K., Alam, M.: Sustainable management of water treatment sludge through 3'R' concept. J. Cleaner Prod. **124**, 1–13 (2016)
5. Makris, K.C., Sarkar, D., Parsons, J.G., Datta, R.: X-ray absorption spectroscopy as a tool investigating arsenic(III) and arsenic(V) sorption by an aluminium-based drinking-water treatment residual. J. Hazard. Mater. **171**, 980–986 (2009)
6. Makris, K.C., Harris, W.G., O'Connor, G.A., Obreza, T.A.: Phosphorus immobilization in micropores of drinking water treatment residuals: implications for long-term stability. Environ. Sci. Technol. **38**, 6590–6596 (2004)

7. Ippolito, J.A., Barbarick, K.A., Elliott, H.A.: Drinking water treatment residuals: a review of recent uses. J. Environ. Qual. **40**, 1–12 (2011)
8. Gadekar, M.R., Ahammed, M.M.: Coagulation/flocculation process for dye removal using water treatment residuals: modelling through artificial neural networks. Desalin. Water Treat. **57**, 26392–26400 (2016)
9. Caporale, A.G., Punamiya, P., Pigna, M., Violante, A., Sarkar, D.: Effect of particle size of drinking-water treatment residuals on the sorption of arsenic in the presence of competing ions. J. Hazard. Mater. **260**, 644–651 (2013)
10. Castaldi, P., Silvetti, M., Garau, G., Demurtas, D., Deiana, S.: Copper(II) and lead(II) removal from aqueous solution by water treatment residues. J. Hazard. Mater. **283**, 140–147 (2015)
11. Putra, R.S., Tanaka, S.: Aluminum drinking water treatment residuals (Al-WTRs) as an entrapping zone for lead in soil by electrokinetic remediation. Sep. Purif. Technol. **79**, 208–215 (2011)
12. Zhou, Y.F., Haynes, R.J.: Removal of Pb(II), Cr(III) and Cr(VI) from aqueous solutions using alum-derived water treatment sludge. Water Air Soil Pollut. **215**, 631–643 (2015)
13. Hovsepyan, A., Bonzongo, J.J.: Aluminum drinking water treatment residuals (Al-WTRs) as sorbent for mercury: implications for soil remediation. J. Hazard. Mater. **164**, 73–80 (2009)
14. Ghorpade, A., Ahammed, M.M.: Water treatment sludge for removal of heavy metals from electroplating wastewater. Environ. Eng. Res. **23**, 92–98 (2017)
15. Elzinga, E.J., Sparks, D.L.: Reaction condition effects on nickel sorption mechanisms in illite-water suspensions. Soil Sci. Soc. Am. J. **65**, 94–101 (2009)
16. Metcalf and Eddy: Waste Water Engineering, 4th edn. Tata McGraw-Hill Education Private Limited, New Delhi, India (2003)

Bioelectricity Generation from Kitchen Waste in a Low-Cost Earthenware Microbial Fuel Cell

Vijay Ranjan Dhulipala, Rishi Gurjar and Manaswini Behera

Abstract Microbial fuel cells (MFCs) are gaining much attention in recent years because they produce energy in the form of electricity, while simultaneously treating wastewater. In this study, the organic compounds obtained from the pretreatment of kitchen waste were used as a substrate in MFC. In order to enhance the rate of hydrolysis, parameters such as pH, solid-to-liquid ratio, and solid retention time under anaerobic conditions were studied and optimized. Two MFCs (1 and 2) having earthen separators and an anode volume of 450 mL and 630 mL, were employed, respectively. The maximum power density for MFC-1 and MFC-2 was 0.040 W/m^2 and 0.044 W/m^2 and maximum volumetric power density of 3.80 W/m^3 and 3.40 W/m^3 were, respectively obtained for a hydraulic retention time of 10 days. The study concludes that earthenware as a cation exchange membrane and kitchen waste as an anolyte were found effective for power generation.

Keywords Microbial fuel cell · Kitchen waste · Volatile fatty acids · Hydrolysis

1 Introduction

Due to rise in energy demand, prices for fossil fuels have gone up. Since fossil fuels are bound to run out sooner or later, it is essential that research in energy generation concepts must be boosted. Born through such circumstances is the idea of using waste as material for energy recovery, i.e., Waste to Energy (WTE). It is estimated that solid wastes generated in Indian cities and towns (Class I cities and Class II towns) range from 52,000 to 85,000 tons every day [1]. Since kitchen waste (KW) is one of the major components of Indian municipal solid waste, which results in high fraction of biodegradable content, i.e., 51% [1–3]. Therefore, it can serve as a substrate for WTE technologies.

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Presently, biomethanation and incineration are the most established technologies for WTE. Whereas, more efficient thermal processes, viz., gasification and pyrolysis are emerging WTE technologies in India [4]. However, these technologies are expensive and attempted in urban areas only. On the contrary, inexpensive treatments like composting and vermicomposting are prevalent in rural areas exclusively to obtain fertilizers. Therefore, an alternative to these technologies that can recover energy rather than consume is bioelectrochemical systems, viz., microbial fuel cell (MFC), microbial electrolysis cell, and microbial desalination cell. Although the energy obtained cannot be utilized to meet the increasing energy demand, it can be used to develop a sustainable water infrastructure [5]. However, to obtain bioenergy from these systems the organic waste must be converted into readily consumable compounds, i.e., volatile fatty acids through hydrolysis.

The electricity generation from solid waste through MFC is an emerging trend in biotechnology. It converts the chemical energy stored in the organic matter into electricity through the catalytic activity of microorganisms using biochemical pathway. Operating under anaerobic condition MFC similar to any other biological treatment process is influenced by parameters such as pH, temperature, substrate load, electron acceptor, structure, and type of cation exchange membrane (CEM) [6]. The separator used in between anode and cathode chamber of MFC affects the MFC performance substantially. Till date, Nafion is the most popular separator in MFC because of its high proton conductivity. However, it is expensive and encounters frequent biofouling when operated for long period. These results in higher cost per unit of energy produced. Hence, it is essential to find a suitable alternate to nafion.

The reduction of initial and maintenance cost through use of cheaper CEM material, along with achieving similar or better performance would improve feasibility of the process for large-scale applications. Ultrex [7], Salt bridge [8], and porcelain septum made from kaolin [9] have been used as an alternative to Nafion. However, the power output was lower than that obtained with Nafion. Interestingly, earthenware was incorporated as CEM for cost-effectiveness of MFCs [10]. A study demonstrated performance of MFC with earthen CEM that had a manufacturing cost less than 1.0 US$ for anode [11]. It reportedly gave maximum power output of 16.8 W/m^3, while simultaneously treating synthetic wastewater. This MFC performed at par with polymer-based MFCs with expensive cathode catalyst.

Further, the substrate type and concentration significantly affect the power generation and organic removal efficiency of the MFC operated under continuous or batch mode. Usually, a higher power output is derived from higher fuel concentration in a varied concentration range [12]. The pH of the anodic electrolyte is vital to the power output and organic matter removal rate in MFC. In order to optimize growth of electrogens near-neutral pH conditions are maintained in almost all the MFCs to boost MFCs power output. This low proton concentration results in high internal resistance of the cell relative to chemical fuel cells having acidic electrolytes [13].

Therefore, an attempt has been made to develop a method to obtain electricity from KW. The proposed work aims at designing MFC suitable for using wastewater obtained through anaerobic digestion of KW. Since adequate means for conducting pilot tests are unavailable, the tests at laboratory scale allow a regulated environment for many variables that are present in practice. Furthermore, these observed trends can be used to understand closely the MFC working at larger scale. And also formulate mathematical models that can predict its response to various conditions.

2 Materials and Methods

2.1 Materials

The KW includes leftover food and vegetable residues, except meat and bones, and the same was collected from the kitchen of Mahanadi Hall of Residence (MHR), IIT Bhubaneswar campus. The composition and characteristics of the collected KW are mentioned in Tables 1 and 2, respectively. The characteristics were determined from 7 days of waste sampling. The hydrolysis of waste was carried out in a sealed container (Signoraware Modular Square) having a volume of 2.6 L.

Table 1 Composition of kitchen waste

Sr. No.	Constituent	Percentage value (Approx.)
1	Cooked rice	44
2	Cereals	8
3	Cooked vegetable	14
4	Chapatti	25
5	Salad	5
6	Miscellaneous items	4

Table 2 Characterization of kitchen waste

Sr. No.	Parameters	Value
1	pH	6.70 ± 0.10
2	COD (g/L)	50 ± 4.2
3	Moisture content, %	71.84 ± 4.17
4	TS, %	28.16 ± 4.14

2.2 *Experimental Procedure*

2.2.1 Hydrolysis of Kitchen Waste

Batch experiments were conducted in 2.6 L capacity reactors. A total of seven reactors, each having 2.6 L capacity, were fed with ground KW. An electric mixer was used for grinding. The characteristics of feed wastewater were optimized through stabilization of operating parameters, viz., solid-to-liquid ratio and pH. Next, the optimized conditions of solid-to-liquid ratio and pH analysis were incorporated to determine optimum digestion time. The chemical oxygen demand (COD) of wastewater was determined at 2 days interval and was duly noted. After optimizing hydrolysis of KW, the feed was characterized. The feed was diluted based on the analytical results, to maximize efficiency of MFC.

2.2.2 MFC Fabrication and Design

The MFCs employed for energy generation from KW were dual chambered as shown in Fig. 1. The MFC-1 and 2 incorporated an earthen anode compartment having a working volume of 450 mL and 630 mL, respectively. The thickness of earthen proton exchange membrane was 5 mm. A plastic container was used as cathode chamber that accommodates earthen pot and graphite electrodes. After placing the pots and electrodes in the cathode chamber, it was filled up with water

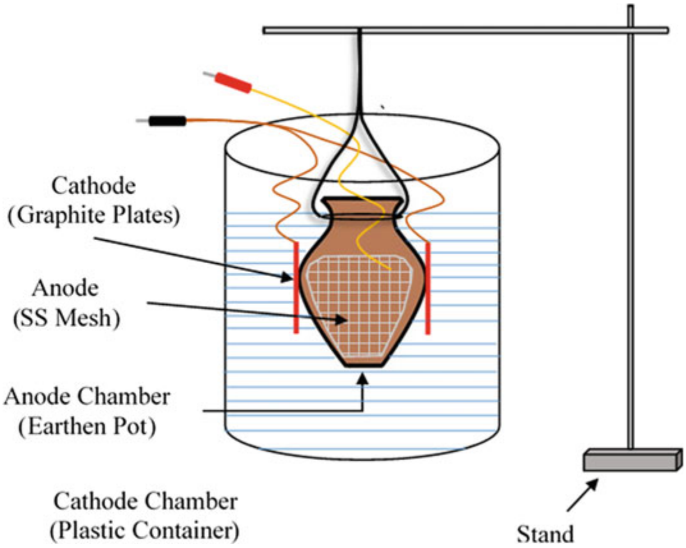

Fig. 1 Schematic diagram of MFC Setup

such that graphite electrodes were completely submerged. A pair of diffusers were placed in the cathode chamber to provide oxygen to complete biochemical reaction.

These earthen pots were prepared from soil (sourced from Bhubaneswar, India). They were baked at 550–650 °C for 6.0 h. The stainless steel mesh (10 cm × 5 cm) as an anode electrode and graphite sheet (10 cm × 5 cm) as cathode electrode were employed in MFC fabrication. The stainless steel mesh having a surface area of 320 cm^2 was fitted along the inner wall of the earthen pot. Whereas, the four cathode electrodes collectively having a surface area of 200 cm^2 were placed adjacent to the membrane. The electrical circuit was established through concealed copper wire with an external resistance (100 Ω), except when stated otherwise.

2.2.3 MFC Start-up

The anaerobic lake bottom sludge (IIT Bhubaneswar campus) was used to inoculate anode chambers of the MFCs. The inoculum sludge was subjected to heat treatment (at 100°C to suppress methanogens) and later sieved. Further, a sludge volume of 100 mL and 150 mL was supplemented to the anode of MFC-1 and 2, respectively. The MFCs were operated under batch mode and the wastewater obtained from pretreatment of KW was fed to the MFCs at a hydraulic retention time (HRT) of 10 and 8 days to acclimatize the biomass.

2.3 Analytical Methods

The KW obtained from the hostel premises was characterized for pH, chemical oxygen demand (COD), moisture content, and total solids. The wastewater obtained during the anaerobic digestion of solids (for different ratios), was analyzed for pH, COD. All the analyses were done to optimize the wastewater prior to its feed to MFC. The pH was determined by pH meter (HACH, HQ 40d). The COD analysis was performed with COD Digester (HACH, DRB 200) and Spectrophotometer (HACH, DR 2800). The power generated from MFC was calculated with a Multimeter (ExTech, 470). The polarization studies were conducted by varying external resistance between 5000 Ω and 10 Ω. All the analyses were in accordance with standard methods [14].

Scanning Electron Microscopes and Energy Dispersive Spectroscopy (SEM-EDS) analysis were carried out on the earthen pot to obtain its elemental composition. The pot was crushed and grounded into soil that was later sieved using 50-micron sieve prior to analysis.

3 Results and Discussion

3.1 *Kitchen Waste*

3.1.1 Solid-to-Liquid Ratio

The batch studies were conducted simultaneously on three reactors loaded with 3%, 5%, and 7% of solid-to-liquid (S/L) ratio of kitchen waste at ambient temperature. The pH and COD toward the end of every subsequent two days were observed. The pH inside the reactor was maintained between 6 and 7 (by NaOH and conc. HCl). The COD values obtained at a particular solid-to-liquid ratio are shown in Fig. 2. It can be observed that the COD concentration at 5% solid-to-liquid ratio is highest among other ratios and was used for the next phase of study.

3.1.2 PH Analysis

After selecting a 5% solid-to-liquid ratio, the pH optimizing studies were conducted under different pH, viz., 5, 6, and 7 for a digestion period of 10 days. The pH in the reactors was monitored daily and maintained by NaOH and conc.HCl. The effect of pH is shown in Fig. 3.

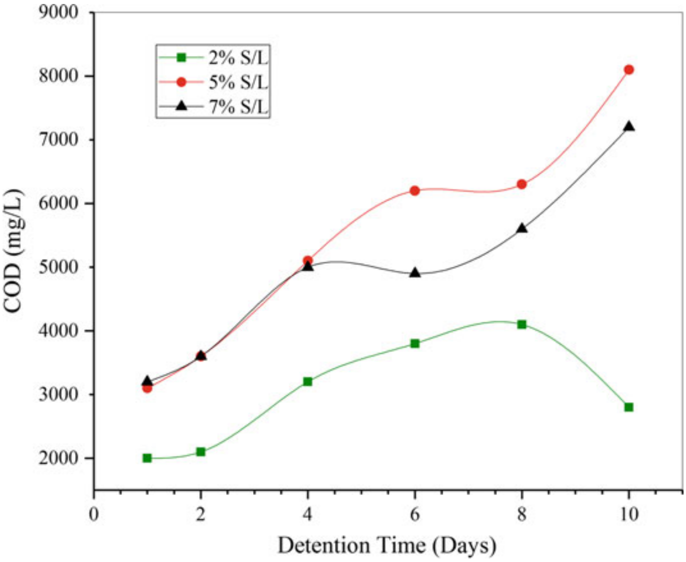

Fig. 2 COD value with digestion time for 2%, 5%, and 7% S/L ratio

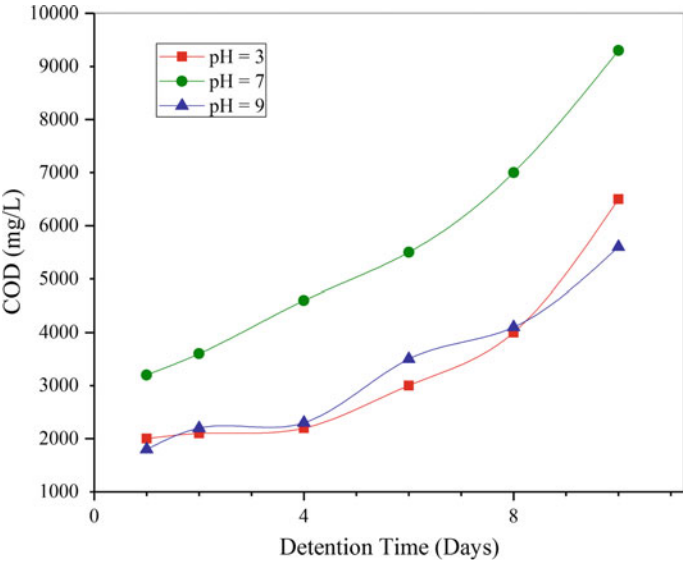

Fig. 3 Variation of COD at different pH at 5% S/L ratio

3.1.3 Influence of Digestion Time

The digestion time is the key parameter for the performance of a hydrolysis reactor, as it determines the solid solubilization efficiency. The COD concentration initially from 3200 mg/L (first day) rose to a maximum of 9200 mg/L (tenth day). This was followed by a gradual dip in concentration. This suggests that hydrolysis of waste was maximum during the first 10 days of digestion period. The variation in COD concentration with digestion time after optimization is shown in Fig. 4.

3.1.4 Hydrolysis Yield

The hydrolysis is the difference between the inlet and final particulate COD in the digester over the inlet COD. The rate is found to be decreasing over time, as shown in Fig. 5.

3.2 Microbial Fuel Cell (MFC) Operation

3.2.1 Composition of the Earthenware Separator

The clay minerals comprise of two basic units, viz., silicon tetrahedral and octahedral unit. The silicon tetrahedral has one silicon (Si^{+4}) and four oxygen (O^{-2}),

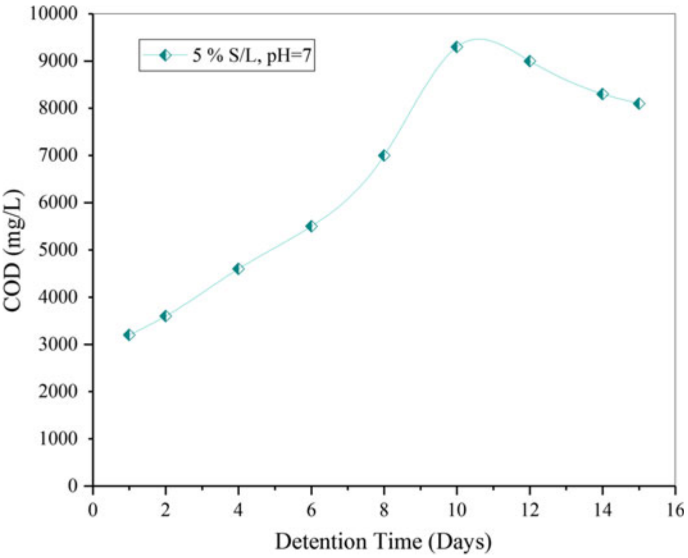

Fig. 4 COD value with digestion time for 5% S/L ratio at pH 7

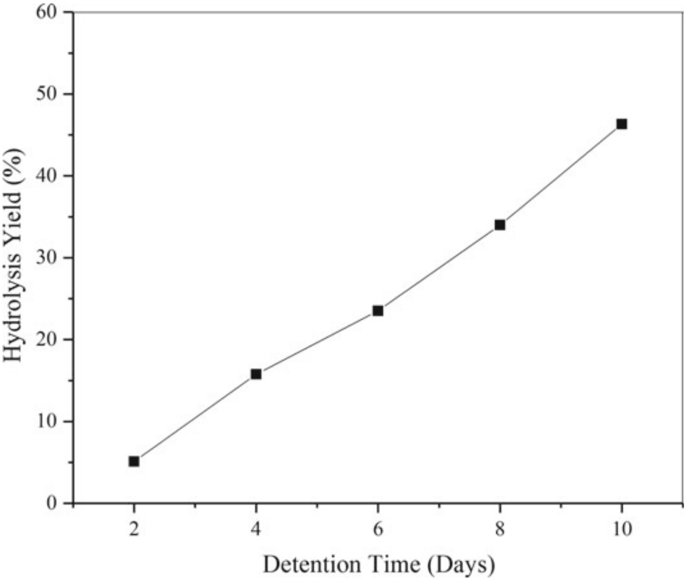

Fig. 5 Hydrolysis yield observation of kitchen waste

Table 3 Elements present in the earthen pot sample

Element	Weight, %	Atomic, %
Mg	1.96	2.42
Al	21.67	24.05
Si	58.73	62.61
K	4.90	3.76
Ca	1.23	0.92
Ti	0.93	0.58
4. Fe	5. 10.58	6. 5.67
7. Totals	8. 100.00	

here the base oxygen share with other tetrahedral units. This results in a net negative charge (–1) on the unit. Moreover, this negative charge is responsible for the cation exchange capacity of the clay [15]. Therefore, the earthen material was subjected to SEM-EDS analysis, and the composition of the same is shown in Table 3. The earthenware consists of 58.73% of silica, which indicates that the earthen material manly comprises of silicon tetrahedron unit.

3.2.2 Wastewater Treatment

After commissioning, the MFCs were operated with wastewater possessing high initial COD concentration of 6800–8700 mg/L. The anolyte pH in both the MFCs was maintained at 7.0. Further, COD removal efficiencies of 86.2% and 80.8% for MFC-1 at 10 and 8 days HRT were observed, respectively. However, for MFC-2 efficiency was 90.9% at 10 days retention time.

The COD removal efficiency improved with higher HRT. However, the COD removal efficiency was superior in MFC-2 because of higher available surface area for proton exchange at 10 days HRT (Fig. 6).

3.2.3 Electricity Harvesting

The various parameters, viz., current, voltage, power per unit volume, and power density obtained from MFC-1 and 2 at pH (7) and different HRTs, with 100 Ω external resistance are shown in Tables 4 and 5, respectively.

3.2.4 Polarization Studies

The polarization studies were performed under various external resistance ranging between 10 Ω and 5000 Ω. During polarization, internal resistance and maximum power densities of the MFC obtained are shown in Table 6. Further, the slope of

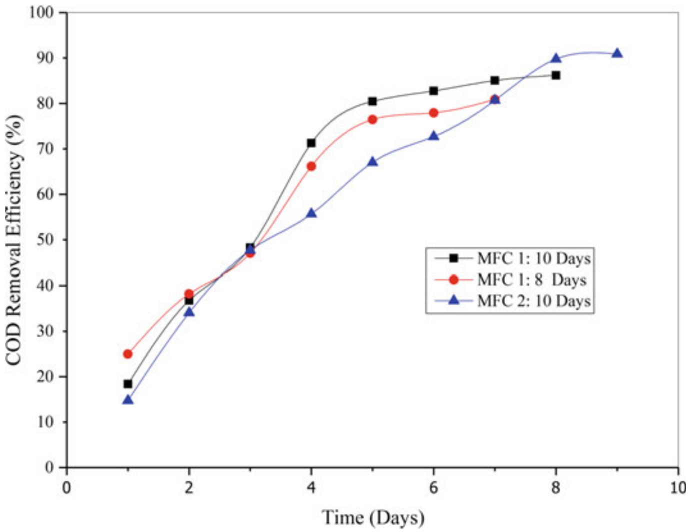

Fig. 6 Percentage of COD removal versus time plotted for MFC 1: 10 and 8 days HRT and MFC 2: 10 days HRT

Table 4 Electricity generation in MFC-1 with 100 Ω external resistance

pH	HRT (Days)	Current (A) (1×10^{-3})	Voltage (V)	Power density (W/m^2)	Power per unit volume (W/m^3)
7	10	3.9	0.39	0.040	3.80
7	8	3.4	0.34	0.031	2.89

Table 5 Electricity generation in MFC-2 with 100 Ω external resistance

pH	HRT (Days)	Current (A) (1×10^{-3})	Voltage (V)	Power density (W/m^2)	Power per Unit Volume (W/m^3)
7	10	4.7	0.47	0.044	3.40

Table 6 Polarization in MFCs with variable external resistance

pH	MFC	Maximum power density (W/m^2)	Internal resistance (Ω)
7	MFC-1	0.049	183
7	MFC-2	0.043	172

voltage versus current plot, i.e., internal resistance was also calculated. The power density and voltage curves obtained for current density are plotted and are shown in Figs. 7 and 8, respectively.

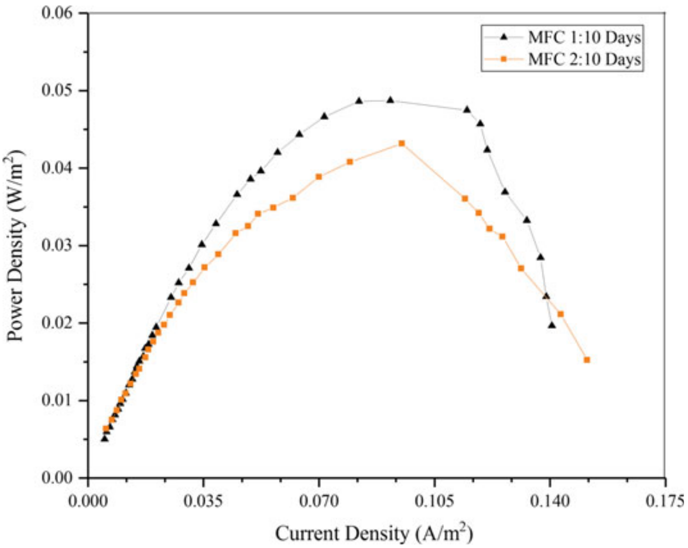

Fig. 7 Power density versus current density for MFC 1 and MFC 2

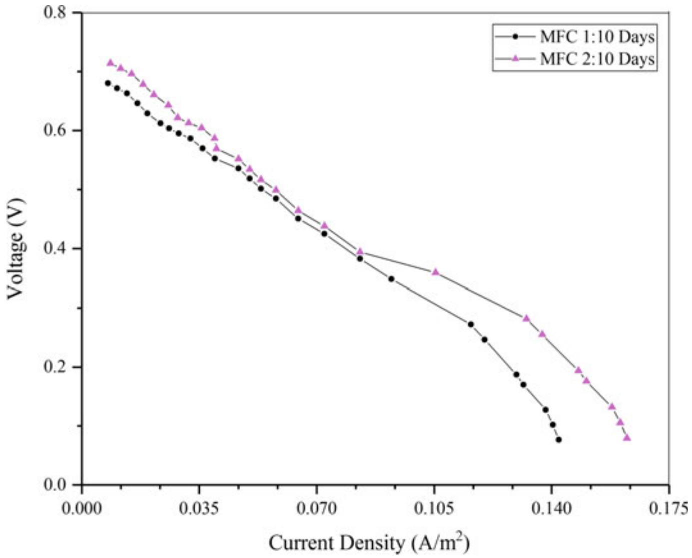

Fig. 8 Voltage versus current density for MFC 1 and MFC 2

3.2.5 Kinetic Studies of Hydrolysis of Kitchen Waste

Hydrolysis being the rate-determining step of the anaerobic digestion process [16]. Large particles with higher surface to volume ratio are hydrolyzed more slowly than smaller particles. The rate of the first-order kinetics is defined by the relationship [17]:

$$-\frac{dC}{dt} = k.C \tag{1}$$

$$t = (-1/k).\ln\left(\frac{C}{C_o}\right) \tag{2}$$

Here

k = First Order Specific Rate Constant

C = COD at time (t) (g/L)

C_o = COD at time (t = 0) (g/L)

The graph of the above rate of oxygen demand for the anaerobic hydrolysis is determined in Fig. 9.

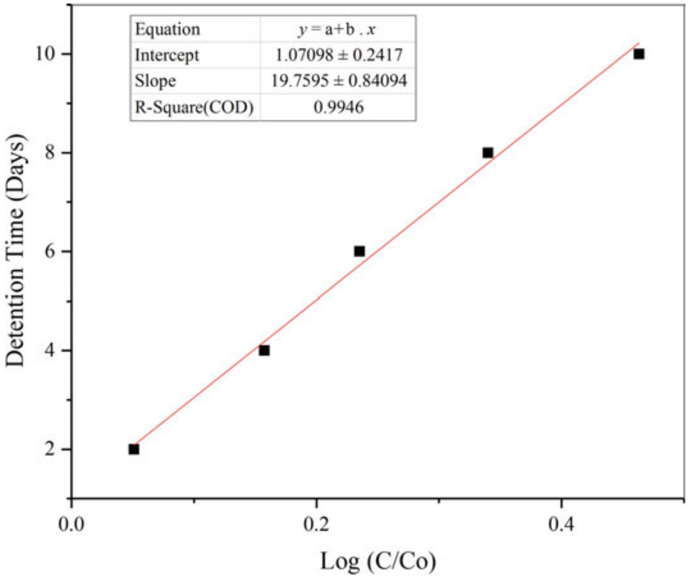

Fig. 9 The rate constant for hydrolysis of kitchen waste

4 Conclusions

This study observed that factors such as pH, S/L ratio and digestion time played an important role in hydrolysis of KW. Further, the optimization study revealed a pH 7 and a 5% solid-to-liquid ratio for a digestion period of 10 days for pretreating KW. In case of MFCs, the surface area of the earthen pot affected the power generation. The MFC with higher surface area generated higher power, which can be attributed to higher proton transfer through earthenware separator. Additionally, the volumetric power density in MFC-1 was observed to be 3.80 W/m^3 and 2.89 W/m^3 for 10 and 8 days, respectively. Whereas, it was 3.40 W/m^3 for MFC-2 for 8 days. Moreover, the manufacturing cost of these earthen pot MFC is about INR 450. Hence, improved performance of earthen-MFC can make this technology commercially viable. However, with time a drop in power output was observed due to biofilm growth on the cathode, which requires further exploration in order to make the technology robust. Additionally, use of clay minerals having high cation exchange capacity such as vermiculite and bentonite can be used to improve the MFC performance. The study establishes kitchen waste as a potential source for WTE technologies.

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References

1. Gerlagh, R., van Beukering, P., Verma, M., Yadav, P.P., Pandey, P.: Integrated modelling of solid waste in India. CREED Working Paper Series No. 26 (1999)
2. Krishna, D., Kalamdhad, A.S.: Pre-treatment and anaerobic digestion of food waste for high rate methane production—a review. J. Environ. Chem. Eng. **2**(3), 1821–1830 (2014)
3. Planning Commission, Government of India: Report of the task force on waste to energy (volume I)—in the context of integrated municipal solid waste management, Technical Report, http://planningcommission.nic.in/reports/genrep/rep_wte1205.pdf (2014)
4. Energy Alternatives India: India MSW to energy a white paper—status, opportunities and bottlenecks, Technical Report, http://www.eai.in/ref/wp/india-msw-to-energy.html (2013)
5. Logan, B.E.: Microbial Fuel Cells, 1st edn. Wiley, New Jersey (2008)
6. Logan, B.E., Regan, J.M.: Microbial fuel cells—challenges and applications. Environ. Sci. Technol. **40**, 5172–5180 (2006)
7. Rabaey, K., Boon, N., Siciliano, S.D., Verhaege, M., Verstraete, W.: Biofuel cells select for microbial consortia that self-mediate electron transfer. Appl. Environ. Microbiol. **70**, 5373–5382 (2004)
8. Min, B., Cheng, S., Logan, B.E.: Electricity generation using membrane and salt bridge microbial fuel cells. Water Res. **39**, 1675–1686 (2005)
9. Park, D.H., Zeikus, J.G.: Improved fuel cell and electrode design for production of electricity from microbial degradation. Biotechnol. Bioeng. **81**, 348–355 (2003)
10. Behera, M., Ghangrekar, M.M.: Electricity generation in low cost microbial fuel cell made up of earthenware of different thickness. Water Sci. Technol. **64**, 2468–2473 (2011)

11. Behera, M., Jana, P.S., Ghangrekar, M.M.: Performance evaluation of low cost microbial fuel cell fabricated using earthen pot with biotic and abiotic cathode. Bioresour. Technol. **101**, 1183–1189 (2010)
12. Du, Z., Li, H., Gu, T.: A state of the art review on microbial fuel cells: a promising technology for wastewater treatment and bioenergy. Biotechnol. Adv. **25**(5), 464–482 (2007)
13. Picioreanu, C., van Loosdrecht, M.C.M., Curtis, T.P., Scott, K.: Model based evaluation of the effect of pH and electrode geometry on microbial fuel cell performance. Bioelectrochem. **78**(1), 8–24 (2010)
14. Standard Methods: Standard Methods for Examination of Water and Wastewater, 21st edn. American Public Health Association, Washington DC (2005)
15. Murthy, V.N.S.: Geotechnical Engineering—Principle and Practices of Soil Mechanics and Foundation Engineering, 2nd Indian Reprint, pp. 11–14. CRC Press, Taylor and Francis Group, New York, USA (2012)
16. Veeken, A., Hamelers, B.: Effect of temperature on hydrolysis rates of selected biowaste components. Bioresour. Technol. **69**, 249–254 (1999)
17. Jash, T., Ghosh, D.N.: Studies on the solubilization kinetics of solid organic residues during Anaerobic Biomethanation. Energy **21**(7/8), 725–730 (1996)

Relevance of Physicochemical and Nutritional Variables During Rotary Drum Composting of Water Hyacinth with Biochar Amendment

Siddhartha Paul, Mayur Shirish Jain and Ajay S. Kalamdhad

Abstract Biochar (BC) is characterized by lower moisture content and enriched carbon whose utilization in composting successfully improves the efficacy of composting process by increasing the thermophilic temperature and period. However, relevance or interplay of physicochemical and nutritional variables for in-vessel composting of water hyacinth with BC amendment has rarely been investigated. Therefore, the essence of the present work is to assess the effect of BC amendment (0 and 2.5 kg in 100 kg mix) to a mix of water hyacinth, cow dung, and sawdust. Hence, the findings reveal that with BC amendment, thermophilic temperature of 56.9 °C was reached and lasted for more than 3 days, necessary for pathogen remediation. Furthermore, strong relationship among physiochemical and nutritional variables with significant correlation among the same was observed as inferred from scatterplot matrix; hence, provides valuable information for improving various physicochemical and nutritional variables in contrast to compost application in agro-sectors.

Keywords Water hyacinth · Scatterplot matrix · Composting · Physicochemical variables · Rotary drum

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1 Introduction

Water Hyacinth (WH), originating in South America and covering around 23.2% wetland area in northeast India, was first introduced in West Bengal (India) as an ornamental plant, but it soon becomes a nuisance throughout the country. Also, WH has infested vast wetlands and has imposed serious threats around the globe, viz., blocking irrigation canals, reducing fish population, averting navigation, eutrophication, etc. [1, 2]. Management of WH is onerous owing to its regeneration from seed and stem pieces [3].

Composting, a promising technique for managing the nuisance of WH, can biodegrade and stabilize the readily degradable organics of WH into lesser degraded humic compound, and final compost is suitable for land application as soil conditioner or fertilizer. WH composting can solve two problems, such as check the growth of WH and reduce chemical fertilizer usage to agricultural lands as a nutritional source. Windrow or pile composting is one such well-practiced technique of a nonreactor, agitated solid bed system [4]. However, rotary drum compost gained immense popularity in recent years in composting various types of weeds owing to its faster degradation process [5, 6]. In addition to that, quality of compost can be explained by the amount of N, P, and K and other nutritional parameters, viz., Ca, Mg, and Na in final compost. Addition of biochar (BC) has improved nutritional quality of other aquatic weeds such as Hydrilla verticillata after composting [7]; however, its impact on composting of WH remains unexplored.

BC, a recalcitrant material produced by pyrolysis of organic waste, such as biomass of plant, algae, and sewage sludge [8], is enriched with carbon that resists decay and withstands in soils for extended time [9]. Verheijen et al. (2009) [10] reported that based on process parameters of biomass type and thermal conversion, BC holds about moisture content of 1–15%. The author further mentioned that the BC can be characterized by volatile solids of 0–40% and mineral ash of 0.5–5% as well as some organic carbon. In addition to that, amendment with BC has other benefits, such as enhancement in plant growth, improvement in cation exchange capacity and water holding capacity [11, 12]. BC amendment has been considered as a nutrient conditioner by reducing nitrogen losses with improvement in nitrogen availability in lignocellulosic and poor nitrogen materials [13].

However, the literature on interplay between various nutritional parameters in rotary drum composting of WH with BC amendment is scanty. Hence, principle interest of this research lies in exploring the potency of customly designed in-vessel rotary drum composter for WH composting with BC amendment as well to decipher correlation among various variables involved in the process.

2 Material and Methodology

2.1 Preparation of Biochar

BC was procured from a private manufacturer based in India. *Prosopis juliflora* biomass was slowly pyrolyzed at 400–500 °C in an oxygen less atmosphere to produce BC. A typical sample of BC was ovendried to determine total organic carbon (TOC), moisture content (MC), volatile solids (VS), and C/N ratio and was found out to be 1.8%, 88%, 48.08% and 454:1, respectively.

2.2 Collection of Waste Materials and Setup of Reactor

Rotary drum composting of WH with BC amendment was performed at Indian Institute of Technology Guwahati (India). Ingredients comprising of WH, cow dung (CD), and sawdust (SD) with 2.5% BC amendment were used in the present composting study. In present study, WH (85.9% MC, 72.6% VS, 39.67% TOC, and 16:1 C/N ratio) was collected from a lake inside IIT Guwahati campus and was mixed with CD (85% MC, 86% VS, 46.99% TOC and 27:1 C/N ratio) that was collected from nearby dairy farm. Furthermore, SD (18% MC, 68% VS, 37.16% TOC, and 150:1 C/N ratio) was collected from nearby sawmill for preparing a homogeneous mixture with CD to avoid lump formation.

Two separate combinations of drum composting were produced having following mixes (on wet weight basis):

a. **R0 (control):** WH (60 kg) + CD (30 kg) + SD (10 kg) + BC (0 kg)
b. **R2.5:** WH (60 kg) + CD (30 kg) + SD (10 kg) + BC (2.5 kg)

2.3 Mechanism of Composting

Two rotary drum composters (R0 and R2.5) with 550L capacity, aligned horizontally and cylindrical in shape as shown in Fig. 1, were employed for composting of WH with and without BC, respectively. Angles were welded from inside longitudinally for ensuring proper agitation via rotation. To facilitate sufficient aeration, homogenization composting process of the mixes, drums were rotated daily for one time. During the entire composting process, digital thermometer probe comprising of a temperature sensor was used to monitor bottom, middle, and top temperatures of the composting mixtures after every 4 h daily. Three readings were averaged for each mixture. Ambient temperature was also measured using with no extra addition of water and with same temperature probe throughout the composting process. Also, a 20-day retention time was taken for composting process since it

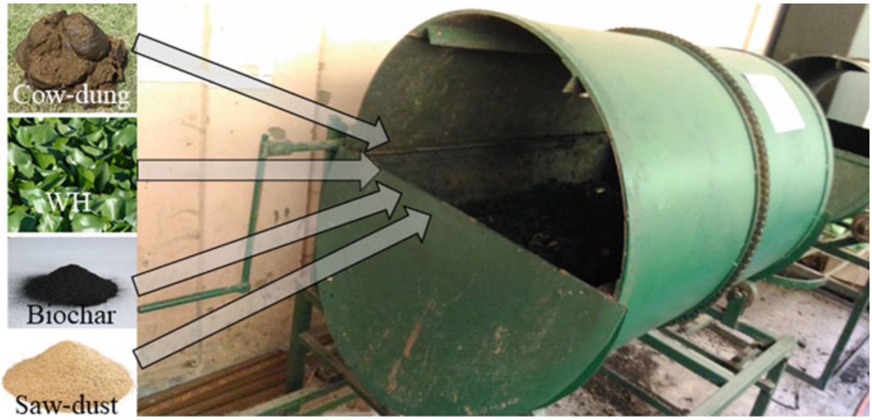


Fig. 1 Setup of the Rotary drum composting of WH with biochar amendment

enhances the degradation and stabilization of waste [14]. Grab sampling (triplicates) was done from different positions of the drum throughout the composting period from 0 to 20 days, followed by air-drying and sieving through 0.2 mm for homogenizing the samples for further analysis.

2.4 Analysis of Sample

pH was measured by shaking the samples mechanically for 2 hr in deionized water with 1:10 (w/v) waste to water extract ratio. Total nitrogen (TKN) and total phosphorus (TP) were quantified using Kjeldahl method and Stannous chloride method (acid digestion), respectively. Flame photometer was employed to estimate potassium (K) by digesting 0.2 g sample (air-dried 212 µ sieved) with 10 mL H_2SO_4 and $HClO_4$ (5:1) at 300 °C for 2 hr. However, MC was measured by ovendrying sample for 24 h at 105 °C followed by computing with formula using [15]. Ash content (weight loss on ignition at 550 °C) and VS was quantified using muffle furnace [16] and formula adopted from [17], respectively. However, TOC was estimated as followed by [18].

2.5 FTIR Analysis

To analyze for change in functional groups before and after composting, FTIR study was performed by mixing 1 mg pre-desiccated sample with 300 mg powdered KBr in a mortar followed by 3 min compression at 10 MPa. FTIR spectrum was traced from 4000–400 cm^{-1} wavenumber with 16 scans at resolution of 4 cm^{-1}.

2.6 Statistical Analysis

To investigate the correlation among the various variables involved in the composting process, Pearson's correlation coefficient was analyzed in Origin Pro software and depicted in the scatterplot matrix. The variables included for scatterplot analysis were: TKN, TP, K, VS, and TOC.

3 Result and Discussion

3.1 Temperature and Moisture Content

During commencement of composting process, mean temperatures of two trials in core of R0 and R2.5 were 34.2 ± 1.8 and 36 ± 2 °C, respectively. Minimum and maximum ambient temperatures ranged from 22.4 ± 0.7 to 26.5 ± 0.5 °C, respectively, during the complete composting process (Fig. 2).

Both the drums depicted a similar trend of temperature increment with a rapid activation in degradation rate. This heat generated can be attributed to initiation of microbial decomposition thus necessitating the monitoring of temperature becomes vital to decipher the process of composting [19]. Moreover, increment in temperature was higher in R2.5 than that in R0 owing to BC amendment as bulking agent that enhanced the composting reaction which led to temperature rise in the mixture [20]. The thermophilic condition (>45 °C) was achieved on second day for R2.5, whereas on sixth day for R0. However, rotation of drum daily attributed to heat loss leading to decrease in temperature of the composting mix. BC amendment also increased the thermophilic phase during composting of WH unlike R0 (control).

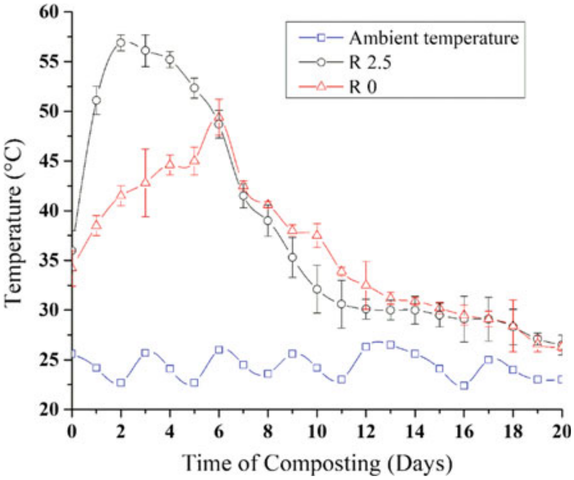


Fig. 2 Variation in temperature during the composting period

Similar trend was observed for temperatures in studies using BC as additive for composting of manure [21]. Investigation on other organic waste composting showed that during process of composting 55–60 °C temperature should be retained for more than 3 days to reduce pathogen as well as gain standard sterilization [20]. In current investigation, R2.5 achieved the temperature requirement of 55–60 °C that lingered for more than 3 days in thermophilic phase. These results infer that optimum BC amendment, i.e., in R2.5 (2.5% BC addition) accelerated the process of composting by supplying readily available carbon for microbes. Therefore, degradation of organics could be accelerated by elevating C/N ratio to an optimum value by adding readily biodegradable carbonaceous substances [22].

Initial MC was higher in WH (90–92%), and CD (85–87%) but lower in SD (14–16%) and BC (1.5–2.5%). High MC reduces availability of air in the pore spaces of organics. The process of composting is significantly affected by environmental conditions (pH, MC, and aeration) which plays a key role in maintaining suitable composting environment. Also, MC influences the activity of microbes and physical structure, thus imparting a major impact on degradation of organics [7, 23]. Several organics can be effectively composted in the range (about 25–80% MC on a wet basis) [4, 14]. Initial MC in the present investigation was recorded and is shown in Fig. 3. It must be noted that decomposition of organics by microbes mainly causes loss of moisture in the mix [24]. BC amendment acts as a bulking agent providing the optimum air-filled porosity as well as control moisture levels in organics to be composted [25, 26]. Due to the presence of readily available biological decomposable organics, thermophilic temperature (>45 °C) was observed without any formation of leachate during the composting process in R2.5, unlike R0 where a small quantity of water on day 4 was noticed (personal observation). Hence, BC played a vital part in reducing moisture, prohibiting leachate formation in the degradation period.

3.2 Physicochemical Parameters

Changes in TKN, TP TOC, VS, K, and pH are illustrated in Fig. 4. Here, TKN, TP, and K showed higher increasing trend in case of R2.5 than in R0. This can be attributed to increase in surface area and porosity due to BC amendment [7]. However, TOC, VS showed a decreasing trend which might be due to the decrease in organic matter during the composting process owing to the decomposition of organics by microbes and carbon loss in the form of carbon dioxide [27].

3.3 Ftir

From FTIR spectrum (Fig. 5), it is evident that there is a sharp reduction in the peak intensities for R2.5 than that of R0 at 1622.64, 1319.28, and 1027.17 cm^{-1}

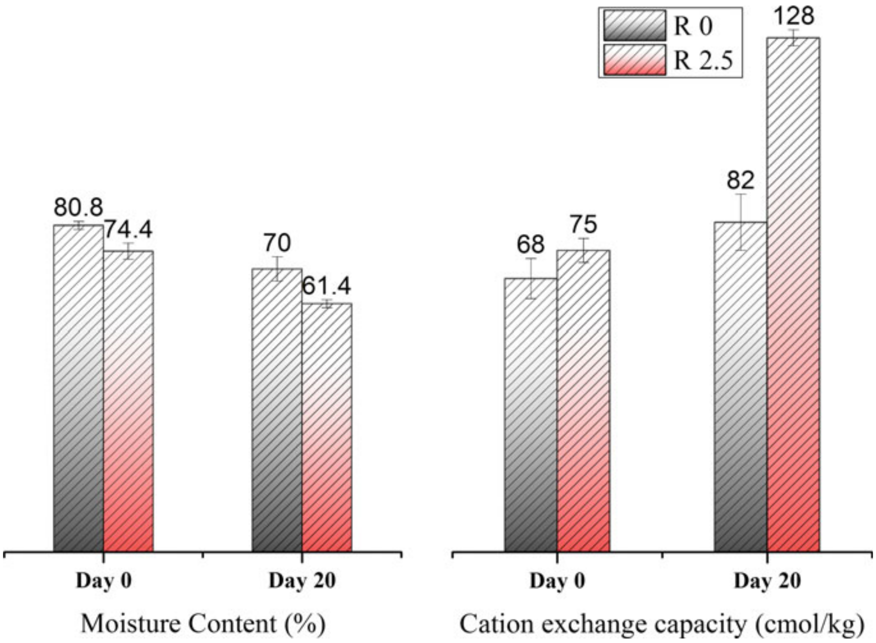


Fig. 3 Changes in moisture content and cation exchange capacity before and after composting

wavenumber that are attributed to deformation of C = C, C–C–O, C–O, C–H and rupturing of C = O stretch in hemicellulose and cellulose present in WH [28]. Furthermore, decrement in band intensities at respective wavenumber of 3333.3 and 2921.22 cm^{-1} corresponding to OH and CH stretches are due to rupturing of cellulose hydrogen bonds and splitting of methyl/methylene groups of cellulose [29]. Also, change in N–H bend (primary amines) is observed at 1619 cm^{-1} in composting of R2.5. Hence, reduced peak intensity and broad peaks indicated cellulose breakdown and low crystallinity of WH with BC amendment, respectively [30].

3.4 Scatterplot Matrix

Various parameters interact with each other and help to achieve best efficiency during composting process. It is unavoidable to neglect the interaction/relation between various nutritional parameters and therefore, it becomes necessary to determine the extent of correlation between them. This is depicted in the form of scatterplot matrix among various nutritional parameters (Fig. 6).

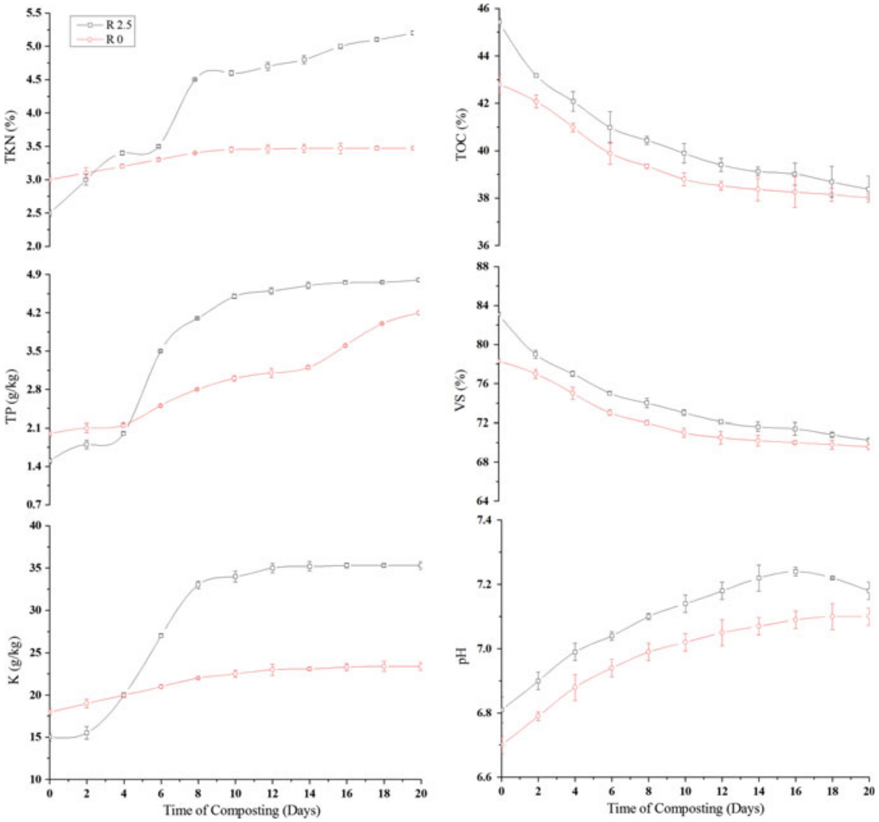
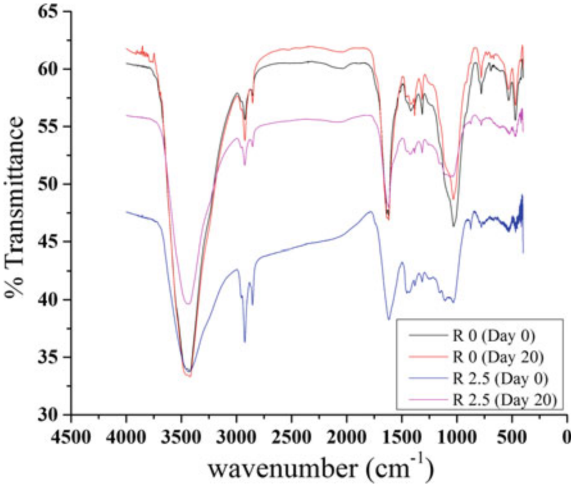


Fig. 4 Variation in nutritional variables during the composting period

Fig. 5 FTIR spectra of initial and final compost for R0 and R2.5



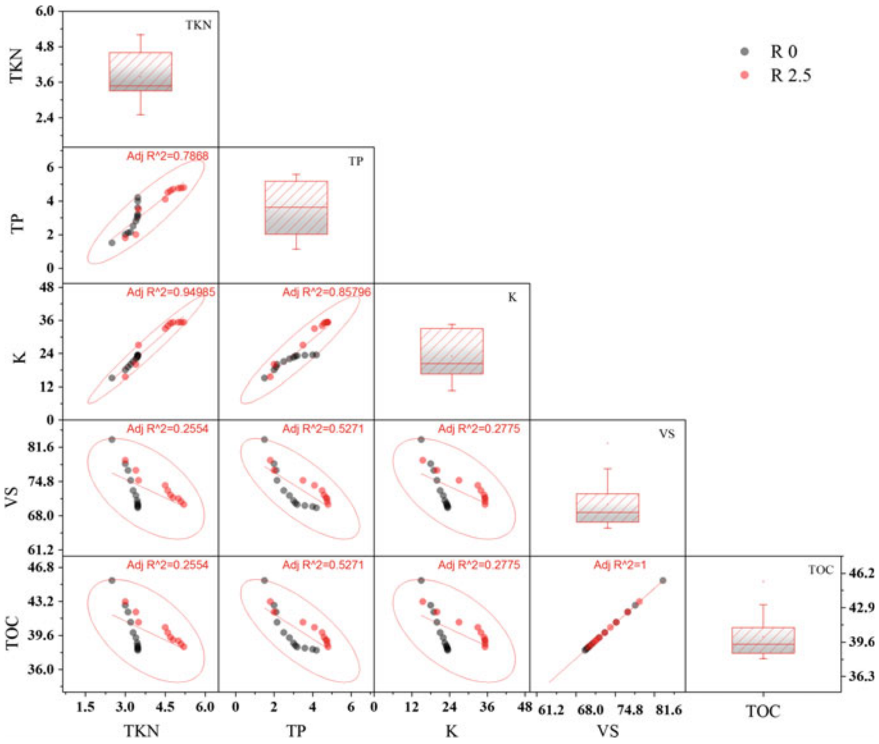


Fig. 6 Scatterplot matrix depicting the relevance of various nutritional variables

4 Conclusion

The present research established the relevance among various physicochemical and nutritional variables with BC amendment in rotary drum composting of water hyacinth thereby improving agronomic value of end compost. This investigation revealed that with BC amendment in a small proportion (2.5%), thermophilic temperature was achieved faster and lingered for longer duration (>3 days) which is necessary for pathogenic kill. Furthermore, MC was attenuated significantly owing to the sorption of the same by BC, reducing leachate generation in the process. Furthermore, BC addition catalyzed the degradation rate as evident from the improved reduction rate of VS attributing to better degradation of organic content. In a concluding remark, attempt to understand the inter-relationship among the various variables involved proved to be fruitful in deciphering their correlation, although future attempt needs to be made to exploit the use of such investigation for improving the degradation process of other types of waste.

References

1. Balirwa, J.S.: Lake Victoria Wetlands and the Ecology of the Nile Tilapia. Routledge (2017)
2. Gezie, A., Assefa, W.W., Getnet, B., Anteneh, W., Dejen, E., Mereta, S.T.: Potential impacts of water hyacinth invasion and management on water quality and human health in Lake Tana watershed, Northwest Ethiopia. Biol. Invasions **20**(9), 2517–2534 (2018)
3. Gunnarsson, C.C., Petersen, C.M.: Water hyacinths as a resource in agriculture and energy production: a literature review. Waste Manage. **27**(1), 117–129 (2007)
4. Haug, R.T.: The Practical Handbook of Compost Engineering. Lewis Publishers, Boca Raton, FL, USA (1993)
5. Jain, M.S., Kalamdhad, A.S.: Efficacy of batch mode rotary drum composter for management of aquatic weed (Hydrilla verticillata (Lf) Royle). J. Environ. Manage. **221**, 20–27 (2018)
6. Vishan, I., Sivaprakasam, S., Kalamdhad, A.: Isolation and identification of bacteria from rotary drum compost of water hyacinth. Int. J. Recycl. Org. Waste Agric. **6**(3), 245–253 (2017)
7. Jain, M.S., Jambhulkar, R., Kalamdhad, A.S.: Biochar amendment for batch composting of nitrogen rich organic waste: effect on degradation kinetics, composting physics and nutritional properties. Biores. Technol. **253**, 204–213 (2018)
8. Bird, M.I., Wurster, C.M., de Paula Silva, P.H., Bass, A.M., De Nys, R.: Algal biochar–production and properties. Biores. Technol. **102**(2), 1886–1891 (2011)
9. Jindo, K., Sonoki, T., Matsumoto, K., Canellas, L., Roig, A., Sanchez-Monedero, M.A.: Influence of biochar addition on the humic substances of composting manures. Waste Manage. **49**, 545–552 (2016)
10. Verheijen, F., Jeffery, S., Bastos, A.C., van der Velde, M., Diafas, I.: Biochar Application to Soils, a Critical Scientific Review of Effects on Soil Properties, Processes and Functions (Office for the Official Publ. of the European Communities, Luxembourg). Google Scholar (2009)
11. Steiner, C., Das, K.C., Melear, N., Lakly, D.: Reducing nitrogen loss during poultry litter composting using biochar. J. Environ. Qual. **39**(4), 1236–1242 (2010)
12. Cross, A., Sohi, S.P.: The priming potential of biochar products in relation to labile carbon contents and soil organic matter status. Soil Biol. Biochem. **43**(10), 2127–2134 (2011)
13. López-Cano, I., Roig, A., Cayuela, M.L., Alburquerque, J.A., Sánchez-Monedero, M.A.: Biochar improves N cycling during composting of olive mill wastes and sheep manure. Waste Manage. **49**, 553–559 (2016)
14. Singh, J., Kalamdhad, A.S.: Effect of rotary drum on the speciation of heavy metals during water hyacinth composting. Environ. Eng. Res. **18**(3), 177–189 (2013)
15. Tiquia, S.M., Tam, N.F.Y.: Elimination of phytotoxicity during co-composting of spent pig-manure sawdust litter and pig sludge. Biores. Technol. **65**(1–2), 43–49 (1998)
16. Kalamdhad, A.S., Pasha, M., Kazmi, A.A.: Stability evaluation of compost by respiration techniques in a rotary drum composter. Resour. Conserv. Recycl. **52**(5), 829–834 (2008)
17. Barrington, S., Choinière, D., Trigui, M., Knight, W.: Effect of carbon source on compost nitrogen and carbon losses. Biores. Technol. **83**(3), 189–194 (2002)
18. Mohee, R., Mudhoo, A., Unmar, G.D.: Windrow co-composting of shredded office paper and broiler litter. Int. J. Environ. Waste Manage. **2**(1–2), 3–23 (2008)
19. Bernal, M.P., Alburquerque, J.A., Moral, R.: Composting of animal manures and chemical criteria for compost maturity assessment: a review. Biores. Technol. **100**(22), 5444–5453 (2009)
20. Liu, W., Huo, R., Xu, J., Liang, S., Li, J., Zhao, T., Wang, S.: Effects of biochar on nitrogen transformation and heavy metals in sludge composting. Biores. Technol. **235**, 43–49 (2017)
21. Sánchez-García, M., Alburquerque, J.A., Sánchez-Monedero, M.A., Roig, A., Cayuela, M.L.: Biochar accelerates organic matter degradation and enhances N mineralisation during composting of poultry manure without a relevant impact on gas emissions. Biores. Technol. **192**, 272–279 (2015)

22. Nakasaki, K., Watanabe, A., Kitano, M., Kubota, H.: Effect of seeding on thermophilic composting of tofu refuse. J. Environ. Qual. **21**(4), 715–719 (1992)
23. Han, W., Clarke, W., Pratt, S.: Composting of waste algae: a review. Waste Manage. **34**(7), 1148–1155 (2014)
24. Varma, V.S., Mayur, C., Kalamdhad, A.: Effects of bulking agent in composting of vegetable waste and leachate control using rotary drum composter. Digestion **2**(4), 4 (2014)
25. Eftoda, G., McCartney, D.: Determining the critical bulking agent requirement for municipal biosolids composting. Compos. Sci. Util. **12**(3), 208–218 (2004)
26. Singh, W.R., Kalamdhad, A.S.: Potential for composting of green phumdi biomass of Loktak lake. Ecol. Eng. **67**, 119–126 (2014)
27. Singh, J., Kalamdhad, A.S., Lee, B.K.: Reduction of eco-toxicity risk of heavy metals in the rotary drum composting of water hyacinth: waste lime application and mechanisms. Environ. Eng. Res. **20**(3), 212–222 (2015)
28. Li, C., Knierim, B., Manisseri, C., Arora, R., Scheller, H.V., Auer, M., Vogel, K.P., Simmons, B.A., Singh, S.: Comparison of dilute acid and ionic liquid pretreatment of switchgrass: biomass recalcitrance, delignification and enzymatic saccharification. Biores. Technol. **101** (13), 4900–4906 (2010)
29. He, Z., Wang, Z., Zhao, Z., Yi, S., Mu, J., Wang, X.: Influence of ultrasound pretreatment on wood physiochemical structure. Ultrason. Sonochem. **34**, 136–141 (2017)
30. Barua, V.B., Raju, V.W., Lippold, S., Kalamdhad, A.S.: Electrohydrolysis pretreatment of water hyacinth for enhanced hydrolysis. Biores. Technol. **238**, 733–737 (2017)

Treatment of Wastewater from Beverage/Soft Drink Industry by Microwave Photolytic Process

Anil Swain, Neha Shukla and Neelancherry Remya

Abstract The present study explored the treatment of soft drink (beverage) industry wastewater (SDIW) in microwave alone system and in microwave photolytic system. A rapid degradation and mineralization of the wastewater were observed within one hour of treatment time. The mineralization efficiency in terms of chemical oxygen demand (COD) removal was 78.7%, 81.0%, and 88.6%, respectively, in the system with MW and MW photolysis with one EDL and two EDL at a MW output power of 400 W. Increase in MW power from 400 W to 600 W indicated 4%, 15.5%, and 8.9% increase in the mineralization efficiency of SDIW with the corresponding value of 82%, 95.9%, and 97.3%, respectively, in the three systems. The DO in various systems showed 1.2 to 1.4 mg/L variation during the treatment process. The MW with EDL systems showed higher reduction in DO than that of MW systems, owing to the higher rate of generation of powerful hydroxyl radical, which could result in the rapid oxidation of the organics SDIW in MW photolytic systems compared to MW alone system. On the other hand, the pH showed only a minute variation (<0.5) in all the systems investigated.

Keywords Industrial wastewater · Microwave · Mineralization · Photolysis · Treatment

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1 Introduction

Water is an important raw material which contributes 80% of the total raw materials used in carbonated soft drinks industries [1]. The production of one liter soft drink consumes about four liters of freshwater [5]. Even though water is the major ingredient in the manufactured product of these industries, only about 30% of the total water consumed is converted to the product. A major portion of the water input is used to meet the water requirement for cooling, floor cleaning, and washing which is eventually disposed as wastewater. The wastewater also includes wasted soft drinks and syrups, washing water from bottles and cans washing, etc. Bottle and can washing wastewater contributes 50% of the total wastewater generated by this industry [9], generally having a light gray color with pH 10 due to presence of caustic soda. Washing of soft drink bottles also includes detergents, surfactants, sodium hydroxide, acids, sodium hypochlorite, and chlorine solution [7]. On the other hand, wastewater from floor cleaning and cooling may include detergents and disinfectants along with the lubricants used in the machinery. The wasted soft drinks and syrup impart sugars, artificial colors, flavors, sweeteners, and preservatives to the SDIW. The components in SDIW wastewater thus impart high organic content, turbidity, dissolved solids, sulfate, chlorides, nitrates, etc. to SDIW [1, 3, 4].

At present, several biological and physicochemical treatment technologies have been developed to treat SDIW similar to municipal wastewater [3, 14]. The low biodegradability of components in SDIW, dependency on the treatment process environment (such as pH and temperature) and presence of bio-refractory compounds in SDIW, the biological treatment for SDIW results in poor treatment efficiency or longer duration time. On the other hand, physicochemical techniques such as flocculation, air stripping, coagulation, reverse osmosis, and activated carbon adsorption generally require a posttreatment of adsorbent to remove the accumulated pollutants.

Advanced oxidation processes (AOPs), which relie on the production of highly reactive oxidizing species, are efficient and nonselective method for the rapid degradation of many organic and inorganic pollutants including the bio-refractory compounds. Among various AOPs, microwave (MW) based treatment methods exhibited improved treatment efficiency within a short time due to the rapid, selective, and volumetric heating property of MW [10, 12]. On the other hand, ultraviolet (UV) radiation with very high energy is capable of destructing strong chemical bonds, which could result in pollutant degradation [6]. MW has been coupled with photochemical reactions for complex wastewater treatment is gaining attention in recent years [12–12]. MW photolysis and photocatalysis exhibited improved degradation efficiency of several compounds. This could be attributed to the specific heating property of MW. The dielectric heating under low-energy MW ranging from 0.4–40 J per mole of photon at $\upsilon = 1–100$ GHz causes the thermochemical activation of the pollutant by dielectric heating. On the other hand, UV–vis radiation with an energy of 600–170 kJ per mole of photon at wavelength of 200 to 700 nm causes chemical activation by excited reactions [11]. However, the UV irradiation with conventional UV lamp is limited due to the turbidity of wastewater. To overcome this difficulty, electrodeless discharge lamp (EDL), which could generate UV under MW irradiation, was used in the present study instead of conventional UV lamp.

The present study investigated the effectiveness of MW photolysis (MW + UV) for the treatment of SDIW. The effect of process parameters such as MW output power and UV source on the treatment efficiency was investigated. The effectiveness of the treatment process was in terms of COD removal efficiency, total phosphate (TP) removal efficiency, and total Kjeldahl nitrogen (TKN) removal efficiency with respect to time.

2 Materials and Methods

The synthetic wastewater used for the MW photolytic treatment was prepared by mixing appropriate quantities of polyethylene glycol 200, corn sweet high fructose 55, silicone grease, ethanol, acetone, potassium hydrogen phosphate, ferrous sulfate heptahydrate, sodium hydrogen carbonate, sodium fluoride, sodium hypochlorite, and ammonium hydrogen carbonate [8]. The initial characteristics of the prepared sample analyzed in terms of pH, alkalinity, biochemical oxygen demand (BOD), total solids (TS), total dissolved solids (TDS), total suspended solids (TSS), total nitrate (TN), and total phosphate (TP). Subsequently, the prepared sample was stored at 4 °C for further use. The characterization of the samples was performed as per the standard methods [2].

3 Experimental Setup

The MW photolytic experiments were performed in batch mode using a modified microwave reactor with MW irradiation frequency of 2450 MHz [13]. The experiments were conducted in a Pyrex vessel reactor equipped with lamp holders for the electrodeless discharge lamps (EDLs) (Fig. 1(a)). The EDL contained a cylindrical Pyrex tube with a diameter of 17 mm and a length of 100 mm, filled with argon and other excitable ions as well as free electrons. The MW exposure could result in sequential excitation of electrons and ions inside the EDL, and the relaxation of excited ions could generate UV irradiation. The EDLs under MW exposure is shown in Fig. 1(b). One liter of SDIW was placed in Pyrex vessel reactor and subsequently, the MW experiments were conducted (1) without EDLs, (2) with one EDL, and (3) with two EDLs. The experimentation time was set as 1 h. Samples were taken at various treatment intervals and residual COD, TKN, and TP were determined.

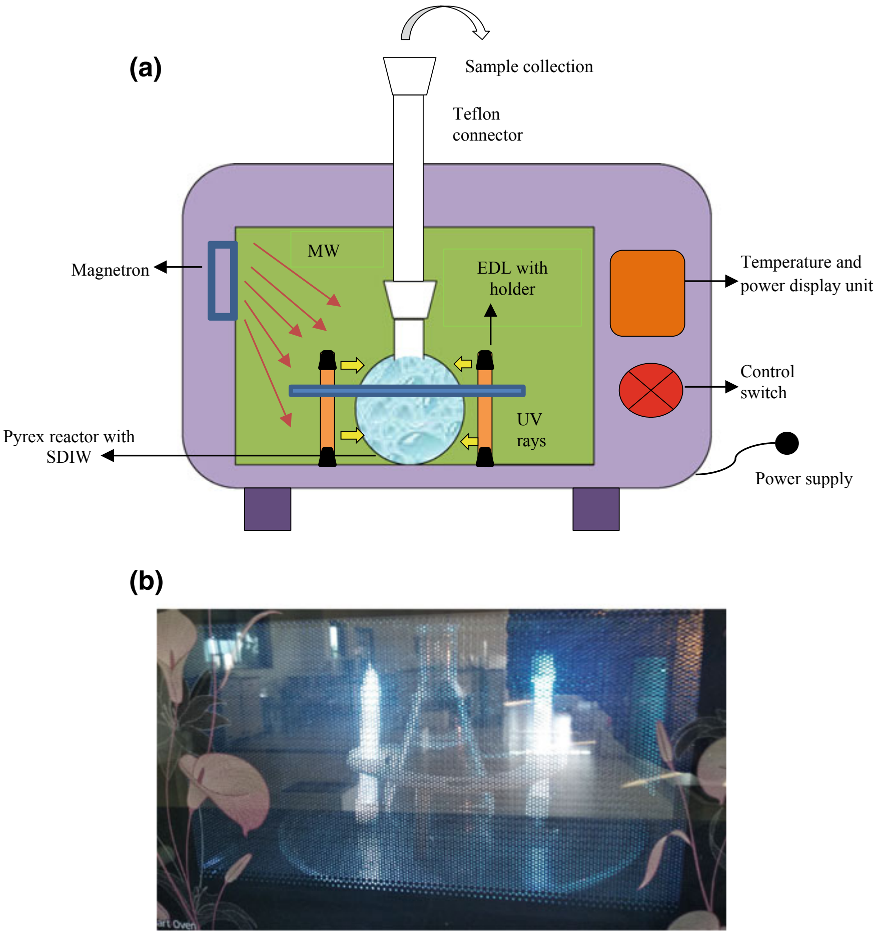

Fig. 1 **a** Schematic diagram of the MW photolytic reactor. **b** EDLs emitting UV irradiation under MW exposure

4 Results and Discussion

4.1 Initial Characteristics of SDIW

The wastewater mimicking the characteristics of SDIW was prepared by dissolving the required chemicals in distilled water. After adding the chemicals, the pH of the system was adjusted around eight with the addition of KOH. Thereafter, the components were stirred with a magnetic stirrer for 4–5 h and later stored at 4 °C to prevent the microbial action. The prepared SDIW was characterized by its initial properties. The chemical analysis result of the prepared synthetic wastewater is presented in Table 1. The prepared SDIW was alkaline in nature with high amount

Table 1 Initial characteristics of SDIW

Parameter (mg/L)	Reported SDIW characteristics	Synthetic SDIW characteristics
TDS	750–1200	1150
TSS	26–90	38
Alkalinity	1000–3500	1115
BOD	600–4500	3200
COD	1200–8000	4400
TN	150–300	128
TP	20–40	3.2

of BOD, COD, TN, and TDS. The wastewater characteristics were comparable with the reported values for various parameters.

4.2 Mineralization of SDIW

The mineralization efficiency of the SDIW in the three systems, i.e., MW, MW photolysis with one EDL (MW + 1EDL) and MW photolysis with two EDLs (MW + 2EDLs), were estimated as the COD removal efficiency. The mineralization efficiency of the three systems were 78.7%, 81.0%, and 88.6%, respectively, in the MW, MW + 1EDL, and MW + 2EDLs systems at 400 W MW power. However, when the MW output power was increased to 600 W, the COD removal efficiency in the three systems were, respectively, 82%, 95.9%, and 97.3% within 60 min (Fig. 2). The result indicated improvement in the mineralization efficiency with MW photolysis compared to MW systems. This is due to the coupled effect of MW and UV destruction of pollutants in the MW photolysis systems. Conversely, the comparable COD removal efficiencies in the MW photolysis systems indicate that the removal efficiency almost reached equilibrium with one EDL and increase

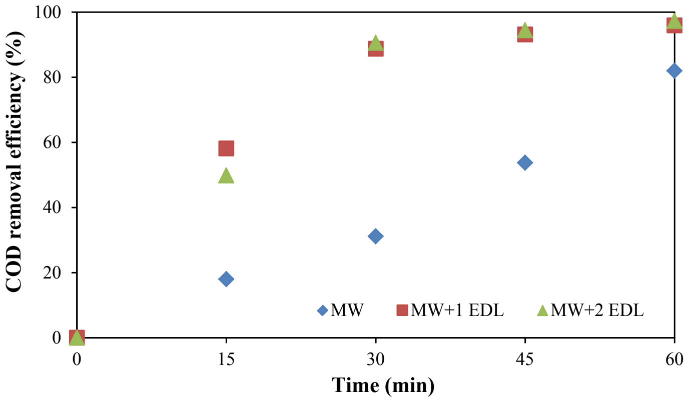

Fig. 2 Mineralization efficiency of SDIW at a different time of the treatment

in the UV source will seldom improve the treatment efficiency. However, the increase in the MW power from 400 W to 600 W could improve the mineralization efficiency in all the systems. The respective increase in mineralization was 4, 15.5, and 8.9% in the three systems. The improvement in mineralization in the MW photolysis system with an increase in MW power could be due to increased excitation of electrons and ions in the EDLs with subsequent increase in the UV intensity.

4.3 TKN Removal Efficiency

TKN removal efficiency of the SDIW in the MW systems at a MW output power of 600 W with one EDL and two EDLs were comparable during the treatment time of 60 min, with a slightly improved performance in the MW with one EDL system. The removal efficiency showed a rapid increase within 15 min with a removal efficiency of 43.7 and 35.9% in the systems with one EDL and two EDL, respectively. After 60 min, the removal efficiency of the two photolysis systems was, respectively, 86.9% and 85.4%. The TKN removal efficiency at different time intervals is shown in Fig. 3.

4.4 Total Phosphate Removal Efficiency

Figure 4 shows the total phosphate (TP) removal in the MW, MW with one EDL and MW with two EDL systems. The TP removal increased gradually in the MW system and reached a maximum value of 56.8%. On the other hand, MW photolysis systems

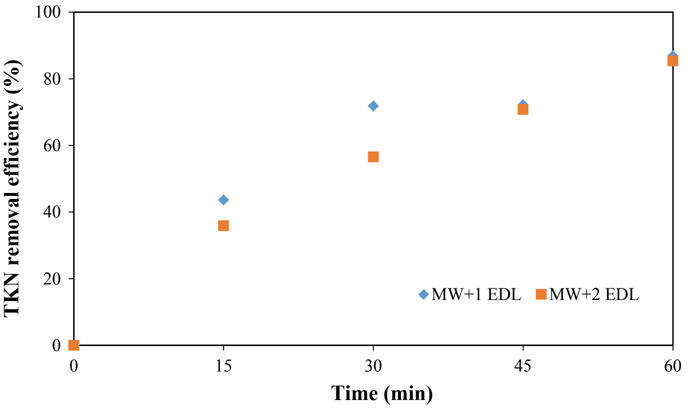

Fig. 3 TKN removal efficiency at different time of the treatment

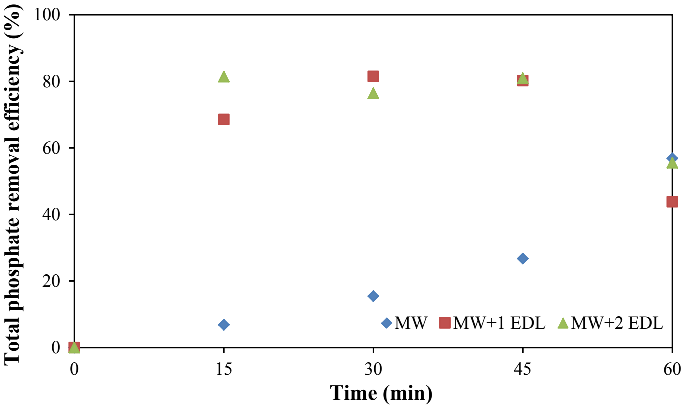

Fig. 4 Variation in the total phosphate removal efficiency at a different time of the treatment

with EDL showed rapid increase in the TP removal within 15 min of treatment time and a slower improvement thereafter until 45 min. At the end of 45 min, the TP removal efficiency was 80.2 and 80.9% in the MW photolytic systems with one and two EDL, respectively. However, the TP in the aqueous phase showed an increasing trend after 45 min. This may be due to the precipitation of phosphate during the early stage of treatment time and solubilization of the precipitate thereafter. The white precipitate was formed on the reaction vessel at the end of the treatment time. However, further analysis is required to determine the actual cause for the increased phosphate concentration toward the end of the treatment time.

4.5 Variation in PH and Dissolved Oxygen (DO)

The pH and DO was monitored as a function of time in the three systems, i.e., MW alone system, MW photolysis system with one EDL and MW photolysis system with two EDLs, with an MW power of 600 W. pH value showed slight increase of less than 0.5 units within 30 min of the treatment time in the three systems and decreased thereafter (Fig. 5). The difference in pH after 60 min of treatment was negligible in the MW photolysis systems, whereas, the initial and final pH of the MW system was 8.1 and 7.7, respectively. Similar results were obtained in the SDIW treatment by ozonation [4]. On the other hand, DO showed decreasing trend within the treatment time in all the three systems studied (Fig. 5). The decrease was within 1.2 to 1.4 mg/L in the three systems. The reduction in DO was higher in MW with EDL systems compared to that of MW systems. Faster rate of DO consumption may be attributed to higher rate of generation of powerful hydroxyl radical, which could result in the rapid oxidation of the organics SDIW in MW photolytic systems compared to MW system.

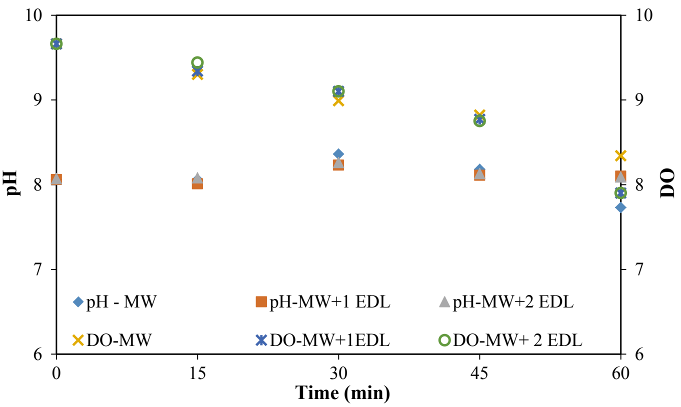

Fig. 5 Variation in pH and DO during the treatment of SDIW

5 Conclusions

The results from the present study indicate the feasibility of MW photolytic method for SDIW treatment. The result indicated a rapid mineralization of SDIW within 60 min of treatment time. The COD removal efficiency at 400 W was 78.7%, 81.0%, and 88.6%, respectively, in the system with MW and MW photolysis with one EDL and two EDLs. The COD removal efficiency showed 4%, 15.5%, and 8.9% increase, respectively, in the three systems with 600 W with the corresponding values of 82%, 95.9%, and 97.3%, respectively. At 600 W, the TKN removal efficiencies in the MW photolytic systems with one and two EDLs were, respectively, 86.9% and 85.4%. The TKN removal showed a gradual increase during the treatment time in MW systems. On the other hand, the TP removal showed a rapid initially in the MW photolytic systems with a decrease in the removal in the removal efficiency after 30 min of treatment. The DO showed a decreasing trend in all the systems; however, the decrease was more in MW photolytic systems compared to MW systems. The decrease in DO in MW photolytic system indicated the improved generation of reactive hydroxyl radical which could result in the rapid degradation of organics from SDIW. The pH showed only minute variation (<0.5) in all the systems investigated.

References

1. Ait Hsine, E., Benhammou, A., Pons, M.-N.: Water resources management in soft drink industry-water use and wastewater generation. Environ. Technol. **26**(12), 1309–1316 (2005) [online]. http://www.tandfonline.com/doi/abs/10.1080/09593332608618605
2. American Public Health Association (APHA), American Water Works Association, Water Environment Federation: Standard Methods for the Examination of Water and Wastewater, 21st edn. (2005)

3. Cuff, G., Turcios, A.E., Mohammad-pajooh, E., Kujawski, O., Weichgrebe, D., Rosenwinkel, K.H.: High-rate anaerobic treatment of wastewater from soft drink industry: methods, performance and experiences. J. Environ. Manage. **220**, 8–15 (2018)
4. García-Morales, M.A., Roa-Morales, G., Barrera-Díaz, C., Balderas-Hernández, P.: Treatment of soft drink process wastewater by ozonation, ozonation-H2O2and ozonation-coagulation processes. J. Environ. Sci. Health—Part A Toxic/Hazard. Subst. and Environ. Eng. **47**(1), 22–30 (2012)
5. Haroon, H., Waseem, A., Mahmood, Q.: Treatment and reuse of wastewater from beverage industry. J. Chem. Soc. Pak. **35**(1), 5–10 (2013)
6. Horikoshi, S., Tsuchida, A., Abe, M., Ohba, N., Uchida, M., Serpone, N.: Microwave discharge electrodeless lamps (MDEL). V. Microwave-assisted photolytic disinfection of Bacillus subtilis in simulated electroplating wash wastewaters. J. Microw. Power Electromagn. Energy : Publ. Int. Microw. Power Inst. **44**(2), 81–87 (2010) [online]. http://www.ncbi.nlm.nih.gov/pubmed/21721320
7. Linares Hernández, I., Barrera Díaz, C., Valdés Cerecero, M., Almazán Sánchez, P.T., Castañeda Juárez, M., Lugo Lugo, V.: Soft drink wastewater treatment by electrocoagulation–electrooxidation processes. Environ. Technol. (U. K.) **38**(4), 433–442 (2017)
8. Narihiro, T., Kim, N.K., Mei, R., et al.: Microbial community analysis of anaerobic reactors treating soft drink wastewater. PLoS One **10** (2015). https://doi.org/10.1371/journal.pone.0119131
9. Ramirez Camperos, E., Mijaylova Nacheva, P., Diaz Tapia, E.: Treatment techniques for the recycling of bottle washing water in the soft drinks industry. Water Sci. Technol. **50**(2), 107–112 (2004)
10. Remya, N., Lin, J.G.: Carbofuran degradation by the application of MW-assisted H2O2 process. J. Environ. Sci. Health—Part B Pestic., Food Contam., Agric. Wastes **46**(4), 350–359 (2011)
11. Remya, N., Lin, J.G.: Current status of microwave application in wastewater treatment—a review. Chem. Eng. J. **166**(3), 797–813 (2011)
12. Remya, N., Lin, J.G.: Microwave-assisted carbofuran degradation in the presence of GAC, ZVI and H_2O_2: influence of reaction temperature and pH. Sep. Purif. Technol. **76**(3), 244–252 (2011)
13. Remya, N., Swain, A.: Soft drink industry wastewater treatment in microwave photocatalytic system—exploration of removal efficiency and degradation mechanism. Sep. Purif. Technol. **210**, 600–607 (2019)
14. Sheldon, M.S., Erdogan, I.G.: Multi-stage EGSB/MBR treatment of soft drink industry wastewater. Chem. Eng. J. **285**, 368–377 (2016)

A Study on the Landfill Leachate and Its Impact on Groundwater Quality of Ghazipur Area, New Delhi, India

Pervez Alam, Mufeed Sharholy and Kafeel Ahmad

Abstract Municipal solid waste disposal in a non-engineered landfill is one of the serious threats to groundwater quality deterioration. In fact, the leachate generated from landfill percolates the strata and reaches to aquifer causing groundwater contamination. The paper aims to analyze the characteristics of landfill leachate along with groundwater quality at various locations in the vicinity for some selected parameters. The grab samples of leachate and groundwater sample have been collected and analyzed as per standard procedure. All the parameters except the pH and electrical conductivity have been observed to be more than the typical values of municipal wastewater. In groundwater, the pH, coliform bacteria and nitrate content have been found to be within the permissible limit at all locations, however, rest of the parameters exceeded the permissible limit. This may happen because of the percolation of leachate through strata. The influence of leachate on groundwater decreases drastically with an increase in distance from landfill site. Maximum contamination has been observed in north and northwestern areas of landfill, especially, at locations GW4 and GW5. The groundwater quality in vicinity of landfill site revealed the unsuitability for both household and commercial uses.

Keywords Solid waste disposal · Landfill leachate · Leachate characteristics · Groundwater quality · Non-engineered landfill

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1 Introduction

Solid waste is plonked in uncovered excavated pits and in slums and are exposed to water held underground in soil or pores, besides being subjected to penetration from rain, snow storm, etc. commonly known as precipitation. Whenever, rainfall transpires the solid waste begins to seize water resulting disintegration of solid waste. Consequently, disintegrated solid waste products in the form of leachate proceed into the water by the impeachment. Disposal of waste material by burying it in a landfill has been spotted as one of the serious threat to the resources of groundwater [1]. Whole world has come under the radar of this threat [2]. The threat can be proven from the fact that a study in El-Akader landfill location in north Jordan was carried out and it was found that the plonking of wastes at open locations cause severe danger to aquifers in that area [3]. Out of the engendered community and public solid waste in India, more than 90% is disposed off in an inappropriate way [4]. Areas that are in vicinity of landfills have a bigger possibility of groundwater pollution may be due to the presence of leachate starting from the dumping location in close proximity to the landfill. The leachate crisis is aggravated mainly because landfills do not have proper collection arrangement, hence, increasing the chances of debauchery of leachate via the sheets of landfill to pollute the groundwater [5]. Due to defective and non-engineered landfills, pollution of soil takes place on its connection with leachate [6]. Contact of leachate with soil, surface water, and groundwater causes pollution crisis may result in damaging consequences on man and environment. Leachate development at the moment has been regarded as one of the biggest problems that require good management [7]. Numerous problems related to contamination of groundwater via leachate percolation have been verified in USA and India [8]. Lots of cases remains unidentified and cannot get noticed mainly because of unawareness of people that the source of water they are using for various purposes is contaminated and unfit for use [9]. There are numerous ways by which the contamination of surface and groundwater can be assessed like laboratory and by mathematical modeling [10]. The formation of leachate varies mostly from landfill to landfill and also on the features of site. The perilous constituents in leachate, which are majority in numbers, are the weighty metals. According to Salam et al. [11] in different wastes mainly electronic waste, painting waste, and used batteries are accountable for the occurrence of weighty metals in the landfills. Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), Total Nitrogen (TN), Electric conductivity (EC) and pH of the leachate in winter session remains much higher than summer session, while other parameters like Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), Metals, ORP, and inorganic nitrogen shows very less distinction between the two seasons [12]. A study done by Gupta and Rajamani in 2015 [13] reveals that monsoon season's leachate is less dangerous and contaminated than the leachate in summer and wintertime of year. The presence of these heavy metals affects both the surface and groundwater [14]. The main objective of this paper is to study the characteristics of landfill leachate along with groundwater quality at various locations in the vicinity for some selected parameters such as TDS, pH, EC, alkalinity, chloride contained, sulfate contained, nitrate contained, BOD_5, COD, iron, coliform organisms, and hardness.

2 Study Area

Delhi is the principal city of India. It covers an area nearly equal to 1,483,000 m^2 lying between latitudes 28°35 North and Longitude 77°12 east situated next to an altitude of 120 m. Weather conditions in Delhi vary drastically. Summer season in Delhi starts from early April and ends in the month of July. Groundwater level in Delhi ranges between 15 and 20 m depth. Topography of Delhi is alienated into three parts, the plains, the flood plain of Yamuna, and the ridge. The population of Delhi which is about 14 million engenders about 7000 metric tons of garbage per day. Solid waste generated here, disposed of from factories, industries, houses, hospitals, etc., is about 150–600 mg/day. Delhi city generates approximately 8,500 tons of MSW on daily basis in 2006 at the pace of 500 g/capita/day. More than 90% of the MSW collected is disposed off in landfills and the rest goes for composting. The three active landfill sites in the city are Ghazipur landfill in East Delhi, Okhla Landfill in South Delhi, and Bhalswa Landfill in North Delhi. These three landfills receive MSW from all 12 zones of the MCD as well as areas served by NDMC and DCB. The city has three compost plants for treatment of MSW. In addition, there is a compost plant for treatment of the waste generated from vegetable markets. The locations of the existing landfill sites and the compost plants are shown in Fig. 1

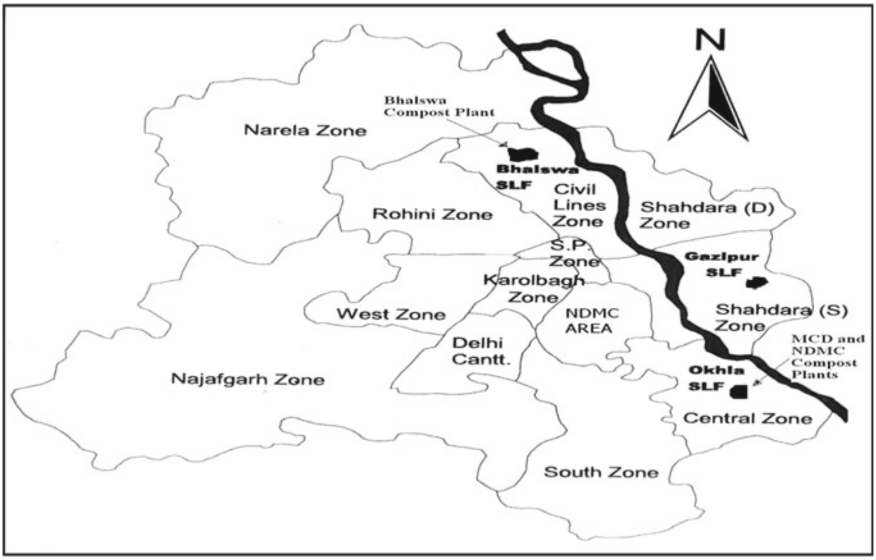

Fig. 1 Locations of existing landfills and composting plant at New Delhi, India (*Source* CGIS)

Since, the MSW has low calorific value varying between 528 and 895 kcal/Kg, and the energy recovery by incineration is not feasible.

The initial landfill began in Delhi in 1975 close to Ring road. In 1978, two further landfills were on track next to Timarpur and Kailash Nagar up to now 17 landfill locations are packed and clogged. Right now, three huge landfill locations are running these are Ghazipur, Okhla, and Bhalswa. These sites extend to a vicinity of about 1.5×10^3 km^2.

3 Materials and Methods

Leachate mostly emerges from the sites where the waste is plonked; areas near these landfills are more prone to groundwater pollution. Groundwater pollution affects the beauty of environment besides causing several problems to the one using this water. Increase in population at a faster rate has resulted in more studies on impact of landfill on surface and groundwater [15]. This study holds more importance in developing countries like India because of backwardness among people.

3.1 Site Selection

Ghazipur landfill site has been chosen for the analysis because this site is still in use since it came into existence after 1984. This site extends to a vicinity of about 3×10^5 m^2 and located in the neighborhood of National Highway 24. Waste of about 2200–2300 metric tons/day is deselected to a stature of about 12–20 m. The waste deselected at this location consists of waste from places where people resides. Manufacture and devastation waste carrying fine aggregates, pieces of bricks and chunk of solid material like concrete are also discarded [16]. Waste from nearby fowl bazaar, fish farm, butcher domicile, other farmhouses and medical waste which is not communicable is also disposed off.

The location is unplanned lying nearer to the ground and is openly dumped. These wastes are thrown in an unsatisfactory manner which creates lot of problems. The waste is neglected on its own accord devoid of separation, excluding the tease choosers who fumble in the course of rubbish and lay a hand in separating it. They usually gather flute objects, synthetic, and metals, and vend these wastes to the reprocessing bodies [17]. At this location of landfills two water weary wells are equipped, which are employed for cleaning of ravage deletion vehicles and safeguarding of weighty ground stirring equipments.

3.2 Groundwater Analysis

Groundwater is generally used for the purpose of drinking and irrigation at Ghazipur area. Hence, it is necessary to carry out its analysis, which will obviously be beneficial for the people and decision-makers of that area. The samples of groundwater have been collected and stored at 4 °C temperature in environmental engineering laboratory. In the laboratory, samples were analyzed TDS, pH, EC, Alkalinity, Chloride contained, Sulfate contained, Nitrate contained, BOD_5, COD, Iron, Coliform organisms and Hardness in a similar way as they were for Leachate. The collected samples were also investigated for the existence of Coliform bacteria because existence of this type of bacteria is key sign of aptness of water. The groundwater sampling locations are described in and Fig. 2 and Table 1, respectively.

3.3 Sampling and Analysis of Data

Six samples of leachate were collected on monthly basis from May to October from Ghazipur landfill site. Grab sampling of leachate in 1000 ml clean plastic bottles was prepared. For investigating the impact of leachate on groundwater, groundwater samples from existing hand pumps located in and around Ghazipur landfill site were collected. From each location, a 1000 ml samples were collected using clean plastic bottles. After collection, the samples were stored at 4 °C temperature

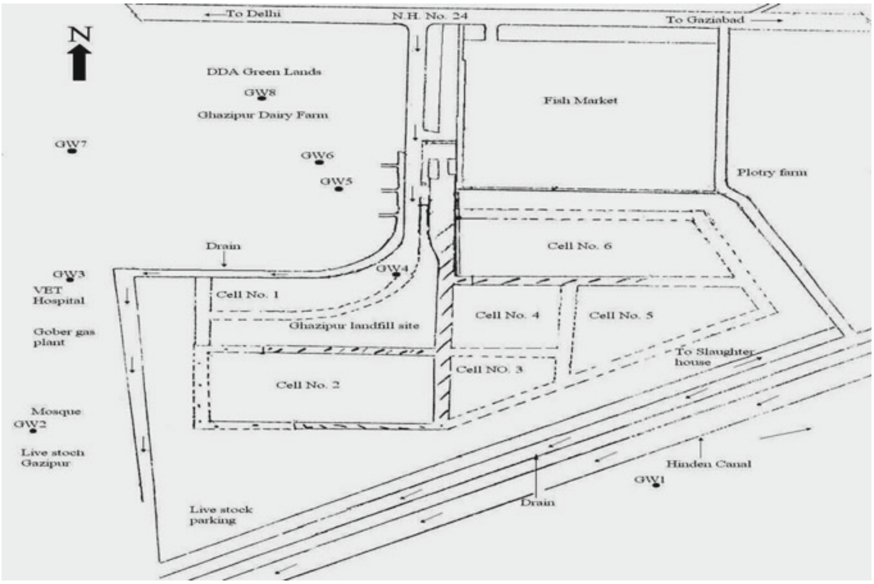

Fig. 2 Ghazipur landfill site and groundwater samples locations

Table 1 Groundwater sampling location at Ghazipur landfill site

Sample no.	Source	Location	Distance from landfill site (m)
GW1	Hand pump (HP)	Mulla Colony, near Hinden Canal	250 (South)
GW2	HP	Near the Mosque, Ghazipur Dairy Farm	225 (West)
GW3	HP	Near VET hospital, Ghazipur Dairy Farm	175 (West)
GW4	HP	Near tube well site in the premises of Ghazipur landfill site	25 (Southwest)
GW5	HP	Road No. 4, Ghazipur Dairy Farm	200 (North)
GW6	HP	Road No. 5, Ghazipur Dairy Farm	275 (North)
GW7	HP	Near Kamal hotel, Ghazipur Dairy Farm	475 (Northwest)
GW8	HP	Road No. 6, Ghazipur Dairy Farm	400 (North)

in environmental engineering laboratory. In laboratory, samples were analyzed as per Standard Methods for the Examination of Water and Wastewater published by American Public Health Association [18]. In addition to this, the collected samples were also investigated for the existence of coliform bacteria.

4 Results and Discussion

4.1 Characteristics of Leachate

The high value of conductivity (1156–1405 MHO/cm) indicates the existence of dissolved materials in the samples (22,690–34,525 mg/l) shows in Fig. 3. Conductivity is susceptible to the deviations in dissolved solids, with which it has almost direct mathematical relationship and mineral content. The pH values vary from 6.9 to 7.8 owing to soaring alkalinity attentiveness in the leachate samples, which ranged from 2123 to 3256 mg/l. Hardness of leachate was also very high and remains in between 4312 and 5623 mg/l. It is the sum of the calcium and magnesium present in leachate. During rainy season (July and August), the hardness of leachate increases and reaches to a maximum level of 5623 mg/l. Chloride was found maximum (2294 mg/l) in October and minimum in August (1765 mg/l). It is present in abundance and is essentially not retained by soil because it is nonreactive both physically and biologically. It diffuses quickly and often signals the advancement of a plume of contaminated water. The variation of hardness, alkalinity, and chloride, hardness, TDS, BOD, COD, sulfate, nitrate, iron is shown in Fig. 4.

BOD_5 and COD were found to be high, which is an obvious signal of the sever infectivity and may lead to degradation of groundwater quality. Nitrate was found to be maximum (136 mg/l) in the month of July and minimum (76 mg/l) in the month of October. Sulfate contained vary on or after 210–314 mg/l and iron

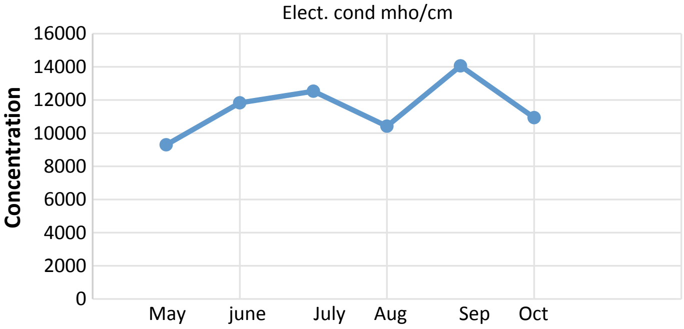

Fig. 3 Variation of electrical conductivity of leachate

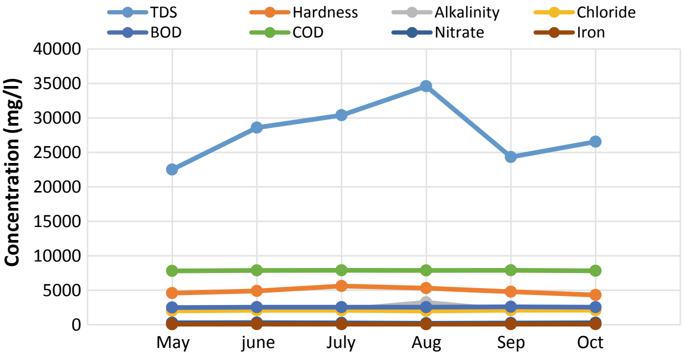

Fig. 4 Variation of hardness, alkalinity, chloride, TDS, BOD, COD, sulfate, nitrate, iron of leachate from Ghazipur landfill

contained remains very high (52–78.6 mg/l) as shown in Fig. 4, which indicates that the iron and steel too are disposed of in the landfill and it can give reddish-brown color to groundwater. A summary of the contaminant concentration in the leachate samples compared with the typical values of municipal wastewater is presented in Table 2. This table shows that the leachate of Ghazipur landfill site is highly contaminated and can produce ill effect to the groundwater. It is further clear that the MSW in Delhi has high biodegradable. It may produce leachate with high organic contained, some industrial, hospital and hazardous wastes are also reaching the MSW disposal site, therefore, the leachate may have much higher concentration of all below parameters.

Table 2 Comparison of the physicochemical characteristics of leachate from Ghazipur landfill site with typical wastewater

Parameter	Mean value	Range	Typical value of wastewater concentration[a]
TDS (mg/l)	28,509	22,690–34,525	250–850
pH	7.4	6.9–7.8	6–8.5
Electrical conductivity (MHO/cm)	1314	1156–1405	2250
Alkalinity (mg/l)	2711	2123–3256	50–200
Chloride (mg/l)	2041	1765–2294	30–100
Sulfate (mg/l)	276	210–314	200
Nitrate (mg/l)	107	76–136	20–40
BOD_5 (mg/l)	2176	2128–2216	50–100
COD (mg/l)	7933	7874–7998	250–1000
Iron (mg/l)	65.95	52–78.6	0.05–0.1
No. of coliform (MPN/100 ml)	262	240–300	10
Hardness (mg/l)	5002	4312–5623	50–100

[a] All value in mg/l except pH without unit and conductivity in MHO/cm

4.2 Variation of Groundwater Parameters

TDS indicates the amount of total dissolved salts present in water. TDS at all samples were falling among 304 and 1253 mg/ltr. The TDS absorption was extremely soaring at sampling station GW3, GW4, GW5, except for station GW1 and GW2 all were more than the permissible limit. TDS have high values at some stations mainly because of disposal of large amount of pollutants at the site. Soaring presences of TDS reduces the scrumptiousness and may lead to gastrointestinal annoyance in humans [19]. The pH of all the eight groundwater locations was ranging from 6.9 to 8 with minimum at GW3 and maximum at GW4, while Electronic conductivity indicates the quantity of material dissolved in water, conductivity of water at the site has been ranging from 799 MHO/cm to 3568 MHO/cm. Out of the eight locations selected for sampling GW3, GW4, GW5, GW8 have conductivity more than the desired limit. Alkalinity is a measure of the capacity of water to neutralize acids. The alkalinity of water at all the sampling stations ranges from 199 mg/l to 597 mg/l; except for GW1 station, all other stations were having alkalinity more than the desirable limit. The water has high alkalinity along with soaring pH, TDS and TH is dangerous to human health, besides this alkaline water also give unpleasant taste. An excess of Chlorine (Cl^-) in water is frequently in use as key to contamination and deemed as outliner for groundwater infectivity [20]. The presence of Cl^- in the groundwater samples was falling among 68 mg/l to 716 mg/l. Chloride concentration at station GW4, GW5, GW6 was found to be comparatively high. Household sewages, stimulants, and septic tanks, innate resources such as rainfall, the suspension of liquid additions are responsible for the presence of chloride in high concentration in groundwater. High concentration of Cl^- level is dangerous to people affecting from heart or kidney sickness (WHO, 1997). As we know that, the sulfate is a salt of sulphuric acid and it contains the anion $SO4^{-2}$ or the divalent group. Sulfate was remains in the range of 35 mg/l to 440 mg/l. At station GW5 and GW6 it was found to be very high and except for station GW1, GW2 and GW3 all were exceeding the permissible limit. The excess amount of sulfate present in groundwater may lead to Osmotic Diarrhea. The concentration of nitrate (Na+) was varying 1.3–23 mg/l. The soaring concentration of Na+ may pose threats to persons who have circulatory disease problems. From this point of view, water was found to be safe. BOD (Biochemical Oxygen demand) for all the eight locations of the chosen study area was varying between 0.9 and 2 mg/l. It is found out to be more than the permissible limit that shows a very high amount of organic matter. The COD of all eight groundwater samples vary from 12 to 92 mg/l, with sampling station GW4 having the maximum level of COD. The high amount to COD levels indicates the existence of macrobiotic contaminants in water.

Presence of iron in the water samples was varying from 0.02 to 3.56 mg/l. The Iron Concentration was above the permissible limit for all eight groundwater samples collected. According to Rowe et al. (1992) [21], if iron is present in watercolor of water is also changed. Total coliform was found to be well within the range of permissible limit that is from 0 to 2 MPN/100 ml. Hardness is computation of the number of divalent ions (brackish with two positive charges) like calcium, magnesium, and iron present in water [22]. Mg^{2+} and Ca^{2+} ions are frequently there in large numbers. These ions easily get reacted with soap and make scum formation very difficult. Hardness of water at site was ranging from 216 to 684 mg/l in terms of $CaCO_3$. Hardness has been beyond the permissible limit except for sample station GW1. The excess of Ca^{2+} causes problems in the body such as stones in kidney and bladder and annoyance in passage of urine. Excess Mg^{2+} causes laxative effect, which obviously is the case here. So water is too hard may not be used for drinking but deficiency may cause serviceable changes. It is vital for a lot of enzyme arrangements [23] (Figs. 5 and 6).

4.3 Effect of Distance on Pollution of Groundwater

(i) **Hardness, TDS, alkalinity, and chloride**: Variation of hardness, alkalinity, chlorides, and TDS with distance for the landfill site is shown in Fig. 7. It is clear that when distance was 25 m hardness was 1300 mg/l, but it decreases to 900 mg/l, when distance of 200 m was reached, there was slight decrease by about 100 mg/l, at a distance of 275 m was reached i.e., hardness was 800 mg/l at this point. Finally, after reaching 400 m distance, hardness was nearing 700 mg/l. As far as Alkalinity is concerned, it decreases from

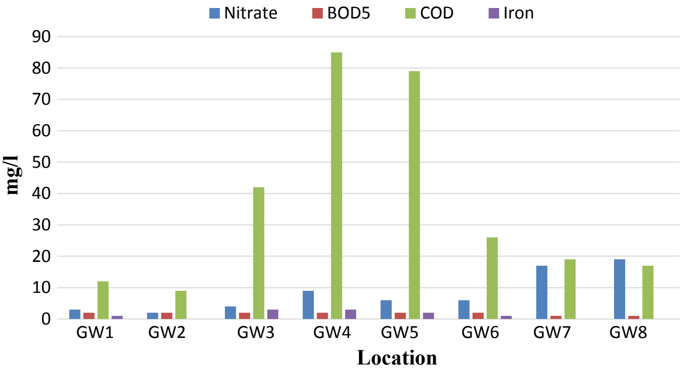

Fig. 5 Variation of nitrate, BOD_5, COD, and iron at different ground water location

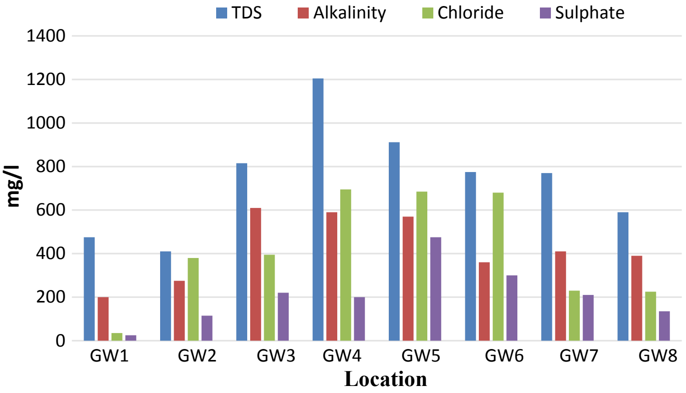

Fig. 6 Variation of TDS, alkalinity, chloride, sulfate, and hardness at different ground water location

600 mg/l at 25 m to 325 mg/l at 400 m. At 200 m and 275 m alkalinity was about 550 mg/l and 320 mg/l, respectively. Chloride contents decreased a lot from 655 mg/l at 25 m to 325 mg/l at 400 m. However at 200 m there was just a slight change in chloride content, i.e., from 655 mg/l at 25 m to about 653 mg/l at 200 m may be due to presence of leachate in good amount at that point after that there was a considerable decrease by about 25 mg/l in chloride content at 275 m. Significant Change was in TDS of water from 1300 at 25 m to 650 at almost 655 mg/l at 400 m. At 200 m and 275 m, TDS were about 900 mg/l and 800 mg/l. Hence, from the discussion it is clear that as the distance increases the location of landfill the level of parameters like hardness, alkalinity, chloride, and TDS were decreasing.

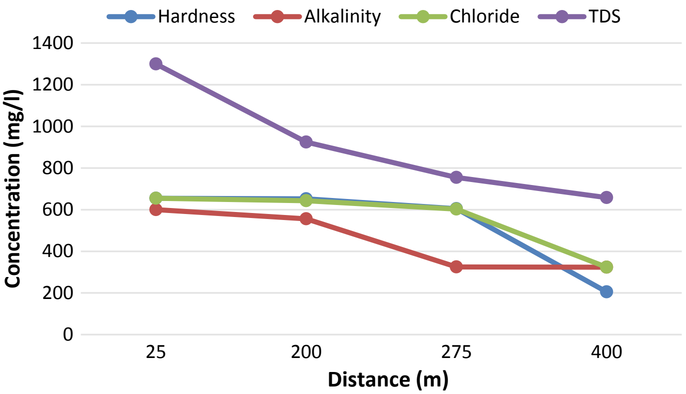

Fig. 7 Variation of hardness, alkalinity, chloride, and TDS with the distance

(ii) **pH Value**: Effect of distance on pH value of the groundwater at the selected Ghazipur landfill site given graphically in Fig. 8. We can see that when we moved 25 m from landfill site pH value was 8, at 200 m it was 7.8, moving further 75 m that is at 275 m, pH value of the sample decreases to about 7.6. Finally when a distance of 400 m was reached pH value was 7.3 clearly showing that with increases in distance from landfill site pH value was decreasing.

(iii) **BOD and COD**: Variation of BOD and COD with increase in distance is shown in Fig. 9. BOD was almost constant from 25 to 275 m i.e., about 3 mg/l. However, it decreases slightly from 3 mg/l at 275 m to 1.5 mg/l at 400 m. As far as COD is concerned with increase in distance the chemical oxygen demand (COD) decreases significantly, when distance was 25 m

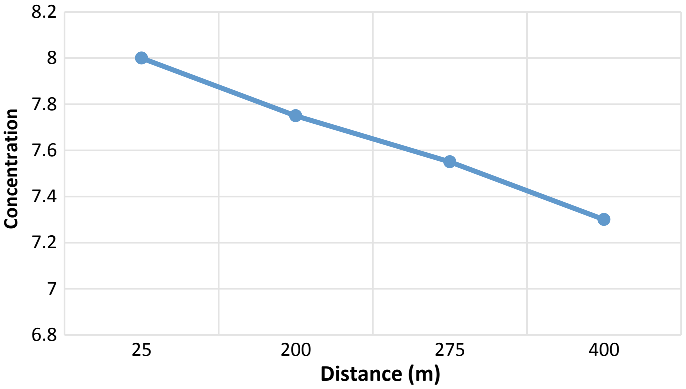

Fig. 8 Variation of pH value with the distance from Ghazipur landfill

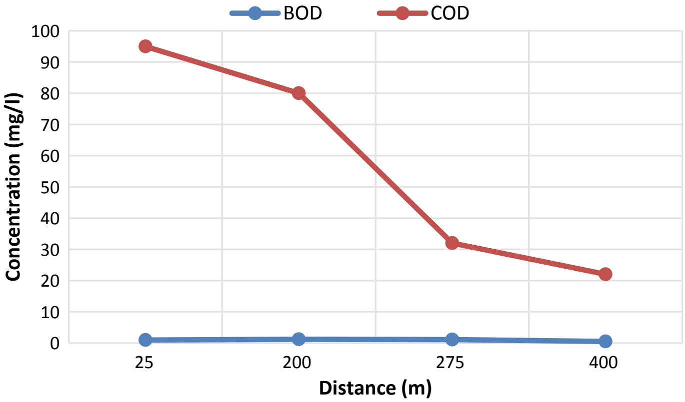

Fig. 9 Variation of BOD and COD with the distance from Ghazipur landfill site

COD was between 95 mg/l, when distance of 200 m COD was about 80 mg/l. When we moved 275 m from the landfill site COD was 30 mg/l. Finally, COD decreases to 20 mg/l at a distance of 400 m. Hence, it can be concluded that with increase in distance BOD changes slightly, however, COD changes significantly.

(iv) **Iron**: As shown in Fig. 10, iron content was as high as 3.2 mg/l when we moved 25 m from the landfill site, at the distance of 200 m it was 2.8 mg/l, when we moved 275 m from the landfill site iron content was as low as 1 mg/l. Finally, at 400 m distance it was 0.7 mg/l. Hence, when the distance was increasing iron content decreases significantly.

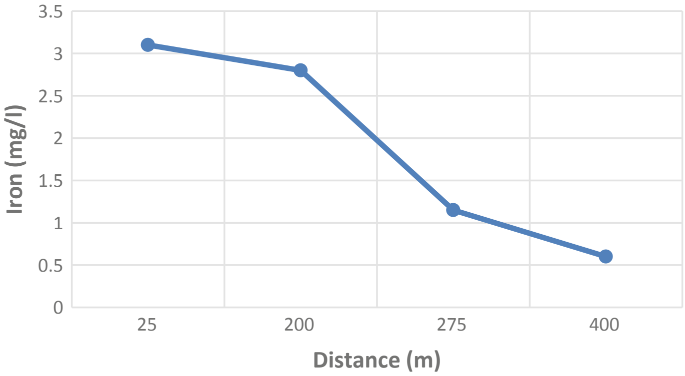

Fig. 10 Variation of iron with the distance at landfill site

5 Remedial Measures for the Groundwater Pollution

The result of groundwater monitoring shows that the landfill Leachate is contaminating the groundwater quality of Ghazipur. Corrective remedial measures are necessary for the improvement of groundwater quality. This can be achieved by proper management of landfill leachate, its treatment and disposal. Ghazipur Landfill site is not provided with concrete lining, leachate collection system, and treatment system. So, it is a non-engineered landfill. In such conditions, only possible options that could be stalked are:

(i) Provision of impermeable membrane for limiting the infiltration of landfill leachate.
(ii) Extraction and treatment of landfill leachate, so that less amount can be transferred to groundwater.
(iii) Vegetable cover also helps in the formation of leachate by the method of transpiration.

6 Conclusions

It has been observed that the contamination of groundwater is in excess in north and northwestern areas of landfill, and the effluence is in excess in the vicinity. The contamination level has been decreasing steadily with distance from landfill in north and west direction. The landfill leachate influences the groundwater adversely in the propinquity of the landfill, due to which the groundwater surge in northern and western direction. The excessive presence of TDS, Chloride, Sulfate, iron, etc. in groundwater mainly in vicinity of landfill locations cautions its eminence, and hence makes it unsuitable for both household and commercial use. It can be concluded that reason due to which groundwater has been found to be polluted is the presence of leachate. However, with increase in distance from the landfill location the water pollution has been reduced drastically, but few parameters especially iron, TDS and chloride content have been still not in the range of permissible limit, and hence, groundwater in that area on the whole is deemed as unfit for well-being of the community.

References

1. Fatta, D., Papadopoulo, A., Loizidou, M.: A study on the landfill leachate and its impact on the groundwater quality of the greater area. Environ. Geochem. Health **21**(2), 175–190 (1999)
2. United States Environmental Protection Agency (US EPA): Office of Drinking Water, a Ground Water Protection Strategy for the Environmental Protection Agency 11 (1984)

3. Abu-Rukah, Y., Al-Kofahi, O.: The assessment of the effect of landfill leachate on ground water quality—a case study: El-Akader landfill site north Jordan. J. Arid Environments **49**, 615–630 (2001)
4. Chatterjee, R.: Municipal solid waste management in Kohima City–India. Iran J Environ Health Sci and Eng **7**(2), 173–180 (2010)
5. Kanmani, S., Gandhimathi, R.: Assessment of heavy metal contamination in soil due to leachate migration from an open dumping site. Journal of Applied Water Science **3**, 193–205 (2013)
6. Mukherjee, S., Mukhopadhyay, S., Hashim, M.A., Gupta, B.A.: Contemporary environmental issues of landfill leachate: assessment and remedies. Critical Reviews in Environmental Science and Technology **45**, 472–590 (2015)
7. Adeolu, A.O., Ada, O.V., Gbenga, A.A., Adebayo, O.A.: Assessment of groundwater contamination by leachate near a municipal solid waste landfill. African Journal of Environmental Science and Technology **5**(11), 933–940 (2011)
8. Biswas, B., Kumar, A., Babu, S., Bhattacharyya, S., Chakrabarti, J.: Studies on environmental quality in and around municipal solid waste dumpsite. Journal of Resources, Conservation and Recycling **55**, 129–134 (2010)
9. James, S.C.: Metals in municipal landfill leachate and their health effects. Am. J. Public Health **67**(5), 429–432 (1977)
10. Moo-Young, H., Johnson, B., Johnson, A., Carson, D., Lew, C., Liu, S., and Hancock, K: Characterization of infiltration rates from landfills: supporting groundwater modeling efforts. Environ Monit Assess **96**, 283–311 (2004)
11. El-Salam, M.M.A., Abu-Zuid, G.I.: Impact of landfill leachate on the groundwater quality: a case study in Egypt. J. Adv. Res. **6**(4), 579–586 (2014)
12. Zhao, J., Lu, X.-Q., Luo, J.-H., Liu, J.-Y., Xu, Y.-F., Zhao, A.-H., Liu, F., Tai, J., Qian, G.-R., Peng, B.: Characterization of fresh leachate from a refuse transfer station under different seasons. Int. Biodeterior. Biodegradation **85**, 631–637 (2013)
13. Gupta, A., Rajamani, P.: Toxicity assessment of municipal solid waste landfill leachate collected in different seasons from Okhala landfill site of Delhi. J. Biomedical Science and Engineering **8**, 357–369 (2015)
14. Sumaiya, A.H., Raisi, A., Sulaiman, H., Suliman, F.E., Abdallah, O.: Assessment of heavy metals in leachate of an unlined landfill in the Sultanate of Oman. Int. J. Environ. Sci. Development **5**(1), 60–63 (2014)
15. Saarela, J.: Pilot investigations of surface parts of three closed landfills and factors affecting them. Environ. Monit. Assess. **84**, 183–192 (2003)
16. Mohan, S., Gandhimathi, R.: Removal of heavy metal ions from municipal solid waste leachate using coal fly ash as an adsorbent. J. Hazard. Mater. **169**(1–3), 351–359 (2009)
17. Agarwal, A., Singhmar, A., Kulshrestha, M., Mittal, A.K.: Municipal solid waste recycling and associated markets in Delhi. India. Res. Conserv. Recycling **44**, 73–90 (2005)
18. APHA-AWWA-WPCF, Standard Methods for the Examination of Water and Wastewater, 15th edn. American Public Health Association, Washington, DC, USA (1994)
19. Loizidou, M., Kapetanios, E.: Effect of leachate from landfills on underground water quality. Sci. Total Environ. **128**, 69–81 (1991)
20. Bureau of Indian Standards (BIS): Indian Standard Specification for Drinking Water), IS 10500, pp. 2–4 (1991)
21. Rowe, R.K., Quigley, R.Q., Booker, J.R.: Clay barrier systems for waste disposal facilities. E & FN Spon, London, UK (1995)
22. Wurts, A.: William: understanding water hardness. World Aquaculture **33**(1), 16–17 (1992)
23. World Health Organization (WHO): Guidelines for Drinking Water Quality, 2nd edn, vol. 2, pp. 940–949, Health Criteria and Other Supporting Information, World Health organization, Geneva (1997)

Effect of Attrition on Silica Sand as Bed Material in Circulating Fluidized Bed System

**Prabhansu, Jyoti Bhushan Singh, Prakash Chandra,
Malay Kumar Karmakar and Pradip K. Chatterjee**

Abstract To understand the effect of attrition, a series of experiments were conducted in CFB test setup installed at CSIR-CMERI Durgapur using common silica sand. Using standard sieves, three different samples were prepared, containing sample size between 0.106–0.425, 0.212–0.600, and 0.300–0.800 mm of mean Sauter diameter 0.314, 0.414, and 0.520 mm, respectively. Five sets of experiments were conducted for each sample and its mean value is presented in this paper. The attrition of bed particles was found to be higher for larger particles. Sample-III showed the greatest reduction in size as it contained most of the larger particles initially, which got reduced considerably after stipulated run time. It was found from the set of experiments that the mean Sauter diameter for sample-I, II, and III (0.314, 0.414, and 0.520 mm) reduced to 0.312, 0.410, and 0.513 mm, respectively.

Keywords Attrition · Silica sand · Mean sauter diameter · Circulating fluidized bed system

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1 Introduction

Circulating Fluidized Bed (CFB) systems are known for their high heat and mass transfer rates, nearly isothermal conditions, high throughput, and high conversion rates. One of the major problems associated with CFB systems is attrition of bed materials due to high superficial gas velocities associated with it. Whether it is the case of combustion or gasification, attrition of bed materials, catalysts, etc., has to be taken into account. This often leads to inefficiencies of catalysts and bed agglomerations in fluidized bed systems. Although attrition for silica sand is not higher as compared to other bed materials like limestone and dolomite, still we have considered this for the present study as it is readily available and is commonly used as bed materials for gasification and combustion reactions in fluidized bed systems.

Attrition of bed materials in CFB occurs as a result of abrasion and defragmentation [1, 2]. Abrasion is the process of wearing the surface materials away and is generally more responsible for fines production. The production of particle fragments allows for the possibility of a greater rate of surface abrasion, as the daughter particles resulting from a fracture are nonspherical, and the protuberances are more easily worn compared to spherical particles. The locations where attrition highly occurs in CFB are (1) fluidized bed, (2) conveying lines and risers, (3) cyclones or other gas-particle separation devices, (4) hoppers and standpipes, and (5) rotating seals or screw feeders [3]. Further, attrition on sand particles can be found in the literature [4–6], where it has been shown that diameter of particles has direct relation with the attrition rate.

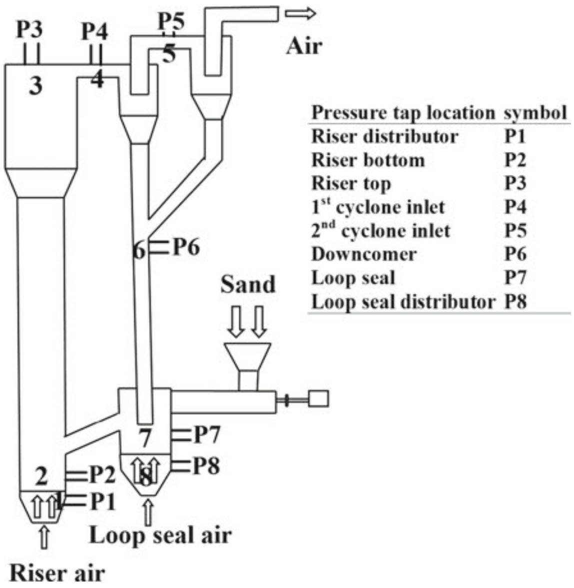
The purpose of this study was to investigate the attrition of sand bed material, so as to determine the rate of loss of bed materials in CFB operations.

2 Methods and Materials

The lab-scale CFB setup under consideration is installed at CSIR-CMERI Durgapur. The body of the experimental set up is made up of stainless steel. Some portions of riser and downcomer are made with transparent Plexiglas to visualize the solids flow. The present CFB test set up is shown schematically in Fig. 1. The system consists of a fast bed riser, double cyclones to separate the solid particulates and a downcomer with loop seal. The loop seal is a nonmechanical valve used to have effective control of solid recirculation and to establish leak-tight operation in the loop [7, 8]. The riser exit is connected tangentially to cyclone in horizontal direction. The solid particles are supported by bubble cap type air distributor plates at riser and loop seal.

A separate compressor unit is installed to supply air to the riser and the loop seal. Pressure taps, mounted at different locations, are fitted with filter screens to prevent solid particles leakage from the bed to the manometer.

Fig. 1 Schematic representation of CFB setup



Pressure tap location	symbol
Riser distributor	P1
Riser bottom	P2
Riser top	P3
1st cyclone inlet	P4
2nd cyclone inlet	P5
Downcomer	P6
Loop seal	P7
Loop seal distributor	P8

In order to investigate the flow characteristics, silica sand samples of three different Sauter diameters were used. These samples were prepared using different wire mesh sieves and their properties are presented in Table 1.

Air is introduced at two locations—(a) at the bottom of riser and, (b) at the bottom of loop seal chamber. The air flows to the riser and the loop seal are supplied through two separate pipelines, and each flow is controlled by a regulating valve. The riser is maintained in fast bed condition and the seal air keeps the loop seal in bubbling fluidization regime. The airflow rates are measured using variable area type rotameters.

Table 1 Properties of sand samples used

Material	Sand # I	Sand # II	Sand # III
Size range (μm)	106–425	212–600	300–800
Sauter mean diameter (μm)	314	414	520
Sphericity	0.86	0.86	0.86
Particle density (kg/m^3)	2500	2500	2500
Bulk density (kg/m^3)	1410	1417	1447
Voidage at minimum fluidization condition, ε_{mf}	0.413	0.410	0.406
Minimum fluidization velocity at 27 °C, m/s	0.077	0.131	0.198
Particle terminal velocity at 27 °C, m/s	2.07	2.53	2.86
Archimedes number	2668	6116	12,119
Group of Geldart's classification	B	B	B

Table 2 Parameters of cold model test set up

Parameter	Value	Unit
Height of riser	3.23	m
Inside diameter of riser		
Upto 2.0 m height	0.075	m
Beyond 2.0 m height	0.100	m
Length of downcomer standpipe	2.191	m
Inside diameter of downcomer standpipe	0.050	m
Inside diameter of loop seal	0.100	m
Height of loop seal	0.250	m
Diameter of inlet of cyclone	0.050	m
Total height of cyclone	0.400	m
Velocity of airflow in riser	4.1–9.0	m/s
Velocity of air flow in loop seal	0.14–0.85	m/s

The test run was conducted and during each experiment, the setup was allowed to continuously run for 5 h using each type of bed sample. The input parameters as well as dimensions are shown in Table 2. Bed inventory was kept constant at 6–7 kg for the entire set of experiments with these sand samples. Compressed air was supplied to the riser and loop seal bubble-capped distributor plates, from air tank, where continuous supply is provided by the air compressor line. The system was allowed to run for 5 h under steady-state at atmospheric conditions. Superficial gas velocities were maintained at 4.1–4.5 m/s for sample-I, 5.8–6.2 m/s for sample-II and 7.7–8.2 m/s for sample-III, respectively. Loop seal aeration was maintained between 0.14 and 0.85.

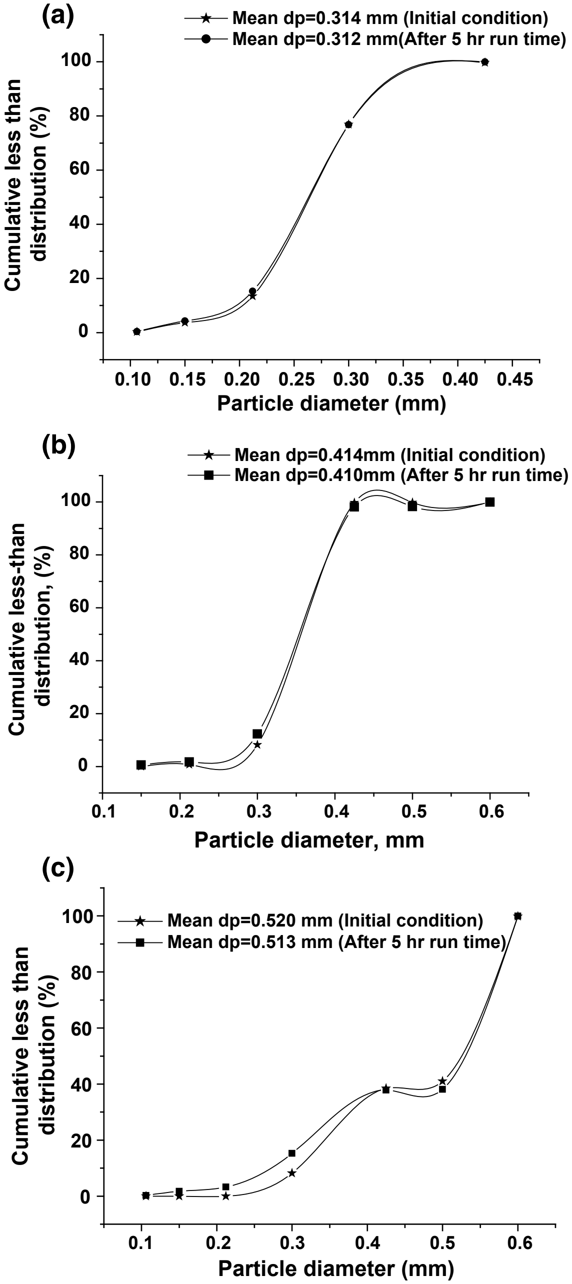
3 Results and Discussions

After each run, a sample of solid particles from the bed was collected to study the attrition phenomena. The initial and final cumulative distribution of each sand sample is shown in Fig. 2a, b and c.

It is clear from Fig. 2a that the attrition is minimal for sample # I (size: 0.106–0.425 mm), as there is very little difference observed in the initial and final distribution of the mixture. However, it is obvious from Fig. 2b that there is attrition for sample # II (size: 0.212–0.600 mm), due to which the presence of particles smaller than 0.3 mm is observed after the run time. Similarly, in Fig. 2c for sample # III (size: 0.300–0.800 mm), one may find that major attrition occurs for particles diameters in the range of 0.4–0.6 mm which has collectively increased the net amount of finer particles.

Attrition of sand occurs mainly because of Mechanical stresses. Mechanical stresses are those that are a result of compression, tensile, or shear stresses on particulate material, which might occur as a result of simple support of static loads

Fig. 2 **a** Initial and final cumulative less than particle-size distribution of sand sample # I, **b** Initial and final cumulative less than particle-size distribution of sand sample # II, **c** Initial and final cumulative less than particle-size distribution of sand sample # III



(Static stress) or more complex due to the dynamic motion of particles (Kinetic stress). Static stress occurs as a result of very low or no motion of sand particles, mainly in the lower portion of downcomer, at the bottom section of a riser, or in a silo. Kinetic stresses involve the motion at high velocity including impacts with the surface of the wall in a riser. It also occurs at lower velocity, where two or more particles rub against each other. The larger size particles, as a result of mechanical stresses, get reduced to finer particles.

4 Conclusions

Investigation on attrition of common silica sand was conducted in CFB system to understand its defragmentation using three different sample sizes. It was found from the series of experiments that larger particles have shown greater defragmentation whereas smaller particles have shown less change. The mean Sauter diameter of sample-I was changed from 0.314 to 0.312 mm. similarly for sample-II and III, it was changed from 0.414 mm and 0.520 to 0.410 and 0.513, respectively. Further work is required on getting the actual attrition rate at both atmospheric and gasification temperatures.

References

1. Werther, J., Reppenhagen, J.: Attrition in fluidized beds and pneumatic conveying lines. In: Fluidization, Solids Handling and Processing. William Andrew Publishing, Westwood (1999)
2. Bayham, S.C., Breault, R., Monazam, E.: Particulate solid attrition in CFB systems—an assessment for emerging technologies. Powder Technol. **302**, 42–62 (2016)
3. British Materials Handling Board: Particle Attrition: State-of-the-Art Review, Trans Tech Publications, London (1987)
4. Gungor, A., Eskin, N.: Hydrodynamic modeling of a circulating fluidized bed. Powder Technol. **172**, 1–13 (2007)
5. Gungor, A.: Predicting axial pressure profile of a CFB. Chem. Eng. J. **140**, 448–456 (2008)
6. Gungor, A., Yildirim, U.: Two dimensional numerical computation of a circulating fluidized bed biomass gasifier. Comput. Chem. Eng. **48**, 234–250 (2013)
7. Basu, P., Cheng, L.: An analysis of loop seal operations in a circulating fluidized bed. Trans. Inst. Chem. Eng. **78** A, 991–998 (2000)
8. Bareschino, P., Solimene, R., Chirone, R., & Salatino, P.: Gas and solid flow patterns in the loop-seal of a circulating fluidized bed. Powder Technol. **264**, 197–202 (2014). https://doi.org/10.1016/j.powtec.2014.05.036

Status of Handling and Management of Lead–Acid Batteries in Five Districts of Punjab (India)

Preetinder Kaur, Puneet Pal Singh Cheema and Hardeep Singh Rai

Abstract The Lead–acid batteries (LAB) sector has been one of the most discussed and dissected sectors due to its environmental implications. In India, there has always been a demand-supply gap for lead due to the unorganized or informal nature of lead–acid batteries handling and management, which is one of the major sources of lead. The purpose of the present study was to develop baseline information regarding the handling and management of new and used lead–acid batteries in five districts of Punjab state, i.e., Ludhiana, Sangrur, Jalandhar, Mohali, and Faridkot during a year's period. Scope of the study also covered the status of recycling of lead–acid batteries and lead recovery from used batteries. It was found that the LAB sector and its stakeholders were, in many ways, not regularized and there was lack of information and awareness on procedures, norms, and more importantly the health hazards of dealing with lead. Registered recyclers were found to be recycling only 23% of the total used batteries collected by dealers, highlighting the role of unregistered recyclers in recycling process of used batteries. It was recommended to integrate the unorganized sector workforce into the collection process of used batteries as this sector has batter capability to penetrate into local levels.

Keywords Demand-supply gap · Informal sector · Lead–acid batteries management · Recyclers · Stakeholders

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1 Introduction

As the demand for lead–acid batteries (LAB) in India increases due to the growth in telecommunications, households, motor vehicles and industries, environmental controls are lagging behind leading to widespread pollution and lead poisoning. In India, the lead–acid battery sector always had two distinct sections, organized or formal sector, and unorganized or informal sector. There has always been a demand-supply gap for lead in India, mostly fuelled by the increasing demand of a growing automobile industry [6]. Due to lack of considerable lead resources in developing countries, optimum usage of secondary lead recovered from spent lead–acid batteries is becoming crucial nowadays [8]. Before the Battery Rules came into being, the technologies adopted by most of the lead smelters, battery re-conditioners and allied trades in lead–acid battery sector were environmentally unsafe. Realizing this, on May 25, 2000, a draft notification on the Batteries (Management and Handling) Rules, 2000 was issued by the Government of India's Ministry of Environment and Forests (MoEF) under the Environment Protection Act, 1986.

After subsequent discussions and consultations, the Batteries (Management and Handling) Rules were enacted on May 16, 2001. This was done with a view to regularize the sector. These rules aimed at keeping a track of all lead–acid batteries being sold/imported and also laid down a schedule for the buyback of the used batteries by various relevant stakeholders. The stakeholders are bound to submit half-yearly returns to the respective State Pollution Control Boards with details regarding their activities pertaining to lead–acid batteries during that period. There are gap areas in the existing policy and also in the implementation of these rules. The perception and needs of some of the stakeholder groups require better and due attention for formulating amendment to the existing rules. Still others need to be included under the purview of the rules [15].

Used lead–acid batteries (ULAB) form an important secondary source of lead, especially in countries, which are not otherwise rich in lead resources [3, 4]. Used lead–acid batteries must be properly stored so that the acid from those batteries does not spill or leak out and contaminate soils or water nearby [2, 9, 14]. The treatment of used lead–acid batteries for recovering lead is important from the point of view of lead production as well as pollution abatement, otherwise the battery scrap leads to serious disposal problems [5, 11, 12]. Lead poisoning is most common heavy metal poisoning that affects the workers handling the spent batteries by elevating their blood lead levels [10]. So, hygienic practices might, therefore, be a preferred way to reduce lead exposure at workplace [1]. The airborne lead concentration in developing countries like India is seven-fold greater than developed countries like United States [7].

Small-scale industries generate high levels of pollution and create problems to environment resulting in obstacle for sustainable development [13]. This is the case with lead–acid batteries in India, which are recycled mainly by small-scale smelting units operating in both the organized and unorganized sectors. A large number of backyard smelting units and recyclers are operating in India recovering lead from batteries in a crude manner, causing lead pollution in surrounding areas and affecting the health of workers [7]. So, the scope of the present study included the collection and documentation of baseline data regarding the handling and management of new and used lead–acid batteries. Determination of status of recycling of LAB and lead recovery from ULAB was also an important component of this work.

2 Methodology

Study Area: The study was carried out in Punjab, a northern state of India. Punjab is subdivided into 23 districts and this study includes only five distinct districts named Faridkot, Jalandhar, Ludhiana, Sangrur, and Mohali. The major stakeholders dealing with lead–acid batteries were mainly found in these districts of Punjab. As per 2011 census data, Faridkot has an area of 1458 km^2 with 0.62 million population, Jalandhar is spread over an area of 2632 km^2 and has 2.18 million population, Ludhiana is most populated district of Punjab with 3.48 million population over an area of 3767 km^2, Mohali has an area of 1092.64 km^2 with 0.98 million population and Sangrur spreads over 3685 km^2 with 1.65 million of population.

The different stakeholder groups that had been surveyed were identified from the Batteries (Management and Handling) Rules, 2001 amended in the year 2010. This included manufacturers, importers, recyclers, dealers, bulk consumers, reconditioners and auctioneers. After identification of the relevant stakeholders, the next step was to develop questionnaires for targeted stakeholder groups based on the returns filed to Punjab Pollution Control Board (PPCB). Since the problems faced by different stakeholders were varied and in many respect distinct from one another, so separate questionnaires were developed for collecting the information from these groups. These questionnaires covered various aspects related to management of lead–acid batteries like disposal of used batteries, quantitative and qualitative information, recycling of lead, management practices, public awareness, etc.

After identifying the stakeholder groups and developing the questionnaires, the survey of the relevant stakeholder groups was conducted in these five districts of Punjab from May 2016 to April 2017.

3 Results and Discussions

3.1 Movement of Lead–Acid Batteries During Its Life Cycle

Survey helped to outline the movement cycles of new lead–acid batteries, used/scrap batteries, and recycled lead in the lead–acid battery life cycle. These movements are shown in Figs. 1, 2, and 3 and dotted arrow indicates those exchanges where leakages into the informal sector were observed or probable.

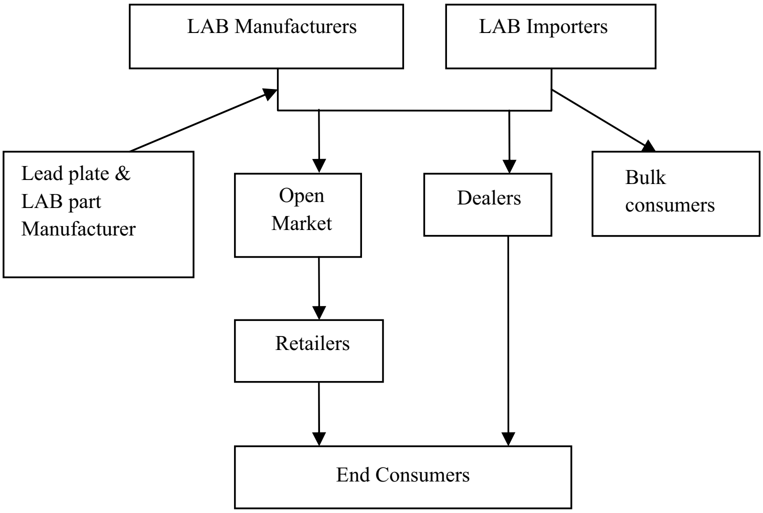

Fig. 1 Forward movement of new LAB’s

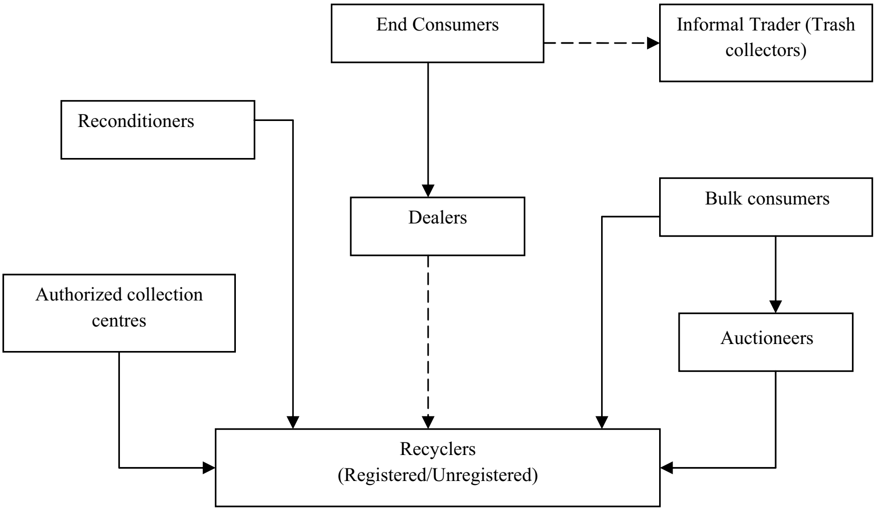

Fig. 2 Movement of scrap/used LABs

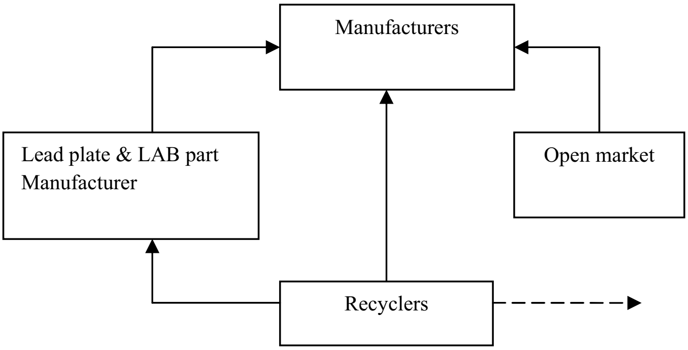

Fig. 3 Movement of recycled lead

3.2 Status of Various LAB Units/Stakeholders

During the survey, emphasis was laid on every stage of battery's life cycle, i.e., manufacturing, sale, use, recycle, and recovery of lead. The data collection was carried out in each of the five districts of Punjab. Identified manufacturers, dealers, bulk consumers, assemblers and recyclers were approached with a specific questionnaire for the collection of data in each of the five districts. The stakeholder wise distribution of the surveyed units or the sampling size for survey is shown in Table 1.

Some of the common observations about various stakeholders in the studied districts were:

a. Dealers accepted the used batteries from customers on the basis of Rupees 500–2000 per battery.
b. Only few redeemed batteries were sent back to the concerned company/brand of LAB with a lot of paperworks involved therein.

Table 1 Status of various LAB stakeholders in studied districts

S. No.	Name of unit	Faridkot	Jalandhar	Ludhiana	Mohali	Sangrur
1	Manufacturers	–	–	7	–	4
2	Importers	–	–	–	–	–
3	Bulk consumers	3	–	–	30	1
4	Dealers	50 R[a]–0 UR[b]–50	96 R–10 UR–86	308 R–66 UR–242	74 R–40 UR–34	56 R–20 UR–36
5	Registered recyclers	1	11	9	–	1
6	Assembler	–	–	–	–	–
7	Reconditioner	3	–	–	–	–

[a] R registered LAB dealers with PPCB
[b] UR unregistered LAB dealers

c. Instead, dealers preferred to send used LAB (ULAB) to unregistered recyclers, as they would offer more lucrative deal to dealers as compared to company rates. Almost negligible paperwork was found to be involved in this route of ULAB recycling.
d. It was also found that some dealers refused to accept the used batteries and they would suggest the customers to sale their batteries directly to unregistered recyclers.
e. The lead recovered by recyclers through recycling process is about 60% of the weight of battery.
f. While purchasing the used batteries, unregistered recyclers drain out the water and acid at the auction site and then according to the battery weight auction are performed. This practice of draining out the acid poses grave danger to humans and results in the pollution of the adjoining land.
g. Bulk consumers, like power plants, refineries, industrial units, etc. returned ULAB to their respective head of departments, where auction of these ULAB would be carried out twice or thrice a year and only registered recyclers were allowed to take part in auction.
h. It was also noticed that bulk consumers kept on storing the scrap batteries until a sufficient number of batteries were collected for carrying out auction. The storage of these scrap batteries often pose a serious environmental hazard as no proper storage mechanism is usually followed as shown in Fig. 4.

Fig. 4 Unsafe storage of scrap batteries

1. Faridkot District: Presently, there are total 50 dealers in Faridkot district. Out of which, not a single dealer was registered. There were only one registered recycler and no manufacturer, importer, and assembler were found in this district. There were three battery reconditioners present in the city but they were in the process of shifting their business because people prefer to get new battery instead of repairing an old one.

   Total sale of lead–acid batteries by dealers in the district of Faridkot in a year was estimated to be 10,714 in number and 180 MT by weight and ULAB collected by dealers are 7339 in number and 110 MT by weight. In contrast, only 10.5 MT ULAB reached to registered recyclers in a year from which 6.3 MT of lead was recovered and rest of ULAB was found to be going to unregistered recyclers as shown in Fig. 5. Out of the total batteries received for recycling, only 6% of batteries are recycled by registered recyclers (received from dealers) and 94% of batteries are recycled by unregistered recyclers (collecting 39% from consumers and 55% from dealers).
2. Jalandhar district: As per study, Jalandhar district had 96 dealers out of which only 10 dealers were found to registered with PPCB. 11 nos. of registered recyclers were also found to be operating from this district whereas no importer, bulk consumer, manufacturers, assembler, and reconditioner were located here. The total number of sale of lead–acid batteries from dealers in a year was around 1,00,579 in number and 1016 MT by weight. Whereas, 32,310 ULAB of 484 MT weight were collected back by dealers and registered recyclers were able to collect 387 MT of ULAB for recycling from which 227 MT lead was recovered as shown in Fig. 6. 38% of batteries collected are received by registered recyclers whereas 62% batteries are recycled by unregistered recyclers from which 52% ULAB is received from by consumers and 10% from dealers.
3. Ludhiana District: Ludhiana is the largest district among the studied areas, which spreads over an area of 3767 km^2. with 3.48 million population (as per 2011 census data). Ludhiana district had 308 dealers out of which only 66 dealers were registered with PPCB. Being the most populated and industrialized district of Punjab state, maximum number of manufacturers was also located in Ludhiana.

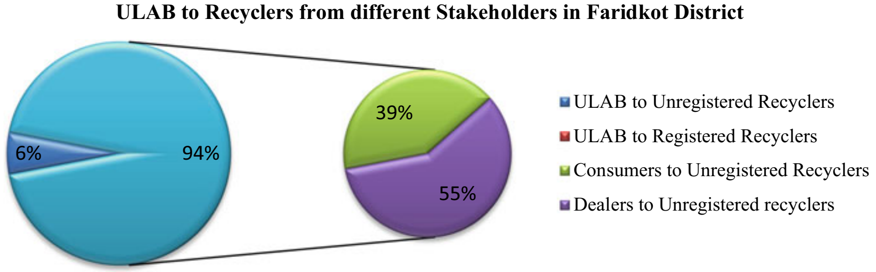

Fig. 5 Flow of LAB through different stakeholders in Faridkot District

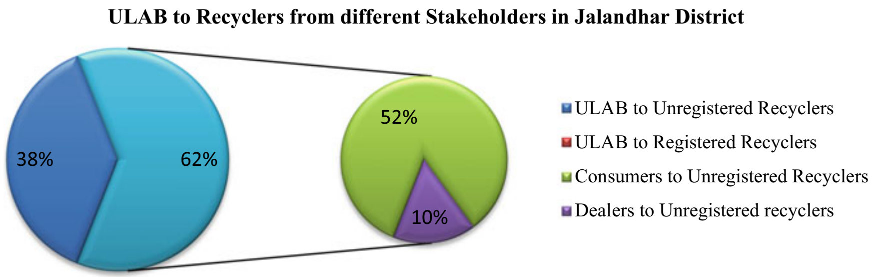

Fig. 6 Flow of LAB through different stakeholders in Jalandhar District

The lead–acid batteries sold by dealers in a year were around 2,72,857 in number and 4194 MT by weight and ULAB collected were 1,84,854 in number and 2772 MT by weight. Registered recyclers received 720 MT of ULAB for recycling and from these ULAB around 338 MT lead was recovered as shown in Fig. 7. ULAB received by registered recyclers is 17% on other hand 83% ULAB is received by unregistered recyclers (23% contributed by consumers and 50% contributed by dealers).

Visit to the recycling unit of an unregistered recycler revealed the uncontrolled smelting of lead (as shown in Fig. 8) thus creating great health risk to the persons involved due to the lead fumes.

4. Mohali district: Mohali district spreads over an area of 1092.64 km^2 with 0.98 million population (as per 2011 census data). Mohali district was found to have 94 dealers out of which 40 dealers were registered with PPCB. Due to the proximity of this district to the state capital, large number of bulk consumers (30 in number) was recorded in this district. These bulk consumers constituted industrial units, regional offices of telecom companies, head offices of government departments etc.

   The annual sale of lead–acid batteries from dealers was established at around 23,224 in number and 437 MT by weight. Whereas, 10,410 ULAB of 156 MT weight are collected back by dealers as shown in Fig. 9. There are no registered

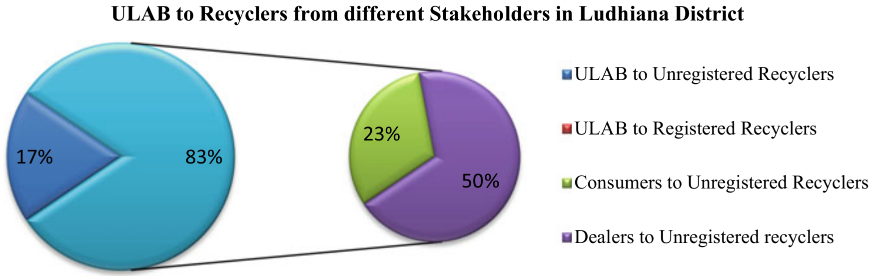

Fig. 7 Flow of LAB through different stakeholders in Ludhiana District

Fig. 8 Smelting unit of unregistered recycler in Ludhiana

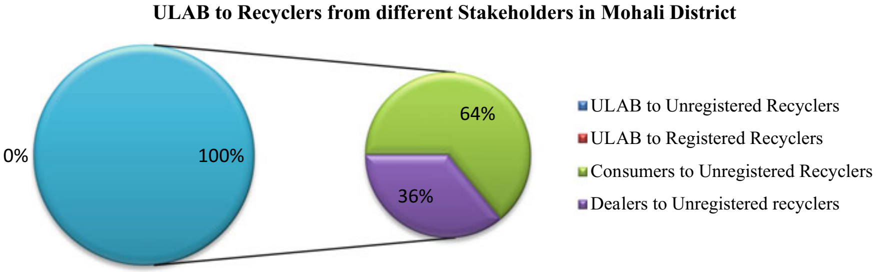

Fig. 9 Flow of LAB through different stakeholders in Mohali District

recyclers in city so all ULAB are sent to unregistered recyclers; 64% sent by consumers and 36% by dealers.

5. Sangrur District: Sangrur district had 56 dealers out of which only 20 dealers were found to be registered with PPCB, one registered recycler, four manufacturers, and one bulk consumer were also found to be located in this district. The lead–acid batteries sold by dealers annually were around 13,016 in number and 225 MT by weight and ULAB collected were 3035 in number and 45 MT by weight. Registered recycler of this district received only 25 MT of ULAB for recycling as shown in Fig. 10. ULAB collected by registered recyclers is only 11% whereas 89% of batteries are recycled by unregistered recyclers, among which 80% are received from consumers and 9% from dealers.

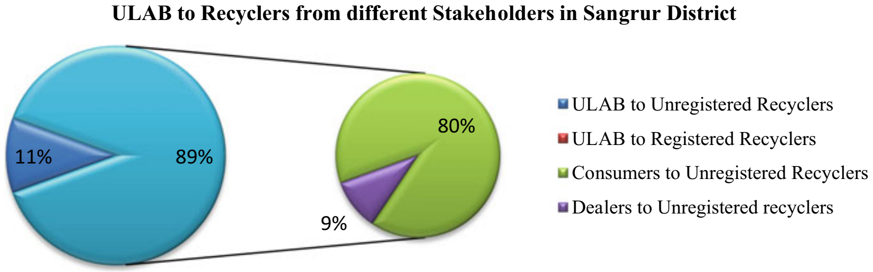

Fig. 10 Flow of LAB through different stakeholders in Sangrur District

4 Conclusions

Only 23% of the total identified dealers were found to be registered with PPCB in the studied five districts. The reason for non-registration of the dealers was the perception that it was not mandatory to get registered. Difficulty in understanding the formalities involved in the registration process due to their low level of education was also a major hurdle in the registration of dealers.

Among the surveyed districts, only Faridkot district was found to not having any registered dealers and which was the main reason that existing registered recyclers in the district were receiving the minimum, i.e., 5.8% of ULAB for recycling. Jalandhar district had maximum number of registered recyclers but still, only 38% of annual LAB sold by dealers was received by registered recyclers for recycling. The deep penetration of the unregistered recyclers in the recycling routes of the ULAB was found to be responsible for this pattern.

Out of total amount of LAB sold to consumers, 81% of ULAB were found to be diverted through the unregistered recyclers and there was no evidence of safe and sound recycling practices being adopted.

5 Compliance with Ethical Standards

Funding This study was funded by Punjab Pollution Control Board, Patiala (Punjab) vide letter no. EPA/2012/1834.

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval This chapter does not contain any studies with human participants or animals performed by any of the authors.

Informed Consent Informed consent was obtained from all individual participants included in the study.

References

1. Ahmed, K., Ayana, G., Engidawork, E.: Lead exposure study among workers in lead acid battery repair units of transport service enterprises, Addis Ababa, Ethiopia. J. Occup. Med. Toxicol. **3**, 30 (2008). https://doi.org/10.1186/1745-6673-3-30 PMCID: PMC2612669
2. Basel Convention series: Technical guidelines for the environmentally sound management of waste lead-acid batteries (2003)
3. Bode, H.: Lead-Acid Batteries. Wiley, New York (1997)
4. Cooper, A.: Research update from European advanced lead acid battery consortium. J. Power Sources, **88**, 53–70 (2000)
5. Dongjie, N.: Lead acid battery waste both from mining and other industry. 3rd Asia-Pacific Regional Workshop on Hazardous Waste Management in Mining Industry, APCHW, Beijing (2000)
6. Genaidy, A.M., Sequeira, R., Tolaymat, T., Kohler, J., Rinder, M.: An exploratory study of lead recovery in lead-acid battery lifecycle in US market: An evidence-based approach. Sci. Total Environ. **407**(1), 7–22 (2008)
7. Gottesfeld, P., Pokhrel, A.K.: Lead exposure in battery manufacturing and recycling in developing countries and among children in nearby communities. J. Occup. Environ. Hyg. **8**, 520–532 (2011)
8. Kannan, G., Devika, K.: A genetic algorithm approach for solving a closed loop supply chain model: a case of battery recycling. Appl. Math. Model. **34**, 655–670 (2010)
9. Keri, J., Precsko, J.: Development and use of a new system for environmentally clean recycling of lead battery scrap. J. Power Sources **53**, 297–302 (1995)
10. Mattle, T.A., et al.: Lead poisoning among household members exposed to lead acid battery repair shops in Kingston, Lamaica. Int. J. Epidermilogy **18**(4), 874–881 (1989)
11. Muller, R.: Lead supply and demand in the Western world, recent developments and outlook into the 1990s. In: Proceedings of 10th International Lead Conference Nice, France, Lead Development Association, London (1991)
12. Patrick, L.: Lead toxicity, a review of the literature. Altern. Med. Rev. **11**, 2–22 (2006)
13. Rabah, M.A., Barakat, M.A.: Energy saving and pollution control for short rotary furnace in secondary lead smelters. Renew. Energy. **23**, 561–577 (2001)
14. Rahangdale, R.V.: Waste management in lead-acid battery industry: a case study. World J. Appl. Environ. Chem. **1**, 7–12 (2012)
15. West Bengal Pollution Control Board: Status of Batteries Waste Management as per Batteries (Management & Handling) Rules in West Bengal (2012)

Assessment of Ferrous Slag with Relevance to Physico-chemical Properties

M. S. Anjali, M. Poorani, S. Shrihari and B. M. Sunil

Abstract Blast furnace slag is generated as a by-product in the production of iron. Large quantities of slag are visible in the industrial premises that can have adverse effects on the environment. To mitigate such problems, proper environmental management of slag is of great concern. In this regard, a qualitative and quantitative evaluation of ferrous slags such as crystallinity, surface morphology, and elemental composition were done using X-Ray Diffraction and Field Emission Scanning Electron Microscope with EDS (Energy Dispersive X-Ray Spectrometer), respectively. It is also characterized to determine heavy metals and functional groups using Atomic Absorption Spectroscopy and Fourier Transform Infrared Spectroscopy techniques for various geo-environmental applications. The non-plastic slag material showed 85–92% sand-size particles and 8–15% silt-size particles. The SiO_2 and CaO values were found to be high followed by Al_2O_3, MgO, and other compounds. Since slag performed similarly to sand, it could be used as an alternative source of sand.

Keywords Ferrous slag · Physico-chemical characteristics · Heavy metals

1 Introduction

During the manufacture of pig iron, huge quantities of slag are generated as a by-product worldwide [1–6]. The waste dumps of slag can be visible in and around the iron industry occupying large areas of land [6]. It needs to be cleared off from the locality as it affects depletion of natural resources such as land and water and ultimately in the deterioration of quality besides threatening the environment. The best waste management practice can prevent the problems of contamination of industrial wastes to a considerable extent. The reuse of industrial by-products is one

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of the waste minimization processes. Resource recycling is generally promoted to effectively utilize or reuse the slag [7, 8].

The potential utilization of slag lies in its effective reuse in place of naturally available materials. Hence, it is advisable to reuse slag in place of sand which faces a drastic situation as excessive sand mining results in environmental discrepancy and finally led to enforcing more stringent rules and regulations. In this regard, researches must be focussed to use an alternative material to river sand as both have comparable characteristics.

The technology of treating wastewater with wastes has already been established. Presently, blast furnace slag has found potential applications in the treatment of acid mine drainage, polluted sources of water, and wastewater which contain nutrients and heavy metals and hence it is not considered as a waste material. The physical and chemical composition of ferrous slag varies depending upon the places or sources of generation, the temperature at the time of water quenching and the process changes, different methods of operations, or the differences in methodologies involved [9].

The slag has found applications in landfills [5], drainage works and as a soil conditioner for the growth of both plants and microbes [10]. It can be used as a barrier material against leachate containing heavy metals. The ferrous slag has an important role in the treatment of wastewater. It is a good neutralizing agent against acidic soil [3] and therefore finds its application in the treatment of acid mine drainage. It could be used for remineralization and conditioning of soil such as liming agent and fertilizer [1, 3, 10–12]. It is reported that marine block made of ferrous slag could be used as decontaminant for both water and bottom sediment in the marine environment [3].

The primary objective of the present work is to assess ferrous slag with relevance to physico-chemical properties and its suitability for various environmental/geo-environmental engineering applications.

2 Materials and Methods

The granulated blast furnace slag was collected from Kirloskar Ferrous Industries Limited, Bevinahalli, Koppal District, Karnataka, India. Laboratory tests were conducted to find the suitability of slag for various geo-environmental applications. The geotechnical properties such as grain size analysis, specific gravity, and permeability experiments were performed according to Indian standards [13–15]. The pH was determined by mixing 3 g of slag sample with 75 ml distilled water. The suspension was stirred and allowed to stand for 1 h and the average pH of the samples was found [16]. The chemical composition of slags such as silica, alumina, ferric oxide, and calcium oxide were also analyzed [17].

The granulated slag was ground, powdered, and sieved through 105 μ sieve. The sample less than 105-micon sieve was then subjected to various analyses. The X-ray diffraction spectrum of powdered, granulated slag samples were done using X-Ray

Diffractometer (JEOL DX GE-2P, Japan) with CuK_α (λ = 1.514Å) radiation at an accelerating voltage of 30 kV, 20 mA in the scan range of 2θ = 20°–90° at a speed of 2°/min. The surface morphology and microstructure were visualized along with the major elemental chemical composition mass percentage using Field Emission Scanning Electron Microscope with Energy Dispersive X-Ray Spectrometer (ZEISS Sigma 300). The functional groups are determined using Fourier Transform Infrared Spectroscopy technique (Bruka Alpha II).

The presence of heavy metals in blast furnace slag such as lead, cadmium, chromium, copper, manganese, and zinc was analyzed by acid digestion method using Atomic Absorption Spectroscopy (GBC 932 Plus). The batch leaching with distilled water and toxicity characteristic leaching procedure was performed to determine the release of these metals into the leachate. For the distilled water leaching test, 5 g sample was mixed with 25 ml distilled water and was shaken in a rotary shaker for 24 h. For the TCLP test, 4 g sample was mixed with 20 times extraction fluid, 1M sodium acetate buffer and shaken in a rotary shaker for 18 h with 30 ± 2 rpm [18–20]. The leachate was then filtered using 42 No filter paper, diluted to 100 ml, and analyzed for various heavy metals.

3 Results and Discussion

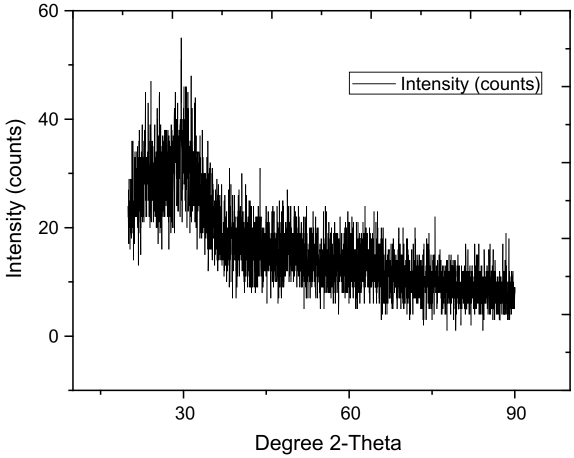
The results of dry sieve analysis showed that sand-size and silt-size particles were in the range of 85–92% and 8–15%, respectively. This result is similar to the values reported in the literature wherein the percentage of medium sand (0.425–0.85 mm) was high and silt-clay particles were 2.10% [7]. The effective size D_{60} was 1.5 and uniformity coefficient was 5.56. The physicochemical properties are listed in Table 1.

The average pH of the samples was found to be 9. The pH of the media reported by Kietlińska and Renman [21] was 9.13, but high values ranging from 9.7–12.2 were also observed due to the dissolution of Ca^{2+} content of the slag into the solution [3, 7, 22]. It is an important parameter since phosphorus removal is dependent on strong alkaline conditions and large amounts of soluble calcium [11].

Table 1 Physicochemical properties of slag

Properties	Value
Specific gravity	1.65
Permeability	2.63×10^{-4} cm/s
pH	9.0
SiO_2	30–34%
Al_2O_3	18–22%
Fe_2O_3	0.5–0.6%
CaO	30–34%

Fig. 1 XRD spectrum of blast furnace slag

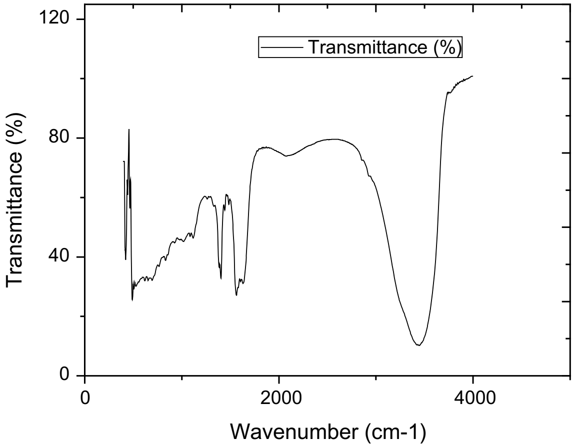


The average values of CaO and SiO_2 values of the slag were found to be in the range prescribed by Lewis [10], Hedström and Rastas [23], and Hallberg and Renman [24]. The Al_2O_3 values were found to be higher than that mentioned by Dimitrova and Mehenjeiv [25], Kietlińska and Renman [21], Lu et al. [22], Johansson [26] and the levels of Fe_2O_3 were nearest to the results of Hizon-Fradejas et al. [7], and Hallberg and Renman [24].

The irregular X-ray diffraction spectra of granulated slag represented its amorphous nature since no significant peaks were found as shown in Fig. 1. It is in agreement with other results [8, 25, 27, 28].

The FTIR spectrum is shown in Fig. 2. It indicates that the O–H group was present around 3400–3500 cm^{-1}. The bands at 1630 cm^{-1} and 1562 cm^{-1} might be attributed to O–O–H groups. The bands at 1630 cm^{-1} represented C–O groups [29]. The bands at 3464 cm^{-1} and 1635 cm^{-1} indicated the presence of adsorbed

Fig. 2 FTIR spectrum



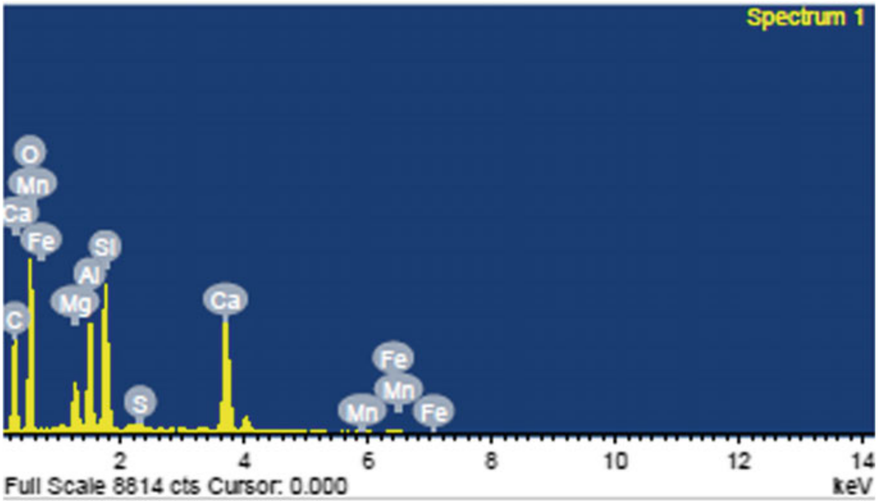


Fig. 3 Elemental composition of slag

water whereas 860–1450 cm^{-1} due to Si–O–Si groups [28]. The bands around 1100 cm^{-1} and 760 cm^{-1} in the figure showed polymorphs of SiO_2. The wavenumber 619 cm^{-1} and 488 cm^{-1} might be due to Fe–O groups.

The SEM images of the slag showed the highly porous texture of slag which indicates its use as an adsorbent. The elemental composition and SEM images at different magnifications are depicted in Figs. 3 and 4.

Figure 5 shows the mean values of heavy metals in acid digestion test (ADT), distilled water leaching test (DWLT), and toxicity characteristic leaching procedure (TCLP). Even though the slag samples contain heavy metals, the leaching of metals from the sample was less particularly in DWLT compared to TCLP, which is depicted in the figure. In the present study, the TCLP conducted at acidic pH indicated a higher concentration of elements in the leachate compared to the DWLT operated at the neutral condition. The test results of blast furnace slag reported by Kietlińska and Renman [21] for Cr, Cu, and Zn were 46.4 ppm, 10.5 ppm, and 87.1 ppm, respectively. Hizon-Fradejas et al. [7] obtained low values for Zn, Cu, Cr, and Cd in leaching test as 0.103 mg/L, 0.013 mg/L, 0.006 mg/L, and 0.003 mg/L, respectively. The ASTM water leachate test result reported by Proctor et al. [1] showed 0.0038 mg/L for Cr, 0.0014 mg/L for Mn, and nil for Cd. The present study showed about 1, 5, and 7% increase in the concentrations of Cu, Zn, and Pb from the reported data. The TCLP test results indicated 1 and 1.8% increase in Cr and Cd concentrations whereas 8% decrease in Zn concentration from the reported study. The variation might be due to the pH difference between the extraction liquids and the leachate as pointed out by Tiwari et al. [20]. It is reported that iron slag might be used safely in aquatic systems without deteriorating water quality [5].

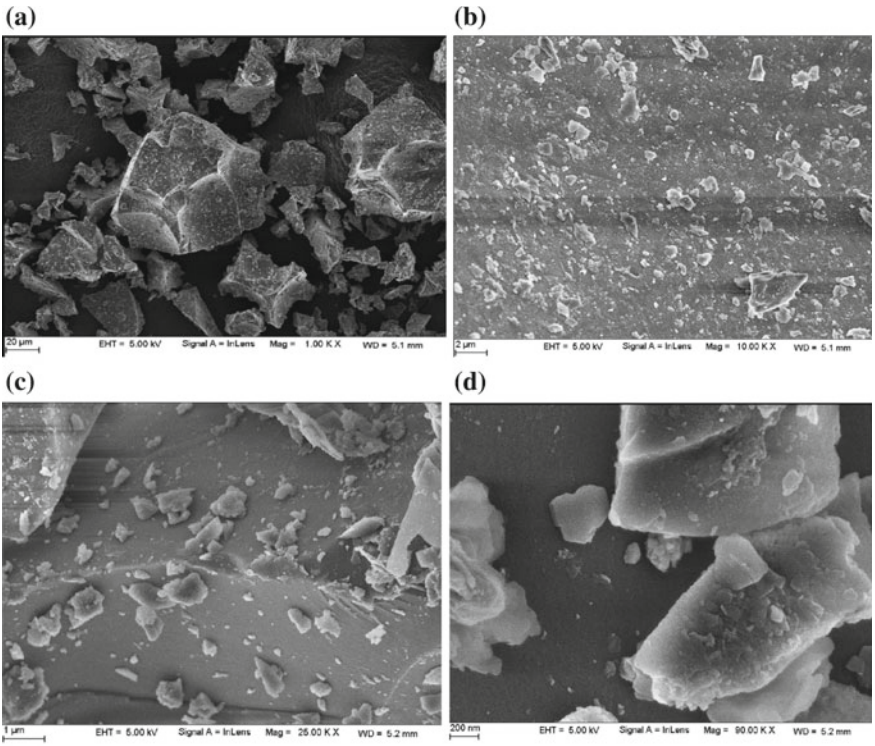
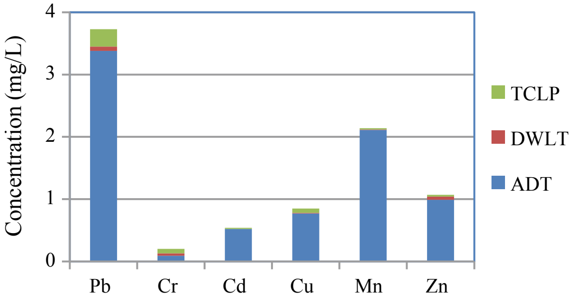


Fig. 4 SEM images of slag at **a** 1KX **b** 10 KX **c** 25KX and **d** 90KX

Fig. 5 Mean values of heavy metals



4 Conclusion

The assessment of slag is necessary to find its potential for multiple uses in the field of geo-environment to counteract the problems associated with its disposal. The analysis shows that it is mainly composed of silica, calcium oxide, alumina, and magnesium oxide with a little amount of iron. The presence of calcium oxide increases the pH value and hence it could be employed in extensive applications in wastewater treatment especially for acidic wastes, phosphorus removal, etc. The highly porous texture increases its absorption rate and could be used in the construction of wetlands and as barrier and liner material in landfill sites. The leachate analysis of slag shows that heavy metals are not likely to be released from the slag in distilled water during the batch test. Conversely, it is to be proved that slag could be used for liquid wastes containing heavy metals.

References

1. Proctor, D.M., Fehling, K.A., Shay, E.C., Wittenborn, J.L., Green, J.J., Avent, C., Bigham, R. D., Connolly, M., Lee, B., Shepker, T.O., Zak, M.A.: Physical and chemical characteristics of blast furnace, basic oxygen furnace, and electric arc furnace steel industry slags. Environ. Sci. Technol. **34**(8), 1576–1582 (2000)
2. Johansson Westholm, L.: The use of blast furnace slag for removal of phosphorus from wastewater in Sweden—a review. Water **2**(4), 826–837 (2010)
3. Isawa, T.: Update of iron and steel slag in Japan and current developments for valorisation. In: Malfliet, A., et al. (ed.), 3rd International Slag Valorisation Symposium, pp. 87–98. Leuven, Belgium (March 2013)
4. Li, G., Guo, M.: Current development of slag valorisation in China. Waste Biomass Valorization **5**(3), 317–325 (2014)
5. Indian Minerals Yearbook 2012 (Part- II: Metals & Alloys). Slag- Iron and Steel (Final Release), 51st edn. The government of India, Ministry of Mines, Indian Bureau of Mines (January 2014)
6. Lim, J.W., Chew, L.H., Choong, T.S., Tezara, C., Yazdi, M.H.: Overview of steel slag application and utilization. In: MATEC Web of Conferences, vol. 74, p. 00026. EDP Sciences (2016)
7. Hizon-Fradejas, A.B., Nakano, Y., Nakai, S., Nishijima, W., Okada, M.: Evaluation of blast furnace slag as basal media for eelgrass bed. J. Hazard. Mater. **166**(2), 1560–1566 (2009)
8. Gong, G., Ye, S., Tian, Y., Wang, Q., Ni, J., Chen, Y.: Preparation of a new sorbent with hydrated lime and blast furnace slag for phosphorus removal from aqueous solution. J. Hazard. Mater. **166**(2), 714–719 (2009)
9. Korkusuz, E.A., Beklioğlu, M., Demirer, G.N.: Use of blast furnace granulated slag as a substrate in vertical flow reed beds: field application. Bioresour. Technol. **98**(11), 2089–2101 (2007)
10. Lewis, D.W.: Properties and uses of iron and steel slags. National slag association report MF 182-6. Presentation at a Symposium on Slag, South Africa (1982)
11. Johansson, L., Gustafsson, J.P.: Phosphate removal using blast furnace slags and Opoka-mechanisms. Water Res. **34**(1), 259–265 (2000)
12. Kalyoncu, R.S.: Slag–iron and steel. US geological survey minerals yearbook (2001)
13. IS: 2720 (Part 3) 1980 (Reaffirmed 2002) Method of test for soils—Determination of Specific gravity
14. IS: 2720 (Part-4) 1985 (Reaffirmed 2006) Indian standard methods of test for soils—Grain size analysis
15. IS: 2720 (Part 17) 1986 (Reaffirmed 2002) Method of test for soils—Laboratory determination of permeability
16. IS: 2720 (Part 26) 1987 (Reaffirmed 2002) Method of test for soils—Determination of pH value

17. IS: 1727-1967 (Reaffirmed 2004) Silica, alumina, ferric oxide, calcium oxide and magnesium oxide
18. Usepa, U.: EPA Method 1311-Toxicity Characteristic Leaching Procedure. The United States Environmental Protection Agency, Washington, DC (1992)
19. Sarode, D.B., Jadhav, R.N., Khatik, V.A., Ingle, S.T., Attarde, S.B.: Extraction and leaching of heavy metals from thermal power plant fly ash and its admixtures. Polish J. of Environ. Stud. **19**(6), 1325–1330 (2010)
20. Tiwari, M.K., Bajpai, S., Dewangan, U.K., Tamrakar, R.K.: Suitability of leaching test methods for fly ash and slag: a review. J. Radiat. Res. Appl. Sci. **8**(4), 523–537 (2015)
21. Kietlińska, A., Renman, G.: An evaluation of reactive filter media for treating landfill leachate. Chemosphere **61**(7), 933–940 (2005)
22. Lu, S.G., Bai, S.Q., Shan, H.D.: Mechanisms of phosphate removal from aqueous solution by blast furnace slag and steel furnace slag. J. Zhejiang Univ.-Sci. A **9**(1), 125–132 (2008)
23. Hedström, A., Rastas, L.: Methodological aspects of using blast furnace slag for wastewater phosphorus removal. J. Environ. Eng. **132**(11), 1431–1438 (2006)
24. Hallberg, M., Renman, G.: Removal of heavy metals from road runoff by filtration in granular slag columns. In: Proceedings of the 11th International Conference on Urban Drainage. Edinburgh, Scotland, UK (2008)
25. Dimitrova, S.V., Mehanjiev, D.R.: Interaction of blast-furnace slag with heavy metal ions in water solutions. Water Res. **34**(6), 1957–1961 (2000)
26. Johansson, L.: Industrial by-products and natural substrata as phosphorus sorbents. Environ. Technol. **20**(3), 309–316 (1999)
27. Chiang, Y.W., Santos, R.M., Elsen, J., Meesschaert, B., Martens, J.A., Van Gerven, T.: Towards zero-waste mineral carbon sequestration via two-way valorization of ironmaking slag. Chem. Eng. J. **249**, 260–269 (2014)
28. Hongo, T.: Synthesis and identification of Allophane from waste blast furnace slag. ISIJ Int. **55**(12), 2700–2702 (2015)
29. https://www.utdallas.edu/~scortes/ochem/OChem_Lab1/recit_notes/ir_presentation.pdf

Analysis of E-Waste Ceramics as a Fine Aggregate for Rigid Pavements for Replacement of M-Sand and River Sand

B. R. Vinod, Rajesh Gopinath, Suhas Prasad, H. M. Kavitha, Mukund Mohta and Ahan Ganapathy

Abstract The present research deals with feasibility analysis of complete replacement of fine aggregates by E-waste ceramics in the rigid pavement as per IRC 58:2002. The specimens were cast and cured for 7th and 28th days and subjected to standard tests for comparison of effectiveness of E-waste Ceramics as fine aggregate instead of River Sand and M-Sand. From the laboratory studies, it was concluded that the maximum replacement by E-waste Ceramics in rigid pavement without compromising on safety and stability requirements was achieved as 100%. The cost analysis projected a saving of INR 5,50,000 per km for rigid pavements constructions with the application of 100% ceramics. This accounts fro savings of about 20–23% of total investment for utilizing Sand as fine aggregate in road construction projects. The study has successfully introduced depreciation in construction costs and also invariably leads to protection and restoration of the riverine ecosystems.

Keywords Aggregates · Pavement · E-waste ceramics · Rigid · Landfills

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1 Introduction

Rapid and rampant urbanization is expected to enhance the world urban population exponentially. To cater this demand, there is a necessity to construct more roads and improve road connectivity in the coming years [1]. River Sand as a fine aggregate is one of the major ingredients for rigid pavement construction as it accounts for 30–35% of the volume of concrete used in road infrastructure projects [2]. As urbanization and globalization are inevitable, so is the demand for River Sand which is by far the best for this form in construction industry [3]. As need for fine aggregates in preparing concrete is unavoidable and increasing day by day, the River Sand cannot suffice to meet the rising demand. The manufacturing of every single ton of cement necessitates about 6–7 times more tons of sand [4]. This has invariably led it to brink of extinction owing to rampant and illegal mining.

As an outcome of this demand, excessive River Sand mining leads to severe environmental problems such as destruction of riparian habitat, degradation and coarsening of streambed along with lowering of water table near it, and change in flow velocity and discharge velocity [5]. To overcome these, several studies have explored an alternative solution without compromising the stability requisites in roads as a dynamic load bearings structure in the form of ceramics [6–8] and E-waste plastics [9–11]. However these are far from being effective as complete replacement to River Sand; and hence this has led the construction industry to focus on other forms such as M-Sand, which also has issues such as blasting of quarry's, workability, and larger proportion of microfines, leading to graver impacts on environment including exhausting of water resources [12].

The present study strives to overcome these dire environmental consequences by attempting to utilize E-waste ceramics as an effective and sustainable solution. E-waste ceramics is a form of E-waste (Fig. 1) which by definition is any "obsolete or discarded Electronic or Electrical equipment" [13], and arises from both the public and private sectors [14]. Unfortunately, the existing E-waste recycling process is highly underdeveloped, causing widespread injury to both the natural

Fig. 1 E-wastes (*Source* Google)

Fig. 2 E-waste ceramics

environment and its various lifeforms [15]. With respect to the Indian context, though the rules and guidelines have been notified by the MoEF&CC in 2011 [16], yet millions tons of E-wastes Ceramics (Fig. 2) which unlike other E-wastes are nonrecyclable and nonbiodegradable is finding its way into the municipal landfills [13]. E-waste Ceramics are actually known as Ferrites in the industrial terms. These are generally used by the electric industries in the manufacturing of insulators, transformers, various microwave components and magnetic industries in the manufacturing of loudspeakers, refrigerators, and small electric motors [17, 18].

2 Scope of Present Study

There are no current researches that innovate the application of Electronic waste ceramics to replace fine aggregates, except a few which advents the application of E-waste ceramics as coarse aggregates in Bituminous Concrete Grade-1 Mix [17] and in Semi-Dense Bituminous Concrete Grade-2 Mix [18]. The key objectives of the present study include examining the feasibility for complete replacement of River Sand and M-Sand with E-waste Ceramics as fine aggregate, thereby also proposing an environmentally safe utilization and disposal technique for E-waste ceramics w.r.t. E-waste Management. While doing so, the research aims to develop low-cost rigid pavement by introducing depreciation in cost of road construction, via, ascertainment of financial viability, cost-benefit analysis, and cost comparison with respect to life cycle analysis.

3 Experimental Methodology

The raw materials used for this study included E-waste Ceramics, River Sand, M-Sand, cement, and coarse aggregates. E-waste Ceramics was procured from ER3 Solutions in its raw state, and subsequently crushed (Fig. 3) so as to pass through the standard IS 4.75 mm sieve as per IS 383:1970 [19]. It was then subjected to tests for Specific Gravity, Bulking, Bulk Density, and Particle Size Distribution. River Sand and M-Sand which were used as fine aggregates in control specimens were also subjected to these tests to ascertain the suitability as per IS 383:1970 [19].

OPC 53 Grade of cement was used for the study. The coarse aggregates employed for this research had a size of 20 mm, and its crushed shape was angular. While the concrete mix design was calculated with outcome in adherence to IS 10262:2009 [20]; the M35 grade concrete, water–cement ratio, and slump were chosen in accordance with IRC 15:2011 [21]. Further, standard triplicate specimens for E-waste ceramics and the two “controls” of size 150 × 150 × 150 mm were cast using the mix design in adherence to IS 456:2000 [22].

Upon curing, all the cubes were subjected to compression test in a C.T.M. (Compression Test Machine) as depicted in Fig. 4, and its results were compared with that of the control specimen. Further, Standard triplicate cylindrical specimens for E-waste ceramics and the two “controls” having height of 300 mm and diameter of 150 mm as specified by IS 456:2000 were cast according to the derived mix design [22]. Upon curing, all these cylinders were subjected to Split Tensile Test in a C.T.M. (Fig. 5) and their results were compared.

Further, Standard triplicate specimens for E-waste ceramics and the two “controls” were cast as per computed concrete mix design in accordance with IS 456:2000 [22]. The Flexure test was then carried out in C.T.M. upon curing for the flexure beams; for all these specimens. Figures 6 and 7 showcases the photographs of random specimens cast and their curing, respectively.

Fig. 3 Crushed E-waste ceramics

Fig. 4 Compression test machine

Fig. 5 Split tensile test

Fig. 6 Casting of specimens

Fig. 7 Curing of specimens

Finally, Life Cycle Analysis was accomplished with methodology as adopted by Indian Govt. in “Pradhan Mantri Gram Sadak Yojna” [22]. The economics analysis methods used commonly for this purpose includes present worth, annualized cost and rate of return [23]. The inputs as part of the computations were assessed based on the present market rates, inflation rate and newly incepted G.S.T. [24]. The determination of the initial cost of construction and maintenance cost for the design period of 20 years formed the crux of the computation. To conclude, Cost-benefit analysis was conducted for soliciting rigid pavement with E-waste ceramics over River Sand and M-Sand.

4 Results and Discussions

The concrete mix design was obtained as Coarse Aggregate 1159 kg/m^3, Fine Aggregate 679 kg/m^3, Cement 414 kg/m^3 and Water–Cement Ratio 0.45. The overall ratio is therefore 1:1.62:2.75 (Cement: Fine Aggregate: Coarse Aggregate). Results of Basic Tests on Fine Aggregates conducted in adherence to IS 383:1970 [19] is showcased in Table 1.

As can be observed, the Specific Gravity of E-waste Ceramics was found to be greater than both River Sand and M-Sand; due to probable presence of heavy metals thereby indicating the possibility of producing a higher density concrete. This means that E-waste Ceramics is 3.4 times heavier than water. Therefore usage of E-waste Ceramics will result in high strength concrete than control specimen.

Table 1 Results of basic tests on fine aggregates

Parameters (Unit)	E-waste ceramics	River Sand	M-Sand
Specific Gravity	03.40	02.67	02.63
Bulk Density (kN/m^3)	28.75	14.50	15.10
Bulking (%)	03.00	16.17	19.26

Comparatively, River Sand and M-Sand have lesser specific gravity; and therefore they shall contribute to a less dense concrete with low compression strength. The Bulk Density of E-waste Ceramics of 2933.33 kg/m^3 was higher than the typical range of River Sand (1600–2100 kg/m^3) and of M-Sand (1500–1700 kg/m^3). As in, this has no direct effect but has an indirect effect on drying shrinkage, thereby potentially aiding in production of high density concrete [25]. The results for Bulking Test indicate non-bulking in case of E-waste Ceramics, while for River Sand and M-Sand bulk, it is about 16–19%. Therefore application of E-waste ceramics enhances the durability of the concrete, since volume increase upon contact with the water weakens strength of concrete [25].

Results for Characteristics and Tests on Concrete under standard conditions as per IS 10262:2009 for the specimens casted with computed mix design is discussed herewith [20]. The Density characteristic for specimen with E-waste ceramics, River Sand and M-Sand is 2773.34 kg/m^3, 2411.86 kg/m^3 and 2340.75 kg/m^3 respectively.

Greater the density, higher is its resistance to cracking; and better is its protection from harsh external environments, and concrete becomes more impermeable thereby making it more durable. Denser concrete has the attributes of more impermeability, less crack formation, greater resistance to harsh external environmental conditions, better compression, tensile and flexure strength [20].

From Fig. 8, it is evident that 7th day Compression Strength was greater in specimen with E-waste ceramic, than in specimens with River Sand and M-Sand respectively; thereby resulting in dense concrete. It can be observed that the 7th day strength achieved by E-waste ceramics cube is much higher than the design strength and hence it can be opened for traffic at an early stage itself upon its laying. Since 7th day compression strength results determines the early age characteristics of concrete and suitability of concrete, E-waste Ceramics shows much higher strength

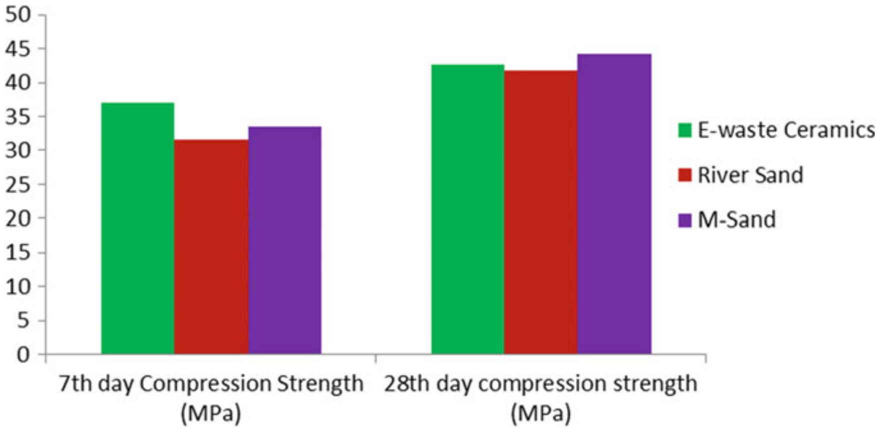

Fig. 8 Comparison of compression strength on 7th and 28th day

Fig. 9 Failure of tensile specimen

than the other two control specimens, thereby indicating its greater suitability in paving roads.

One of the major parameters that defines the durability of the road is the ultimate strength of concrete i.e., 28th day compression strength. In this context, the Compression Strength with E-waste Ceramics is greater than that with River Sand; and relatively lesser than that with M-Sand. However, as the target strength achieved under proper laboratory conditions is 43.25 MPa and is well above the design strength (35 MPa); therefore it is considered to be suitable. Hence resultant concrete is superior, and most suitable for road construction. Failure of a tensile specimen with E-waste ceramic under split tensile strength upon loading in a C.T.M. is depicted in Fig. 9.

As evident from Fig. 11, the 7th day Tensile strength is only slightly higher in specimen with E-waste ceramics than River Sand and M-Sand due to the initial internal bonding between the aggregates. But, for the 28th day the specimen with E-waste Ceramic has much greater tensile strength than other two control specimens, therefore it's proved that it possesses more cracking resistance to concrete, than the specimens with River Sand and M-Sand.

Figure 10 shows the failure of Flexure Beams of concrete specimens with E-waste ceramic upon application of two point loads. The Flexural strength of concrete mainly determines the bending strength of roads due to vehicular loads, and therefore is a very important factor in the design of pavements. The 28th day flexural strength of concrete with E-waste ceramics was found to be greater than the other two control specimens as can be observed in Fig. 12. Hence this surpasses the requirement of minimal flexure strength of 4.5 MPa stipulated by IRC: 15-2011 [21]. Hence, specimen with E-waste Ceramics has better bending strength upon construction of roads [26].

The Results of life cycle analysis is most sensitive to the factors of inflation, discount rate, and analysis period. The statistical findings have been presented in Table 2. The initial cost of flexible pavements is lower than that of rigid pavements with E-waste Ceramic, River Sand, and M-Sand. However, rigid pavement with E-waste Ceramics; in the long run (inclusive of maintenance costs and

Fig. 10 Failure of flexure beam

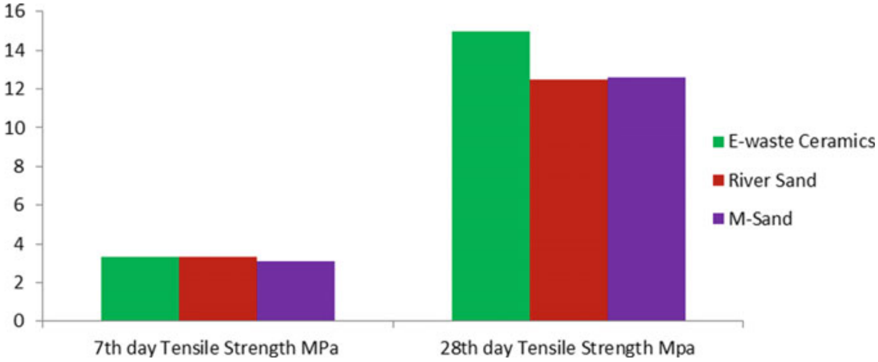

Fig. 11 Comparison of tensile strength on 7th and 28th day

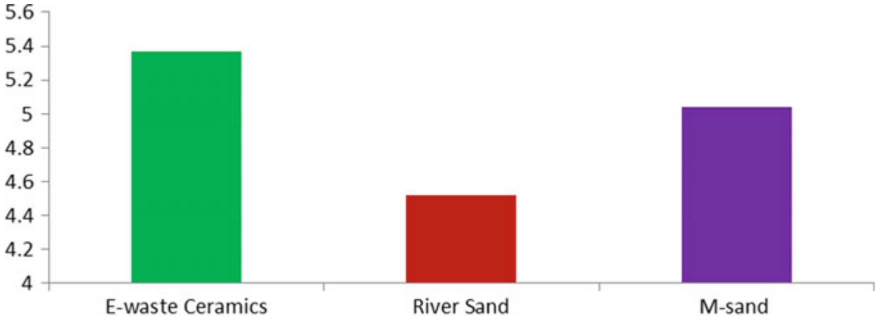

Fig. 12 Comparison of flexural strength on 7th and 28th day

Table 2 Summary of initial and life cycle cost

Pavement type	Initial cost (Lakhs/km)	Life cycle analysis (construction & maintenance cost (Lakhs/km))
Flexible pavement	21.0	33.6
Rigid pavement with E-waste ceramics	25.5	26.8
Rigid pavement with River Sand	27.0	28.3
Rigid pavement with M-Sand	27.5	28.8

environmental remediation costs) is the most economical of all forms of pavement construction. Also with the increase in the rate of urbanization, infrastructure development has been on the rise. As per five-year plans, India has a road network of 5,472,144 km as of March 31, 2015 [27], and there are plans of adding another 66,117 km in the forthcoming years [28]. The raw materials required for the construction of this quantum of roads are therefore immense and the total requirement of sand for the road infrastructure shall be about 114 million tons. While the cost of laying a rigid pavement with river sand amounts to about 27 lakhs/km, cost of sand alone accounts for 5.5 lakhs/km. The quantity of sand safeguarded from construction of 1 km four-lane highway is 285 tons (760 cum) upon 100% replacement with E-waste Ceramics. Therefore replacement by E-waste Ceramics saves at least 20–23% of the net cost of laying roads. This demand can be easily met with the 7200 tons produced annually by two Indian firms alone. However, as evident from the sparsely available literature, there is no direct data available with respect to wholesome generation rate of ferrites due to lack of proper policy in place. The successful outcome of this research, therefore, mandates framing of policies toward generation, disposal, reuse, and recycling of E-waste Ceramics.

5 Future Scope of Study

There are various types of E-waste ceramics specimens available and its effect on concrete has to be studied. The effect of E-waste ceramics concrete specimen has to be studied on various environmental attributes.

6 Summary

With the increase in the rate of urbanization, roadways development has been on a steady rise. With the exhaustion of natural resources due to excessive sand mining in rivers and hillocks, the availability of fine aggregate is becoming scarce and costly. The present study achieves the development of a low-cost rigid pavement by replacing M-Sand and River Sand with 100% E-waste ceramics as fine aggregates. The 7th day compressive strength with E-waste Ceramics specimen was more than that with M-Sand and River Sand specimen. Also, while the 28th day Compression Strength was more with E-waste Ceramics than that with River Sand specimen; it was relatively lesser for specimen with M-Sand. The 28th day tensile strength of E-waste Ceramics specimen was more than that of both M-Sand and River Sand specimens. The same can be confirmed for 28th day flexure strength, thereby surpassing the requirement of minimal flexure strength of 4.5 MPa as stipulated by IRC 015. These laboratory scaled findings hence ensure stability and safety upon replacement of with E-waste ceramics. Inadvertently, this research also resolves environmental hazards associated with disposal of nonbiodegradable E-waste ceramics into municipal landfills and health hazards from illegal irresponsible recycling.

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Bibliography

1. Gopinath, R., Lokesh, Y., et al.: Real-time noise-violation mapping from road-traffic network for entire Bangalore city. Bull. Civ. Eng. **60**(1), 177–181 (2017)
2. Sustainable Sand Mining Management Guidelines. http://pib.nic.in/newsite/PrintRelease.aspx?relid=155423
3. Gopinath, R., Vinod, B.R.: E-Waste ceramics can replace river sand & M-sand in road construction. Evening Today-Bangalore Edn. **1**(8), 4 (25 Sept 2018)
4. Strategy on Resource Efficiency—NITI Aayog. https://www.niti.gov.in/writereaddata/files/document_publication/
5. UNEP—The environmental impact of sand mining. http://threeissues.sdsu.edu/three_issues_sandminingfacts01.html
6. Zimbili, O., Salim, W., Ndambuki, M.: A review on the usage of ceramic wastes in concrete production. Int. J. Civ., Environ., Struct., Constr. Arch. Eng. **8**(1), 91–95 (2014)
7. Siddesha, H.: Experimental studies on the effect of ceramic fine aggregate on the strength properties of concrete. Int. J. Adv. Eng., Sci. Technol. **1**(1), 71–76 (2011)
8. Hitesh, K., et al.: Durability of concrete with ceramic waste as fine aggregate replacement. Int. J. Eng. Tech. Res. **3**(8), 196–199 (2015)
9. Suchithra, S., Manoj, K., Indu, V.S.: Study on replacement of coarse aggregate by E-waste in concrete. Int. J. Tech. Res. Appl. **3**(4), 266–270 (2015)
10. Harish, M., Aravind, S.B.: An experimental laboratory study on utilisation of E-waste as a partial replacement of fine aggregates in concrete. Int. J. Res. Eng. Technol. **5**(8), 100–108 (2016)
11. Bharat, D., Devansh, J., Gyanendra, S.: Utilization of E-waste as a partial replacement of coarse aggregate in concrete. Int. J. Sci. Res. Dev. **3**(11), 6–9 (2016)

12. Construction Building Materials Suppliers in Bangalore. https://materialtree.blogspot.com/2016/ (2016)
13. Lundgren, L.: The global impact of E-waste: addressing the challenge by Karin Lundgren, pp. 1–72. International Labour Office. ISBN 978-92-2-126897-0 (2012)
14. E-Waste In India—Rajya Sabha. http://rajyasabha.nic.in/rsnew/publication_electronic/E-waste_in_india.pdf
15. E-waste, toxic link, Factsheet E-waste, Number 31, pp. 1–6 (2007)
16. E-waste Management Rules. Government of India Ministry of Environment, Forestry and Climate Change, 23 Mar 2016
17. Gopinath, R., Lokesh, Y., et al.: Study on strength and physical properties of bituminous concrete grade-1 mix with E-waste ceramics as replacement to aggregates. Sci. Isr.-Tech. Advant.S **17**(4), 184–188 (2015)
18. Gopinath, R., Lokesh, Y., et al.: A study on the effective management of E-waste ceramic by its utilization as a replacement to aggregates in SDBC grade-2 mix. Int. J. Innov. Appl. Stud. **7**(3), 981–984 (2014)
19. IS 383:1970, Specification for Coarse and Fine Aggregates from Natural Sources for Concrete (R2011)
20. IS 10262:2009, IS Guidelines for concrete mix design proportioning (2009)
21. IRC 015:2011, Standard Specifications and Code of Practice for Construction of Concrete Roads (2011)
22. IS 456:2000, Plain and Reinforced Concrete—Code of Practice (2000)
23. Grameen Sampark—Pradhan Mantri Gram Sadak Yojna. http://pmgsy.nic.in/downloads/10janjun06_eng.pdf
24. Akhai, M., Mohammed, S., et al.: Life cycle cost analysis of road pavements in rural areas. Int. J. Sci. Technol. Manag. **5**(8), 260–267 (2016)
25. Schedule of Rates for the year 2016–17 Govt. order No. WRD 282 KBN 2015, Bangalore, 22 Dec 2015
26. IRC 37:2012, Guidelines for the Design of Flexible Pavements, 3rd Rev. (2012)
27. National Cent Indian road network—Wikipedia. https://en.wikipedia.org/wiki/Indian_road_network
28. Road Infrastructure in India—IBEF. https://www.ibef.org/industry/roads-india.aspx

Insight into a Waste Material-Based Bioreactor for Nutrient Removal from Domestic Wastewater

Prangya Ranjan Rout, Rajesh Roshan Dash and Puspendu Bhunia

Abstract The feasibility of simultaneous nitrification denitrification and phosphate removal in a single-stage fixed-bed bioreactor was evaluated in this study. The bioreactor was packed with industrial wastes and agricultural wastes mixed in a definite proportion. A newly isolated simultaneous nitrifying and denitrifying bacterial strain was immobilized on the packed bed materials to facilitate nutrient removal. The bioreactor was fed with both real and synthetic wastewater under variable start-up and steady-state experimental conditions including hydraulic retention time (HRT), mode of aeration and nutrient loading rate and operated for 70 days continuously. In the steady-state condition ammonia, nitrate, and phosphate removal efficiencies of synthetic wastewater were 87.1–92.8%, 69.4–88.4%, and 88.4–100%, respectively, while the corresponding values of real domestic wastewater were 88.7–93.1%, 70.5–87.2%, and 84–89.4%, respectively. This work publicized the promising application prospect of the developed bioreactor in domestic wastewater treatment primarily focusing on nutrient removal.

Keywords Nutrient removal · Domestic wastewater · Industrial wastes · Agricultural wastes · Single-stage fixed-bed bioreactor

1 Introduction

Nitrogen and phosphorus, known as biostimulants, are essential for growth and development of life. However, sustained input of nutrients to aquatic environment leads to eutrophication. Eutrophication induced hazardous effects that are mostly

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accountable for the deterioration of water quality and eutrophication continues to rank at the top of the water quality hardships globally [1]. Consequently, treatment objective of most of the contemporary wastewater treatment plants have shifted from traditional sole carbon removal to simultaneous carbon and nutrient removal approach [2]. In recent years, to meet the more stringent effluent nutrient regulations, the treatment technologies have been improved and modified to get higher nutrient removal efficiencies. However, the processes are still facing many challenges from nutrient removal prospective. Therefore, there is a dire need to develop dependable domestic wastewater nutrient removal technologies that would be able to deal with the prevalent nutrient eradication issues.

Furthermore, achieving synergistic nitrogen and phosphorus in the single-stage bioreactor is highly desirous for minimization of substrate requirements and simplification of process configurations as compared to conventional bioreactors for nutrient removal. So, innovative wastewater treatment systems are essential for realizing the simultaneous nitrogen and phosphorus removal.

This study aimed at designing and developing a single unit packed bed bioreactor with immobilized specific microbial species to carry out simultaneous nitrification, denitrification, and phosphorus removal. The bioreactor was packed with industrial waste material (dolochar) as a potential reactive media for phosphate removal through physicochemical approach [3–5]. Likewise, a equivolume mixture of waste organic solid substances (WOSS) was used as another packing material for serving as carbon source to accelerate heterotrophic denitrification process [6, 7]. The packing materials were used as biofilm carriers for the immobilization of a microbial monoculture, *Bacillus cereus* GS-5 strain for enhanced simultaneous nutrient removal [8, 9]. The integration of biological as well as physicochemical approach for nutrient removal was attempted by selective use of microbial strain and packing materials. The nutrient removal performance was evaluated under different experimental conditions.

2 Materials and Methods

2.1 Bioreactor Configuration

Many small-scale bioreactors were configured using acrylic sheets. Figure 1 shows the actual image of the bioreactors with length, breadth, and height of 10, 10, and 30 cm, respectively. The adsorbent and carbon sources were packed inside the bioreactor in alternative manner and distributed in four to five layers. The media materials were bounded by glass wool covered holed acrylic plates in both the top and bottom side of the reactor to prevent media and biomass loss from the reactor. In addition, the arrangement was meant to facilitate equal distribution of influent across the packed bed. With the mentioned dimension and considering bed porosity of 72%, resultant working volume of the bioreactor was 1800 mL.

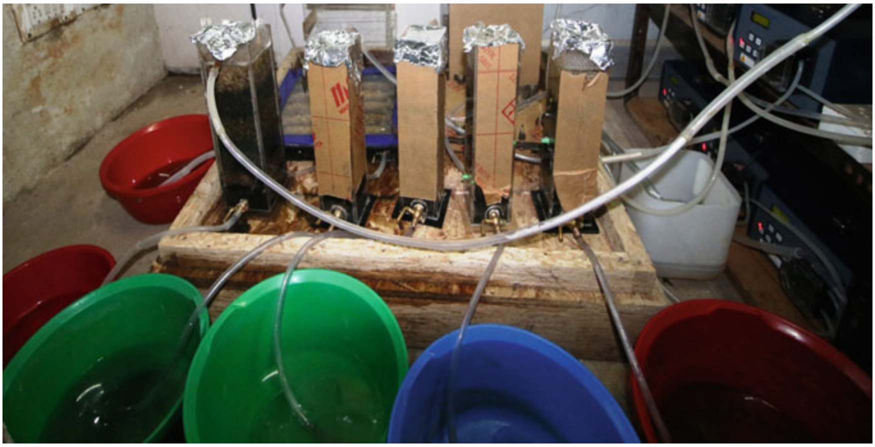

Fig. 1 Small-scale single-stage bioreactors engaged in nutrient removal

2.2 Microbe Immobilized Substrates

Bacillus cereus GS-5 strain was grown in a sterilized nutrient medium with composition of sodium acetate1.3 g, ammonium sulfate 0.472 g, basal medium 1.53 g, potassium nitrate 0.722 g, magnesium sulfate 0.2 g, calcium chloride 0.5 g, dipotassium hydrogen phosphate 0.113 g, and trace element solution 2 mL in 1 L of distilled water. The incubation conditions followed were 35 ºC temperatures, 7 pH, 125 rpm, and 36 h time period [10]. Fully grown cultures were centrifuged for 10 min at 7500 rpm and cells were collected as pellets after discarding supernatant. The cells were then washed repeatedly with 0.2% sterilized saline solution, and afterwards suspended in basal media added with essential microelements, carbon, and nitrogen sources for further use as an inoculum in the bioreactor.

500 g/L of dolochar and 100 g/L of WOSS were mixed with the nutrient medium in Erlenmeyer flasks and subjected for sterilization in autoclave at 121 °C, 15 psi for 20 min followed by addition of 10% v/v inoculum into the individual flasks. The incubation of the flasks was done under the experimental condition as mentioned above. To avoid nutrient shortage, 20% fresh media were added two times a week and to accelerate growth, proliferation, and biofilm formation 5% inoculum was added once in a week. The process continues for two weeks for biomass immobilization via microbial colonization on the carrier surface. Subsequently, the microbe immobilized carrier materials were taken out of the flasks and packed inside the bioreactor for further application.

Table 1 Characteristics of synthetic and real domestic wastewater

Characteristics	Synthetic domestic wastewater	Actual domestic wastewater
Ammonium (ppm)	30–100	56.7 ± 4.3
Nitrate (ppm)	30–100	8.9 ± 3.4
Phosphate (ppm)	5–20	5.1 ± 1.6
Nitrite (ppm)	–	0.55 ± 0.75
pH	7.5 ± 0.1	6.5 ± 0.5
Dissolved oxygen (ppm)	–	0.75 ± 0.2

2.3 Domestic Wastewater

Real domestic wastewater as well as synthetic solution emulating domestic wastewater condition was used in this work. In order to effectively control the experimental conditions and due to the unbalanced composition of actual wastewater, the synthetic wastewater was used. The same was prepared by dissolving (g/L) sodium acetate 1.4, ammonium sulfate 0.472, basal medium 1.53, potassium nitrate 0.722, magnesium sulfate 0.2, calcium chloride 0.5, dipotassium hydrogen phosphate 0.113, and 2 mL/L of trace element solution in tap water. The trace solution consisted of the following compounds (mg/L) 0.05 $CuSO_4 \cdot 5H_2O$, 0.05 $AlCl_3 \cdot 6H_2O$, 0.25 $CoCl_2 \cdot 6H_2O$, 0.05 H_3BO_3, 0.5 $FeSO_4 \cdot 7H_2O$, 0.01 $Na_2MoO_4 \cdot 2H_2O$, 0.5 $MnCl_2 \cdot 4H_2O$, 0.05 $ZnCl_2$, 0.15 $CuCl_2$, 0.02 $NiSO_4 \cdot H_2O$, and 0.01 Na_2SeO_3. The pH was adjusted within 6–7 by adding base or acid as desired. The optimization of experimental parameters was performed with synthetic wastewater. After optimization, the real domestic wastewater was used to assess the nutrient removal performance efficiency of the bioreactor at the optimum conditions. The real domestic wastewater from the same source as reported in our earlier publication [8, 9] was collected and used in this study. The characteristics of both types of wastewater used in this work are shown in Table 1.

2.4 Analytical Techniques

NO_3^--N, NO_2^--N, and NH_4^+-N concentrations were measured by following the sodium salicylate, sulfanilic acid, and the Nessler method, respectively, colorimetrically in a UV/VIS spectrophotometer (Perkin-Elmer Lambd-25) [11]. Phosphate measurement was also done colorimetrically following vanadomolybdophosphoric acid method, the detail procedure of which was discussed elsewhere [3, 4]. The chemical oxygen demand (COD) concentration was determined by colorimetric method (5220-D) as per the procedure mentioned in the standard methods for the examination of water and wastewater [12]. All the samples were filtered through 0.45 μm membrane filter (PVDF, Whatman, UK) prior to analysis.

3 Results and Discussions

3.1 Preliminary Studies for Optimizing Factors

Based on the literature some of the key experimental parameters like DO and HRT that govern simultaneous nitrification–denitrification and denitrifying phosphate removal were selected and subsequently optimized in this work [13–15]. The bioreactor was packed with WOSS as the sole external carbon sources for the heterotrophic microbe to carry out the metabolic activities since the carbon source contained in the domestic wastewater was limited to meet the microbial requirement. The biodegradation and carbon release from WOSS is a complex process. So using WOSS as carbon source made it difficult to study the effect of C/N ratio as an experimental parameter and also the option of exploring the effects of different carbon sources got restricted. So, both these parameters were opted out for this study and every detail of WOSS as a carbon source has already been discussed in our earlier publications [6, 7]. The bioreactor was operated in the ambient room temperature since it was beyond the scope of the study to regulate the bioreactor temperature at 35 °C as optimized in the earlier study [8]. Nevertheless, the optimized pH (7.5) was maintained in this study by acid and base addition as desirous. For studying the effects of DO on performance efficiency, different modes of aeration were opted to imitate the optimized DO level. In addition, HRT as a key parameter for the bioreactor performance was optimized in this study.

3.2 Nitrification and Physicochemical Ammonium Removal

Figure 2 demonstrates the ammonium removal efficiency and its concentration in the input and output of the bioreactor under different experimental conditions. After the start-up period, the ammonium input amplified progressively to examine its effect on the nitrogen elimination efficiency of the bioreactor. Real wastewater was fed to the bioreactor in the final phase of the operational period. Experimental conditions fixed during steady-state operation were 4 h HRT, 7.5 mL/min flow rate, and 2.65 ± 0.1 mg/L DO (achieved via dynamic aeration). As shown in Fig. 2, starting with 100 mg/L, the ammonium removal efficiency of 57.4% was reported on the day 1 of the operation. Till day 11, the trend of increasing ammonium removal continued with the last reported efficiency of 83% followed by three days of steady performance efficiency varying in 83–85% range and the average efficiency till day 14 was calculated to be nearly 70%. No appearance of nitrate till 8th day as evident from the figure indicated adsorptive ammonium removal during the mentioned period. Beyond first week of operation, commencement of ammonium removal via biological means was marked by progressive appearance of nitrate in increased concentrations in the reactor output confirming biofilm formation.

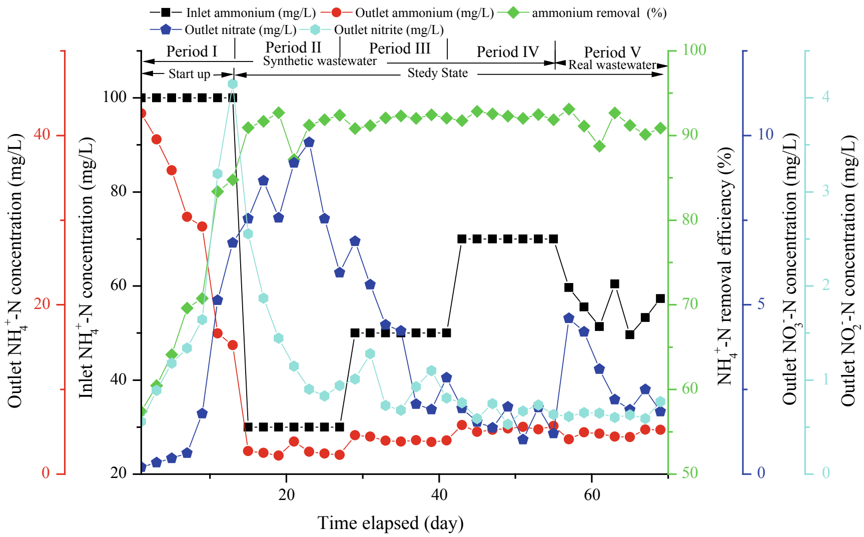

Fig. 2 Demonstration of ammonium removal, inlet ammonium concentration and outlet ammonium, and nitrate and nitrite concentration of the bioreactor

Starting with 30, 50, and 70 mg/L of ammonium in stage II, III, and IV of the bioreactor operation, the average output concentrations were below the allowable discharge limit with respective concentrations of 2.4, 4.3, and 5.8 mg/L [16]. The observation indicated that steady-state ammonium removal efficiency improved with increased input ammonium concentration, which was attributed to the resilience of mature biofilm to variation in influent ammonium loadings [14]. In the last phase of operation while dealing with real wastewater, in spite of variable inlet ammonium concentration in 49.62 to 60.46 mg/L range, the reactor exhibited efficient ammonium removal with average outlet concentration of 4.8 mg/L. The progressive accumulation of nitrate and nitrite to maximum concentrations of 9.8 and 3.1 mg/L, respectively, and subsequently decreasing to 1.02 and 0.59 mg/L in that order was witnessed from the figure. The synergistic ammonium removal and appearance of nitrate and nitrite, the intermediates of nitrification mechanism in the reactor effluent confirmed biological ammonium removal mediated by nitrification and denitrification. More precisely the mechanism is heterotrophic nitrification and aerobic denitrification as exhibited by the immobilized microbial strain *Bacillus cereus* GS-5, the same novel nutrient removal metabolic pathway was reported in our recent publications [8, 9].

3.3 Denitrification and Physicochemical Nitrate Removal

Figure 3 depicts the nitrate removal efficiency and its concentration in the input and output of the bioreactor under different experimental conditions. Similar experimental conditions and process flow as discussed in previous section were followed for nitrate removal. As shown in Fig. 3, starting with 100 mg/L, the nitrate removal efficiency of 45.2.4% was reported on the day 1 of the operation. Till day 7, the trend of increasing nitrate removal continued with 56.6% in 7th day followed by fast increase to 75.5% on 11th day afterwards three days of steady performance efficiency varying in 75.5–76.8% range and the average efficiency till day 14 was calculated to be nearly 60%. No appearance of nitrite till 7th day as evident from the figure indicated adsorptive nitrate removal during the mentioned period. Beyond first week of operation, commencement of nitrate removal via biological means was marked by progressive appearance of nitrite in increased concentrations in the reactor output along with enhanced nitrate removal beyond 15th day confirmed biofilm formation and stabilization.

Starting with 30, 50, and 70 mg/L of nitrate in II, III, and IV stage operation of the bioreactor, the average output concentrations were below the allowable discharge limit (10 mg/L) with respective concentrations of 6.6, 7.6, and 8.5 mg/L [16]. The observation indicated that steady-state nitrate removal efficiency improved with increased input nitrate concentration with passage of time, which

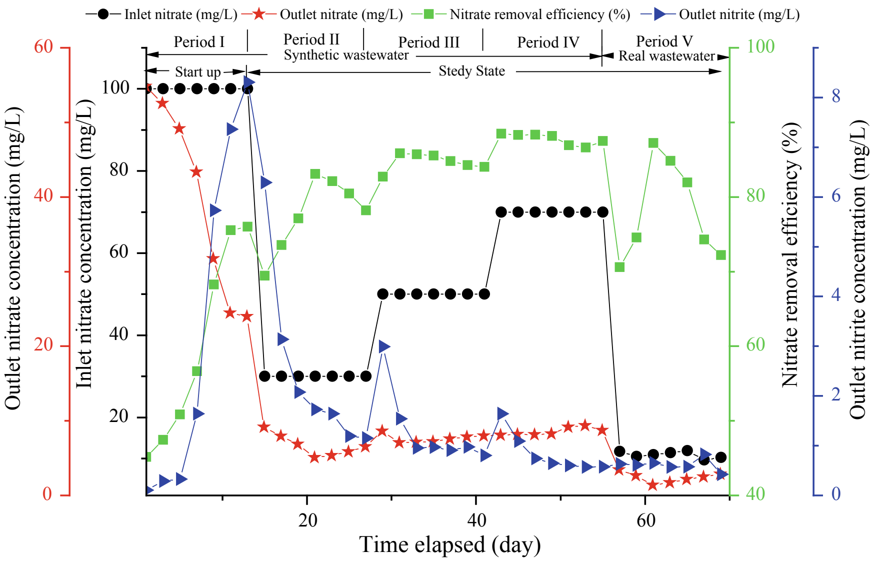

Fig. 3 Demonstration of nitrate removal, inlet nitrate concentration, and outlet nitrate and nitrite concentration of the bioreactor

was attributed to the resistance of mature biofilm to variation in influent nitrate loadings [14]. In the last phase of operation while dealing with real wastewater, in spite of variable inlet nitrate concentrations in 9.6–11.9 mg/L range, the reactor exhibited efficient ammonium removal with average outlet concentration of 2.3 mg/L. The progressive accumulation of nitrite, the denitrification intermediate to maximum concentration of 8.3 on 13th day and subsequently decreasing to below 1 mg/L beyond 31st day was witnessed from the figure. The momentary nitrite build-up signifying inadequate denitrification is attributed to the lag phase of the nitrite reductase prior to fully functioning and also due to competitive activity suppression by nitrate reductase [13]. The synergistic nitrate removal and appearance of nitrite, the intermediates of denitrification mechanism in the reactor effluent confirmed biological nitrate removal mediated by denitrification. More precisely, the mechanism is aerobic denitrification of nitrate to nitrogen gas under limited aeration condition through nitrite pathway as exhibited by the immobilized microbial strain *Bacillus cereus* GS-5 and the same novel nutrient removal metabolic pathway has already been reported in our earlier publications [8, 9].

3.4 Denitrifying and Physicochemical Phosphate Removal

Figure 4 displays the phosphate removal efficiency and its concentrations in the input and output of the bioreactor under different experimental conditions. Similar experimental conditions and process flows as discussed in previous section were followed for phosphate removal. As shown in Fig. 4, starting with 20 mg/L, the phosphate removal efficiency of 95. 4% was reported on the day 1 of the operation. The phosphate removal trend varied in the range of 95.7–100% till 41st day with reported average removal efficiency of 97.6%. After 42nd day steady performance efficiency with average removal efficiency of 90.4% was observed. Starting with 5 and 10 mg/L of phosphate in II and III stage operation of the bioreactor, there was no significant difference marked in the average removal efficiencies with the corresponding values of 99 and 97%. However, in phase IV by increasing the inlet phosphate concentration to 15 mg/L, the average removal efficiency reduced to 95%. In the last phase of operation, the reactor was supplied with real wastewater with variable inlet phosphate concentrations of 4.5–6 mg/L, the removal efficiency fluctuated in between 87.5 and 89.4% accordingly. During the entire operation period irrespective of the inlet phosphate concentration, the observed outlet concentrations were always below 1 mg/L, the allowable discharge limit for phosphate [16]. The highly efficient phosphate removal in the bioreactor was mainly attributed to the following three factors (i) adsorptive removal by activated carbon-based media material, dolochar, (ii) biological means via denitrifying phosphate removal as exhibited by the immobilized *Bacillus cereus* GS-5 strain, and, (iii) microbial assimilation as a nutrient for vital functions like metabolite synthesis, growth and proliferation [8, 17, 18]. Out of the above mentioned phosphate removal

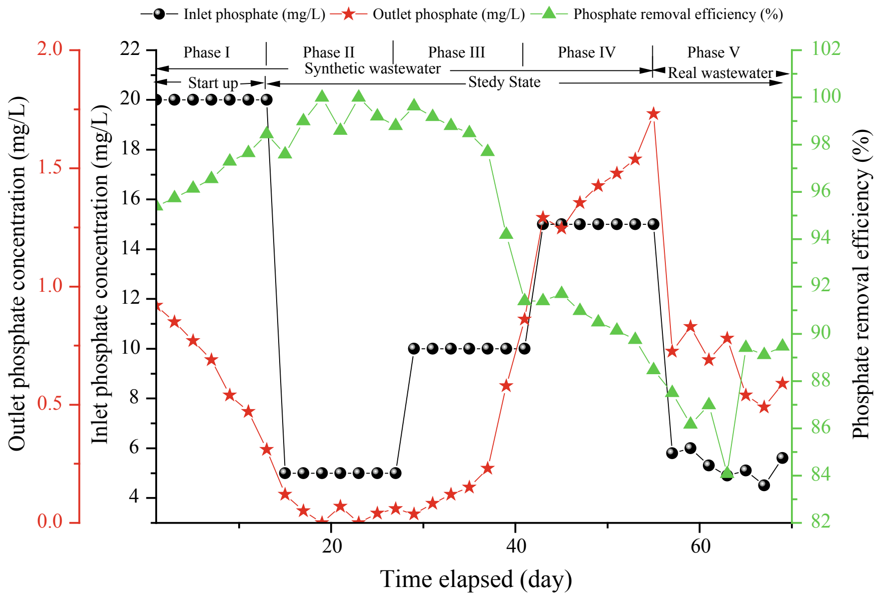

Fig. 4 Demonstration of phosphate removal, inlet, and phosphate concentration of the bioreactor

mechanisms, dolochar-based physicochemical approach contributed maximum phosphate removal with calculated contribution of more than 70%, whereas phosphate removal by biological means was approximately 26%.

4 Conclusions

In this study, the newly isolated microbial strain *Bacillus cereus GS-5* immobilized laboratory scale single-stage fixed-bed bioreactors were developed for the realization of synergistic nitrogen and phosphorous removal. The bioreactors demonstrated outstanding simultaneous nutrient elimination efficiency from low, medium and high strength synthetic wastewater and from real domestic wastewater as well. The main mechanism of nitrogen removal, ammonium, and nitrate, in particular, was observed to be through heterotrophic nitrification and aerobic denitrification feature of the *Bacillus cereus GS-5* strain, whereas phosphate was primarily removed by dolochar mediated physicochemical means. Only 26% of phosphate was removed by biological means through the denitrifying phosphate removal feature of the immobilized microbial biomass. Therefore, the fixed-bed bioreactor with advanced nutrient removal mechanisms can be recommended as an imperative alternative for nutrient confiscation from domestic wastewater.

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References

1. Rout, P.R., Dash, R.R., Bhunia, P.: Development of an integrated system for the treatment of rural domestic wastewater: emphasis on nutrient removal. RSC Adv. **6**(54), 49236–49249 (2016)
2. Guadie, A., Xia, S., Zhang, Z., Guo, W., Ngo, H.H., Hermanowicz, S.W.: Simultaneous removal of phosphorus and nitrogen from sewage using a novel combo system of fluidized bed reactor–membrane bioreactor (FBR-MBR). Bioresour. Technol. **149**, 276–285 (2013)
3. Rout, P.R., Bhunia, P., Dash, R.R.: Effective utilization of a sponge iron industry by-product for phosphate removal from aqueous solution: a statistical and kinetic modelling approach. J. Taiwan Inst. Chem. Eng. **46**, 98–108 (2015)
4. Rout, P.R., Dash, R.R., Bhunia, P.: Nutrient removal from binary aqueous phase by dolochar: highlighting optimization, single and binary adsorption isotherms and nutrient release. Process Saf. Environ. **100**, 91–107 (2016)
5. Rout, P.R., Bhunia, P., Dash, R.R.: Evaluation of kinetic and statistical models for predicting breakthrough curves of phosphate removal using dolochar-packed columns. J. Water Process Eng. **17**, 168–180 (2017)
6. Rout, P.R., Bhunia, P., Dash, R.R.: Assessing possible applications of waste organic solid substances as carbon sources and biofilm substrates for elimination of nitrate toxicity from wastewater. J. Hazard. Toxic. Radioact., 04016027 (2016)
7. Rout, P.R., Dash, R.R., Bhunia, P.: Effectiveness of aegle shell (AS) and groundnut shell (GS) as carbon sources for bio-denitrification of nitrate rich aqueous solution. Adv. Sci. Lett. **22**(2), 354–358 (2016)
8. Rout, P.R., Bhunia, P., Dash, R.R.: Simultaneous removal of nitrogen and phosphorous from domestic wastewater using Bacillus cereus GS-5 strain exhibiting heterotrophic nitrification, aerobic denitrification and denitrifying phosphorous removal. Bioresour. Technol. **244**, 484–495 (2017)
9. Rout, P.R., Dash, R.R., Bhunia, P., Rao, S.: Role of Bacillus cereus GS-5 strain on simultaneous nitrogen and phosphorous removal from domestic wastewater in an inventive single unit multi-layer packed bed bioreactor. Bioresour. Technol. **262**, 251–260 (2018)
10. Sen, S.K., Raut, S., Satpathy, S., Rout, P.R., Bandyopadhyay, B., Mohapatra, P.K.D.: Characterizing novel thermophilic amylase producing bacteria from Taptapani Hot Spring, Odisha, India. Jundishapur J. Microbiol. **7**(12), 1–7 (2014)
11. Bartošová, A., Michalíková, A., Sirotiak, M., Soldán, M.: Comparison of two spectrophotometric techniques for nutrients analyses in water samples. In: Research Papers Faculty of Materials Science and Technology Slovak University of Technology, vol. 20(32), pp. 8–19 (2012)
12. APHA.: Standard methods for the examination of water and wastewater. American Public Health Association, American Water Works Association, Water Environment Federation, Washington **17**, 1.5–3.12 (2005)
13. Hu, Z., Zhang, J., Li, S., Wang, J., Zhang, T.: Effect of anoxic/aerobic phase fraction on N_2O emission in a sequencing batch reactor under low temperature. Bioresour. Technol. **102**(9), 5486–5491 (2011)
14. Li, W., Loyola-Licea, C., Crowley, D.E., Ahmad, Z.: Performance of a two-phase biotrickling filter packed with biochar chips for treatment of wastewater containing high nitrogen and phosphorus concentrations. Process. Saf. Environ. **102**, 150–158 (2016)

15. Kong, Z., Feng, C., Chen, N., Tong, S., Zhang, B., Hao, C., Chen, K.: A soil infiltration system incorporated with sulfur-utilizing autotrophic denitrification (SISSAD) for domestic wastewater treatment. Bioresour. Technol. **159**, 272–279 (2014)
16. Metcalf, E., Eddy, E.: Wastewater Engineering: Treatment and Reuse. McGrawHill, New York (2003)
17. Wen, X., Zhou, J., Li, Y., Qing, X., He, Q.: A novel process combining simultaneous partial nitrification, anammox and denitrification (SNAD) with denitrifying phosphorus removal (DPR) to treat sewage. Bioresour. Technol. **222**, 309–316 (2016)
18. Zhou, Y., Ganda, L., Lim, M., Yuan, Z., Kjelleberg, S., Ng, W.J.: Free nitrous acid (FNA) inhibition on denitrifying poly-phosphate accumulating organisms (DPAOs). Appl. Microbiol. Biotechnol. **88**(1), 359–369 (2010)

Incorporation of Earthworms and Dolochar in Biofilter: An Attempt Towards Maximizing Nutrients Removal

Rajneesh Singh, Kundan Samal, Puspendu Bhunia and Rajesh Roshan Dash

Abstract In the pursuit of finding an ecologically safe and sustainable technique for the remediation and reuse of effluents generated from the industries and housing colonies, biofilters have been considered. However, biofilters too have limitations such as low removal rate of nutrients. The present work is an attempt to enhance the nutrient removal potential of vermifilter, to make it more versatile. A layer of dolochar, a waste product from sponge iron industry, was added at the end of the horizontal vermifilters to assist in removal of nutrients. The resultant effluent from this setup was analyzed and monitored over a period of 60 days. The total phosphorus removal from the integrated setup was obtained between a range of 34.0–43.3%, while phosphate phosphorus removal was 46.6–61.3%. Total nitrogen removal also reached to a range of 8.3–23.7%. The study concludes that the incorporation of dolochar unit in vermifilter facilitates nutrient removal from wastewater and thus contributes toward reducing the increasing pollution load and minimizing scarcity of water by reusing the treated effluent from the vermifilter.

Keywords Brewery wastewater · Vermifilter · Earthworm · Dolochar · Nutrients · Organics

1 Introduction

Of late, the effluents from the domestic and industrial chores are constantly posing a threat to the aquatic ecosystem. In performing miscellaneous chores relating to the domestic and industrial operations, wastewater gets generated which further adds pollutants such as organics and nutrients to the aquatic ecosystem. In addition to the abovementioned problem, the scarcity of water is also happening due to the over exploitation of the existing water resources. To counter the water scarcity and pollution

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in the aquatic ecosystem, treatment, and reuse of the wastewater is greatly desirable [6, 10, 11]. Among many existing treatment technologies, the biofilters have proved its mettle in treating domestic wastewaters for safe disposal and reuse purposes. However, despite being a cost-effective and eco-friendly solution, biofilters could not gain much popularity due to inefficiency in removing nutrient from wastewater.

In order to achieve high nutrient removal efficiency from biofilters, earthworms were incorporated by many researchers [2, 6, 8, 9, 12] which eventually increased the nitrification rate. In addition, the incorporation of earthworms was even seen to have increased the phosphate concentration in the effluent. Owing to the above shortcomings of vermifilter as well as biofilter, Singh et al. [7] recommended that the vermifilters must be combined with an adsorption unit to take care of the bypassed phosphorous from the active unit of vermibedding. In the present study, the vermifilters contain a positioned column of dolochar as an adsorptive layer to enhance the performance of vermifilters in removing phosphates. In addition, horizontal subsurface flow was provided to the vermifilters, which were mostly of vertical subsurface flow type. The objective of the present work is to enhance the nutrient removal potential of vermifilters to counter the limitations associated with its field scale application.

2 Materials and Methods

Vermifilters of dimension 80 cm in length, 20 cm as width, and 20 cm as depth were fabricated by plexiglass (Fig. 1). Baffles of 16 cm long were placed vertically along with the width of the fabricated setup to guide the flow in a curvilinear

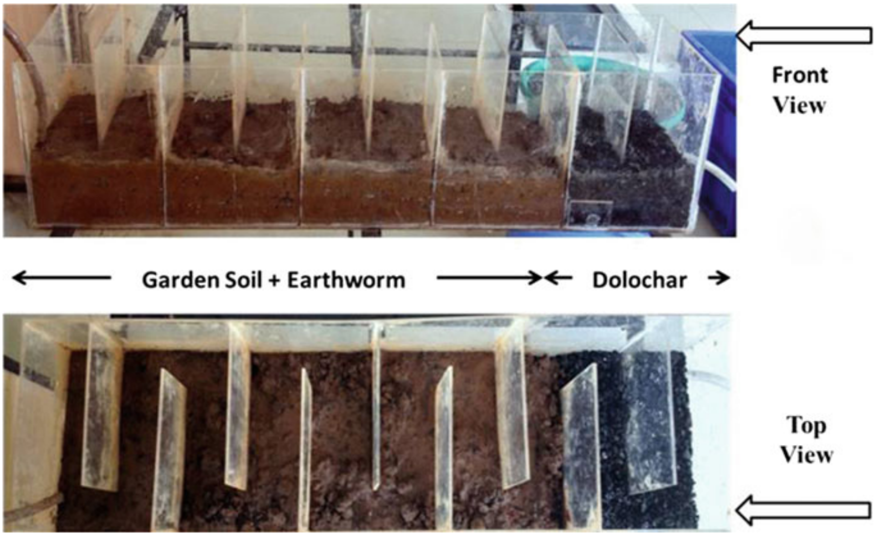

Fig. 1 Reactor used in the study

manner. The initial 64 cm length of the reactor was filled with soil mix. The soil mix was prepared by mixing garden soil with the compost brought from nearby nurseries in a ratio of 4:1. The remaining 16 cm length of the reactor was further filled using dolochar to assist in the adsorption of phosphates. The soil mix and dolochar were filled up to the height of 10 cm only, while the remaining 10 cm was filled as freeboard. After filling up of the reactors using soil mix and dolochar, earthworms *Eisenia Fetida* were released. The reasons behind opting for *Eisenia Fetida* are (a) high reproducibility (b) potential to survive short exposure to the waterlogged conditions and (c) aeration of surface due to its surface-dwelling tendency [7–9]. After inoculation of earthworms, tap water was applied over the bedding to facilitate leaching out of the added organics and nutrients. After a week of tap water application, brewery wastewater was prepared according to Tam et al. [13] and was applied over the bedding. The wastewater applied over the bedding was synthetically prepared due to the high transportation costs involved in bringing real brewery wastewater from the breweries. Another reason behind opting for synthetic brewery wastewater was the high fluctuation in pollutant concentration on the basis of practices being followed at breweries. Box-Behnken Design (BBD) was used to design the experimental runs. The factors chosen for the BBD were Hydraulic Loading Rate (HLR), influent COD, and Earthworm Density (EWD). The influent COD was varied between 2000–4000 mg/L, according to Tam et al. 2005 and the earthworms were inoculated in the reactors between the range of 0–10000 earthworms/m^3. The wastewater was varied by varying the Hydraulic Loading Rates (HLRs) between the range of 1.8–4.15 m^3/m^2/day as a result of the HLR and influent organics variations, the organic loading rates of the system also varied between the range of 2,25–11.25 kgCOD/m^3 day. The concentration of nutrient was also maintained according to the literatures [13]. The TN concentration in the influent was varied between the range of 90–115 mg/L while the concentration of TP in the influent varied between 55–75 mg/L. The phosphate phosphorus concentration varied between the range of 25–55 mg/L. The resulting effluent from this setup was collected up to a period of 60 days at analyzed at a frequency of 4 days. The system took around 24–28 days to achieve steady state of removal. The steady state of the system was considered when the variations in the COD removal were within or less than 5%, only.

The samples taken from the influent and effluent end were further analyzed for Total Nitrogen (TN), Total Phosphorus (TP), and phosphate phosphorus (PO_4^{3-}-P) [1]. The obtained concentrations from the effluent end were further compared with the concentration at the influent end. The removal efficiencies were calculated according to the below given formula

$$\text{Removal efficiency (\%)} = ((1 - (C_e/C_0))*100)$$

where C_e and C_0 are the concentrations at the influent and effluent end.

3 Results and Discussion

3.1 Nitrogen Removal

The TN removal results suggested that despite being an aerobic system, denitrification took place in the vermifiltration, which however was not observed in the results from the literature [2, 4]. TN removal efficiency from a vermifilter containing earthworms resulted the efficiencies up to 24–25% (Fig. 2). The above observation indicates toward the fact that the providing horizontal subsurface flow to the vermifilters has made the lower layer of vermifilters anoxic, resulting in higher rates of denitrification. Conversely, the nitrogen entering the reactor in the form of ammonium or organic nitrogen is nitrified in the upper layer, due to the availability of Dissolved Oxygen (DO). The high availability of DO is due to the activities done by earthworms such as burrowing and tunneling through the soil bedding. The tunnels formed throughout the soil bedding serves as capillaries and helps in the diffusion of dissolved oxygen to the bedding. The dissolved oxygen further avails itself for nitrification. The nitrified products in the form of nitrate and nitrite further percolate to the lower layer, which is submerged due to the flow being horizontal subsurface in nature. The denitrified end products escaped to the atmosphere in the form of gases. In addition, the consumption of nutrients by the microbes for their energy needs may also be a reason behind the removal of nitrogen from the system. However, the removals due to use of nutrients in the energy need are comparatively minimal.

Apart from the above, it was observed that the denitrification potential of the vermifilter was quite higher than the biofilters having no earthworms (EWD of 0). For instance, a system containing no earthworm resulted TN removal of 8.29 ± 3.62%, while the system containing earthworms at the EWD of 10000 resulted the average TN removal of 21.56 ± 3.8%. Both of these experiments were conducted at the same influent COD and HLR. The above differences obtained between the biofilters and vermifilters indicated that the presence of earthworm

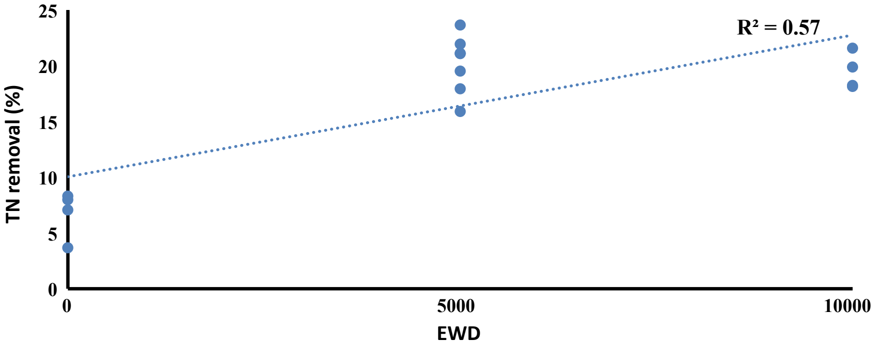

Fig. 2 Impact of EWD on TN removal

plays a great role in denitrification. The probable reason behind higher denitrification could be the presence of higher concentration of nitrates and nitrites, resultant of nitrification occurred in the system due to the presence of high DO.

3.2 Phosphorous Removal

Despite being a biological treatment system, removal of phosphorus from the vermifilter is reported to be unaffected of any biological mechanism [10, 11]. Having said above, the phosphorus removal from vermifilter still remains a challenge compared to the nitrogen removal. Instead, the phosphorus concentration was reported to be increased in many cases [6, 7]. The increase in the effluent phosphorus concentration could be due to the mineralisation and enzymatic breakdown exerted by the presence of earthworms, which converts the Org.-P to PO_4^{3-}. The Org.-P can come from the leaching of the bedding material and the Org.-P supplied along with the influent. The newly converted PO_4^{3-} and the PO_4^{3-} supplied along with the influent are further bypassed from the vermifilters, resulting in the rise of the PO_4^{3-} concentration in the reactor.

However, in this study, reduction in the PO_4^{3-}-P concentration was seen. The removal of Total Phosphorus (TP) and phosphate phosphorous (PO_4^{3-}-P) was observed to be within the range of 30–44% and 39–61%, respectively. The high removals of TP and PO_4^{3-}-P from the developed systems can be attributed to the presence of dolochar in the vermibed. The addition of an adsorbent layer into the bedding was suggested by many previous researchers, to achieve higher PO_4^{3-}-P removal from vermifilter [3, 7]. The reason behind opting dolochar as an adsorptive layer is its exceptional capabilities in phosphate adsorption [5]. In addition, cheap and easy availability of the dolochar is also a reason behind choosing dolochar as an adsorbent for this study. The spent dolochar may later be used as the fertilizer for the horticultural activities. The applicability of dolochar as a fertilizer has already been verified by Rout et al. [5].

However, during initial days of experiment comparatively high amount of phosphorus was observed in the effluent, which can be attributed to the liberation of the bound form of phosphorus from the bedding. The earthworm introduction in the vermin ecosystem made a great change with respect to the phosphorus removal. From Fig. 3, one can observe that the addition and increase in earthworms have a greater role to play in the phosphorus removal process. For example, TP removal from a run with no earthworms resulted 34.01 ± 2.87% efficiency, while a vermifilter with EWD of 10000 yielded a removal efficiency of 43.29 ± 4.32%. These different TP removals between different reactors could be due to the grinding activity of earthworms. The grinding of soil by earthworms in their gut makes soil particles finer and it, in turn, results in higher specific surface area of the soil particles. In addition, the result obtained from the runs with different earthworms population from the studies carried out by other researchers also reinforces the above theory [12].

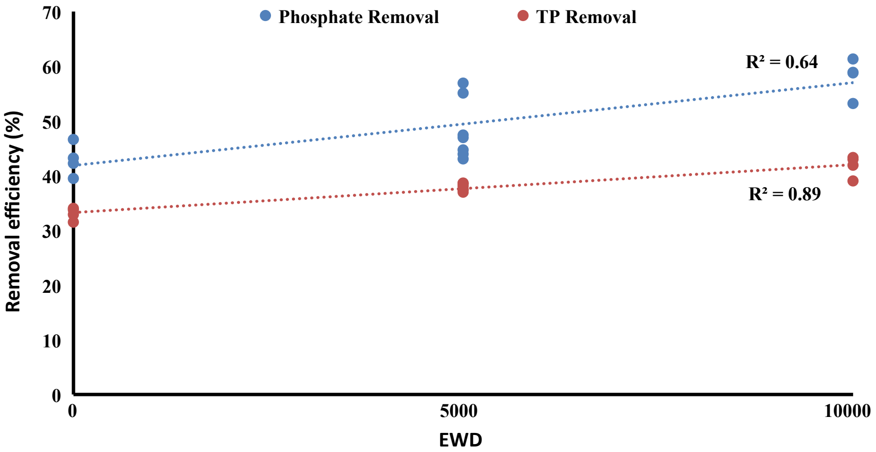

Fig. 3 Impact of EWD on phosphorous removal

The average phosphorus removal efficiency from a vermifilter with EWD of 10000 was 43.29 ± 4.32%, while the efficiency from the run with EWD of 5000 was 38.85 ± 1.73%. The variation in the removal rates could be due to the variations in the intensity of earthworm activities. This additional analysis of differences in removal at different EWD also reinforces the role of earthworms playing in the phosphorus removal (Fig. 3). However, in some cases it was observed that mere earthworms were not the only the factor active in removal of PO_4^{3-}-P. For instance, an experimental run with EWD of 5000 was observed to yield PO_4^{3-}-P removal efficiencies between 43 and 57%. Such variations in removal from different experimental runs can be attributed to the other contributing factors, one of which is Hydraulic Loading Rate (HLR). As the variation in HLR could lead to the variation in interaction time between the soil particles and the pollutants, which in turn could increase/decrease the removal potential of a vermifilter.

4 Conclusion

This study was conducted with an aim to achieve higher nutrient removal from the vermifilter and biofilters. In enhancing the removal of nutrients earthworms and dolochar was incorporated. The outcomes of this study suggest that the incorporation of dolochar can contribute in phosphorus removal by adsorbing it onto its surface. In addition, the denitrification of the system can also be improved due to the joint action of earthworms and the flow being horizontal subsurface. The results suggest that incorporation of earthworms and dolochar unit in vermifilter can serve as a key tool in improving nutrient removal performance of biofilters and can give an impetus to make this technology widely acceptable.

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References

1. APHA: Standard Methods for the Examination of Water and Wastewater, twentieth ed. American Public Health Association, American Water Works Association, Water Environmental Federation, Washington, USA (2005)
2. Arora, S., Rajpal, A., Bhargava, R., Pruthi, V., Bhatia, A., Kazmi, A.A.: Antibacterial and enzymatic activity of microbial community during wastewater treatment by pilot scale vermifiltration system. Bioresour. Technol. **166**, 132–141 (2014)
3. Del Bubba, M., Arias, C.A., Brix, H.: Phosphorus adsorption maximum of sands for use as media in subsurface flow constructed reed beds as measured by the Langmuir isotherm. Water Res. **37**, 3390–3400 (2003)
4. Kumar, T., Rajpal, A., Arora, S., Bhargava, R., Prasad, K.S.H., Kazmi, A.A.: A comparative study on vermifiltration using epigeic earthworm *Eisenia fetida* and *Eudrilus eugeniae*. Desalin. Water Treat. **57**, 6347–6354 (2016)
5. Rout, P.R., Dash, R.R., Bhunia, P.: Effective utilization of a sponge iron industry by-product for phosphate removal from aqueous solution: a statistical and kinetic modelling approach. J. Taiwan Insti. Chem. Eng. **46**, 98–108 (2015)
6. Samal, K., Dash, R.R., Bhunia, P.: Treatment of wastewater by vermifiltration integrated with macrophyte filter: a review. J. Environ. Chem. Eng. **5**, 2274–2289 (2017)
7. Singh, R., Bhunia, P., Dash, R.R.: A mechanistic review on vermifiltration of wastewater: design, operation and performance. J. Environ. Manage. **197**, 656–672 (2017)
8. Singh, R., Bhunia, P., Dash, R.R.: COD removal index—a mechanistic tool for predicting organics removal performance of vermifilters. Sci. Total Environ. **643**, 1652–1659 (2018)
9. Singh, R., Bhunia, P., Dash, R.R.: Understanding intricacies of clogging and its alleviation by introducing earthworms in soil biofilters. Sci. Total Environ. **633**, 145–156 (2018)
10. Singh, R., Bhunia, P., Dash, R.R.: Optimization of bioclogging in vermifilters: a statistical approach. J. Environ. Manage. **233**, 576–585 (2019)
11. Singh, R., Bhunia, P., Dash, R.R.: Optimization of organics removal and understanding the impact of HRT on vermifiltration of brewery wastewater. Sci. Total Environ. **651**, 1283–1293 (2019)
12. Sinha, R.K., Bharambe, G., Chaudhari, U.: Sewage treatment by vermifiltration with synchronous treatment of sludge by earthworms: a low cost sustainable technology over conventional systems with potential for decentralization. Environmentalist **28**, 409–420 (2008)
13. Tam, K., Yang, C., Matsumoto, M.R., Crowley, D.E., Sheppard, J.D.: Comparison of PCR-DGGE and selective plating methods for monitoring the dynamics of a mixed culture population in synthetic brewery wastewater. Biotechnol. Prog. **21**, 712–719 (2005)

Removal of Fluoride from Aqueous Solution Using Coal-Coated with $FeCl_3$

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Abstract The fluoride contamination problem of groundwater of the rural areas in India is a serious threat due to unavailability of alternate safe water sources. In the present study, the coal-coated with FeCl3 was used for fluoride mitigation due to abundant availability of the raw coals in the surroundings of the affected areas of Bankura district, West Bengal, India. The raw coal was crushed into particle sizes less than 0.3 mm and further processed for the coating of $FeCl_3$. The characterization of the adsorbent done by XRD, FESEM and EDAX reveals that the adsorption process was physicochemical in nature. The batch, kinetic and column studies results showed that the maximum fluoride removal efficiency, adsorption capacity and performance of the column were found as 96%, 88.6 mg/g and 98%, respectively, and the adsorption mechanism best fit to Freundlich isotherm, pseudo-second order kinetics, and Yoon–Nelson and Thomas breakthrough models. The column had achieved the breakthrough point (i.e. 1.5 mg/L F^- conc.) in approximately 20 h at the flow rate of 2 ml/min, initial fluoride conc. of 20 mg/L and bed depth of 5 cm.

Keywords Adsorption process · Batch study · Coal-coated with $FeCl_3$ · Column study · Fluoride removal · Batch experiment

1 Introduction

Fluoride concentrations exist naturally in soil, water, foods and several minerals, such as fluorapatite and fluorite. Fluoride is essential for health and sustenance of the body if lesser than 1.5 mg/L [45] but excess fluoride concentration causes diseases related to bone, teeth, skin, nervous system, kidney, liver and respiratory

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system [39]. The groundwater in the western part of West Bengal (Birbhum, Nalhati, Bankura, Purulia, Midnapore and Bardhaman districts) are highly fluoride contaminated [7, 28]. Due to unavailability of surface water sources, the people in these areas are fully dependent on contaminated water for domestic, agriculture and farm uses [12]. Several fluoride removal technologies have been developed based on precipitation–coagulation, ion exchange, electro-coagulation, membrane separation process, adsorption, electrodialysis, etc. [33]. The method based on adsorption principle is the best methodology of fluoride removal due to its ease of operation, worthwhile of the procedure, high fluoride removal efficiency and high quality water and conceivably in regeneration [42]. The people lived in the affected areas of Bankura district, West Bengal, India are poor and cannot effort the sophisticated technologies because they are costly, difficult to operate and difficulty in instalment. The coal was selected as adsorbent because of the abundant and easy availability in study area. Therefore, an attempt is made to draw sustainable solution for fluoride remediation by using coal-coated with $FeCl_3$.

2 Materials and Methods

2.1 Preparation of Adsorbents

The collected coal was washed and dried then crushed by rubber hammer and sieved to particle sizes of less than 0.3 mm by sieving machine. 1 M HCl (100 mL volume) was prepared by taking 8.3 mL HCl and makeup to 100 mL with distilled water and put them in pick jar (500 mL capacity) and stirred it by heavy duty stirrer at 350–400 rpm and then add 10 g powdered coal (less than 0.3 mm sizes) and 1.1648 g of iron fillings were added into it and the mixtures were run for 10–15 min. After 10–15 min, 1.975 g of $KMnO_4$ in the mixture were added and while adding ($KMnO_4$) the speed of stirrer was also increased (up to 2300 rpm) to prevent formation of gel or clotting. After the formation of liquid, the setup was run for 2 h at low speed (350–450 rpm). When pH reaches 7 (after 2 h) the stirrer was stopped and the mixture was filtered by filter paper. The filtrate was washed and filtered repeatedly 2–3 times. Then the filtrate dried in hot air oven at 60 °C to remove all the moistures present in it.

2.2 Chemicals and Reagents

The sodium fluoride (AR Grade, Merck) used for the preparation of stock solutions were purchased from Merck Limited, Mumbai. The plastic wares were used to store the stock solutions and also to conduct the batch and column experiments. Deionized water was used to conduct all the experiments. Analytical grade of chemicals was used to conduct the laboratory experiments. The concentrations of fluoride were detected using Ion-selective electrode (Orion 4 Star, Thermo Scientific) with the addition of buffer solution (TISAB-III, Orion). The physico-chemical characterization of the adsorbents was analysed by XRD (X'Pert PRO PANalytical), FESEM (Zeiss-SIGMA) and EDAX (QUANTA FEG 250).

2.3 Batch and Kinetic Study Procedure

A stock solution (1000 mg/L F^- concentration) was prepared by dissolving 2.2789 g of NaF (Assay 97%) in 1000 mL of distilled water and from it a concentration of 10 mg/L was prepared by appropriate serial dilutions. Different conical flasks (250 mL capacity) containing desired adsorbent dosage and 50 mL volume of desired fluoride ion concentration and pH were agitated in shaker (155 rpm) at constant temperature (30 °C) for different desired time intervals. After desired contact time intervals, the mixtures were centrifuged at 3000 rpm for 5 min to separate the adsorbent and solutions. Then the solutions were filtered by Whatman no. 42 filter paper and supernatant were analysed for residual fluoride ion concentration by Fluoride Ion meter (Thermo scientific) using TISAB-III as the adjustment buffer according to the standard method described in APHA [2]. The removal efficiency (%) and adsorption capacity (mg/g) of the adsorbents are calculated by the following equations [17]:

$$\text{Fluoride removal efficiency } (\%) = (C_i - C_e) \times 100/C_i \tag{1}$$

$$\text{Adsorption capacity } (\text{mg/g}) = (C_i - C_e) \times V/(m \times 1000) \tag{2}$$

where C_i = Initial fluoride concentration (mg/L), C_e = Equilibrium fluoride concentration (mg/L), V = Volume of sample (mL) and m = Mass of adsorbent (g). The variations of parameters studied were dose variation (0.1–5 g), shaker speed (75–200 rpm), temperature (15–70 °C), initial concentration (0.1–100 mg/L) and contact time (1–300 min).

2.4 Column Study Procedure

The column experiment was performed by designing a column (ID = 25 mm, height 300 mm) with base made up of perforated glass plate. The two outlet pipes (ID = 5 mm) were inserted at bottom and another at height of 250 mm from base. The bottom was filled with cotton wool (3 mm thickness) then adsorbent (coal-coated with $FeCl_3$) was filled up to 5 cm height and then covered by cotton wool (3 mm thickness). The top end was air tightened by rubber cork with nozzle surmounted in it. The desired initial fluoride concentration was continuously sucked through silicon tube (ID = 5 mm) from a reservoir (20 L capacity) by peristaltic pump (Everest analyticals, EA-110S-50-DPM) and desired flow rate maintained by it. The constant freeboard of 3–5 cm was maintained throughout the experiment. The effluents were collected at fixed time intervals and analysed for residual fluoride concentration by Ion meter. The column experiment was performed at standard atmospheric condition and room temperature (25 ± 2 °C). The experiment was performed by flow rate variation (flow rates = 1 mL/min, 2 mL/min, 3 mL/min; Bed depth = 5 cm; Initial fluoride concentration = 10 mg/L), bed depth variation (bed depths = 5 cm, 10 cm, 15 cm; flow rate = 1 mL/min, Initial fluoride concentration = 10 mg/L) and initial concentration variation (initial concentrations = 10 mg/L, 20 mg/L, 30 mg/L; flow rate = 1 mL/min; bed depth = 5 cm).

3 Theory

3.1 Theory of Batch and Kinetic Study

The pseudo-first order, pseudo-second order, Weber–Morris and Elovich kinetics were used to find the rate of fluoride sorption onto the surface of the adsorbents. The isotherm study was carried out to draw the relations between solute and adsorption mechanisms at solid surfaces. Different isotherm patterns like Langmuir, Freundlich, Dubinin–Raduskevich and Temkin were experienced in the present work to define the appropriate solute transport mechanism [13, 29]. The equations of the adsorption kinetics and isotherm models and thermodynamics study are shown in Table 1. To draw the best fit line, the coefficient of determination (R^2) was used which denotes the strength of the linear association between variables x and y such that $0 \leq R^2 \leq 1$. The quantity R^2 was calculated by the mathematical formula [5, 19]:

$$R^2 = \sum (y_c - y_a)^2 / \sum \left((y_c - y_a)^2 + (y_c - y_e)^2 \right) \tag{3}$$

where y_e, y_c and y_a are the experimental value, calculated value and average of the experimental values, respectively.

3.2 Theory of Column Study

The performance of the column studies was evaluated from breakthrough curves. The breakthrough curves were obtained by plotting the normalized fluoride concentration (C_t/C_0) versus cumulative time (V_T) at time t for a given bed depth height (H) and flow rate (q). Here, C_t is the effluent fluoride concentration at time t and C_0

Table 1 Modelling of batch and kinetic experiments data

Sl. No.	Model name	Equations	Plot	Evaluated parameter	References
Kinetic study					
1	Pseudo-first order	$\log(Q_e - Q_t) = \log Q_e - r_1.t/2.3$	$\log(Q_e - Q_t)$ versus t	Q_e, r_1	[20, 23]
2	Pseudo-second order	$t/Q_t = 1/(r_2.Q_e^2) + (1/Q_e).t$	t/Q_t versus t	Q_e, r_2	[9, 22]
3	Weber–Morris	$Q_t = K_{ip}.t^{1/2} + C$	Q_t versus $t^{1/2}$	K_{ip}, C	[41, 44]
4	Elovich	$Q_t = 1/E_2 \ln(E_1.E_2) + 1/E_2 \ln t$	Q_t versus ln t	E_1, E_2	[1]
Isotherm study					
5	Langmuir isotherm	$C_e/Q_e = C_e/Q_0 + 1/(Q_0 b_L)$	C_e/Q_e versus C_e	Q_0, b_L	[13, 21]
6	Freundlich isotherm	$\log Q_e = \log K_f + (1/n) \log C_e$	$\log Q_e$ versus $\log C_e$	K_f, n	[11, 24]
7	Temkin isotherm	$Q_e = B \ln C_e + B \ln A_T$	Q_e versus $\ln C_e$	B, A_T	[32, 35]
8	Dubinin–Raduskevich	$\ln Q_e = -r_{ad} \epsilon^2 + \ln Q_m$	$\ln Q_e$ versus ϵ^2	Q_m, r_{ad}	[8], [35]
	Thermodynamics study				
9		$K_d = Q_e/C_e$		K_d	[27]
10		$\ln K_d = \Delta S/R - \Delta H/RT$	1/T versus $\ln K_d$	ΔH, ΔS	[29, 34]
11		$\Delta G = \Delta H - T\Delta S$		ΔG	[32]

is the inlet fluoride concentrations. The volume (V_T) at any time t can be calculated by equation [18]:

$$V_T = q.t/1000 \tag{4}$$

where q is the flow rate (mL/min) and t the run time (min) of the column, respectively. When the effluent fluoride concentration becomes equal to the influent fluoride concentration after a long run time then the column is assumed to be exhausted [18]. The total quantity of fluoride adsorbed (M_{ads}) in milligram (mg) by the column can be calculated by equation [18]:

$$M_{ads} = M_{total} - M_{pass} \tag{5}$$

where $M_{total} = V_{total}C_0$ = Total quantity of fluoride applied through the column (mg) and M_{pass} = Area under normalized breakthrough curve, i.e. C_t/C_0 versus Cumulative time (V_T).

The total fluoride removal efficiency, i.e. column performance (CP) by the column was calculated by equation [20]:

$$\mathrm{CP}\ (\%) = (\mathrm{M_{ads}}/\mathrm{M_{total}}) \times 100 \tag{6}$$

The total adsorption capacity (Q_e) in mg/g of the adsorbent was obtained by equation:

$$\mathrm{Q_e} = \mathrm{M_{ads}}/\mathrm{m} \tag{7}$$

where m = mass of the adsorbent in the column bed.

The Empty Bed Contact Time (EBCT) in minute (min.) is calculated by expression:

$$\mathrm{EBCT\ (minute)} = \mathrm{V/q} \tag{8}$$

where V = Empty bed volume in cm^3 and q = Flow rate in mL/min.

4 Results and Discussion

4.1 Characterization of the Adsorbent

The adsorbents were physically and chemically characterized by EDAX, SEM and XRD. The chemical compositions were determined by EDAX (Fig. 1) and the results were as follows (% wt.): C (36.1), O (33.5), Fe (13.8), Al (2.7), Si (11.4), Cl (0.66), Ca (0.1) Mn (1.9). The SEM images (Fig. 2) of the adsorbent showed that the large agglomeration of the fluoride ions on the surfaces and holes of the adsorbent in post-adsorption. It indicates that the adsorption process occurred up to maximum limits. The results of XRD (Match! 3 software) showed that quartz (Entry no. 96-900-0776) were found at 2ϴ angles of 20.9° in pre-adsorption and graphite (Entry no: 96-901-2231) were found at 2ϴ angles of 26.7° in post-adsorption process (Fig. 3).

4.2 Batch and Kinetic Study Results

Effect of dose variation

The effects of dose variation on fluoride sorption were studied by plotting adsorbent dose versus uptake capacity (Fig. 4). The stability in uptake capacity after further dose of 2 g was due to deficiency of fluoride ions for further adsorption.

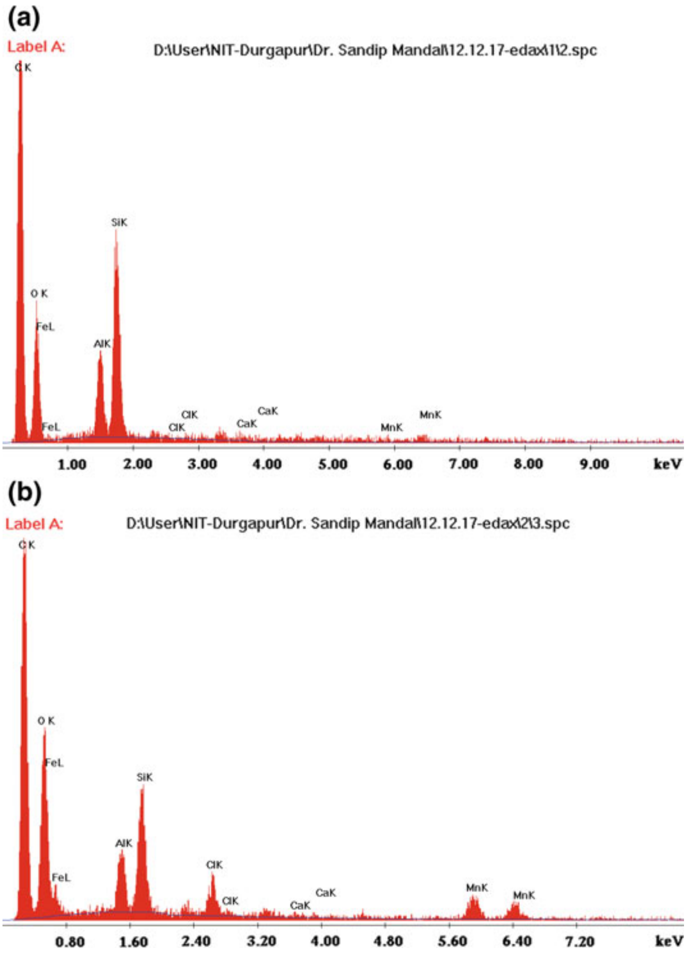


Fig. 1 EDAX analysis **a** pre-adsorption, **b** post-adsorption

Effect of shaking speed variation

The effect of the shaking speed onto fluoride removal efficiency was plotted against shaking speed versus. fluoride removal efficiency (Fig. 5). At higher shaking speeds (> 50 rpm) less significant change in fluoride removal efficiency were observed. The rate of adsorption is governed by two factors, i.e. film diffusion and inter-particle diffusion and that can be expressed by modified Arrhenius equation [27] as $R_{ads} = S.F$, where R_{ads} = rate of adsorption, S = sticking probability, F = incident molecular flux = $P/(2\pi mkT)^{1/2}$, P = gas pressure, m = mass of one molecule, k = Boltzmann constant, T = temperature. Thus at constant mass, temperature and pressures, $R_{ads} \propto S$, i.e. rate of arrival of molecules at the surface which had decreased due to high centrifugal force generated at higher speeds.

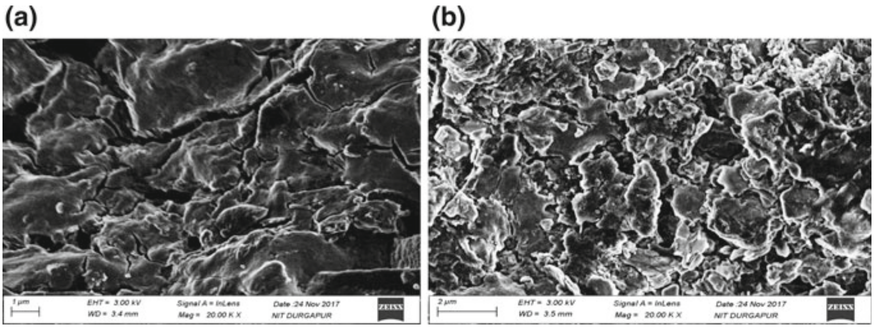


Fig. 2 SEM images **a** pre-adsorption, **b** post-adsorption

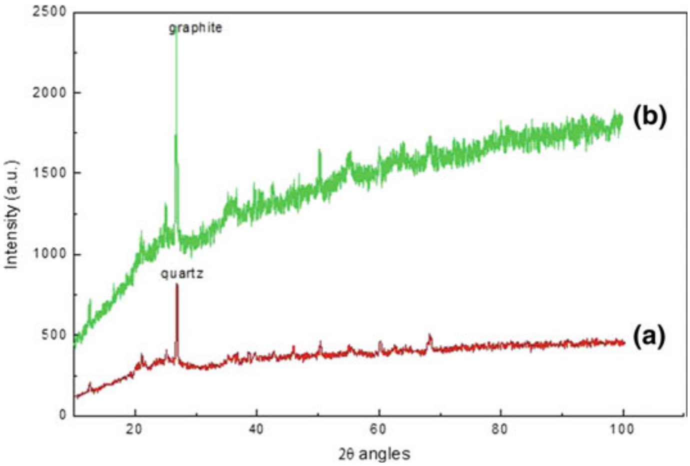
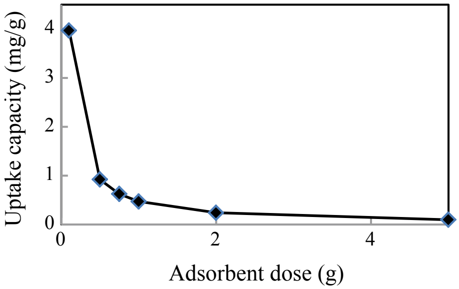


Fig. 3 XRD patterns **a** pre-adsorption, **b** post-adsorption

Fig. 4 Effects of adsorbent dose on fluoride sorption at 25 °C and fluoride concentration of 10 mg/L



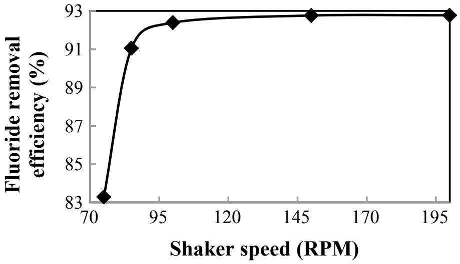


Fig. 5 Shaking speeds versus fluoride removal efficiency at 25 °C and Initial fluoride concentration used of 10 mg/L

Effect of temperature variation

The effects of temperature on fluoride sorption were studied by varying the temperatures from 15 to 70 °C. The free energy changes (ΔG), enthalpy changes (ΔH) and entropy changes (ΔS) were evaluated by plot of 1/T versus $\ln K_d$(Vant Hoff equation) with equations given in Table 1 [37] and obtained results were tabulated in Table 2.

All the evaluated parameters were positive. The positive ΔH revealed the endothermic [4, 37] process by the increased surface coverage, expansion and creation of the reactive and active sites at the higher temperatures. The positive ΔS indicate that the randomness at interfaces with adsorbents had increased [36, 37]. The positive ΔG indicates that the adsorption process was non-spontaneous.

Adsorption kinetics study

The pseudo-first order, pseudo-second order, Weber–Morris and Elovich kinetics were studied (Fig. 6) to find the rate of fluoride sorption onto the surface of the adsorbents by using the adsorption kinetics equations given in Table 1 and obtained kinetic constants were tabulated in Table 3.

The adsorption mechanism adapted to pseudo-second order kinetics with the highest coefficient of determination ($R^2 = 1$) with pseudo-second order rate constant of 4.45 g/mg-min. As contact time increased from 1 min to 5 h the fluoride removal efficiency also increased up to 1 h of contact time with maximum removal efficiency of 93% then onwards due to desorption process occurred there were no significant changes in fluoride removal efficiency.

Table 2 Evaluated thermodynamic parameters onto fluoride sorption for coal-coated with $FeCl_3$

Adsorbent	ΔH (KJ/mol)	ΔS (KJ/mol-K)	ΔG (KJ/mol)					R^2
			15 °C	30 °C	45 °C	60 °C	70 °C	
Coal-coated with $FeCl_3$	14.2	49.3	13.4	12.7	11.9	11.2	10.7	0.9789

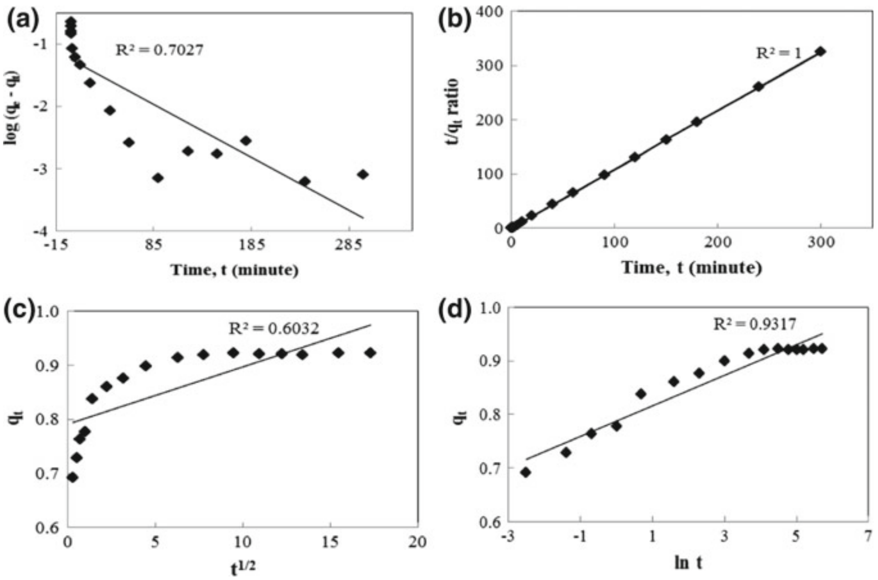


Fig. 6 Adsorption kinetic models **a** Pseudo-first order, **b** Pseudo-second order, **c** Weber–Morris, **d** Elovich

Table 3 Adsorption kinetics constants for fluoride sorption onto the surface of the coal-coated with $FeCl_3$

Pseudo-first order	r_1(min^{-1})	Q_e(mg/g)	R^2
	0.02	60.0	0.7027
Pseudo-second order	r_2(g/mg min)	Q_e(mg/g)	R^2
	4.45	92.0	1
Weber–Morris	K_{ip}(mg/g min$^{1/2}$)	C	R^2
	0.01	0.79	0.6032
Elovich	E_2(g/mg)	E_1(mg/g min)	R^2
	35.21	3E + 10	0.9317

Adsorption isotherm study

The equations of the adsorption isotherm models (shown in Table 1) were used to plot the different isotherm patterns like Langmuir, Freundlich, Temkin and Dubinin–Raduskevich (Fig. 7). The adsorption isotherm constants for fluoride sorption onto the adsorbent were tabulated in Table 4.

The adsorption process fitted to Freundlich isotherm with the highest coefficient of determination (R^2 = 0.9757) and Freundlich constant for adsorption intensity (n = 0.55) revealed that the adsorption process was chemical in nature [41]. The maximum adsorption capacity of the adsorbent (Q_m) was evaluated as 88.6 mg/g by

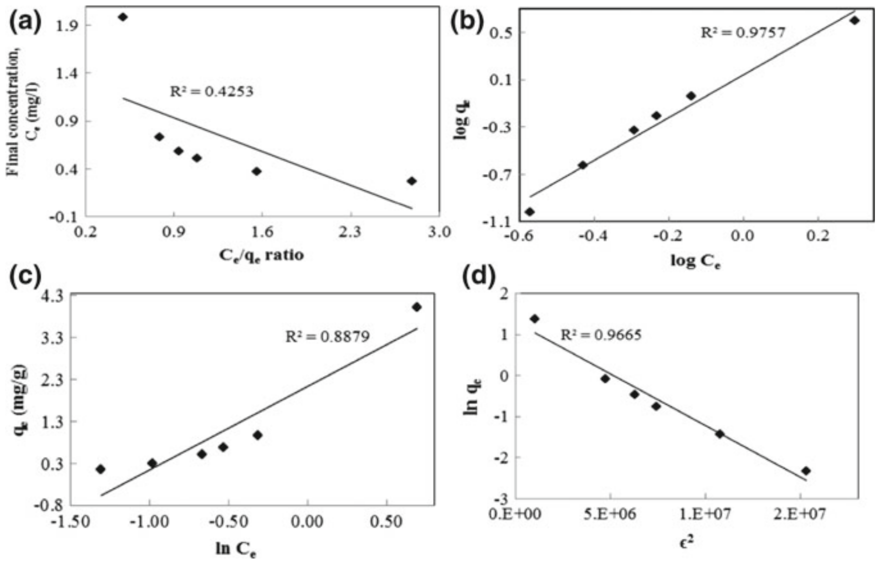


Fig. 7 Adsorption isotherm models **a** Langmuir, **b** Freundlich, **c** Temkin, **d** Dubinin–Raduskevich

Table 4 Adsorption isotherm constants for fluoride sorption onto the surface of the coal-coated with $FeCl_3$

Langmuir	Q_0 (mg/g)	b_L (L/mg)	R^2
	60.2	0.36	0.4253
Freundlich	K_f ($\mu g^{1-(1/n)}$ $L^{1/n}$ g^{-1})	n	R^2
	1.39	0.55	0.9757
Temkin	A_T (L/g)	B (J/mol)	R^2
	2.86	1.99	0.8879
Dubinin–Raduskevich	r_{ad} (mol^2/kJ^2)	Q_m (mg/g)	R^2
	3.0E-07	63.3	0.9665

Halsey equation ($Q_m = K_f C_0^{1/n}$) with initial concentration ($C_0 = 10$ mg/L) and Freundlich isotherm constant ($K_f = 1.39$). From Langmuir isotherm, the nature and feasibility of the adsorption process were calculated by $R_L = 1/(1 + Q_0 b_L)$ and it was found to be 0.58 ($0 < R_L < 1$) indicates that the adsorption was favourable [10]. From Dubinin–Raduskevich isotherm the mean free energy ($E = 1/(\sqrt{2}\ r_{ad})$ was calculated as 1.29 kJ/mol it indicates that the adsorption mechanism was physisorption ($E < 8$ kJ/mol) in nature [37].

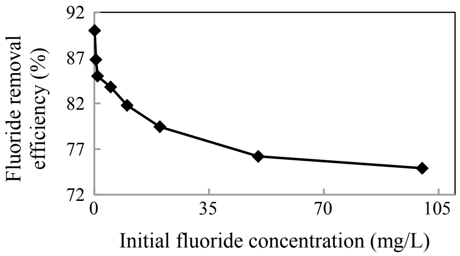


Fig. 8 Effect of initial fluoride concentration on fluoride sorption by the coal-coated with $FeCl_3$ at 25 °C (pH = 7 ± 0.2)

Table 5 Comparative analysis of fluoride sorption onto various adsorbents

Sl. No.	Adsorbent	Initial F^- conc. (mg/L)	Adsorption capacity (mg/g)	Removal efficiency (%)	References
1	Bleaching powder	5.0	0.13	90	[14]
2	Brick powder	1.2	0.70	56	[28]
3	Chitosan beads	20.0	1.57	75	[46]
4	Broken bricks	6.0	0.10	75	[43]
5	Cellulose	8.0	1.11	75	[39]
6	Coal-coated with $FeCl_3$	10.0	88.60	96	Present work

Effects of initial fluoride concentrations

The fluoride removal efficiency decreased linearly up to 50 mg/L of initial fluoride concentration then afterwards no significant changes in removal efficiency (Fig. 8) because the binding capacity of adsorbent become saturated at the higher initial fluoride concentrations [16] (Table 5).

4.3 Column Study Results

The fixed-bed column study for fluoride mitigation by the adsorbent was studied in down-flow mode. The observations were made at 1 h interval up to exhausting point. The permissible limits of fluoride concentrations in drinking water set as 1.5 mg/L [45]. Thus, a breakthrough concentration for the column study was fixed as 1.5 mg/L [34].

Effect of flow rate variations

The column experiment was conducted with initial influent fluoride concentration of 10 mg/L, bed depth of 5 cm and flow rate variations of 1 mL/min, 2 mL/min and 3 mL/min at normal room temperature and atmospheric conditions. The

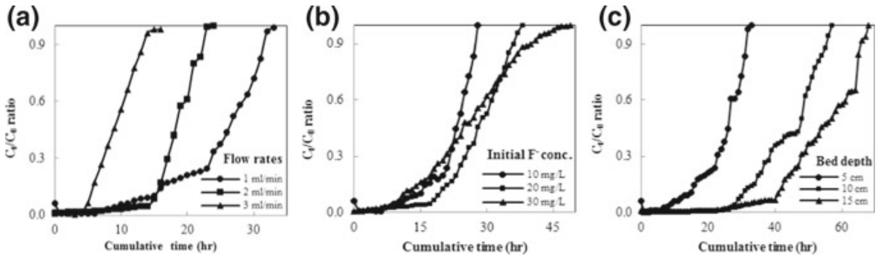


Fig. 9 Breakthrough curves onto fluoride sorption of coal-coated with $FeCl_3$ **a** Effect of flow rates [H = 5 cm, C_0 = 10 mg/L, Φ = 2.5 cm], **b** Effect of initial fluoride concentrations [H = 5 cm, q = 1 mL/min, Φ = 2.5 cm], **c** Effect of bed depths [q = 1 mL/min, C_0 = 10 mg/L, Φ = 2.5 cm]

Table 6 Evaluated parameters of column study onto fluoride sorption of coal-coated with $FeCl_3$

Parameters	T_B (hr.)	T_E (hr.)	V_B (L)	V_E (L)	EBCT (min)	M_{ads} (mg)	Q_e (mg/g)	CP (%)
Flow rate (mL/min)								
1	12.4	45.5	0.74	2.73	24.5	19.0	38.1	95.9
2	9.5	30.7	1.14	3.68	12.3	28.2	56.4	98.1
3	4.4	15.8	0.78	2.84	8.2	29.2	58.4	97.7
Initial F^-conc. (mg/L)								
10	11.5	42.6	0.69	2.5	2.4	16.2	32.4	96.5
20	14.3	48.2	0.86	2.9	1.2	44.6	89.2	97.8
30	11.6	46.1	0.71	2.8	0.8	85.9	171	97.4
Bed depth (cm)								
5	12.2	44.3	0.73	2.7	24.5	18.9	37.9	95.4
10	23.4	78.6	1.41	4.7	49.1	32.9	32.9	96.3
15	29.1	101.2	1.75	6.1	73.6	39.4	26.3	96.6

breakthrough curve was obtained by plotting normalized fluoride concentrations (C_t/C_0) versus cumulative time (V_T) as shown in Fig. 9a and the column performances and other calculated parameters of the adsorbent were tabulated in Table 6.

The performance of the column (98.1%) at 2 mL/min is highest due to the fact that the rate of diffusion of the solutes onto the pores of the sorbents is low [3] at lower flow rates.

Effect of initial fluoride concentrations

The effect of initial fluoride concentrations on column performance and other parameters were investigated by varying the influent fluoride concentrations from 10 mg/L to 30 mg/L at flow rate of 1 mL/min and bed depth of 5 cm as shown in Fig. 9b and evaluated parameters onto the fluoride sorption of the adsorbent are tabulated in Table 6. From Fig. 9b it was observed that the breakthrough curve saturated earlier at lower influent concentrations due to the fact that at higher concentrations the fluoride saturates the column bed earlier and thereby shortens the breakthrough time.

Effect of bed depths

The bed depth of the adsorbent strongly affects the effluent fluoride concentrations. The effect of bed depth onto fluoride sorption of the coal-coated with $FeCl_3$ as shown in Fig. 9c and other evaluated parameter like total adsorbed fluoride quantity, treated water volume at breakthrough point, column exhausted time, breakthrough time, column performance and adsorption capacity at different bed depths of the adsorbents were presented in Table 6. The column performance efficiency had increased with increase in bed depth due to the more contact time between adsorbent and adsorbate. The breakthrough curves at lower bed depths are steeper than higher bed depths due to the fact that with smaller bed depths the column exhausted more quickly than other higher bed depths.

4.4 *Modelling of Breakthrough Curves*

Yoon–Nelson model

Yoon and Nelson [48] have developed less complicated model to represent the breakthrough of adsorbate onto the surface of adsorbent and it can be expressed mathematically as [20]:

$$\ln(C_t/(C_0 - C_t)) = K_{YN}t - \tau K_{YN} \tag{9}$$

where K_{YN} is the rate constant (min^{-1}) and τ is the time required for 50% adsorbate breakthrough (min). K_{YN} and τ were obtained from the slope and intercepts in the linear plots of $\ln(C_t/(C_0-C_t))$ versus t and the calculated values were tabulated in

Table 7 Modelling of breakthrough curves at different bed depths [C_0 = 10 mg/L, q = 1 mL/min, Φ = 2.5 cm]

Model	Bed depth (cm)	K_{Th} (mL/mg-min)	Q_e (mg/g)	R^2	Plot	References
Thomas model	5	0.024	90.5	0.9112	$\ln(C_0/C_t-1)$ versus t	[3, 37]
	10	0.016	74.8	0.9412		
	15	0.012	55.3	0.9441		
		K_{YN} (min^{-1})	τ (min)	R^2	Plot	References
Yoon–Nelson model	5	0.235	23.8	0.9112	$\ln(C_t/(C_0-C_t))$ versus t	[3, 45]
	10	0.157	44.9	0.9412		
	15	0.119	55.3	0.9441		

Table 7. The results showed that with increase in bed depth the K_{YN} values decreased and τ values increased also the experimental time (τ_{exp}) and calculated time (τ_{cal}) for achieving effluent fluoride concentrations to 50% of the initial fluoride concentration was almost same.

Thomas model

Thomas [40] developed the equation based on the three assumptions that the adsorption process follows Langmuir model with no axial dispersion, the rate of adsorption kinetic force obeys second order reversible reaction and the model assumes a separation factor, which is applicable for both favourable and unfavourable isotherms. The linear form of the model can be written as:

$$\ln(C_0/C_t - 1) = (K_{Th}Q_e m/q) - K_{Th}C_0 t \tag{10}$$

where m is the mass of adsorbent (g), Q_e is the maximum adsorption capacity (mg/g), K_{Th} is the Thomas rate constant (mL/mg-min) and q is the flow rate (mL/min). C_0 and C_t are the influent and effluent concentration of the column, respectively. The K_{Th} and Q_e values obtained from the slope and intercepts of the linear plot of ln $((C_0/C_t)-1)$ versus t for the flow rate (q) were tabulated in Table 7. The maximum adsorption capacity (Q_e) obtained by Thomas model and theoretically calculated were same and it was observed that Thomas rate constant and the adsorption capacity were decreased with the increment of bed heights.

5 Conclusions

The conclusions of the present work were summarized in the following points:

(i) Batch study revealed that the adsorption capacities depend on pH, temperature, shaking speed, initial fluoride ions concentration and the dosages of the adsorbents. The maximum fluoride adsorption capacities and the removal efficiencies taken place at the optimum pH of 7, the adsorbent dose of 2 g, equilibrium time of 3 h, shaking speed of 155 RPM and at the temperature of 25 °C ± 2 °C.

(ii) Kinetic study revealed that the adsorbent had reached the equilibrium within 3 h and maximum fluorides adsorption by the adsorbent had taken place within 2 h and the sorption mechanism best fitted to pseudo-second order kinetics.

(iii) The thermodynamic study revealed that the adsorption mechanism was non-spontaneous and endothermic in nature.

(iv) According to best fit, the isotherm models can be arranged as: Freundlich > Dubinin–Raduskevich > Temkin > Langmuir. The maximum fluoride removal efficiency and maximum adsorption capacity of the adsorbent were 96% and 88.6 mg/g, respectively.

(v) The SEM images, XRD patterns and EDAX analysis of the adsorbent confirmed that the adsorption had taken up to maximum limits by physicochemical process.
(vi) Column study revealed that the highest adsorption capacity (88.6 mg/g) and column performance (98%) had achieved at flow rate of 2 mL/min, initial fluoride concentration of 20 mg/L and bed depth of 5 cm and these values (Q_e and fluoride removal eff.) are satisfactory with the results obtained by batch and kinetic studies.
(vii) The modelling of breakthrough curves best fitted to Thomas and Yoon–Nelson models with moderate to high value of coefficient of determination ($R^2 = 0.9112$ to 0.9441) at different bed depths.

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References

1. Akpomie, K.G., Dawodu, F.A.: Potential of a low-cost bentonite for heavy metal abstraction from binary component system. Beni Suef Univ. J. Basic Appl. Sci. **4**, 1–13 (2015)
2. APHA: Standard methods for examination of water and wastewater. American Public Health Association WWA, Washington, DC (2005)
3. Baral, S.S., Das, N., Ramulu, T.S., Sahoo, S.K., Das, S.N., Chaudhury, G.R.: Removal of Cr (VI) by thermally activated weed Salvinia cucullata in a fixed-bed column. J. Hazard. Mater. **161**(2–3), 1427–1435 (2009)
4. Bouberka, Z., Kaoha, S., Elmaleh, S., Derriche, Z.: Sorption study of an acid dye from an aqueous solution using modified clays. J. Hazard. Mater. **119**, 117–124 (2005)
5. Chang, C.F., Chang, C.Y., Chen, K.H., Tsai, W.T., Shie, J.L., Chen, Y.H.: Adsorption of naphthalene on zeolite from aqueous solution. J. Colloid Interface Sci. **277**(1), 29–34 (2004)
6. Daniel, W.W.: Biostatistics: a foundation for analysis in the health sciences. Wiley, New York (1999)
7. Datta, A.S., Chakrabortty, A., De Dalal, S.S., Lahiri, S.C.: Fluoride contamination of underground water in West Bengal, India. Res. Rep. Fluoride **47**(3), 241–248 (2014)
8. Dubinin, M.N., Zaverina, E.D., Radushkevich, L.V.: Sorption, and structure of activated carbons: adsorption of organic vapours. J. Phys. Chem. **21**, 1351–1362 (1947)
9. Fan, Q., Li, P., Chen, Y., Wu, W.: Preparation and application of attapulgite/iron oxide magnetic composites for the removal of U(VI) from aqueous solution. J. Hazard. Mater. **192** (3), 1851–1859 (2011)
10. Foo, K.Y., Hameed, B.H.: Insights into the modelling of adsorption isotherm systems. Chem. Eng. J. **156**, 2–10 (2010)
11. Freundlich, H.M.F.: Over the adsorption in solution. J. Phys. Chem. **57**, 385–471 (1906)
12. Ghosh, A., Mondal, S.: Application of multivariate statistics towards the geochemical evaluation of fluoride enrichment in groundwater at Shilabati river bank West Bengal. Environ. Eng. Res., India (2018)
13. Giles, C.H., Macewan, T.H., Nakhwa, S.N., Smita, D.: System of classification of solution adsorption isotherms, and its use in diagnosis of adsorption mechanisms and in measurement of specific surface areas of solids. J. Chem. Soc. (Resumed) **11**, 3973 (1960)

14. Hamdaoui, O.: Batch study of liquid-phase adsorption of methylene blue using cedar sawdust and crushed brick. J. Hazard. Mater. **135**(1–3), 264–273 (2006)
15. Kagne, S., Jagtap, S., Thakare, D., Devotta, S., Rayalu, S.S.: Bleaching powder: a versatile adsorbent for the removal of fluoride from aqueous solution. Desalination **243**, 22–31 (2009)
16. Kamble, S.P., Jagtap, S., Labhsetwar, N.K., Thakare, D., Godfrey, S., Devotta, S., Rayalu, S. S.: Defluoridation of drinking water using chitin, chitosan, and lanthanum-modified chitosan. Chem. Eng. J. **129**, 173–180 (2007)
17. Kumar, E., Bhatnagar, A.M., Jung, W., Lee, S., Kim, S., Lee, G., Song, H., Choi, J., Yang, J., Jeon, B.: Defluoridation from aqueous solutions by granular ferric hydroxide (GFH). Water Res. **43**, 490–498 (2009)
18. Kumar, P.A., Chakraborty, S.: Fixed-bed column study for hexavalent chromium removal and recovery by short-chain polyaniline synthesized on jute fibre. J. Hazard. Mater. **162**(2–3), 1086–1098 (2009)
19. Kundu, S., Gupta, A.: Arsenic adsorption onto iron oxide-coated cement (IOCC): regression analysis of equilibrium data with several isotherm models and their optimization. Chem. Eng. J. **122**(1–2), 93–106 (2006)
20. Kundu, S., Gupta, A.K.: As (III) removal from aqueous medium in fixed bed using iron oxide-coated cement (IOCC): experimental and modelling studies. Chem. Eng. J. **129**(1–3), 123–131 (2007)
21. Lagergren, S.: About the theory of so-called adsorption of soluble substances. Ksven Vetenskapsakad Handl. **24**(4), 1–39 (1898)
22. Langmuir, I.: The adsorption of gases on plane surfaces of glass, mica, and platinum. J. Am. Chem. Soc. **40**, 1361–1403 (1918)
23. Lie, T., Liu, Y., Peng, Q., Hua, X., Liao, T., Wanga, H.: Removal of lead (II) from aqueous solution with ethylenediamine-modified yeast biomass coated with magnetic chitosan microparticles: kinetic and equilibrium modelling. Chem. Eng. J. **214**, 189–197 (2013)
24. Liu, Z., Chen, X., Zhou, L., Wei, P.: Development of a first order kinetics-based model for the adsorption of nickel onto peat. Min. Sci. Technol. (China) **19**(2), 230–234 (2009)
25. Mall, I.D., Srivastava, V.C., Agarwal, N.K., Mishra, I.M.: Adsorptive removal of malachite green dye from aqueous solution by bagasse fly ash and activated carbon-kinetic study and equilibrium isotherm analyses. Colloids Surf., A **264**(1–3), 17–28 (2005)
26. Mann, S., Mandal, A.: Performance of low-cost adsorbents for the removal of fluoride ions—an overview. Int. J. Eng. Sci. Innovative Technol. (IJESIT) **3**(3), 2319–5967 (2014)
27. Mobasherpour, I., Salahi, E., Ebrahimi, M.: Thermodynamics and kinetics of adsorption of Cu (II) from aqueous solutions onto multi-walled carbon nanotubes. J. Saudi Chem. Soc. **18**(6), 792–801 (2014)
28. Mondal, S., Kumar, S.: Investigation of fluoride contamination and its mobility in groundwater of Simlapal block of Bankura district, West Bengal, India. Environ. Earth Sci. **76**(22), 778 (2017)
29. Mondal, S., Mahanta, C.: Evaluation of arsenic adsorption capacity of indigenous materials for their suitability as filter media. Desalin. Water Treat. **84**, 309–323 (2017)
30. Pandey, P.K., Choubey, S., Verma, Y., Pandey, M., Chandrashekhar, K.: Biosorptive removal of arsenic from drinking water. Bioresour. Technol. **100**(2), 634–637 (2009)
31. Rani, B., Maheshwari, R., Chauhan, A.K., Bhaskar, N.S.: Defluoridation of contaminated water employing brick powder as an adsorbent. Int. J. Sci. Nat. **3**(1), 78–82 (2012)
32. Ranjan, D., Talat, M., Hasan, S.H.: Biosorption of arsenic from aqueous solution using agricultural residue ‘rice polish’. J. Hazard. Mater. **166**(2–3), 1050–1059 (2009)
33. Razbe, N., Kumar, R., Kumar, P.R.: Various options for removal of fluoride from drinking water. IOSR J. Appl. Phys. **3**(2), 40–47 (2013)
34. Reza, R., Singh, G.: Heavy metal contamination and its indexing approach for river water. Int. J. Environ. Sci. Technol. **7**(4), 785–792 (2010)

35. Senthil, K.P., Ramalingam, S., Senthamarai, C., Niranjanaa, M., Vijayalakshmi, P., Sivanesan, S.: Adsorption of dye from aqueous solution by cashew nut shell: Studies on equilibrium isotherm, kinetics and thermodynamics of interactions. Desalination **261**(1–2), 52–60 (2010)
36. Sundaram, S.C., Viswanathan, N., Meenakshi, S.: Defluoridation of water using magnesia/chitosan composite. J. Hazard. Mater. **163**(2–3), 618–624 (2009)
37. Suneetha, M., Sundar, B.S., Ravindhranath, K.: Removal of fluoride from polluted waters using active carbon derived from barks of Vitexnegundo plant. J. Anal. Sci. Technol. **6**, 15 (2015)
38. Temkin, M.I., Pyzhev, V.: Kinetics of ammonia synthesis on promoted iron catalyst. Acta Physicochim. URSS **12**, 217–222 (1940)
39. Teotia, M., Teotia, S.P.S., Singh, K.P.: Endemic chronic fluoride toxicity and dietary calcium deficiency interaction syndromes of metabolic bone disease and deformities in India: Year 2000. Indian J. Paediatr. **65**(3), 371–381 (1998)
40. Thomas, H.C.: Heterogeneous ion exchange in a flowing system. J. Am. Chem. Soc. **66**(10), 1664–1666 (1944)
41. Vimonses, V., Lei, S., Jin, B., Chris, C.W.K., Saint, C.: Kinetic study and equilibrium isotherm analysis of Congo Red adsorption by clay materials. Chem. Eng. J. **148**(2–3), 354–364 (2009)
42. Waghmare, S.S., Arfin, T.: Defluoridation by adsorption with chitin—chitosan-alginate-polymers-cellulose-resins-algae and fungi—A review. Int. Res. J. Eng. Technol. (IRJET) **2**(6), 1179–1197 (2015)
43. Waghmare, S.S., Arfin, T.: Fluoride removal from water by various techniques: review. Int. J. Innovative Sci. Eng. Technol. **2**(9), 560–571 (2015)
44. Weber, W.J., Morris, J.C.: Kinetics of adsorption on carbon from solution. J. Saint. Eng. Div. **89**, 31–60 (1963)
45. WHO: Fluoride in drinking water. Background document for preparation of WHO Guidelines for drinking-water quality, World Health Organization, Geneva (2003)
46. Wijesundara, T.: Low-cost defluoridation of water using broken bricks. In: 30th WEDC International Conference, Vientiane, Lao PDR (2004)
47. Wu, F.C., Tseng, R.L., Juang, R.S.: Characteristics of Elovich equation used for the analysis of adsorption kinetics in dye-chitosan systems. Chem. Eng. J. **150**(2–3), 366–373 (2009)
48. Young, H.Y., Nelson, J.H.: Application of gas adsorption kinetics I: A theoretical model for respirator cartridge service life. Am. Ind. Hyg. Assoc. J. **45**(8), 509–516 (1984)
49. Zhang, Y., Wang, D., Liu, B., Gao, X., Xu, W., Liang, L., Xu, Y.: Adsorption of fluoride from aqueous solution using low-cost bentonite/chitosan beads. Am. J. Anal. Chem. **4**, 48–53 (2013)

Solid Waste Generation Data Variability in India—An Unnoticed Hurdle

Renu Hujare and Kashinath Telsang

Abstract Availability and reliability of waste generation data is a disregarded problem in a developing country like India. Inconsistency in waste generation data is confirmed by comparing cities and states with the national-level data. It is found that data for cities and urban India are in close match with each other, which is not the case between urban India and states. Almost 22% of literature documents studied is dependent on limited data generated by CPCB and NEERI. Waste quantity is erroneously estimated when inappropriate population data is considered. This causes a wider range of percentage variability and larger values of standard deviation indicating inefficiency in data collection. The literature review explores current challenges faced in maintaining reliable waste generation data. The study recommends involvement of academic and research institutes in handling waste management database in collaboration with government. Further, the study suggests various technical and policy changes for better waste management.

Keywords MSW generation · Reliability · Data variability · Data comparability · NEERI · CPCB · Data inconsistency

1 Introduction

An efficient solid waste management system stresses the need for availability, reliability, and comparability of waste generation data [1]. Various aspects of waste management like sizing, quantification and spacing of community bins, collection and transportation vehicles, capacity of transfer stations and landfill sites, selection of treatment options [2], and their design depend on proper measurement of present

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and future waste generation and its characterization [3–6]. Additionally, reliable data on waste generation per capita is useful for comparing waste management of various cities and countries [7].

In order to design and establish technologies for material and energy recovery, it is important to develop demonstrative pilot projects keeping in view the Indian scenario of waste management [8]. In such case, continuous monitoring of the project is necessary which will require a strong backup of waste generation database. Additionally, India's varied geographic and climatic conditions have to be kept in view while quantifying waste generation [9]. Present conditions reveal that no special efforts are being taken in this regard [8, 9]. Majority of the focus is concentrated on constructing disposal facilities [8].

In case of developed nations, continuous past and current data on waste management are found to be updated properly in literature, which is not the case of developing nations [10, 11]. Incomplete and unreliable data is not suitable for applying in waste generation prediction models, which then have to be supported by some assumptions, thereby decreasing the clarity of the future predictions [10, 12]. To avoid such complexities it is important that every municipality maintains data for all the waste management activities it conducts, like daily data of waste generation quantity and monthly data of waste characterization, performance of processing, and disposal facilities [12]. Lack of official historical data and inconsistency in existing data is a major hurdle while studying the solid waste management of developing nations like India [13–17].

The data analysis reveals that there is a lack of proper documentation of data in annual reports of government. Significant number of research/literature documents are still dependent on CPCB and NEERI for waste generation data. Also, while calculating waste generation data in kg/capita/data, inappropriate population data has been considered leading to erroneous estimates of waste quantity. This leads to higher measure of variability and standard deviation indicating inefficiency in data collection.

It is necessary to be aware of the basic hurdles that are being faced in managing solid waste in India. If these hurdles are ignored, then the efficiency of waste management system will be reduced. The physical efforts and financial supports provided will be wasted, if the efficiency is lowered leading to irregular management of waste. Waste of efforts will be demotivating for the laborers and other authorities involved in the system. Thus, the entire system will be operated in haphazard manner paying no due importance to the discipline that is required for the expected efficiency.

The current study focuses on confirming the lack of availability and reliability of waste generation data in India. Mrs. Almitra Patel highlighted the intensity of the then waste management crisis in India, which led to framing and implementation of Municipal Solid Waste (Management & Handling) Rules, 2000. Since then, these rules have undergone multiple reformations. But the basic problem of improper database of waste management activities has not been noticed by the governing authorities. Although it is documented in literature many times the problem has not been given due importance. The current study aims at bringing to notice the basic hurdle of efficient waste management that is improper data maintenance.

2 Status of Waste Generation Data Availability and Reliability

As per Municipal Solid Waste (Management & Handling) Rules, 2000 the term "municipal solid waste" represents commercial and residential wastes generated in municipal or notified areas. As such, the areas which lie beyond municipal authority are deprived of proper waste management services. Waste generation rate in kg/capita/day is measured by dividing total waste generated per day given in tones per day (TPD) by population of the concerned region. In reality, waste generation is only measured for urban areas as per the Municipal Solid Waste (Management & Handling) Rules, 2000. This quantity of waste generated is divided by the population of entire state or country which comprises both rural and urban areas. This results in a lower kg/capita/day value of waste generation rate. Hence, actual waste generated by the entire state or nation, which should be a very high value, is not quantified properly. It causes underestimation of resource requirements, lack of technical/managerial inputs, and availability of reliable and updated information [4, 18].

As per Central Pollution Control Board (CPCB) annual report of 2014–15, India generated 1,41,064 tons per day (TPD) of municipal solid waste which does not include waste picked up by Kabadiwalas from households and from the streets by ragpickers [19]. On the other hand, as per the report of the Task Force on Waste to Energy (WtE) (2014) of the Planning Commission, the 7935 urban centers of India generated 1,70,000 TPD of MSW [20]. This conflict in data regarding the actual waste generation in urban India exists due to the absence of a system of periodic collection of data on waste generation [20].

Additionally, if we compare above data with the projected waste data from 2014 to 2015, it ranges between 2,35,980 TPD (at the rate of 0.556 kg/capita/day)–2,43,526 TPD (at the rate of 0.561 kg/capita/day) [21]. Thus, there is a huge difference in the actually recorded and projected MSW generation data, which can lead to a lot of incorrect estimations of the required waste management infrastructure. Even though these waste quantities remain unconsidered in the planning process of waste management and related policies they end up in our landfills [22]. This leads to underestimation of waste, which can cause inadequate preparation for larger landfill space requirement in future [22].

As per the latest report of Planning Commission (2014), the actual collection of waste generated daily in India is just 68% [19]. The waste that remains uncollected often lies outside the collection bins due to improper design, capacity, location, and poor attitude of the community toward using bins [19]. Few cities have achieved some progress in waste management, but many cities and towns have not even initiated the measures leading to an improper waste management, due to which the

Supreme Court order of complete compliance to the rules by 2003 could not be achieved by urban local bodies (ULBs) [13].

In India, there is unavailability of primary data on per capita waste generation and its characteristics. Additionally, there is no consideration towards influence of informal sectors. This is reflected in different values and projections of waste generation given by different study reports which make it difficult to assess the land requirement for disposal and select appropriate treatment techniques [23].

The issue with the data on waste generated per capita per day presented by Indian researchers is that most of the figures are extrapolated values drawn from the data reported in the study documents generated by CPCB with assistance of National Environmental Engineering Research Institute (NEERI, Nagpur) during 2004–2005 for 59 cities (35 metro cities and 24 state capitals) [9, 24]. The data acquired in such manner is then just multiplied with rural/urban population data (or both inclusive) of the respective year to quantify the amount of solid waste generated in that year. Nonuniformity in type of population used leads to an incorrect estimation of data and hence, improper management [25].

Considering above issues, the current work is motivated towards the study of waste generation data availability, reliability, and comparability at national, state, and regional levels. Literature study has been done to identify various hurdles in availing reliable and comparable waste generation data and possible solutions to overcome these hurdles are presented.

3 Methodology

We have reviewed and collected data from various research documents along with CPCB and State Pollution Control Boards' (SPCBs) annual reports. To confirm the problems related to waste management in India, which is already presented in above sections, the current study method has been divided into four major parts.

3.1 *Assessment of Percentage Data Availability*

Current study is mostly based on open source data availability. CPCB and all SPCB websites were accessed for their annual reports on waste management in their administrative areas. Count of total annual reports "accessible" on CPCB website between 2001 and 2017 was found, as majority of the waste generation data recording was done in this period. Further, the count of annual reports of the total which "actually" provided waste generation data was identified. Percentage of data availability was measured as the ratio of number of annual reports "actually" providing the waste generation data to the total number of annual reports "accessible" to public from 2001 to December 2017. Similar methodology was followed in case of various SPCBs.

3.2 Assessment of Percentage Researchers Dependent on CPCB and NEERI for MSW Data

Many researchers have expressed lack of waste generation data availability in India. As a result, these researchers have to be dependent on data generated through limited number of nationwide surveys conducted by NEERI, Nagpur and CPCB, Delhi [27]. Apart from these organizations, Environment Protection and Research Institute (EPTRI) in 1999–2000, Federation of Indian Chambers of Commerce and Industry (FICCI) in 2009, and Central Institute of Plastics Engineering and Technology (CIPET) in 2010–2011 have conducted waste generation data surveys across the cities of India [64].

The measure of this "dependency" of researchers and practitioners on limited sources of data was found by studying totally 153 number of research papers (on Indian case studies) and government reports (excluding annual reports of CPCB and SPCBs). In order to assess these literature/research documents and government reports, they have been classified as per Fig. 1 into directly and indirectly dependent documents. Directly dependent documents are those who have extracted waste generation data directly from NEERI and CPCB study reports, while indirectly dependent documents are those who extracted data of NEERI and CPCB study reports cited in other research papers or government reports.

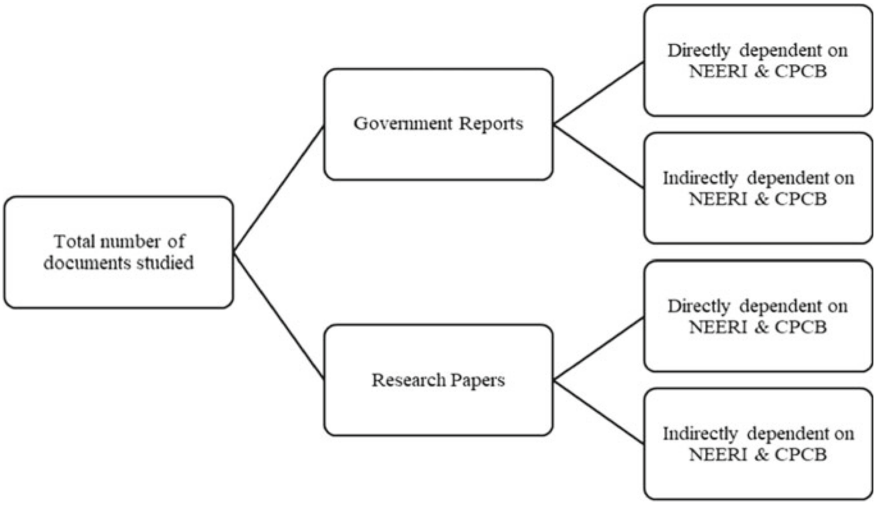


Fig. 1 Flowchart for classification of literature documents based on 'dependency' on NEERI and CPCB for waste generation data

The percentage dependency was measured as follows:

- Total percentage dependency on NEERI and CPCB was measured as the ratio of number of directly plus indirectly dependent documents to the total number of documents studied.
- Percentage dependency of "government reports" on NEERI and CPCB was measured as the ratio of number of directly plus indirectly dependent government reports to the total number of government reports studied.
- Percentage dependency of "research papers" on NEERI and CPCB was measured as the ratio of number of directly plus indirectly dependent research papers to the total number of research papers studied.

3.3 Data Variability and Comparability of Recorded Data

In order to analyze data availability in current study, the waste generation data available in literature documents was collected, organized, and converted to a uniform unit of kg/capita/day. This is used as the standard unit for data comparison at city, state, and national level.

For understanding data variability and comparability, waste generation data in kg/capita/day for different cities and states was compared with India's measure of kg/capita/day. For this purpose, data for years 2001 and 2011 was considered, as for most of the regions waste generation data of other years is scarcely available.

The literature documents studied majorly recorded waste generation data in the form of tones per day (TPD) for a corresponding population and year data. In rare cases, waste generation data was directly presented in the form of kg/capita/day. Hence, whenever waste generation data was found to be in the form of TPD it was converted to kg/capita/day by using following expression:

$$\mathrm{kg/capita/day} = \frac{\text{tones per day}}{\text{population}} \tag{1}$$

For easy representation, India was divided into five regions, each consisting of a set of states based on the availability of data as shown in Table 1. In order to consolidate the evidence of lack of comparability, data from at least one major city (whose data was available) was compared with respective state's data.

3.4 Data Variability and Comparability of Predicted Data

The projections of waste generation based on CPCB or NEERI data (based on availability) were compared with the projections done by various individual researchers for different cities. Variations in the projections from different sources available, helped in understanding their reliability.

Table 1 Division of various states into five categories

State	City	State	City	State	City
North		*East*		*Central*	
Jammu & Kashmir	Srinagar	Arunachal Pradesh	Itanagar	Uttar Pradesh	Lucknow
Himachal Pradesh	Shimla	Assam	Guwahati	Jharkhand	Ranchi
Punjab	Chandigarh, Jalandhar	Sikkim	Gangtok		
Uttarakhand	Dehradun	**West**		**South**	
Haryana	Sonepat	Gujarat	Ahmedabad	Andhra Pradesh	Vishakhapatnam
		Rajasthan	Jaipur	Tamil Nadu	Chennai
				Kerala	Kollam, Thrissur, Kozhikode, Kochi
				Karnataka	Mangaluru, Mysuru, Bengaluru

4 Data Analysis

Various literature/research documents and government reports were studied for data collection. This data was verified and represented graphically which revealed lack of availability, reliability, and comparability of waste generation data in India.

4.1 Assessment Percentage of Data Availability

In Fig. 2 it can be seen that only 12 states of India along with union territories of Puducherry and Delhi have accessible annual reports on their websites. It was found that all of the reports accessible in case of Gujarat, Maharashtra, Puducherry, Tamil Nadu, and Delhi provided waste generation data, whereas, in case of Andhra Pradesh, Goa, Himachal Pradesh, Meghalaya, Tripura, and Uttarakhand no data was available in their accessible annual reports. The state of Meghalaya has the highest number of annual reports accessible to the public, but none of them provide any MSW generation data. Punjab, Madhya Pradesh, and Karnataka SPCB websites provide 18%, 18%, and 12% of MSW generation data from the 53%, 24%, and 18% of accessible annual reports, respectively. Annual reports of Rajasthan and Karnataka are available only on purchase. Annual reports of West Bengal were available but difficulty was encountered in acquiring them due to some website problem, hence its data is not considered in our study.

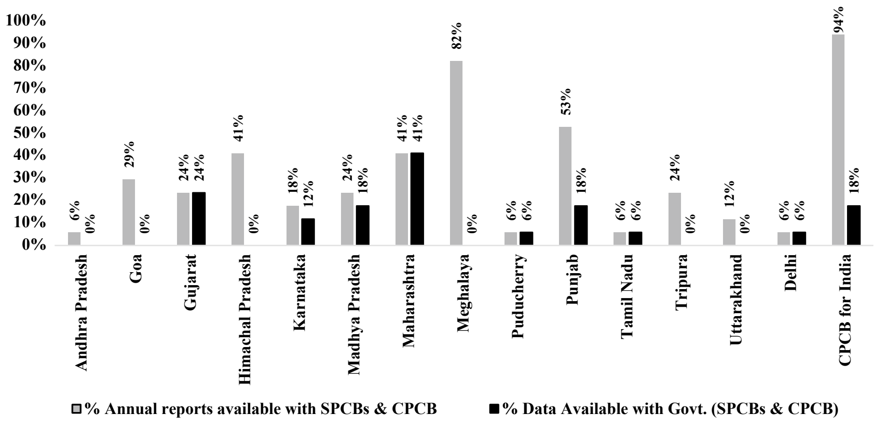


Fig. 2 Waste generation data “available” with CPCB and SPCBs

CPCB website provided access to almost 16 reports for the years from 2000–2001 to 2015–2016 measuring to 94% of annual reports availability out of which only 3 reports (18%) provided MSW generation data. Study of various SPCBs’ websites revealed that there were no annual reports available for Kerala, Telangana, Orissa, Chattisgarh, Arunachal Pradesh, Assam, Haryana, Bihar, Jammu & Kashmir, Jharkhand, Manipur Mizoram, Nagaland, Uttaranchal, Uttar Pradesh, and Daman, Diu and Dadra Nagar Haveli. These websites were found to be focusing more on water, air, and noise quality problems in their regions, which signify that waste management still remains an overlooked problem in many parts of our country. It can be also concluded that there is no uniformity among the annual reports generated by various states. It is important to provide a uniform pattern for annual reports mentioning all the details of waste management system of a particular city, state, or country. If uniform pattern of annual reports is achieved, data generated can be easily organized and analyzed.

4.2 Assessment of Percentage Researchers Dependent on CPCB and NEERI for Waste Generation Data

Total 153 number of randomly selected (readily available) literature documents like research papers by academicians, individual researchers, PhD thesis, government reports by Indian organizations, World Bank, etc., were studied. It was found that out of the sample 153 documents, 61% were research papers and 39% were government reports. The further distribution of documents is shown in Fig. 3.

As per Fig. 4 out of 153 documents studied 22% are dependent on MSW generation data from NEERI and CPCB studies. Out of these 22% documents, 71% documents have directly extracted the data while 29% have indirectly extracted the

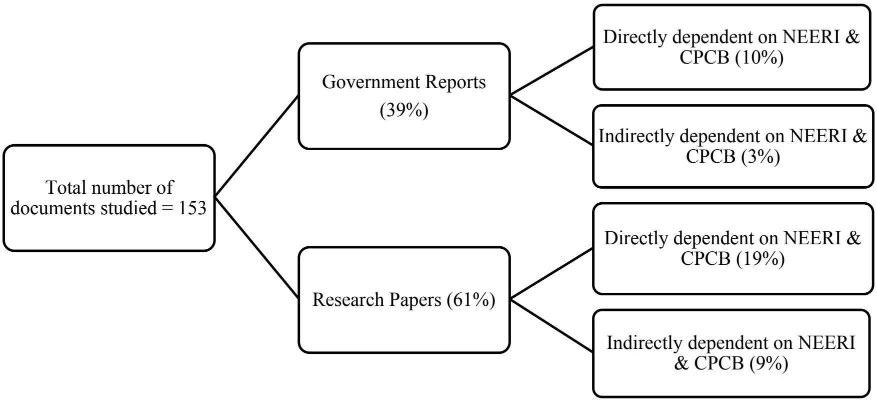


Fig. 3 Percentage "dependency" on NEERI and CPCB for waste generation data

Fig. 4 Total "dependency" of researchers on NEERI and CPCB for waste generation data

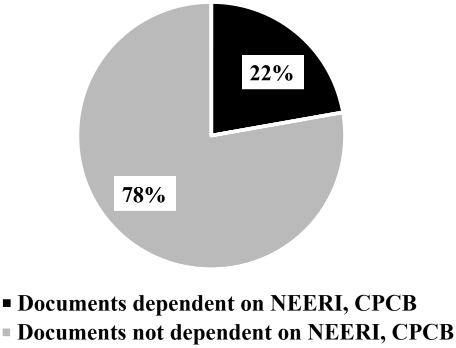
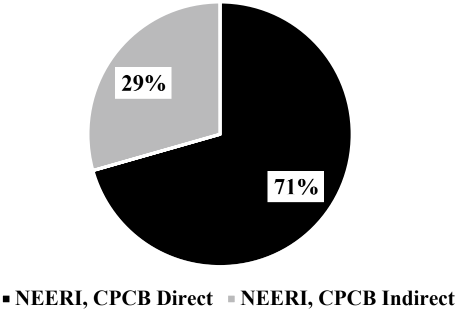


Fig. 5 Direct and Indirect "dependency" of researchers on NEERI and CPCB for waste generation data



data (from other research papers or reports who have cited NEERI/CPCB data) from NEERI and CPCB studies as shown in Fig. 5.

This reveals that still a significant portion of literature documents on waste management in India are extrapolating data from the old surveys of NEERI and

CPCB. Hence, it is necessary to extend the prowess of nationwide data surveys from a single organization to other research and academic organizations well distributed in every state, such that the entire responsibility of maintaining the database will be taken by these organizations and act as nodal organizations for the respective states.

4.3 Data Variability and Comparability of Recorded Data

As already stated, the current study is dependent on data collected from literature documents comprised of research papers by academicians, individual researchers, PhD thesis, and government reports from various organization like CPCB and SPCB, etc.

Initially, variation in city-wise data based on tones per day (TPD) waste generation has been studied. In the following Fig. 6 variation in tones per day (TPD) waste generation for one city cited from two different sources for same year has been shown. For example consider Kolkata Metro City, where one reference documented 3834 TPD of waste generation and another reference documented 7659 TPD for same year, i.e., 2001. Thus, a huge difference in both recorded values raises a doubt regarding reliability of data recorded by both literature documents. Similar trend is depicted for various big cities as shown in Fig. 6 exhibiting variability in data ranging from almost 11–95%.

In the current study, as already explained, kg/capita/day is considered as standard unit of comparison of waste generation data at city, state, and national level. Hence, entire data that was acquired from literature documents was converted to kg/capita/day. A few hurdles were faced while selecting reliable data which are discussed below.

1. Sometimes, data was available for two consecutive years like 2001 and 2002 (for example the data values being 565 TPD and 3867 TPD, respectively) or 2010 and 2011 (for example the data values being 2985 TPD and 658 TPD, respectively) from different literature documents. Such a "big difference" in

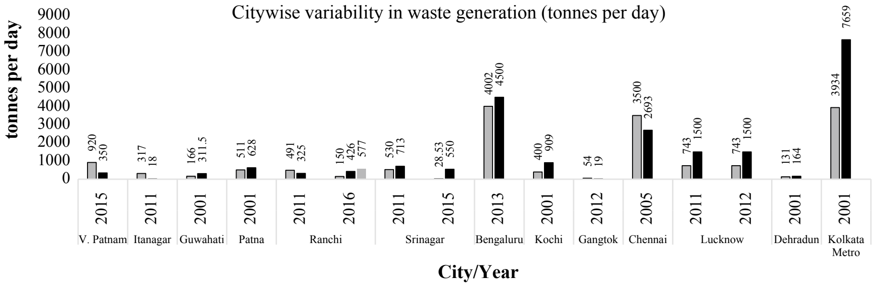


Fig. 6 Variation in waste generation data (TPD) from different literature sources recorded for common years with respect to various cities [13, 24, 28–39, 41]

values used to raise a doubt regarding data reliability. As in a time period of 1 year such vast difference in waste generation is not practically possible. In these cases, the year with higher data value was considered for further study as it is better to adopt higher values and design a waste management system with greater factor of safety.

2. Similarly, many times there used to be two to three literature documents who recorded different values of waste generation data for the same year and region, which led to difficulty in identifying the reliable data for the analysis. To solve this difficulty, the population data given by these literature documents was matched with the Census of India's population records for the required year and region. The data source that matched with Census of India records was selected making the comparative analysis reliable.
3. Absence of standard data collection method has led to inconsistency in waste generation data. This inconsistency was observed due to the type of population data considered for calculating kg/capita/day value. For instance, consider two literature documents using same value of waste generation data in tones per day. In one of the document, the population data represented urban plus rural population. In other documents, population represented only urban population which gave higher value of kg/capita/day, upon calculation as per expression (1), compared to the first document for same region, year, and tones per day data. Hence, to validate waste generation data in form of kg/capita/day or tones per day, the population data was cross-checked with Census of India data for the required year and region. This method enabled collection of data which helped in producing a reliable research study.
4. Waste generation data available was not based on regular time interval like monthly, annual, or decadal. It was available for any random year without any proper frequency of time. If the data was available consistently for every year or decade, estimation and analysis of kg/capita/day would become easier.
5. At times, the same research organization presented different data for same time period in their documents. If such inconsistent data is considered for waste estimation the results will be unreliable.

In order to confirm, if the calculated kg/capita/day value is reliable or not, the corresponding value of population data was cross-checked with the records of Census of India (COI). If both values of population match with each other, the corresponding data in kg/capita/day was considered for analysis.

In current study, waste generation data for 2001 and 2011 is considered as maximum of the entire data collected for the current study that belongs to this time period. There were instances when the data for 2010 was available instead of 2011. In such cases, the closest year's data, i.e., 2010 year's data was considered for analysis based on an assumption that there will not be much increase in waste generation within time period of 1 year.

Based on the above method kg/capita/day of various states was compared with that of India. The comparison revealed that the datasets were not in a good match with each other leading to unreliability. On the other hand, comparison of kg/capita/

day for city and that for urban India were in good match with each other. This situation needs to be improved to make our waste management system efficient.

As already mentioned, in this study, India is divided into five categories as per Table 1. Depending on this, a graphical representation is given in Fig. 7. Considering Western region, it can be observed that only Gujarat and Rajasthan

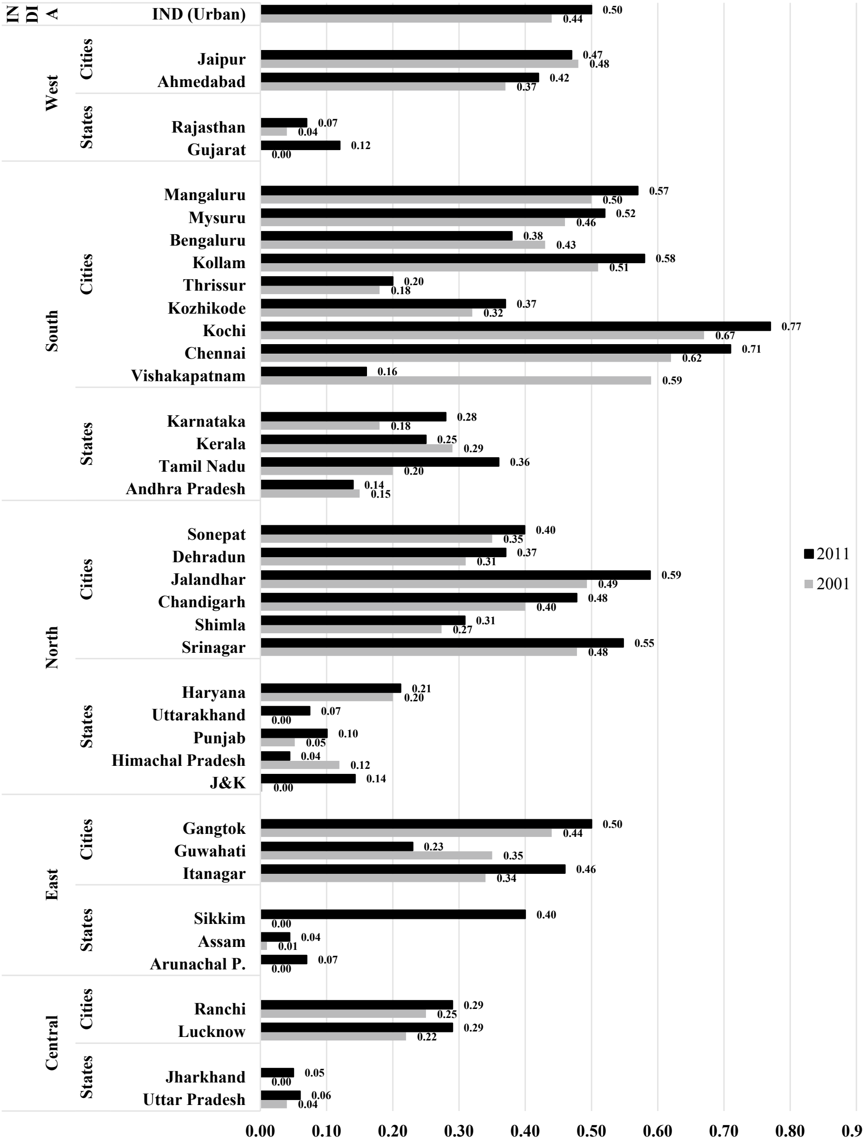


Fig. 7 Comparison of waste generation data (kg/capita/day) for five regions of India [2, 13, 23, 24, 29–32, 37, 40, 43–52]

have documented data on waste generation. Their state-level kg/capita/day value (0.00–0.12) is differing a lot from that of city level kg/capita/day data values for Ahmedabad and Jaipur (0.37–0.47). But kg/capita/day value for urban India is quite close to that of Western city-level data, all values falling in the range of 0.37–0.50 kg/capita/day.

It can be also seen that waste generation in kg/capita/day for Gujarat in year 2011 and Sikkim, Arunachal Pradesh, Jharkhand for the year 2001 was zero that is not practically possible, as waste generation will always happen in presence of continuous process of production and utilization of any material. Likewise, data for kg/capita/day of major cities of South, North, East, and Central India is depicting a trend of confirmation with data for urban India, whereas, comparison of states and cities reveals lot of disparity in the data. This wide difference can be attributed to the type of population (rural/urban) considered for calculation of kg/capita/day value.

It is observed that while calculating kg/capita/day for cities, actual urban population is considered which is in confirmation with Municipal Solid Waste (Management & Handling) Rules, 2000. But for calculation of kg/capita/day of states entire population (rural plus urban) is used to divide the waste generated by Urban Local Bodies (ULBs).

In case of measure of kg/capita/day at national/country level, urban population data and its waste generation is considered. This is the reason why kg/capita/day value for cities and urban India has lesser difference.

But one positive aspect that can be seen in Fig. 7 is that the state of Sikkim and its capital city Gangtok have their kg/capita/day values almost close to each other with very less difference. This could be due to small size of state with less population, or it could be due to high literacy rate leading to proper data management of waste generation.

In addition to comparative analysis as explained above, percentage variability of waste generation data was measured. Percentage variability indicated the measure of variation of kg/capita/day value for a particular state or city compared to kg/capita/day value of India. It was found by considering kg/capita/day value for India, i.e., 0.44 as the base value (zero percentage) for year 2001 and 0.50 for year 2011 [30]. Based on this, percentage variability was calculated using the following expression:

$$\%\ \text{Variability for a region} = \frac{\text{kg per capita per day of that region} - \text{kg per capita per day of India}}{\text{kg per capita per day of India}} \times 100 \tag{2}$$

It can be seen in Fig. 8 that variability ranges from (−)100% to (−) 73% for various states studied in 2001. First, the negative variability indicates lower values of kg/capita/day for states compared to India's value for kg/capita/day. This discrepancy is due to consideration of rural plus urban population for calculating kg/capita/day data for states. In Fig. 9 range of variability for states in 2011 reduced to (−) 91% to (−) 20%. This improvement can be attributed to implementation of data collection practice that was brought in 2000 by Municipal Solid Waste

(Management & Handling) Rules. On the other hand, in 2001 MSW Rules were just implemented and hence data collection practice was not done efficiently due to lack of proper technology and infrastructure which was not fully developed then.

The range of variability for cities in 2001 as per Fig. 8 is (−) 59% to (+) 52%. This range is closer to the baseline measure of India compared to that of variability

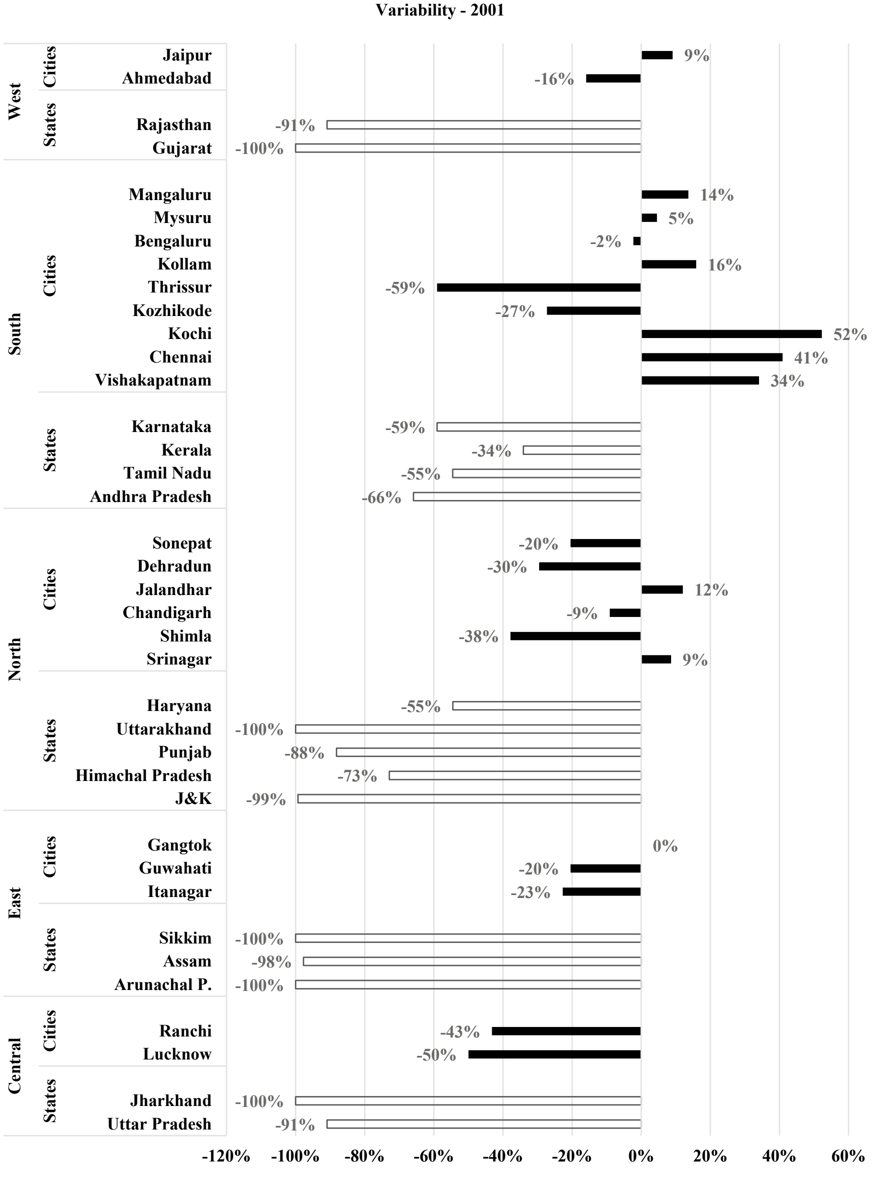


Fig. 8 Percentage variability of kg/capita/day waste generation data for states and cities in 2001

range of states as explained above. This is attributed to consideration of only urban population in calculating kg/capita/day value for cities. It can be observed in Fig. 9 that in case of cities, the variability range is quite wider than expected (although for both years it is narrower than that of states). The variability range for cities in 2011 is between (−) 68% and (+) 54%. The wider range of variability is an indication of

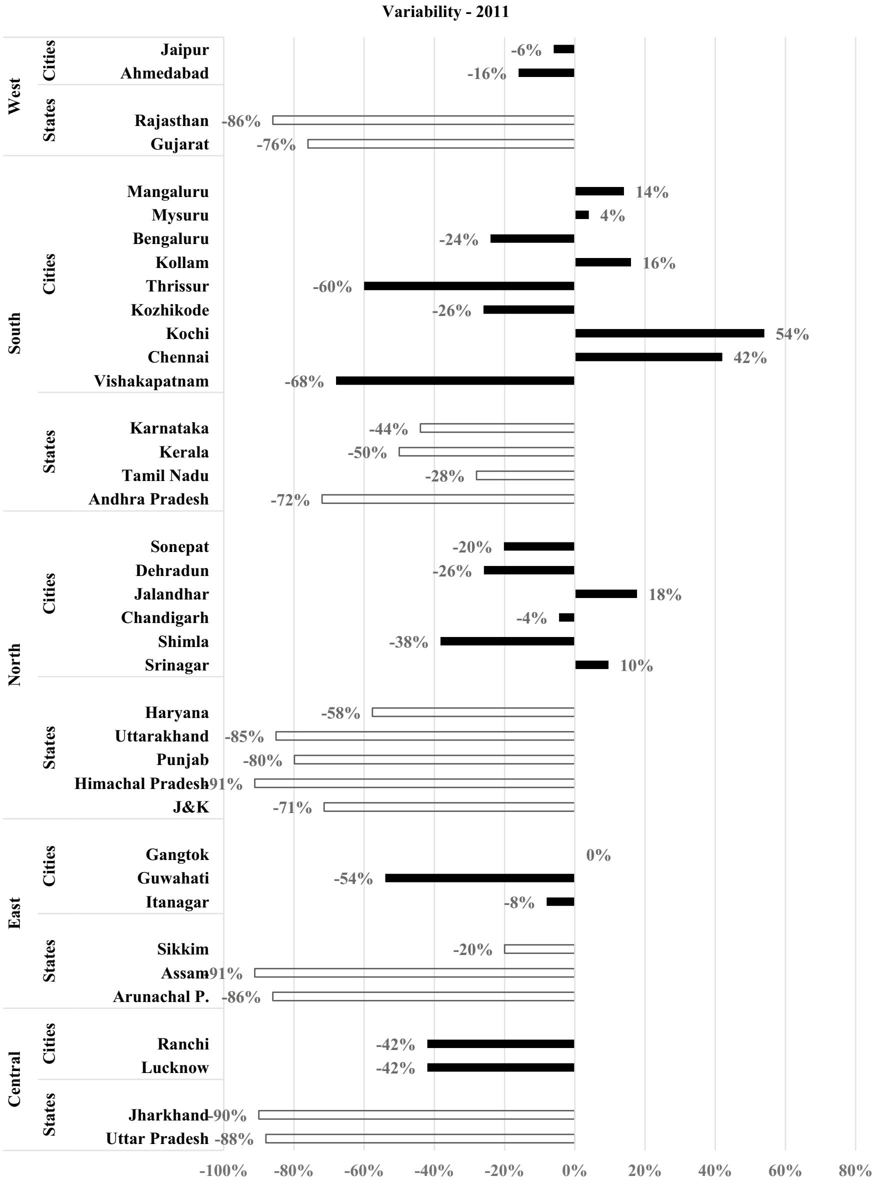


Fig. 9 Percentage variability of kg/capita/day waste generation data for states and cities in 2011

unreliability in the data collected in cities, in spite of provision of high-end technologies for efficient waste management. If the period from 2001 to 2011 is considered, with time, the data collection has worsened to some extent which is possibly attributed to inefficiency and lethargy in collection of proper waste generation data which might be developed due to the monotonous nature of job and casual approach of the laborers.

In order to calculate "σ" values for cities and states, Indian average value of 0.44 kg/capita/day and 0.50 kg/capita/day [30] was considered as the mean. Calculation of average of all the values of cities as well as states was not feasible because of the unreliability of the recorded data. From Figs. 10 and 11 it can be seen that the values of "σ" for states are higher compared to that of cities for both 2001 and 2011. This is due to the consideration of additional rural population for calculating kg/capita/day value for states. In case of cities, "σ" value is closer to the mean, depicting a better scenario of data reliability.

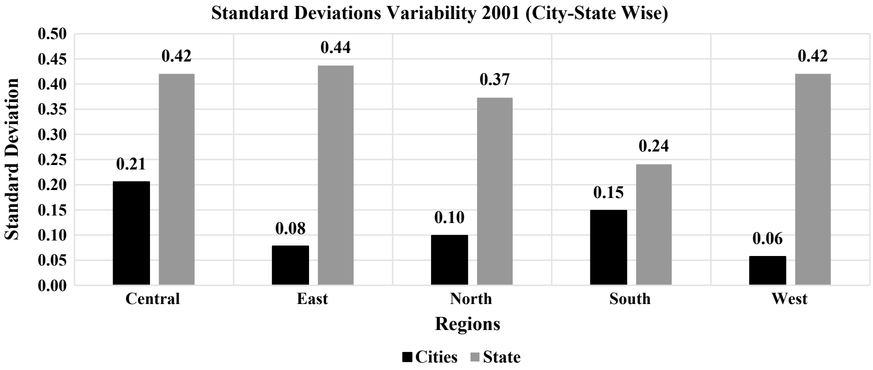


Fig. 10 Standard deviation for cities and states in the year 2001

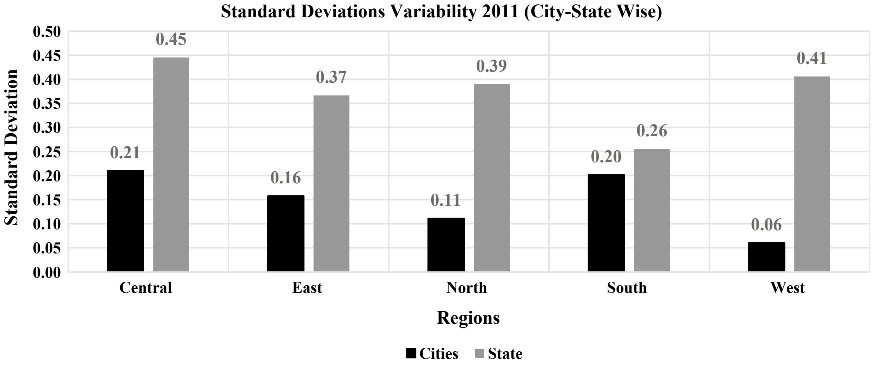


Fig. 11 Standard deviation for cities and states in the year 2011

Comparing cities in 2001 with that of 2011, it can be seen that "σ" values are higher in latter's case. An increase in "σ" value from 2001 to 2011 is observed for cities, which is not a good indication with regard to proper waste management system. Larger "σ" values are indicating inefficient collection of data.

4.4 Data Variability and Comparability of Projected Data

Various researchers have projected MSW generation of their cities for a different set of years. Some have projected decadal growth for e.g., for year 2001, 2011, 2021, 2031 and so on, while some have projected for years 2015, 2025, 2035, and so on. This difference in set of years considered made it difficult to compare the projections. Hence, we selected the data available for very few cities for the years 2001 and 2011 (as major data was available for these years) and compared with a projection presented by [13] which is based on the CPCB data in association with NEERI [13].

It is seen from Fig. 12 that the projected values of 2001 and 2011 given by individual researchers in [32, 41, 42] are not matching the projected values given by [13]. This reveals the inconsistency in the basic data and methodology considered for projecting the futuristic MSW generation data. The projections done by [13] are almost double of the one done by [41] and [32] for Greater Kolkata and Guwahati, respectively. As kg/capita/day data for 2011 for Guwahati City was not available, we have considered 2010 data presented by [32] (assuming the change in kg/capita/day from 2010 to 2011 to be insignificant). Projections done by [42] for Agartala,

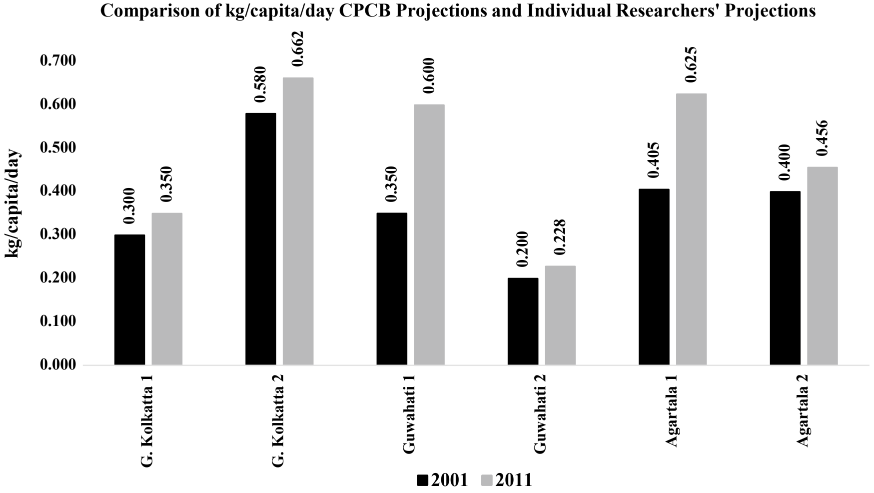


Fig. 12 Comparison of CPCB projections of per capita generation of MSW with individual researchers' projections

although not same, but are somewhat close to the projections done by [13]. It can be seen from Fig. 12 that the years considered for projection by various researchers are varying thereby reducing data availability for comparison. Discrepancies in basic data of waste generation will lead to huge erroneous projections which will reflect into an undermanaged or overmanaged MSW system.

5 Problems Encountered in Data Maintenance

The basic waste generation data is collected in different ways in each city. Additionally, there is no guarantee of the data being actually collected at all [53]. Likewise, there are various factors that influence reliability of the waste generation data are as follows:

- Problems like missing data of waste collection, unknown or improper methods of waste collection, estimating waste quantity without any basis, unaccountability of seasonal variations, misreporting of local waste generation data to national authorities contributed by lack of education and improper training of local staff in developing countries [39]. Such factors create hurdles in maintaining data properly.
- Another problem encountered in collecting reliable data is that waste generation data is recorded at the final disposal site when significant part of waste generated is already recycled [39]. This leads to underestimation of waste quantity.
- Inefficient/lethargic and inadequate workers tend to sweep the streets irregularly leaving behind the waste on the streets unattended [23, 54, 55]. Also, the workers replaced frequently from their jobs lead to inefficient collection as they need some time acquiring all the skills of proper sweeping [56].
- Incomplete measurement of waste generated happens when there are inadequate vehicles and equipment due to lack of funding [18], the size, and the location of garbage bins is improper [55] leading to overflow of waste and insufficient removal of waste from bins [23, 39, 54].
- Collection and transportation system is affected if the road width is varying in cities which are developed without any preplanning [54]. In such cases, the community bins placed in narrow lanes are difficult to access and hence often ignored which keeps them overflowing [23, 39].
- Informal sector or ragpickers are not integrated with mainstream waste management which causes unaccountability of the data regarding waste that is collected by them for recycling [23, 54].
- Usually, migrants living as slum dwellers in cities do not register their residence for the services of waste collection with the local authority [57]. Due to which their residences are not considered by the waste collection team [26, 58]. As a result, the slum dwellers tend to burn their uncollected waste or dump it into nearby open areas and water bodies [7].

- Waste measured in terms of volume differs from that measured in terms of weight which results into huge error in the waste generation data [22]. The waste measured in terms of volume is based on density which varies with factors like time, place, type of waste components, and the percentage of moisture content.
- Some Material Recovery/Processing Facilities do not have the provision of properly maintained truck weighing scales in order to measure the incoming waste streams [22, 39, 55].
- At times, even if the Material Recovery/Processing Facilities are provided with the weighing scale facility, there is no assurance that all the waste will pass through the facility. This is because homogenous streams of recyclables like office papers, cardboards, and aluminum tins generated from various offices and industries may be directly transported to the industries which use these wastes as feedstock in their processes. It is not mandatory for the latter to report the waste quantity they recycle each year as well as sometimes they are even unwilling to report the data [22].

6 Resolving Data Maintenance Problems

- Already many municipalities have provided their citizens with two dustbins (for dry and wet waste). This practice should be made compulsory to all municipalities and gram panchayats.
- The waste collector should be provided with an electronic device which can be a tablet or a smartphone to record the quantity of dry and wet waste weighed at every household during collection. These tablets or smartphones could be installed with a waste management application/software connected to GPS. It can be developed exclusively for the waste management system which should be accessible for feeding data only by authorized people of the system like waste collectors, sweepers, collection and transportation workers, workmen at transfer stations, MRF, and disposal sites, waste management supervisors and managers. The data generated from this application should be open to public viewing on the respective municipal websites for information.
- NGOs and informal sector (ragpickers) should be roped in for keeping an account of recycled waste [56, 59]. The recycling system and its stakeholders should be commercialized by maintaining payment receipts. The waste recycler should provide a payment receipt against the quantity and type of waste collected from the consumer (waste generator). These payment receipts should be regularly submitted to municipalities which further should be properly organized and analyzed by local research institutes in collaboration with municipalities. An innovative door-to-door collection initiative has been undertaken by Pune Municipal Corporation (PMC) under SWaCH model (Solid Waste

Collection and Handling) which helps in cost-effective, high-resource recovery, and labor-friendly collection of waste [19] by employing local labor force.

- Community bins should be installed with sensors indicating overflow of waste. They should be well-guarded from stray animals by covering them with barbed wires or some other suitable option.
- The waste collecting vehicles should be provided with pulley system to directly pickup the community bin and unload its waste into the vehicle (this system is already implemented in metropolitan cities like Mumbai). A weighing system should be provided along with the pulley to weigh the community bin directly when it is being pickedup by the pulley. To avail such system government should provide sufficient funding considering the intensity of waste management issue in our country. Such practice will ensure that the waste is measured at the source of generation and not at the final disposal site.
- The citizens should be taxed to augment for inadequate resources required for waste management process of municipal bodies. Till date, no such tax has been levied for solid waste management [23].
- Registration of the residential details of the slum dwellers (who are majorly the migrating population) will help in providing the waste collections services to them properly, and hence an account of right quantity of waste generated can be maintained [7].
- Association of government authorities and NGOs/private partners should be encouraged for waste management activities for maintaining the exact account of waste quantity during the entire process of management.
- Involving low-income group as labor for collection of waste from difficult to access areas like community bins located in narrow lanes, instead of employing heavy machinery can be a good option which would also help in generating income for the labor. This strategy can be refined further by spending on the training of a small group of labor to acquire right skills of work instead of spending lot of funds on a larger group of labor which is difficult to manage.
- Transportation vehicles should be leakproof and properly covered. The number of community bins should be increased with optimized spacing [5] for easy accessibility to avoid overflow and littering [56]. The storage containers can be designed for overestimated quantity of waste [56].
- Collection efficiencies are directly proportional to the density of the population in the area being served. Densely populated areas are provided with high rate of collection coverage as compared to the thinly populated areas [24, 60]. Hence, it is important to utilize the actual population data being served with collection service instead of statistical population data for properly estimating the waste generation [7, 61, 62].
- Specialized agencies involved in measuring the waste generation from various production industries is called as an input method. Although such a system provides regular data updates regarding present and future estimates of waste generation from any industry, it is expensive for a developing country like India [63]. Hence, there is an alternative method of waste estimation called output method. This method is based on load count analysis in which actual waste transported to

landfills is measured, which comparatively requires less efforts and finance [63]. National government should take an initiative in encouraging both methods of estimation by funding various agencies both at national level and local levels.
- Providing subsidies for planning and setting up new waste treatment facilities on a condition of collecting reliable waste management data can be a beneficial strategy. Such a data compilation system has been implemented by Japanese government [7].
- Additionally, the population database which is created every decade through Census of India, should also include the information regarding quantity of waste generated data per person or per household counted.
- Involvement of nodal research organizations and well-established academic institutions like IITs, NITs and other eminent colleges, state-wise or region-wise in MSW research projects collaborating with the local governments of the respective cities should be stressed upon. These organizations should be assigned with particular areas near them for entire responsibility of data collection and analysis. Students can be involved on large scale in such research projects funded by the national government. One such national government venture is Unnat Bharat Abhiyan wherein students are involved in government projects benefitting rural areas, which can be extended to solid waste management in India as well.

7 Conclusion

Availability of reliable waste generation data and a proper reporting methodology are the most important factors for an efficient solid waste management and effective policy-making and implementation.

Our study has revealed data reliability and availability problem in India, which is a common scenario in developing nations. Waste generation rates and characterization of MSW in different parts of India depend on varying climates, habits and living standards which should be properly studied and this has been exactly not considered while collecting data from municipal authorities or while doing actual sampling.

Annual reports on waste management are not accessible on the SPCB websites of all states. Additionally, data is not provided in all of the accessible annual reports of CPCB and SPCBs. Almost 22% of literature documents studied is dependent on the limited database generated by CPCB and NEERI. Waste generation data in kg/capita/day for cities is in close sync with that of urban India. But in case of comparison of states and urban India it is varying a lot. The reason behind such a huge difference is that while calculating kg/capita/day value for states, rural population has also been considered which is ignored in case of cities. Reduction in the range of variability for states from 2001 to 2011 is an indication of improved data collection. But in case of cities the range has increased to some extent which can be attributed to inefficiency in data collection due to lack of motivation, in spite of provision of high-end technologies for waste management. Similarly, increase in "σ" values from 2001 to 2011 in case of cities is indicating lack of proper waste management data collection.

In order to generate a reliable database it is necessary to include various renowned academic, research, and government institutions in each state of India to conduct research projects on solid waste management in various cities and towns of that state.

Additionally, various policies like taxation, collaboration with NGOs and rag-pickers, implementation of waste counting methods in industries, technological upliftment of collection methods, design improvements in community bins, commercialization of the collection process, etc., should be implemented.

The above discussed are all technical aspects of improving the solid waste management system in our country. The hurdle of improper data collection and waste management will be diminished only when everyone is provided with basic need of education. It is only proper education that will inculcate moral values in citizens which will help India survive sustainably against all environmental problems.

References

1. Afroz, R., Hanaki, K., Tudin, R.: Factors affecting waste generation: a study in a waste management program in Dhaka City, Bangladesh. Environ. Monit. Assess. **179**, 509–519 (2011)
2. Kumar, S., Smith, S.R., Fowle, G., Velis, C., Kumar, S.J., Arya, S., Rena, Kuma, R., Cheeseman, C.: Challenges and opportunities associated with waste management in India. Roy. Soc. Open Sci. **4**, 1–11 (2017)
3. Singh, V.: Legal Control Mechanism for Waste Management by Local Self-Governments in Punjab: An Analysis. Thesis Report. Guru Nanak Dev University, Amritsar (2013)
4. Goel, S.: Municipal solid waste management (MSWM) in India: a critical review. J. Environ. Sci. Eng. **50**, 319–328 (2008)
5. National Environmental Engineering Research Institute-Municipal Solid Waste Management in India: Present Practices and Future Challenge, Information. http://saahas.org/wp-content-saahas/uploads/2015/02/SWMindia10.pdf
6. Kumar, A.: Existing situation of municipal solid waste management in NCT of Delhi, India. Int. J. Soc. Sci. **1**, 6–17 (2013)
7. Kawai, K., Tasaki, T.: Revisiting estimates of municipal solid waste generation per capita and their reliability. J. Mater. Cycles Waste Manage. **18**, 1–13 (2015)
8. Siddiqqui, M.A.: Municipal solid waste management in India-status and challenges: an overview. Int. J. Biol. Res. **3**, 12–133 (2018)
9. Naveen, B.P., Malik, R.K., Kontoni, D.P.N.: Municipal Solid Waste Management in India—Challenges and Feasible Solutions. In: 8th International Conference from Scientific Computing to Computational Engineering, pp. 290–297, Athens (2018)
10. Kolekar, K.A., Hazra, T., Chakrabarty, S.N.: Prediction of municipal solid waste generation for developing countries in temporal scale: a fuzzy inference system approach. Glob. Nest J. **19**, 511–520 (2017)

11. Parmar, R., Pamnani, A.: Review for MSWM in Indian cities and town. Int. J. Latest Technol. Eng. Manag. Appl. Sci. **6**, 47–49 (2017)
12. Pandey, S., Malik, J.K.: Industrial and urban waste management in India. Technical Report. TERI—The Energy and Resources Institute (2015)
13. Annepu, R.K.: Sustainable solid waste management in India. Thesis Report. Waste-to-Energy Research and Technology Council, Columbia University (2012)
14. Kolekar, K., Hazra, T., Chakrabarty, S.N.: A review on prediction of municipal solid waste generation models. Procedia Environ. Sci. **35**, 238–244 (2016)
15. Sinha, S., Bhatia, R.K.: Challenges in municipal solid waste management in Indian cities: a case study of Bilaspur (Chhattisgarh). Int. Res. J. Eng. Technol. **3**, 2035–2040 (2016)
16. Kawai, K., Huong, L.T.M., Osako, M.: Accumulation and Reliability of Data on Municipal Solid Waste Management in Urban Areas of Vietnam. J. Jpn Soc. Civ. Eng., Ser. G (Environmental Research) **68**, 465–471 (2012)
17. Hanrahan, D., Srivastava, S., Ramakrishna, A.S.: Improving Management of Municipal Solid Waste in India: Overview and Challenges. Technical Report. Environment Unit South Asia Region—The World Bank (2006)
18. Patel, N.K., Baredar, P.: Opportunity and challenges of municipal waste disposal in India. Int. J. Innovative Res. Sci. Technol. **3**, 253–264 (2016)
19. Mani, S., Singh, S.: Sustainable municipal solid waste management in India: a policy agenda. Procedia Environ. Sci. **35**, 150–157 (2016)
20. Planning Commission: Report of the Task Force on Waste to Energy-In the Context of Integrated MSW Management (Vol. II). Technical Report. Planning Commission (2014)
21. Bhada, P.: Feasibility Analysis of Waste-To-Energy as a Key Component of Integrated Solid Waste Management in Mumbai, India. Thesis report. Columbia University (2007)
22. Shin, D.: Generation and Disposition of Municipal Solid Waste (MSW) in the United States—A National Survey. Thesis Report. Columbia University (2014)
23. Joshi, R., Ahmed, S.: Status and challenges of municipal solid waste management in India: a review. Cogent Environ. Sci. **2**, 1–18 (2016)
24. Central Pollution Control Board (CPCB)-Suggestive/Indicative "The National Action Plan for Municipal Solid Waste Management" Information. http://164.100.107.13/Municipal_Solid_Waste.php (2017)
25. Narain, S., Sambhyal, S.S.: Not In My Backyard. Centre for Science and Environment, New Delhi (2016)
26. Zhu, D., Asnani, P.U., Zurbrugg, C., Anapolsky, S., Mani, S.: Improving Municipal Solid Waste Management in India: A Sourcebook for Policy Makers and Practitioners. The World Bank, Washington, DC (2008)
27. Beigl, P., Wassermann, G., Schneider, F., Salhofer, S.: Forecasting Municipal Solid Waste Generation in Major European Cities. In: 9th International Congress on Environmental Modelling and Software, pp. 1–6. BYU Scholars Archive, Vienna (2004)
28. Feedback Infra Private Limited., Eco Save Systems Pvt. Ltd.: Detailed Project Report on Municipal solid Waste Management for Visakhapatnam. Technical Report. Andhra Pradesh Urban Finance & Infrastructure Development Corporation (2015)
29. Central Pollution Control Board (CPCB) Information. http://cpcb.nic.in/uploads/hwmd/trend_46_cities_list.pdf
30. Debnath, A., Mitra, A.: Challenges of solid waste accumulation and management in a growing urban area—a study of Itanagar Town of Arunachal Pradesh. In: Seventh Biennial Conference of Indian Society for Ecological Economics (INSEE) on Global Change, Ecosystems, Sustainability, pp. 4–8, Tezpur University (2013)
31. Central Pollution Control Board Information. http://164.100.107.13/Municipal_Solid_Waste.php
32. Chakraborty, A., Goswami, A., Deb, A., Das, D., Mahanta, J.: Management of waste generated in Guwahati City and the incorporation of geocells at the landfill site. J. Civ. Eng. Environ. Technol. **1**, 5–7 (2014)

33. Meinhardt Singapore Pte. Ltd. (India Branch): City Development Plan for Ranchi: Technical Report, JnNURM Scheme, Ranchi Municipal Corporation (2007)
34. Chief Executive Officer: Request for Proposal for Development of Integrated Solid Waste Management System for Ranchi Municipal Corporation on Public Private Partnership (PPP). Technical Report, JnNURM Scheme, Ranchi Municipal Corporation (2010)
35. State Action plan on climate Change, Govt. of Jammu & Kashmir Information. http://www.jkdears.com/eers/eers/orders/Final%20Report%20SAPCC.pdf
36. Naveen, B.P., Kaddi, S.K., Basha, R.H.: Solid Waste Management Activities in Bruhat Bengaluru Mahanagara Palike. In: 4th World Conference on Applied Sciences, Engineering & Technology, pp. 24–26, Kumamoto University, Japan (2015)
37. Kumar, M., Nandini, N.: Community attitude, perception and willingness towards solid waste management in Bangalore city, Karnataka. India. Int. J. Environ. Sci. **4**, 87–95 (2013)
38. State of Environment Report-Tamil Nadu 2005, Govt. of Tamil Nadu Information. http://www.environment.tn.nic.in/SoE/images/WasteManagement.pdf
39. Hoornweg, D., Bhada-Tata, P.: WHAT A WASTE: a global review of solid waste management. In: Urban Development Series-Knowledge Papers, The World Bank (2012)
40. Archana, Ali, D., Yunus, M., Dutta, V.: Assessment of the status of municipal solid waste management (MSWM) in Lucknow—Capital city of Uttar Pradesh, India. J. Environ. Sci. Toxicol. Food Technol. **8**, 41–49 (2014)
41. Das, S.: Estimation of municipal solid waste generation and future trends in greater metropolitan regions of Kolkata, India. J. Ind. Eng. Manag. Innovation **1**, 31–38 (2014)
42. Santra, A., Debbarma, D., Sen, S., Mitra, S.: Municipal solid waste management system in Agartala City, Tripura. India. Hill Geogr. **2**, 37–49 (2014)
43. National Solid Waste Association of India-ENVIS Centre Information. http://nswaienvis.nic.in/pdf_FF/Population%20and%20Municipal%20Solid%20Waste%20Generation%20in%20India.pdf
44. Vij, D.: Urbanization and solid waste management in India: present practices and future challenges. Procedia-Soc. Behav. Sci. **37**, 437–447 (2012)
45. Central Pollution Control Board (CPCB)-Status Report on Municipal Solid Waste Management Information. http://www.indiaenvironmentportal.org.in/files/file/MSW_Report.pdf (2013)
46. (SIPMIU), Urban Development and Housing Department.: India: North-Eastern Region Capital Cities Development Investment Program-Gangtok Solid Waste Management Subproject: Technical Report, North-eastern Region Capital Cities Development Investment Program (RRP IND 35290), Government of Sikkim (2012)
47. Central Pollution Control Board (CPCB)-Consolidated Annual Review Report (2014–15) on Implementation of Municipal Solid Wastes (Management and Handling) Rules, 2000 Information. http://164.100.107.13/Municipal_Solid_Waste.php (2016)
48. Central Pollution Control Board (CPCB)-Consolidated Annual Review Report (2015–16) on Implementation of Municipal Solid Wastes (Management and Handling) Rules, 2000 Information. http://164.100.107.13/Municipal_Solid_Waste.php (2017)
49. Suchitwa Mission Local Self Government Department (Thiruvananthapuram, Kerala) Information. https://www.researchgate.net/publication/267301163_STATUS_OF_MUNICIPAL_SOLID_WASTE_GENERATION_IN_KERALA_AND_THEIR_CHARACTERISTICS
50. Department of Ecology & Environment-State of the Environment Report, 2003 (Waste Management) information. http://parisara.kar.nic.in/pdf/wastemgmt.pdf (2003)
51. Chanakya, H.N., Shwetmala, Srisha Malayil, S.: Sustainable small scale solid waste management for the future. In: Proceedings of Kerala Environment Congress 2010, Focal Theme-Solid and Liquid Waste Management, pp. 34–47, Centre for Environment and Development, Thiruvananthapuram (2010)
52. Singh, A.: Municipal solid waste management in current status and way municipal solid waste management in current status and way forward. Thesis Report. Rajasthan State Pollution Control Board (2011)

53. Wilson, D., Rodic, L., Scheinberg, A., Velis, C.A., Alabaster, G.: Comparative analysis of solid waste management in 20 cities. Waste Manage. Res. **30**, 237–254 (2012)
54. Mohanty, C.R., Mishra, U., Beuria, P.R.: Municipal solid waste management in Bhubaneswar, India—a review. Int. J. Latest Trends in Eng. Technol. **3**, 303–312 (2014)
55. Chatterjee, R.: Municipal solid waste management in Kohima City-India. Iran. J. Environ. Health. Sci. Eng. **7**, 173–180 (2010)
56. McAllister, J.: Factors influencing solid-waste management in the developing world. Thesis Report. Utah State University (2015)
57. Central Pollution Control Board (CPCB)-Consolidated Annual Review Report (2013–14) on Implementation of Municipal Solid Wastes (Management and Handling) Rules, 2000 Information. http://164.100.107.13/Municipal_Solid_Waste.php (2015)
58. Gogoi, L.: Municipal solid waste disposal: a case study in Guwahati city to mitigate the manmade disaster. IOSR J. Humanit. Soc. Sci. **9**, 55–60 (2013)
59. HSMI/WMC (UIFW-New Delhi): Citywide best practices in solid waste management in collection, transportation & disposal. Project Report. Institute for Housing & Urban Development Studies, Rotterdam (1997)
60. Choudhary, M., Choudhary, M.: Trends of urban solid waste management in Agartala City, Tripura, India. Univers. J. Environ. Res. Technol. **4**, 227–235 (2014)
61. Al-Khatib, I., Monou, M., Zahra, A., Shaheen, H., Kassinos, D.: Solid waste characterization, quantification and management practices in developing countries: a case study: Nablus district—Palestine. J. Environ. Manag. **91**, 1131–1138 (2010)
62. Roy, A.T., Deb, U., Mazumder, R.: Sustainable urban waste management in Silchar municipal area: an application of contingent valuation method in Cachar District of Assam. Int. J. Humanit Soc. Sci. Invent. **2**, 25–33 (2013)
63. Nadeem, K., Farhan, K., Ilyas, H.: Waste amount survey and physio-chemical analysis of municipal solid waste generated in Gujranwala-Pakistan. Int. J. Waste Res. **6**, 1–8 (2016)
64. CPHEEO.: Municipal Solid Waste Management Manual (Part II). Ministry of Urban Development, New Delhi (2016)

Influence of Recycling on the Incinerability of Municipal Solid Waste

Roshni Mary Sebastian, Dinesh Kumar and Babu J. Alappat

Abstract Material and energy recovery are vital elements of an integrated municipal solid waste (MSW) management scheme. Although recycling is an environment-friendly alternative for waste management, higher waste generation rates necessitate faster treatment techniques like incineration. The viability of waste incineration nevertheless, depends on the incinerability of the feed to furnace. To prevent operational failures, it becomes quintessential to ensure the incinerability of the MSW feed. To facilitate this decision-making, the incinerability index or *i*-Index, a tool to quantify incinerability on a scale of 0–100 and determine the feasibility of incineration has been devised by the authors. This paper focusses on the estimation of incinerability of MSW when different components are recovered for recycling. MSW generated in a developed country like USA and metro like Delhi in India, a developing country, with relatively high waste generation and recycling rates were considered for the study. *i*-Index value for raw MSW generated in USA was computed as 72.54 using USEPA data while MSW generated in South Delhi had lower *i*-Index of 66.7. After maximum material recovery, *i*-Index of residual MSW in USA amounted to 68.8, in contrast to MSW in Delhi, which amounted to 49.7. Although recycling of combustible fractions adversely affects the incinerability, it was counter balanced by the recovery of food fraction for composting resulting in a mild increase in incinerability. Variation in *i*-Index and thus the incinerability with the recycling of different components are investigated for assessing the feasibility of incineration of the residual MSW.

Keywords Municipal solid waste · Recycling · Incinerability · Waste to energy

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1 Introduction

The increase in waste volumes and the shortage in the availability of land have led to the use of waste fractions for material and energy recovery operations in addition to conventional management techniques like composting and landfilling [1]. While incineration helps to recover energy from waste, recycling ensures material recovery, which can reduce the consumption of virgin materials in manufacturing processes [2]. European countries incinerated about 26.7% and recycled 28.8% of their municipal solid waste (MSW) in 2015 as per Eurostat database. Asian countries like China and Japan, on the contrary, incinerate about 30 and 80% of the MSW, with negligible recycling [3]. The fraction of combustibles in the MSW in developed countries is more than 40%, while it is less than 25% in most of the developing countries [4]. Subsequently, while developed countries practice both incineration and recycling operations simultaneously, recycling of materials reduces the overall heat content of MSW, making thermal energy recovery difficult. For instance, while Switzerland incinerates one half of the total MSW generated and recycles the other half, Thailand recycles 11% of its MSW and incinerates less than 1% of the generated MSW [3]. Figure 1 shows the quantity of MSW recycled and incinerated in different economies. The perplexing question now is 'Does recycling reduce the incinerability of the residual MSW or the left over MSW?'

MSW composition is instrumental in determining the management strategies [5]. The detrimental effect of recycling on waste to energy (WtE) projects have been reported, with the exact extent of it unknown. Waste incineration in conjunction with recycling is deemed as sustainable management strategy in developed countries [6, 7]. However, the incinerability of the MSW left after recycling needs to be quantified prior to implementing thermal WtE techniques. Recycling is a significant part of waste management in many European countries and the United States of America. In contrast to this, in developing countries like India, it continues to be an informal activity. India generated nearly 127,485 tonnes of MSW per day per

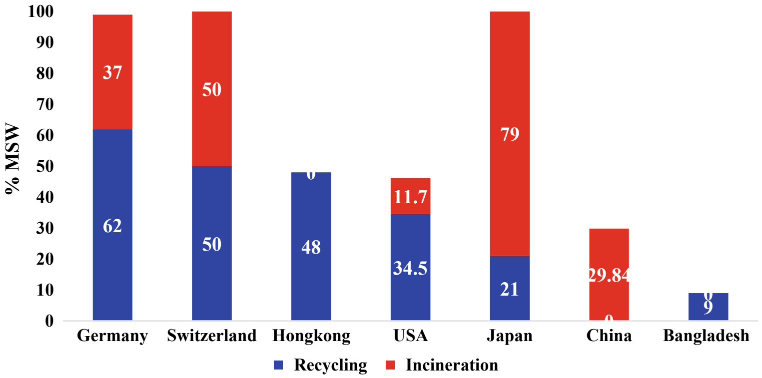

Fig. 1 Rate of recycling and incineration of MSW in different economies

annum in the period from 2009–2012 as per The Energy and Resources Institute (TERI) data [8] and the amount is anticipated to nearly double by 2025 [4]. Delhi, the capital city alone generates more than 10,000 tonnes of MSW per day as per unofficial records. There are three waste incineration plants in Delhi, located at Narela Bawana, Okhla and Ghazipur, which collectively incinerate about 5250 TPD of MSW, as per Department of Environment, Government of National Capital Territory (NCT) of Delhi. The informal sector comprising recyclists, ragpickers and other hierarchy of dealers are responsible for recycling about 17% of the MSW generated [8]. Incineration being an economy intensive technology can be implemented only when the thermal properties of the feed left after the informal recycling activities are appreciably high. Thus, there is a need to thoroughly assess and quantify the incinerability of MSW to ensure the feasibility of the process. The present work is aimed at estimating the variation in the incinerability of MSW generated in South Delhi, with the residents belonging to economically affluent section of the society. The incinerability shall be quantified when different component fractions shall be recycled at different rates. A unique composite indicator for incinerability called the incinerability index or *i*-Index for MSW shall be used to quantify and project the variations [10].

2 Methodology

i-Index is a tool, which evaluates the amenability of MSW to be incinerated completely to sterile ash by incorporating the potential environmental impact, probable energy recovery, as well as fiscal feasibility of the process. The incinerability of MSW is quantified on a scale of 0–100 using the parameters shown in Fig. 2 [9].

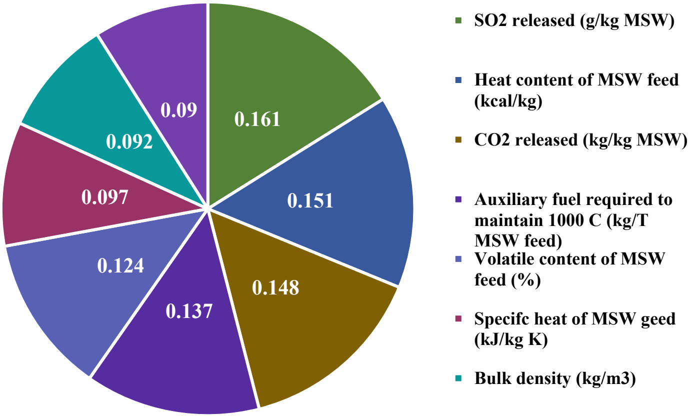

Fig. 2 Relative weightage of input parameter to compute *i*-Index for MSW

To estimate the variations in the incinerability, different components of MSW were assumed to be recycled at different rates. Each of the input parameters was then computed for different recycling rates. *i*-Index for MSW was then computed using the formula

$$\text{Incinerability index or } i - \text{Index for MSW} = \frac{\sum_{i=1}^{n} w_i P_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

where w_i is the relative weightage of the *i*th parameter as shown in Fig. 2 and P_i is the normalised parameter value [10, 11].

The composition of the MSW generated in South Delhi in the month of March 2017 was collected from the North Delhi Municipal Corporation. Figure 3 demonstrates the same. The input parameters collected from NDMC were then normalised to compute the *i*-Index. This amounted to 66.7.

To account for the effect of increasing informal recycling activities in Delhi on the incinerability of the residual MSW, a theoretical approach was adopted. For this, initially, the individual MSW components were assumed to be segregated out from the feed stream and the incinerability of the leftover MSW was estimated. Accordingly, paper, plastic, inert fraction, biodegradable components, etc., were individually assumed to be segregated out and the incinerability of left over MSW was determined. Further, the incinerability of the MSW when entire combustibles are removed and only combustibles are present was also evaluated. The subsequent sections show the detailed results in each case.

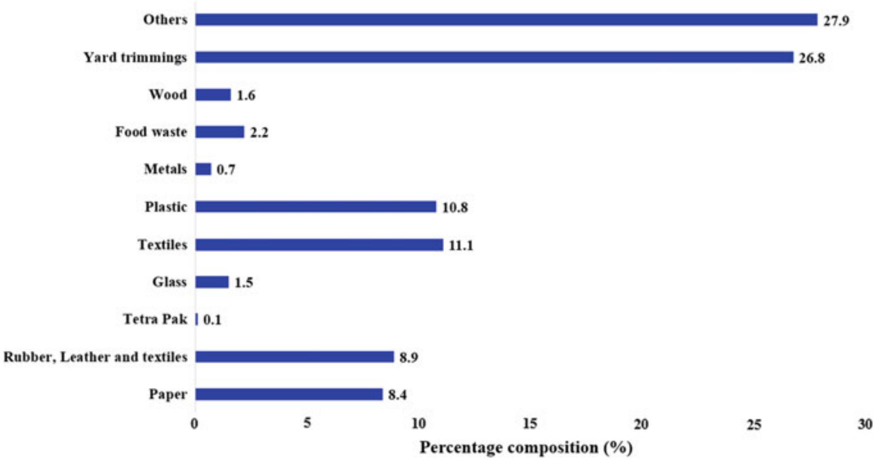

Fig. 3 Composition of MSW generated in South Delhi

3 Variation in Incinerability of MSW with Recycling of Component Fractions in Developing Economy: A Theoretical Approach

The feasibility of incineration of MSW for waste disposal with energy recovery is determined by the thermal properties of the feed. The MSW generated in developing countries comprises high food and inert material fractions and hence, pre-treatment operations may facilitate in improving its incinerability. *i*-Index for MSW was used to compute the incinerability of the feed after informal recycling activities as well. The hypothesis of recycling of individual materials was taken as Approach A. Approach B involved the segregation of different components together and its consequences on the incinerability of MSW.

3.1 Approach A: Recycling of Individual Components

MSW is a highly heterogeneous waste stream with a multitude of component fractions. The innate heat content of each fraction determines the net heat content of the MSW, while plastic, paper, etc., increase the overall calorific value of MSW, inert fractions like stones, sand, silt, etc., which forms the bulk of the MSW in developing countries reduce the net heat content. However, incinerability being a multidimensional property, a decision cannot be made by just assessing the heat content. *i*-Index for MSW was, hence, computed to determine the variation in the incinerability of MSW when individual component fractions were recycled.

3.1.1 Recycling of Plastic Fraction

The Central Pollution Control Board (CPCB) records the annual plastic waste generation in Delhi as 0.25 MT/y [12]. The MSW generated in South Delhi has about 10.8% of plastic fraction. Plastic waste is one of the most significant contributors to the heat content of the waste and removal of this fraction reduces the net calorific value of the MSW considerably. Assuming 100% of the plastic fraction was removed from the MSW, *i*-Index was computed. *i*-Index amounted to 57.3, which was nearly 14.1% less than that of the raw MSW (66.7). An evident reduction in incinerability of MSW may, thus be observed. The incinerability of MSW when 50% of the plastic fraction was removed was also computed. Figure 4 illustrates the variation in *i*-Index values at different recycling rates.

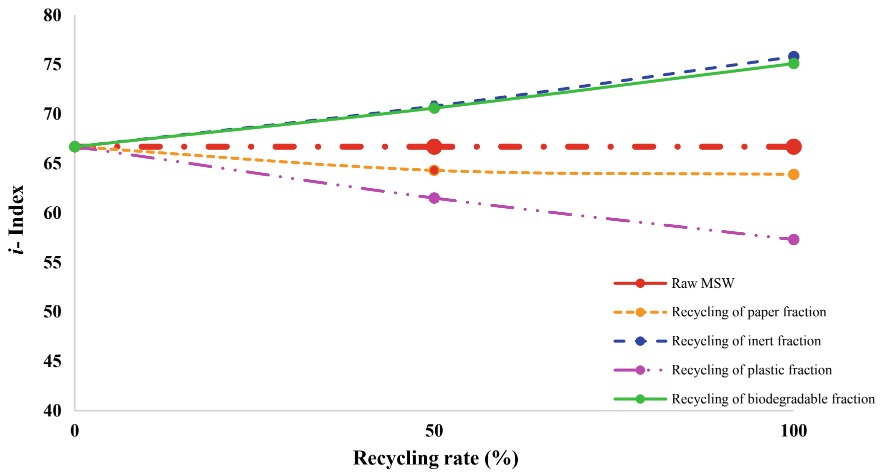

Fig. 4 Variation in incinerability of MSW with recycling of different fractions of MSW

3.1.2 Recycling of Paper Fraction

Numerous life cycle assessment studies report that recycling of paper is superior to incineration or landfilling with respect to energy recovery aspect [13–15]. However, in countries were segregation operations are not prevalent, segregation of individual components becomes a complex task. Recyclable components are collected by informal recyclers through house-to-house collection or from municipality bins in Delhi. Specific items like paper and cardboard are collected by large dealers. White paper, fresh newspaper, cartons, mixed shredded paper etc., are collected hence. However, how it influences the incinerability of the MSW feed to the WtE projects needs to be analysed. The MSW generated in South Delhi has nearly 8.5% of paper fraction. The thermal properties of the MSW left after segregating the paper fraction were theoretically approximated to compute *i*-Index that amounted to 63.9. This was about 4.27% less than that of raw MSW, while this may not seem to be a huge reduction, it should be noted that the incinerability of raw MSW is in itself quite low in comparison to the MSW generated in developed countries as evident from Fig. 5. Increase in recycling of paper and packaging items was reported to reduce the feasibility of WtE projects by Abedini et al. [6]. However, simultaneous recycling of certain amount of paper and plastic fraction along with the segregation of food and yard wastes for composting may not reduce the overall incinerability [6, 16]. However, this will be quantified in subsequent sections.

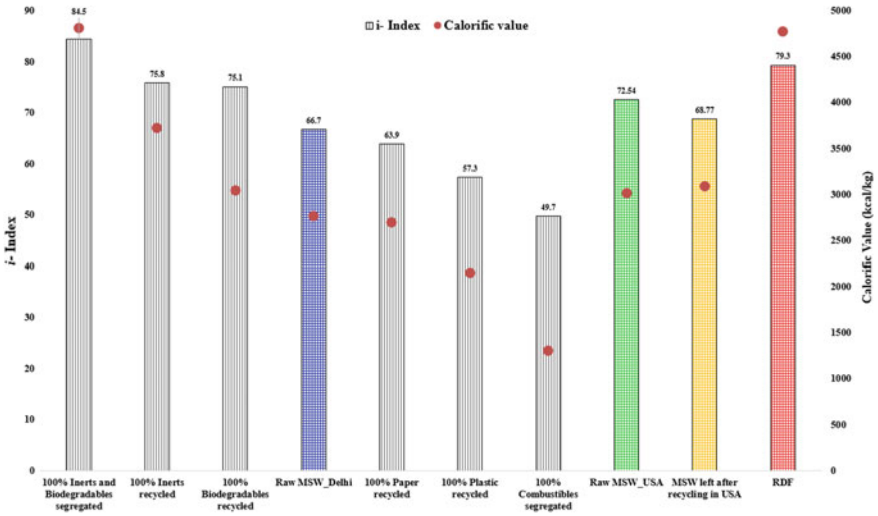

Fig. 5 Variation in *i*-Index values for MSW in different cases under consideration

3.1.3 Recycling of Inert Fraction

The quantum of construction and demolition (C & D) waste as well as other inert materials generated is approximately a third of the total MSW generated. The Ministry of Environment and Forestry (MoEF), Government of India (GOI) released the Construction and Demolition Waste Management Rules, 2016, which mandates the implementation of the 3R concept in handling C & D wastes, besides segregation at source. Although C & D waste was collected as a separate stream to an extent in Delhi, it was mostly disposed in landfills exhausting landfill capacities considerably. Two C & D waste recycling plants are now operational in Delhi at Shastri Park and Burari, of 500 TPD capacity each. Despite these measures, the MSW still has around 30% of incombustible components, which reduces the net heat content and increases the bulk density of MSW. Street sweepings, constructions debris, dust, silt, sand, metals, glass, ceramics, etc., collectively contribute to this fraction. To estimate the variation in incinerability with the removal of inert components, *i*-Index was computed. *i*-Index increased by 13.6% from that of raw MSW to 75.8.

The residual MSW has thus a significant increase in incinerability. Figure 4 demonstrates this trend at 50 and 100% recycling rates.

3.1.4 Recycling of Food and Yard Waste

The wet components, comprising yard and food wastes constitute about 30% of the MSW in South Delhi. The presence of green wastes increases the net moisture content and tends to reduce the overall heat content of MSW. The biodegradable fraction is best treated by biological techniques like anaerobic digestion or composting.

The former is one of the best energy recovery techniques from the biodegradable components [17], while the latter converts them into compost with potential applications. Although drying the biodegradables and then incinerating them may be practised, it may not be economically feasible. *i*-Index of the MSW left after segregating the biodegradable fraction amounted to 75.1, which was about 12.6% more than the *i*-Index for raw MSW, denoting a clear increase in the incinerability of MSW. The incinerability of the residual MSW at 50 and 100% segregation of biodegradables is shown in Fig. 4. A further improvement in the incinerability of MSW can be obtained if both the inert and the biodegradable fractions are removed simultaneously.

3.2 Approach B: Simultaneous Segregation of Different Components

While approach A was focussed on the recycling of individual component fractions, different components are simultaneously removed from the waste stream in Approach B. Two hypothetical cases, in which residual MSW consists of only combustible fractions and 0% combustible fractions were subjected to incinerability assessment studies. Furthermore, a case study of MSW generated in USA was also studied to evaluate the variation in incinerability as opposed to that in a developing economy.

3.2.1 Segregation of Inert and Biodegradable Fractions

The presence of nearly 60% of inert and biodegradable fractions increases the net moisture content, bulk density and consequently reduces the heat content and volatile content of the MSW. Segregating these components and concentrating the combustible fractions can considerably increase the calorific value of MSW. The source segregation practices facilitate the incineration of feed consisting of combustible fractions in developed countries. On the contrary, the MSW generated in developing countries like India are highly heterogeneous and efficient segregation is rarely carried out. The hypothesis of complete segregation of inert and biodegradable fractions was still assumed and *i*-Index totalled up to 84.5, as evident from Fig. 5.

3.2.2 Segregation of Combustible and Non-compostable Fractions

Another hypothesis of segregation of entire combustible fraction was also analysed to understand the extent of its effect on the incinerability of MSW. Paper, plastic, textiles, leather, etc., were assumed to be completely segregated out in this case. The residual MSW is composed of inert fraction and biodegradables in this case.

Besides necessitating high auxiliary fuel requirement, the thermal properties of the feed like heat content, bulk density and volatile content were quite unfavourable. This was apparent from the *i*-Index value computed which amounted to 49.7, apparent from Fig. 5.

3.2.3 Variation in Incinerability of MSW with Recycling in a Developed Economy

In order to compare and contrast the effect of recycling on the incinerability of MSW generated in developed and developing economies, MSW generated in the United States of America (USA) was also analysed. USA recycled and composted about 35% of their MSW in 2012 and the reliance on incineration for energy recovery and waste disposal has decreased over the years. The effect of recycling was quantified using *i*-Index. The data for the same was collected from EPA database [18], while the raw MSW had *i*-Index value of 72.54, post-recycling the value reduced by nearly 5.2% to 68.78. Tables 1 and 2 shows the parameter and normalised values for each case.

4 Conclusion

Recycling and incineration have become sustainable waste management practices in developed and developing countries alike. However, numerous studies report poor feasibility of WtE projects post-recycling activities. In a city like Delhi with informal recycling activities highly prevalent, it becomes quintessential to quantify the incinerability of MSW left after recycling activities. Different recycling scenarios were considered where both individual as well as a combination of components were assumed to be recycled/segregated from the feed stream. The incinerability of the leftover MSW or the residual MSW was then computed using *i*-Index on a scale of 0–100. The properties of MSW generated in USA were also analysed prior to and post-recycling to compare it against the MSW generated in a developing economy. It was observed that while the removal of paper and plastic fractions with high innate heat content reduced the incinerability of the residual MSW, removal of biodegradable as well as inert components led to an appreciable increase in the incinerability of the MSW generated. While both energy and material recovery options are sustainable, the feasibility of WtE projects may be affected by material recovery operations, and hence the quantification of incinerability becomes crucial prior to framing the management strategies.

Table 1 Parameter and normalised values for different MSW feeds (Approach A)

Parameter	Raw MSW_{Delhi}	Normalised value (P_i)	100% paper recycled	Normalised value (P_i)	100% plastic recycled	Normalised value (P_i)	100% inerts recycled	Normalised value (P_i)	100% biodegradables removed	Normalised value (P_i)
Bulk density (kg/m^3)	545	57.2	565.25	56.38	586.05	55.07	163.5	94.7	708	48
CO_2 released (kg/kg MSW)	1.2	54.9	1.1	59	0.98	63	0.96	65.2	0.98	63.2
Heat content (kcal/kg)	2770.1	87.3	2696.6	86	2149.4	74.8	3722.6	97.3	3046.3	90.6
Moisture content (%)	22.1	79.2	23.5	78	24.4	78	28.34	76.2	8	91.2
Auxiliary fuel required (kg/T MSW)	1.3	97.2	1.4	60	43.9	41.7	0	99.99	0	99.9
SO_2 released (g/kg MSW)	3.56	30.8	3.3	39.2	3.56	31.2	2.53	61	2.78	53.4
Specific heat (kJ/kg K)	1.8	61.9	1.93	55.3	2	51.7	2.65	23.8	1.4	69.1
Volatile content (%)	55.9	71.6	55.0	71.5	54.5	71.1	69.09	81	70.5	85
i-Index	**66.7**		**63.9**		**57.3**		**75.8**		**75.1**	

Table 2 Parameter and normalised values for different MSW feeds (Approach B)

Parameter	100% combustibles and non-compostables	Normalised value (P_i)	0% combustibles	Normalised value (P_i)	Raw $\mathrm{MSW}_{\mathrm{USA}}$	Normalised value (P_i)	Residual $\mathrm{MSW}^{1}_{\mathrm{USA}}$	Normalised value (P_i)
Bulk density (kg/m^3)	180	94	700	48.5	100	96.85	400	66.8
CO_2 released (kg/kg MSW)	0.74	72.3	0.49	64.7	1.18	55.3	1.25	52.4
Heat content (kcal/kg)	4808.6	99.99	1307	40.2	3012	90.99	3087	91.9
Moisture content (%)	10	90	31.48	74.5	20.78	80.19	27.24	77
Auxiliary fuel required (kg/T MSW)	0	99.99	72.65	23.9	0	99.9	0	99.9
SO_2 released (g/kg MSW)	1.82	69.6	1.83	69.3	3.23	36.56	3.12	42.7
Specific heat (kJ/kg K)	2.05	51.7	2.99	11.6	1.952	55.40	2.08	47.9
Volatile content (%)	87.9	97	48.4	59	61.23	76.10	56.1	72
i-Index	**84.5**		**49.7**		**72.5**		**68.8**	

[1] Residual MSW is the MSW left after recycling in this context

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References

1. Lino, F.A.M., Bizzo, W.A., Da Silva, E.P., Ismail, K.A.R.: Energy impact of waste recyclable in a Brazilian metropolitan. Resour. Conserv. Recycl. **54**, 916–922 (2010)
2. Morris, J.: Recycling versus incineration: an energy conservation analysis. J. Hazard. Mater. **47**, 277–293 (1996)
3. Mian, M.M., Zeng, X., Nasry, A.A.N.B., Al-Hamadani, S.M.Z.F. Municipal solid waste management in China: a comparative analysis. J. Mater. Cycles Waste Manag. **19**, 1127–1135 (2017)
4. Hoornweg, D., Bhada-Tata, P.: A Global Review of Solid Waste Management. World Bank Urban Development Series. Knowledge Papers no. 1–116 (2012)
5. Koufodimos, G., Samaras, Z.: Waste management options in southern Europe using field and experimental data. Waste Manag. **22**, 47–59 (2002)
6. Abedini, A.R., Atwater, J.W., Fu, G.Y.: Effect of recycling activities on the heating value of solid waste: case study of the Greater Vancouver Regional District (Metro Vancouver). Waste Manag. Res. **30**, 839–848 (2012)
7. Merrild, H., Larsen, A.W., Christensen, T.H.: Assessing recycling versus incineration of key materials in municipal waste: the importance of efficient energy recovery and transport distances. Waste Manag. **32**, 1009–1018 (2012)
8. TERI. http://terienvis.nic.in/index3.aspx?sslid=4110&subsublinkid=1348&langid=1&mid=1 (2017). Accessed 18 December 2017 at 22.37
9. Agarwal, A., Singhmar, A., Kulshrestha, M., Mittal, A.K.: Municipal solid waste recycling and associated markets in Delhi, India. Resour. Conserv. Recycl. **44**, 73–90 (2005)
10. Sebastian, R.M., Kumar, D., Alappat, B.J.: A technique to quantify incinerability of municipal solid waste. Resour. Conserv. Recycl. **140**, 286–296 (2019). https://doi.org/10.1016/j.resconrec.2018.09.022
11. Sebastian, R.M., Kumar, D., Alappat B.J.: Identifying Appropriate aggregation technique for incinerability index. Environmental progress and sustainable energy. AIChE, pp. 1–10 (2018). https://doi.org/10.1002/ep.13068
12. CPCB. Status of implementation of Plastic Waste Management (PWM) status of plastics waste management in India. Central Pollution Control Board India (2015)
13. Finnveden, G., Ekvall, T.: Life-cycle assessment as a decision-support too—the case of recycling versus incineration of paper. Resour. Conserv. Recycl. **24**, 235–256 (1998)
14. Laurijssen, J., Marsidi, M., Westenbroek, A., Worrell, E., Faaij, A.: Paper and biomass for energy? Resour. Conserv. Recycl. **54**, 1208–1218 (2010)
15. Villanueva, A., Wenzel, H.: Paper waste—recycling, incineration or landfilling? A review of existing life cycle assessments. Waste Manag. **27**, 29–46 (2007)
16. Magrinho, A., Semiao, V.: Estimation of residual MSW heating value as a function of waste component recycling. Waste Manag. **28**, 2675–2683 (2008)
17. Burnley, S., Phillips, R., Coleman, T., Rampling, T.: Energy implications of the thermal recovery of biodegradable municipal waste materials in the United Kingdom. Waste Manag. **31**, 1949–1959 (2011)
18. EPA. Municipal solid waste generation, recycling, and disposal in the United States: facts and figures for 2012, 1–13 (2014)

Seasonal and Spatial Variation of DO and BOD for Assessment of the Water Quality of Brahmaputra River

Siddhant Dash, Smitom Borah, Kunwar Raghvendra Singh and Ajay S. Kalamdhad

Abstract In this study, an attempt has been made to monitor the water quality of the Brahmaputra river by analysing two major parameters, viz., DO and BOD by plotting various curves to determine the seasonal as well as the spatially variation of the parameters along the river stretch. The seasonal variation of DO in the Upper Assam region showed similar trends for the pre- and the post-monsoon period with a decreasing trend as the river flows from Kherghat to Dibrugarh and thereafter shows an increase of DO levels near Dhenuka paharh. A decreasing trend was again observed as the river passes through the Nimatighat region. Similarly, for the monsoon season the variation of DO showed an increasing trend as it passes through Dibrugarh and as the river progresses towards the downstream, discharges from various cities along the river stretch blend with the river water, thereby increasing its pollution levels and hence a decreasing trend was observed for the DO in the downstream portion of the Upper Assam region. As far as the variation of BOD along the river stretch is concerned, it was observed that it varies inversely as the DO, which can be seen as an appropriate co-relationship between the two parameters. Similarly, variations of the BOD and DO were obtained for the Lower Assam region. The spatial variation of the BOD and DO showed the map of the depicting the variation of the parameters along the entire river stretch. Proper visualisation of the maps obtained would thereby help in predicting the stretch most polluted so that proper river training works can be done to restore the water quality in the river.

Keywords Water quality · Brahmaputra · Spatial and temporal assessment

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1 Introduction

Rivers are one of the prime sources of surface water in the world. It serves as a multipurpose parameter required for the sustenance of human beings on this planet, such as source of drinking water, irrigation, industries, and recreational purposes. Moreover, water is a lifeline for different other species living either underwater or on the earth's crust, thus making it a primary source of livelihood. However, with the passage of time, levels of pollution in the surface as well as groundwater has also increased significantly due to many anthropogenic or natural causes (anthropogenic causes being the key reason), thereby degrading the quality of water, especially surface water, at many places over the years [1]. This has, in turn, has led to growth of a plethora of water-borne diseases as the surface water serves as an important source of drinking water. Correspondingly, the polluted waters have severely affected the aquatic ecosystem, resulting in the extinction or endangerment of many species of freshwater flora and fauna [2]. Considering the river ecosystem, which is the most affected amongst the surface waters due to the increasing levels of pollution, the changing riverine ecosystem also disturbs the economic activities of the area along with the danger of extinction of several flora and fauna. With increased pollution levels, recreational activities are hindered and thereby making the water unfit for any purpose. Many examples can be cited where the rivers have turned into drains today due to discharge of untreated effluents directly into the river to such an extent that the restoration of the quality of river water virtually became impossible, rendering it unfit for any purpose [3]. This severely affects the economy of the region, particularly those regions where river serves as the backbone for economic development. Hence, continuous monitoring of the river water should be executed in order to ensure that the pollution levels are well within the recommended limits and the rivers continue to exist productively.

In this study, two major parameters have been adopted for the analysis to define the water quality of the river Brahmaputra in Assam, i.e., Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD). The Brahmaputra River flows through the entire Assam state. But unfortunately, Assam does not have any Sewage Treatment Plants due to which the wastewater from the households in different parts of Assam gets discharged directly into the river through the tributaries joining it. Also, there are no major industries adjacent to the river stretch for the river water to get polluted through industrial discharge. Hence, the pollution in the river is mainly due to the discharge of untreated/partially treated sewage effluents due to which the DO and BOD parameters have been considered. DO refers to the amount oxygen dissolved in the river water. It is a crucial water quality parameter by virtue of which the freshness of the water can be determined. It also serves as the lifeline for the aquatic ecosystem to flourish as this serves the total oxygen requirement for the entire ecosystem including the microorganisms, which sustain and flourish in the river water. The organic matter present in the river water is equivalently represented by BOD. It is the total oxygen required by the aerobic microorganisms to break down the biodegradable matter present in the water.

BOD is taken as the standard parameter for determining the pollution levels in the river water, as more will be the BOD, there are more chances for the freshwater to become septic and unfit for drinking purposes as well as for the flora and fauna to exist.

2 Study Area

Brahmaputra is one of the major rivers in Asia and the widest in India [4]. It originates from Angsi Glacier, located in the northern side of the Himalayas in the great gorges and enters India through Arunachal Pradesh. It then flows southwest through the Assam valley and enters the Bangladesh border before merging with the

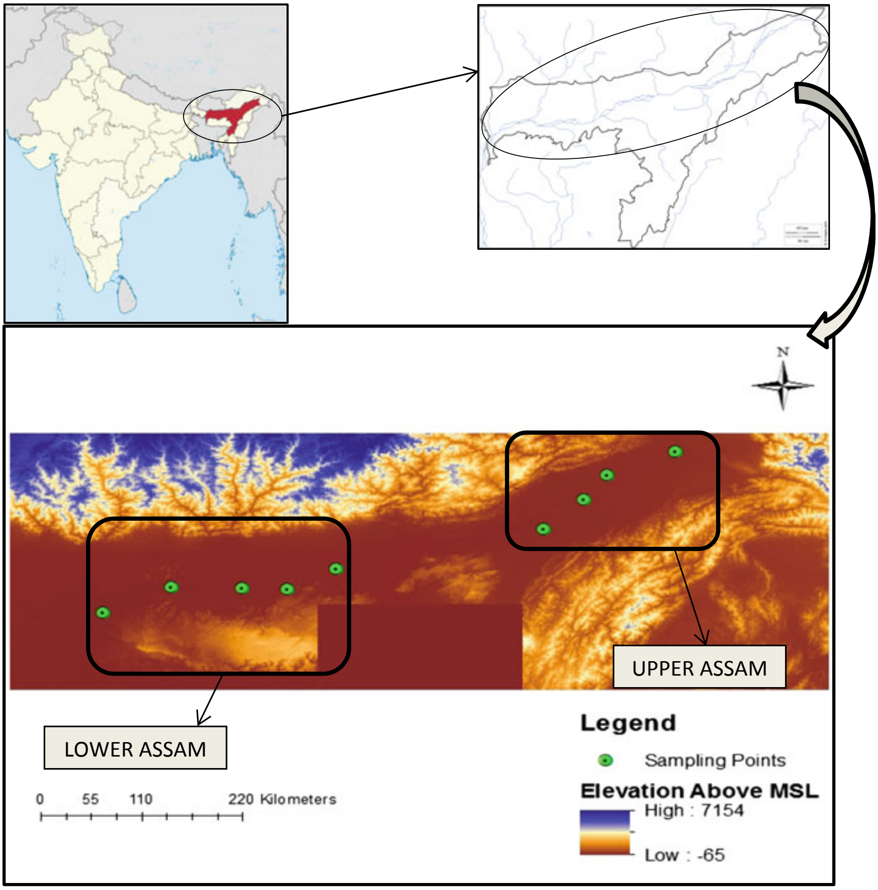


Fig. 1 Study area with location of the sampling points

Ganges and terminating at the Bay of Bengal. It, therefore, shares its boundaries with China, India, and Bangladesh. It is the tenth-largest river in the world by discharge and the fifteenth longest. About 3848 km long and having an average depth of 38 m and maximum depth of 120 m, the river stretches from 30°23′N 82° 0″E at the source to 25°13′24″N 89°41′41″E at the mouth. From Indian perspective, the Brahmaputra River is very vital for irrigation and transportation in the north-eastern part of the country, thereby helping in the boost of economy of the region. The study area comprises of the entire Brahmaputra river stretch in the Indian subcontinent flowing through the state of Assam. Nine sampling points have been considered for the study, four in the Upper Assam region and five in the Lower Assam belt, for the analysis of two primary water quality parameters, i.e., Biochemical Oxygen Demand (BOD) and Dissolved Oxygen (DO). The study area along with the sampling points is shown in Fig. 1.

3 Materials and Methodology

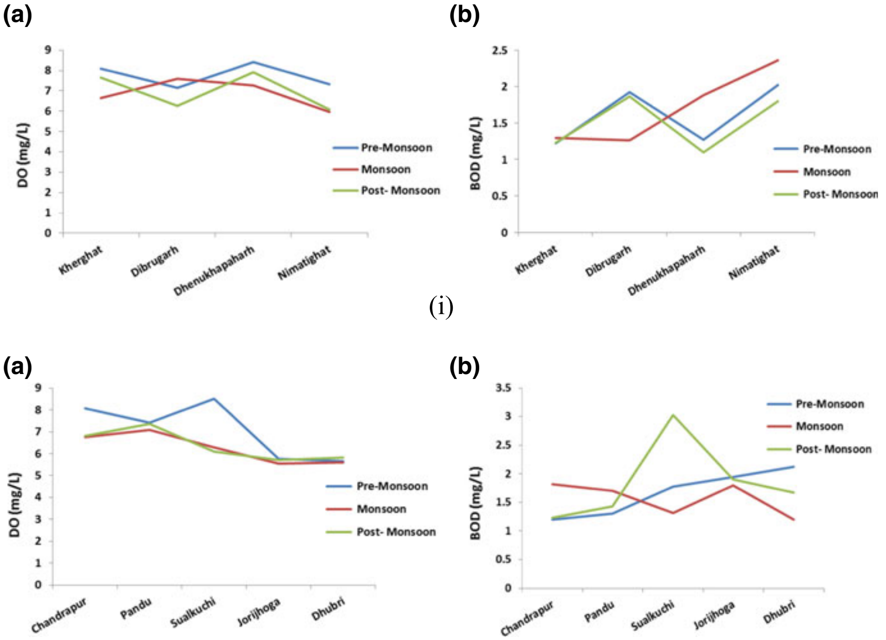
The water quality data have been collected from the Assam Pollution Control Board for a period of 12 months for nine sampling points as discussed above. The data collected was for the entire stretch of the river, which was first divided into two parts; Upper Assam and Lower Assam, for convenience. Hence, four points in the Upper Assam and five points in the Lower Assam region were considered for the analysis of the data. The yearly data was then divided into three seasons, viz., pre-monsoon, monsoon, and post-monsoon season. The pre-monsoon season encompassed the data collected from the sampling points for the months of January–April; monsoon season comprised of the data for the months of May–September and the post-monsoon from October to December. The primary parameters that have been considered for the analysis are BOD and DO since the major pollutants that affect the river water are the untreated/partially treated sewage from the households along the entire stretch of the river. The annual data was then analysed and the mean and standard deviation of the data were calculated. Curves were plotted to visualise the seasonal variation of the parameters for both Lower and Upper Assam region. These curves provided the seasonal variation of the water quality parameters for different stretches of the river considered in the study, both for Upper and Lower Assam region.

For the spatial variation of the water quality parameters, the data was analysed in ArcGIS 10.3.1. The weights of the parameters for every month were assigned to each of the sampling points considered and “Radial Basis Functions” Interpolation technique was applied to the data imported, which resulted in generation of maps with smooth curves that showed the variation of the DO and BOD along the entire stretch of the river for the 12 months period.

4 Results and Discussion

4.1 Seasonal Variation

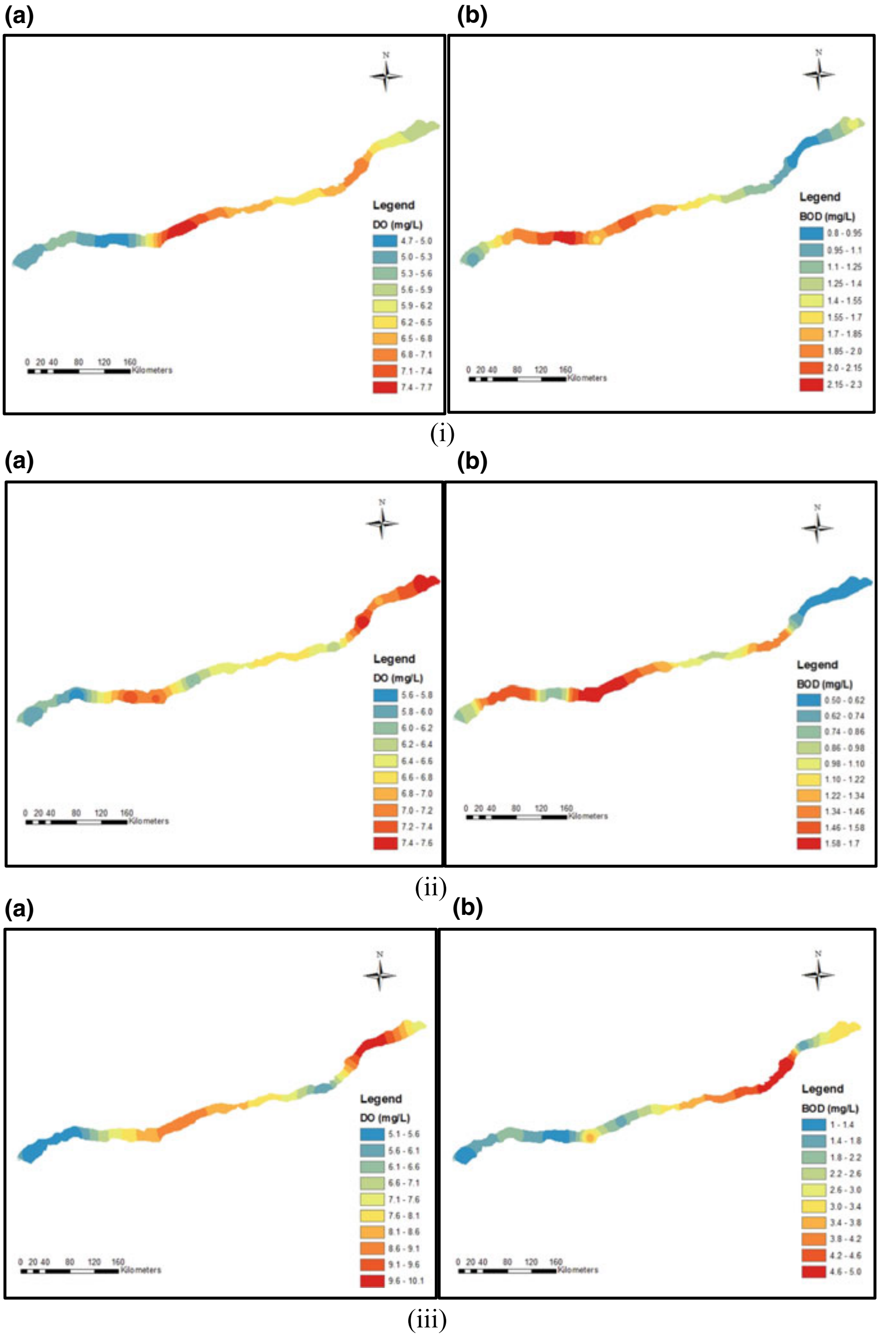
The seasonal variation of the DO and BOD for Upper and Lower Assam regions has been shown in Fig. 2. Considering the variation in DO in the Upper Assam region, it is clearly observed from the curve 3(i)(a) that the DO shows an identical trend for pre- and post-monsoon season, respectively. A decreasing trend is observed as the river flows from Kherghat to Dibrugarh. This may be mainly due to the discharge of untreated/partially treated sewage effluents from the settlements nearby as Kherghat is mainly a hilly region whereas Dibrugarh is a district of relatively higher population. The trend thereafter shows an increase of DO levels near Dhenukapaharh as there is no significant discharge of effluents into the river due to very low density of population in that area. The increase in the levels of DO can be mainly vindicated due to the fact that reaeration occurs along the river stretch due to its self-purification capacity. Again a decreasing trend is observed as the river passes through the Nimatighat region, which again is a densely populated area and the untreated/partially treated effluents are discharged directly into the river due to the absence of an STP for treating the sewage. Again for the monsoon season the variation is unlike that as compared to the pre- and post-monsoon season.



(i)

(ii)

Fig. 2 Seasonal variation of **a** DO and **b** BOD for (i) upper Assam and (ii) lower Assam region

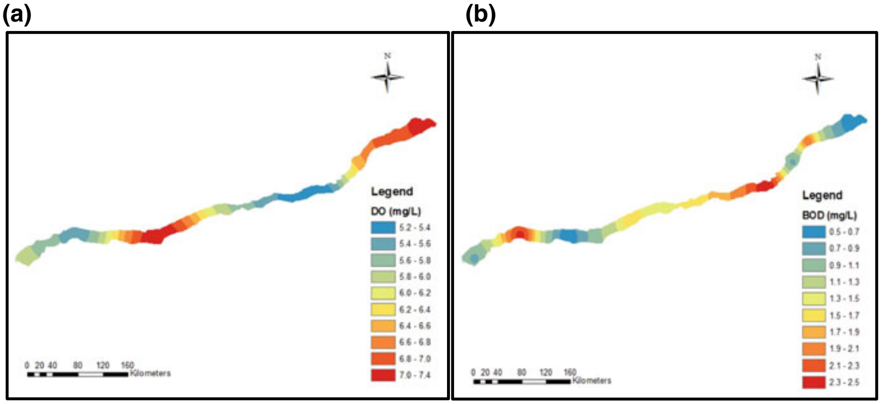


(i)

(ii)

(iii)

Fig. 3 Spatial variation of **a** DO and **b** BOD for the month of (i) May 2016 (ii) June 2016 (iii) July 2016 (iv) August 2016 (v) September 2016 (vi) October 2016 (vii) November 2016 (viii) December 2016 (ix) January 2017 (x) February 2017 (xi) March 2017 (xii) April 2017



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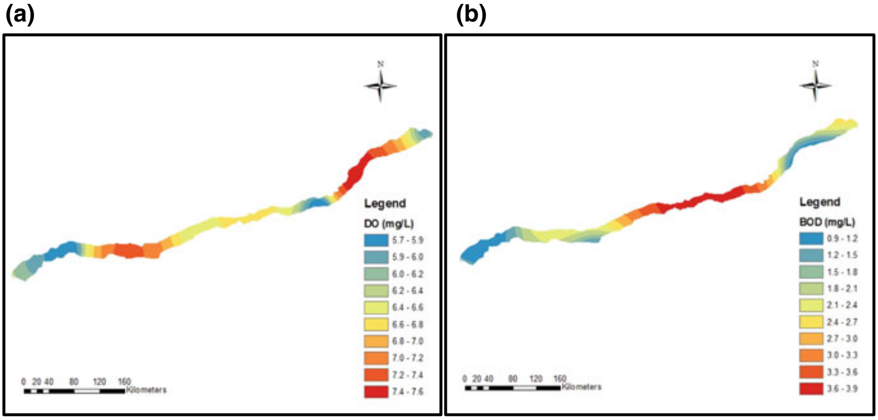

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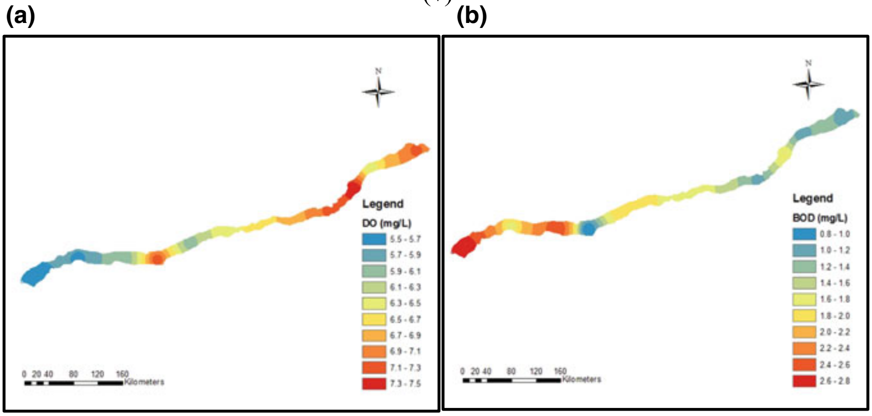

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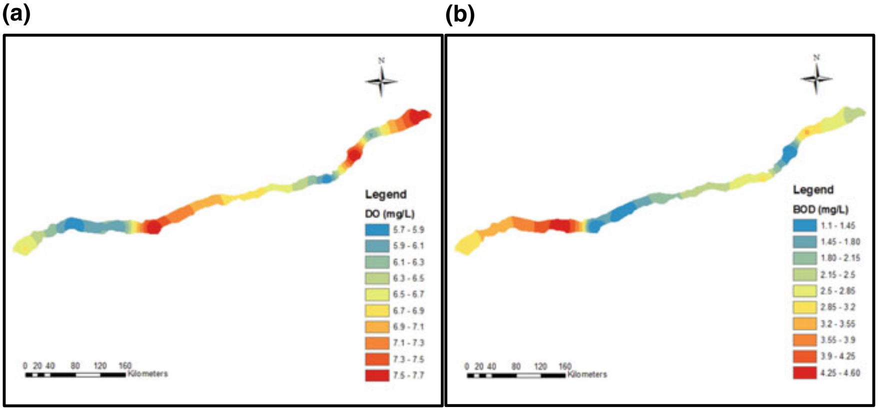
Fig. 3 (continued)



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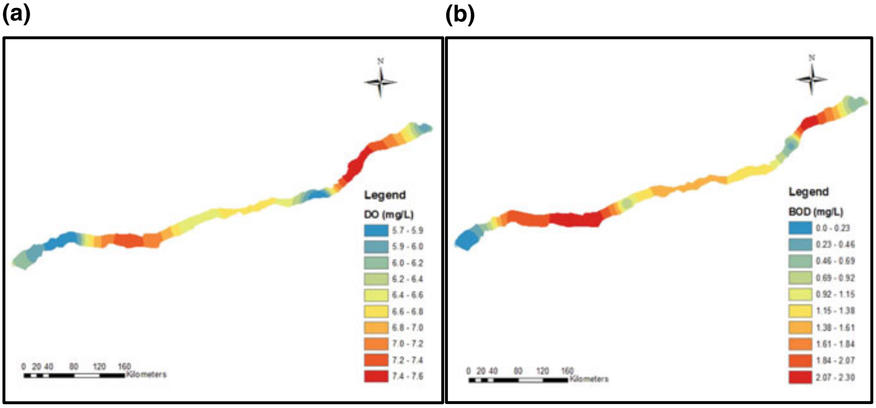

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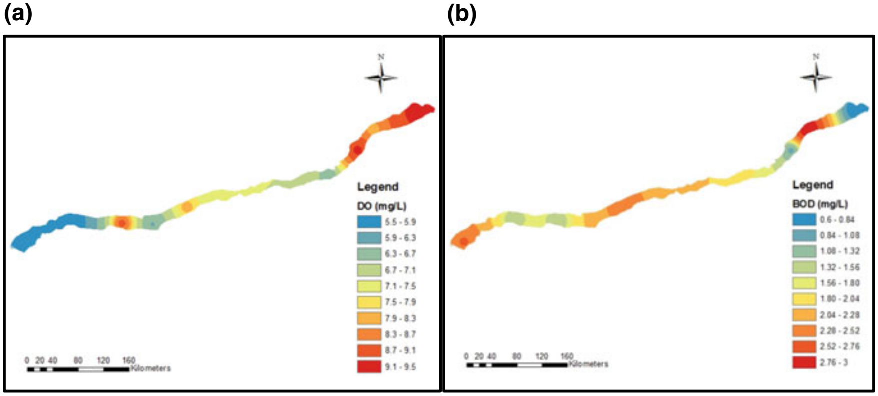

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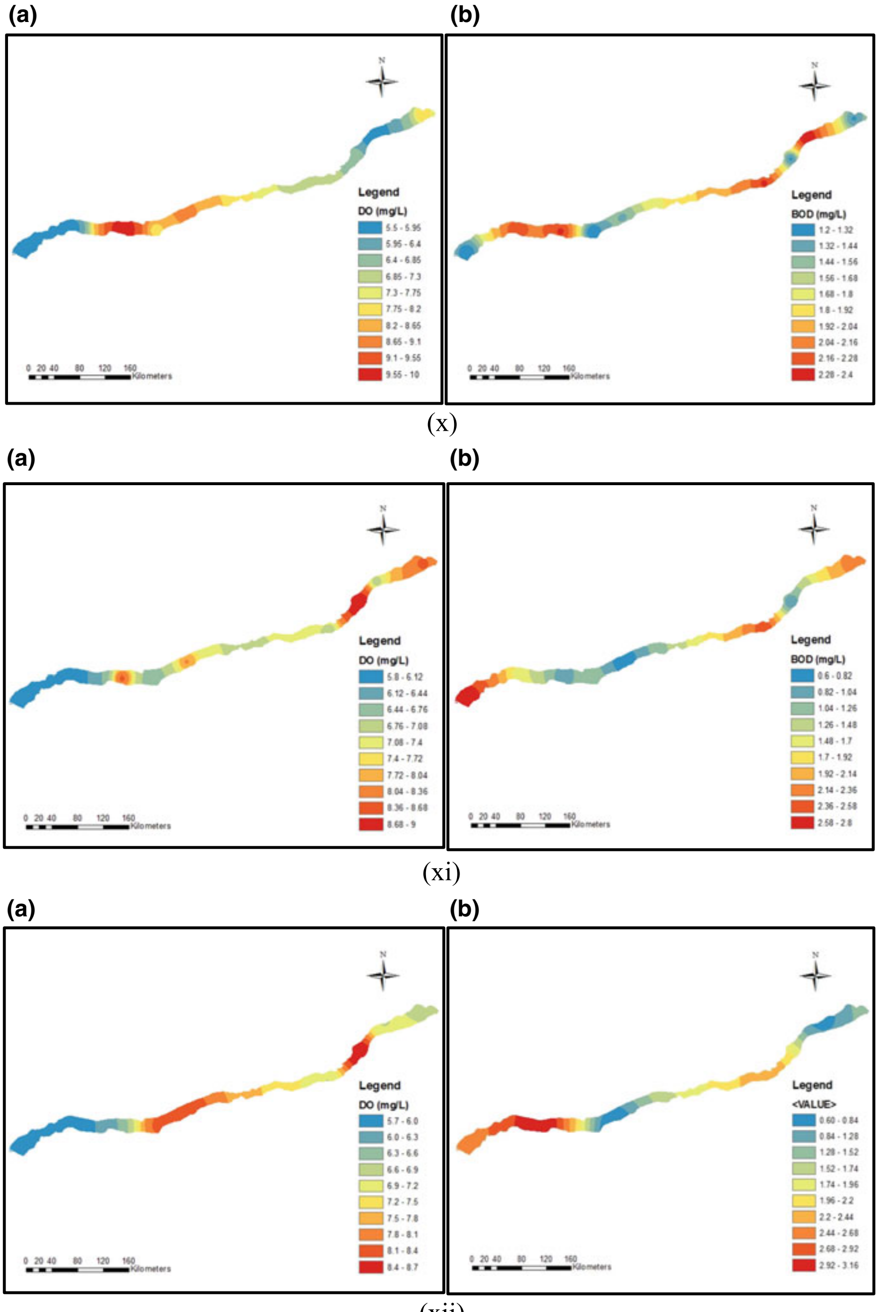

(x)

(xi)

(xii)

Fig. 3 (continued)

Here, the DO shows an increasing trend as it passes through Dibrugarh. The chief reason may be the dilution of the river water due to heavy discharges during the monsoon season. As the river progresses towards the downstream, discharges from various cities along the river stretch blend with the river water, thereby increasing its pollution levels and hence a decreasing trend is observed for the DO in the downstream portion of the Upper Assam region. As far as the variation of BOD along the river stretch is concerned, it can be clearly observed that it varies inversely as the DO, which can be seen as an appropriate co-relationship between the two parameters. Similarly, the variation of DO and BOD for various seasons along the river stretch for the Lower Assam region is shown in Fig. 2(ii).

4.2 Spatial Variation

The spatial variation depicts the variation of the DO and BOD parameters along the entire river stretch. The spatial variations have been shown in Fig. 3 for the entire 12 months period. This will help in determining the stretch of the river which is most polluted. Various hotspots can be delineated from these generated maps, which prove to be the major contributors of the pollution load in the river so that proper river rejuvenation options such as decentralised sewage treatment can be adapted for that portion of the river so as to restore the quality of water in the river stretch.

5 Conclusion

This study presents a spatial as well as seasonal variation of BOD and DO parameters for Brahmaputra River, which would thereby help in the monitoring of its water quality. As observed from the curves obtained for the seasonal variation, DO and BOD parameters correlate each other appropriately and hence provide an idea of the changes in the water quality for different seasons of the year. The spatial variation provided maps of the variation of the two parameters for the entire river stretch and for every month of the yearly data collected. The results obtained can also be used to analyse the stretch of the river which is most affected by the discharge of untreated/partially treated effluents in different seasons of the year so that proper measures can be taken to improve the quality of the water and restore to its original state.

Acknowledgements The authors acknowledge the support of the Assam Pollution Control Board for providing sampling data for a period of 12 months from nine sampling points.

References

1. Singh, K.R., Dutta, R., Kalamdhad, A.S., Kumar, B.: Risk characterization and surface water quality assessment of Manas River, Assam (India) with an emphasis on the TOPSIS method of multi-objective decision making. Environ. Earth Sci. **77**(23), 780 (2018)
2. Ouyang, Y., Nkedi-Kizza, P., Wu, Q.T., Shinde, D., Huang, C.H.: Assessment of seasonal variations in surface water quality. Water Res. **40**(20), 3800–3810 (2006)
3. Agrawal, K.P.: 2012. YAMUNA-Lifeline of the Country in Danger. NISCAIR-CSIR, New Delhi
4. Gain, A.K., Wada, Y.: Assessment of future water scarcity at different spatial and temporal scales of the Brahmaputra River Basin. Water Resour. Manage. **28**(4), 999–1012 (2014)

Recycling-Oriented Characterization and Recovery Potential of Rare Earth Elements in Compact and Linear Fluorescent Lamps

Shailendra Kumar Singh and Subrata Hait

Abstract In the present study, end-of-life compact fluorescent lamps (CFLs) and linear fluorescent lamps (LFLs) have been characterized for the content of rare earth elements (REEs) to estimate the recovery potential of REEs in India based on their average obsolescence rate and waste generation. Yttrium (Y as Y_2O_3) in CFLs and europium (Eu as Eu_2O_3) in LFLs were observed to be the prevalent REE present with an average content of 251.8 mg/g and 9.7 mg/g, respectively. The content of REEs does not show statically significant ($P < 0.05$) difference in various brands of CFLs and LFLs. Further, the results advocated that around 2237 tons of REEs comprising of about 2154 tons from waste CFLs and 83 tons from waste LFLs could be recovered in India in the year 2017. It can be inferred from the present study that the end-of-life CFL and LFL waste streams could be viable secondary resource for recycling of REEs.

Keywords E-waste · Compact fluorescent lamp · Linear fluorescent lamp · Rare earth elements · Recycling · Recovery potential

1 Introduction

The growing magnitude and variety of lighting equipment used in the modern society accompanied with the rapid advancement and increasingly rapid obsolescence rate have added burden to the electronic waste (e-waste) stream. In India, an increase in the waste generation from the end-of-life lighting equipment has also been contributed by the Bachat Lamp Yojana (2009), a Government of India initiative promoting the substitution of incandescent lamps to energy-saving compact fluorescent lamps (CFLs) and linear fluorescent lamps (LFLs) through which about 500 millions of CFLs were distributed during the year 2004–2014 [1]. Around

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tenfold increase in the sale of CFLs from 43 million in 2004 to 453 million in India in 2014 has been reported [1]. During the same period, i.e., 2004–2014, ELCOMA [1] has reported an increase in the sale of LFLs from 175 million to 234 million in India. Further, the replacement of CFLs by the energy-efficient light-emitting diode (LED) bulbs as promoted by the UJALA scheme (2015), a Government of India initiative has led to the buildup of end-of-life CFLs and LFLs. The CFLs and LFLs are mainly composed of metal caps, glass, three-band phosphor powders (Blue, Green, and Red) and small amounts of mercury in which three-phosphor powders forming a complex structure of rare earth elements (REEs) [2, 3]. The International Union of Pure and Applied Chemistry (IUPAC) have defined seventeen elements in the periodic table consisting of lanthanide series lanthanum (La)–lutetium (Lu) (atomic number 57–71) along with scandium and yttrium (39) as REEs. REEs have been classified into two major subgroups: light REEs (atomic number 57–63) and heavy REEs (atomic number 39, 64–71) except scandium [4]. REEs, i.e., Y, Ce, Eu, and Tb are used as fluorescent material on the inner layer of CFLs and LFLs. The inner coating of fluorescent glass tubes is coated with phosphor powder, which is able to absorb the UV light from electrically charged mercury vapor present in the glass tubes and produce visible light based on an appropriate combination of blue, green, and red emitters. Phosphors are widely used for general illumination in fluorescent lightings and displays. Owing to the presence of REEs along with mercury, the indiscriminate disposal of end-of-life CFLs and LFLs along with the municipal solid waste (MSW) stream not only leads to loss of resources but also presents hazards to the humans as well as to the environment.

The primary source of REEs is the mineral deposit ores spread worldwide, but confined mainly in China, USA, and Australia. In terms of value, the permanent magnets (38%), lamp phosphors (32%), and metal alloy (13%) contain greater than 80% of the REE market [5]. Of late, China being the largest producer and exporter in the world has shrunken the REE export from 85 to 90% to around 50% while increased the REEs price more than 600% and thereby narrowed down the overall REEs supply [5–7]. Thus, the balance between the primary and secondary resource reservoir is principally important in establishing the complements between the demand and supply of REEs. The potential secondary resources of REEs as evident from available scientific literature could be scraps (residue emerged during metal production/recycling), end-of-life products, viz., lighting equipment, Ni–MH battery and landfilled industrial residues such as phosphorus, gypsum, and red mud [5, 8–10]. Owing to the growing demand and limited resource availability, the occurrence in CFLs and LFLs coupled with their rapid obsolescence rate can serve as the potential secondary resource reservoir for recycling and recovery of REEs. However, it has been reported that a meager 1% of REEs has been recycled so far from the end-of-life waste streams [5].

Owing to the trade control and limited availability in very few countries in the world, there is a huge scope of recycling and recovery of REEs from the end-of-life waste streams, especially end-of-life CFLs and LFLs in view of their rapid obsolescence rate. Characterization of these obsolete products for REEs content is the prerequisite prior to the recycling from the waste streams. In this context, the study mainly focuses on the exhaustive characterization of four brands of end-of-life CFLs and three brands of end-of-life LFLs for REEs scoping towards profitable recycling. Further, the recovery potential of REEs arising out of these obsolete CFL and LFL waste streams has been estimated from their average obsolescence rate and waste generation in India for the year 2017.

2 Materials and Methods

2.1 Collection of Obsolete CFLs and LFLs

Four brands of obsolete CFLs and three brands of obsolete LFLs were used for the experimental purpose. The CFLs and LFLs of equivalent wattage of respective brands were collected in ample quantity from the households and scrap dealers in and around Bihta, Patna, Bihar, India.

2.2 Sample Preparation

In order to prepare samples for characterization, aluminum end caps, circuit boards, plastics and glass from the obsolete CFLs and LFLs were removed manually by means of a hacksaw, screwdrivers, pliers, etc. Phosphor powder containing rare earth elements was scratched manually and extracted from the obsolete lamps for characterization of individual REEs. The dismantling of obsolete CFLs and LFLs and extraction of phosphor powder are schematically presented in Figs. 1 and 2, respectively.

2.3 SEM/EDS Analysis for the Characterization of REEs

The quantitative characterization of REEs in the phosphor powder samples obtained from obsolete CFLs and LFLs was conducted by the scanning electron microscopy/energy-dispersive X-ray spectroscopy (SEM/EDS) (EVO 18, Zeiss, Germany). The samples were observed under the SEM at magnification of 100× and power of 20 keV for the generation of elemental spectral lines in the EDS to explore the morphology and the REEs composition and contents.

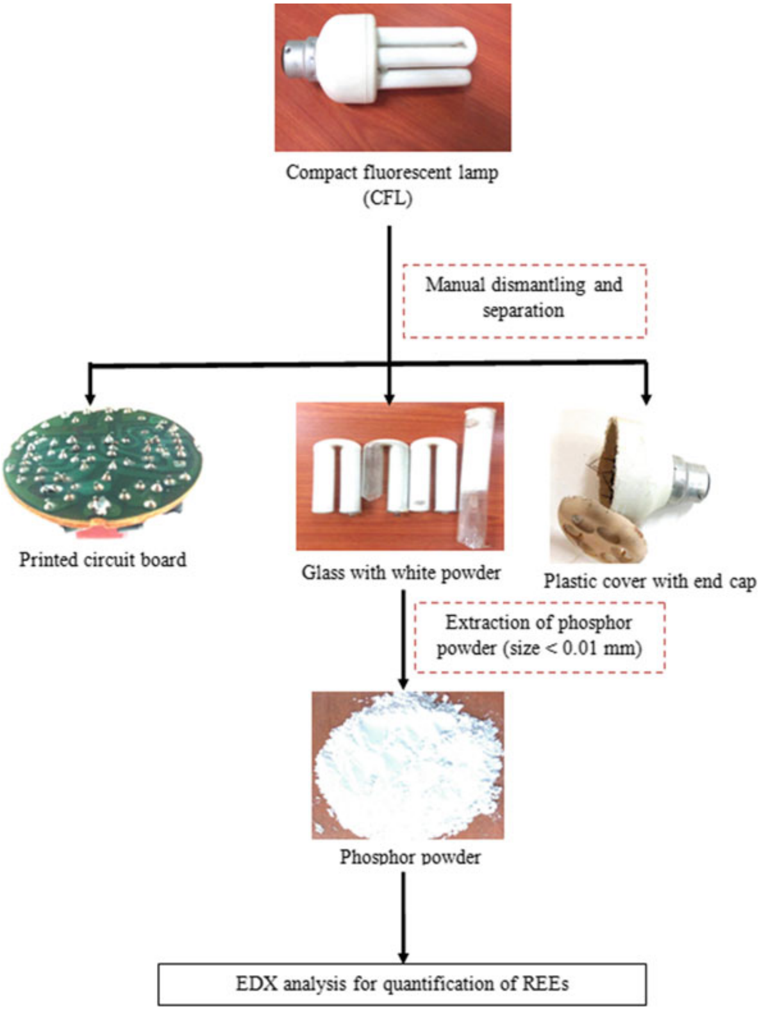


Fig. 1 Manual disassembling of obsolete CFLs and extraction of phosphor powder

2.4 Statistical Analysis

In order to analyze significant differences in the individual REE content in the phosphor powder of obsolete CFLs of four brands and obsolete LFLs of three brands, one-way analysis of variance (ANOVA) as a statistical tool was used. For identifying the contrast of the differences among individual REE content in obsolete

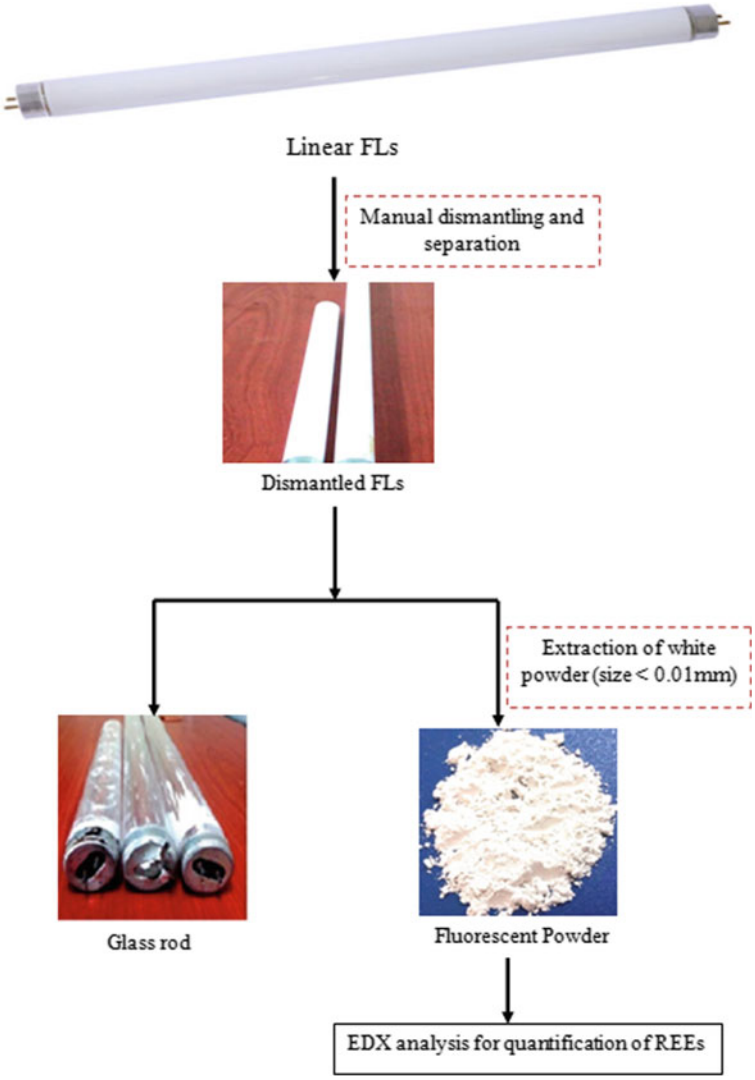


Fig. 2 Manual disassembling of obsolete LFLs and extraction of phosphor powder

CFLs and LFLs of different brands, Tukey's HSD (honestly significantly differences) test as a post hoc analysis was also performed. The statistical significance for the tests was assessed at a probability level of $P < 0.05$. The SPSS Package (Version 22) was used for performing all the statistical analyses.

2.5 Estimation of Recovery Potential of REEs from Obsolete CFLs and LFLs in India for the Year 2017

In order to determine the recovery potential of REEs, the estimation of end-of-life CFLs and LFLs generation is necessary from these two waste streams in India for the year 2017 based on their obsolescence rate. The amount of waste generation in terms of end-of-life CFLs and LFLs can be estimated for the year 2017 using the sales data for CFLs and LFLs in India based on their average obsolescence rate. The generalized frameworks adopted for the estimation of recovery potential of REEs from obsolete CFLs and LFLs are presented in Table 1.

Following assumptions were made while estimating recovery potential of REEs from the obsolete CFLs and LFLs:

- This study was restricted to only two major end-of-life products in the lighting industry, i.e., CFLs and LFLs. Hence, the waste generation and the recovery potential of REEs in this study referred to the contributions from these two end-of-life products only.
- It was assumed that the sales data for CFLs and LFLs obtained from databases available and already published annual reports and affiliated websites represented the overall Indian market scenario.
- The potential annual waste generation for CFLs and LFLs was estimated based on sales data of the concerned product in respective year, i.e., products were

Table 1 Procedural framework for estimating recovery potential of REEs from obsolete CFLs and LFLs

Steps		Example
Step-1: Selection of various waste streams which contains REEs		**A, B, C, D**…
Step-2: Country's total number of specific durable items to become obsolete during their Obsolescence age		**N** {From literature}
	Step-2a: Life period/Obsolescence age adopted for analysis	**T** (in years) {From literature}
	Step-2b: Range of life periods/obsolescence age of given products for estimation of potential annual REEs generation	**T1–T2** (in years) {From literature}
Step-3: Estimated the total sale of product with respect to their life period		**S** (in millions) {From literature}
	Step-3a: Average unit weight of the selected waste material	**I** (in grams) {Experimental data}
	Step-3b: Conversion of the total waste generation for the year 2017	**SI** (in tons) [(million × gram/10^6) = tons]
	Step-3c: Percentage weight of waste materials which contains REEs	**X** (in wt%) {Experimental data}
	Step-3d: Conversion of total waste streams into recovery potential of REEs for the year 2017	**SIX** (in tons) [SI (tons) × X/100 = SIX (tons)]

supposed to become obsolete in the year 2017 after satisfying their obsolescence rate or life cycle period.

- The obsolescence rate or life cycle period for CFLs and LFLs was considered as standard and assumed to be the mean of several values collated from available scientific literature. However, the unit weight of these two products was obtained from experiments and observations in this study.

3 Results and Discussion

3.1 REEs Contents in Obsolete CFLs and LFLs from SEM/EDS Analysis

A total of 12 samples of obsolete CFLs of four different brands and nine samples of obsolete LFLs of three different brands were characterized for the average content of REEs, i.e., Tb, Ce, Dy, Er, Eu, Gd, Ho, La, Nd, Pr, Sc, Sm, Tm, Yb, Y, and Lu employing the scanning electron microscopy/energy-dispersive X-ray spectroscopy (SEM/EDS). The contents of REEs found in various brands of obsolete CFLs and LFLs are presented in Tables 2 and 3, respectively. Further, the morphological characterization of representative samples of the phosphor powder obtained from the obsolete CFLs and LFLs under the SEM (see Figs. 3a and b) confirmed the presence of the REEs as reported in Tables 2 and 3. Statistically insignificant ($P < 0.05$) difference in the contents of REEs in various brands of obsolete CFLs and LFLs was observed.

As evident in Table 2, Y in terms its oxide was found to be the most abundant REE in the phosphor powder of various brands of CFLs with an average content of 251.8 mg/g. Other REEs which were observed to present in significant amount in the phosphor powder of various brands of CFLs include Ce, Eu, Lu, Nd, Pr, Sc, Tb, and Yb (Table 2). The highest abundance of Y in the CFLs can be attributed to the presence of red phosphor comprising of a complex of its oxide (Y_2O_3: Eu^{3+}). The red phosphor among the three-band phosphors is generally used in the higher proportion for providing fluorescence in CFLs [2]. This can be further explained by the fact that the highly pure oxide of Y is used in making of red phosphor present in complex structure of the three-band phosphors. Other REEs such as Eu and Ce in form of their oxides are used in CFLs for providing high luminance, rich coloration and long life [2, 13].

It was observed that Ce, Eu, Tb, and Yb among the REEs were present in abundance in the phosphor powder of obsolete LFLs of Brand 1 (Table 3). However, Ce and Yb were not present in other brands of obsolete LFLs. On the contrary, Dy was only present in the phosphor powder of obsolete LFLs of Brand 3. Europium (Eu) as its oxide was found to be the most abundant REE present in the end-of-life LFLs with an average content of 9.7 mg/g. Among other REEs, Ce, Tb, and Yb were observed to present as their oxides in the end-of-life LFLs with an

Table 2 Content of REEs as their oxides in obsolete CFLs

CFL brands	REEs (mg/g)									Reference
	Y_2O_3	CeO_2	Eu_2O_3	Tb_4O_7	Yb_2O_3	Sc_2O_3	Pr_2O_3	Lu_2O_3	Nd_2O_3	
Brand 1	223.0 ± 36.4	41.4 ± 12.0	29.2 ± 10.7	23.6 ± 12.8	21.9 ± 16.9	1.7 ± 1.1	31.7 ± 2.9	5.7 ± 1.1	9.3 ± 2.9	This study
Brand 2	292.4 ± 105.0	34.6 ± 17.3	37.8 ± 15.6	24.0 ± 15.6	21.6 ± 15.2	N.D.	N.D.	6.5 ± 2.9	N.D.	
Brand 3	228.3 ± 24.0	30.3 ± 3.0	18.2 ± 2.8	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	
Brand 4	210.9 ± 19.0	26.7 ± 2.2	20.8 ± 2.1	N.D.	N.D.	10.5 ± 1.9	N.D.	N.D.	N.D.	
Literature	155.1 – 469.0	7.0 – 53.0	9.5 – 44.0	22.0 – 26.0	N.A.	N.A.	N.A.	N.A.	N.A.	[11, 12]

N.D.: Not detected; N.A.: Not available

Table 3 Content of REEs as their oxides in obsolete LFLs

LFL brands	REEs (mg/g)				Reference
	Tb_4O_7	Eu_2O_3	Yb_2O_3	CeO_2	
Brand 1	5.3 ± 2.5	5.8 ± 0.8	3.2 ± 2.2	6.0 ± 4.6	This study
Brand 2	6.1 ± 2.4	12.3 ± 8.8	N.D.	N.D.	
Brand 3	26.5 ± 6.3	12.7 ± 5.3	N.D.	N.D.	
Literature	0.5 – 2.0	0.9 – 4.0	N.A.	4.0	[11]

N.D.: Not detected; N.A.: Not available

average content of 5.4 mg/g, 8.5 mg/g, and 2.4 mg/g, respectively. The presence of Ce and Yb in obsolete LFLs of Brand 1 only may be plausibly due to the use of different REEs with same properties in other brands, i.e., Brand 2 and 3 of obsolete LFLs for the common purpose of providing fluorescence [2]. The presence of Ce, Eu, and Tb in LFLs can be attributed to the use of these REEs, which are optically active because of the presence of 4f electrons [14]. Due to the strongest and lightest magnetic properties of REEs, these are unique cache in terms of light emission [14].

3.2 Recovery Potential of REEs from Obsolete CFLs and LFLs in India for the Year 2017

Estimation of Obsolete CFLs and LFLs Generation in India for the Year 2017

The estimation of end-of-life CFLs and LFLs generation was necessary in order to determine the recovery potential of REEs from these two waste streams in India for the year 2017 based on their obsolescence rate. The average obsolescence rate for CFLs and LFLs was assumed to be 2 years and 3 years, respectively, as collated from the available scientific literature [15–17]. Based on their average obsolescence rate, the amount of waste generated in terms of end-of-life CFLs and LFLs was estimated for the year 2017 using the sales data for CFLs (in 2015) and LFLs (in 2014) in India. The estimation of waste generation in terms of end-of-life CFLs and LFLs in India for the year 2017 is summarized and presented in Table 4. The total waste generation in terms of end-of-life CFLs and LFLs in India in 2017 was estimated to be 45,720 tons and 64,250 tons, respectively. Out of which, the total weight of phosphor powders specifically containing REEs was determined to be 5486.4 tons and 3212.5 tons from the end-of-life CFL and LFL waste streams, respectively, in India in 2017 (Table 4).

Recovery Potential of REEs from Obsolete CFLs and LFLs in India for the Year 2017

The recovery potential was estimated using the average content of individual REEs from the SEM/EDS analysis and the total weight of phosphor powders from end-of-life CFLs and LFLs specifically containing REEs in India in the year 2017. The recovery potential of individual REEs from obsolete CFLs and LFLs in India

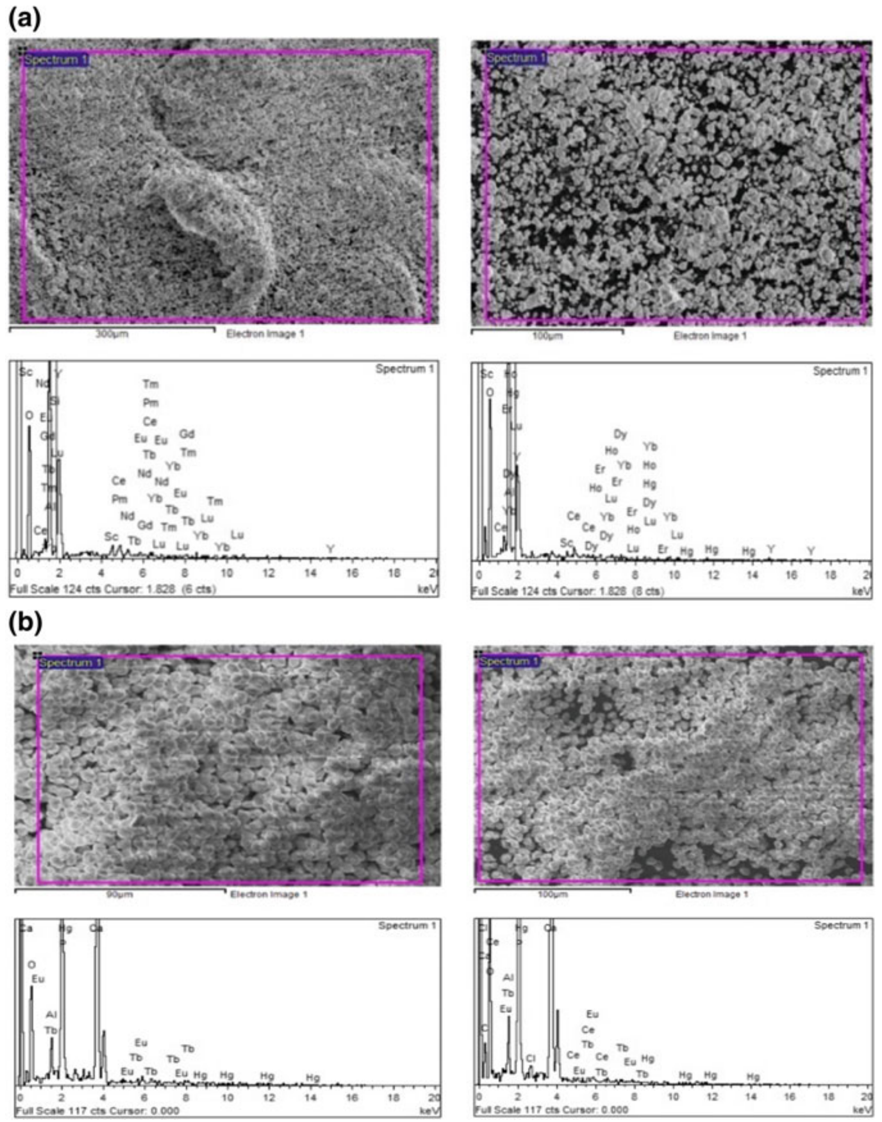
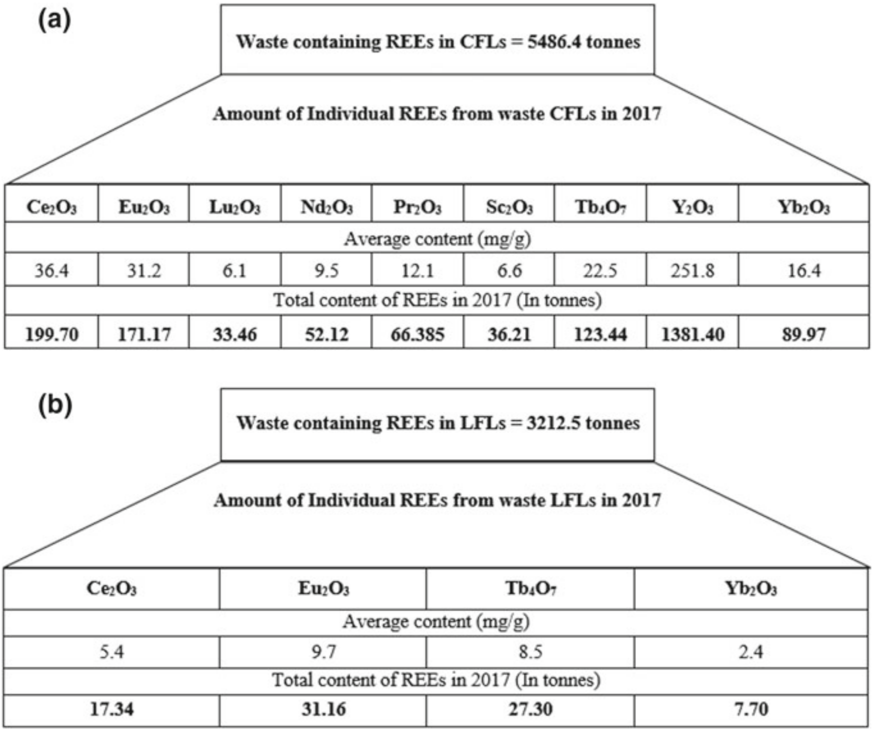


Fig. 3 Representative SEM images of phosphor powder of obsolete **a** CFLs and **b** LFLs

for the year 2017 is presented in Fig. 4a, and 4b, respectively. The combined recovery potential of REEs in the end-of-life CFLs and LFLs in India for the year 2017 is summarized in Table 5. The total recovery potential of REEs from obsolete CFL and LFL waste streams as secondary resource in India for the year 2017 was estimated to be around 2237 tons comprising around 2154 tons from CFLs and around 83 tons from LFLs.

Table 4 Estimation of obsolete CFLs and LFLs generation in India for the year 2017

Steps	CFLs	LFLs
Step-1: Selection of various waste streams which contains REEs	Four brands	Three brands
Step-2: Country's total number of specific durable items to become obsolete during their Obsolescence age	Obsolescence rate (years)	
Step-2a: Life period/Obsolescence rate adopted for analysis	2	3
Step-2b: Range of life period/obsolescence rate of given products for estimation of potential annual REEs generation	2–3	2–4
	Source of data	
	[15, 17]	[16, 17]
Step-3: Estimation of the total sales of product with respect to their discarded life period	Total sale of above-mentioned products (in millions)	
	In 2015	In 2014
	381	257
Step-3a: Source of data for sales of product in respective years	Source of data	
	[1]	[1]
Step-3b: Average unit weight of the selected end-of-life products (observed in this study)	Unit weight (g)	
	120	250
Step-3c: Conversion of the total waste generation in the year 2017	Waste generation in the year 2017 (in tons)	
	45,720	64,250
Step-3d: Range of %wt. of the product part, i.e., phosphor powders containing REEs relative to the total weight of the end-of-life product (observed in this study)	%wt. of phosphor powder containing REEs relative to the product	
	8.8–14.56	3.00–6.46
Step-3e: Average %wt. of phosphor powders containing REEs relative to the total weight of the end-of-life product (observed in this study)	12	5
Step-3f: Estimation of total weight of phosphor powders from end-of-life CFLs and LFLs specifically containing REEs in India in the year 2017	Weight of phosphor powder containing REEs in the year 2017 (in tons)	
	5486.4	3212.5


(a)

Waste containing REEs in CFLs = 5486.4 tonnes

Amount of Individual REEs from waste CFLs in 2017

Ce_2O_3	Eu_2O_3	Lu_2O_3	Nd_2O_3	Pr_2O_3	Sc_2O_3	Tb_4O_7	Y_2O_3	Yb_2O_3
Average content (mg/g)								
36.4	31.2	6.1	9.5	12.1	6.6	22.5	251.8	16.4
Total content of REEs in 2017 (In tonnes)								
199.70	**171.17**	**33.46**	**52.12**	**66.385**	**36.21**	**123.44**	**1381.40**	**89.97**

(b)

Waste containing REEs in LFLs = 3212.5 tonnes

Amount of Individual REEs from waste LFLs in 2017

Ce_2O_3	Eu_2O_3	Tb_4O_7	Yb_2O_3
Average content (mg/g)			
5.4	9.7	8.5	2.4
Total content of REEs in 2017 (In tonnes)			
17.34	**31.16**	**27.30**	**7.70**

Fig. 4 Recovery potential of individual REEs from obsolete **a** CFLs and **b** LFLs in India for the year 2017

Table 5 Summary of total recovery potential of REEs in obsolete CFLs and LFLs in India for the year 2017

REEs (as oxide)	CFLs (t)	LFLs (t)	Total recovery potential of individual REEs (t)
Ce_2O_3	199.70	17.34	217.04
Eu_2O_3	171.17	31.16	202.33
Lu_2O_3	33.46	Nil	33.46
Nd_2O_3	52.12	Nil	52.12
Sc_2O_3	36.21	Nil	36.21
Tb_4O_7	123.44	27.30	150.74
Y_2O_3	1381.40	Nil	1381.4
Yb_2O_3	89.97	7.70	97.67
Pr_2O_3	66.38	Nil	66.38
Total	**2153.85**	**83.50**	**2237.35**

4 Conclusions

Characterization of four brands of end-of-life CFLs and three brands of end-of-life LFLs for REEs was conducted scoping towards their recovery and recycling. Further, the recovery potential of REEs from these obsolete CFL and LFL waste streams was estimated from their average obsolescence rate and waste generation in India for the year 2017. Following inferences can be drawn from the study:

- Statistically insignificant ($P < 0.05$) difference in REE contents in various brands of end-of-life CFLs was observed. Yttrium (Y) was found to be the most abundant REE present in the end-of-life CFLs as a secondary resource. Average content of individual REEs as their oxides in the CFLs found to be: Ce (36.4 mg/g), Eu (31.2 mg/g), Lu (6.1 mg/g), Nd (9.5 mg/g), Pr (12.1 mg/g), Sc (6.6 mg/g), Tb (22.5 mg/g), Y (251.8 mg/g) and Yb (16.4 mg/g).
- End-of-life LFLs were characterized to contain REEs, such as Ce, Eu, Tb and Yb with their average content of 5.4 mg/g, 9.7 mg/g, 8.5 mg/g, and 2.4 mg/g, respectively, in terms of their oxides. Statistically insignificant ($P < 0.05$) difference in REE contents in various brands of end-of-life LFLs was observed. Europium (Eu) was found to be the most abundant REE present in the end-of-life LFLs as secondary resource.
- The total recovery potential of REEs from obsolete CFL and LFL waste streams as secondary resource in India for the year 2017 was estimated to be around 2237 tons comprising around 2154 tons from CFLs and around 83 tons from LFLs.
- This characterization study is believed to help to prioritize the elements among REEs present in the end-of-life CFLs and LFLs for profitable beneficiation for resource conservation and circulation.

References

1. ELCOMA: ELCOMA Vision 2020: Vision document. Electric Lamp and Component Manufacturers Association of India (ELCOMA). http://www.elcomaindia.com/wp-content/uploads/ELCOMA-Vision-2020.pdf. (2015)
2. Gupta, C.K., Krishnamurthy, N.: Extractive metallurgy of rare-earths. Int. Mater. Rev. **37**, 197–248 (1992)
3. Wu, Y., Yin, X., Zhang, Q., Wang, W., Mu, X.: The recycling of rare earths from waste tricolor phosphors in fluorescent lamps: a review of processes and technologies. Resour. Conserv. Recycl. **88**, 21–31 (2014)
4. Alonso, E., Sherman, A.M., Wallington, T.J., Everson, M.P., Field, F.R., Roth, R., Kirchain, R.E.: Evaluating rare earth element availability: a case with revolutionary demand from clean technologies. Environ. Sci. Technol. **46**, 3406–3414 (2012)
5. Binnemans, K., Jones, P.T., Blanpain, B., Van Gerven, T., Yang, Y., Walton, A., Burchert, M.: Recycling of rare earth: a critical review. J. Clean. Prod. **51**, 1–22 (2013)
6. Massari, S., Ruberti, M.: Rare earth elements as critical raw materials: focus on international markets and future strategies. Resour. Policy **38**(1), 36–43 (2013)

7. Wang, H., Xue, S., Zhao, F., Chen, W.: Effects of Ga, Al, Ag, and Ce multi-additions on the properties of Sn-9Zn lead-free solder. J. Mater. Sci.: Mater. Electron. **21**, 111–119 (2010)
8. Brunner, P.H.: Urban mining a contribution to reindustrializing the city. J. Ind. Ecol. **15**, 339–341 (2011)
9. Schüler, D., Buchert, M., Liu, R., Dittrich, S., Merz, C.: Study on Rare Earths and Their Recycling. Final Report for the Greens/EFA Group in the European Parliament, Darmstadt, Germany (2011)
10. Jones, P.T., Geysen, D., Tielemans, Y., Van Passel, S., Pontikes, Y., Blanpain, B., Quaghebeur, M., Hoekstra, N.: Enhanced landfill mining in view of multiple resource recovery: a critical review. J. Clean. Prod. **55**, 45–55 (2012)
11. Tunsu, C., Ekberg, C., Retegan, T.: Characterization and leaching of real fluorescent lamp waste for the recovery of rare earth metals and mercury. Hydrometallurgy **144–145**, 91–98 (2014)
12. Machacek, E., Richter, J.L., Habib, K., Klossek, P.: Recycling of rare earths from fluorescent lamps: Value analysis of closing-the-loop under demand and supply uncertainties. Resour. Conserv. Recycl. **104**, 76–93 (2015)
13. Zhang, J., Zhao, B.: Separation Hydrometallurgy of Rare Earth Elements, pp. 19–54. Springer International Publishing, Switzerland (2016)
14. Wang, X.H., Mei, G.J., Zhao, C.L., Lei, Y.G.: Recovery of rare earths from spent fluorescent lamps. In: 5th International Conference on Bioinformatics and Biomedical Engineering (iCBBE), pp. 1–4. Wuhan, China (2011)
15. Rubab, S., Kandpal, T.C.: Resource-technology combinations for domestic lighting in rural India: a comparative financial evaluation. Energy Source **19**, 813–831 (1997)
16. Mukerjee, A.K.: Comparison of CFL-based and LED-based solar lanterns. Energy. Sustain. Dev. **11**, 24–32 (2007)
17. Mahapatra, S., Chanakya, H.N., Dasappa, S.: Evaluation of various energy devices for domestic lighting in India: technology, economics and CO_2 emissions. Energy. Sustain. Dev. **13**, 271–279 (2009)

Integration of GIS and AHP-ANP Modeling for Landfill Site Selection for Nagpur City, India

Trupti Lokhande, Alka Kote and Sandip Mali

Abstract In developing countries, rapid increase in urbanization has increased generation of municipal solid waste, exerting pressure on present solid waste management infrastructure. Old landfill sites are inadequate to cope with a massive quantity of generated waste. In Nagpur city, Maharashtra, India, existing landfill site has reported to cause environmental nuisance, and there is need to identify new landfill site. This paper attempts to integrate geographical information systems (GIS) and multiple criteria decision analysis (MCDA) in landfill site selection process. Based on regional conditions and regulatory rules, fourteen parameters were selected and classified under environmental, sociocultural, and economic criteria. Five regions were identified as suitable alternatives for landfill site, among which 'Site 1' in Kuhi region of Nagpur district was selected as the most suitable landfill site. Despite 10% variation in importance weights of parameters, the sensitivity analysis results remained unchanged. Field investigations were conducted to check accuracy of the results.

Keywords Analytical hierarchy process · Analytic network process · Geographical information system · Landfill · Multiple criteria decision analysis · Solid waste management

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1 Introduction

Solid waste management (SWM) is an essential service for any city. It consists of storage and collection of waste, transfer, and transport of waste to processing center, and finally waste disposal [11]. Sanitary landfill is an integral part of SWM for waste disposal [1]. The suitable landfill site is required to be selected for waste disposal. This is crucial for preventing contamination of environmental resources due to landfill and to minimize nuisance to the society in its vicinity [7].

A prerequisite for landfill site selection is an evaluation of various parameters, viz., rivers, lakes, highways, airport, flood plain, parks, wetlands, critical habitat areas, groundwater table, coastal regulation zone, buffer zone, etc. [11, 14]. Conventionally, this evaluation is carried out by conducting physical surveillance of land, making it a complex process.

Geographical information system, an advanced technology for spatial analysis, can accurately process this huge amount of spatial data in order to select a suitable landfill site [4–7, 16, 17].

Analytical hierarchy process (AHP) and analytic network process (ANP) are multiple criteria decision-making methods which help in finding the most suitable landfill site among various alternatives [6, 13, 15–17]. AHP and ANP use Saaty's fundamental scale for calculating importance weights of criteria by performing pairwise comparison [12].

This paper attempts to integrate GIS with AHP and ANP models in landfill site selection process for identifying most suitable landfill site for Nagpur city, Maharashtra, India. A sequential methodology is proposed for precise comparison of landfill site alternatives to increase the reliability of the results. Field investigations were made to check the accuracy of the results.

2 Materials and Methods

2.1 Study Area

Nagpur city is situated between 78°30″ to 79°30″ East Longitude and 20°30″ to 21° 45″ North Latitude in the eastern part of Maharashtra, India [7]. The population of the city is 2,405,665 which generates 1000 MT/day of municipal solid waste [2, 10].

The study area considered for identifying suitable landfill site comprises administrative area of Nagpur city (225.08 km^2) and adjoining region in the range of 10 km [7]. The villages within 10 km radius are from region 1—Kuhi, region 2—Kalmeshwar NE, region 3—Kalmeshwar SW, region 4—Kamptee, region 5—Parseoni and region 6—Saoner. Figure 1 shows the location of Nagpur city in Maharashtra, India.

Out of 1000 MT/day waste generated, daily 830 MT waste is landfilled and remaining 170 MT is composted at Bhandewadi landfill, Nagpur [10]. The

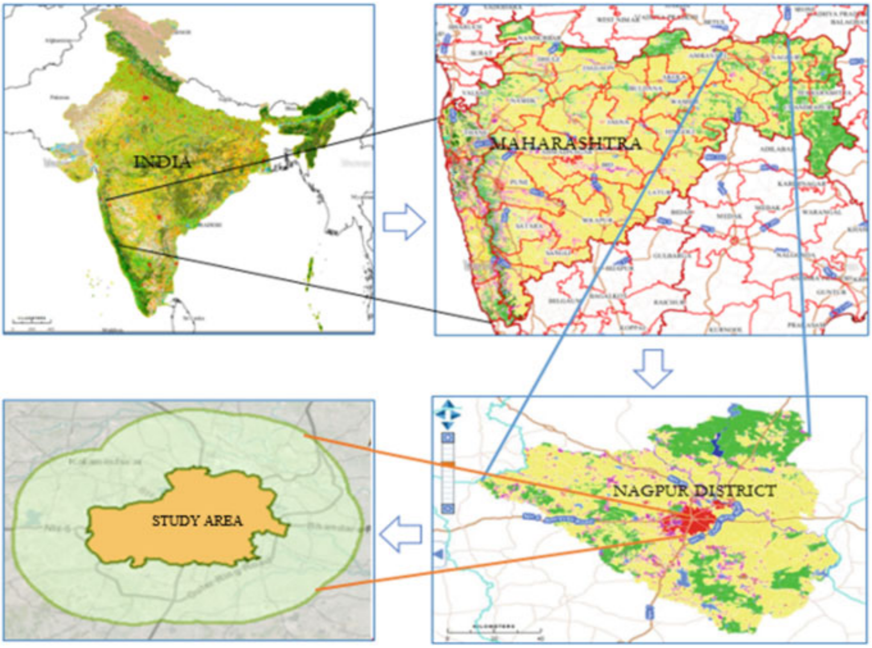

Fig. 1 Location of Nagpur city, Maharashtra, India

available landfill area at Bhandewadi is 0.0409 km^2 [10]. The estimated landfill area is 0.3017 km^2 for biodegradable waste and 0.3151 km^2 for inert waste for future waste generation. Thus, the present available landfill area will be insufficient to handle waste disposal for the next 10 years.

2.2 Data Collection and Software

In this study, maps obtained from Department of Survey of India were used for data extraction for various criteria related to environment, socio-culture, and economy [7]. The toposheet of Nagpur city with scale 1:250,000 and satellite images in the tagged image format with scale 1:2500 were used. The projected coordinate system used in GIS application was WGS_1984.

Expert choice® software was used for AHP analysis and Super Decision® software for ANP analysis. Pairwise comparison of the criteria was carried by experts in environmental engineering domain *namely* research scholars, academicians and on-site engineers using Saaty's fundamental scale [3]. The scale ranges from 1 to 9, where 1 is for equal importance and 9 is for extreme importance [12]. The criteria were categorized into three group—environmental, sociocultural, and economic [8] (Fig. 2). Distance from rivers, lakes, depth of groundwater, soil type,

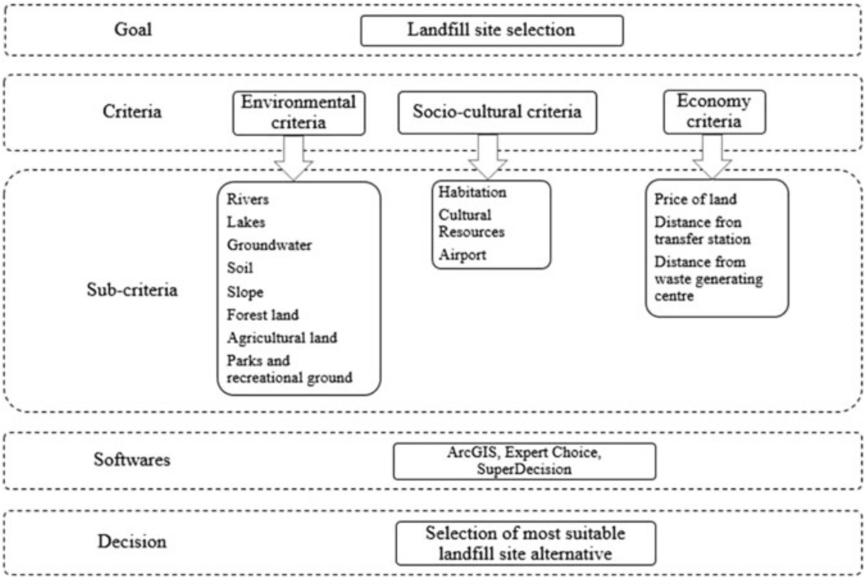

Fig. 2 Various criteria and software used for landfill site selection

slope, forest land, agricultural land, and parks were considered under environmental criteria group. Sociocultural criteria group included distance from habitation, cultural resources, and airport. Price of land and transportation cost incurred due to transport of waste from transfer station and waste generating centers to the landfill sites were considered under economic criteria group. AHP model was used to calculate importance weights of criteria and to obtain suitability map for landfill site alternatives in GIS environment. ANP model was used to rank the alternatives and perform sensitivity analysis.

2.3 Methodology

Integration of GIS and AHP-ANP in solid waste management process was proposed to present the restrictiveness, complexity, and enhancement of result accuracy for identification of suitable landfill site for Nagpur city, India (Fig. 3). Preliminary geo-database was prepared in GIS environment. Shapefiles were prepared for each location criteria [14]. The geoprocessing tool was used to provide a buffer around the shapefiles. Vector dataset was converted to raster dataset for spatial analysis. Reclassified maps were prepared by assigning cell value ‘0’ to restricted zone and ‘1’ to suitable area, keeping buffer distance as conditional parameter. These maps were used as input data for obtaining suitability map using AHP analysis.

Importance weights for criteria were calculated from pairwise comparison using AHP model [13, 17]. Spatial-AHP extension ext_ahp.dll was used in GIS

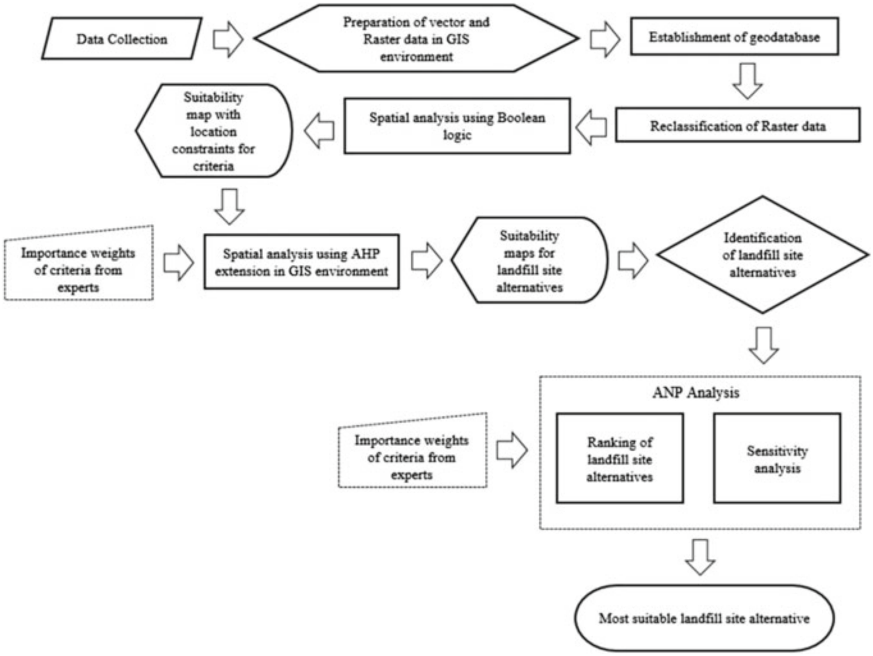

Fig. 3 Flowchart of methodology for landfill site selection

environment to obtain suitability maps with landfill site alternatives for Nagpur city [9, 16]. The landfill site alternatives obtained from AHP analysis were ranked using ANP model. Sensitivity analysis was performed by varying the importance weights of the criteria to study its impact on the ranking of the alternative sites. Finally, site visits were conducted to check the availability of land in the identified suitable regions.

3 Results and Discussion

3.1 Analytical Hierarchy Process Model

Ten experts' responses were used for AHP analysis. Individual suitability maps for these responses were prepared in GIS environment using spatial analysis tool (Fig. 4a–j).

Figure 4 shows suitability of a region for landfill varies from person to person. Area near river is the least suitable area for landfill as per expert 1 (Fig. 4a). Whereas, area near habitation is the least suitable area for landfill as per expert 10 (Fig. 4j). A combined matrix for all experts' responses was prepared to eliminate this inconsistency. Table 1 shows the calculated importance weights of criteria for

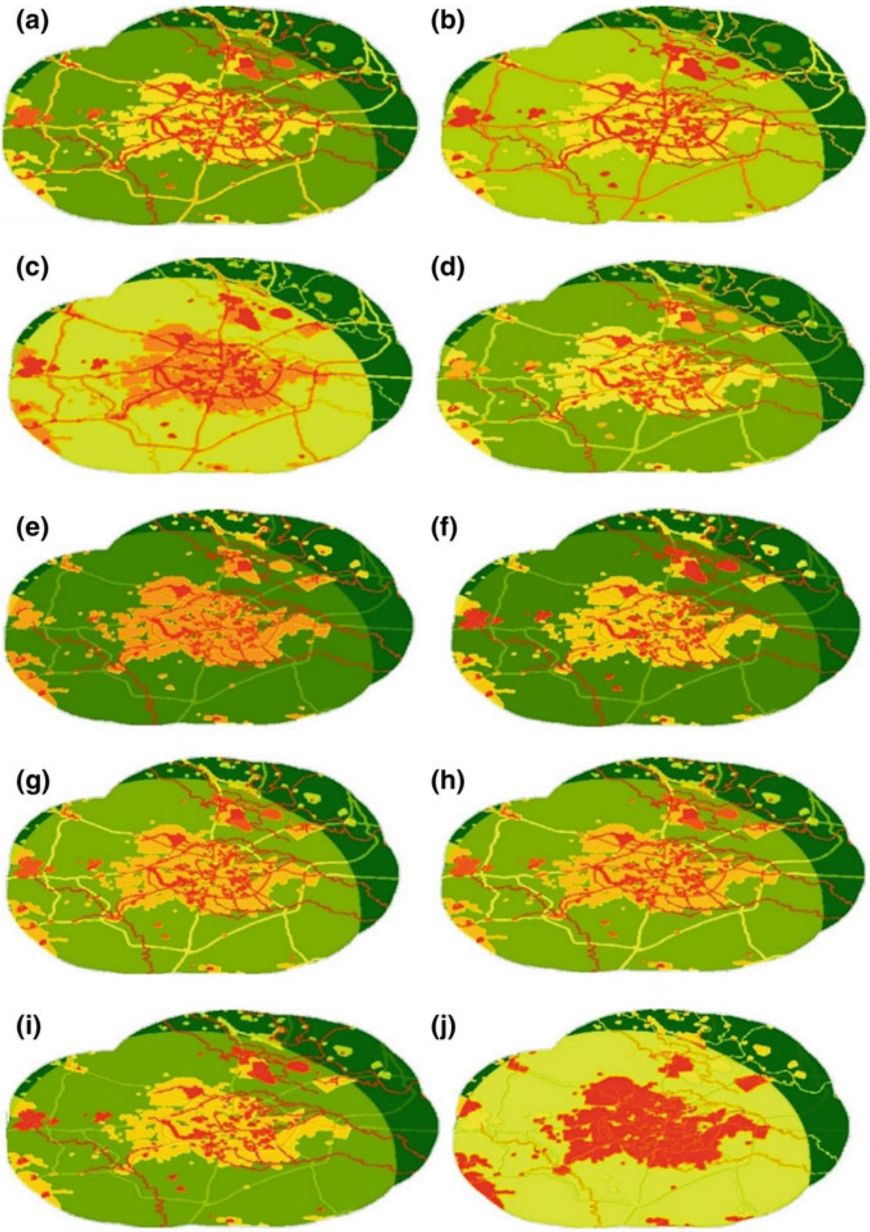

Fig. 4 Suitability maps for landfill using analytical hierarchy process with (a) expert 1 response (b) expert 2 response (c) expert 3 response (d) expert 4 response (e) expert 5 response (f) expert 6 response (g) expert 7 response (h) expert 8 response (i) expert 9 response (j) expert 10 response

Table 1 Calculated importance weights of criteria

Criteria	Importance weights of criteria with respect to experts										
	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Expert 9	Expert 10	Combined
River	0.234	0.155	0.077	0.161	0.243	0.255	0.208	0.226	0.245	0.177	0.286
Groundwater	0.186	0.108	0.065	0.123	0.192	0.121	0.171	0.245	0.163	0.138	0.216
Lakes	0.114	0.064	0.058	0.106	0.092	0.124	0.114	0.118	0.085	0.043	0.131
Slope	0.068	0.021	0.037	0.058	0.040	0.097	0.08	0.026	0.105	0.023	0.068
Forest land	0.049	0.152	0.106	0.057	0.048	0.074	0.068	0.028	0.056	0.021	0.087
Agricultural land	0.040	0.059	0.086	0.08	0.104	0.084	0.041	0.102	0.036	0.100	0.096
Parks	0.027	0.048	0.098	0.033	0.029	0.035	0.026	0.035	0.059	0.021	0.061
Soil	0.023	0.036	0.068	0.06	0.077	0.38	0.021	0.067	0.039	0.010	0.056
Habitation	0.110	0.034	0.054	0.034	0.053	0.076	0.104	0.07	0.092	0.215	0.546
Cultural Resources	0.055	0.107	0.043	0.023	0.053	0.034	0.048	0.03	0.041	0.048	0.336
Airport	0.018	0.043	0.340	0.008	0.008	0.011	0.022	0.013	0.014	0.012	0.118
Price of land	0.041	0.074	0.540	0.085	0.275	0.028	0.052	0.025	0.043	0.009	0.142
Distance from TS	0.018	0.074	0.108	0.085	0.027	0.015	0.029	0.011	0.016	0.145	0.395
Distance from WGC	0.016	0.025	0.108	0.085	0.007	0.006	0.016	0.005	0.006	0.040	0.191
Consistency Index	0.38	0.21	0.00	0.21	0.17	0.16	0.05	0.12	0.3	0.48	0.10

TS – Transfer station, WGC – Waste generating center

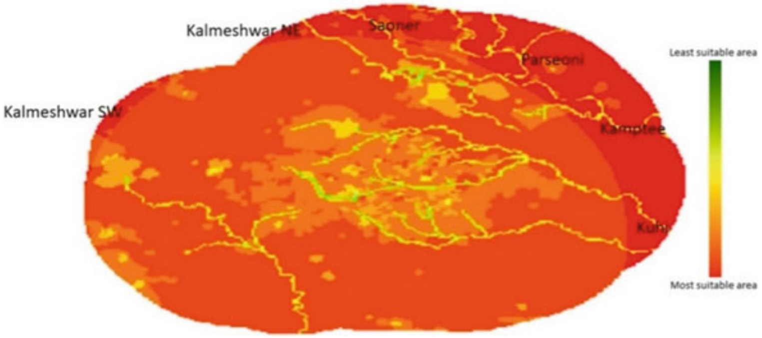

Fig. 5 Suitability map for landfill using analytical hierarchy process with combined response

individual as well as combined responses. The combined matrix was used to prepare final suitability map indicating region 1, region 2, region 3, region 4, region 5, and region 6 as the landfill site alternatives for Nagpur city (Fig. 5).

3.2 Analytic Network Process Model

The priorities of alternatives were obtained from analytic network process (ANP) by performing pairwise comparison of criteria, sub-criteria, and alternatives (Fig. 6). Region 1 with highest priority value was selected as the most suitable

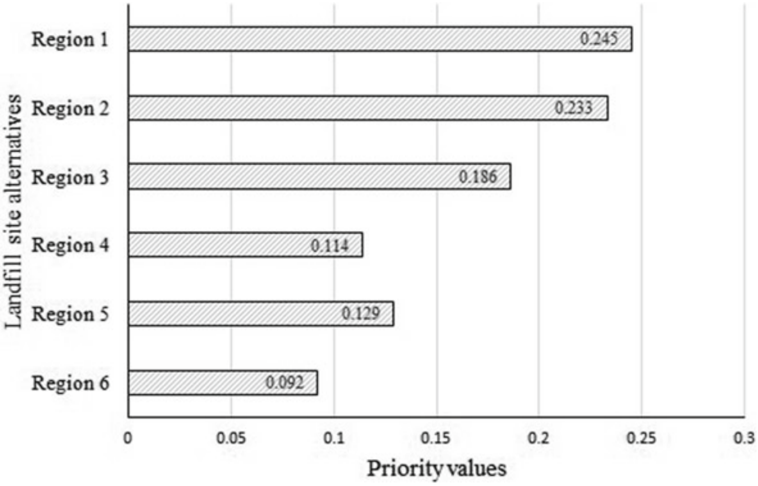

Fig. 6 Priority values of landfill site alternatives using analytic network process model

landfill site alternative. The ranking of alternatives obtained from ANP analysis was – region 1 as rank 1 site followed by region 2, region 3, region 5, region 4, and region 6.

3.3 Sensitivity Analysis

To perform sensitivity analysis, important criteria were selected. Figure 7 shows sensitivity analysis results with respect to criteria—river. The ranking of region 1 and region 2 was interchanged beyond 50% variation. The ranking of region 3 changed beyond 10% variation. The ranking of regions 4, 5, and 6 remained unchanged.

Figure 8 shows sensitivity analysis results with respect to criteria – transfer station. The ranking of region 1 and region 2 was interchanged with no change in ranking of other regions at 20% variation. The ranking of all the regions remained same between 20 and 60% variation.

It was noted that overall sensitivity analysis results remained same within 10% variation of importance weights of all criteria. Thus, the study result for identification of suitable landfill site selection for Nagpur city is stable for 10% uncertainty in expert's responses.

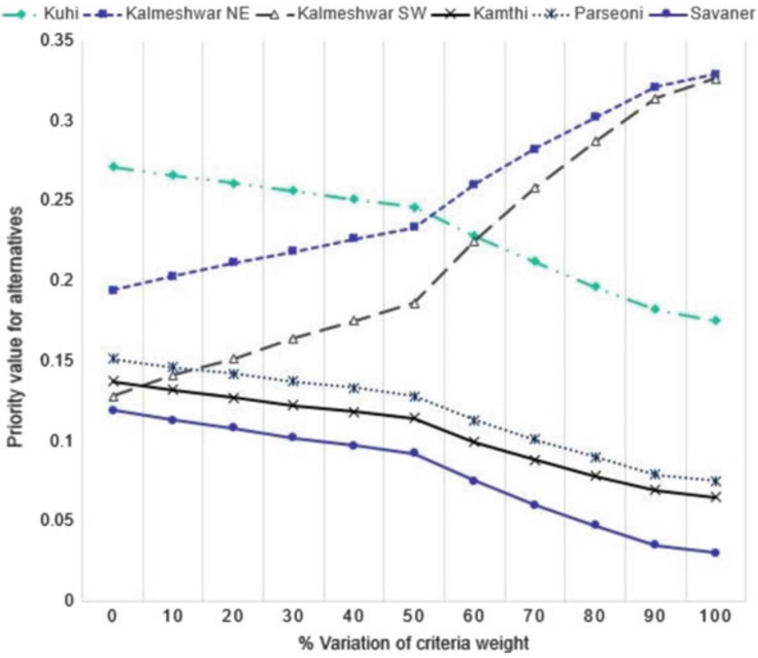

Fig. 7 Sensitivity analysis with respect to criteria – river

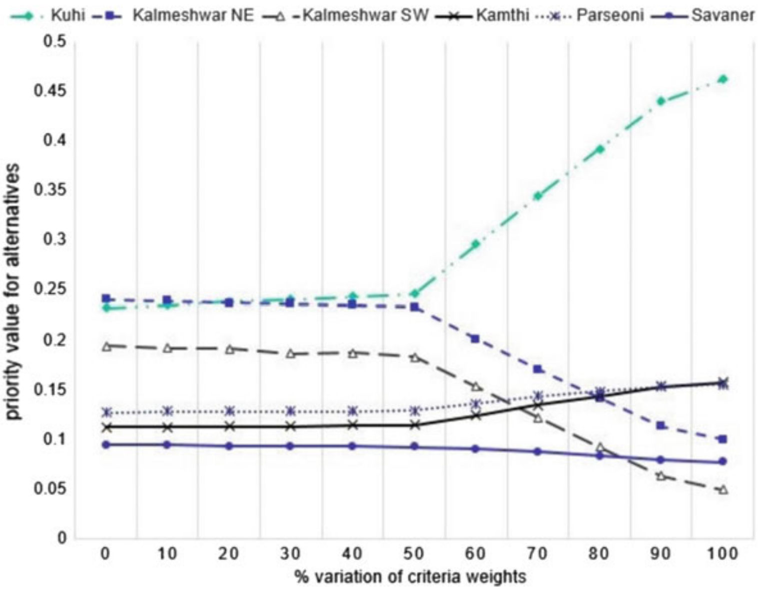

Fig. 8 Sensitivity analysis with respect to criteria – transfer station

Fig. 9 Site photos taken at region 1–Titur, Kuhi, Maharashtra, India

3.4 Validation with Site Visits

Site visits were required to check the availability of land at identified landfill site alternatives. ‘Titur’ village was identified as the suitable area in region 1. Agricultural land and road accessibility are available (Fig. 9). ‘Borgaon’ village in region 2 has forest land, agricultural land, and ‘Junapani’ stone quarry. It has good road accessibility (Fig. 10). Region 5 and 6 do have availability of agricultural land, however the distance from transfer station is considerably more.

Fig. 10 Site photos taken at region 2—Borgaon, Kalmeshwar NE, Maharashtra, India

4 Conclusion

This study showed that integration of GIS, AHP, and ANP proved to be effective in identification of landfill site. The study provided rational outcome for selecting the particular landfill site alternatives. Titur village in region 1 was the most suitable landfill site at a distance of 24.5 km from transfer station in southeast region of Nagpur city. Borgaon village in region 2 was the second most suitable landfill site at a distance of 20.2 km from transfer station in northwest region of Nagpur city. The study, however, does not incorporate public and political opinions.

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References

1. Al-Jarrah, O., Abu-Qdais, H.: Municipal solid waste landfill siting using intelligent system. Waste Manag. **26**, 299–306 (2006)
2. Census: Government of India, New Delhi, India (2011). http://www.censusindia.gov.in/pca/SearchDetails.aspx?Id=602951
3. Chang, N.B., Parvathinathan, B., Breeden, J.B.: Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region. J. Environ. Manage. **87**, 139–153 (2008)
4. Delgado, O.B., Mendoza, M., Granados, E.L., Geneletti, D.: Analysis of land suitability for the siting of inter-municipal landfills in the Cuitzeo Lake Basin, Mexico. Waste Manage. **28**, 1137–1146 (2008)
5. Dikshit, A.K., Padmavathi, T., Das, R.K.: Locating potential landfill sites using geographic information systems. J. Environ. Syst. **28**(1), 43–54 (2001)
6. Effat, H.A., Hegazy, M.N.: Mapping potential landfill sites for North Sinai cities using spatial multicriteria evaluation. Egypt. J. Remote Sens. Space Sci. **15**, 125–133 (2012)

7. Lokhande, T., Mane, S.: Identification of suitable landfill site alternatives using GIS—a case study. Int. J. Eng. Sci. Comput. **7**(9), 14825–14828 (2017)
8. Mahnaz, E., Homaee, M., Mahmodi, S.: An integrated multi criteria approach for landfill siting in a conflicting environmental, economical and socio-cultural area. Waste Manage. **32** (8), 1528–1538 (2012)
9. ESRI (Environmental Systems Research Institute), ArcGIS Desktop Help, Redlands, California, USA (1969). http://resources.arcgis.com
10. MSW (Municipal Solid Waste), Annual report on implementation of solid waste management rules. Maharashtra Pollution Control Board, Maharashtra, India (2016). http://mpcb.gov.in/muncipal/pdf/Annual_Report_MSW_2015_16.pdf
11. MSWM (Municipal Solid Waste Management), Manual on municipal solid waste management. Central Public Health and Environmental Engineering Organization (CPHEEO), Ministry of Urban Development, Government of India, New Delhi, India (2000)
12. Saaty, T.L.: Decision making with the analytic hierarchy process. Int. J. Serv. Sci. **1**(1), 83–98 (2008)
13. Shahabi, H., Keihanfard, S., Ahmad, B.B., Amiri, M.J.T.: Evaluating Boolean, AHP, WLC methods for the selection of waste landfill sites using GIS and satellite images. Environ. Earth Sci. (2013)
14. SWM (Solid Waste Management), S.O. 1357(E) notification, Solid waste management rules. Ministry of Environment, Forest and Climate change, New Delhi, India (2016)
15. Tuzkaya, G., Onut, S., Tuzkaya, U.R., Gulsun, B.: An analytic network process approach for locating undesirable facilities: an example from Istanbul, Turkey. J. Environ. Manage. **88**, 970–983 (2008)
16. Vasiljević, T.Z., Srdjević, Z., Bajćetić, R., Milorodov, M.V.: GIS and the analytical hierarchy process for regional landfill site selection in transitional countries: a case study from Serbia. Environ. Manage. **49**(2), 445–458 (2012)
17. Wang, G., Qin, L., Chen, L.: Landfill site selection using spatial information technologies and AHP: A case study in Beijing, China. J. Environ. Manage. **90**, 2414–2421 (2009)

Evolution of Waste-to-Energy Technology—An Indian Perspective Projects

Umesh Chaudhary and Jyotishman Pathak

Abstract Waste-to-Energy (WtE) is still at a preliminary phase in the developing countries have a large population like India. Despite the fact that WtE is as expected to develop at an acceptable rate due to an essential part of the waste management program (WMP). Under WMP, Govt. investing a substantial amount of money for the growth of the WtE industrial technology but past WtE projects have got a low success rate. Several earlier projects got failed due to LACK OF EXPERTISE of the plant operation, selection of the wrong set of technology, the mismatch between plant design and waste characteristics, lack of Govt. support, poor project development, financial viability, and pollution concerns. The collapse of WtE industrial technology plants in India due to the earlier mentioned cause. This has made Govt. and supporters attentive of taking up WtE projects. Based on that, the paper presents several steps for the development of WtE and suitable cause for which the WtE industrial projects in India step on to a declined path. Also, the necessary recommendation for the future path.

Keywords Air pollution control · Emissions · Energy recovery · Project development · Waste-to-Energy (WtE)

1 Introduction

Waste-to-Energy (WtE) is the process of energy generation from waste materials through various thermal and biological treatments of nonrecyclable waste mass into usable heat or electricity. Most of the countries (worldwide) are adopting WtE as an

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integral option of their waste management programs (WMP). When it comes to the mass treatment of Municipal Solid Waste (MSW), WtE offers a better and scientific solution of reducing the waste mass quantities and thus saving the valuable land area. Further, the energy recovery becomes an additional advantage from waste mass through WtE project. It is a well-proven technology in most of the countries, but could not provide a single successful project till now, no matter it is Mass Incineration (MI) of MSW or the combustion of Refuse Derived Fuel (RDF). In fact, the RDF process is considered to be more useful for the Indian waste rather than mass incineration because of the mixed and heterogeneous nature of the Indian waste with a considerable proportion of dust and dirt, debris and moisture [1]. However, the past projects showed that even the projects based on the RDF technology were unable to run for a long time because of numerous reasons. These are

- Lack of expertise of the plant operators for the concept of WtE.
- Selection of the wrong set of technology no standardization for the process.
- Mismatch between waste characteristics and plant design inefficient combustion.
- Poor project development by the authorities benefited flyby-night operators.
- Lack of regulatory support from the Govt. and financial viability.
- Pollution of the various types of toxic emissions—inefficient flue gas treatment.

All the above-mentioned reasons resulted in a "BAD TRACK RECORD" of WtE projects and formed a negative image in India [2]. The "Not In My Back Yard —NIMBY" syndrome further added up into these drawbacks. Consequently, a mindset has been developed for the non-willingness of the Govt. and promoters to set up good projects based on MSW. This paper will review the journey of WtE industry in India and figure out the key reasons for their nonperformance. Since there is not enough literature available on this sector, therefore, information and the data available on the websites and published reports of various Govt. departments, news articles, and internal corporate research are used as the references to authenticate the documented material in this paper.

2 Global Evolution of WtE

The evolution of WtE globally is a long story of learning and experience.

a. The first destructor in England, built in Manchester in 1876, was reported to be operating 30 years.
b. The second country to use waste combustion was built in the United States of America (USA) in the year 1885 [3].

By 1910, hundreds of combustors had been built in the USA, UK, and other developed countries also followed suit. After about 1950, as land became more expensive, and the population blossomed, local Govt. began to hire engineers to build refractory chambers to burn the waste and even wash down the smoke considerably. In 1961, New York issued a law ensuring each apartment house has its waste burning facility. Around 17000 small combustors were installed without any Air Pollution Control (APC) measures, and subsequently, the law was withdrawn in 1966. Till the 1970s, large incinerators installed without APC measures, by the time when the detection of dioxins and other harmful pollutants in the waste combustor filter ashes caused violent public opposition, especially in European countries. The issue of the toxic effects of dioxins on human health had become the subject of research throughout Europe. Significant technological advancements to deal with the pollutants (including dioxins) and further tighten up emission limits, thus initiated with the start of the 1980s. In 1986, Germany produced an amended regulation (TA Luft 86). It took further few years to develop a complete understanding to deal with the enormous range of pollutants in stacks of different WtE plants. The effects of the new regulations and the newly developed technology become visible in the tests of the numerous waste combustion plants, e.g., the results of experiments in a US waste combustor in 1989 [4]. The results of this technical progress for the further stiffen of the emission limits formed the basis of the EU Waste Incineration Directives (WID) issued in 2000 (European Parliament and Council, 2000) and is today the international air emission guidelines. Soon, these plants were transformed from a pollution source into a pollution sink, and more projects start coming, especially in developed countries for the efficient management of solid waste. As per an approximation, there are around 1000 WtE Incineration based plants worldwide till now.

3 Development of WtE in India

This section will present the Indian historical perspective on WtE projects covering details of all past projects attempted in India, outlining their key features and reasons for nonperformance. For a better understanding, the projects have been divided into two parts, i.e., the first generation and the second generation projects as shown in Fig. 1.

3.1 First Generation WtEs

The first generation of WtEs of the developed India is as follow:

(i) Timarpur MSW Processing Complex, Delhi (1987): India’s first commercial WtE plant was established in the year 1987 by Municipal Corporation of Delhi (MCD) with financial assistance from Govt. of Denmark with the aim to address the dual problems of the waste disposal and the electricity shortage faced by the city. The capacity of the plant was 300 tons per day (TPD) to generate 3.75 MW electrical power. It was set up at the cost of Rs. 25 crores by M/s Volund Miljoteknik of the Denmark that also supplied the incineration technology.

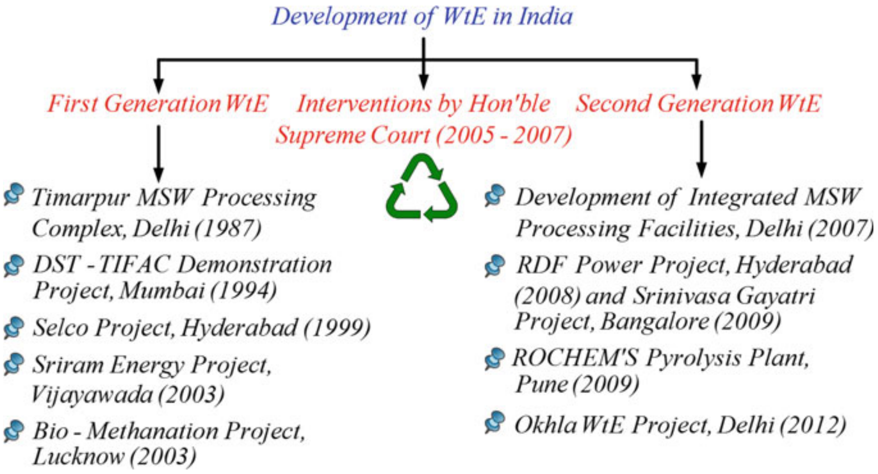

Fig. 1 One process of development of WtE in India

The MSW plant started operation on a pilot basis but the shut down three years later in 1991 (Public policy team, Athena infonomics, May 2012).

The main reason for the poor performance of the Timarpur Project was a mismatch of the calorific value (CV) of incoming refuse (600–700 kcal/kg) with the plant design of 1460 kcal/kg net CV. Further, the plant was designed for screened garbage, and unscreened garbage affected the performance of equipment, as the mixed waste led to the incomplete combustion. A screening plant of 100 TPD capacity was installed in 1989 to get over the design defect, and the plant commenced its operation again, but did show some improvement and had to be shut down in 1990 (Department of Economic Affairs, GoI, 2009). India lost the arbitration case at the Hague because the “suitable waste” to be provided by the city was not defined in the agreement. Apart from the low heat value, shortcomings of the Solid Waste Management (SWM) systems in vogue at that time also reported for failure [5].

(ii) DST-TIFAC Demonstration Project, Mumbai (1994): In 1994, the Department of Science & Technology (DST) analyzed the reasons for the failure of the Timarpur project. It developed a technology that was suitable for Indian waste. A demonstration project of 150 TPD capacities was commissioned at the Deonar dump yard of the Mumbai Municipal Corporation (MMC) for converting MSW to fuel pellets in 1994. RDF pellets with a moisture content around 10–15% and CV in the range of 2500–2800 kcal/kg were indigenously produced by MSW processing. The processing operation consists of various unit operations, viz. screening, shredding, drying and air classification (DST, GoI). The pellets produced were test marketed in and around Bombay, and the separated soil containing delicate organic matter was used as a soil enricher. The experience of this plant was used to develop a model that indicated the suitability of the design for a commercial scale MSW processing plant. Initially, RDF plants based on DST-TIFAC were setup in

mid-nineties [6]. After that, DST, through its autonomous wing Technology, Information, Forecasting, and Assessment Council (TIFAC) transferred this technology to M/s SELCO International and M/s Sriram Energy Systems (SES).

(iii) Selco Project, Hyderabad (1999): Selco International Ltd. set up a plant of 700 TPD capacity in Gandamguda village of Saroornagar Mandal, Rangareddy district, Hyderabad in 1999, which was later upgraded to 1000 TPD in 2003. A power plant to generate 6.6 MW power through the RDF combustion route was also set up at Elikatta village, Shadnagar Mandal, Mahboobnagar district Mahboobnagar district, Hyderabad in 2003 [6].

Dryers, Hot Air Generator (HAG), and air density separators were used as per DST-TIFAC recommendations. However, screening and shredding operations were absent. Boiler used was traveling grate, stoker fired boiler supplied by Walchand Nagar Industries Ltd., and Electrostatic Precipitators (ESP) was used for flue gas treatment during its initial years of operation, the facility produced above 6.6 MW (more than design power). The plant was burning mixed fuel with a CV of 12 MJ/kg (25% addition of rice husk in RDF), which is sufficient for self-sustained combustion. However, the plant was last operated in November 2009, and now it is running twice every month to keep the machines working [2].

Malfunctioning of the low-quality boiler and air-cooled condenser made the operations unviable. The maintenance cost of the equipment had increased tremendously, resulting in its non-operations. But, apart from that, the key reason for its failure was the poor institutional framework for the project by the Govt. authorities. After installation of the RDF plant, when the plant operator decided to set up a captive power plant, as the sale of RDF to the nearby industry was not proving to be satisfied, the said permission of power plant was given at a separate site at an entire distance of 50 km. The transportation of RDF to the 50 km distance affected the financial model of the plant. Also, the plant was using 20% biomass, the cost of which had increased, making operations unviable, as a unit was already paying Rs 10 per ton of waste delivered to Municipal Corporation. Further, the Andhra Pradesh Transmission Company (APTRANSCO), with which Power Purchase Agreement (PPA) had been signed, reduced the power tariffs mentioned in the PPA due to which company had also suffered substantial financial loses (Planning Commission Report, 2014).

(iv) Sriram Energy Project, Vijayawada (2003): Simultaneous to the implementation of SELCO plant, M/s Shriram Energy Systems, in 2003, also commissioned a 6 MW power plant in Vijayawada based on the DST technology. The plant was built to handle waste from Vijayawada and Guntur districts around 40 km apart. RDF plant in Vijayawada (400 TPD fluff) along with palletization plant at Guntur (300 TPD), pellets transported to Vijayawada followed by the combined power generation of 6 MW. The plant was using approx. 30% of biomass with the fuel [6].

RDF plant had installed only local make shredders only, and dryers, HAG & Air Density Separators (ADS) were not installed. Traveling grate boiler using Alstom Germany design was built with ESP for flue gas treatment [2].

The quality of the RDF produced was reduced due to the absence of drying operations, as the plant has by-passed the rules of the DST-TIFAC recommended process. The absence of a drying system led to low calorific value in the fuel because of the moisture, which in turn caused inefficient boiler operations. A few technical shortcomings in other equipment like condenser and turbine also arose because of poor maintenance. Financial viability also got effected; first, because of increased in the prices of biomass, and; second because of the two toll booths which came up between Vijayawada and Guntur—each way vehicles had to pay around Rs 100–150/—as toll charges. Another reason behind the failure of the Vijayawada plant is believed to be a problem with the supply of poor quality waste to the facility. The plant operated for only 5 to 6 years, and operations shut down in 2008.

(v) Bio-Methanation Project, Lucknow (2003): Another WtE initiative based on bio-methanation technology was tested in 2003, by Lucknow Nagar Nigam (LNN). LNN invited Chennai based Enkem Engineers to be the project promoters, and the SPV called Asia Bio Energy India Ltd. (ABIL) was floated for the project. The ENTEC, an Austria-based firm, provided the BIMA digester technology, which has over 50 WtE plants worldwide. The plant was to use 300 MT of solid waste daily to produce biogas, which was to be used to generate 5 MW power by using biogas as fuel for five gas generators. The estimated project cost is Rs 76 crore (LNN, 2002).

Unfortunately, the plant did not operate successfully and shut down in 2005. There is nothing wrong with technology as such. However, unreliable pretreatment of mixed solid waste (MxSW) for anaerobic digestion and high soil content (around 35 to 50%) made the digestion process difficult, as these plants are susceptible to impurities in the feed. No technical feasibility study was carried out by the LNN w.r.t the waste characteristics viz. a, viz., plant design. Eventually, the plant ceased operations in 2005 after an operational history of 6 months characterized by hiccups [2]. The issue had gone into arbitration under the jurisdiction of Hon'ble High Court. Various high-level meetings were held between LNN, ABIL, MNRE, and Financial Institution (IDFC), but no concrete solution was worked out [7].

> # The failure of Lucknow plant in 2005 was the second major failure of WtE industry in India after the Timarpur project in 1987, and these failures continued till the closure of SELCO Hyderabd Project in 2008 and Sriram Energy Vijaywada plant in 2009. However, closure of the Lucknow plant specifically (though based on bio-methanation technology) attributed to the rise of mass opposition to the entire WtE facilities in the country and put a big question on the applicability of these technologies w.r.t Indian waste.

4 Interventions by Hon'ble Supreme Court (2005–2007)

The failure of the two major plants (Timarpur and Lucknow) and subsequent oppositions by various environmental organizations, led to the interference of the largest legal institution of the country to ascertain the future WtE industry in India.

The Supreme Court had, on May 6, 2005, prohibited the Govt. to sanction any further subsidies to such plants. The decision had cameup in the hearing of well-known case of Almitra Patel vs. Union of India, where an additional petition had been filed to stop the support of such WtE projects in India. Hon'ble Supreme Court noted that the bio-methanation based WtE plant at Lucknow had not lived up to its promise and had ordered the Govt. to constitute a committee to inspect the Lucknow plants and submit report. Accordingly, a 14-member body was constituted, chairing Dr. D. K Biswas, former head of the Central Pollution Control Board (CPCB). The decision of the committee could be the major downfall for the WtE industry, as many of the Govt. financial institutions stopped supporting such projects [8].

Pursuant to the Hon'ble Supreme Court order, a detailed report was submitted by the expert committee on January 2, 2006. The broad recommendations of the committee were as follows:

- The projects based on bio-methanation should be taken up only on segregated/uniform MSW plant unless it is demonstrated that in Indian conditions, the waste segregation plant can separate waste suitable for bio-methanation.
- The essential point to processing and treatment of nonrecyclable waste as an integrated system of segregation/collection/transportation of waste mass to promote pilot projects.
- The technology set should be based on the quantity and quality of waste and local conditions for treatment of MSW.
- The judgment point of view about the capability of the particular technology should not be based on the operational problems of one plant (Lucknow) and therefore, petitioner's objection may not be justified to providing support (subsidy) to WtE projects.

Having regard to the relevant facts mentioned in the Committee's report, the court on May 16, 2007 modified the order passed earlier and permitted Ministry of New & Renewable Energy (MNRE) to go ahead with five pilot projects, keeping in view the recommendations made by the expert committee. Accordingly, MNRE formulated a scheme to produced power using MSW and to providing financial assistance for setting up five Pilot projects. The main objectives of the "Programme on Energy Recovery from MSW" were: (1) To set up five Pilot projects for recovery of energy from MSW; and (2) To create conductive conditions and environment, with fiscal and financial regime, to develop, demonstrate and disseminate utilization of MSW for recovery of energy.

For reference, those 5 projects are: RDF Power Project (Hyderabad), Srinivasa Gayatri Resource Recovery (Bangalore), Rochem Pyrolysis Plant (Pune), Jindal's Okhla Plant (Delhi) and IL & FS Ghazipur Plant (Delhi) (MNRE).

4.1 Second Generation WtEs

The second generation of WtEs of the developed India is as follow:

(i) Development of Integrated MSW Processing Facilities, Delhi (2007): After the two decades of the Timarpur failure and willingness of Hon'ble Supreme Court to set up WtE projects, Delhi Govt. along with the MCD (Now trifurcated into 3 zones) again initiated a proposal to set up projects for the processing of MSW. Two projects were conceptualized in 2007; first at Okhla (in South Delhi) and the second at Ghazipur (in East Delhi). It was recommended by the Govt. in the bid conditions to use DST-TIFAC technology for both these projects. The bid of the Okhla plant was won by M/s Jindals Ecopolis, and that of Ghazipur plant was won by a consortium of M/s DIAL (GMR group of companies) and M/s SELCO International. The plant at Okhla was to produce 16 MW power by using 450 TPD RDF produced at Okhla and 225 TPD RDF produced at Timarpur and transported to Okhla (Environmental Clearance, Okhla Plant, MoEF). However, it was later changed by the company, and a power plant based on the MI technology was established at Okhla [5]. The plant is currently in big discussions as the nearby residents filed a complaint about the pollution against the plant in Delhi High Court in 2009, which was later transferred to National Green Tribunal (NGT) in 2013.

During this time, closure of the SELCO Hyderabad plant in 2008 reduced the confidence of DIAL on its partner company in setting up the Ghazipur project. As a result, DIAL lost interest, and the project was left by the company. Later on in 2009, on request of Delhi Govt., M/s IL&FS Environmental Infrastructure & Services Ltd. took over the Ghazipur project and did internal R&Ds to improve the RDF preparation and boiler technology.

(ii) RDF Power Project, Hyderabad (2008) and Srinivasa Gayatri Project, Bangalore (2009): In the years 2008 and 2009, two new entries entered in the list. The first was in Hyderabad (at Nalgonda District) by M/s RDF Power Projects Ltd. and second, was in Bangalore (at Mandur District) by M/s Srinivasa Gayatri Resource Recovery Pvt. Ltd. The Hyderabad plant was to process 800 TPD MSW to produce 11 MW power. On July 16, 2000, this project was initially sanctioned and revived on February 2, 2005, and claiming operations since 2008 as per their official websites and project-related documents. However, as per the visit conducted by the fact finding team formed by the Delhi High Court on August 1, 2011, in the case of Okhla plant hearing, the plant at Nalgonda was found nonoperational, and even the civil work was not completed. The project has now been taken over by IL&FS Environmental Infrastructure & Services Ltd as the promoter company is showing its inability to complete the project.

The other project of Srinivasa Gayatri (Bangalore) for generating 8 MW power from 800 TPD waste is still in the implementation phase. As per MNRE, the proponent has backed out from the project. The reasons for non-implementation of both these projects were exactly not known, however, abovementioned two projects are the clear examples of "Fly by Night—FbN" operators to grab the capital subsidies and heavy loan amounts from the Govt. and financial institutions due to poor structuring and loose contracts and then eventually backed out leaving the responsibility on the authorities.

(iii) ROCHEM'S Pyrolysis Plant, Pune (2009): In between so many glitches of WtE projects throughout the country, Pune Municipal Corporation (PMC) was planning their luck with a new experiment. It was a special project in which fuel was planned to convert into Syn gases using the pyrolysis technology to produce green power. Something that had not been tried ever on MSW in India and even not in the World. Both the PMC and MNRE were having high hopes with the technology. M/s Rochem Green Energy Pvt. Ltd. was selected to set up the plant with a capacity of processing 700 TPD MSW to produce 378 TPD RDF and subsequent pyrolysis of the same to produce 12 MW power.

The RDF line with 35 TPH capacity was imported from Bollegraaf, Netherlands, and Shredders were procured from Metso, Finland. The gasification technology for this project was procured from Concord Blue Towers, Germany. In the processing plant side, the RDF line with capacity 35 TPH was commissioned and presently running at the capacity of 150–200 TPD for 4–5 days in a week. The maximum load of the plant to date is 260–80 tons for 12 h. and results not satisfactory. In the power plant side, only one tower completed out of three to date, and gases from the plant is currently being flared since the power plant based on the pyrolysis technology has not been commissioned yet. The company claimed that the first phase of a 2.99 MW capacity is already commissioned and operating for meeting the auxiliary requirements. However, as per the visit of the MNRE officials, only the RDF plant is operational, and RDF is being palletized and sold into the market. The first phase is not completed at present, and the plant is meeting its auxiliary requirement by running a diesel generator (DG) sets.

(iv) Okhla WtE Project, Delhi (2012): The dispirited e.g. of so-called second-generation projects in Hyderabad, Bangalore, and Pune, as mentioned in the above sections, once again started making a negative image of the WtE industry throughout the country. All these plants either stopped working because of technical and financial shortcomings, poor project planning, or backing out of the promoters leaving the project and authorities in a gray. There was again a big question on the feasibility and success of these kinds of projects. But, with positive hope, the plant at Okhla (Delhi) was made operational by M/s Jindals Ecopolis in 2012.

The Okhla WtE plant started processing around 2050 tons of waste to generate over 16 MW power. The project cost was estimated at 175 crores, later escalated to 240 crores (Planning Commission Report, 2014). The boiler uses moving grate, mass incineration technology from HBG China. Flue gas treatment system incorporates Semi-Wet Reactor (SWR) and bag filter from Wuxi GHPE China. With the operation of the Okhla WtE Plant, again, the Govt. authorities had high expectations to come with a foolproof solution for the waste problems. However, the path of the WtE industry in India still consisted of many more difficulties. Since its initiation, the Okhla plant had faced a massive public protest by the environmental

NGOs and local residents due to NIMBY syndrome. Further, the proponent had violated the primary conditions issued by MoEF in its environmental clearance letter and changed the configuration by adopting mass incineration technology instead of RDF, which was also mentioned to be used in the project DPR approved by MNRE [5].

The project is presently in operation, but there are a few problems with the incineration process, especially poor quality combustion due to the presence of moisture, inerts, and construction debris in the waste. As a result, two parameters—SPM and Dioxins were continuously being found beyond range during inspections by monitoring authorities. On June 03, 2013, the Indian Express article mentioned the pollutant level from Okhla WtE, 25 times higher. In other instances, due to higher SPM, some filter bags got damaged [9]. The plant was immediately taken under maintenance and cleaning. In a hearing of the Jindal's plant, NGT, has already cleared its view on the need for preprocessing of MSW as far as Indian waste is concerned. NGT on 28/05/2013, directed the proponent to install a segregation plant before subjecting the waste to incineration [10]. On February 25, 2014, the TOI article mentioned the stand of the Parliamentary Standing Committee on Urban development to seek a countrywide ban on WtE due to the massive protest against the Okhla plant [11].

> # These factors hugely contributed to making up an adverse scenario for the WtE industry in India. Especially, the case of Okhla WtE plant boosted up the negative image of WtE and initiated a country wide discussion on the banning of such kinds of projects and instead establish projects based on composting, recycling, etc. Though it is evident from the worldwide scenario that WtE is the only solution for large countries like India having no land area. Other technologies can always work in integration with the WtE facilities.

5 Status of a Few Upcoming Plants

The status of upcoming WtE plants in India has been presented in Fig. 2.

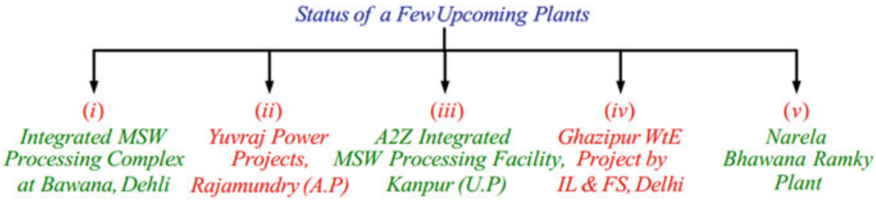

Fig. 2 Different upcoming plants

5.1 *Integrated MSW Processing Complex at Bawana, Delhi*

M/s Ramky Engineers Ltd. is setting up an integrated landfill site consisting of a compost plant and a WtE plant at Narela-Bawana area of Delhi. The plant capacity as per the Ministry of Environment and Forest (MoEF) is 4000 TPD of MSW to generate 36 MW power. The power plant consists of two boilers (56 tons per hour (TPH) capacity each) that can produce energy up to 40 MW. Initially, the plant will produce 24 MW power from 1200 TPD RDF left after the waste screening in the compost unit. The Boiler technology is moving grate Chinese boiler, and the Flue Gas Conditioning System (FGCS), Grabs, and the turbine have been purchased from China (Similar to the case of Okhla WtE). FGCS consists of the lime treatment, Activated Carbon Injection (ACI), and bag filters. Almost 80% work has been completed for the WtE. However, further work has been put on hold for the last few months due to a legal dispute between the company and North Delhi Municipal Corporation (NDMC). The authority is now saying (after completion of 80% of work) that the clause of establishing the WtE plant at the site was not in agreement; however, as per the company, the energy recovery from screened waste material is in the project scope. As per the company, the National Environmental Engineering Research Institute (NEERI), as a third party, already authenticated the view of the company, but they are not getting the green signal from the NDMC to start the work (IAAD, 2014).

5.2 *Yuvraj Power Projects, Rajahmundry (A.P.)*

The company is setting up three RDF plants—one each at Rajahmundry, Tadepalligudem, Samalkota districts of Andhra Pradesh, which will be capable of processing about 1100 TPD of MSW. A 13 MW power generation unit at Rajahmundry will also be proposed to be established, and RDF will be transported to Rajahmundry from the other two locations. There are two boilers: 30 TPH for 5 MW and 50 TPH for 10 MW power generation. The PPA for the project is signed with Tata Power. The cost of the project is Rs 1000 million approx., and the land area is 18 acres. The estimated RDF yield will be 650 TPD with GCV of 2200 to 2500 kcal/kg and moisture contents around 30%. Mixing of 15% rice husk of around 3200 kcal/kg CV is also proposed as per Detailed Project Report (DPR) (CDM Project Design Document, UNFCC, 2011).

Thought the work of the power plant is partly completed, however, work for processing plants not started yet and the status is as follows:

a. Rajahmundry Processing Plant—Land not allotted.
b. Kakinada Processing Plant—3 acre land allotted in samalkot, but work not started yet.

c. T.P. Gudam Processing Plant—Land not allotted.

The work of the power plant was started in 2010 and now on grasp since 2012. The 30 TPH boiler work is 80% complete, and for 50 TPH boiler, only order has been placed to the thermo-dyne, till now. The work for the Balance of Plant (BOP) not completed. There are a few issues in the PPA and needs revision.

5.3 A2Z Integrated MSW Processing Facility, Kanpur (U. P.)

The company proposed to set up a 700 TPD RDF to 15 MW power project as a part of their integrated collection, transportation, processing, and disposal mandates with the Kanpur Nagar Nigam (KNN), Uttar Pradesh. One 75 TPH CFBC boiler was installed for steam generation by M/s AV&UE Ltd., which has supplied a second-hand Chinese boiler, turbine, and generator to M/s A2Z Ltd. ESP was installed for flue gas cleaning.

The WtE facility started trial runs of boiler, ESP, and auxiliaries last year in 2014, but was having troubles as RDF moisture content was high. Subsequently, dryers were installed, but successful commissioning is not achieved till now due to poor quality fuel. The boiler was originally designed for rice husk and coal with drum feeders and screw conveyors as fuel feeding arrangements. Later, it was modified to gravity feeding with punch feeding arrangements using flap gates and chutes for fuel distribution. These modified arrangements again had various shortcomings for RDF feeding and needed to be improved (IL&FS research). Further, processing plant operations were also not satisfactory because of the used of local equipment. The collection & transportation services of the company were also got affected due to financial viability. Presently, the facility is in an abandoned stage, and KNN has canceled the contract with M/s A2Z Ltd. and looking for new vendors to run the facility.

5.4 Ghazipur WtE Project by IL&FS, Delhi

The IL&FS Environmental Infrastructure & Services Ltd. (IEISL) Delhi is establishing the 12 MW WtE project based on RDF technology. As mentioned in Section III-C1, the project was taken over by the IL&FS environment in 2009, when the consortium of DIAL and Selco backed out. The project will process 2000 TPD of MSW coming to the Ghazipur dump site in the East Delhi area and produce 12 MW power. The project is purely based on the DST-TIFAC recommended process for MSW preprocessing and has also got the technology approval from MNRE.

The boiler and flue gas technology for the project have been procured from M/s Keppel Seghers (Belgium), and the turbine generator has been supplied by M/s Siemens. M/s ISGEC Heavy Engineering Ltd. is doing the manufacturing of the boiler, and M/s Clair Engineering is fabricating the flue gas treatment system as per the Keppel Seghers design. The total project cost is around 316 crores, and the land area is 5.73 acres. Presently, the commissioning activities are going on, and the project will start producing power by December 2015. The company has taken care of all the measures learned from past failures, like preprocessing, proper quality equipment, specialty, boiler, gas cleaning systems, etc. However, the actual performance can be justified only when the plant will start operations.

Apart from the positively affecting the health and hygiene of the nearby household by processing new MSW project. The MSW projects enterprises for the generation of employment. Alternatively, maintenance and functionality literacy are producing societal benefits. The project will also help to save at least 260 acres of limited urban land valued at over Rs 2000 crores by December 2016.

5.5 Narela-Bhawana Ramky Plant

MCD corporation launched India's largest WtE plant at Narela-Bawana, by March 2017, made operational. Built on 100 acres of land valued at over the Rs 456 crores plant, however, seems to be failing on almost all counts.

The plant will process nearly 2500 MTPD and generate 24–25 MW of electric power. This will help Rohini and Civil Lines areas, most of the garbage is offloaded at the Narela-Bawana landfill, which is the new and only engineering/sanitary landfill in the city. Nowadays, Delhi generated about 9000 MT of solid waste filth per day. Here, the process of nearly 1200 MT is appropriate by the Ghazipur WTE plant producing 12 MW of electrical energy, while the Okhla WTE uses almost 1300 MT of waste generating 1600 MW of the electricity.

The Okhla WTE plant is currently under controversy in the National Green Tribunal (NGT) with the household of the Sukhdev Vihar having a question the court for administration to relocate it.

For the opening of the new Narela-Bawana WTE is not only good news; someone from Delhi can be expected. The NMCD administrators declared that it would be run by the Hyderabad-based company, which is known as Ramky, which is declined to collect garbage from each household and segregate, it is biodegradable and nonbiodegradable, fertilizer the organic materials into the muck, and then, process only the nonorganic into the WtE plant.

A new Bhalswa WtE plant is also in the pipeline to arrest the phenomenon of fires, said the official.

6 Conclusion

WtE is a proven waste handling technology world over but has very less success in India. The reason behind is the Indian waste is highly heterogeneous in composition and size, and also, the way it gets collected makes it very dirty, mixed with soil, road sweepings (dust), drain desilting, etc. along with the moisture. The use of Chinese, European, and other technologies, in a replicated manner, had not given any successful model in India. As it is learned from the above analysis that there cannot be a single-handed solution that will work for the treatment and disposal of this kind of mixed waste. Hence, customized, tailor-made, and integrated solutions are the need of the hour should be adopted. Most of the past, WtE initiatives/ interventions were driven by "A TECHNOLOGY", resulted in improper design to handle Indian wastes. As such, there were no issues with the efficiency of these particular technologies, but the mismatch of the quality for the incoming decline with the plant designed caloric value, and the high percentage of inerts led to the closure of most of the plants. Further, the use of poor grade of critical equipment decreased the quality of the final product and increased the maintenance costs. In the absence of Govt. support, financial viability also got affected. At some places, failures were due to poor project planning, ineffective project structuring, lack of interinstitutional cooperation, week regulatory mechanism, and lose of execution of contracts and laws. Finally, pollution concerns and NIMBY syndrome made the path of the WtE industry very difficult. In this way, "POOR TRACK RECORD" track record of WtE facilities in India acted as its most significant obstacle for further development.

It is pertinent to mention that these previous failures can act as a practice to expected WtE projects, but it will not be a reasonable argument against recent facilities. The first WtE plants in India is started since 1987, in India has been undergone two decades of extraordinary economic growth, which can change the lifestyles, in turn to the change. The nature of waste increased its quantity. The change in nature of the MSW developed in a higher percentage of recyclables system and increased in calorific value of wastes. The improvement in the collection of MSW decreased, the fraction of inserts that end up in the MSW stream. During the same time, the WtE industrial technology has been undergone a revolution in technology and from pollution control worldwide. However, for the adequate development of this industry in the Indian context, the following suggestions are strictly recommended for future projects:

i. Elaborate processing is imperative for Indian MSW, which will decrease dependency on the biomass or other supplementary fuel.
ii. Development of the customized, tailor-made and high-grade indigenous solutions for incineration process, and flue gas treatment for better performance and also to reduce the high capital cost of the imported equipment.
iii. Internal R&Ds by the project personnel's in this field developing a knowledge base for the characteristics of Indian waste and choice of right technologies to deal with it.

iv. Adoption of an Integrated approach, which broadly involves; organic fraction should go for composting, or bio-methanation, combustible (fuel component) should go for the incineration; recyclables should be collected, and Inserts including C&D wastes can be converted into usable building products. In the end, only the rejects (10–15% of the total amount) should go for disposal.
v. State-level institutions and ULBs need to strengthen their capabilities with adequate staff and technical capacity in this field to develop knowledge for structuring public-private partnerships in waste management.
vi. Authorities should give the prime importance to the project development work and strict evaluation of technical bids, maybe with the help of appointing third party transaction advisors.
vii. Policies at the national and state-level need to be strengthened with regard to carrying outsource segregation and improving the service level benchmarks of the ULBs in the collection, transportation, processing, and disposal of MSW.
viii. Need for standardization of technology and emission standards for WtE that is developed and approved by the Govt. and framing of monitoring mechanisms to verify and ensure the performance of WtE faculties.
ix. These projects are capital intensive, as they are primarily meant for the scientific disposal of MSW, and should not be given significance linked to the power generation. Hence, support from the Govt. is very much necessary to make success models in this field. For this, tipping fees and product-based subsidies should be encouraged instead of upfront grants to ensure the continuous operations by the project promoters.
x. Strengthening of the regulatory mechanism by the authorities and offering a single-window clearance process to avoid interinstitutional issues.
xi. Transparency plays a key role in avoiding NIMBY syndrome and reducing mass public protests and opposition and therefore, should be given prime importance in every WtE facility.
xii. Generation of credible information by academic institutions and Govt. authorities can boost up the mass awareness in this field.

References

1. Misra, G.P., Kaushal, P.: Requirement of government support for sustainable waste-to-energy (WTE) projects in India. Energy Technology & Ecological Concerns: A Contemporary Approach, 25–31 (2015)
2. Annepu, R.K.: Sustainable solid waste management in India, Master's thesis, Earth Resource Engineering, Earth Engineering Centre, Columbia University (2012)
3. Hickman, H.L.: American Alchemy: The History of Solid Waste Management in the United States. Forester Press, Santa Barbara, CA (2003)
4. Donnelly, J.: Overview of Air Pollution Controls for Municipal Waste Combustors. Air and Waste Management Assoc, United States (1991)

5. Shah, D.: The Timarpur-Okhla waste to energy venture. ENVIS Centre on Municipal Solid Waste Management (2011)
6. Mazumdar, N.B.: MSW to energy in India: the scenario and expectations. FP6 Technology at Work Project Facilitation Workshop, New Delhi (2008)
7. Chary, S., Narender, A.: Public private partnership (PPP): models for waste to energy projects. Administrative Staff College of India, Workshop on Structuring and Implementing Waste to Energy Projects in Municipal Solid Waste Management (2014)
8. Global alliance against pollution, article and discussions, yahoo groups, down to earth
9. Kelkar, K.: Pollution level near Okhla waste-to-energy plant 25 times above limit. The Indian Express (2013)
10. Singh, D.: NGT threatens to shut Okhla waste plant. Hindustan Times (2013)
11. Nandi, J.: Close all waste plants in residential areas; hazardous emissions from mixed solid waste prompts panel to seek countrywide ban. Times of India (2014)

Seasonal Variations in Human Health Impacts of PM_{10}, $PM_{2.5}$, SO_2, and NO_2 Emissions from a Solid Waste Disposal Facility at Turbhe, Navi Mumbai

Hasan Rameez, Vikas Varekar, Navneet Rai and Harshit Mishra

Abstract A supercity Navi Mumbai has a Solid Waste Disposal Facility (SWDF) that processes and disposes 740 tons/day of waste. The emissions from the SWDF cause direct health impacts to the population residing in the vicinity of the facility. Since the severity and extent of health impacts may vary seasonally, the analysis is performed separately for monsoon and non-monsoon seasons for 3 consecutive years: 2011, 2012, and 2013. The hourly concentrations for the pollutants PM_{10}, $PM_{2.5}$, SO_2, and NO_2 have been procured from Navi Mumbai Municipal Corporation, having an ambient air quality monitoring station installed within the SWDF. The population residing within 1 km radius of the monitoring station is considered for the analysis. The human health impact assessment has been performed using AirQ+ model to quantify health risks in terms of mortality and morbidity caused by various short-term health effects, which include total mortality, cardiovascular mortality, respiratory mortality, hospital admissions—cardiovascular diseases, respiratory diseases, and chronic obstructive pulmonary disease. Results demonstrate the seasonal variations in terms of total Excess Number of Cases (ENCs) of all the health effects under consideration for 3 consecutive years during monsoon and non-monsoon seasons, which ranges from 21 to 23 and 152 to 156, respectively. The analysis indicates that PM_{10} contributed most toward ENCs, while NO_2 had no health impacts. This study can be used by policy-makers to evaluate the present scenario for health impacts, which may serve as a tool to assess the existing solid waste management infrastructure and to adopt necessary augmentations for future.

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1 Introduction

Rapid growth of urbanization and industrialization across the globe has led to a drastic increase in the levels of air pollution over the last few decades. Air pollutants such as PM_{10}, $PM_{2.5}$, CO, NO_2, SO_2, and O_3 are known to have various short term and long-term health impacts on the exposed human population [1–5]. The presence of these pollutants above threshold limits in the ambient air may have several human health impacts including many respiratory and cardiovascular diseases that result in large-scale loss of life. Many studies have been conducted across the globe to carry out Human Health Impact (HHI) assessment to quantify the health risks posed by air pollutants in terms of mortalities and morbidities due to several health impacts [6–11].

The mammoth amount of solid waste generation and its disposal is one of the critical issues being faced by Indian metropolitan regions. To mitigate this problem, many solid waste disposal facilities (SWDF) have been deployed in India where the solid waste is processed in various ways before it is finally disposed in the sanitary landfills. These solid waste disposal facilities may contribute significantly to the ambient air pollution through emission of particulate and gaseous pollutants. The resulting elevated levels of pollutants in the ambient air can cause harmful effects to the exposed population. Under the Indian scenario, no past study has been reported for evaluation of health impacts due to the emissions from a SWDF. Hence, a need is felt to carry out the human health impact assessment for a SWDF. Also, India being a tropical country, it receives heavy rainfall in the months of June, July, August, and September (monsoon season), while the other 8 months (non-monsoon season) receive scanty to no rainfall. Since the concentration of pollutants in the air is significantly lower in monsoon as compared to non-monsoon season, therefore, the human health impacts associated with these pollutants may also vary seasonally. Hence, the present study is carried out with the objective of evaluation of the short-term human health impacts of PM_{10}, $PM_{2.5}$, SO_2, and NO_2 emissions from a SWDF by considering the variations between monsoon and non-monsoon seasons. The area selected for this study is the Turbhe SWDF, located in Navi Mumbai.

2 Material and Method

2.1 Study Area

Turbhe solid waste disposal facility comes under the jurisdiction of Navi Mumbai Municipal Corporation (NMMC), Navi Mumbai, situated on the west coast of Maharashtra. It lies between 19°5′N and 19°15′N latitude and 72°55′E and 73°5′E longitude. The climate of the region is predominantly tropical wet type, experiencing average daily temperature variations from 12 °C to 43 °C over the course of year [12]. In 2012, the region received a total rainfall of 2623.4 mm, of which 90% was concentrated in the monsoon season, i.e., June to September [13]. Turbhe SWDF has been in operation since 2008. Navi Mumbai's booming economy and growing population have contributed to about 1.5-fold increase in the amount of solid waste processed and disposed from 491 tons per day in 2008 to a peak of 740 tons per day in 2017. Solid waste coming to this facility undergoes various pre-processes before it is finally disposed into the engineered landfill. These pre-processes include sorting of waste, recycling, composting, refuse-derived fuel generation and landfilling of waste. These pre-processes involve various operations such as local transportation of waste within the facility, loading and unloading of waste from vehicles, drying, crushing, and compaction of waste, and turning of waste piles during windrow composting. Carrying out these operations require consumption of large quantity of fuel on daily basis, which contributes to the concentration of particulate matter and noxious gases such as methane, carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen dioxide, and hydrocarbons.

2.2 Health Risk Assessment Tool

In the present study AirQ+ software, developed by World Health Organization, is used to quantify the health risks in terms of excess number of cases (ENCs) of mortality and morbidity caused due to various health impacts, namely, total mortality, cardiovascular mortality, respiratory mortality, hospital admissions—cardiovascular diseases, respiratory diseases, and chronic obstructive pulmonary disease. The framework of AirQ+ software is based upon the values of relative risk and baseline incidence developed through time-series epidemiological studies.

The HHI assessment is based on the attributable proportion (AP), defined as "the fraction of the health outcome in a certain population attributable to exposure to a given atmospheric pollutant, assuming a proven causal relation between exposure and health outcome and no major confounding effects in that association" [14]. The AP can be calculated using the formula [15].

$$AP = \frac{\sum \{[\mathrm{RR(c)} - 1] * \mathrm{p(c)}\}}{\sum [\mathrm{RR(c)} * \mathrm{p(c)}]} \tag{1}$$

where RR(c) = Relative risk for health outcome in category ‘c’ of exposure

p(c) = Proportion of population in category ‘c’ of exposure.

Relative Risk (RR) is the estimate of the magnitude of an association between exposure and disease. “RR gives the increase in the probability of the adverse effect associated with a given change in the exposure levels and comes from time-series studies, where day-to-day changes in air pollutants over long periods were related to daily mortality, hospital admissions, and other public health indicators” [14]. Mathematically, RR can be defined as [16]

$$\mathrm{RR} = \frac{\text{Probability of event when exposed to air pollution}}{\text{Probability of event when non\_exposedtoairpollution}} \tag{2}$$

The RR value can be calculated as [17]

$$\mathrm{RR} = e^{\beta * \Delta C} \tag{3}$$

where β = Concentration response function (CRF)

ΔC = Change in ambient air concentration.

Concentration Response Function (CRF) is defined as increase in incidence of a health effect per unit change in pollutant concentration. ΔC is the difference between the value of ambient air concentration of a pollutant and its cut off limit, i.e., its permissible limit as established by WHO or other concerned authorities.

The RR values given as input to AirQ+ are corresponding to increase in pollutant concentration by 10 $\mu g/m^3$ above the cutoff limit. From this relative risk value (corresponding to increase of 10 $\mu g/m^3$), the actual relative risk value corresponding to an existing ambient air concentration of the pollutant is calculated as [11].

$$\mathrm{RR}' = 1 + [\Delta C * (\mathrm{RR} - 1)/10] \tag{4}$$

where RR′ = Relative risk corresponding to existing pollutant concentration

RR = Relative risk corresponding to increase of pollutant concentration by 10 $\mu g/m^3$.

If the baseline frequency (I), i.e., the population incidence (number of cases per 100,000) of the given health effect is known, then the excess number of cases per unit population attributed to exposure E can be calculated as [18].

$$\mathrm{I_E} = \mathrm{I} * \mathrm{AP} \tag{5}$$

where I = Frequency/incidence of a health effect per unit population

I_E = ENCs attributable to exposure E per unit population

The ENCs for the population under consideration can be obtained as [18].

$$N_E = I_E * N \tag{6}$$

where N_E = ENCs for population under consideration

N = Size of population under consideration.

The inputs required by AirQ+ includes mean concentration of the pollutants, population under consideration, relative risk values (per 10 µg/m^3 increase of concentration for hazardous substances) for pollutants and baseline frequency of health effects. The hourly concentrations of the pollutants under consideration, i.e., PM_{10}, $PM_{2.5}$, SO_2, and NO_2, have been procured from Navi Mumbai Municipal Corporation's ambient air quality monitoring station installed within the solid waste disposal facility. This data was used to calculate mean concentrations for monsoon and non-monsoon seasons for the years 2011–2013. Four months of June, July, August, and September were considered for monsoon season, while remaining 8 months comprised non-monsoon season. The population within 1 km radius of the facility is considered as the population exposed to the pollution levels measured at the monitoring station. The human health data for the relative risk and baseline incidence values, as adopted from [11, 19], are shown in Table 1.

Table 1 WHO specified values of Relative Risk (per 10 µg/m^3 increase of PM_{10}, $PM_{2.5}$, SO_2, and NO_2) with 95% confidence interval and Baseline Incidence values per 100,000 population

Pollutants	Mortality/morbidity	Relative risk (RR)[c] (95% CI) per 10 µg/m^3	Baseline incidence per 100,000[d]
PM_{10}	Total mortality[x]	1.0074 (1.0062–1.0086)	1013
	Cardiovascular mortality[y]	1.008 (1.005–1.018)	497
	Respiratory mortality[z]	1.012 (1.008–1.037)	66
	HA respiratory disease	1.008 (1.0048–1.0112)	1260
	HA cardiovascular disease	1.009 (1.006–1.013)	436
$PM_{2.5}$	Total mortality	1.015 (1.011–1.019)	1013
	HA COPD[a]	1.0058 (1.0022–1.0094)	101.4
SO_2	Total mortality	1.004 (1.003–1.0048)	1013
	Cardiovascular mortality	1.008 (1.002–1.012)	497
	Respiratory mortality	1.01 (1.006–1.014)	66
	HA[b] COPD	1.0044 (1–1.011)	101.4
NO_2	Total mortality	1.003 (1.002–1.004)	1013
	HA COPD	1.0026 (1.0006–1.0044)	101.4

Source [11, 19]

[a] COPD: Chronic Obstructive Pulmonary Disease

[b] HA: Hospital Admissions

[c] Lower and upper limits (range) of RR values

[d] Baseline Incidence per 100,000 is based on threshold limit given in WHO guideline

[x] International Classification of Diseases (ICD) code number: ICD-9-CM < 800

[y] ICD-9-CM 390–459

[z] ICD-9-CM 460–519

3 Results

The human health impact assessment was carried out for Turbhe SWDF. The concentrations of PM_{10}, $PM_{2.5}$, SO_2, and NO_2 for non-monsoon and monsoon seasons for the duration 2011–2013 are shown in Table 2. Concentration of PM_{10} averaged over the 3-year duration was found to be 13.6 times and 3.5 times the WHO recommended guidelines for non-monsoon and monsoon season, respectively. Similarly, $PM_{2.5}$ concentrations for non-monsoon and monsoon seasons were 9.4 times and 2.4 times the WHO guidelines, respectively. SO_2 concentrations for non-monsoon and monsoon seasons were 2.8 times and 1.6 times the WHO guidelines, respectively. However, the NO_2 concentrations for non-monsoon and monsoon seasons were found to be 0.5 times and 0.3 times the WHO guidelines, respectively. Since the NO_2 concentrations were well within the limits, therefore, no health impacts were found to be associated with NO_2.

The health impacts of various pollutants under consideration were categorized into total mortality, cardiovascular mortality, respiratory mortality, cardiovascular hospitality, respiratory hospitality, and COPD hospitality. The ENCs of these impact categories due to PM_{10}, $PM_{2.5}$, and SO_2 in non-monsoon and monsoon season for the duration 2011–2013 are shown in Fig. 1.

Total Mortality

The ENCs of total mortality (95% CI) were 76 (61–88), 77 (62–91), and 79 (62–92) in the non-monsoon season, and 12 (9–13), 11 (8–12), and 12 (9–13) in the monsoon season, for the years 2011, 2012, and 2013, respectively. The ENCs for total mortality were almost 7 times in non-monsoon as compared to monsoon season. The contributions of PM_{10}, $PM_{2.5}$, and SO_2 were 59, 39, and 8%, respectively, in non-monsoon season; 50, 33, and 17%, respectively, in monsoon season for the year 2011, the trend being almost same for the years 2012 and 2013 (Fig. 2). The value of attributable proportion (95% CI) for PM_{10} was found to be 18.13% (15.44–20.73) for non-monsoon and 4.6% (3.87–5.33) for monsoon season for the year 2011 (Table 3). AP values for SO_2 were 2.36% (1.78–2.82) and 1.17% (0.88–1.4), respectively, for non-monsoon and monsoon. AP values for $PM_{2.5}$ were 13.74% (10.29–17.04) and 3.65% (2.69–4.59), respectively, for non-monsoon and monsoon. AP values followed the similar trend for the years 2012 and 2013. AP

Table 2 Average concentrations of PM_{10}, $PM_{2.5}$, SO_2, and NO_2 for non-monsoon and monsoon seasons, along with their WHO limits

Year	Non-Monsoon (μg/m^3)				Monsoon (μg/m^3)			
	PM_{10}	$PM_{2.5}$	SO_2	NO_2	PM_{10}	$PM_{2.5}$	SO_2	NO_2
2011	281.3	99.3	59.8	13.9	73.9	25.0	29.5	9.8
2012	274.4	97.9	55.3	26.8	69.4	21.1	31.1	13.2
2013	259.9	85.4	53.9	27.1	68.4	25.7	37.7	17.0
Average	271.9	94.2	56.3	22.6	70.6	23.9	32.8	13.3
WHO limits	20.0	10.0	20.0	40.0	20.0	10.0	20.0	40.0

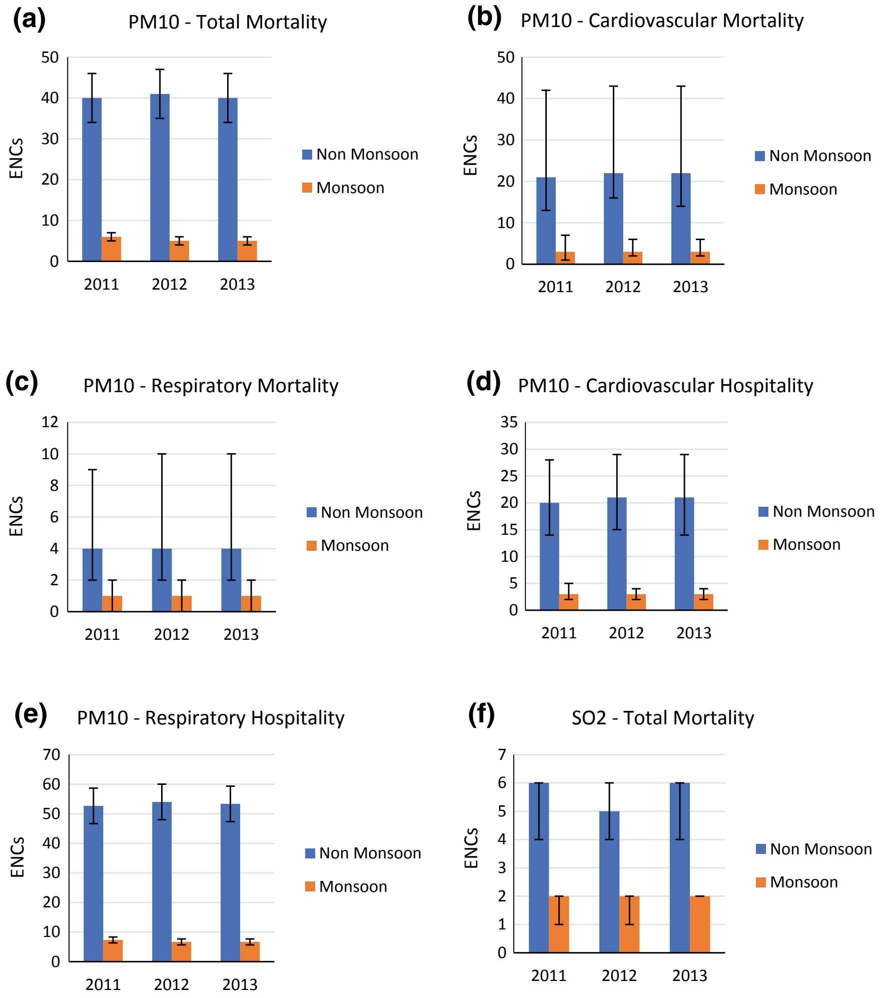

Fig. 1 (a–k) Seasonal variations in ENCs of various health effects due to PM_{10}, SO_2, and $PM_{2.5}$

values suggest that PM_{10} attributes to most total mortalities (among pollutants under consideration) followed by $PM_{2.5}$ and SO_2. NO_2 was also analyzed for total mortality; however, it yielded zero ENCs since its concentration was below WHO guidelines.

Cardiovascular Mortality

The ENCs of cardiovascular mortality (95% CI) were 26 (15–49), 26 (17–49), and 26 (15–49) in the non-monsoon season; 5 (2–8), 5 (2–8), and 5 (2–8) in the monsoon season, for the years 2011, 2012, and 2013, respectively. The ENCs of cardiovascular mortality were found to be 6.5 times in non-monsoon as compared to monsoon season. The contributions of PM_{10} and SO_2 were 81 and 19%,

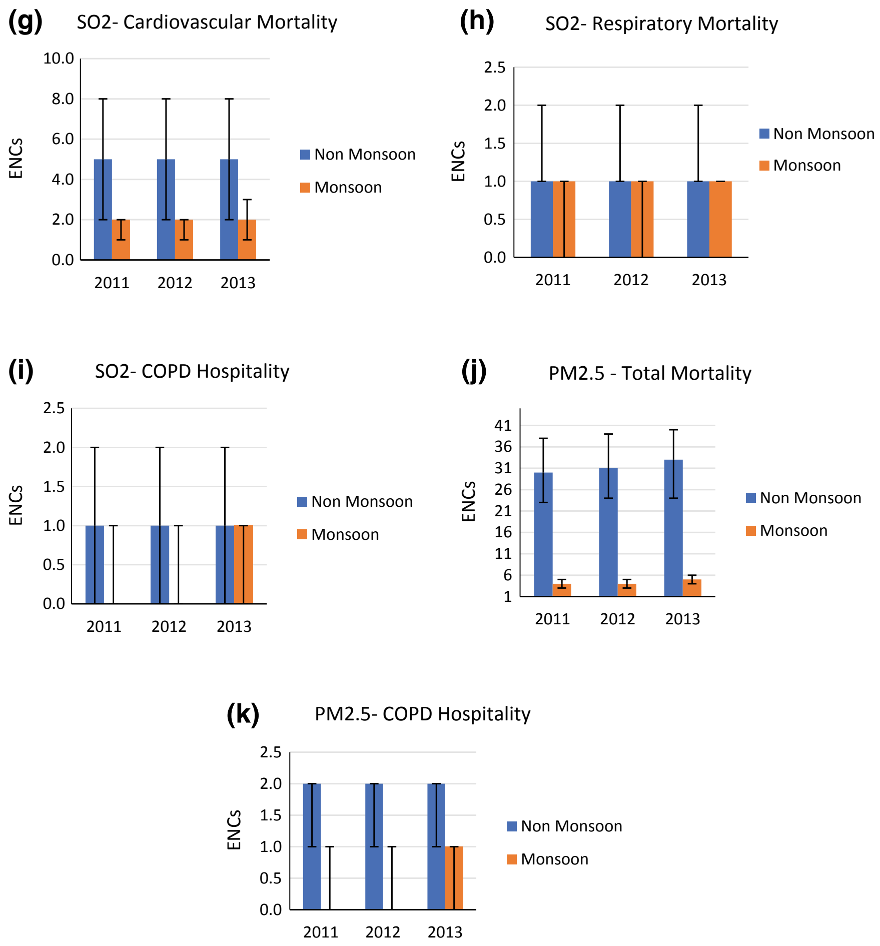

Fig. 1 (a–k) (continued)

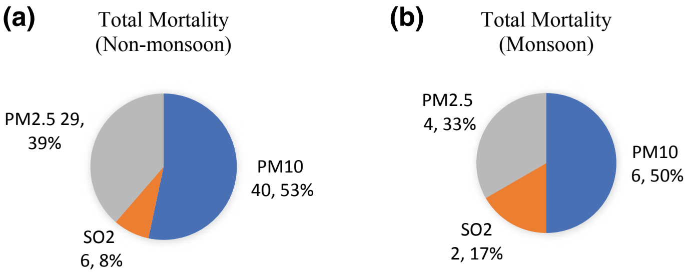

Fig. 2 (a–b) Contribution of individual pollutants in total mortality for non-monsoon and monsoon seasons

Table 3 Estimated Attributable Proportion (AP%) values for PM_{10}, $PM_{2.5}$, and SO_2 for non-monsoon and monsoon seasons

Health point	Air pollutant	2011		2012		2013	
		Non-Monsoon	Monsoon	Non-Monsoon	Monsoon	Non-Monsoon	Monsoon
Total mortality	PM_{10}	18.13 (15.44–20.73)	4.6 (3.87–5.33)	18.13 (15.44–20.73)	4.6 (3.87–5.33)	16.83 (14.31–19.27)	4.22 (3.55–4.88)
	SO_2	2.36 (1.78–2.82)	1.17 (0.88–1.4)	2.18 (1.64–2.61)	1.23 (0.93–1.48)	2.13 (1.6–2.55)	1.49 (1.12–1.79)
	$PM_{2.5}$	13.74 (10.29–17.04)	3.65 (2.69–4.59)	13.74 (10.29–17.04)	3.65 (2.69–4.59)	11.93 (8.91–14.84)	3.74 (2.76–4.71)
Cardiovascular mortality	PM_{10}	19.44 (12.66–38.37)	4.96 (3.14–10.78)	19.44 (12.66–38.37)	4.96 (3.14–10.78)	18.06 (11.72–35.97)	4.55 (2.87–9.9)
	SO_2	4.65 (1.19–6.88)	2.32 (0.59–3.46)	4.3 (1.1–6.37)	2.44 (0.62–3.64)	4.2 (1.07–6.22)	2.95 (0.75–4.39)
Respiratory mortality	PM_{10}	27.67 (19.44–62.68)	7.34 (4.96–20.72)	27.67 (19.44–62.68)	7.34 (4.96–20.72)	25.78 (18.06–59.67)	6.73 (4.55–19.13)
	SO_2	5.78 (3.51–7.98)	2.89 (1.75–4.02)	5.35 (3.25–7.39)	3.04 (1.84–4.23)	5.22 (3.17–7.21)	3.68 (2.23–5.1)
Cardiovascular hospitality	PM_{10}	21.58 (14.98–29.56)	5.57 (3.75–7.92)	21.58 (14.98–29.56)	5.57 (3.75–7.92)	20.06 (13.89–27.59)	5.1 (3.43–7.27)
Respiratory hospitality	PM_{10}	19.44 (12.18–26.08)	4.2 (2.55–5.83)	19.44 (12.18–26.08)	4.2 (2.55–5.83)	17.4 (10.85–23.45)	3.79 (2.29–5.25)
COPD hospitality	SO_2	2.59 (0–6.33)	1.29 (0–3.17)	2.4 (0–5.86)	1.35 (0–3.34)	2.34 (0–5.72)	1.64 (0–4.03)
	$PM_{2.5}$	5.58 (2.16–8.87)	1.43 (0.55–2.31)	5.5 (2.13–8.75)	1.21 (0.46–1.95)	4.82 (1.86–7.67))	1.47 (0.56–2.37)

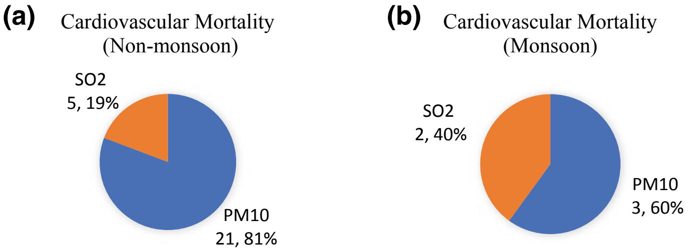

Fig. 3 (a–b) Contribution of individual pollutants in cardiovascular mortality for non-monsoon and monsoon seasons

respectively, in non-monsoon; 60 and 40%, respectively, in monsoon season for 2011 (Fig. 3). AP values of PM_{10} for non-monsoon and monsoon seasons were found to be 19.44% (12.66–38.37) and 4.96% (3.14–10.78), respectively, for the year 2011. AP values for SO_2 were 4.65% (1.19–6.88) and 2.32% (0.59–3.4), respectively, for non-monsoon and monsoon. AP values suggest that PM_{10} attributes more to cardiovascular mortality as compared to SO_2.

Respiratory Mortality

The ENCs of respiratory mortality (95% CI) were 5 (3–10), 5 (3–11), and 5 (3–11) in the non-monsoon season; 2 (1–2), 2 (1–2), and 2 (1–2) in the monsoon season, for the years 2011, 2012, and 2013, respectively. The ENCs of respiratory mortality in non-monsoon season were found to be 2.5 times as compared to monsoon season. The contributions of PM_{10} and SO_2 were 80 and 20%, respectively, in non-monsoon; 50 and 50%, respectively, in monsoon season for 2011 (Fig. 4). AP values of PM_{10} for non-monsoon and monsoon seasons were found to be 27.67% (19.44–62.68) and 7.34% (4.96–20.72), respectively, for 2011. AP values for SO_2 were 5.785% (3.51–7.98) and 2.89% (1.75–4.02), respectively, for non-monsoon and monsoon. AP values suggest that PM_{10} attributes more to respiratory mortality as compared to SO_2.

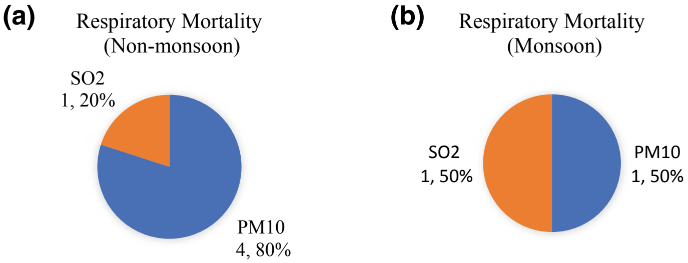

Fig. 4 (a–b) Contribution of individual pollutants in respiratory mortality for non-monsoon and monsoon seasons

Cardiovascular Hospitality

The ENCs of cardiovascular hospitality (95% CI) were 20 (14–28), 21 (15–29), and 21 (14–28) in the non-monsoon season; 3 (2–4), 3 (2–4), and 3 (2–4) in the monsoon season, for the years 2011, 2012, and 2013, respectively. The ENCs of cardiovascular hospitality were found to be 7 times in non-monsoon as compared to monsoon season. PM_{10} solely contributed to all cardiovascular hospitality cases. AP values of PM_{10} for non-monsoon and monsoon seasons were found to be 21.58% (14.98–29.56) and 5.57% (3.75–7.92), respectively, for 2011.

Respiratory Hospitality

The ENCs of respiratory hospitality (95% CI) were 53 (33–71), 53 (33–72), and 53 (33–72) in the non-monsoon season; 7 (4–10), 7 (4–9), and 7 (4–9) in the monsoon season, for the years 2011, 2012, and 2013, respectively. The ENCs of respiratory hospitality were found to be 7.5 times in non-monsoon as compared to monsoon season. PM_{10} solely contributed to all respiratory hospitality cases. AP values of PM_{10} for non-monsoon and monsoon seasons were found to be 19.44% (12.18–26.08) and 4.2% (2.55–5.83), respectively, for 2011.

COPD Hospitality

The ENCs of COPD hospitality (95% CI) were 3 (1–4), 3 (1–4), and 3 (1–4) in the non-monsoon season; 0 (0–2), 0 (0–2), and 2 (0–2) in the monsoon season, for the years 2011, 2012, and 2013, respectively. The ENC values are found to be very low as compared to other hospitalities. This is due to the fact that the pollutants contributing to COPD hospitality are relatively lower in concentrations as compared to PM_{10}, which does not contribute toward COPD hospitality. AP values of $PM_{2.5}$ for non-monsoon and monsoon seasons were found to be 5.58% (2.16–8.87) and 1.43% (0.55–2.31), respectively, for 2011. AP values for SO_2 were 2.59% (0–6.33) and 1.29% (0–3.17), respectively, for non-monsoon and monsoon. AP values suggest that $PM_{2.5}$ attributes more to COPD hospitality as compared to SO_2.

The comparison of ENCs for total mortality and total morbidity (sum all hospital admissions under consideration) between non-monsoon and monsoon seasons for 3-year duration is depicted in Fig. 5. It was found that the ENCs of total mortality

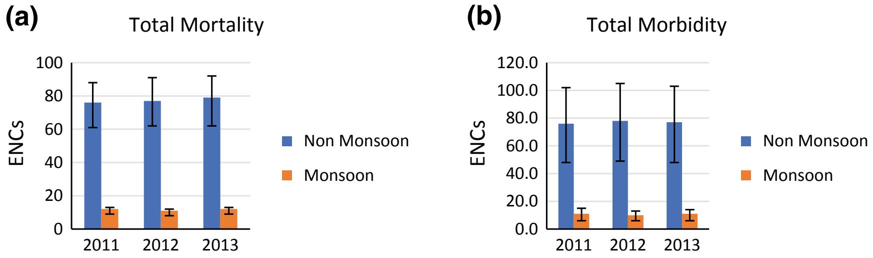

Fig. 5 (a–b) Seasonal variations in total mortality and total morbidity were 76 (61–88), 77 (62–91), and 79 (62–92) in the non-monsoon season, and 12 (9–13), 11 (8–12), and 12 (9–13) in the monsoon season, for the years 2011, 2012, and 2013, respectively. The ENCs of total morbidity were 76 (48–102), 78 (49–105), and 77 (48–103) in the non-monsoon season, and 11 (6–15), 10 (6–13), and 11 (6–14) in the monsoon season, for the years 2011, 2012, and 2013, respectively.

4 Discussion

Navi Mumbai is a coastal city with tropical wet climate that receives 90% of its annual precipitation in the monsoon season, i.e., June, July, August, and September. During these 4 months, the pollutants tend to settle down with raindrops and hence get removed from air, resulting in significant lowering of their concentrations in the ambient air. From 3 years data (Table 2), it is seen that with respect to the non-monsoon season, the average concentration of PM_{10} and $PM_{2.5}$ in the monsoon season gets reduced by 74%, while average concentration of SO_2 and NO_2 in the monsoon season gets reduced by 41%. This indicates that in the monsoon season the removal due to settling down with raindrops is more for particulate matter as compared to SO_2 and NO_2. ENCs for total mortality for non-monsoon season were 6.3–7 times that of monsoon season and ENCs for total morbidity for non-monsoon season were 6.9–7.8 times that of monsoon season. Figure 5 shows that with respect to the non-monsoon season, the ENCs of total mortality and total morbidity in the monsoon season get reduced by 85%.

It is evident from the results that PM_{10} had the maximum health impacts attributable to it, which is supported by the results of other similar researches carried out [20, 21]. Figure 5 shows that the variations in ENCs between monsoon and non-monsoon seasons follow a similar trend across the 3 years duration, signifying the consistency of the results.

There are certain limitations associated with this methodology.

1. Relative risk values adopted for this study have been taken from the previous studies carried out in the other regions. However, according to [14], this is, however, not objectionable if, “there is no compelling evidence that the evidentiary population and target population differ in response to air pollution.”
2. Intermixing and interactive effect of pollutants due to coexistence is not considered in the methodology. Superposition principle is applied while calculating the contribution of individual pollutants to the various health impact categories under consideration.
3. The framework assumes that the considered pollutant concentration levels represent the actual concentration levels that people are exposed to.

5 Conclusion

In the present study, AirQ+ software, developed by WHO, has been used to evaluate the seasonal variations in short-term human health impacts caused by the SWDF to the population exposed in its vicinity. This study aimed at analyzing the variation pattern in the human health impacts between the monsoon and non-monsoon seasons, and the consistency of the results obtained suggest that the seasonality should be taken into consideration while carrying out the human health impact assessments. The information regarding the excess number of cases of various health effects due to critical pollutants may help the concerned authorities to analyze the feasibility of the current infrastructure with respect to the health impacts caused by it, and hence to make the necessary augmentations in technology and policy-making that would reduce the impacts of the facility on human health.

Although this methodology involves certain assumptions with the availability of site-specific data, this methodology offers a quick and effective way to carry out the human health impact assessment. To achieve this, intensive time-series epidemiological studies should be undertaken across the world in order to develop the dose-response function. With the development of site-specific relative risk values for different pollutants, availability of statistics for baseline incidence for different health points and monitoring of key pollutants at critical locations, the human health impact assessment can be carried out with very low level of uncertainties.

Compliance with Ethical Standards

- The authors declare that they have no conflict of interest.
- This chapter does not contain any studies with human participants or animals performed by any of the authors.
- Since the study does not involve any individual participants, any kind of Informed Consent is not applicable.

References

1. Pope, C.A., Thun, M.J., Namboodiri, M.M., Dockery, D.W., Evans, J.S., Speizer, F.E., Heath, C.W.: Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. Am. J. Respir. Crit. Care Med. **151**, 669–674 (1995)
2. Lin, C., Li, C., Yang, G., Mao, I.: Association between maternal exposure to elevated ambient sulfur dioxide during pregnancy and term low birth weight. Environ. Rese. **96**, 41–50 (2004)
3. Jeong, S.: The impact of air pollution on human health in Suwon City Asian. J. Atmos. Environ. **7**, 227–233 (2013)
4. Rahila, R., Siddiqui, M.: Review on effects of particulates, sulfur dioxide and nitrogen dioxide on human health. Inter. Rese. J. Environ. Sci. **3**, 70–73 (2014)
5. Nourmoradi, H., Khaniabadi, Y.O., Goudarzi, G., Daryanoosh, S.M., Khoshgoftar, M., Omidi, F., Armin, H.: Air quality and health risks associated with exposure to particulate matter: a cross-sectional study in Khorramabad, Iran. Health Scope 5. e31766 (2016). https://doi.org/10.17795/jhealthscope-31766

6. Gupta, D., Boffetta, P., Gaborieau, V., Jindal, S.K.: Risk factors of lung cancer in Chandigarh, India. Indian J. Med. Res. **113**, 142–150 (2001)
7. Ghose, M.K., Paul, R., Banerjee, R.K.: Assessment of the status of urban air pollution and its impact on human health in the city of Kolkata. Environ. Monit. Assess. **108**, 151–167 (2005)
8. Zhang, M., Song, Y., Cai, X.: A health-based assessment of particulate air pollution in urban areas of Beijing in 2000–2004. Sci. Total Environ. **376**, 100–108 (2007)
9. Caiazzo, F., Ashok, A., Waitz, I.A., Yim, S.H.L., Barrett, S.R.H.: Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005. Atmos. Environ. **79**, 198–208 (2013)
10. Gurjar, B.R., Ravindra, K., Nagpure, A.S.: Air pollution trends over Indian megacities and their local-to-global implications. Atmos. Environ. **142**, 475–495 (2016)
11. Maji, K.J., Dikshit, A.K., Deshpande, A.: Human health risk assessment due to air pollution in ten urban cities in Maharashtra, India. Cogent. Environ. Sci. **2**, 1–16 (2016)
12. Navi Mumbai Municipal Corporation: Solid waste management, environmental status report 2012–13 (2013). http://www.nmmconline.com/c/document_library/get_file?uuid=a51d91c6-19ad-40eb-a75e-bde50a58ef2e&groupId=10156. Accessed on 9 Sept 2014
13. Navi Mumbai Municipal Corporation: Navi Mumbai environmental plan for clean, green and healthy city, environmental status report 2009–10 (2010). http://www.nmmconline.com/documents/10156/40405/2.summary.pdf. Accessed on 9 Sept 2017
14. Fattore, E., Paiano, V., Borgini, A., Tittarelli, A., Bertoldi, M., Crosignani, P., Fanelli, R.: Human health risk in relation to air quality in two municipalities in an industrialized area of Northern Italy. Environ. Res. **111**, 1321–1327 (2011)
15. Krzyzanowski, M.: Methods for assessing the extent of exposure and effects of air pollution. Occup. Environ. Med. **54**, 145–151 (1997)
16. Ghozikali, G.M., Mosaferi, M., Safari, H.G., Jaafari, J.: Effect of exposure to O3, NO2, and SO2 on chronic obstructive pulmonary disease hospitalizations in Tabriz, Iran. Environ. Sci. Pollut. Res. **22**(4), 2817e2823 (2014)
17. Mahapatra, P.S., Panda, S., Walvekar, P.P., Kumar, R., Das, T., Gurjar, B.R.: Seasonal trends, meteorological impacts, and associated health risks with atmospheric concentrations of gaseous pollutants at an Indian coastal city. Environ. Sci. Pollut. Res. Int. **21**, 11418–11432 (2014)
18. Goudarzi, G., Geravandi, S., Foruozandeh, H., Babaei, A.A., Alavi, N., Niri, V.M., Khodayar, J.M., Salmanzadeh, S., Mohammadi, J.M.: Cardiovascular and respiratory mortality attributed to ground-level ozone in Ahvaz, Iran. Environ. Monit. Assess. **187**(8), 487 (2015)
19. Miri, M., Derakhshan, Z., Allahabadi, A., Ahmadi, E., Conti, O.G., Ferrante, M., Aval, E.H.: Mortality and morbidity due to exposure to outdoor air pollution in Mashhad metropolis, Iran. The AirQ model approach. Environ. Res. **151**, 451–457 (2016)
20. Schwartz, J., Slater, D., Larson, T., Pierson, W., Koenig, J.: Particulate air pollution and hospital emergency room visits for asthma in Seattle. Am. Rev. Respir. Dis. **174**, 826–831 (1993)
21. Weuve, J., Puett, R., Schwartz, J., Yanosky, J., Laden, F., Grodstein, F.: Exposure to particulate air pollution and cognitive decline in older women. Arch. Intern. Med. **172**, 219–227 (2012)