Design Science and Innovation

Sreenivas Chigullapalli
S. U. Susha Lekshmi
Abhijit P. Deshpande *Editors*

Rural Technology Development and Delivery

Springer

Design Science and Innovation

Series Editor

Amaresh Chakrabarti, Centre for Product Design and Manufacturing,
Indian Institute of Science, Bangalore, India

The book series is intended to provide a platform for disseminating knowledge in all areas of design science and innovation, and is intended for all stakeholders in design and innovation, e.g. educators, researchers, practitioners, policy makers and students of design and innovation. With leading international experts as members of its editorial board, the series aims to disseminate knowledge that combines academic rigour and practical relevance in this area of crucial importance to the society.

More information about this series at https://link.springer.com/bookseries/15399

Sreenivas Chigullapalli · S. U. Susha Lekshmi ·
Abhijit P. Deshpande
Editors

Rural Technology Development and Delivery

Springer

Editors
Sreenivas Chigullapalli
IIT Bombay Development and Relations
Foundation (IITB DRF)
Mumbai, Maharashtra, India

S. U. Susha Lekshmi
I-Hub Foundation for Cobotics (IHFC)
IIT Delhi
New Delhi, Delhi, India

Abhijit P. Deshpande
Department of Chemical Engineering
IIT Madras
Chennai, Tamil Nadu, India

ISSN 2509-5986 ISSN 2509-5994 (electronic)
Design Science and Innovation
ISBN 978-981-19-2311-1 ISBN 978-981-19-2312-8 (eBook)
https://doi.org/10.1007/978-981-19-2312-8

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Conference Organization

Organizing Secretaries

Prof. Abhijit P. Deshapande, Department of Chemical Engineering, Indian Institute of Technology Madras, India
Prof. Devendra Jalihal, Department of Electrical Engineering, Indian Institute of Technology Madras, India

Advisory Committee

Dr. Ketaki Bapat, Scientist "F", O/o PSA to the GoI
Prof. Abhijit P. Deshpande, IIT Madras
Prof. P. B. S. Bhadoria, IIT Kharagpur
Prof. S. K. Kakoty, IIT Guwahati
Prof. R. P. Saini, IIT Roorkee
Prof. Nalinaksh S. Vyas, IIT Kanpur
Prof. Anand B. Rao, IIT Bombay
Prof. S. K. Saha, IIT Delhi
Prof. M. R. Ravi, IIT Delhi

Program Committee

Prof. Abhijit P. Deshpande, Department of Chemical Engineering, IIT Madras
Prof. Devendra Jalihal, Department of Electrical Engineering, IIT Madras
Prof. Shankar Krishnapillai, Department of Mechanical Engineering, IIT Madras
Prof. Palaniappan Ramu, Department of Engineering Design, IIT Madras
Prof. Mathava Kumar, Department of Civil Engineering, IIT Madras

Prof. Satya Narayanan Sheshadri, Department of Applied Mechanics, IIT Madras
Prof. Susy Varughese, Department of Chemical Engineering, IIT Madras
Prof. R. Ravikrishna, Department of Chemical Engineering, IIT Madras
Prof. Muraleedharan, Department of HSS, IIT Madras
Prof. G Venkatesh, CTaP, IIT Madras
Prof. P. B. S. Bhadoria, IIT Kharagpur
Prof. S. K. Kakoty, IIT Guwahati
Prof. R. P. Saini, IIT Roorkee
Prof. Nalinaksh S. Vyas, IIT Kanpur
Prof. Anand B. Rao, IIT Bombay
Prof. S. K. Saha, IIT Delhi
Prof. M. R. Ravi, IIT Delhi
Dr. S Ramesh Sakthivel, NIRD&PR Hyderabad

Local Organizing Committee

Prof. Abhijit P. Deshpande, Department of Chemical Engineering, IIT Madras
Prof. Devendra Jalihal, Department of Electrical Engineering, IIT Madras
Prof. Shankar Krishnapillai, Department of Mechanical Engineering, IIT Madras
Prof. Palaniappan Ramu, Department of Engineering Design, IIT Madras
Dr. S. Ganesan, RuTAG, IIT Madras
Ms. Nalini K, RuTAG, IIT Madras
Mr. Sreenivas Chigullapalli, RuTAG, IIT Madras
Ms. Sandhya Seetharaman, J-PAL
Mr. R. Pradhap, RuTAG, IIT Madras
Mr. Hisham Kv, RuTAG, IIT Madras
Ms. D. Vijayalakshmi, RuTAG, IIT Madras
Ms. R. R. Bhavana, Unnat Bharat Abhiyan, IIT Madras

Conference Summary

This summary describes a three-day programme of presentations, panel discussions and interactive sessions at the second international conference on “Rural Technology Development and Delivery (RTDD)—2020”, which took place during 12–14 March 2020 in IIT Madras, Chennai, India.

The event brought together around 150 like-minded participants to review the role of technology in rural development and to expand the capacity to address current and future development challenges and interlinkages between technology and policy. It also provided a valuable networking opportunity and offered a platform for further cooperation among the technology development institutions and technology dissemination organizations.

The conference began with the welcome address by Prof. Bhaskar Ramamurthy, Director, IIT Madras, and continued with the invited and technical sessions briefing on topics of conference themes. It concluded with a set of discussions on RuTAG—Way Forward, describing new and noteworthy initiatives relevant to the conference theme, especially technology dissemination and scale-up in rural areas.

Conference Organizers

Rural Technology Action Group (RuTAG), IIT Madras, organized and hosted the second international conference on “Rural Technology Development and Delivery (RTDD)” during 12–14 March 2020. RTDD 2018, the first event in the series, was organized by RuTAG IIT Delhi, focused on bringing together faculties and students from all RuTAG centres to discuss their achievements, difficulties, challenges on rural technology development and delivery, and the way forward in the next 10–15 years. In addition, other organizations working in the similar directions were invited to submit papers and participate to evolve a sustainable synergy between participants. The conference also had discussions on “dissemination” and “scaling of rural innovations” and the possibility of funding through other schemes of the government.

Funding Support

The conference was funded by the Office of the Principal Scientific Adviser to the Government of India.

Venue

The conference was held at the Centre for Industrial Consultancy and Sponsored Research (IC & SR), IIT Madras.

Number of Attendees

The total number of participants in the conference was about 150, composed of faculty and researchers from academics, development practitioners, NGOs, representatives from government agencies and research institutes and industry.

Overview

Over the three days of 12–14 March 2020, RTDD 2020 brought together practitioners and experts for a critical examination of the issues related to the rural technologies and their dissemination challenges from a community perspective. The conference combined presentations by experts and researchers with structured discussion sessions on the cross-cutting areas such as technology and entrepreneurship, technology and policy. It also outlined the opportunities in the space of rural technologies with a focus on implementation challenges.

The objectives of the conference include:

1. To foster discussion and strengthen the connections between researchers and development practitioners/NGOs
2. To discuss the issues related to technology development and dissemination to rural areas
3. To understand the challenges in the rural technology entrepreneurship.

Conference Format

The three-day conference is comprised of:

- Seven invited sessions (common), with 2–4 speakers per session. Each speaker was given 20 min to present, followed by 10 min for questions.
- Eight technical sessions (parallel), with three speakers per session. Each speaker was given 15 min to present, followed by 5 min for questions.
- One roundtable on "Technology and Policy" chaired by Prof. V. R. Muraleedharan, IIT Madras
- One panel discussion "Technology Challenges in Rural Entrepreneurship" chaired by Prof. Ashwin Mahalingam, IIT Madras
- One session on "RuTAG—Way Forward" with the RuTAG core team
- Poster session
- Stalls and exhibits of various handicrafts/organic products/technologies.

The conference was structured to foster discussion between participants around the core themes of the conference. Each day of the conference also allotted 1 h for lunch and 30 min for morning and afternoon tea to allow participants to continue their discussions after each session.

Roundtable on "Technology and Policy"

Roundtable on "Technology and Policy" focused on the linkages between technology-aided development and policy landscape in the rural ecosystem. The session had panellists from academia, industry, start-ups and CSR/development organizations. The focus of the roundtable was on the PURA—Provision of Urban Amenities to the Rural Areas—with a special emphasis on digital technologies for rural development, rural employment and livelihoods, innovations and rural entrepreneurship, a synergy between regulation and development. The roundtable also discussed synergy across different policy environments and regulations on rural technology development and delivery. The roundtable focused on the following issues:

1. Farmer productivity in India has lagged other countries, whether measured in terms of output per farmer or in terms of yield per hectare farmed. Improving farmer productivity is a prerequisite to improving rural incomes. Is the low productivity because of low adoption of technology in the farming sector or due to other reasons? How can we use technology in an effective way to change this situation?
2. President Kalam coined this interesting phrase "PURA" which stands for provision of urban amenities in rural areas. The basic idea was that provision of such amenities will enhance standard of living in rural areas (through, e.g., clean drinking water, better sanitation and health care, better education). More than that, it will also open up many more avenues for economic growth in the rural

areas. What steps should the government or local communities take to push for such amenities in their neighbourhoods?

3. India has had a strong ancient tradition of the use of technology in different activities. The Indus Valley Civilization had very detailed urban planning. Wootz steel invented in South India was considered superior to many other materials at that time (2000 years ago) and was exported for sword making by the Arabs. Ancient India also seemed to know about sustainable use of natural resources like water and land. Indian craftsmen used a variety of tools to develop their wares. Ayurveda had answers to some of the more chronic medical conditions. We seem to have lost most of these over time. Does it make sense to recover some of these ancient methods and apply modern technology to them?
4. Rate of innovation seems to have increased exponentially in the last few decades, especially with the advent of the Internet. Does the presence of Internet and mobile phone technology open up radically new ways of addressing the problems of rural India? What is the enabling role that various stakeholders (government, community, technology providers, donors, etc.) can play to accelerate this?
5. Is regulation good or bad for rural India? For instance, villagers use vehicles in which pump-set motors (or electric motors now) are mounted on a three- or four-wheel cart to provide a low-cost transport which is clearly not certified and is environmentally pretty damaging. If we apply regulation, then the cost goes up so much that it becomes unaffordable for the rural consumers. Same goes with locally produced detergents and soaps, etc. The safety norms that one would apply in urban factories also do not apply to rural machines and mills. Should the government adopt different standards for urban and rural areas? Or should they maintain standards but use subsidies or other interventions in rural areas? Or should they simply overlook rural areas (in any case the regulatory infrastructure does not have the capacity to cover the whole country)?
6. India is a diverse country, and each area has its own context and individuality. As a result, a solution that works in one place may not work in another place. How do we go about assessing the viability of a technology for a given context? If we have tried it out in one place, say in Kerala, then how can we determine whether it will work in Bihar or West Bengal?

Panel Discussion on "Technology Challenges in Rural Entrepreneurship"

A panel discussion on "Technology Challenges in Rural Entrepreneurship" was held with a mix of panellists from incubation centres, academia, start-ups and CSR. The panellists discussed the rural ecosystem and the possibilities for technology-based entrepreneurship, governance and regulation issues, uptake of technologies by the rural consumers and challenges for such enterprises.

Conference Themes

There were three verticals of **Research, Practice** and **Policy** for each of the following themes:

- Innovative designs for rural livelihoods

It covered product and process design in various sectors such as agriculture and agroprocessing, handicrafts and livestock management that impact rural livelihoods positively.

- Rural water resources

It emphasized on rural watershed management for groundwater and surface water resources, decentralized water and waste water management.

- Rural energy systems

It highlighted rural energy production, distribution, storage and use and decentralized energy management.

- Rural landscapes/Rural Environment

It made emphasis on conservation of rural landscapes, waste management and environmental protection.

- Smart technologies for rural development: Education, Health care and ICT

It gave significance to mobile apps, artificial intelligence, robotics, machine learning and virtual reality in sectors of rural education, health care and ICT.

Conference Website

https://web.iitm.ac.in/rtdd2020/

Preface

The second international conference on "Rural Technology Development and Delivery (RTDD)" was held at IIT Madras during 12–14 March 2020. The conference brought together a wide range of researchers and practitioners in the field of rural technology solutions and sought to recognize, encourage and promote scientific research related to innovative designs for rural livelihoods, rural water resources, energy applications in rural areas, rural landscapes or rural environment, and smart technologies for rural development on education, health care and ICT. The conference also demonstrated how many of the rural problems could be treated as R&D challenges with a focus on "dissemination" and "scaling of rural innovations" and the possibility of further funding opportunities.

The first international conference on "Rural Technology Development and Delivery (RTDD): RuTAG" and its synergy with other initiatives were organized by IIT Delhi in 2018, focusing on "researching rural problems," and its conference proceedings (ISBN: 978-981-13-6435-8) are available on Springer. The RTDD 2020, the second in the series, is also being brought out as proceedings through this effort.

The RTDD 2020 made an effort to promote mainstream researchers, UG and PG students and various organizations to showcase, sensitize, understand and take up various rural problems in the above-mentioned areas to design and develop cost-effective technology solutions for rural communities.

Publishing peer-reviewed papers with rural focus, in a monograph like this, can ensure a wider reach. This will motivate many new researchers as well as students to identify more research challenges from the rural context. These proceedings could also spread real-life solutions across the global community. We hope that this monograph RTDD 2020 contributes to global stakeholders engaged in rural technology development and dissemination.

Mumbai, India — Sreenivas Chigullapalli
New Delhi, India — S. U. Susha Lekshmi
Chennai, India — Abhijit P. Deshpande

Acknowledgements

We are grateful to all those whose contributions made the second international conference on “Rural Technology Development and Delivery (RTDD)” at IIT Madras during 12–14 March 2020 successful and the launch of this monograph a reality. Our sincere gratitude towards the office of the PSA for the financial assistance, especially Prof. K. Vijay Raghavan for his consent to conduct this conference and Dr. Ketaki Bapat for her enthusiasm and support. We thank them for having faith in RuTAG IIT Madras to host the second conference in the series on RTDD. We sincerely thank the local advisory committee for conceptualizing the themes and providing the conference format. The conference brought together stakeholders from academia and the development sector. The participatory discussion and exchange of ideas throughout the conference attested to the need of documenting the technical knowledge base through these proceedings.

The authors of this monograph were speakers and panellists of RTDD 2020. We thank these authors for their manuscripts to be assembled as thematic monograph. We also thank all the reviewers for reviewing the papers and providing their feedback. This process involved multiple iterations, and we thank authors and reviewers for their cooperation throughout.

We express our gratitude towards Prof. S. K. Saha, Coordinator and Principal Investigator, RuTAG IIT Delhi, for his help and motivation for initiating this monograph. We sincerely acknowledge the support of the administration of IIT Madras, our colleagues and the staff of RuTAG IIT Madras (Dr. S. Ganesan, Ms. K. Nalini, Mr. R. Pradhap, Mr. Hisham Kv, Ms. D. Vijayalakshmi and Ms. Bhavana). We thank all the other RuTAG centres, especially RuTAG IIT Delhi, for their tremendous support. We also thank the production team from Springer for their help in streamlining the proceedings volume.

Sreenivas Chigullapalli
S. U. Susha Lekshmi
Abhijit P. Deshpande

Contents

Editors and Contributors

About the Editors

Sreenivas Chigullapalli is working as a Project Manager at Development and Relations Foundation, IIT Bombay. Prior to joining IIT Bombay, he worked as the Project Officer at the Rural Technology Action group (RuTAG) at the Indian Institute of Technology (IIT) Madras. He held teaching, research, and consulting positions at IIT Bombay, AP International Institute of Information Technology (AP IIIT) Nuzvid—Rajiv Gandhi University for Knowledge Technologies (RGUKT), Indian Institute of Science (IISc) Bengaluru, Indian Institute of Management (IIM) Bengaluru and Byrraju Foundation. His research interests include bioenergy, climate policy, and sustainable development. He is pursuing a Ph.D. in Climate Studies (Bioenergy and Climate Change Mitigation) at IIT Bombay. He received his Master's degree in Technology and Development from the Centre for Technology Alternatives for Rural Areas (CTARA), IIT Bombay, and Bachelor's degree in Biotechnology from Jawaharlal Nehru Technological University (JNTU) Hyderabad.

Dr. S. U. Susha Lekshmi is currently working as Program Manager at I-Hub Foundation for Cobotics (IHFC), Technology Innovation Hub at IIT Delhi. Earlier, she worked as a SERB National Post-Doctoral Fellow at the Department of Mechanical Engineering, Indian Institute of Technology (IIT) Delhi in collaboration with Rural Technology Action Group (RuTAG IIT Delhi). She also worked in RuTAG IIT Delhi prior to her post-doctoral fellowship. Her areas of research interests are multi-disciplinary, ranging from rural technology and development, electrical and magnetic characterization of geomaterials, evaluation of non-invasive soil sensors, soil and water conservation, and system dynamics modeling of soil management. Her academic profile includes a Ph.D. in the area of Environmental Geotechnology from the Department of Civil Engineering, IIT Bombay; a Master's in Technology & Development from Centre for Technology Alternatives for Rural Areas (CTARA), IIT Bombay; and Bachelor's in Agricultural Engineering from Kerala Agricultural

University. She has published her research outcomes in various peer-reviewed international journals, national and international conferences, and contributed a book chapter as well. She also worked as a Visiting Researcher at the University of Strathclyde, Scotland, with the financial support of the European Commission via the Marie Curie IRSES project.

Abhijit P. Deshpande is Professor-in-charge of Rural Technology Action Group Indian Institute of Technology (IIT) Madras since January 2017. In these years, RuTAG has continued efforts towards projects impacting livelihoods such as on Electronic Jacquard for Pattamadai mat weaving, and initiated projects in agri-technology such as paddy thresher. He is a Professor in the Department of Chemical Engineering at the Indian Institute of Technology Madras. He teaches courses on Polymers, Rheology, and undergraduate Chemical Engineering subjects. His research interests include polymer rheology, gels, and gelation.

Contributors

Imtiyaz Ali HRED, IIT Roorkee, Roorkee, India

Nikhilesh Bagade CTARA, IIT Bombay, Mumbai, India

Saumendra K. Bajpai Department of Applied Mechanics, Indian Institute of Technology Madras, Chennai, India

Bhagavatheeswaran Centre for Social Development, Nagercoil, India

Upendra Bhandarkar Mechanical Engineering, IIT Bombay, Mumbai, India

N. Chandana Centre for Technology Alternatives for Rural Areas, Indian Institute of Technology Bombay, Mumbai, India

Pennan Chinnasamy Centre for Technology Alternatives for Rural Areas (CTARA), Indian Institute of Technology Bombay, Mumbai, India;
Rural Data Research and Analysis (RuDRA) Lab, Indian Institute of Technology Bombay, Mumbai, India

Abhijit P. Deshpande Department of Chemical Engineering, Indian Institute of Technology Madras, Chennai, India

Karve Anand Dinakar Samuchit Enviro Tech, Pune, India

Satish Dulla Centre for Technology Alternatives for Rural Areas, IIT Bombay, Mumbai, India

Vijay Honkalaskar IIT Bombay, Mumbai, India;
Sulok Chetana Pratishthan, Satara, India

Aniket Hulage Thermal and Fluids Engineering Specialization, Mechanical Engineering, IIT Bombay, Mumbai, India

Ramesh Chandra Joshi HRED, IIT Roorkee, Roorkee, India

Sashindra Kumar Kakoty Center for Rural Technology, Indian Institute of Technology Guwahati, Guwahati, India

Ajaykumar R. Kambekar Department of Civil Engineering, Sardar Patel College of Engineering, Mumbai, India

S. B. Kedare DESE, IIT Bombay, Mumbai, India

Rupali Khanolkar Rural Technology Action Group (RuTAG), IIT Bombay, Mumbai, India

Yogesh Kulkarni Vigyan Ashram, Pabal, Pune, India

Yogeshwar Kumar Jansamarth NGO, New Delhi, India

Sasangbaha Mandi Ergonomics and Occupational Physiology Laboratory, Department of Physiology, University of Kalyani, Kalyani, Nadia, West Bengal, India

Deepak Marla Mechanical Engineering, IIT Bombay, Mumbai, India

Tandra Mondal Department of Agriculture and Rural Development, RKMVERI, Narendrapur, Kolkata, India

Pranab Kumar Nag School of Environment and Disaster Management, RKMVERI, Narendrapur, Kolkata, India

Pratik Naik Rural Technology Action Group (RuTAG), IIT Bombay, Mumbai, India

S. Namasivaya Naveen Department of Applied Mechanics, Indian Institute of Technology Madras, Chennai, India

Yashwant Prasad Department of Mechanical Engineering, Indian Institute of Technology Delhi, New Delhi, India

Baburaj A. Puthenveettil Department of Applied Mechanics, Indian Institute of Technology Madras, Chennai, India

James Rajanayagam Centre for Social Innovation and Entrepreneurship, IIT Madras, Chennai, India

Anand B. Rao Rural Technology Action Group (RuTAG), IIT Bombay, Mumbai, India;
Center for Technology Alternatives for Rural Areas (CTARA), IIT Bombay, Mumbai, India

Bakul Rao Centre for Technology Alternatives for Rural Areas, Indian Institute of Technology Bombay, Mumbai, India

Subir Kumar Saha Department of Mechanical Engineering, Indian Institute of Technology Delhi, New Delhi, India

Subhashis Sahu Ergonomics and Occupational Physiology Laboratory, Department of Physiology, University of Kalyani, Kalyani, Nadia, West Bengal, India

Alankrita Saikia Center for Rural Technology, Indian Institute of Technology Guwahati, Guwahati, India

R. P. Saini HRED, IIT Roorkee, Roorkee, India

S. K. Singal HRED, IIT Roorkee, Roorkee, India

Aman Srivastava Centre for Technology Alternatives for Rural Areas (CTARA), Indian Institute of Technology Bombay, Mumbai, India

Nitish Kumar Tripathi Department of Applied Mechanics, Indian Institute of Technology Madras, Chennai, India

Pawle Md. Umar Ravish Sardar Patel College of Engineering, Mumbai, India

Shraddha Vekhande CTARA, IIT Bombay, Mumbai, India

Part I
Innovative Designs for Rural Livelihoods

Chapter 1
Solar-Grid Hybrid UPS System-Based Variable Speed Bageshwari Wool Charkha

R. P. Saini, S. K. Singal, Imtiyaz Ali, and Ramesh Chandra Joshi

1 Modified Bageshwari Wool Charkha

1.1 Introduction

The wool weaving and spinning have been the traditional occupation of the remote area people of the Himalayan region. Wool spinning provides the main source of earning. Late Shri J. S. Tangnia introduced a traditional charkha for wool weaving and spinning in the year of 1926 for spinning yarn in the district Bageshwar of the state of Uttarakhand. Before 1926, the local people were spinning and twisting the thread by katwa. After invention of this charkha, the demand for the charkha increased. Late Shri J. S. Tangnia had dedicated this charkha to Mahatma Gandhi at Kurmanchal Rally in 1929. With continuous increase in charkha demand, charkha manufacturing workshop was opened by him in the year of 1934. Various tools and labor were collected for manufacturing of charkha. This charkha manufacturing process was repeated till 1943. The spinning output of a traditional Bageshwari charkha was much less in quantity as well as in quality due to involvement of more physical work (Mudgal 1996). Many people are still using the traditional charkha to maintain their earnings. Since its inception, various modifications have been made to improve the performance along with low physical strength requirements for its operation.

1.2 Preliminary Investigation and Problems Identifications

In order to detect and mitigate the issues faced by spinners on traditional Bageshwari charkha, RuTAG IIT Roorkee team visited Bageshwar district of Uttarakhand. The

R. P. Saini (✉) · S. K. Singal · I. Ali · R. C. Joshi
HRED, IIT Roorkee, Roorkee, India
e-mail: rp.saini@hre.iitr.ac.in

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_1

team conducted a meeting with spinners of local as well as adjoining villages with the help of regional coordinator of Himalaya trust. The following problems were enlisted based on the feedback of operators.

1. Non-uniform filling of bobbin,
2. Non-uniform thickness thread of yarn,
3. Manually operated and low productivity.

2 Modifications in Traditional Bageshwari Charkha

To rectify problems listed above, a traditional Bageshwari charkha was modified during the phase-1 in four stages to remove these problems raised by operators, and after modification, charkha was given to the spinners for field testing (Saini et al. 2019).

Based on the feedback received from the spinners, Bageshwari charkha was modified in phase-2. A variable speed solar-grid hybrid UPS system-based modified Bageshwari wool charkha is shown in Fig. 1 which is now introduced with speed controller, solar PV, battery, inverter, compact gearbox, mobile charger, control mechanism. In order to assess the performance and efficiency of modified Bageshwari charkha, a testing was organized for the artisans of Rajasthan under the direction of RuTAG coordinator. Based on the feedback from artisans and further requests for field trial, one set of modified Bageshwari charkha has been sent for field trail for spinning yarn.

2.1 Design of Solar-Powered Bageshwari Wool Charkha

See Fig. 2.

2.2 Specification of Solar-Based Bageshwari Wool Charkha

The variable speed solar-based modified Bageshwari wool charkha comprises of solar panel (75 W), electric motor (110 W), battery (12 V) with 4-V rechargeable battery operated by foot pedal. Further, a knob control is provided to adjust the coarse and fine spinning of wool. This system has advantages of a USB socket, battery backup, and lightweight structure, and its components can easily be assembled and disassembled. Main components of the solar-based Bageshwari wool Charkha are as listed in Table 1 (Fig. 3).

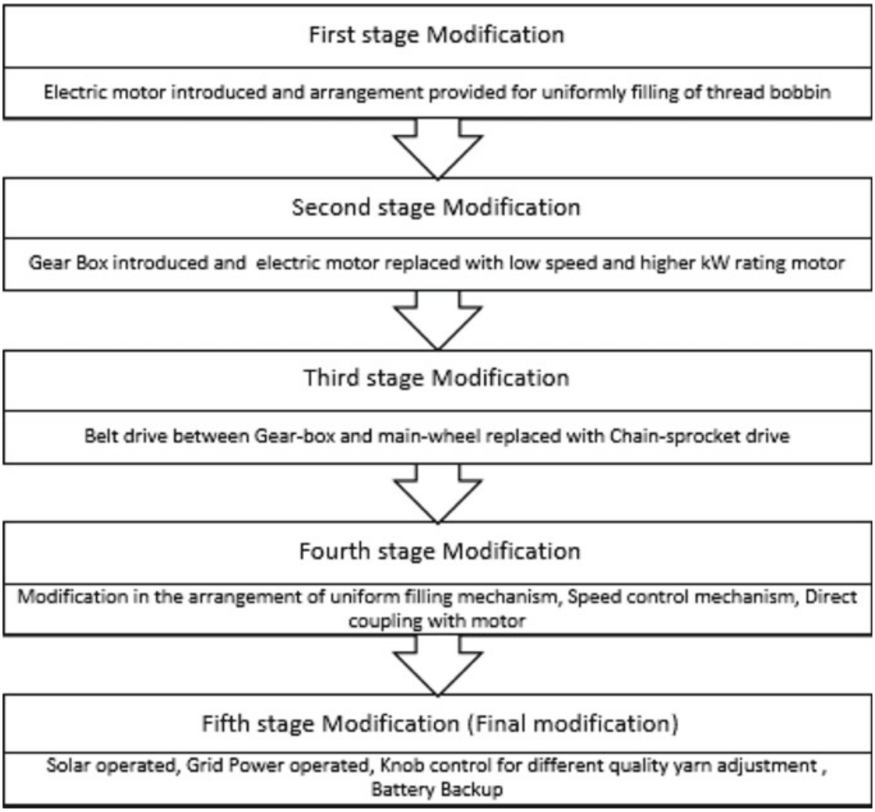


Fig. 1 Different stages of modification for traditional Bageshwari charkha

2.3 Specifications of Solar PV for Bageshwari Charkha

Bageshwari wool charkha is being operated in interior rural areas where no assured electric supply is available. Therefore, solar energy could open a new avenue for operating charkha under solar mode. Solar panels of various capacities are now readily available. In view of these, Bageshwari wool charkha integrated with solar mode operation while retaining its manual operation. The Solar PV System installed along with the battery is capable of providing power to run the charka and its connected lighting for 3–4 h in a day. The photograph of solar PV for Bageshwari charkha is shown in Fig. 4. Specifications of the solar PV integrated with Bageshwari charkha are given in Table 2.

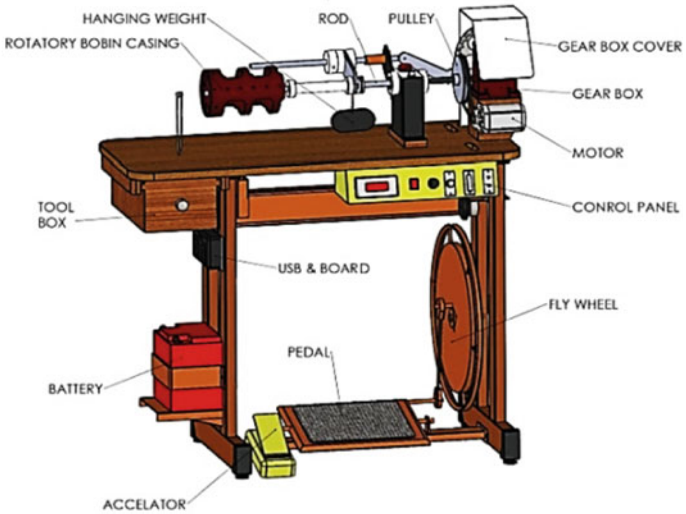


Fig. 2 Design of modified Bageshwari wool charkha

Table 1 Components of the modified Bageshwari wool charkha

S. No.	Component	Specification
1	Generator (Dynamo)	4 V, 0.03 mAh
2	LED Light	4 V
3	D.C. voltmeter	6–100 V
4	Motor	220 V, 50 Hz, 110 W, R.P.M 7500
5	Switch and Socket	220 V Inverter output
6	Knob control	Coarse and fine adjustment
7	Gear box (gear ratio)	1:48
8	Solar panel	75 W
9	Fly wheel	Dia-17″, Thickness-18 mm
10	Tool box	14.5″ × 11.5″ × 6″

2.4 Power Supply Observations and Calculation Table

The grid power input and battery backup observations are recorded at different speeds of motor shaft. The RPM is controlled by using knob control circuit which is provided for coarse and fine yarn adjustment. In case of grid connectivity, a single-phase 220 V, 50 Hz, AC power supply shall be used for its operation. While operating with backup power, minimum operating voltage for battery is 10 V which will automatically be displayed in voltmeter and the machine will stop working with power backup having lower voltage than 10 V. The observations and calculations for grid and battery power

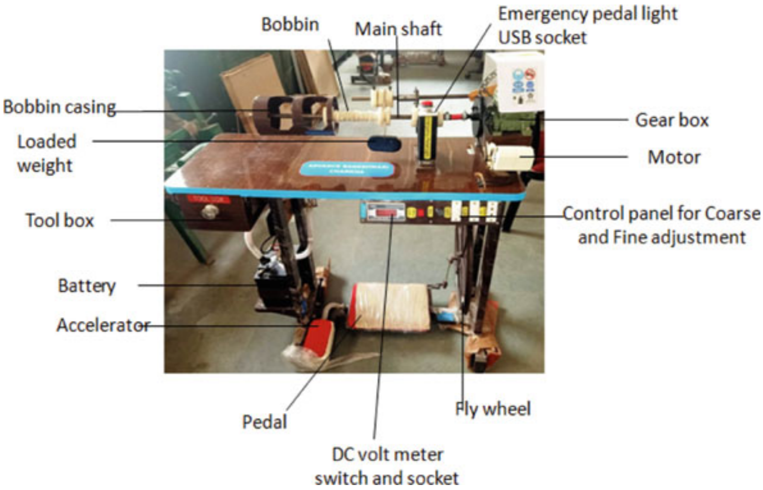


Fig. 3 Photograph of modified Bageshwari wool charkha

Fig. 4 Photograph of solar PV system for Bageshwari charkha

Table 2 Specifications of solar PV integrated with Bageshwari charkha

S. No.	Component	Specification
1	Solar PV system	75 W
2	Inverter	12 V DC input
3	Production rate	1200–1500 gm/8 h
4	Battery	12 V, 35 Ah
5	Battery backup	Available
6	Battery backup capacity	3–4 h/day
7	Yarn Production	Fine quality

Table 3 Grid power input observation and calculation

S. No.	Fine	Coarse	R.P.M	Volts	Amps	Watt	Unit (h)
1	FULL	FULL	1064	230	0.28	64.4	0.06
2	FULL	MIN	600	230	0.29	66.7	0.06
3	MIN	FULL	800	230	0.30	69	0.06
4	5	1	510	230	0.28	64.4	0.06
5	FULL	2	720	230	0.30	69	0.06
6	FULL	3	810	230	0.29	66.7	0.06
7	FULL	4	916	230	0.28	64.4	0.06
8	FULL	5	1000	230	0.30	69	0.06

Table 4 Backup power observations and calculation

S. No.	Coarse	Fine	Battery Volt		R.P.M	Amps	Watt	Backup
			Without load	With load				
1	FULL	FULL	12.5	12.1	960	0.26	59.8	6.02
2	FULL	MIN	12.5	12.1	556	0.28	64.4	5.59
3	MIN	FULL	12.5	12.1	690	0.31	71.3	5.04
4	5	1	12.5	12.1	680	0.29	66.7	5.39
5	FULL	2	12.5	12.1	555	0.29	66.7	5.39
6	FULL	3	12.5	12.1	690	0.28	64.4	5.59
7	FULL	4	12.5	12.1	824	0.28	64.4	5.59
8	FULL	5	12.5	12.1	830	0.28	64.4	5.59

at constant voltage are summarized in Tables 3 and 4. For Fine and Coarse Speed adjustment of the flyer a Knob Control is used and its position is indicated from Full to Minimum in the tables along with flyer speed achieved and power consumed.

2.5 *Performance Assessment of Solar-Based Modified Bageshwari Charkha*

A training workshop program was held at laboratory to analyze the performance of solar-powered motorized Bageshwari wool charkha working with spinning of local wool from Rajasthan and Uttarakhand during June 19–21, 2019 in association with trainer Smt. Kusum Bhandari from Aadhar NGO, Dehradun. Weavers Mr. Premsukh and Mr. Prem Kumar from Jaipur Rugs Company Pvt. Ltd., Rajasthan participated in training program and also operated the charkha for spinning the local wool. The training photos are shown in Fig. 5.

Fig. 5 Training sessions photographs at RuTAG center IIT Roorkee

Various parameters such as yarn quality, time is taken and production of yarn from sheep wool were observed (Muhammad 2011). Spinning the "mixture of wool" while running charkha operating in manual, motorized, and solar mode were analyzed. The modified wool charkha would be beneficial to the spinner and for the cottage industry for the production of yarn with local fiber from Uttarakhand and Rajasthan. This could be a source of employment and increase the income. For performance assessment of modified Bageshwari charkha, feedback from trainer was received in comparison with traditional charkha. Detailed summary of conclusions on traditional charkha and solar-based modified charkha is summarized in Table 5.

Table 5 Detailed summary of conclusions

S. No.	Observations	Modified charkha	Traditional charkha
1	Operating	Manually/electrically/solar	Manually
2	RPM	150–3000	1300
3	Speed of spindle	Variable	Variable
4	Count	Higher count for local wool	Lower
5	Production rate	High	Low
6	Production capacity	1500 gm/8 h	600 gm/8 h
7	Battery backup	Available	Not available
8	Strength of yarn	Excellent	Good
9	Wool to be spun	Local Sheep, Merino, Australian	Local Sheep, Merino, Australian
10	Toolbox	Provide for accessories	Not available

3 Economical and Technical Aspects

3.1 Comparative Assessment

Performance-wise, modified Bageshwari wool charkha has outperformed the traditional charkha. With the help of a modified Bageshwari wool charkha, a spinner can spin wool up to 200 g per hour and 1600 g per day. Whereas on the contrary, on traditional Bageshwari charkha a spinner spins around 70–80 g of wool in an hour and approximately 600 g in a day. On an average, a unit of modified Bageshwari charkha yields 1.6 kg and 1.4 kg of local wool and Merino wool, respectively in a day, which is 2.5 times more productive than traditional charkha.

As per the observation of NGO (Himalayan Trust Bageshwar), it has been concluded that on a traditional charkha a weaver could earn approximately Rs. 90–150 in a day by spinning Tibetan and Merino Wool. On the contrary, after the introduction of modified Bageshwari wool charkha, a weaver can earn up to Rs. 250–350/- per day, which increases weavers' daily income by 2.5 times. It may also vary according to the caliber of spinner and quality of raw material. The modified charkha will definitely be able to provide more income to the users due to more spinning in a given time duration.

3.2 Livelihoods

Spinning of wool for weaving can boost local livelihoods, as raw wool is easily available and local people are well versed in spinning and weaving. Migration in the state over the last 10 years could be slow down. The limitation of hard labor has been replaced through mechanically operated charkha and an increased output can motivate spinners for more production and earnings through improved Bageshwari Wool Charkha. As number of users will increase, more and more people will get the livelihood, particularly for underprivileged public in a given area.

4 Impact on the Environment

The state of Uttarakhand has emerged as a hub in hand spinning and weaving business. Where more than 60,000 families are associated with this business and will be directly benefited from the development of charkha. The modified charkha operated electrically using single-phase motor of 75 W consumes only 0.6 units of electricity in a day by working for 8 h, which costs about Rs. 2.0 per day. The developed charkha is nature friendly in itself as neither does it consumes any fossil fuel nor does it emit any kind of combustion during operation, which reduces the risk of explosion and fire hazard. It is easy to operate, ensures safety of the operator, and has no human drudgery. Further, R&D has been conducted to reduce the total cost of integration of charkha with renewable energy sources. As such no environmental problems have yet been observed/faced.

5 Conclusion

Traditional Bageshwari Charkha has been the main source of income by spinning locally grown wool in the Himalayan region peoples. In this study, the traditional charkha is modified in five stages to remove the problems raised by operators. The improved charkha is provided with a solar PV panels and a battery backup has also been introduced for night operations. The quality of thread has been improved by knob control mechanism.

To assess the performance finally of solar-based modified Bageshwari wool charkha, a training program has been conducted for the artisans from Rajasthan under the guidance of RuTAG coordinator from the office of the government in association with various NGOs. Based on the feedback from artisans and on-demand, one set of modified Bageshwari charkha has been sent to introduce the innovation at their warehouse in Bikaner in the state of Rajasthan. These amendments in charkha are very beneficial for considerable amount of population of the Uttarakhand state for spinning locally grown wool. In order to provide the benefit to the villagers working in wool spinning, the training programs are organized in various locations in hilly states. We are also working to connect the local communities with the local entrepreneurs for the technology adoption.

References

Mudgal R (1996) Economic dimensions of rural development. Sarup & Sons Publication, New Delhi

Muhammad A (2011) To study how to improve the productivity of yarn and fabric production in a production mill. Master's Thesis, Textile Hogskolan-Hogskolan I Boras

Saini RP, Singal SK, Ali I, Joshi RC (2019) Development of modified Bageshwari Wool Charkha. In: Saha S, Ravi M (eds) Rural technology development and delivery. Design science and innovation. Springer, Singapore

Chapter 2
Fab Lab for Appropriate Technologies

Yogesh Kulkarni

1 Introduction

Vigyan Ashram is located in Pabal, a small village in India. The nearest city is Pune, about 65 km away. Established in 1983, Vigyan Ashram is engaged in developing technological solutions to problems of rural India. Vigyan Ashram trains rural youth on new technologies and helps them to start technology-based businesses. Over these years, Vigyan Ashram has developed several low-cost technologies viz. low-cost housing, ferrocement water storage tanks, low-cost agriculture tools etc. These are simple and innovations specific to local conditions. They help in reducing drudgery and improve productivity. Until 2002, Vigyan Ashram was using traditional fabrication tools to develop appropriate solutions.

In 2002, Dr. Neil Gershenfeld of MIT (USA) introduced the concept of digital fabrication to the Vigyan Ashram team. Dr. Gershenfeld is of the firm belief that we need advanced technologies to solve some of the world's pressing problems. Dr. S. S. Kalbag, founder of Vigyan Ashram, was against giving readymade solutions to the rural youth. He wanted to train rural youth on modern tools so that they can develop technologies to solve their own problems as well as problems of their communities. The interaction of Dr. Kalbag and Dr. Gershenfeld led to establishment of a "Fab Lab" at Vigyan Ashram. Thereafter, Vigyan Ashram started using digital fabrication along with traditional tools. In this article, the author describes effectiveness of using modern tools in the Fab Lab to solve location specific problems.

Y. Kulkarni (✉)
Vigyan Ashram, Pabal, Pune 412403, India
e-mail: vapabal@gmail.com

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_2

2 What Is a Fab Lab?

High end manufacturing and design hardware-software is a major reason for industrial and human productivity, high quality of goods and higher process efficiency. Modern industries use a variety of digital fabrication tools, computer-controlled machines, and a variety of proprietary design software. These are typically used exclusively by trained staff working in those industries. It is out of bounds for the common man.

A Fab Lab on the other hand, is a community centre for digital fabrication with a collection of prototyping tools. It comprises of Laser cutting machines, CNC engravers, Vinyl cutting machines, 3D printers, electronics & sensors, and Open-Source design software. You can design your idea/concept on a computer using the Open Source design software and can get it printed using above-mentioned computer-controlled machines. The Fab Lab provides open access for common people to use such facilities and to make their own projects/solutions.

Fab Lab is now a global movement led by the Fab Foundation, USA. There are more than 1600 Fab Labs around the world and they are increasing exponentially. Fab Labs operate on the philosophy of "Learn, Make, Share" philosophy. Common interest, expertise, and common problems help in building collaboration amongst Fab Labs across the world. It can be thought of as a distributed R&D network across the globe (Fig. 1).

Fig. 1 Fab Lab at Vigyan Ashram

3 What Is Appropriate Technology?

An Appropriate Technology solution is that which is location specific, low-cost, and built using sustainable technologies. It takes into account local wisdom and engages local people in solving problems. Often, they are very simple technologies that help in reduction of manual labour and improving productivity. In general, Appropriate Technology emphasizes decentralized production and use of local materials.

Various agriculture tools, Do-It-Yourself dryers, housing, and sanitation solutions etc. have been developed by many organizations working in the area of Appropriate technology. But most of these technology solutions use traditional fabrication methods. The manufacturing process used requires manual skills and adaptive intelligence on the part of the fabricator. This makes it difficult to replicate or disseminate the solution to other locations.

Such factors limit the growth and adoption of the appropriate technology movement. Due to this, Appropriate Technology is often perceived as inferior to modern technologies. But now there is a possibility to change this perception by adoption of digital fabrication in development of appropriate technologies.

4 Using Fab Lab for Developing Appropriate Technology Solution

Being located in a rural part of India, Vigyan Ashram is deeply connected with its community members. These members often narrate problems they face to Vigyan Ashram and request for solutions. Vigyan Ashram maintains such requests as a potential projects list to be offered to its students. Resident students as well as interns from engineering colleges pick up projects best suited to their interests. Many of these projects are then executed using the facilities available at the Fab Lab.

This approach enables many objectives:

1. Students get to use the Fab Lab facilities and learn the intricacies of the computer-controlled hardware and design software.
2. They get to use these facilities to solve real-life problems, brought up by the community.
3. Interacting with the community during the prototyping, design, and trial phases enables them to practice communication skills, problem-solving skills, and involve the community members in the design process.
4. The community members involved in the solution design are best suited to give relevant feedback and inputs, as well as have the enthusiasm to test the prototypes.

This process improves the chances that the solution is able to satisfy the core requirements of being an appropriate technology i.e. Is it solving local problems?

Does it involve the community and incorporate wisdom of the local people? Does it use local resources and is it built using sustainable technologies?

Here are examples of some appropriate technology development projects using the Fab Lab at Vigyan Ashram.

1. **Egg Incubator**: Vigyan Ashram team had come across the need to develop a small hatchery for brooding native chicken. The demand for native chicken meat was increasing and many rural entrepreneurs were keen on setting up poultry farms that supplied native chicken. However, they needed a good supply of chicks. This led to another potential business opportunity namely the setting up of a hatchery. However, an enabling technology was needed.

Anil Gadhe, a student of Vigyan Ashram, collected data about the natural hatching process of eggs. He observed broody hens and kept records of temperature, humidity, and rotation of their eggs. Using the Fab Lab facilities, he designed an egg incubator using these parameters.

Another student of electronic engineering, helped in reducing cost of humidity sensors by using temperature sensor and traditional dry and wet bulb humidity measuring formulas. He used micro-controllers to develop a humidity sensor which is reliable and at 10% of the cost of commercially available sensors.

Anil has taken this project ahead and started his own unit manufacturing egg incubators. He sells his incubators to women self-help groups. These SHGs run business of growing and selling chicks. This helps in increasing their income and eggs to meet nutritional need of their families.

Digital design tools at the Fab Lab enabled iterating through the design process. Laser and 3D printers enabled prototyping. And most importantly, electronics design helped in making egg incubator into a commercial product.

2. **Rice Dehusking Machine**: Rice is a staple food for most Indians. However, most of the nutrients and bran gets lost during polishing of raw rice using a rice huller. Therefore, there is growing demand for brown rice which is more nutritious but whose production uses the traditional but laborious hand pounding method (Fig. 2).

Self-help group women near Rajgurunagar town, wanted a machine to make brown rice. There is a good demand from nearest city Pune for hand pounded brown rice. Manually method of making rice is not only laborious and results in more breakage of rice grain. It is not a scalable method either given the increase in demand. Vigyan Ashram offered this as a project to its agricultural engineering students. Since 2014, many students worked on the problem as their final year project. Every year, new students build on the work done by the students of the previous year. First version of rice dehusking machine was launched in 2016.

It went through further design and prototyping iterations and is now commercially available and sold by Climber Engineers.

Fig. 2 Rice de-husking machine

3. **Solar Dome Dryer**: Farmers in Bhimashankar wanted to dry wild vegetables and Pudina (Mint) in order to increase their shelf life. Pudina is known for its aroma and taste, and is in high demand. They wanted the aroma to be retained in the drying process. Multiple students worked on the projects. Projects were divided into multiple small individual projects for e.g.

   (a) Designing CAD design of dryer using software like Solidworks.
   (b) Carrying out CFD (computational fluid dynamic) analysis of dryer to determine airflow.
   (c) Designing of drying apparatus to find out drying property of substrate.
   (d) To draw drying curve of substrate (Figs. 3 and 4).

After four years of various trials by student volunteers, the design of a dome dryer design is ready for large-scale production and deployment. M/s Anandghana Industries a local firm, is using these domes for in-situ drying of vegetables, pudina, and other herbs at farmers field itself.

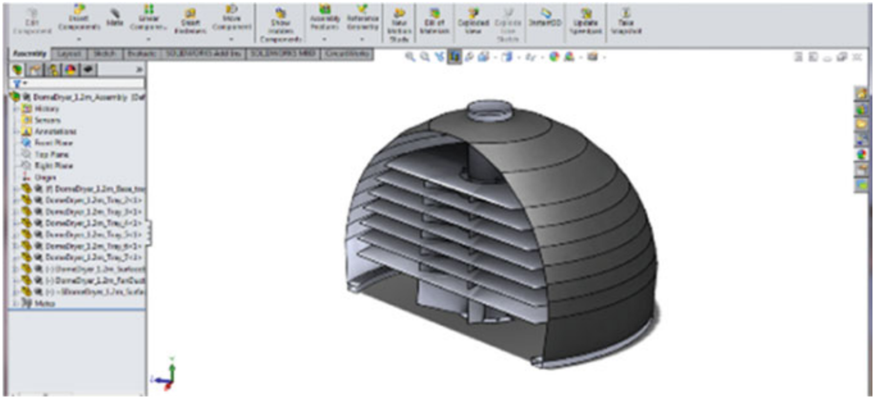


Fig. 3 Sketch of the dome dryer

Fig. 4 Solar dome dryer

5 Conclusion

In this paper, the author has shared his experiences at Vigyan Ashram in using digital fabrication in solving problems brought forth by rural Indians. He has also shown how these can be used to realize new business and entrepreneurship opportunities.

Use of digital fabrication brings standardization and reproducibility. It also makes iterative design easy. Appropriate technology aims at reducing cost but that does not mean giving a lower quality product to the customer. Digital fabrication helps in achieving quality by local production and cost reduction. The author has compared his experiences as a traditional maker and as a Fab Labber in Table 1.

Vigyan Ashram has been documenting of all its work, and making it available online adopting the open-source sharing philosophy. These documents are available on its blog http://vadic.vigyanashram.blog/. The author believes that decentralized

Table 1 Comparison between traditional and digital fabrication

Traditional makers	FAB LABBERS
Use traditional tools	Use modern + digital + traditional tools
Solution developed is many times localized. It is difficult to replicate	Due to standardization, digital design, proper documentation. It is easy to replicate
Use multiple ways to reach goals. Flexible approaches by using existing resources	Same as traditional makers
Cost of innovation is low due to unstructured R&D efforts. Use of frugal resources	Flexibility in machining. Better finish and high replicability makes it more relevant

production, use of local material, and use of advancements in electronics, hardware, and software will enable appropriate technologies to become more widely adopted, sustainable technologies.

References

Fab Foundation Homepage, https://fabfoundation.org/. Last accessed 2020/07/12
Vigyan Ashram blog, http://vadic.vigyanashram.blog/. Last accessed 2020/01/12
Vigyan Ashram Homepage, http://vigyanashram.com/. Last accessed 2020/07/12

Chapter 3
Development of an AC Motor Powered Device for Making Tulsi Mala Beads

Yashwant Prasad and Subir Kumar Saha

1 Introduction

Tulsi mala, a string of 108 prayer beads (see Fig. 1), is commonly used for spiritual practices known as *japa* (Japamala. 2004).These malas are used to keep the count while chanting and reciting a mantra so that one can focus on sound and meaning of mantra rather than counting the repetition. In the *Brij* area around Mathura, Brindavan, and Bharatpur, families earn their livelihood by making these Tulsi mala beads. Jait Village, situated at 10 km from Mathura, is the largest producer of Tulsi beads in India, where more than 2000 families are involved in this bead making process. The plantation of Tulsi plant is also done at Jait. Both *Rama and Shyam* Tulsi are cultivated but the quantity of *Rama* Tulsi is more. The byproduct of Tulsi such as leaves and seeds are sold to ayurvedic medicine manufacturing industry. Artisans involved in making beads buy Tulsi stem from Jait. Around 80% of the beads produced have size less than 15 mm diameter, and remaining 20% of the beads produced have sizes ranging between 15 and 25 mm diameter. The artisans from Jait use traditional hand-operated lathe like device (see Fig. 2) made of wood to make beads where the sitting posture is not ergonomically comfortable. To eliminate human power and reduce drudgery (Gupta et al. 2015), RuTAG IIT Delhi developed a Tulsi bead making device (see Fig. 3) which is powered by 12 V DC motor. During the demonstration of this DC powered device at Jait, the NGO Human Social Welfare Society, Hathras expressed the need for updating the device so that it can also be used to make beads of sizes up to 25 mm diameter as the DC powered motor has the limitation of making beads only up to 10 mm diameter. To overcome this limitation, RuTAG IIT Delhi has taken up the task which resulted in a new device that runs on 100-W AC motor.

Y. Prasad (✉) · S. K. Saha
Department of Mechanical Engineering, Indian Institute of Technology Delhi, New Delhi, India
e-mail: prasadyash2011@gmail.com

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_3

Fig. 1 Tulsi mala made with device shown in Fig. 2

Fig. 2 Traditional hand-operated lathe like device for making Tulsi beads

This paper is organized as follows: Sect. 2 introduces the problem statement, which is followed by design of AC powered device in Sect. 3. Section 4 discusses tests conducted in field and users' feedback. Section 5 provides the conclusions.

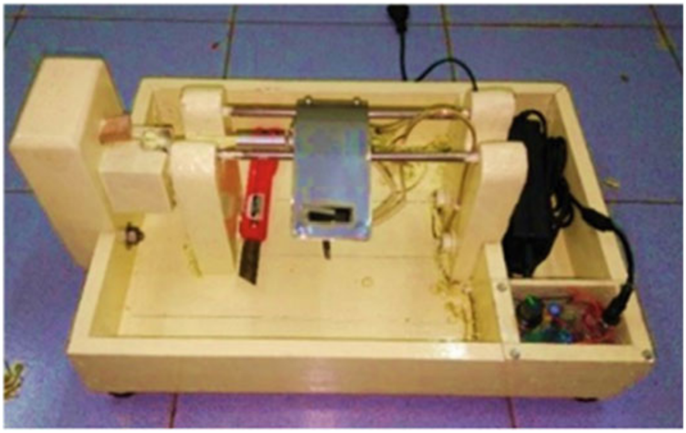


Fig. 3 Tulsi beads making device of RuTAG IIT Delhi that runs on 12 V DC

2 Problem Statement

Several feedback were gathered from the users of Tulsi mala bead making device, developed by RuTAG IIT Delhi that run by 12 V DC motor (Gupta et al. 2015). A Tulsi bead maker from Nadbai village, Bharatpur, Rajasthan, who consistently uses this device told that it produces a lot of sound and vibration which irritates her and her neighbors. The motor heats up within half an hour of operation while cutting beads of size more than 10 mm diameter. She had to wait for an hour for the motor to cool down. She also mentioned that more often Tulsi stem jumps out of the stem holder during the operation. Few other users mentioned that for them the requirement is to make bigger beads, where the sizes vary from 15 to 25 mm diameter. As per the preliminary research, the problem statement was defined as to redesign Tulsi mala bead making device which can produce beads up to 25 mm diameter where the design should take care of at least the sound, vibration, and motor heating.

3 Design Discussion

Human hand can generate about 54 W of power from cranking (Jansen and Slob 2003) which is enough to cut beads. The spindle of the traditional lathe-type device for making Tulsi beads rotates at 1500 rpm on hand cranking. The cutting force for turning 20 mm Tulsi stem is approximately 35 N. While performing cutting operation of Tulsi stem of 10 mm diameter, 12 V DC motor draws a maximum of 3 A current, and the shaft rotates at around 7500 rpm. So, the maximum power drawn by the motor is approximately 36 watts. At these values of power and rotational speed, the cutting force is approximately 10 N. From the above two observations, it can be

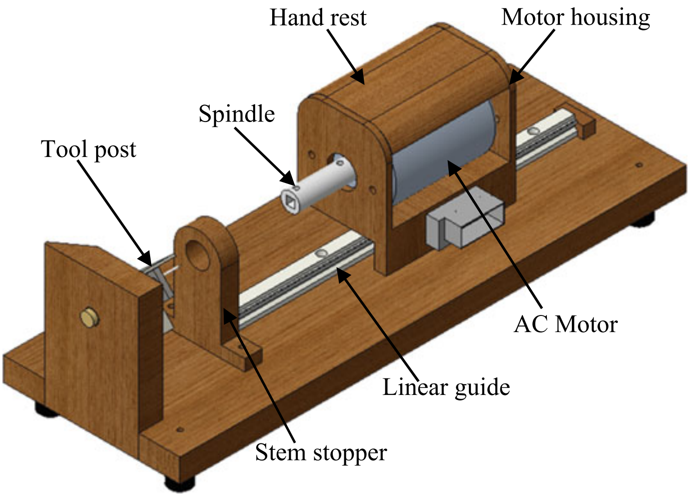


Fig. 4 CAD model of new Tulsi beads making device that runs on AC power

confirmed that a force of 10 N is enough to cut Tulsi beads. At this cutting force, to cut 25 mm diameter bead, the selected motor must supply 0.125 Nm torque. Research suggests that the general cutting speed be 3000 rpm for wood below 50 mm diameter (Craft Supplies USA 2012), which means that the power required to fulfill the torque and speed requirement is approximately 40 W. Since electricity was available in the villages where Tulsi beads are produced, and also considering other factors such as price and availability, an AC motor with the nearest available power rating was selected.

The modified Tulsi mala bead making machine is powered with 100 watts, 7500 rpm AC motor (see Figs. 4 and 5a). This motor is equipped with a clutch (see Fig. 5b) that acts as a speed regulator and is operated with foot. A wooden C-clamp was designed as a motor housing. A wooden hand rest (see Fig. 4) is provided with C-clamp. It acts as insulator and thus avoids direct contact of hands with the motor that gets heated up while operation. Hence, one can operate the machine even when the motor gets heated. An MGN 15 linear guide rail with bearing (see Figs. 4 and 5c) was used for the linear motion of the motor. As the shape of a Tulsi stem is not uniform throughout its length, an unbalance is created during the rotation of the motor shaft which generates vibration and noise. The selected linear bearing and guide rail combination has the capability to absorb vibration and sound to an acceptable range of 85 dBA (NIH 2020). A 1.5 mm round bit with sharp tip is used to make hole in the beads. An adjustable tool post (see Figs. 4 and 5d) was designed in such a way that it can accommodate Tulsi stem of diameters ranging from 5 to 25 mm. The orientation of the tool post can be adjusted as per user's convenience. A spindle with tapered square slot (see Figs. 4 and 5e) has been designed to grip Tulsi stem of different sizes. A grub screw in the spindle design holds the stem tightly and restricts it not to jump out of the spindle. For improving the safety of the machine,

(a) AC motor (100 watts, make: USHA)

(b) Clutch (Make: USHA)

(c) Linear bearing and guide rail (Make: HIWIN)

(d) Adjustable tool post with pin

(e) Spindle to hold stem

(f) The device with enclosure

Fig. 5 **a** AC motor (100 W, make: USHA), **b** Clutch (Make: USHA), **c** Linear bearing and guide rail (Make: HIWIN), **d** Adjustable tool post with pin, **e** Spindle to hold stem, **f** The device with enclosure

stem stopper (see Fig. 4) was incorporated in the design which also restricts the stem from flying off the spindle during operation. The device has been designed in such a way that it can be placed on a table and the user can operate it comfortably by sitting on a chair or a stool. An enclosure (see Fig. 5f) was designed to cover the device which also contains a small toolbox. Turning tool (see Fig. 6) used to cut beads is fabricated by local blacksmith with conventional forging technique. The fabricated Tulsi beads making device is shown in Fig. 7. The total weight of the device is around 5 kg with the enclosure. The cost of fabrication of the device is between ₹6000 and 8000. Efforts were made to make the device compact, lightweight, portable, safe, and user friendly.

Fig. 6 Turning tool for making beads

Fig. 7 New Tulsi beads making device of RuTAG IIT Delhi powered by AC motor

4 Field Tests and Feedback

The feedback and testing of the new device were carried out at Jait Village, Mathura, U.P., and Nadbai Village, Bharatpur, Rajasthan. During testing, the artisans were first trained to operate the device and then asked to cut beads of different sizes and shapes. The artisans learned to operate the device within five minutes. The beads produced with the new device is shown in Fig. 8. As the Tulsi stem is curved, some skin remains on the bead surface even after turning operation. This is later removed by polishing operation where the malas are rubbed on a rough surface for achieving better finish. The device was tested by artisans ranging from 15 to 50 years of age. An artisan who has 20 years of experience of making Tulsi beads produces a bead

Fig. 8 Beads of 20 mm produced during testing

of 20 mm diameter in 6–8 s using traditional lathe-type device. In 4–5 attempts, he started cutting the bead of same size in 8–10 s using the new device. It is expected that an artisan will produce a bead faster once he or she has practiced sufficiently and is habitual in operating the device. The AC motor powered device will reduce fatigue and drudgery of an artisan as it eliminates human efforts on powering the device. Due to this, an artisan can work for a longer duration tirelessly and can focus more on cutting beads. This device will also open an opportunity for females and children in the family to participate in the bead making process.

5 Conclusions

The new device was developed by taking continuous feedback from the users. The design has taken care of ergonomics where an artisan can sit on a chair or a stool comfortably and operate the machine with foot. This was tested successfully at Jait village, Mathura, U.P. and Nadbai village, Bharatpur, Rajasthan. During testing, bead sizes ranging from 10 to 25 mm diameter were produced successfully. RuTAG IIT Delhi organized a regional workshop in Mathura on December 16, 2019, which focused on Tulsi mala bead making device. The device was demonstrated, and a training on how to use it and how to make the beads was conducted. More than 20 artisans participated in the workshop. It takes on an average 5 min for the artisans to learn and operate the device. Few devices were handed over to Lupin foundation and Human Social Welfare Society to spread their utility among the artisans. A local carpenter from Hodal, Haryana, has been identified to manufacture the device and to sell it. The expected cost of the device is between ₹6000 and 8000. Few artisans who attended the workshop were ready to buy the device at this price. Also, NGOs Human Social Welfare Society and Lupin Foundation will be supporting the artisans in purchasing the device through the government schemes and funding. Training sessions and dissemination of the machines will be carried out in future also.

Acknowledgements The authors would like to appreciate RuTAG IIT Delhi employees Mr. Davinder Pal Singh, Mr. Mangal Sharma, Mr. Rajkumar Gupta, and Mr. Suraj Bhat for supporting the project in problem identification, concept generation and evaluation, CAD modeling, machine fabrication, and feedbacks. The authors wish to express their appreciation to the Office of the PSA, Government of India for their financial support to this project.

References

Craft Supplies USA (2012) Determining Safe Wood Lathe Speeds, http://blog.woodturnerscatalog.com/2012/08/safe-wood-lathe-speeds/. Last accessed 10 Jan 2020

Gupta RK, Sharma M, Singh DP, Suthar B, Saha SK (2015) Women empowerment by technology supported manufacturing of beads from Holy Basil. Curr Sci 1660–1664

Jansen A, Slob P (2003) Human power; comfortable one-hand cranking. In: International conference on engineering design. ICED, Stockholm

Japamala (2004) Wikipedia, https://en.wikipedia.org/wiki/Japamala. Last accessed 10 Jan 2020

NIH (n.d.) It's a noisy planet, https://www.noisyplanet.nidcd.nih.gov/parents/too-loud-too-long. Last accessed 10 Jan 2020

Chapter 4
Farm Household Accounting System for Financial Analysis in Distressed Areas of Rural India

Nikhilesh Bagade, Bakul Rao, S. B. Kedare, Shraddha Vekhande, and Vijay Honkalaskar

1 Introduction

The world Bank reported that 39% of the total world's employment in 1994 was in the agriculture sector, which reduced to 20% in 2010, and the percentage of agriculture in the total GDP of the world was 8% in 1995, which reduced to 3.9% in 2014 (World Bank 2016). This indicates the extinction of the agriculture sector and a future crisis in the food sector. In addition, farmers' suicide across the globe is an alarming indicator of agrarian distress (Kher 2015; Goffin 2014; Behere and Bhise 2009). The changes in the agriculture sector have been driven by economic growth and cost/price squeeze, technology change, public policies, and demand for food to cater to the growing population (Smith et al. 2007). One of the main reasons for the agrarian distress is complexities involved in the interactions of agriculture industrialization, liberalization of food, and agriculture market that further manifests the economic and financial crisis of a country (Ploeg 2010). The agrarian distress in developing countries has manifested the problems of indebtedness and declining nutrition for the majority of the poor, which has further resulted in adverse employment possibilities, and declining income (Patnaik 2003).

In India, the challenging situation in agriculture could be factorized as technologies, infrastructure, natural resources, and economic environment (Mishra 2008; Das 2015; Merriott 2016; Dhas 2009). The challenging situation is reflected in the cultivation, its yield, and heavy credit (Mishra 2008; Dhas 2009; TISS 2005).

N. Bagade (✉) · B. Rao · S. Vekhande
CTARA, IIT Bombay, Mumbai, India
e-mail: nikhileshsd@gmail.com

S. B. Kedare
DESE, IIT Bombay, Mumbai, India

V. Honkalaskar
Sulok Chetana Pratishthan, Satara, India

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_4

Insufficient income from agriculture to meet the increasing expenditure on agriculture input, education, marriage, and healthcare add to the agrarian distress (Mishra 2008; Dhas 2009; TISS 2005; IGIDR 2006). The consequences of agrarian distress can be listed as replacement/supplement of agriculture-based livelihood, practicing resource-intensive agriculture technologies, fragmented resource ownership, deteriorated economic condition and social structure, uncertainties in cultivation, and the vicious cycle of debt (Mishra 2008; Dhas 2009; TISS 2005; IGIDR 2006; Siddiqui 2015; Sahay 2010; Pujari and Biru 2007; Honkalaskar et al. 2018). Out of 270,940 farmer suicides reported in India by National Crime Record Bureau (NCRB) from 1995 to 2015, 60,750, i.e., 22.4% of the farmer suicides were reported from Maharashtra of which maximum was from Yavatmal district (Sarkunde 2014). In this region, the suicide mortality rate (number of farmers committing suicide per 100,000 farmers) for male farmers has increased from 17 to 53 from 1995 to 2004 (Behere and Bhise 2009).

Various studies regarding agrarian distress focused on the economic agrarian distress and discussed the agriculture GDP, agriculture labor, gross yield, gross production, input cost, and average debt (Ploeg 2010; Mishra 2008; Dhas 2009; Jodhka 2012). However, the performance of the smallest social unit which is the farm and the farm household (FHH) has not been studied yet in the context of analyzing agrarian distress (Mishra 2008; Dhas 2009; Siddiqui 2015). Moreover, changes in farm and FHH with cost/price squeeze and technology change have not been studied yet (Smith et al. 2007). The farm income analysis, including the cost of cultivation and crop earning, can be used to estimate the level of variability among different farm groups and for studying the economics of household farming (Severini et al. 2016; Surjit 2017).

Rotan (2003) articulated the farm-level financial transaction in the form of financial statements for analyzing farm performance and commented on changes in assets, liabilities, equity, gross revenue, and net income of sampled farms in the United States. Mishra and Williams (2009) compared balance sheets and income statements of new and beginning farmers versus all other farmers in the United States and commented on the asset, equity, liability, and long-term debt. The financial analysis is necessary to determine the financial viability, assess the financial plan, advise for improving financial performance, and to plan and control operations (Selvavinayagam 1991). Farm financial analysis is in practice for the big farms and agriculture cooperative firms. However, financial analysis has not been practiced and eventually not developed as a method for FHHs' to study agrarian distress in India. For conducting financial analysis of FHH, financial statements need to be prepared and financial performance measures need to be computed (Financial Guidelines for Agriculture Producers 2011). In the present study, financial analysis has been conducted for the farmers in the agrarian distressed area of Yavatmal district, Maharashtra, India (refer to Fig. 1) because it gives the worst scenario of agrarian distress.

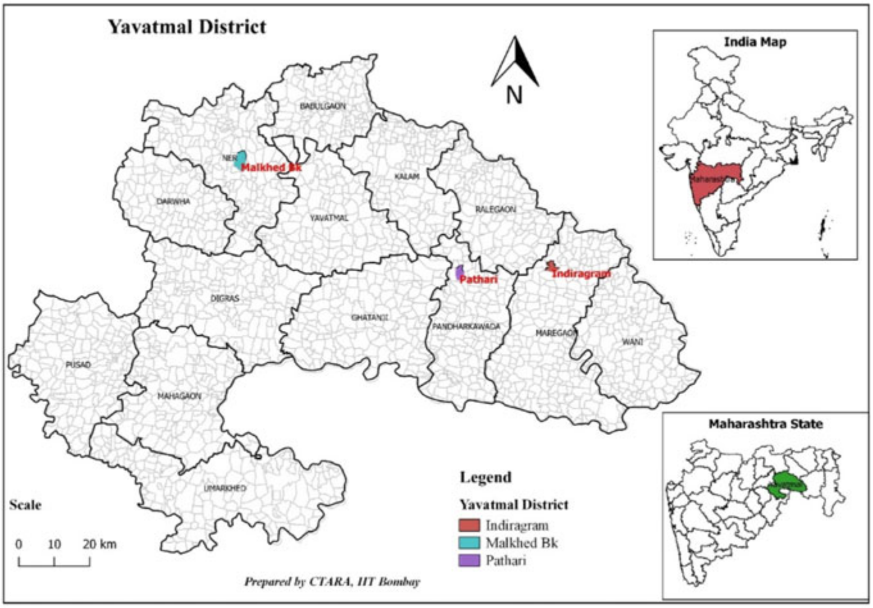


Fig. 1 Yavatmal District Map, prepared by SDG group CTARA IIT Bombay (2019)

2 Methodology

To prepare the financial statements the financial data was to be collected from the sampled farm households (FHHs) and accordingly the survey has to be designed. The financial statements were used further to compute financial performance measures. The financial performance measures were used further to categorize the FHHs and to decide the remedies for improving the financial performance of the FHHs.

2.1 Financial Statements

For preparing financial statements at the farm household (FHH) level, annual financial transactions and asset valuation were captured. Various financial statements have been studied to design a format for FHH financial statements (Selvavinayagam 1991; Financial Guidelines for Agriculture Producers 2011; Plastina 2017; Edwards 2017; Alan et al. 2001). Moreover, the context of the study area Yavatmal needs to be understood for designing a format for FHH financial statement. The completeness, accuracy, and consistency of farm financial statements were ensured while designing a format (Alan et al. 2001).

There have been four financial statements namely balance sheet, income statement, statement of change in owner equity, and statement of cash flow considered in this study. This study focuses on the financial analysis of FHH as a unit that includes farm transactions, transactions related to non-farm livelihood sources, and domestic transactions. The mentioned four financial statements have been prepared for the farm, non-farm livelihood sources, and domestic transactions as separate units, and for the complete FHH (including farm, non-farm, and domestic transactions) as a unit.

The valuation of farm assets, non-farm assets, domestic assets, and savings at the beginning of the year and end of the year was captured in the statement of owner equity. In addition, the change in a total asset in one year, net income, and change in equity was captured in the statement of owner equity. An earning and expenditure for farms and for non-farm livelihood sources were captured in the income statement. The cash flow on a farm, cash flow in non-farm livelihood sources, loan details, savings, and withdrawals for self-consumption were captured in the statement of cash flow. At last, the current assets and liabilities, fixed assets and liabilities, total assets and liabilities, a change in net worth, and working capital were captured in the balance sheet.

2.2 Financial Performance Measures

The financial performance measures applicable for the context of the study area Yavatmal were selected from the 21 farm financial performance measures given by FFSC (Financial Guidelines for Agriculture Producers 2011) based on the attributes for selection (Sharma 2012) and limitations (Alan et al. 2001) of the financial performance measures. For the farm as a unit, three financial performance measures namely farm earnings ratio (FER), farm net income (FNI), and rate of return on farm asset (FROR) were considered for the further analysis (refer to points 1, 2, and 3 in Table 1). For the farm household (FHH) as a complete unit, financial performance measures namely FHH earnings ratio (HER), FHH net income (HNI), rate of return on FHH asset (HROR), and debt to FHH asset ratio (HDAR) were considered (refer point 4, 5, 6, and 8 in Table 1). The changes in the net worth of FHH were measured with the percentage change in a net worth of FHH (HPCNW) (refer to point 7 in Table 1). To convey the relationship between net farm earnings and the required amount for domestic expenses, a new financial measure was introduced as a farm net income to domestic expenses ratio (FNIDE) (refer to point 9 in Table 1).

2.3 Survey Design

The survey questionnaire was designed based on the four financial statements. The survey questionnaire includes financial data for annual expenses on food, festivals, health education, agriculture, traveling, and annual earnings from agriculture, wages, trading, and service providing (Centre for Micro Finance 2006; NSS 2012, 2011,

Table 1 Financial performance measures are considered for analysis. Developed based on FFSC (Financial Guidelines for Agriculture Producers 2011)

			Financial measures	Description	
Farm	Liquidity	1	Farm earnings ratio (FER)	= Total farm earning / Total farm expenditure	Total farm earning is earning from crop sales, renting of the farm, crop insurance received, and animal product sell. Total farm expenditure is spending on crop cultivation costs and animal rearing
		2	Farm net income (FNI)	= Total farm earning − Total farm expenditure	
	Profitability	3	Rate of return on farm assets (FROR)	= farm net income / Total farm assets	For the farm net income refer to point 2 in this table. Total farm asset is sum of own land, farm equipment, and animals with its appreciation or depreciation
Farm household	Liquidity	4	FHH earnings ratio (HER)	= Total FHH earning / Total FHH expenditure	Total FHH earning is earning from the farm and non-farm livelihood sources. Total FHH expenditure is expenditure on the farm and non-farm livelihood sources and domestic expenses. Non-farm livelihood sources are wage earnings, product trading, service providing, renting the services, and monthly salary offering jobs. Domestic expenses include the amount spent on food, festivals and events, healthcare, education, and traveling
		5	FHH net income (HNI)	= Total FHH earning − Total FHH expenditure	

(continued)

Table 1 (continued)

			Financial measures	Description	
	Solvency	6	FHH debt to asset ratio (HDAR)	= Total FHH liabilities / Total FHH assets	Total FHH liabilities are FHH expenses and long-term liabilities of the FHH. Total FHH assets are total FHH earnings and FHH fixed assets. For FHH earnings and FHH expenses refer to point 4 in same table. Long-term liability includes the pending loan repayment. FHH fixed asset is asset valuation of the farm, non-farm livelihood sources, and HH asset
		7	Percentage change in net worth for FHH (HPCNW)	= (Total FHH asset at the end of the year − Total FHH asset at the beginning of the year) / Total FHH asset at the beginning of the year	The depreciation/sell and appreciation/purchase of the FHH asset and FHH net income. For FHH assets refer to point 6 in this table. For FHH net income refer to point 5 in this table
	Profitability	8	Rate of return on FHH assets (HROR)	= FHH net income / Total FHH assets	For FHH net income refer to point 5 in this table. For total FHH assets refer to point 6 in this table
	New ratio	9	Farm net income to domestic expenses ratio (FNIDE)	= farm net income / Total domestic expenses	For farm net income refer to point 2 in this table. For total domestic expenses refer to point 5 in this table

2013; Qaim 2010). The survey format also includes agriculture and house asset valuation.

A quota sampling method was used to identify the cases in each predominant category so as to reflect the diversity of the population (Neuman 2013). The predominant categories of agriculture identified in Yavatmal were irrigated/non-irrigated land and tribal/non-tribal habitats (Census of India 2011; Yavatmal 2012; Dongare 2013). Also, the agro-ecological regions in Yavatmal (1) Deccan plateau, hot semi-arid ecoregion, and (2) Western Maharashtra plateau, hot moist semi-arid eco- sub-region were considered in the predominant categorization (Yavatmal 2012). Three representative villages namely Indiragram, Malkhed, and Pathari were identified in Yavatmal for the study (refer to Fig. 1 and Table 2). The designed survey format was used to conduct a survey of 150 farm households (FHHs) in three villages. The 150 FHHs represented resource variations (land size, irrigation facility, soil type, and agriculture equipment), variations in livelihood options (animal wage-earning, product trading, service providing, monthly salary offering jobs, and renting services), and variations in family size, education, and working age. Moreover, the financial data was collected to represent the variations in weather conditions, rainfall patterns, pest attacks, and support from Government schemes. In Yavatmal, there was a drought in the year 2017–18 and 2018–19, a severe attack of pink ball worm on cotton crop in the year 2017–18, and crop loan waiver scheme in the year 2017–18 hence to capture the variations the data for these three years (from the same FHHs) was collected in

Table 2 Sampled villages, developed based on the Census, 2011

	Indiragram	Malkhed	Pathari
Tehsil	Maregaon	Ner	Kelapur
Households	192	575	385
Population	760	2,319	1,241
Working population in agriculture (%)	68	37	57
Literacy rate	Male (80%), Female (59%)	Male (91%), Female (77%)	Male (82%), Female (67%)
Majority population	ST (95%)	OBC (74%)	SC (39%), ST (17%), OBC and NT (44%)
Irrigated land (%)	0	70	40
Non-irrigated land (%)	100	30	60
Agro-ecological zone	Western Maharashtra plateau, hot moist semi-arid eco-sub-region	Deccan plateau, hot semi-arid ecoregion	Western Maharashtra plateau, hot moist semi-arid eco-sub-region
Remarks	2nd and 3rd generation farmers, hilly terrain, got the farm in land sealing act	Black soil, large landholding	Mixed population, mixed soil type

Table 3 Zone calculation using financial performance measures

	FPM	Poor zone (P)	Average zone (A)	Good zone (G)
1	FER	FER < 1	P < FER < G	(Mean + SD) < FER
2	FNI	FNI < 0	P < FNI < G	(Mean + SD) < FNI
3	FROR	FROR < 0	P < FROR < G	(Mean + SD) < FROR
4	HER	HER < 1	P < HER < G	(Mean + SD) < HER
5	HNI	HNI < 0	P < HNI < G	(Mean + SD) < HNI
6	HDAR	HDAR > (Mean + SD)	P < HDAR < G	max of [(Mean–SD) or 0] > HDAR
7	HPCNW	HPCNW < 0	P < HPCNW < G	(Mean + SD) < HPCNW
8	HROR	HROR < 0	P < HROR < G	(Mean + SD) < HROR
9	FNIDE	FNIDE < 1	P < FNIDE < G	(Mean + SD) < FNIDE

FPM financial performance measures, refer to Table 1 for the details, *SD* standard deviation

the Indian currency namely Rupee (₹). For the selection of FHH in the villages, a snowball-sampling method was used, wherein the different cases were considered based on the referral by previous cases (Neuman 2013). The variations considered in sampling are reflected in the higher standard deviation values in some cases.

2.4 Zones of Financial Performance Measures

After collecting the data of 150 farm households (FHHs) for three consecutive years 2016–17, 2017–18, and 2018–19; financial statements for each FHH for three years were prepared and based on which financial performance measures were computed. The financial performance measures were grouped into the good zone, average zone, and poor zone as shown in Table 3.

2.5 Farmers' Grouping

With the zones created for the financial performance measures, the surveyed farm households (FHHs) for three consecutive years (2016–17, 2017–18, and 2018–19) were categorized into the five different groups. The studies regarding economic agrarian distress have mentioned the concerns of farmers (Ploeg 2010; Mishra 2008; Dhas 2009; Jodhka 2012; Severini et al. 2016; Surjit 2017) and in the current study these concerns have been grouped under four categories, (i) FHHs not earning profit from farm, (ii) FHHs not able to earn sufficient from farm to meet their domestic expenditure, (iii) FHHs not able to save money and repay the debt at the end of the year, and (iv) FHHs putting their asset at risk.

3 Financial Analysis

3.1 Descriptive Statistics

The statistical summary of the financial data collected from the same 150 farm households (FHHs) for three consecutive years 2016–17, 2017–18, and 2018–19 (currency is Indian Rupee ₹) is summarized in Table 4, Figs 2, 3, and 4. The average land ownership is 6.9 acres in 86% of the surveyed FHHs and there is an increase in the land price from 2016–17 to 2018–19. The land prices are dependent on the irrigation facility, road access to the farmland, and soil type. The total land in operation is 7.3 acres in 2016–17 and 2018–19 and 6.9 acres in the year 2017–18. About 86% of the FHHs own the cattle of which 73% FHHs own bulls, 81% FHHs use cattle manure on the farm, and 23% of the FHHs earn by selling animals and animal-derived products. The animal expenses per day are ₹4.3, ₹3.5, and ₹4.8, respectively in the year 2016–17, 2017–18, and 2018–19.

In 2016–17, 44% of the FHHs cultivated an average of 7.5 acres of irrigated land by spending an average of ₹12,357 per acre and earning an average of ₹25,590. In 2017–18, 45% of the FHHs cultivated an average of 6.9 acres of irrigated land by spending an average of ₹11,802 per acre and earned an average of ₹23,760. In 2018–19, 46% of the FHHs cultivated an average of 7 acres of irrigated land by spending an average of ₹12,838 per acre and earned an average of ₹24,466. In 2016–17, 71% of the FHHs cultivated an average of 5.8 acres of non-irrigated land by spending an average of ₹9982 per acre and earned an average of ₹17,552. In 2017–18, 71% of the FHHs cultivated an average of 6 acres of non-irrigated land by spending an average of ₹9970 per acre and earned an average of ₹18,132. In 2018–19, 70% of the FHHs cultivated an average of 6.1 acres of non-irrigated land by spending an average of ₹10,226 per acre and earned an average of ₹15,923 (Fig. 2).

Along with farming, there are 53% of the FHHs engaged in wage-earning, 11% in product training, 14% in service providing, and 16% of the FHHs engaged in monthly salary offering jobs during the year 2016–17 to 2018–19. From the year 2016–17 to 2018–19 the percentage of the pucca houses is increased from 67 to 69% and FHHs using LPG is increased from 47 to 81%; moreover 35% of the FHHs own motorcycle. Per person per day expenses on food are increased from the ₹29.6 to ₹31.0 from 2016–17 to 2018–19. In 83% of the FHHs, an average of 1.3 persons per FHH consumes tobacco and spends an average of ₹15.6 per person per day (half of the total food expenses amount) on it which goes up to ₹7400 per year per FHH that is about 10% of total expenses of 57% FHHs (Fig. 3).

About 76% of the FHHs save money in the bank, in the insurance policies, or in the microfinance groups. There are 77%, 73%, and 81% of FHHs who took a loan and 24%, 25%, and 27% of FHHs who did not repay it, respectively in the year 2016–17, 2017–18, and 2018–19. The reasons behind taking loans are marriage expenses (50% of the FHHs), house repair and construction (45% of the FHHs), and health treatment (30% of the FHHs). The data of 150 FHHs from three villages in Yavatmal for three consecutive years 2016–17 to 2018–19 is arranged in the form of

Table 4 Descriptive statistics of surveyed data

		Measured parameters		Unit	2016–17	2017–18	2018–19
A	*Land*						
	1	Land ownership	HH	%	85.7	87.4	86.9
	2	Irrigated land cultivators	HH	%	43.8	44.7	45.8
	3	Non-irrigated land cultivators	HH	%	71.4	70.9	70.1
	4	Land valuation per acre	Min	₹‘000	95.0	120.0	130.0
			Max	₹‘000	950.0	1000.0	1020.0
	5	Well valuation	Min	₹‘000	70.0	60.0	65.0
			Max	₹‘000	375.0	350.0	370.0
	6	Motor and pump valuation	Min	₹‘000	13.0	12.0	13.0
			Max	₹‘000	20.0	18.0	18.0
	7	Pipe set valuation	Min	₹‘000	24.0	22.0	20.0
			Max	₹‘000	75.0	70.0	60.0
B	*Cattle*						
	1	Cattle ownership	HH	%	86.7	86.4	85.0
	2	Having bulls	HH	%	72.4	73.8	73.8
	3	Earning using animal	HH	%	24.8	22.3	23.4
	4	Using cattle manure	HH	%	81.0	80.6	80.4
	5	Cattle expenses per animal per day	Avg	₹	4.3	3.5	4.8
			SD	₹	11.7	6.1	15.0
	6	Goat valuation	Min	₹‘000	3.6	4.0	4.5
			Max	₹‘000	4.5	5.0	6.0
	7	Cow valuation	Min	₹‘000	0.8	1.0	1.2
			Max	₹‘000	10.8	12.0	15.0
	8	Bull valuation	Min	₹‘000	10.8	12.0	14.0
			Max	₹‘000	24.0	25.0	26.0
C	*Domestic*						
	1	Pucca house	HH	%	67.0	68.0	69.2
	2	LPG	HH	%	46.7	48.5	81.3
	3	Motorcycle	HH	%	36.2	35.9	34.6
	4	House valuation	Min	₹‘000	35.0	40.0	50.0
			Max	₹‘000	570.0	600.0	640.0
	5	Education	Avg	₹/cpd	29.6	32.8	33.7
			SD	₹/cpd	71.4	76.4	78.2
			HH	%	59.0	58.0	60.0
	6	Addiction	HH	%	83.0	83.0	81.0
I		HH saving money	HH	%	75.2	76.7	76.6

(continued)

Table 4 (continued)

		Measured parameters		Unit	2016–17	2017–18	2018–19
J	*Loan details*						
	1	Interest rate	Min	%	5.0	5.0	5.0
			Max	%	50.0	50.0	50.0
	2	Amount taken	Min	₹‘000	2.0	2.0	2.0
			Max	₹‘000	550.0	300.0	371.0
			HH	%	77.0	73.0	81.0
	3	Pending liabilities	Min	₹‘000	3.0	3.0	15.0
			Max	₹‘000	720.0	576.0	900.0
			HH	%	23.8	25.2	27.1

Avg average, *SD* standard deviation, **min**imum, **max**imum, ₹/cpd—₹/person/day

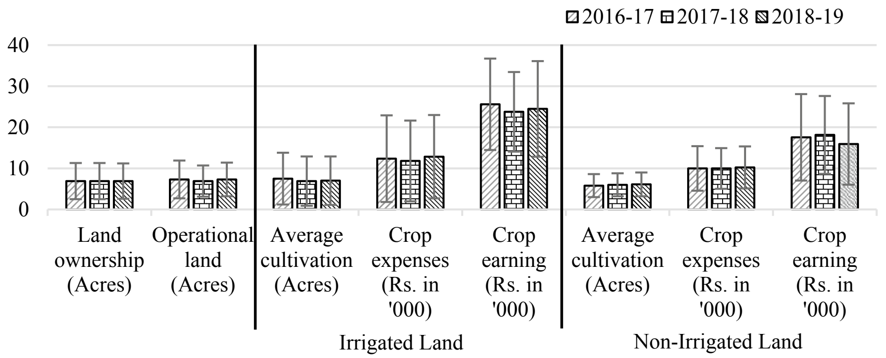


Fig. 2 Land ownership and crop earnings from irrigated and non-irrigated land in Yavatmal during 2016–17 to 2018–19

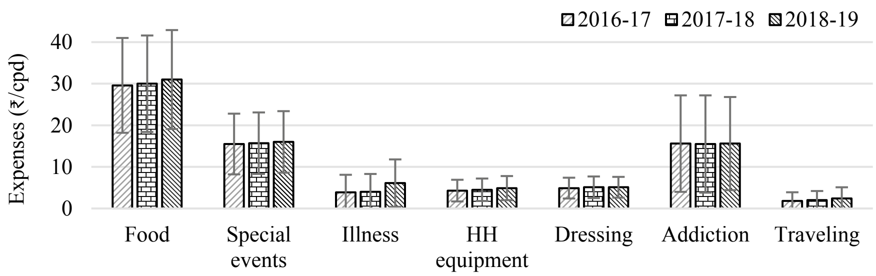


Fig. 3 Domestic expenses in ₹ per capita per day in Yavatmal during 2016–17 to 2018–19

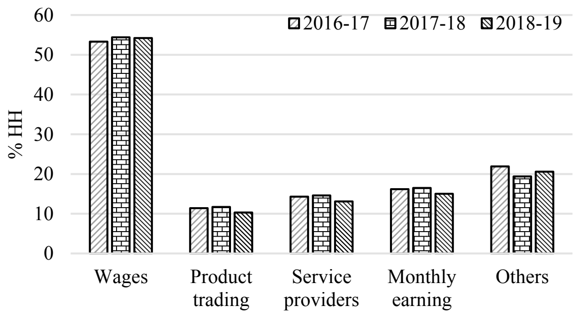


Fig. 4 Non-farm livelihood sources in Yavatmal during 2016–17 to 2018–19

four financial statements as described in Sect. 2.1 and used further to compute the financial performance measures.

The standard deviation of the cattle expenses is very high because of the high rearing cost of the buffalo and milking cows. In addition, FHHs are taking health treatment either in the Government operated public health center paying minimal fees or in the private hospitals in nearby towns paying more fees plus transport charges. Hence, the variations in the health expenses are reflected in its standard deviation value. Similarly, there is a high standard deviation in the expenses of education because of the difference in fee structure and traveling expenses between Government schools and private schools in nearby towns.

3.2 Financial Performance Measures

The nine (refer to Table 1) financial performance measures are computed based on the financial statements. The average values for each of the financial performance measures with its standard deviation (SD) for three years individually are given in Table 5. The crop production is reduced due to the drought in the year 2017–18 and 2018–19 and the attack of the pink ball worm on cotton in the year 2018–19. The reduction in crop production eventually reduces the average value of farm earnings ratio (FER) from 1.95 to 1.78, farm net income (FNI) from ₹77,675 to ₹66,165, and that of return on farm asset (FROR) from 0.068 to 0.047 during the year 2016–17 to 2018–19. The reduction in net farm income and increase in the prices of domestic commodities eventually reduces the average value of FHH earnings ratio (HER) from 1.06 to 1.01 and FHH net income (HNI) from ₹16,919 to ₹9417 during the year 2016–17 to 2018–19. Moreover, the rate of return on FHH assets (HROR) is reduced from 0.009 to −0.004, and that of farm net income to domestic expenses ratio (FNIDE) from 0.606 to 0.493 during the year 2016–17 to 2018–19.

In addition to this, the reduction in net farm household (FHH) income and compromising the FHH asset during consecutive two droughts reduces the average value of percentage change in a net worth of FHH (HPCNW) from 0.050 to 0.022 during the year 2016–17 to 2018–19. Despite the reduction in FHH income and FHH assets, the

Table 5 Financial performance measures computed based on surveyed data

FPM		U	2016–17		2017–18		2018–19	
			Avg.	SD	Avg.	SD	Avg.	SD
1	FER		1.952	0.900	2.022	0.904	1.770	0.821
2	FNI	₹	77,675.899	82,618.192	73,228.689	70,364.924	66,165.977	99,398.558
3	FROR		0.068	0.126	0.073	0.130	0.047	0.103
4	HER		1.057	0.309	1.066	0.281	1.010	0.345
5	HNI	₹	16,919.032	81,941.681	19,595.592	85,506.137	9471.865	106,792.690
6	HDAR		0.176	0.154	0.172	0.152	0.178	0.163
7	HPCNW		0.050	0.121	0.042	0.142	0.022	0.150
8	HROR		0.009	0.054	0.011	0.057	-0.004	0.058
9	FNIDE		0.606	0.622	0.555	0.502	0.493	0.820

FPM financial performance measures, refer to Table 1 for the details, *U* unit, *Avg* average, *SD* standard deviation

average value of debt to FHH asset ratio (HDAR) is not changed (0.176 in 2016–17 to 0.178 in 2018–19) because of the crop loan waiver scheme issued in the year 2017–18. Using the average value and standard deviation of the financial performance measures (refer to Table 5), the zones are created using the equations given in Table 3. The zones created (refer to Table 6) are used further to categorize the farm households into four different groups.

3.3 Categorization of the Farmers

1. **Farming is not profitable**: It is observed that there is a systematic increase in percentage of farm households (FHH) not earning profit from the farm in the years the study was carried out (refer to points A1, A2, A3, B1, B2, and B3 in Table 7). There are 9%, 10%, and 21% of FHH in the poor zone of farm earnings ratio (FER), farm net income (FNI), and rate of return on farm asset (FROR) in the years the study was carried out. The effect of the drought (in the year 2017–18 and 2018–19) and pink ball worm attack on the cotton (in the year 2017–18) is reflected as an increase in the percentage of FHH in the poor zone of FER, FNI, and FROR from 2016–17 to 2018–19. The reasons for earning less profit include increased input cost because of the repeated sowing, unmeasured fertilizer application, use of expensive pesticides and herbicides, and expensive labor. Thus, to earn profit from the farm for the identified group of farmers, the need is to achieve average agriculture production with minimum input costs.
2. **Farm earnings is not sufficient to meet domestic expenses**: It is observed that there is a systematic increase in percentage of FHHs not able to meet the domestic expenses from farm earnings in the years the study was carried out

Table 6 Zones were created for the nine selected ratios for three years using surveyed data

	U	Poor zone (FPM)			Average zone (FPM)					Good zone (FPM)		
2016–17												
1		FER	<	1.000	1.000	<	FER	<	000002.852	000002.852	<	FER
2	₹	FNI	<	0.000	0.000	<	FNI	<	160,294.091	160,294.091	<	FNI
3		FROR	<	0.000	0.000	<	FROR	<	000000.195	000000.195	<	FROR
4		HER	<	1.000	1.000	<	HER	<	000001.366	000001.366	<	HER
5	₹	HNI	<	0.000	0.000	<	HNI	<	098860.714	98,860.714	<	HNI
6		HDAR	>	0.330	0.330	>	HDAR	>	000000.022	000000.022	>	HDAR
7		HPCNW	<	0.000	0.000	<	HPCNW	<	000000.171	000000.171	<	HPCNW
8		HROR	<	0.000	0.000	<	HROR	<	000000.062	000000.062	<	HROR
9		FNIDE	<	1.000	1.000	<	FNIDE	<	000001.228	000001.228	<	FNIDE
2017–18												
1		FER	<	1.000	1.000	<	FER	<	000002.927	000002.927	<	FER
2	₹	FNI	<	0.000	0.000	<	FNI	<	143,593.613	143,593.613	<	FNI
3		FROR	<	0.000	0.000	<	FROR	<	000000.203	000000.203	<	FROR
4		HER	<	1.000	1.000	<	HER	<	000001.348	000001.348	<	HER
5	₹	HNI	<	0.000	0.000	<	HNI	<	105,101.729	105,101.729	<	HNI
6		HDAR	>	0.324	0.324	>	HDAR	>	000000.019	000000.019	>	HDAR
7		HPCNW	<	0.000	0.000	<	HPCNW	<	000000.184	000000.184	<	HPCNW
8		HROR	<	0.000	0.000	<	HROR	<	000000.068	000000.068	<	HROR
9		FNIDE	<	1.000	1.000	<	FNIDE	<	000001.057	000001.057	<	FNIDE
2018–19												
1		FER	<	1.000	1.000	<	FER	<	000002.590	000002.590	<	FER
2	₹	FNI	<	0.000	0.000	<	FNI	<	165,564.535	165,564.535	<	FNI
3		FROR	<	0.000	0.000	<	FROR	<	000000.150	000000.150	<	FROR
4		HER	<	1.000	1.000	<	HER	<	000001.356	000001.356	<	HER
5	₹	HNI	<	0.000	0.000	<	HNI	<	116,264.554	116,264.554	<	HNI
6		HDAR	>	0.341	0.341	>	HDAR	>	000000.014	000000.014	>	HDAR
7		HPCNW	<	0.000	0.000	<	HPCNW	<	000000.172	000000.172	<	HPCNW
8		HROR	<	0.000	0.000	<	HROR	<	000000.054	000000.054	<	HROR
9		FNIDE	<	1.000	1.000	<	FNIDE	<	000001.313	000001.313	<	FNIDE

U unit, *FPM* financial performance measures, refer Table 1 for the details

(refer point C1, C2, and C3 in Table 7). There are 79%, 85%, and 86% of FHH in the poor zone of farm net income to domestic expenses ratio (FNIDE) in the years the study was carried out. The effect of the drought (in the year 2017–18 and 2018–19) and pink ball worm attack on the cotton (in the year 2017–18) is reflected as an increase in the FHH percentage in the poor zone of FNIDE from 2016–17 to 2018–19. The reasons for not earning sufficient from the farm to meet the domestic expenses include increased expenses on health, education,

Table 7 Comparison of financial performance measures for farmers' categorization

	2016-17					2017-18					2018-19				
FER Vs FNI	*A1*		₹0<FNI <₹160294			*A2*		₹0<FNI <₹143594			*A3*		₹0<FNI <₹165565		
			P	A	G			P	A	G			P	A	G
	1<FER <2.9	P	9	0	0	1<FER <2.9	P	10	0	0	1<FER <2.6	P	21	0	0
		A	0	66	12		A	0	64	13		A	0	56	9
		G	0	6	7		G	0	9	5		G	0	8	5
FER Vs FROR	*B1*		0<FROR <0.195			*B2*		0<FROR <0.203			*B3*		0<FROR <0.150		
			P	A	G			P	A	G			P	A	G
	1<FER <2.9	P	9	0	0	1<FER <2.9	P	10	0	0	1<FER <2.6	P	21	0	0
		A	0	71	7		A	0	73	4		A	0	61	5
		G	0	10	3		G	0	10	4		G	0	9	4
FER Vs FNIDE	*C1*		1<FNIDE <1.2			*C2*		1<FNIDE <1.1			*C3*		1<FNIDE <1.3		
			P	A	G			P	A	G			P	A	G
	1<FER <2.9	P	9	0	0	1<FER <2.9	P	10	0	0	1<FER <2.6	P	21	0	0
		A	64	8	6		A	65	0	12		A	57	5	4
		G	6	1	6		G	10	0	4		G	7	2	4
HER Vs HDAR	*D1*		0.330>HDAR >0.022			*D2*		0.324>HDAR >0.019			*D3*		0.341>HDAR >0.014		
			P	A	G			P	A	G			P	A	G
	1<HER <1.4	P	5	36	0	1<HER <1.3	P	6	40	0	1<HER <1.4	P	11	40	0
		A	10	37	0		A	9	30	0		A	5	31	0
		G	1	11	0		G	2	14	0		G	2	11	0
HER Vs HROR	*E1*		0<HROR <0.062			*E2*		0<HROR <0.068			*E3*		0<HROR <0.054		
			P	A	G			P	A	G			P	A	G
	1<HER <1.4	P	41	0	0	1<HER <1.3	P	46	0	0	1<HER <1.4	P	51	0	0
		A	0	44	3		A	0	32	7		A	0	34	2
		G	0	8	4		G	0	11	5		G	0	9	4
HER Vs FNI	*F1*		₹0<HNI <₹98861			*F2*		₹0<HNI <₹105102			*F3*		₹0<HNI <₹116265		
			P	A	G			P	A	G			P	A	G
	1<HER <1.4	P	41	0	0	1<HER <1.3	P	46	0	0	1<HER <1.4	P	51	0	0
		A	0	43	4		A	0	37	2		A	0	32	4
		G	0	2	10		G	0	9	7		G	0	6	7
HER Vs FER	*G1*		1<FER<2.9			*G2*		1<FER<2.9			*G3*		1<FER<2.6		
			P	A	G			P	A	G			P	A	G
	1<HER <1.4	P	5	34	2	1<HER <1.3	P	7	37	2	1<HER <1.4	P	17	32	3
		A	3	38	6		A	3	28	8		A	5	26	5
		G	1	7	4		G	0	12	4		G	0	7	6
HRORVsFROR	*H1*		0<FROR <0.195			*H2*		0<FROR <0.203			*H3*		0<FROR <0.15		
			P	A	G			P	A	G			P	A	G
	0<HRO R<0.062	P	5	33	3	0<HRO R<0.068	P	7	37	2	0<HRO R<0.054	P	17	30	5
		A	2	46	4		A	2	40	1		A	4	36	3
		G	2	3	2		G	1	6	5		G	1	4	1

Shaded values are %HH in that group, *P* poor zone, *A* average zone, *G* good zone special events, and addiction. The other reasons are a reduction in land size per farm household, intense agriculture practices with high input costs, increased risk and uncertainty in farming, and the need for periodic earning sources. Thus, to earn sufficient from the farm to meet domestic expenses, the need is to rely on the cost-effective agriculture practices and/or to rely on the allied agriculture earning sources and/or to rely on the non-farm earning sources.

3. **FHH is not able to save money and repay the debt at the end of the year**: It is observed that there is a systematic increase in percentage of FHHs not able to repay the debt in the years the study was carried out (refer point E1, E2, E3, F1, F2, and F3 in Table 7). There are 41%, 46%, and 51% of FHH in the poor zone of FHH earnings ratio (HER), FHH net income (HNI), and rate of return on FHH asset (HROR) in the years the study was carried out. The effect of the drought (in the year 2017–18 and 2018–19) and pink ball worm attack on the cotton (in the year 2017–18) is reflected as an increase in the FHH percentage in the poor zone of HER, HNI, and HROR from 2016–17 to 2018–19. The reasons behind not being able to repay the loan include capital-intensive cropping patterns, expenses on events like marriage and rituals, and increased risk in crop production. The situation can be avoided by reducing unnecessary personal expenses and reducing the dependency on the capital-intensive cropping pattern. The same number of FHHs were not able to save the money at the end of the year. The reasons for insufficient savings at the end of the year include increased domestic expenses, inefficient way of earning from the farm and non-farm livelihood sources, dependency on agriculture, unexpected expenses, and planned significant expenses. Thus, to save money at the end of the year, personal expenses need to be reduced (addiction expenses, expenses on marriage, and death rituals), and/or farm earnings need to be increased and/or to rely on non-farm earning sources.

4. **FHH putting the asset at risk**: It is observed that irrespective of the increase in the FHHs are not able to earn from the farm, not able to meet domestic expenses from farm earnings, and are not able to save money at the end of the year; there is no increase in the FHH putting the asset in risk in the years the study was carried out (refer point D1, D2, and D3 in Table 7). There are 16%, 17%, and 18% of FHH in the poor zone of debt to FHH asset ratio (HDAR) in the years the study was carried out. Because of the loan waiver scheme (in the year 2017–18), the effect of drought (in the year 2017–18 and 2018–19) and pink ball worm attack on the cotton (in the year 2017–18) did not reflect as an increase in the FHH percentage in the poor zone of HDAR from 2016–17 to 2018–19. The reasons for putting the asset at risk include taking massive, long-term and costly (high-interest rate) loans for marriages, health reasons, house construction, land development, and developing irrigation facilities. Thus, to prevent the asset from risk, it is necessary to reduce the expenses on special events, invest in insurance policies, adopt low-cost and less dependent agriculture practices, and procure the government schemes for agriculture and personal asset development and operations.

4 Conclusion

The financial analysis was used to study agrarian distress in India and to categorize the farm households (FHHs) based on their financial performance. The financial data of 150 FHHs from three representative villages in Yavatmal, India were collected for three consecutive years 2016–17, 2017–18, and 2018–19. The financial data was arranged in the form of four financial statements and these financial statements were used to compute nine selected financial performance measures. The combinations of financial performance measures were used to categorize the FHHs into four different groups.

The effects of natural calamities (drought and pest attack), Government schemes (loan waiver scheme), and market interaction (fertilizer, seed, and pesticide cost, high-interest rate on loan, and crop selling price) were captured in the financial analysis of the FHHs. Moreover, the effect of soil quality, irrigation facility, terrain, landholding of FHH, social structure, and variations in non-farm livelihood sources was captured in the financial analysis with the help of 150 FHHs from three representative villages in agrarian distressed district Yavatmal, India. Hence, the trend of FHHs in not earning profit from the farm, not being able to meet domestic expenses from the farm, not able to save the money, putting assets at risk, and not being able to repay the loan can be estimated for the other villages in Yavatmal.

The categorization of the FHHs based on the financial analysis can be used further for identifying the FHHs being trapped in a vicious cycle of debt, farmers putting their assets at risk, inefficient utilization of assets, and finding the debt repayment capacity of the FHHs. Moreover, this categorization can be useful in identifying the possible defaulters in loan repayment, the FHHs entirely dependent on farming, and the need for upgrading/supplementing/changing the farming livelihood. The financial analysis of the FHHs can be useful for policymakers and district planners in the design and implementation of farm-based policy interventions and for the FHHs in their financial decision-making.

Acknowledgements The authors would like to thank the partner NGO 'Deendayal Bahu-Uddeshiya Prasarak Mandal' for providing a platform to interact with farmers in Yavatmal, India. The authors are thankful for the 150 farm households from Indiragram, Malkhed, and Pathari who participated in the survey activity and gave a glimpse of their beautiful lives.

References

Alan M, Cole E, Craig D, Michael B (2001) Measuring and analysing farm financial performance. Centre for Food and Agricultural Business Purdue University

Behere PB, Bhise MC (2009) Farmers' Suicide: across culture. Indian J Psychiatry 51(4):242–243

Census of India (2011) District Census Handbook Yavatmal. Directorate of Census Operations, Maharashtra

Centre for Micro Finance (2006) Insight into the cash flow of rural households. Centre for micro finance, Jaipur

Das L (2015) Agrarian crisis in India: causes, consequences and remedies. Int J English Lang Hum III(X):615–631
Dhas C (2009) Agriculture crisis in India: the root cause and consequences. Munich Personal RePEc Archive
Dongare (2013) Ground Water Information Yavatmal District Maharashtra. Government of India, Ministry of Water Resources, Central Ground Water Board, Central Region, Nagpur
Edwards W (2017) Farm financial statements. IOWA State University
Financial Guidelines for Agriculture Producers (2011) Farm Financial Standards Councils, USA
Goffin (2014) Farmers' mental health: a review of the literature. Accident Compensation Corporation Policy Team, New Zealand
Honkalaskar VH, Kedare SB, Bagade N (2018) Understanding agrarian crisis: a participatory and qualitative systemic analysis. J Agric Stud 6(1):261–298
IGIDR (2006) Suicide of farmers in Maharashtra. Indira Gandhi Institute of Development Research, Mumbai
Jodhka SS (2012) Agrarian changes in the times of (neo-liberal) 'crises'. Econ Polit Wkly XLVII(26 & 27):5–13
Kher D (2015) Farmer suicides: a global phenomenon, 6 May 2015. Available: http://pragati.nationalinterest.in/2015/05/farmer-suicides-a-global-phenomena/. Accessed 25 Nov 2016
Merriott D (2016) Factors associated with the farmer suicide. J Epidemiol Glob Health
Mishra S (2008) Risks, farmers' suicides and agrarian crisis in India: is there a way out? Indian J Agric Econ 63(1):38–54
Mishra CW, Williams R (2009) Factors affecting financial performance of new and beginning farmers. Agric Finance Rev 69(2):160–179
Neuman WL (2013) Social research methods. Dorling Kindersley India, New Delhi
NSS (2011) Level and pattern of consumer expenditure. National Sample survey office, NSO, GoI, New Delhi
NSS (2012) Household consumer expenditure across socio-economics group, NSS 66th round. National Sample Survey Office, Government of India, New Delhi
NSS (2013) Public distribution system and other sources of household consumption. NSSO, MSPI, GOI, New Delhi
Patnaik U (2003) Global capitalism, deflation and agrarian crisis in developing countries. J Agrar Change 3(1 and 2):33–66
Plastina (2017) Financial Performance measure for IOWA farm. IOWA State University
Ploeg JDVD (2010) The food crisis, industrialized farming and the imperial regime. J Agrar Chang 10(1):98–106
Pujari, Biru BK (2007) Jansunvai on present agrarian crisis a report. Gene Campaign
Qaim M (2010) Benefit of genetically modified crops for the poor: household income, nutrition, and health. New Biotechnol 27(5):552–557
Rotan B (2005) Analysis of financial statements: local farm supply, market co-ops, 2003. United States Department of Agriculture
Sahay GR (2010) Globalization, liberalization and agrarian distress: a study of suicides among farmers in India. Tata Institute of Social Science, Mumbai
Sarkunde M (2014) Yavatmal: District of Farmers' Suicide, 9 Mar 2014. Available: http://www.boloji.com/index.cfm?md=Content&sd=Articles&ArticleID=15601. Accessed 9 Jan 2017
Selvavinayagam (1991) Financial analysis in agriculture project preparation. Food and Agriculture Organization of United Nation, Rome
Severini S, Tantari A, Di Tommaso G (2016) The instability of farm income. Empirical evidences on aggregation bias and heterogeneity among farm groups. Bio-Based Appl Econ 5(1):63–81
Sharma RS (2012) Ratio analysis in farm management. Int J Recent Res Rev 1:47–50
Siddiqui K (2015) Agrarian Crisis and Transformation in India. Econ Polit Econ 2(1):3–22
Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B, Sirotenko O (2007) Agriculture. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds) Climate change 2007: Mitigation. Contribution of working group III to the fourth

assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA
Surjit V (2017) The evolution of farm income statistics in India: a review. Review Agrar Stud 7(2):39–61
TISS (2005) Causes of farmers' suicides in Maharashtra: an enquiry. Tata Institute of Social Science, Mumbai
World Bank (2016) The World Bank, The World Bank Group, 2016. Available: http://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?end=2010&name_desc=false&start=1994&view=chart. Accessed 2020
Yavatmal CO (2012) Yavatmal District, 29 Oct 2012. Available: http://yavatmal.nic.in/. Accessed Jan 2017

Chapter 5
Usability Assessment of Pedal Threshing Operation in Rice Farming

Tandra Mondal and Pranab Kumar Nag

1 Introduction

In paddy cultivation, the separation of grain and straw of the harvested crop is conventionally carried out by the manual labor intensive methods. Manual beating of paddy pinnacles is a common method to separate grain and straw (Datt 2003). Rubbing of paddy pinnacles by foot, animal trampling of paddy are the other methods. The beating method of paddy threshing often caused substantial grain loss due to shattering. The process of paddy threshing by foot trampling often causes the sharp edges of paddy kernels to wound the feet of the farm women. The threshing operation takes away nearly one-fourth of the total energy utilized in paddy cultivation (Kathrivel and Sivakumar 2003). The farmer in small land holdings, due to their prevailing in socio-economic conditions, cannot afford to deploy large- capacity, power-driven threshers (Quick 1998); also the rice grown in less than 1 ha land holding is not suitable for mechanical harvesting and threshing, and therefore, the labor intensive, drudgery-prone manual method prevails. The energy consumption is about 17–21.5 kJ/min in manual method of threshing, and the severity of work is categorized as heavy work (Nag and Nag 2004). Apart from the work severity, the output with such conventional methods is low due to the slow pace of work. There is a growing popularity of using pedal operated threshers among farmers in small and marginal land holdings. The pedal operated paddy thresher is an improved and convenient technology developed for minimizing drudgery and grain losses in comparison to the traditional threshing operation (Khadatkar et al. 2018). Khayer et al. (2017) attempted toward optimization of economic and ergonomic measures to depict the plausible options for adjustments to workstation and product design parameters in pedal threshing operation. Kwatra

T. Mondal (✉)
Department of Agriculture and Rural Development, RKMVERI, Narendrapur, Kolkata, India
e-mail: tandraghum@gmail.com

P. K. Nag
School of Environment and Disaster Management, RKMVERI, Narendrapur, Kolkata, India

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_5

et al. (2010) suggested that modification of in the design criteria of threshing drum can make it more acceptable in the field.

Whereas, attention has been placed on more efficient and productive farming tools and implements, the perceived views about the needs and operability of different implements and devices among marginal and small holding farmers have yet to be addressed. Challenge remains in analyzing farm tools and methods, based on the functional design and operability, man–machine compatibility and gender friendliness. The present contribution explores depicting relative usability analysis of the pedal threshers operations in evaluating its functionality in paddy threshing used by the farmers in small and marginal holdings. The idea of usability was originated from a very sophisticated science, such as analysis of complex systems, process operations, human–computer interaction, and it has been gradually implicated in other areas of study (Han et al. 2001; Harrison et al. 2013). In recent times, the user-centered design has been practiced as a philosophy rooted in the idea that users must take center-stage in the design of any computer system (Lewis and Sauro 2017).

2 Methods and Materials

One hundred and thirty-nine farm workers who regularly operate pedal threshers were included in the study. The pedal operated threshing requires both leg and hand coordination, i.e., an operator is standing with one leg on the pedal and the other leg on the ground. The operator (men or women) keeps spreading the crop bundle on the rotating drum to get ear heads detached. By adjusting the bodyweight between two legs, a person attains stable position in pedal threshing. The force is exerted on the pedal on its downward movement and the operator lifts the leg when the pedal moves upward. Thus the retardation of the pedal by the weight of the leg is less (Fig. 1). A structured interviewer-administered questionnaire was introduced among the operators, who were engaged in field operation. The questionnaire covered recording of the physical characteristics of the operators, detailed mechanical, and design features of the pedal thresher machine, such as the length, width, and the circumference of threshing drum, number, and size of the wired loop (Fig. 2). The free load of the drum was calculated from the recorded time duration when the operator was asked to pedal the device for five times and time it took to return to the initial rest position. The physiological parameter (such as, heart rates) was recorded during the threshing operation. Based on the recording of heart rates during work and rest, the oxygen consumption (energy expenditure) of the operators was predicted (Nag 1981) for three different age groups, i.e., less than 30 years, 30–39 years, and above 40 years. The pedal threshing operations of all the operators were video graphed in order to assess the postural stress and the risk level associated with the posture, using the Rapid Upper Limb Assessment (RULA) worksheet. From the time record of activities and the work cycles obtained from the video-graphs, the productivity of the thresher machines was obtained. The productivity indicator of a threshing machine is often taken as the grain and straw output but the grain output

Fig. 1 **a**, **b** Workers engaged in threshing paddy with pedal thresher; **c** pedal thresher; **d** workers engaged in paddy threshing with power thresher

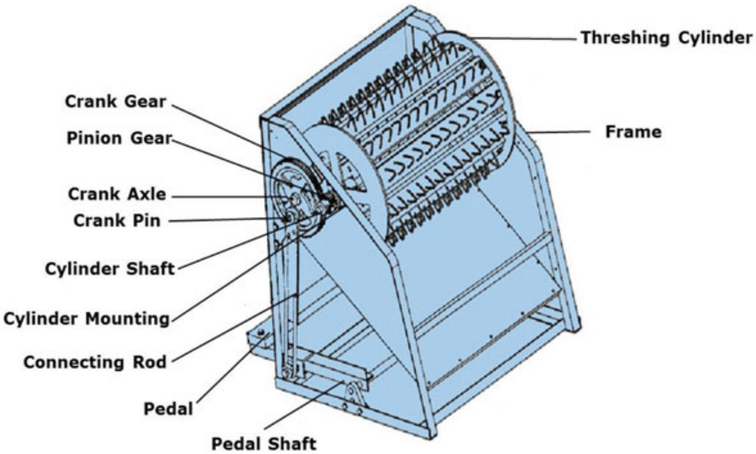


Fig. 2 Design features of pedal thresher

depends on the quality of the crop variety. As the variety of the crop is not taken into consideration, the land area covered for threshing of the crop per unit time was considered. On average 10 plants of paddy crop formed a bunch.

In this analysis, the average plant to plant spacing was taken as 15 cm × 15 cm. Hence, the productivity of threshing machines was calculated in terms of land area covered. The equation is mentioned is:

$$A = \frac{s \times n \times 10 \times 60}{t} \quad (1)$$

where A = area covered (m^2/min), s = plant spacing, n = number of bunch, t = time frame.

The pedal thresher operators suffer from different health discomfort, a frequent cough, and cold due to exposure to organic dust generated during paddy threshing paddy, muscular fatigue due to prolong holding of crop material, pain in leg, the chances of finger messing up in the threshing drum. The interview schedule included the above stated variables, and the perceived responses of the operators were noted on an agreement scale of 1–5 (strong disagreement to strong agreement) on the likely presence of the stressors. The data on physical, physiological, and machine characteristics were treated for statistical analysis, including principal component analysis (PCA). The recorded observations of the pedal thresher operators were yielded into a selective usability criteria, as the following (Fig. 3):

Sophistication—level of technology, user demands in operation, and competency;

Orientation—worker orientation, aptitude, and skill toward a particular job or tool;

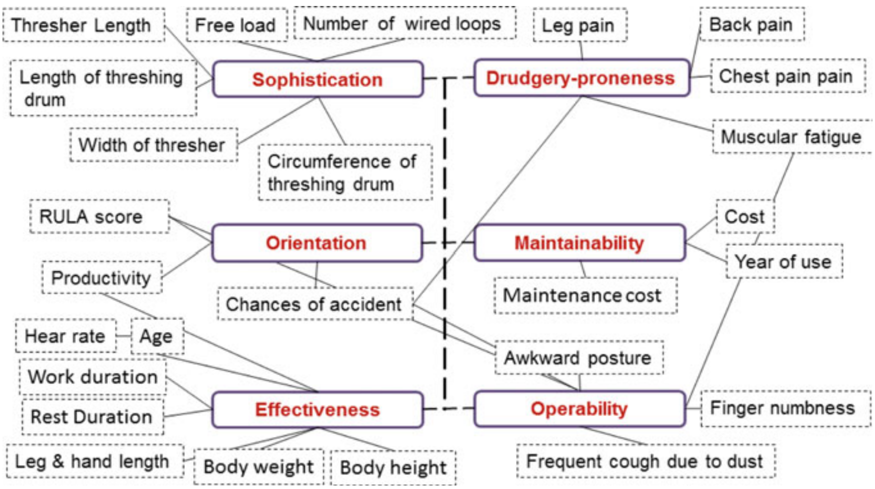


Fig. 3 Usability criteria for pedal thresher

Effectiveness—tool or method to evaluate the man–machine compatibility;

Operability—the extent of the use of a specific tool or machinery for maintaining work safety;

Maintainability—the cost and effort required to keep a machine or tool in working condition; and

Drudgery proneness—the harmful effects on human health due to work severity, or design incompetency of a tool or machine.

From the PCA and weightages obtained for different aspects, the relative functionality of the operators in pedal threshing were determined.

3 Results

The physical characteristics of the pedal thresher operators are shown in Table 1. The study covered 49% male (48.9%) and 51% female pedal thresher operators. The average body weight and body height of the female and male workers were 45 kg and 152.3 cm, and 50 kg and 162.5 cm respectively. The operators were further grouped according to the age range, i.e., below the age of 30 years, 30–39 years, and above 40 years of age. The average leg length of female and male respondents for the age groups of below 30 years, 30–39 years, above 40 years were 84 ± 9.6 cm, 85 ± 9.8 cm, and 84 ± 6.1 cm, and 91.4 ± 5.3 cm, 94 ± 4.4 cm, and 91.4 ± 4 cm respectively. The average hand length of female and male respondents for the age groups of below 30 years, 30–39 years, above 40 years were 57 ± 3.7 cm, 58 ± 3.7 cm, and 56 ± 3.2 cm, and 61 ± 5.4 cm, 62.2 ± 3.5 cm, and 60 ± 4 cm respectively. The average working time is 7.6 h per day.

The pedal threshers which were included in the study belonged to twelve different brands. On average, these pedal threshers were in use for the last 6 years. The threshers are grouped into three categories, based on the circumference of the threshing drum, i.e., 76–91 cm, 92–105 cm, and 106–121 cm, and labeled the threshers as pedal

Table 1 Physical characteristics of the workers (values are means ± SD)

		Male ($N = 68$)		Female ($N = 71$)		
Age (years)	<30	30–39	>40	<30	30–39	>40
Weight (kg)	48.7 (±8.3)	51.9 (±6.8)	50.5 (±7.2)	45.2 (±6.6)	46.2 (±7.1)	43.4 (±5.7)
Height (cm)	162.7 (±6.7)	164.8 (±4.4)	161.2 (±5.8)	151.6 (±7)	154.7 (±5.2)	150 (±4.4)
Leg length (cm)	91.4 (±5.3)	93.9 (±4.4)	91.4 (±4)	83.9 (±9.6)	85 (±9.8)	84 (±6.1)
Hand length (cm)	60.8 (±5.4)	62.2 (±3.5)	59.9 (±4)	56.8 (±3.7)	58 (±3.7)	55.8 (±3.2)

Table 2 Design characteristics and productivity of three types of pedal thresher (values are means ± SD)

		Weight (kg)			ANOVA
Variables	Pedal Thresher 1 (76–91 cm) (N = 56)	Pedal Thresher 2 (92–105 cm) (N = 67)	Pedal Thresher 3 (106–21 cm) (N = 15)	Pooled (N = 137)	F-value (df = 2, 137)
Circumference of threshing drum (cm)	84.6 (±3.7)	97.4 (±4.2)	113.5 (±4.7)	93.9 (±10)	340.2 (ρ < 0.01)
Length of threshing drum (cm)	40.4 (±1.7)	46.3 (±2.16)	54 (±2.16)	44.8 (±4.8)	322.9 (ρ < 0.01)
Length of thresher (cm)	70 (±3.18)	71.8 (±3.6)	75.7 (±3.3)	71.5 (±3.8)	16.86 (ρ < 0.01)
Number of wired loops	151 (±5.2)	148 (±9.6)	158 (±12.8)	138 (±9)	8.14 (ρ < 0.01)
Free load (seconds)	73 (±45.8)	84.8 (±35.3)	87 (±43.6)	80 (±40.9)	1.5 (NS*)
Productivity (m^2/min)	2.5 (±1.08)	2.9 (±0.88)	2.8 (±0.54)	2.7 (±0.96)	3.43 (ρ < 0.05)

thresher 1, 2, and 3 respectively. The design characteristics of the pedal threshers are given in Table 2. One-way ANOVA indicated that the design characteristics of the threshers were significantly different, as substantiated by the F values for different variables. That is, the length of the threshing drum ($F_{(2,139)} = 322.9$, $\rho < 0.01$), the length of thresher ($F_{(2,139)} = 16.86$, $\rho < 0.01$), and the number of wired loops ($F_{(2,139)} = 16.86$, $\rho < 0.01$) differed significantly with different types of pedal thresher. However, the free load of the threshing drum did not change significantly with the threshers. The productivity expressed in terms of square meter area of harvested crop being threshed varied significantly with different types of pedal threshers ($F_{(2,139)} = 3.43$, $\rho < 0.05$). The productivity output of pedal thresher 1 was much lower than pedal thresher 2 and 3.

The average heart rates of the male and female respondents during pedal threshing activity, as given in Table 3 were obtained for the age group 30–39 years as 107.4

Table 3 Physiological characteristics of the workers (values are means ± SD)

		Male (N = 68)		Female (N = 71)		
	< 29	30–39	> 40	< 29	30–39	> 40
Heart Rate (beats/min)	104 (±10)	107.4 (±15.5)	102.4 (±15)	105.6 (±9.5)	109.6 (±11.8)	101 (±6.8)
O_2 (l/min)	0.5 (±0.2)	0.7 (±0.3)	0.7 (±0.2)	0.5 (±0.2)	0.8 (±0.2)	0.7 (±0.1)

Table 4 Integrated RULA score with prioritization of risk level of pedal thresher operators

RULA score	Actions required	Male ($N = 68$) (%)	Female ($N = 71$) (%)	Total ($N = 139$) (%)
2	Acceptable	19.1	14.3	16.7
3–4	Investigate further	80.9	85.7	83.3

± 15.5 beats/min (males) and 109.6 ± 11.8 beats/min (females). The corresponding predicted oxygen uptake values were 0.7 ± 0.3 l/min (males) and 0.8 ± 0.2 l/min (females) in 30–39 years age group. From the analysis shown in Table 4, only 16.7% of total number of cases fell under an acceptable category and 83.3% of the cases required further investigation for design modification. Number of acceptable postures was lesser among the female respondents (14.3%) in comparison to the male respondents (19.1%). Minimum RULA score indicated lesser amount of posture related discomfort among the users. Figure 3 includes pictures of workers engaged in threshing paddy grains using pedal thresher as well as power thresher.

From the Principal Component Analysis (PCA) and weightages obtained for different usability aspects, the human perception in the pedal threshing operation was determined. The process was applied to maintain parity between all the variables. Further weightage of each item was derived by multiplying the factor loading and component score. The average weight of each factor was obtained. Using the following formulae mentioned below, each factor was normalized in the due process. In the process of normalization, the relative weight of each principal component was obtained.

$$N_i = \sum_{i=1}^{n} \frac{x_{ji}\overline{x}_j}{\sigma_j} * W_j \tag{2}$$

where, N_i = Normalized value of ith sample, x_{ji} = Actual value of the indicator j for ith sample, $\overline{x}_j$ = Mean value of indicator j, σ_j = Standard deviation of indicator j, W_j = Relative weightage of the indicator j.

Thus, the average score of each component was derived by summing up the normalized value of each indicator. The following formula was used to achieve the average score for each element:

$$X_i = \frac{\sum_{i=1}^{n} A_i}{N} \tag{3}$$

where, X_i = Average score of an individual component of the ith sample, A_i = Actual score of indicators for ith sample, N = Number of indicators included in each component.

The average score derived from the above-mentioned method was eventually used to establish a linear relationship among the principal component in the form of an equation. Cronbach's alpha test was applied to examine the reliability, i.e., the internal consistency of the indicators of the principal components. Cronbach's alpha describes the co-efficient of reliability. A high and positive alpha value indicates a higher internal consistency. To assess whether there was a difference between the principal components in different groups of the same tool, one-way ANOVA was applied.

Initially, the variables identified in Principal Component Analysis (PCA) were compared among the groups, and accordingly, the polar graph was drawn to show the relative score for design features, stress, and strain related to the tool.

Figure 4 showed the perception of the pedal thresher operators, indicating that 75.4% of the female operators and 71% of the male operators suffered from muscular fatigue due to the prolonged holding of crop bundles for threshing. The prevalence of back pain (69.6%) and leg pain due continuous pedaling (89.8%) were greater among the female operators, as compared to the male operators. The operators (84%) frequently suffered from a cough as threshing with pedal thresher release profuse amount dust. The pedal threshers generally devoid of any safety cover, therefore 41.8% of the male respondents and 23.1% of female respondents felt the chances of fingers being crushed during operation. Three different types of pedal thresher are compared (Fig. 5), that operators of the pedal thresher 3 were more prone to back pain (73.3%), chest pain (73.3%), and leg pain (93.3%), as compared to the other two type of pedal thresher. The problem of a cough due to the emission of dust was also 86.7% among the user of pedal thresher 3. Nearly 40% of the total number of users of pedal thresher 2 and pedal thresher 3 felt that there are high chances of occurrence of accident in threshing operation. Majority of the operators i.e., 76.8% and 83.6% of the user of pedal thresher 2 and pedal thresher 3 respectively noted that the working posture as uncomfortable and awkward.

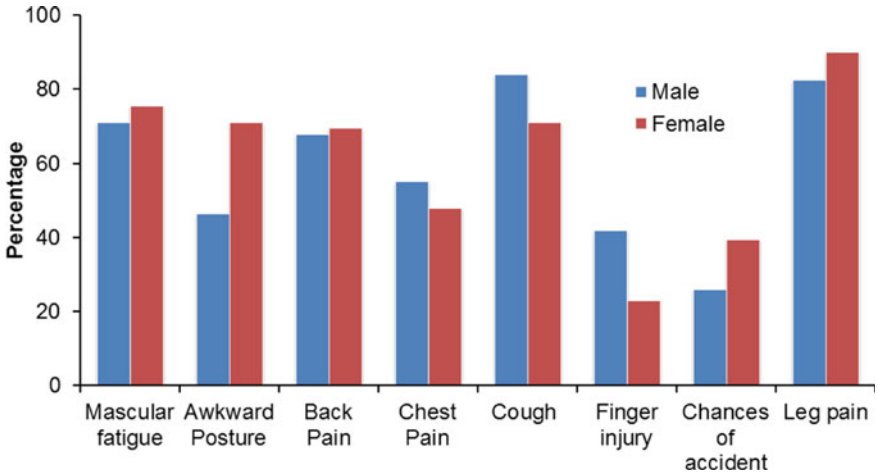


Fig. 4 Perception regarding the prevalence of pain and discomfort among male and female pedal thresher operators

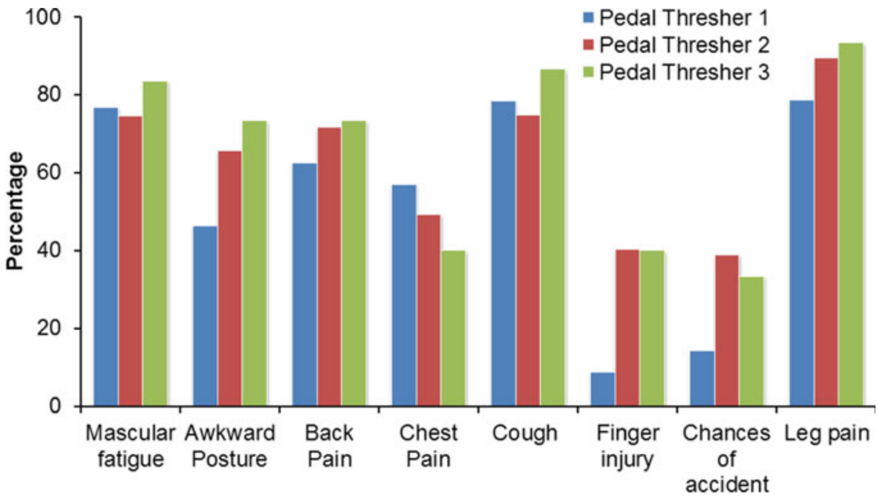


Fig. 5 Perception regarding the prevalence of pain and discomfort among the user of three different types of pedal thresher

The criteria related to morphological features of the pedal thresher, physical characteristics of the operator, and perception of the user regarding threshing operation were analyzed. The PCA was performed with 26 items to identify component loading. The analysis using varimax rotation (Kaiser normalization) yielded three components. The maximum number of iteration is 4. All the components are having Eigen values greater than one. These components together explain 65.9% of the total variance (Table 5). The principal components (PC) thus yielded are labeled according to the nature of the component, i.e., PC1 (design features), PC2 (body dimension), and PC3 (bodily strain). The components are described as follows:

Design Features (PC1): The PC1 consisting of three variables, i.e., length of threshing drum, the circumference of threshing drum, and length of the thresher, explained 26.6% of the total variance. Hence, it was labeled as design features.

Body Dimensions (PC2): The second component consisting of the body height, length of leg, length of hand, and body weight of the pedal thresher, explained 23% of the total variance. As this component consists of a physical description of the user, hence it is termed as a bodily dimension.

Bodily Strain (PC3): The third component consisting dimensions related to the perception of the operators, i.e., muscular fatigue due to the holding of crop materials, awkward work posture adopted during operation, and back pain, explained 16.3% of the total variance. Hence, it was termed as bodily strain.

The Cronbach's reliability score (alpha value) of the design features (PC1), body dimension (PC2), and bodily strain (PC3) were 0.932, 0.877, and 0.594 respectively (Table 5). These components show a high level of reliability. A quantitative indicator of work severity was proposed after normalizing the component score.

Table 5 Principal component loading in defined aspects of threshing with pedal thresher and reliability score

Factors	Items	Component loading	Component score coefficient	Summated weight	Reliability score
PC1: design features (3 items, 26.6% of variance explained)	Length of threshing drum	0.964	0.688	1.6	0.932
	Circumference of drum	0.964	0.688		
	Length of thresher	0.656	0.436		
PC2: Body dimensions (4 items, 23% of variance explained)	Height of the user	0.927	0.597	1.5	0.877
	Leg length of the user	0.790	0.437		
	Hand length of the user	0.692	0.376		
	Weight of the user	0.676	0.621		
PC3: Bodily strain (3 items, 16.3% of variance explained)	Muscular fatigue	0.759	0.732	1.50	0.594
	Back pain	0.742	0.657		
	Awkward Posture	0.712	0.731		

$$\text{WSI} = 0.3 * X_1 + 0.3 * X_2 + 0.4 * X_3 \quad (4)$$

where, WSI = Work Severity Indicator, X_1 = Design Features, X_2 = Body Dimensions, X_3 = Bodily strain.

That is, the equation for work severity indicator of threshing operation with pedal thresher included three dimensions, i.e., design features of the thresher, physical description of the user, and perception of the user regarding the pain and discomfort related to this work as well as the device. Though, the bodily strain (PC3) explained only 16.3% of the total variance, the relative weight of the component in the equation was highest. One-way ANOVA showed that (Table 6) the design features (PC1) differed significantly. ($F_{(2,139)} = 268.1$; $\rho < 0.01$), but the change of the other two components were not significant. The equation to calculate work severity indicator of threshing operation with pedal thresher is a simple expression to compare different types of pedal thresher.

The PCA yielded three factors which include ten items clubbed under different factors. The scores for each item are compared among three different types of pedal thresher. The studied pedal thresher was divided into three groups depending upon the circumference of threshing drum, i.e., 76–91 cm, 92–105 cm, 106–121 cm and labeled

Table 6 Factor values obtained for threshing with types of pedal thresher

Factors	Pedal thresher 1 (76–91 cm)	Pedal thresher 2 (92–105 cm)	Pedal thresher 3 (106–21 cm)	Analysis of variance (df = 2139)
	Mean (±sd)	Mean (±sd)	Mean (±sd)	F value
PC1: design features	3.8 (±0.12)	4 (±0.16	4.7 (±0.14)	268.1 ($\rho < 0.01$)
PC2: bodily dimensions	3.9 (±0.27)	3.9 (±0.27)	3.8 (±0.24)	0.691 (NS)*
PC3: bodily strain	3.3 (±0.96)	3.5 (±0.85)	3.3 (±0.96)	0.5 (NS)*

as pedal thresher 1, 2, and 3 respectively. Figure 6 compares different variables identified in the PCA analysis and accordingly attempted to arrive an integrated picture of comparison of different pedal threshers. The design features such as, circumference of threshing drum, length of threshing drum, and length of thresher, differed for three different types of the pedal threshers. Pedal thresher 3 had the highest circumference of threshing drum followed by pedal thresher 2 and 1 respectively. There was no difference in the physical features of the operators, i.e., body height, length of leg, and length of the hand, with the type of pedal thresher used; however as observed the average body weight of the user of pedal thresher 3 was more compared to the other two groups. As shown in Fig. 5, the perceived bodily strain of the users of pedal thresher 3 was found to be higher in comparison to the other two groups.

Figure 7 shows the outcome of relative usability analysis of the three types of pedal thresher. Six different criteria (sophistication, orientation, effectiveness, operability, maintainability, and drudgery proneness) were applied to describe the usability of the pedal threshers. In terms of sophistication that refers to the technology applied and user competency in operation, includes variables like length of thresher, length of threshing drum, the circumference of threshing drum, and a number of wired loops. Pedal thresher 2 acquired the highest score followed by pedal thresher 3 and 1. The

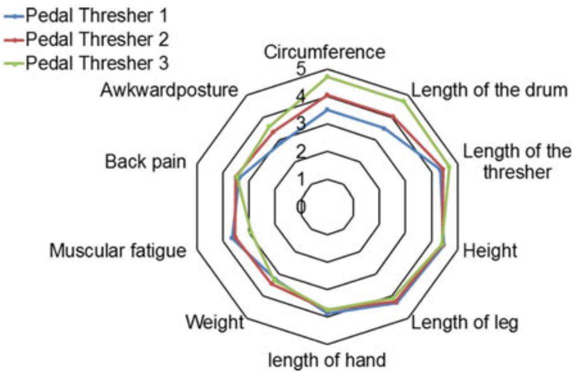


Fig. 6 Relative scores of design features of tools and user stress and strain in relation to pedal thresher in paddy threshing operation

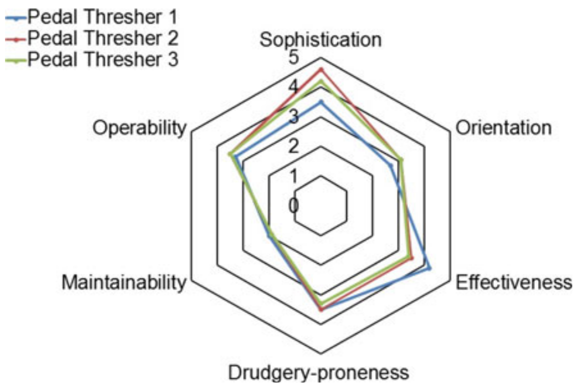


Fig. 7 Usability criteria in relation to pedal thresher operation in paddy harvesting

score for orientation in terms of worker aptitude and skill to the job or tool was highest for pedal thresher 2 and 3. The criteria of effectiveness, that is to evaluate the man–machine compatibility, include physical features of the user, physiological, and productivity dimensions, appeared highest in case of pedal thresher 1 with the smaller circumference of the threshing drum. The score of operability in terms of the use of the machinery for maintaining better work safety appeared better in the case of pedal thresher 2 and 3. The score for maintainability about the cost and effort to keep the machine in working condition was very similar for three types of pedal thresher. As regards the score for drudgery-proneness (effects on human health due to work severity and design incompetency) was similar across the pedal threshers. In overall analysis the usability score of pedal thresher 2 having average threshing drum circumference of 97.4 ± 4.2 cm was found to be superior in comparison to the other threshers. This was further substantiated from the polar graph (Fig. 7) that greater the area would indicate the better the usability score. Polar graph area of the pedal thresher 1, 2, and 3 was 30.5, 36.5, and 33.4 cm^2 respectively.

4 Discussion

This contribution evaluates the functionality of pedal-operated threshers, which are extensively used by the farmers in small and marginal holdings in paddy cultivation. The study covered one hundred and thirty-nine pedal thresher operators with nearly equal proportion of male and female volunteers, and they were divided into three user groups depending upon the circumference of threshing drum, i.e., 76–91 cm, 92–105 cm, 106–121 cm, that are labeled as pedal thresher 1, 2, and 3 respectively. The length of the pedal threshers ranged from 70 ± 3.18 cm (thresher 1), 71.8 ± 3.6 cm (thresher 2), 75.7 ± 3.3 cm (thresher 3) respectively. The length of the threshing drum and the number of wired loops varied significantly in different threshers (Table 2). The threshing drum determines the feeding area. The optimization of its length may allow two operators to work simultaneously. The pedal threshers in common use are devoid of any kind of safety devices. The threshing of paddy crop generates clouds of organic dust and a good percentage of workers suffer from frequent cough and other ailments. The prevalence of a frequent cough was seen mainly among the male workers. Present study showed that the group using pedal thresher 3 was more prone to leg pain, cough, back pain, and muscular fatigue. The elder group was vulnerable to pain in leg and back and prone to a frequent cough. The above 40 years age group also had higher occurrence of accident. The output capacity of the pedal thresher 2 and 3 were greater than pedal thresher 1 indicating increased productivity with the increase in the circumference of the drum.

The length of the thresher has an impact on productivity and workload of the operator and the optimum height of pedal thresher are found to be 81 cm for a north-east population of India (Khayer et al. 2017). The wire loop spacing is an important design criterion about the efficiency of the thresher (Singh et al. 2008). In general, on physiological criteria the work severity in threshing with pedal thresher was moderate to extremely heavy work (Nag and Nag 2004). The lifting and carrying heavy loads, repeated full-body bending (stoop), and highly repetitive handwork are the common risk factors of musculoskeletal disorders among farm workers (Meyers et al. 2000, 2002; Vyavahare and Kallurkar 2012). Several studies indicated that the Indian farmers are subjected to multiple stressors, such as hazardous exposure to thermal stress, dust, biological and chemical hazards, risks of accident at workplaces, level of mechanization, working tools and working hours (Nag and Nag 2003; Pawlak and Nowakowicz-Dębek 2015). To evaluating performance characteristics in farming work, the proportioning of the aspects of work, as technical, working conditions and environmental, mechanistic, biological, and perceptual, has been proposed to compare between traditional and mechanized farming (Nag and Nag 2003).

The pedal threshers are designed from throttle action and the foot operation facilitates the threshing drum to rotate. The weight and size of the drum are determining factor to arrive at preload and after load for the operator to throttle. The manual machine may not be comparable to electrical thresher machine. The frequency at which the throttle action is done, add to the rotation of the drum and therefore optimizing the drum size and weight is critical for the pedal thresher.

As described above, the component scores of three principal components (design features of the thresher, body dimensions of operators, and bodily strains) were normalized to yield a numerical equation to express as work severity indicator (WSI $= 0.3 * X_1 + 0.3 * X_2 + 0.4 * X_3$), where, WSI = Work Severity Indicator, X_1 = Design Features, X_2 = Body Dimensions, X_3 = Bodily strain. The WSI is a maiden attempt to combine multiple dimensions to bring a quantitative indicator for comparison of different pedal thresher. The relative weightage was highest in case of bodily strain. The analysis of data of 139 pedal thresher operators provided a yardstick to choose a pedal thresher for ease of use, less drudgery prone, and more productive.

The concept of usability in farm equipment analysis is a newer domain. The present attempt was made to explore the relative usefulness of the pedal threshers based on the defined usability criteria. Considering the applicability of the concept among the small and marginal farmers, a selected usability dimensions were chosen as sophistication, orientation, effectiveness, operability, maintainability, and drudgery proneness. The graphical area covered under the polar graph represented by different criteria for each type of pedal thresher indicated its relative usability. The analysis of three groups of pedal thresher operators, the pedal thresher 2 (drum circumference ranging from 92 to 105 cm) scored superior on the usability criteria (Fig. 7). In brief, the analysis presented in the study is a modest endeavor to provide a quantitative analysis to define the work severity indicator and usability assessment of manual pedal-operated thresher in small and marginal farming.

References

Datt P (2003) Design of paddy thresher. In: Proceedings of the national workshop on design methodology of agricultural machinery. CIAE, Bhopal, pp 192–198

Han SH, Yun MH, Kwahk J, Hong SW (2001) Usability of consumer electronic products. Int J Ind Ergon 28(3–4):143–151. https://doi.org/10.1016/S0169-8141(01)00025-7

Harrison R, Flood D, Duce D (2013) Usability of mobile applications: literature review and rationale for a new usability model. J Interact Sci 1(1):1–16

Kathrivel K, Sivakumar SS (2003) Empowerment of women in agriculture. Coordination Committee Report of AICRP on Ergonomics and Safety in Agriculture, Tamil Nadu Agricultural University, India

Khadatkar A, Potdar RR, Narwariya BS, Wakudkar H, Dubey UC (2018) An ergonomic evaluation of pedal operated paddy thresher for farm women. Indian J Agric Sci 88(2):280–283

Khayer SM, Patel T, Dewangan KN (2017) Ergonomic design improvement of pedal thresher: an approach combining digital human modelling and response surface analysis. J Ergon S6:003. doi.https://doi.org/10.4172/2165-7556.1000.S6-003

Kwatra S, Vinay D, Sharma S (2010) Comparative study on the manual beating of paddy and manually operated paddy thresher on farm women. J Hum Ergol 32(3):183–187

Lewis JJR, Sauro J (2017) Revisiting the factor structure of the system usability scale. J Usabil Stud 12(4):183–192

Meyers JM, Faucett J, Tejeda DG, Kabashima J, Miles JA, Janowitz I (2000) High risk tasks for musculoskeletal disorders in agricultural field work. In: Proceedings of the human factors and ergonomics society annual meeting, vol 44, no 22. SAGE Publications, USA, pp 616–619

Meyers JM, Miles JA, Tejeda DG, Faucett J, Janowitz I, Weber E, Smith R, Garcia L (2002) Priority risk factors for back injury in agricultural field work: vineyard ergonomics. J Agromed 8(1):39–54. https://doi.org/10.1300/J096v08n01_05

Nag PK (1981) Predicting maximal oxygen uptake of workers engaged in agricultural tasks. J Hum Ergol 10(1):25–33

Nag PK, Nag A (2004) Drudgery, accidents and injuries in Indian agriculture. Ind Health 42(2):149–162. https://doi.org/10.2486/indhealth.42.149

Nag PK, Nag A (2003) A multi-method ergonomic review technique for work analysis and design in farming. In: Ergonomics in the digital age, vol 2. IEA, Seoul

Pawlak H, Nowakowicz-Dębek B (2015) Agriculture: accident-prone working environment. Agric Agric Sci Procedia 7:209–214. https://doi.org/10.1016/j.aaspro.2015.12.019

Quick GR (1998) Global assessment of power threshers for rice. Agric Mech Asia Afr Latin Am 29(3):47–54

Singh KP, Pardeshi IL, Kumar M, Srinivas K, Srivastva AK (2008) Optimisation of machine parameters of a pedal-operated paddy thresher using RSM. Biosys Eng 100(4):591–600. https://doi.org/10.1016/j.biosystemseng.2008.05.004

Vyavahare RT, Kallurkar S (2012) Anthropometric and strength data of Indian agricultural workers for equipment design: a review. Agric Eng Int CIGR J 14(4):102–114

Chapter 6
Agriculture Based on Soil Minerals

Karve Anand Dinakar

1 Introduction

All over the world, the natural flora appears green and healthy, indicating that under natural conditions plants get all the required minerals from the soil, irrespective of the soil type, location, latitude or climate. Even plants brought in from other locations do quite well in their new environment that might be dissimilar to their original one. Laboratory experiments using water soluble salts have given useful information about the role of different mineral elements in the metabolism of plants, but how plants obtain minerals under natural conditions is not clearly understood. According to Harder et al. (1962a) the soil is chemically difficult to understand and a highly complex entity. The same authors (Harder et al. 1962b) have also stated that plants can take up soil minerals only if the latter are in their dissolved state. Mohr and Schopfer (1978) have elaborated the difficulties in understanding the mechanism of uptake of minerals by stating that the soil solution has very low mineral concentration (generally 10^{-6} mol $lit^{-1)}$, a high degree of variability in the concentration of individual ions as well as variability in the total solute concentration from location to location, and occasional predominance in the solution of a single salt such as NaCl. The generally positive response of crop plants to chemical fertilizers suggests that low availability of mineral nutrients in the soil is a major factor limiting agricultural productivity. By using chemical fertilizers, it is possible to overcome this limiting condition, but the cost of chemical fertilizers represents nowadays one of the major cost components in agriculture.

Many farmers in the state of Maharashtra, India, follow an unusual agricultural practice, called *Jeevamrut* (elixir of life). This practice, supposedly described in an ancient *Sanskrit* text, consists of mixing 25 kg sugar, 25 kg cattle dung and 25 L of cattle urine with 500 l of water, and allowing the mixture to stand for about three

K. A. Dinakar (✉)
Samuchit Enviro Tech, Law College Road Pune, India
e-mail: adkarve@gmail.com

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_6

days. The resulting brew, which generally shows acidic pH, is applied to a hectare by mixing it with the irrigation water. Sometimes it is sprinkled on the soil surface, prior to irrigating the field. The practitioners of *Jeevamrut* technique do not apply any chemical fertilizer or organic manure to their fields, and yet they get very high yield, year after year. This fact was verified by the author by visiting and interviewing the farmers who followed the above practice. The author also identified one farmer who did not use *Jeevamrut,* but obtained high yield by applying just 125 kg green leaves ha^{-1} (about 25 kg dry matter) to his field.

There is universal agreement among agricultural scientists that soil micro-organisms play an important role in maintaining soil fertility (e.g. Bollen 1959) but the nature of the activity was not clearly understood. According to Bourguignon (2005a) divalent elements (Ca, Mg, Fe, B, Mn, Cu, Zn and M) are made available to plants by bacteria through a process called chelation. Others are made available to plants by either oxidation or dissolution caused by soil bacteria. Nitrogen, a gaseous element, is fixed by soil bacteria to form amides, which, in turn, are oxidized by another category of soil bacteria to form nitrates. Reduced compounds of sulphur are also oxidized by certain soil bacteria into sulphates. These processes make N_2 and S available to plants. It is also mentioned by the same author that some micro-organisms produce organic acids, which dissolve insoluble carbonates and phosphates in the soil, to make them available to plants. The present author wishes to point out that the above mechanisms make the corresponding minerals available to the bacteria in the soil but not to plants. Bourguignon does not explain how they are transferred from the bacterial cells to the plants. He too mentions the extremely low concentration of the mineral salts in the soil solution as a major difficulty that plants face in taking up minerals directly from the soil (Bourguignon 2005b). The soil micro-organisms do not conduct photosynthesis, and therefore the organic matter falling on the ground serves them as the carbon source. It is the general opinion among soil scientists that micro-organisms contribute to the soil fertility mainly through decomposition of organic matter, whereby the mineral elements sequestered in the organic matter are released into the soil (Buol et al. 2003; www.soilquality.org.au/factsheets/soil-biological-fertility).

The present author does not agree with this view because the organic matter in the soil has its origin mainly in plant residues. These residues are very poor in mineral elements, because almost 95% of the plant biomass is made up of carbon, hydrogen and oxygen (Bourguignon) (Buol et al. 2003). Soil microbes, which lack tissues like cellulose, lignin or chitin, have 15 to 20% minerals on dry weight basis. Therefore, it is unlikely that a soil microbe would take up only carbon from the leaf litter and not the minerals in it. The author conducted an experiment in which 500 mg pure crystalline sugar was dissolved in water and provided to 1 kg vertisol (black cotton soil). This input caused, after 24 h, a 500 fold increase in the microbial population in the soil. Since sugar does not contain any minerals, this experiment showed that soil bacteria can take up the required minerals directly from the soil solution, if they are fed with a carbon source. Similar results were reported by Steiner et al. (2008) with pyrolignious acid (wood smoke condensate containing several organic acids) applied to the soil.

The positive role played by soil bacteria in enhancing soil fertility is explained by the author as follows.

2 The New Hypothesis

Since the discovery of penicillin in 1928, a search was conducted all over the world to find new plant-based antibiotics. It emerged from this world-wide research effort, that roots of all plants exude biocidal compounds into the soil and that these biocides kill soil microbes (National Science Foundation 2005). By placing a few germinating seeds on a petri-plate inoculated with a bacterial strain, the author could observe a bacteria-free zone around the roots. When a similar zone of inhibition is produced by a fungus, it is explained as a mechanism used by it to obtain its nutrition by killing and consuming the bacteria in its vicinity. But the exudation of biocides by the roots is explained as a mechanism by which plants protect themselves from pathogens in the soil (National Science Foundation 2005). But one can equally well argue that through this mechanism the plants kill and consume the soil bacteria in order to obtain mineral compounds from the bacterial cells. This assumption is strengthened by the discovery of digestive enzymes in the root exudates (Adamczyk et al. 2009) and also by a pot experiment in which the author found that the soil in pots with 40 day old plants had 75% less bacteria than corresponding pots without plants. The success of the Root Zone Technology (National Environmental Engineering Research Institute 2019) in reducing the load of bacteria and organic matter in fecally contaminated wastewater is another proof of the fact that plant roots kill bacteria, digest them and absorb the digestate.

An objection that can be raised against this hypothesis is the presence of bacteria in the rhizosphere of plants. This phenomenon can however be explained by the fact that only the micro-organisms that developed resistance to the biocides of a particular plant can survive in its rhizosphere. The fact that the composition of the rhizosphere micro-flora varies according to the host plant species (Marschner et al. 2004) supports this assumption.

3 Discussion

Green algae appear as fossils from the Precambrian era (1.2×10^9 years ago) (Leliert et al. 2012), but they remained confined to the water bodies. Also, according to the same authors, Bryophytes, considered to be the ancestors of the modern vascular plants, were the first plants to have conquered land about 450 million years ago. The hypothesis, that plants obtain their minerals not directly from the soil but from the minerals sequestered in the cells of micro-organisms helps us in understanding this delay. Having the ability to obtain minerals directly from soil, photosynthetic bacteria (e.g. purple bacteria and Cyanobacteria) as well as lichens, must have conquered land much earlier, but green plants (Bryophytes) had to wait, because they did not have the capacity to take up minerals from the soil. They could come on the land only after they developed the ability to kill and digest soil bacteria. Because survival of plants on land depended on this ability, all land plants, which descended from the bryophytes, conserved this mechanism.

The hypothesis that plants take up minerals from the cytoplasm of the soil bacteria also explains why symptoms of mineral deficiency are not seen in plants growing under natural conditions. This is due to the fact that all soils harbor bacteria, in spite of variations in soil characteristics from location to location. When supplied with organic matter, the bacteria proliferate, taking up minerals from the soil during proliferation. Since all living organisms harbor more or less the same minerals, it is immaterial, which bacteria are killed and consumed by the plants.

The fact that some plants kill and consume insects suggests that there might be more such species. Many insects lay their eggs in the soil. It is possible that plants kill and digest the larvae emerging from these eggs by using root exudates. This might be the reason why the desert locusts have their origin in the deserts and not in more fertile regions that their swarms visit for feeding. Many plants known to be immune to nematodes in the soil might be nematophagous.

The idea that plants provide nutrients to soil bacteria and induce them to proliferate, explains many botanical phenomena. Many seeds are accompanied by cellulosic fibers (e.g. seed of cotton). Even the pulp of fruits and the nectar in the flower can be looked at from this perspective. Flower petals of the genus *Madhuca* are fleshy and they store sugar. These floral parts are discarded after fertilization. After falling on the ground, these organs and substances decompose, causing the soil bacteria to proliferate and to enhance the soil fertility.

The above hypothesis also explains why many plants drop water of guttation on the ground in the night. This water generally contains organic acids and sugars, which serve as a source of carbon to help the proliferation of soil bacteria.

4 Conclusions

The above hypothesis provides a scientific explanation to the positive correlation between the population density of the soil microbes and soil fertility. Agronomists accept the importance of applying organic matter to the soil, but under the present practice, farmers apply organic matter in a decomposed form like compost. This practice has arisen from the general observation that plants do better when provided with an external source of minerals. By decomposing organic matter, one reduces its carbon content and enriches the mineral content. But the present paper gives an alternative of applying to the field organic matter having high calorific value and high digestibility. Therefore, new studies would have to be conducted to standardize the quality, quantity and frequency of application of non-composted organic matter to agricultural fields.

The fact highlighted in this paper, that roots of plants produce and exude biocides, can serve as a stimulus for renewed search for biocides in the roots of agricultural crops. The advantage of using agricultural crops is that the source material would be available in huge quantities and in the form of a pure monoculture. Even if such a search failed to yield any medicinally useful antibiotic, one may find biocides that can be used as organic pesticides or as non-polluting substitutes for leather tanning chemicals.

References

Adamczyk B, Godlewski M, Smolandera A, Kitunen V (2009) Degradation of proteins by enzymes exuded by Allium porrum roots—a potentially important strategy for acquiring organic nitrogen by plants. Plant Physiol Biochem 47:919–925

Bollen WB (1959) Microrganisms and soil fertility, Oregon State Monographs, Studies in Bacteriology, Number 1, Published by Oregon State College, Corvallis, Oregon, USA

Bourguignon C (2005a) Regenerating the soil. Other India Press, Mapusa, p 40

Bourguignon C (2005b) Regenerating the soil. Other India Press, Mapusa, p 122

Buol SW, Southard RJ, Graham RC, McDaniel PA (2003) Soil genesis and classification. Iowa State Press, Ames, IA, p 88

Fact Sheets Soil Biological Fertility, www.soilquality.org.au/factsheets/soil-biological-fertility

Harder R, Firbas F, Schumacher W, von Denffer D (1962a) Lehrbuch der Botanik fuer Hochschulen, Gustav Fischer Verlag, Stuttgart, Germany, p 206

Harder R, Firbas F, Schumacher W, von Denffer D (1962b) Lehrbuch der Botanik fuer Hochschulen, Gustav Fischer Verlag, Stuttgart, Germany, p 208

Leliert F, Smith DR, Moreau H, Hedrron MD, Verbruggen H, Delwiche C, DeClerck O (2012) Phylogeny and molecular evolution of the green algae. Crit Rev Plant Sci 31(1):1–46

Marschner P, Crawley D, Yang CH (2004) Development of specific rhizosphere bacterial communities in relation to plant species, nutrition and soil type. Plant Soil 261:199–208

Mohr H, Schopfer P (1978) Lehrbuch der Pflanzenphysiologie, Springer-Verlag, Berlin, Heidelberg, New York, p 477

National Environmental Engineering Research Institute (2019) www.neeri/res.in/content/phytorid-wastewater/treatment/technology

National Science Foundation (2005) Roots engage in underground chemical warfare. ScienceDaily. ScienceDaily, 27 Mar 2005. www.sciencedaily.com/releases/2005/03/050325154057.htm

Steiner C, Das KC, Garcia M, Foerster B, Zech W (2008) Charcoal and smoke extract stimulate the soil microbial community in a highly weathered xanthic ferrasol. Pedobiologia 51:359–366

Chapter 7
Interventions in Hirda Collection and Processing for Optimal Utilization and Value Addition

Rupali Khanolkar, Pratik Naik, and Anand B. Rao

1 Introduction

Terminalia chebula is a large deciduous tree found throughout South and Southeast Asia. In India, it is found in forests of Sub-Himalayan region, West Bengal, Assam, Maharashtra, Madhya Pradesh, Chhattisgarh, Karnataka, and Tamil Nadu (Bag et al. 2013). The tree is known by different names in different Indian languages and in Marathi (the local language of Maharashtra) it is called "hirda". Since this paper has been written in context of Maharashtra, henceforth it has been referred to as hirda.

Hirda tree yields fruits that have medicinal properties and is an important component of many Ayurvedic formulations. It is useful in treatment of cough and is also a good astringent and used in treatment of bleeding gums (Bag et al. 2013; Parnis and Lele 2011). Hirda is known to be an excellent liver stimulant and is useful in increasing appetite. It is also used as a mild laxative (Bag et al. 2013). Hirda powder in combination with musta, sunthi and jaggery is useful for treatment of diarrhea, dysentery, and flatulence (Gupta 2012). It has got applications in leather tanning industry also.

Students of CTARA at IIT Bombay worked with Shashwat, a non-Government organization during May and June 2016. Shashwat has been working with tribal people in Ambegaon, Junnar, and Khed blocks of Pune district for the last 33 years. During field stay of the students, it was found that tribals living in this area have limited livelihood opportunities. It was also found that collection and selling of hirda is an important source of livelihood for the tribals. During this study, the issue of drudgery during decortication of hirda and non-availability of small-scale machines for decortication of hirda was also identified. In response to this, RuTAG IIT Bombay

R. Khanolkar (✉) · P. Naik · A. B. Rao
Rural Technology Action Group (RuTAG), IIT Bombay, Mumbai, India
e-mail: Rupali.khanolkar@iitb.ac.in

A. B. Rao
Center for Technology Alternatives for Rural Areas (CTARA), IIT Bombay, Mumbai, India

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_7

developed a small-scale machine for decortication of hirda. The students also found that though tribals have to undergo a lot of hardships while collecting the hirda, they earn a low share of value generated in the supply chain of hirda.

In the above context, a need was felt to understand the bottlenecks in the supply chain of hirda and help the tribals to get a fair share of the value chain. In view of this, RuTAG IIT Bombay conducted a detailed study to understand the various aspects related to hirda such as production, harvesting, drying, decorticating, processing, and selling in the context of Ambegaon, Junnar, and Khed blocks of Pune district. The main objective of the study was to understand the bottlenecks in the supply chain of hirda and identify potential interventions for optimal utilization and value addition of hirda. This project was initiated in October 2019 through CSR funding of National Scheduled Castes Finance and Development Corporation (NSCFDC). The NGO associated with the project was Shashwat Trust Junnar.

This paper presents the work done by RuTAG IIT Bombay in the above context. The paper presents information regarding the production of hirda based on a household survey conducted by RuTAG IIT Bombay. Methodology adopted by RuTAG for comprehension of various issues related to hirda has also been presented in the paper. The paper also includes information regarding hirda collection and processing and difficulties encountered by the tribals in this regard. The paper also discusses the supply chain of hirda and highlights the challenges encountered by the tribals for initiation of trade of hirda in Ambegaon block. Various problem areas and relevant solutions for the problems proposed by RuTAG have been presented at the end of the paper.

2 Varieties of Hirda

There are two varieties of hirda—"Bal hirda" and "Bhadodya hirda". Tender or unripe hirda without seed is known as Bal Hirda, whereas the mature hirda with seed formation inside the fruit is known as Bhadodya hirda. Bal hirda is collected during April and May when fruit formation has just begun. After the season of collection of Bal hirda is over, during the monsoon the hirda fruits mature and fall down on the ground. This variety is known as Bhadodya hirda. The Bhadodya hirda lying on the ground is collected during November and December once the monsoon is over (Tak et al. 2016). Both the varieties are sun-dried after harvesting. The Bal hirda contains higher amount of active ingredients in comparison with the Bhadodya hirda, therefore, it fetches much higher prices in the market. In Pune district, Bal hirda fetched price of around Rs. 150–200/kg whereas, the Bhadodya hirda fetches price of around Rs. 20–25/kg. This explains the reason behind preference of the tribals for collecting Bal hirda over Bhadodya hirda.

3 Production of Hirda

This section presents information regarding production and collection of hirda in the study area. To study this, the following methodology was adopted.

3.1 Methodology

To study the actual production of Bal hirda and Bhadodya hirda, following methodology was adopted.

- The study was conducted in Ambegaon, Junnar, and Khed blocks of Pune district.
- The NGO Shashwat Trust, Junnar was approached in the context of conducting a household survey. After discussion with the volunteers of the NGO, a list of all the villages engaged in collecting hirda in Ambegaon, Junnar, and Khed blocks was prepared.
- The list of villages included total of 37 villages in Ambegaon block, 24 villages in Junnar block, and 27 villages in Khed block. It was planned that at least 20% of the villages in each block would be surveyed and the data would be extrapolated.
- The survey was conducted between February and March 2020. Till today, survey of 30 villages from Ambegaon out of 37, 15 villages out of 27 in Khed, and eight villages out of 24 in Junnar has been completed. Thus nearly 60% of the total number of villages have been surveyed.
- Number of households in the villages that were not surveyed was calculated with help of 2011 census data.
- The data collected through the household survey was extrapolated for calculations of actual hirda collection.
- The survey included questions regarding hirda production and hirda collection and difficulties in collection of hirda. Also, questions on current practices followed by the tribals for processing and storing the hirda were recorded. Questions regarding selling the hirda and difficulties and challenges faced by them in this process were also asked. The questionnaire also included questions regarding the price obtained for hirda being sold, names of vendors who purchase hirda, and forward linkages of hirda. The challenges and bottlenecks in the supply chain of hirda were also discussed.
- The survey was conducted by volunteers of NGO Shashwat trust, Junnar. It was assumed that the volunteers know the survey region well as they are living in the same area (Fig. 1).

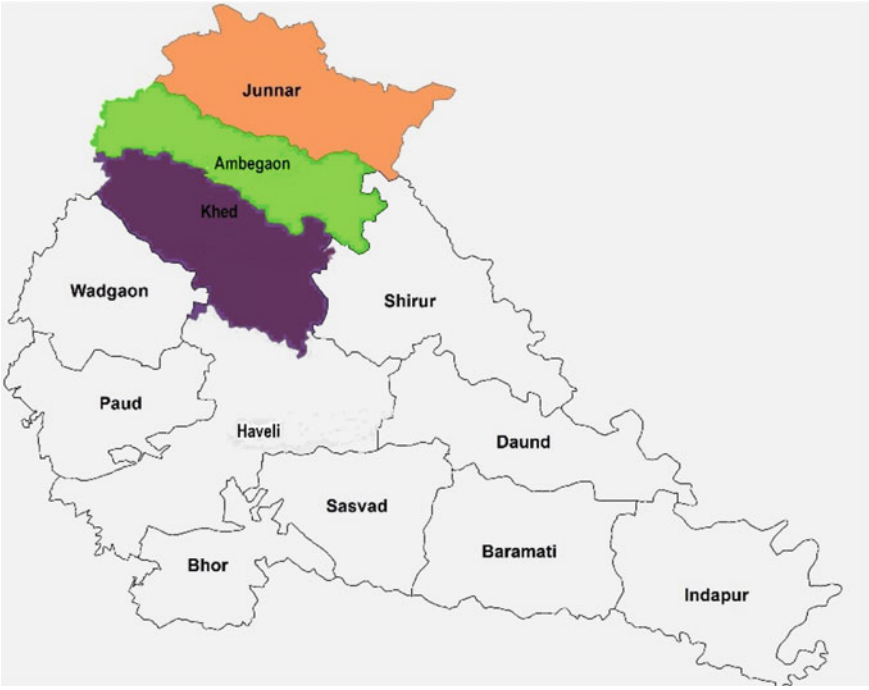


Fig. 1 Study area in Pune district of Maharashtra

3.2 Production of Hirda

The data collected during our household survey has been presented in Tables 1, 2, 3, 4, 5 and 6.

Number of households in villages not surveyed was calculated with help of census 2011 data.

Actual collection = Total no. of households dependent on hirda in the block * average collection of hirda per household (Fig. 2).

Table 1 Collection of Bal hirda (as per household survey)

Name of block	Number of villages surveyed	Number of households surveyed	Collection of hirda (in tons)	Average collection per household (in tons)
Ambegaon	30	2514	537.9	0.21
Khed	15	1725	289.63	0.16
Junnar	8	732	138	0.19

Table 2 Collection of Bhadodya hirda (as per the household survey)

Name of block	Number of villages surveyed	Number of households surveyed	Collection of hirda (in tons)	Average collection per household (in tons)
Ambegaon	30	2514	398	0.16
Khed	15	1725	232	0.13
Junnar	8	732	97	0.13

Table 3 Number of households involved in hirda activity in each block

Name of block	Number of villages surveyed	Number of villages not surveyed	Number of HH surveyed	Number of HH in villages not surveyed	Total number of HH dependent on hirda
Ambegaon	30	7	2514	1060	3574
Khed	15	12	1725	1045	2770
Junnar	8	16	732	1728	2460

Table 4 Actual collection of Bal hirda

Name of block	Number of households dependent on hirda	Average collection of hirda in block (in tons) per household	Actual collection of hirda (in the block) in tons
Ambegaon	3574	0.21	750.54
Khed	2770	0.16	443.2
Junnar	2460	0.19	467.4
Total collection of Bal hirda			1661

Table 5 Actual collection of Bhadodya hirda

Name of block	Number of households dependent on hirda	Average collection of hirda in block (in tons) per household	Actual collection of hirda (in tons)
Ambegaon	3574	0.16	571.84
Khed	2770	0.13	360.1
Junnar	2460	0.13	319.8
Total collection of Bhadodya hirda			1251

To summarize:

- Total collection of Bal hirda in the region was found to be 1661 tons
- Total collection of Bhadodya hirda in the region was found to be 1251 tons
- Overall hirda collection in the region was found to be 2912 tons
- Ambegaon block had the highest collection of hirda (45%) in the region.

Table 6 Region-wise collection of hirda

Name of block	Collection of Bal hirda (in tons)	Collection of Bhadodya hirda (in tons)	Total collection of hirda (in tons)
Ambegaon	750.54	571.84	1322
Khed	443.2	360.1	803
Junnar	467.4	319.8	787
Total	1661	1251	2912

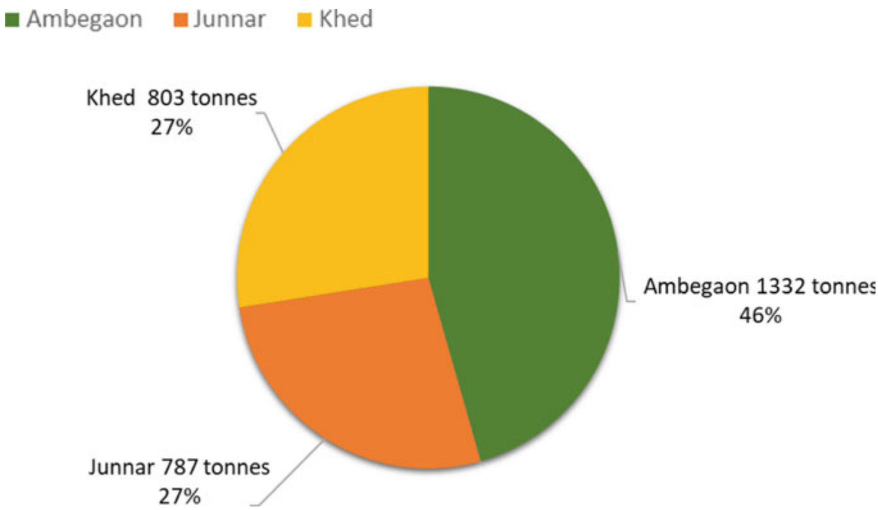


Fig. 2 Region-wise hirda collection

4 Problems Associated with Collection and Processing of Hirda

Majority of the tribal residents of Ambegaon, Khed, and Junnar blocks of Pune district collect hirda for livelihood generation. Hirda trees are available in abundance in the forests in this region. Some of the residents have also grown hirda trees on the farmlands owned by them. In this context, this section presents information regarding the collection and processing of hirda in area under study.

4.1 Safety Issues in Harvesting of Bal Hirda

The harvesting of Bal hirda is done by climbing up on the tree. The tribals use long sticks to thrash the branches with hirda fruits. This causes damage to the hirda tree and disturbs the environmental balance. Also, since the harvesters have to use their hands to thrash the branches resulting in difficulty in balancing themselves, many times the harvesters fall off the tree and meet with an accident.

4.2 Unhygienic Processing and Drying Practices of Hirda

Hirda is usually processed and dried in very unhygienic conditions. For example, prior to drying, Bal hirda is spread on ground followed by stamping on hirda with feet. These unhygienic methods make hirda prone to contamination resulting in reduction of its value in the market. During the discussion with end-users and customers, it was found that the tribals can get a higher value for hirda if it was processed hygienically.

4.3 Governance Issues Regarding Collection of Hirda

RuTAG IIT Bombay studied various regulations by the forest department regarding collection, storage, and transportation of hirda. For this purpose, a meeting was held with the Deputy Conservator of Forests, Junnar Division. The following points came up in the discussion:

- Hirda is listed as a minor forest produce (MFP) by the Forest department. As per the Government rules, collection, storage, transport, and sale of all MFPs (collected from private or forest land) are controlled by the forest department. Therefore, hirda requires storage license and transport permit from the forest department.
- The Provisions of the Panchayats (Extension to Scheduled Areas) Act, 1996 or PESA is a law enacted by the Government of India for ensuring self-governance through traditional Gram Sabhas for people living in the Scheduled Areas of India. Under this provision, the Gram Sabha of PESA villages has right to collection and selling of hirda (The Provisions of the Panchayats (Extension to the Scheduled Areas) Act 1996).

5 Decortication of Hirda

It was found during our study that separating the outer shell of Bhadodya hirda from its seed (decortication) can enhance its value by 3–4 times. In this context, following information was obtained.

5.1 Problems Associated with Current Method of Decortication of Hirda

The process of separating outer shell of Bhadodya hirda from its seed is called decortication. It was found that decortication could help the tribals earn three to five times their current incomes through selling of Bhadodya hirda. Traditionally hirda was manually decorated with help of stones. This activity was having very low productivity and also was full of drudgery (Tak et al. 2018). In view of this issue, RuTAG IIT Bombay has designed a small-scale hirda decortication machine suitable for the tribal areas.

5.2 Hirda Decortication Machine Designed by RuTAG IIT Bombay

RuTAG IIT Bombay has designed a Hirda decortication machine that can decorticate 100 kg of hirda per hour. This machine can operate on single-phase electricity supply. Six hirda decortication machines have been disseminated to various SHGs engaged in collection and processing of hirda through funding from the Tribal Development Department (TDD), Government of Maharashtra. Dissemination of six more machines also has been approved by the TDD and the activity is in progress. There is a scope to build a new market for selling decorticated hirda in the region with the help of the hirda decortication machines (Tak et al. 2018) (Fig. 3).

6 Supply Chain of Hirda

The main objective of this study was to find out bottlenecks in the supply chain and identify potential interventions for optimal utilization and value addition so that the tribals are benefited. Figure 4 explains the supply chain of hirda in the study area.

6.1 Supply Chain of Hirda

- Level 1: The villagers collect hirda from trees. Hirda trees are available in the forest as well as on their own farmland.
- Level 2: The collected hirda is sun-dried and sold to private vendors at level 2. The vendors come to their doorstep for collection of hirda. The private vendors are willing to buy hirda even if it is not dried. These vendors usually offer very less prices and exploit the tribals who need money immediately. The other option possible at level 2 is selling hirda to the "Adivasi societies" supported by the Tribal

Fig. 3 Hirda decorticator by RuTAG IIT B

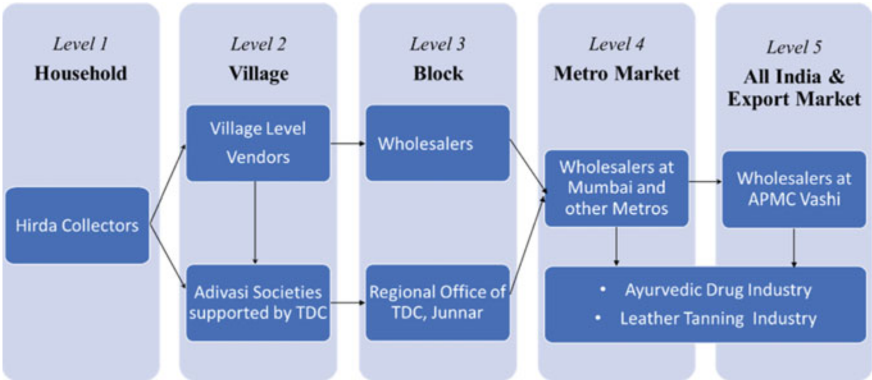


Fig. 4 Supply chain of hirda

development corporation. The Maharashtra state co-operative tribal development corporation (MSCTDC) offers rates according to the minimum support price (MSP) declared by the Government of India for different minor forest produce (MFP).

- Level 3: In level 3 the private vendors either sell the hirda to the wholesalers at Hyderabad or Mumbai directly or they sell it to the regional office of the Tribal development corporation (TDC) at Junnar. The regional office of TDC in turn auctions hirda.
- Level 4: The auctioned hirda is bought by wholesalers based in cities like Mumbai or Hyderabad at level 4. These wholesalers sell it to dealers who deal exclusively in trade of Ayurvedic drugs. These dealers are based either in APMC market in Vashi or Crawford market in Mumbai.
- Level 5: At level 5, the leather tanning companies and pharmaceutical companies manufacturing Ayurvedic formulations buy hirda either from wholesales in Mumbai and Hyderabad or from the drug dealers at APMC market at Vashi.

6.2 Methodology Adopted for Identification of Bottlenecks in Supply Chain

Following methodology was adopted by RuTAG IIT Bombay for identification of bottlenecks in the supply chain of hirda.

- **Discussion with the Tribals**
  A focused group discussion was held among the tribals who collect the hirda. Representatives of NGO Shashwat Trust, Junnar were also invited for the discussion. Various issues related to collection, processing, transport, and sale of hirda were discussed. The tribals were encouraged to identify the difficulties faced in various aspects.
- **Meeting with the Officers of Forest Department**
  For understanding various regulations by the forest department regarding collection, storage, and transportation of hirda a meeting with Deputy Conservator of Forest, Junnar division was held.
- **Meeting with the MSCTDC Office**
  The tribal economy is dependent mainly on the forest produce available in the forest. Traditionally the tribals were exploited by unscrupulous forest contractors, due to their illiteracy and ignorance. The State Government with the intention to free tribals from exploitation promulgated various laws and also initiated concept of minimum support price (MSP). Hirda is categorized as a minor forest produce. Therefore, MSCTDC plays an important role in purchasing hirda from the tribals as per MSP declared by the Government from time to time. For better understanding of this subject and understanding various issues associated with it, RuTAG IIT Bombay team members visited the office of Maharashtra state co-operative tribal development corporation (MSCTDC) at Junnar.

- **Discussion with Ayurvedic Medical Practitioners**
  RuTAG IIT Bombay visited the Ayurvedic medical practitioners to understand importance of hirda in Ayurveda. The quality norms needed for Ayurvedic medicines were also studied during this discussion. Dr. Mandar Akkalkotkar from Tilak Ayurvedic Mahavidyalaya, Pune along with Dr. Ashalata D. Pawar and Dr. Sanjay Talmale from R.A. Podar Ayurved Medical College were the doctors who shared their views and valuable information with the RuTAG team. From the discussion with the medical practitioners, it was concluded that hirda is a very important medicine in the Ayurvedic medical system and it is an essential component of most of the Ayurvedic formulations.
- **Discussion with Pharmaceutical Companies**
  RuTAG IIT Bombay also conducted discussions with pharmaceutical companies based in Mumbai and Pune which are in business with manufacturing Ayurvedic formulations. The objective of conducting this discussion was to explore possibility of establishing a direct channel for selling the hirda collected by the tribals. During the discussion, important issues of concern for the pharmaceutical companies such as the quality of raw material, impurities, and adulteration in the material, packaging requirements, etc. were highlighted.
- **Field Visit to APMC Vashi and Dava Bazar in Mumbai**
  RuTAG IIT Bombay also approached the bulk drug dealers based in APMC Vashi who deal in trade of Ayurvedic medicines. The main reason for this was to explore possibility of establishing a direct linkage between the hirda collectors and the bulk drug dealers. This discussion was expected to generate possibility of higher incomes for the tribals due to direct linkage with dealers at level 5 in the supply chain.
- **Analysis of Case Studies of Successful Entrepreneurs in Trade of Hirda**
  RuTAG IIT Bombay also studied case studies of two enterprises that have successfully established trade of hirda in that region. This was done for understanding various ways in which business can be established.

  It was found that tribals in Dhagewadi village of Bhimashankar region had already established their business of hirda and were successfully exporting hirda. The team members of RuTAG visited Dhagewadi and analyzed the strategy adopted by the NGO Applied Environmental Research Foundation (AERF) who was guiding the tribals. It was found that the tribals were focusing on collection and decortication of hirda in a scientific manner. Lot of importance was given to maintaining hygiene and adhering to standards needed as per the exporting norms. Due to the focused and systematic efforts, the Dhagewadi village enterprise was able to export 12 tons of hirda every year.

  Similarly, case study of Mahalaxmi self-help group in Rajpur Gadewadi village was studied by RuTAG IIT Bombay. This SHG had initiated trade of Bal hirda and Bhadodya hirda under letter of approval from gram Sabha by taking advantage of provisions in PESA act (The Provisions of the Panchayats (Extension to the Scheduled Areas) Act 1996).

Fig. 5 Stakeholders engaged during workshop on supply chain of hirda

- **Workshop on Supply Chain of Hirda**

  RuTAG IIT Bombay also organized a workshop titled "Potential Interventions in the Supply Chain of Hirda for Optimal Utilization and Value Addition" in January 2020. Main objective of the workshop was to facilitate discussion on various issues related to collection, storage, processing, and utilization of hirda. All the stakeholders associated with the supply chain of hirda were invited to the workshop. The invited guests included representatives of tribals who are the hirda collectors, officers of Tribal development department and forest department, and Ayurvedic medical practitioners. Apart from this, purchasers of hirda were also invited. We had also invited representatives of two enterprises who had successfully initiated trade of hirda in Ambegaon region. This helped in getting a 360-degree appraisal of various issues involved (Fig. 5).

  The important discussion areas during the workshop included

- Sustainable and optimal collection and utilization of hirda
- Fair value sharing in value chain of hirda
- Technical issues in the processing (drying and decortication) of hirda
- Environmental issues related to the depletion of hirda trees
- Regulatory and quality issues related to collecting, storing, and transporting hirda
- Issues/bottlenecks in supply chain having impact on the tribals.

7 Bottlenecks in Supply Chain

Following important issues with respect to supply chain were identified.

7.1 Socio-economic Issues

Following socio-economic issues were identified during the study.

- **Tribals Sell Hirda Without Processing**
  Bhadodya hirda has got potential for value addition through decortication. For example, if Sun-dried Bhadodya hirda is sold at rate of Rs. 15/kg, the decorticated Bhadodya hirda can be sold at rate of Rs. 50/kg and the hirda powder can be sold at rate of Rs. 70/kg. However, the tribals sell unprocessed Bhadodya hirda to the middlemen and get low returns on the same. This is because the traditional practice of using stone for decortication is full of drudgery with low output at a low speed with considerable labor. Also, suitable machines for processing hirda are not easily available.
- **Lack of Collective Efforts among Tribals**
  Hirda collection and selling are done as a family-level activity. The tribals do not do this at community level on collective basis. This results in low bargaining power while dealing with the middlemen.
- **Tribals Sell Hirda on Need Basis**
  Being a major source of cash income, hirda is sold as and when need for cash arises. For example, before the monsoon for preparations for farming, for social events like marriage, festivals, school and college admissions of children, etc. Individual family takes decision of selling depending on their need. As a result of this, they are exploited by the vendors and get low prices due to low quantity of hirda and immediate need for money.
- **Limited Access to Markets Offering Higher Price**
  Government has set a mechanism to purchase various NTFPs including hirda at minimum support price (MSP) to protect the tribals from getting exploited. But selling hirda to the Government requires the tribals to transport the hirda to regional office of tribal development corporation (TDC) at Junnar. The other option is to sell the hirda to "Adivasi Societies" supported by the TDC. In both cases selling small quantity of hirda is not a feasible option due to high cost of transport involved. The tribals do not have facility to store hirda hence large quantities cannot be accumulated. The tribals also lose out on the option of selling hirda in higher level markets like APMC Vashi for same reasons. As a result, most of the times, the tribals end up getting exploited and sell hirda for the price offered by traders who either pick up hirda from their doorstep or from the weekly market held in nearby towns. Although the traders offer low price, since they give immediate cash payment, they are preferred by the tribals.

7.2 Governance Issues

A few tribal organizations in Bhimashankar region have made isolated attempts to create an organized entity engaged in hirda trade but they are facing challenges in understanding the legal requirements for that. Hirda trade requires storage license and transport permit from the forest department. Transport of hirda collected from forest land additionally requires certification by the local Gram Panchayat under PESA act. Though these regulations are aimed at ensuring environmental conservation and securing rights of tribals, the permit and licensing processes are not transparent enough. Lack of awareness of the procedure and fear of law are important concerns for these new emerging enterprises initiated by the tribals.

7.3 Environmental and Safety Issues

The Bal hirda has higher demand and fetches higher prices in the market hence it is preferred by the tribals. As the seeds are not developed in the Bal hirda, there could be an adverse impact on the natural regeneration of hirda trees if there is a wide-scale harvesting of Bal hirda instead of the Bhadodya (mature) hirda. Harvesting of Bal hirda has an impact on production of Bhadodya hirda and hence propagation of the hirda trees is affected. Harvesting the Bal hirda is also risky and involves climbing on tall trees. The tribals often fall and meet with accidents during this process.

8 Proposed Interventions

In order to overcome the challenges faced by the tribals following interventions are proposed.

8.1 Disseminating Hirda Decortication Machine

During the discussion with various stakeholders during the workshop held at IIT Bombay, it was found that value of Bhadodya hirda can be enhance 3–4 times by decorticating it. At present, the tribals sell unprocessed Bhadodya hirda to the middlemen. It is proposed that the tribals should be provided with the hirda decortication machines designed by RuTAG IIT Bombay and encouraged to decorticate the hirda with help of the machines. There is a scope to build a new market for selling decorticated hirda in the region.

8.2 Social Entrepreneurship Through FPO

It was found during our study that the tribals are collecting and selling the hirda on basis of individual convenience. There is lack of collective efforts in collection as well as sale of hirda. As a result of this, they are unable to sell hirda to bigger vendors who can offer better prices. As a solution to this problem, it was proposed that a producer organization or a farmer producer organization can be established for the tribals. A Producer Organization (PO) is a legal entity formed by primary producers, such as farmers, milk producers, etc. for sharing of profits or benefits among the members. The main aim of PO is to ensure better income for the producers through collective efforts. Usually, due to long chain of intermediates in supply chain, producer receives only a small part of the value that the ultimate consumer pays. The small producers also do not get the benefit of economies of scale as the produce on individual basis is small. Through aggregation, by forming FPO the primary producers can avail the benefit of economies of scale. They will also have better bargaining power vis-à-vis the bulk buyers of produce and bulk suppliers of inputs. RuTAG IIT Bombay has encouraged the tribals to come together and start trade of hirda through their FPO. The name of the FPO is “Bhimashankar Matsya Krishi va Vanopaj Producer Company Ltd”. There are more than 300 members of this FPO and they have started trade of Bal hirda this year, i.e., year 2020.

8.3 Forward Linkages for Better Value

The SHG and FPOs engaged in collection and processing of hirda need to work with a two-pronged strategy. First, they can act as bulk suppliers of Bal and Bhadodya hirda to the traders in wholesale markets like APMC Vashi and other national level markets. Secondly, they can also supply small batches of Bal and Bhadodya hirda to pharmaceutical companies manufacturing Ayurvedic medicines and also Ayurveda doctors from nearby cities and districts. In view of this, the FPO “Bhimashankar Matsya Krishi va Vanopaj” will have to take storage license from the forest department and build storage system to ensure timely delivery of Hirda as per the requirements of customers. FPO also will have to decide about working capital for purchase of raw hirda and other business-related expenses.

Apart from this, there is also scope for exporting the hirda in bulk. Most of the hirda trees in the tribal areas are cultivated organically. Therefore, it is recommended that the tribals should obtain an “organic certificate” for the hirda collected. This strategy can enhance value of hirda multifold—especially in export consignments.

8.4 Awareness About Legal Framework and Safety Issues

During the study, it was found that the tribals are not clear about the legal requirements regarding collection, storage, transport, and sale of hirda. Lack of awareness of the procedure and fear of law was found to be the important bottlenecks in starting the trade of hirda by the tribals. It is therefore proposed to organize a training program for the tribals for better understanding of the legal framework.

8.5 Hirda Nursery for Environmental Balance

While harvesting hirda fruits from the trees, it is also important to maintain environmental balance. In this context, following points need to be considered

- **Sustainable Harvesting of Hirda**
  During the workshop held by RuTAG IIT Bombay, the forest department has given their recommendations for sustainable harvesting of hirda. It was recommended that maximum of 70% of available hirda fruits can be harvested as Bal Hirda and remaining 30% should be left on the trees and allowed to mature as Bhadodya Hirda. It is therefore proposed to organize an awareness program for the tribals in this regard.
- **Hirda Nursery**
  The forest department is also making efforts for regeneration of hirda trees. Recently, NGO Shashwat trust, Manchar has recently initiated a project for setting up a nursery of hirda trees through funding from Corporate social responsibility (CSR) of Mercedes Benz. The forest department is part of this project. Through this project, nearly one lakh hirda saplings have been distributed to farmers so far. It is recommended to start similar nurseries for regeneration of hirda trees as well as other medicinal plants in the forest (Fig. 6).

9 Conclusion

The study shows that Ambegaon, Junnar, and Khed blocks are the major hirda growing areas of Pune district of Maharashtra. During this study it was estimated that overall hirda collection from Ambegaon region is 1322 tons, Junnar block is 787 tons and Khed block is 803 tons. Total hirda collected in all the three blocks was found to be 2912 tons. It was also found through the study that market price of Bal hirda is almost 7–8 times higher than that of Bhadodya hirda. Therefore, the tribals prefer to collect the Bal hirda over Bhadodya hirda.

It was found that the tribals can enhance their incomes through trade of hirda in following ways

Fig. 6 Proposed interventions for overcoming the bottlenecks

- Decortication of Bhadodya hirda can increase its value by 3–4 times. The tribals can use the hirda decortication machine designed by RuTAG IIT Bombay for this purpose.
- Hygienic processing of hirda—It was also found that the customers at level 4 and level 5 of supply chain of hirda are willing to pay higher prices for hygienically processed hirda. Therefore, the tribals can increase their incomes by adopting hygienic processing of hirda.
- Organic certification for hirda—It was found through case study of the enterprise set up by villagers of Dhagewadi under guidance of AERF that there is a high demand in export market for hirda with organic certification. The tribals can increase their incomes multifold if the organic certification is obtained.
- Collective efforts through forming of FPO—It was found that the tribals collect hirda and sell it in small quantities to the middlemen. As a result of this, the middlemen exploit the tribals and offer low prices for hirda. Therefore, it is recommended that the tribals should put collective efforts into collection and selling of hirda by forming a FPO. The FPO will have a better bargaining power and can also deal with customers at levels 4 and 5 to get better prices for their products.

Through this study, it was also found that there are safety concerns associated with harvesting Bal hirda. Taking precautions and following the safety norms while harvesting Bal hirda is important.

Through this study, it was also highlighted that the tribals are unaware of the laws regarding collection, storage, and transport of hirda. This is one of the hurdles in way of the tribals in initiation of trade of hirda.

The study has also highlighted importance of sustainable harvesting of hirda. Nursery for production of hirda saplings for propagation of hirda trees and maintaining environmental balance has been recommended.

The study conducted by RuTAG IIT Bombay can indeed act as a catalyst to promote activities related to hirda and enhance incomes of the tribals in the given region. The project is expected to set a path for replication in other hirda growing regions of Maharashtra.

Acknowledgements The authors are grateful for funding and support from the National scheduled castes finance and development corporation (NSFDC). We would also like to acknowledge the support provided by the Office of Principal Scientific Advisor to the Government of India through mechanism of RuTAG. We are also grateful to Mr. Budhaji Damase and the members of NGO Shashwat trust Junnar for sharing valuable information regarding collection and processing of hirda in tribal areas of Pune. The authors would also like to thank the officials of the Tribal Development Department, Government of Maharashtra, officials of Forest department, Junnar, along with the Ayurvedic doctors and also the vendors based at Junnar as well as APMC Vashi who deal with trade of hirda. We are also thankful to the NGO Applied Environmental Research Foundation (AERF) and members of Mahalaxmi self-help group in Rajpur Gadewadi village for sharing their experiences of initiating trade of hirda. We would also like to acknowledge contributions of all other stakeholders associated with collection and trade of hirda in the study area.

References

Bag A, Bhattacharyya SK, Chattopadhyay R (2013) The development of *Terminalia chebula* Retz. (Combretaceae) in clinical research. Asian Pac J Trop Biomed 3(3):244

Gupta PC (2012) Biological and pharmacological properties of *Terminalia chebula* Retz. (Haritaki)—an overview. Int J Pharm Pharm Sci 4(3). https://pdfs.seatcscholar.org/5df6/fef5b0269082014b70abb782e0d8b7afad70.pdf. 6 Jan 2020

Parnis A, Lele Y (2011) Bio prospecting of the local wild edible varieties to address the issue of malnourishment in Palghar district. Project report by TERI, the Energy and Resource Institute. https://www.teriin.org/projects/nutrition-security/files/bioprospecting-report.pdf. 24 Dec 2019

Tak P, Haque T, Rao AB (2016) Better livelihood opportunities for tribals through supply chain interventions of hirda. In: 2016 IEEE region 10 humanitarian technology conference (R10-HTC), Agra

Tak P, Haque T, Guha A, Rao AB, Shah NG, Khanolkar R (2018) Study of supply chain, production potential of hirda and design of hirda decortication machine for livelihood generation for tribal people. In: Saha SK, Ravi M (eds) 1st international conference of RuTAG, rural technology development and delivery (RTDD). Springer Heidelberg, pp 248–261

The Provisions of the Panchayats (Extension to the Scheduled Areas) Act (1996)

Chapter 8
An Ergonomic Study for the Development of Low-Cost Work Station for Tribal Sal Leaf Plate Makers

Sasangbaha Mandi and Subhashis Sahu

1 Introduction

India has 8.6% of the tribal population, i.e., more than 104.2 million as per the 2011 census. Tribal peoples are dependent on the forest for sustainable livelihoods (Saha and Sengupta 2014). The major portions of them are inhabitants near the forest area and their entire life revolves around the forest. By providing livelihood wages, jobs, resources, healthy foods, housing materials, medicines, and a broad range of goods and ecosystem services, forests create a valuable role in the socio-economic, culture, and wellbeing of millions of forest-dependent people in rural areas (Islam et al. 2015). Sal leaf plate/cup making is a sustainable livelihood for a large number of tribal women. So, a study on this occupation from an ergonomic perspective is the need of the day to reach the sustainable development goal.

1.1 Stages of Sal Leaf Plate Making

Tribal women of West Bengal, India mostly perform the job for their livelihood involving Sal leaf plate making (Dey and Sahu 2009). There are three stages in plate making process. Female workers are mainly involved in the first two stages of plate making which is the collection of the Sal leaf by using pluckers from the forest. They spend 2–3 h per day after reaching the forest early in the morning for the collection of leaves and bind them properly to carry them home (Fig. 1a and b).

S. Mandi (✉) · S. Sahu
Ergonomics and Occupational Physiology Laboratory, Department of Physiology, University of Kalyani, Kalyani, Nadia, West Bengal 741235, India
e-mail: sasangbahamandi@gmail.com

S. Sahu
e-mail: ssahu@klyuniv.ac.in

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_8

Fig. 1 Collection of Sal leaves

First stage

- **Stitching of leaves and making plate**: After returning home with the bundles of leaves, the green leaves are stitched manually in a sitting posture together using Juna grass or Neem nails. Making of plate needs about 7–8 fresh Sal leaves. Usually, experienced tribal females able to stitch 50–60 plates in one hour. They work for a long time in an awkward posture for making a plate (Fig. 2a and b).

Second stage

Fig. 2 Stitching of Sal leaf using Juna grass

- **Drying of stitched leaf plates**: The stitched leaf plates are allowed to keep on open ground to get moistured throughout the night to avoid any breakage on further processing before which these leaves are kept under the sun for 3–4 h to get dried (Fig. 3).
- **Packaging of dried stitched plates**: The dried stitched plates were bundled into hundred pieces which are kept under pressure using heavyweight generally with stone for about 2–3 h (Fig. 4a and b).
- **Transportation of plates**: Plates are generally transported in an auto-rickshaw or van or bicycle.

Third stage: The third step is making the plate with machine stitching and shaping the plates with the machine. Generally, females are not engaged in this stage of processing.

Fig. 3 Drying of stitched plates in the sunlight

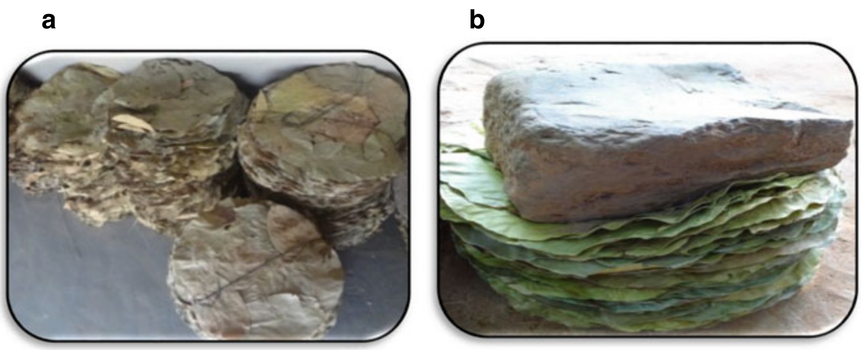


Fig. 4 Packaging of dried stitched plates

Work-related musculoskeletal disorders (WMSDs) are a major occupational disease occurring around the world in both develop and developing countries and India is no exception involving harm to the body's joints, nerves, muscles, tendons, and ligaments that support limbs, neck, and back. These involve inflammatory responses and degenerative issues that impair normal activities causing pain and discomfort. MSD is the leading cause of disability among people during working years as reported (Choobinch et al. 2007).

WMSDs may entail symptoms like discomfort, loss of muscle strength, local or generalized pain, loss of the ability to perform controlled movements or balance reactions, and loss or hypersensitivity of sensation to touch, heat, and pressure (Punnett and Wegman 2004).

The tribal female Sal leaf plate making workers felt maximum discomfort at the neck (75.25%), wrist (60.25%), lower back (85.25%), upper back (67.25%), hip (80.25%), and knee (81.50%) as depicted from an earlier study (Mandi et al. 2019). The current study attempts to develop an ergonomic low-cost workstation to reduce the musculoskeletal problems of the tribal Sal leaf plate maker.

2 Material and Methods

2.1 Designing of Low-Cost Workstation

A folding work table and wearable seat with lumbar support were designed based on posture analysis and activity analysis (Fig. 6). This newly designed prototype was developed based on the ergonomic principle and after several trials.

2.2 Subjects

For evaluation of the user perception, fifty (50) tribal female Sal leaf plate making workers were randomly taken as study participants. Working experience of a minimum of two years with no previous history of chronic ailments was our inclusion criteria.

2.3 Physical Parameters

The Body Surface Area (BSA) (Weisell 2002) and the Body Mass Index (BMI) (Bannerjee and Sen 1955) of all the subjects were deduced from body stature and body weight measured using the Martin anthropometric rod (Takei, Japan) and digital weighing machine (Omron, India), respectively.

2.4 Body Part Discomfort Scale (BPD) Rating

The Sal leaf plate manufacturers' degree of discomfort/pain was measured during work on a 1–10 Body Part Discomfort Scale (Reynolds et al. 1994).

2.5 Evaluation of Postural Stress

The Working posture of Sal leaf plate makers before and after using workstation were analyzed using Rapid Entire Body Assessment (REBA) (Hignett and McAtamney 2000) and Rapid Upper Limb Assessment (RULA) (McAtamney and Corlett 1993) methods.

2.6 Analysis of Statistics

The data were presented as mean ± standard deviation (SD). The Student's *t*-test following Cohen's *d* was used at $p < 0.05$ as the limit of significance to determine statistical significance between the groups according to the parameters evaluated.

3 Result and Discussion

The tribal female engaged in Sal leaf plate making sits on the ground without any back support for a long period. In Fig. 5, a worker is sitting on the ground doing her work, this is the most common posture adopted by them. This adaptation to awkward posture for a long duration leads to wrist pain, elbow pain, neck pain, knee pain, and lower back pain. So, this posture affects muscles, tendons, joints, ligaments, and nerves leading to work-related musculoskeletal disorders. These anthropometric mismatches in work posture can have serious consequences on health and efficiency.

An ergonomic low-cost seat with foam and cloth was developed based on several trials (Fig. 6a). It can be used as a seat on the ground by the female workers in the usual working posture. The folding table can be used as a working surface (Fig. 6b). This newly designed prototype can help to maintain the natural curvature of the spine and reduce the bending of the back during work. The dimension of the workstation prepared is 3 ft. by 1 ft. which is made up of engineered wood and is foldable. The cushion is made up of high-quality foam and both of these cost around INR 750. The material is sustainable and is environmentally friendly that is easily disposable and can be repaired successfully.

Demographic features of the Sal leaf plate makers who participated in the user perception study are given in Table 1. It was observed that most of the female workers

Fig. 5 The posture maintained by the female workers during stitching of Sal leaves the plate

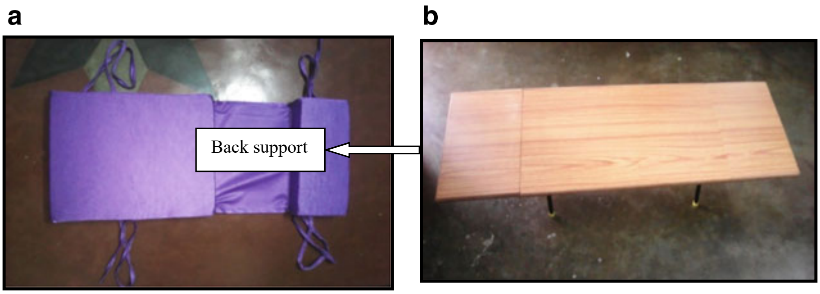


Fig. 6 Newly designed low-cost workstation

Table 1 Physical characteristics of tribal female Sal leaf plate making workers

Parameters	Age (yrs.)	Height (cm)	Weight (kg)	BMI (kg/m^2)	BSA (m^2)	Work experience (yrs.)
Sal leaf plate making workers (*N* = 50)	39.3 ± 12.59 (19.0–70.0)	150.7 ± 7.04 (139.7–170.1)	39.7 ± 6.26 (30.0–57.0)	17.4 ± 2.66 (13.9–25.1)	1.3 ± 0.11 (1.1–1.7)	27.4 ± 12.73 (8.0–60.0)

Data expressed as Mean ± SD (figures in the parenthesis indicate the range) who participated in this study belong to the middle-age group and their BMI lies in the underweight category (<18.0 kg/m^2).

The discomfort among them was due to continuous repetitive work with an awkward posture for a prolonged duration and hence there exists a high probability of development of musculoskeletal disorders (MSDs). Table 2 shows body discomfort felt by the Sal leaf plate makers which were rated using the BPD scale during work, before, and after usage of the new workstation prototype as suggested. The data revealed that the Sal leaf plate makers usually felt a greater degree of discomfort at the elbow, neck, wrist, lower arm, lower back, upper back, knee, and hip/buttock, regions which were found to be significantly ($p < 0.05$) reduced on using the new workstation prototype.

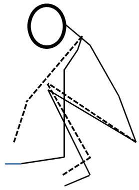
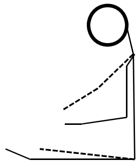
Table 3 presents an ergonomic analysis of the working posture of the Sal leaf plate makers. On analysis, it was found that certain postures for specified work were harmful and needed actions to be implemented to protect the body for further

Table 2 Discomfort rating in different body parts using BPD scale among Sal leaf plate making workers (before and after using work station) ($N = 50$)

Body parts	Before using a workstation	Newly design work station	Student's *t*-value	*P*-value	Cohen's *d*
Head	1.9 ± 0.54 (1.0–3.0)	1.8 ± 0.40 (1.0–2.0)	2.909	<0.05	0.210
Neck	2.8 ± 0.83 (1.0–5.0)	2.2 ± 0.64 (1.0–4.0)	8.267	<0.05	0.809
Shoulder	2.8 ± 1.17 (1.0–6.0)	2.6 ± 0.93 (1.0–5.0)	3.933	<0.05	0.189
Upper arm	3.3 ± 1.15 (1.0–5.0)	3.0 ± 0.89 (1.0–4.0)	4.582	<0.05	0.291
Lower arm	2.3 ± 0.67 (1.0–4.0)	2.0 ± 0.56 (1.0–3.0)	4.801	<0.05	0.485
Elbow	2.1 ± 0.80 (1.0–4.0)	1.6 ± 0.62 (1.0–3.0)	6.499	<0.05	0.698
Wrist	3.2 ± 1.01 (1.0–5.0)	2.4 ± 0.78 (1.0–4.0)	9.497	<0.05	0.886
Upper back	2.7 ± 1.34 (1.0–5.0)	1.8 ± 0.84 (1.0–4.0)	7.846	<0.05	0.804
Lower back	4.2 ± 2.28 (1.0–8.0)	2.5 ± 1.29 (1.0–6.0)	10.657	<0.05	0.949
Hip/buttock	2.1 ± 1.18 (1.0–5.0)	1.5 ± 0.72 (1.0–4.0)	5.610	<0.05	0.613
Knee	1.7 ± 0.78 (1.0–4.0)	1.4 ± 0.56 (1.0–3.0)	4.628	<0.05	0.441
Ankles	1.5 ± 0.66 (1.0–3.0)	1.4 ± 0.49 (1.0–2.0)	3.055	<0.05	0.172

Data represented as mean ± SD (figures in the parenthesis indicate the range)

Table 3 Analysis of working posture of tribal Sal leaf plate making workers before and after using the new work station

Working posture	Stick diagram	Activity	Scores	Action category
		Making leaf plate	REBA—9 RULA—7	• High • Investigate and implement change
		Making leaf plate	REBA—1 RULA—3	• Negligible risk • Further investigation, change may be needed

improvement. Figure 6a and b presents a low-cost prototype of a workstation was designed based on the ergonomic principle. After using the new workstation for two weeks, the user's feedback was collected and overall expressions and feelings of women tribal workers were it reduces the discomfort without hampering their natural way of work.

Hence, the low-cost intervention might be affordable to 75% of the tribal female workers, who had to spend a minimal portion of their income to purchase the same and it might be used by several women on a round basis so that they could reduce the burden to buy it. Since the major portion of the female workers belongs to the lower-income group so, it might not be possible for everyone to buy it but then there exists an alternate solution to build a user-friendly prototype using home available materials like using of bamboo sticks to make the table and using pillows available at home for posture support. For the successful implementation of this intervention, it is essential for a huge production that may be attributed to the self-help groups that will in turn provide them with an income opportunity.

4 Conclusion

As a result of continuous work in an awkward posture, the Sal leaf plate making female tribal workers developed musculoskeletal ailments in various body parts and the problems were found to be alarming. The low-cost workstation designed and developed in this study was ergonomic and helped to reduce musculoskeletal problems in female workers. The designed work station was provided for up-gradation of the working life of the female tribal Sal leaf plate making workers.

Acknowledgements SM would like to acknowledge NFST (Ministry of Tribal Affairs, Govt. of India) and SS acknowledges partial financial support from Kalyani University's PRG, DST-PURSE II for the conduct of this research work. The authors would also like to acknowledge other research support from the Department of Physiology, the University of Kalyani, and all the subjects for their kind cooperation in the report.

References

Bannerjee S, Sen RN (1955) Determination of the surface area of the body of Indians. J Appl Physiol 7(6):585–588. https://doi.org/10.1152/jappl.1955.7.6.585

Choobinch A, Tabatabaei SH, Tozihian M, Ghadami F (2007) Musculoskeletal problems among workers of an Iranian communications company. Indian J Occup Environ Med 11(1):32–36. https://doi.org/10.4103/0019-5278.32462

Dey M, Sahu S (2009) Ergonomic survey of leaf plate making activity of tribal women. In: Gangopadhyay S (ed) Proceedings of international ergonomics conference, HWWE, ergonomics for everyone, pp 433–440

Hignett S, McAtamney L (2000) Rapid entire body assessment (REBA). Appl Ergon 31(2):201–205. https://doi.org/10.1016/S0003-6870(99)00039-3

Islam MA, Quli SMS, Rai R, Singh PK (2015) Livelihood promotion through value addition to household traditional Sal (*Shorea robusta* Gaertn) leaf plate making in Jharkhand, India. Indian J Nat Prod Resour 6(4):320–325

Mandi S, Majumdar P, Sahu S (2019) Work-related musculoskeletal disorders of tribal female Sal leaf platemakers: an unperceived issue. BLDE Univ J Health Sci 4(2):78–84. https://doi.org/10.4103/bjhs.bjhs_38_19

McAtamney L, Corlett EN (1993) RULA: a survey method for the investigation of work-related upper limb disorders. Appl Ergon 24(2):91–99. https://doi.org/10.1016/003-6870(93)90080-5

Punnett L, Wegman DH (2004) Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. J Electromyogr Kinesiol 14(1):13–23. https://doi.org/10.1016/j.jelekin.2003.09.015

Reynolds JL, Drury CG, Broderick RL (1994) A field methodology for the control of musculoskeletal injuries. Appl Ergon 25(1):3–16. https://doi.org/10.1016/0003-6870(94)90025-6

Saha M, Sengupta S (2014) Symbiotic relationship between forest and tribe: a case study of Santal tribe of Jaypur forest, Bankura district, West Bengal, India. Trans Inst Indian Geogr 36(2):235–246

Weisell RC (2002) Body mass index as an indicator of obesity. Asia Pac J Clin Nutr 11(Suppl. 8):681–684

Chapter 9
Scale-Down Tea Processing Unit: Appropriate and Sustainable Technology for Small Tea Growers

Alankrita Saikia and Sashindra Kumar Kakoty

1 Introduction

Tea industry of Assam plays an important role in overall rural economy of India (Baruah 2015). Assam collectively yields 15,000 million pounds of Tea every year (MoSPI 2018). There are 55,191 small and micro tea farmers in the state (MoSPI 2018). Nevertheless, the major concern is that the role of these small tea growers is limited only to production of raw green tea leaves and selling it to other macro tea factories without value addition.

Due to complexities involved in existing large-scale machineries, small tea growers fail to adopt those technologies/machines. They are still dependent on their traditional tools/processes (Ganguli 2014). But these traditional tools cannot cater to their needs. As a result, they are bound to sell excess raw materials to tea processing factories of big estates at a very nominal cost. Thus, they are highly exploited due to absence of affordable tools/machineries for catering to their needs.

The reason behind this situation is due to the absence of alternative set of technology to address the issues that are substantial to the rural-based small tea growers of Assam. This situation accounts for the consistent or even lower economic development among the growers. The complexities of the established high technology fail to penetrate into the sheer fabric of the rural developmental program due to its acceptability among the rural people. According to the recent studies on technological development in rural areas, scholars have found that "appropriate technology" has the potential to uplift the technological needs in such places.

A. Saikia (✉) · S. K. Kakoty
Center for Rural Technology, Indian Institute of Technology Guwahati, Guwahati, India
e-mail: alankritasakiaofficial@gmail.com

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_9

1.1 Appropriate Technology

To address the problems of rural development in all sectors of rural areas; science and technology is considered as an important tool in developmental activities. Therefore, there is a need to introduce appropriate technologies that ensure economic and ecological sustainability and use the available local resources emphasizing technology capacity building for rural people (Rai and Kumar 2012). Another important aspect of rural development is the choice of technology, especially the way we innovate and design them according to the need and size of mass using it and assured added value to the existing methods.

Thus, Appropriate Technology is a framework that aims at building up local capacity, finding need-based solutions, and improving the lives of rural populations by improving the ecology that exists within that area.

1.2 Assam Vision 2030

Rural economy has an ability to change the scenario of economic development pertaining to the rural society if we utilize the potential of the small, micro, and medium enterprises. Assam Vision 2030 includes SDGs to transform Assam into a sustainably developed State by 2030. If we focus on Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. The document highlights the potential of the rural economy in Assam particularly small, and medium-scale agro-processing units, sericulture, horticulture, floriculture, handloom, and textiles. The Government aims to fully utilize the potential of small, tiny, micro, and medium enterprises for fostering industrialization (Bhamra and Niazi 2016).

1.3 Small Tea Growers of Assam

Toward the later decades of 1970, Assam witnessed the increase in growth of smaller tea gardens in the state. These gardens were developed by indigenous local people of Assam. The number of growers increased from 4028 in 1993 to 24,930 in 1999 (MoSPI 2018). From the data available in Tea Board India, the present number of small tea growers in Assam is 55,191. It is difficult to ascertain the exact number of growers as many small tea growers avoid registration with the Tea Board India.

The strength of small tea growers can be categorized as:

I. Scope for entrepreneurship
II. Source of Income and employment to the rural mass
III. Incentives provided by the Tea Board of India
IV. Utilization of land.

Small Tea Growers are providing direct and indirect employment for many. They are providing basic requirements to the people working for the industry and hence delivering better livelihood for the rural people of Assam (MoSPI 2018). The advantages of small tea plantation:

I. Cost-effective
II. Environment friendly
III. Sustainable
IV. Fosters growth of entrepreneurship
V. Rural Industrialization.

The small tea cultivators are proprietors, managers, and advisors in themselves. They need to know the science, technology, and culture behind the tea cultivation in detail. The question of sustainability arises on how the industry will cope with these challenges in future.

1.4 Major Problems

The small tea growers face the biggest problem during the peak tea growing season of the year (April–September) as macro tea manufacturing industries refuse to collect tea from them. This is due to excessive production of tea during the rainy season than the factory demand. Due to these tons and tons of tea leaves are damaged and are unused. As a result of this, they tend to sell the raw tea leaves at a very throwaway price to the macro tea factory outlets. This has shown tremendous downfall in the rural economy. Moreover, from the surveys, it has been found that macro factories refuse to accept the raw materials from the small tea growers due to the low quality of fresh tea leaves plucked from these small tea gardens (MoSPI 2018). The role of small tea growers is marginal in the entire value chain of the tea industry as their role is limited to production of raw green tea leaves and transporting it to other macro tea factories.

Based on field study experience and interaction with the small tea growers, design and development of a need-based technology for small-scale tea growers is initiated and described in the following sections.

2 Theoretical Background

2.1 Production of Black Tea

Drying of Agricultural crops for preservation is an old practiced traditional process. It is done to preserve it for future consumption and to transport it to distant places. Tea crop has a high moisture level at the moment of harvesting, and thus, it could

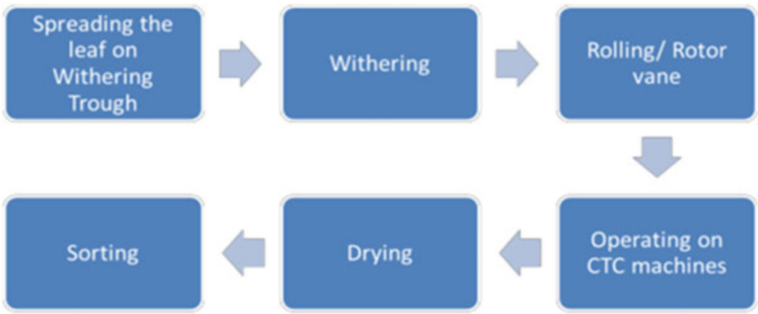


Fig. 1 Flowchart showing detailed manufacturing process of CTC tea

decompose in a relatively shorter period (Clifford 1992). Different processing techniques play a vital role in producing a proper output product so that optimum flavor and quality development take place.

Main Stages of Processing:

1. Partial removal of moisture (Withering)
2. Crushing, Tearing, and curling of Tea Leaves
3. Quality development by exposure to air (Oxidation or Fermentation)
4. Completion of Moisture removal (Drying or Firing)
5. Sieving into size fraction with fire removal (Sorting).

The flowchart of the detailed manufacturing process of CTC Tea is shown in Fig. 1.

3 Objective

The main challenges in terms of establishing a CTC Tea processing unit for small-scaled production are identified as follows:

I. Existing CTC Tea Manufacturing Unit is for large and medium production and hence it requires a large quantity (24 tons of raw tea leaves) which is not feasible for small tea growers.
II. Initial cost and operating cost of CTC Tea Manufacturing Unit are very high.
III. The machines require frequent maintenance which leads to a high maintenance cost.
IV. The manufacturing unit requires a large area for the setup.

Keeping in view all the aspects mentioned above, there is a need of designing a small-scaled CTC Tea Manufacturing unit for the small tea growers of Assam. This paper focuses on design of a small-scaled CTC Roller which is a component of CTC Tea Manufacturing Unit.

4 Methodology

A CTC tea processing unit consists of many parts. However, CTC roller plays the major role in the manufacturing process of CTC tea. Therefore, as the first step, only the CTC roller is taken up for scaling down in the present work.

4.1 CTC Rollers

Crushing, Tearing, and Shearing of tea are the main function of CTC machines. CTC Roller is a unit of CTC machine. It consists of either three or four sets of rolling cutters depending on the production line. Each set consists of one high sped roller and one slow speed roller. First set is used for rough rolling cutting operation and second and third set is used for refining rolling cutting operation.

Each pair of CTC rollers are fixed horizontally and parallel to each other on the CTC machine. They are connected to the motor and both are contra-rotating rollers rotating at a speed ratio of 1:10. The speed range of the slow roller is 55–70 rpm and that of the high-speed roller is 550–700 rpm. The slow roller acts initially as a conveyor apart from providing a surface for cutting. Two most important parts of CTC Rollers are: CTC Roller segment, CTC Roller Cylinder, and Tooth profile (Datta et al. 2007).

CTC Roller Segment: CTC Roller Segment comprises stainless-steel segments of 2 in. width and having an outside diameter that ranges from 8.25 to 13 in. These segments are fitted on the cylindrical mandrel side by side for the entire length of the CTC cylinder. CTC Roller segments are made up of AISI 304 austenitic steel (Lanjewar et al. 2008). It is manufactured by the method of forging as it is a rotating part.

4.2 Design of CTC Roller Segment Using Solid Works

Based on the present dimensions of CTC Roller Segments available in the market, a model of CTC Roller segment is designed in Solid Works as shown in Fig. 2.

Type of CTC Roller Segment: 13 in. diameter with 8TPI-80 helix with V-55 type tooth.

Width = 2 in. (50.8 mm).

CTC Rollers are scaled down to a factor of 0.5 considering the amount of raw tea leaves to be processed. Desired input of fresh tea leave is considered as 10 tons according to the production capacity of small tea farmers. The scaled-down roller segment has been shown in Fig. 3.

Dimensions of new CTC Roller Segment Outer Diameter: 6.5 in. (165.1 mm).

Inner Diameter: 5.315 in. (135 mm), Width: 1 in. (25.4 mm).

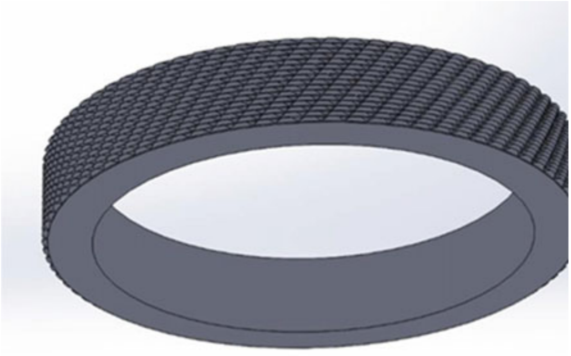


Fig. 2 Parent CTC roller segment

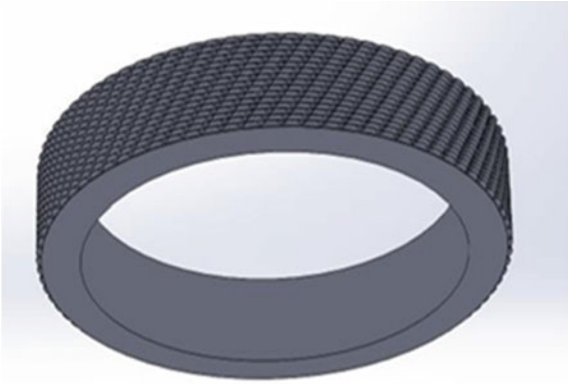


Fig. 3 CTC roller segment scaled down to factor 0.5

4.3 Assembly of CTC Roller Segment and Cylinder

CTC Roller Segments are mounted on the CTC Roller Cylinder mandrel. It consists of a cylinder shaft arrangement, which is connected to a motor. 22 numbers of CTC segments are mounted on each cylindrical mandrel and two CTC Roller Cylinders are meshed keeping an allowance of 0.05 mm as shown in Fig. 4.

4.4 Material Selection for CTC Roller Segment: AISI 304

Austenitic Steel containing chromium and nickel, 300 series is found to be the most suitable for the purpose. They have excellent corrosion resistance and unusually good formability. In the annealed condition, all austenitic steel is non-magnetic. Its strength can be increased by cold working. AISI 304, a type of Austenitic Steels that contains 18% chromium and 8% Nickel, has been selected as the material for the

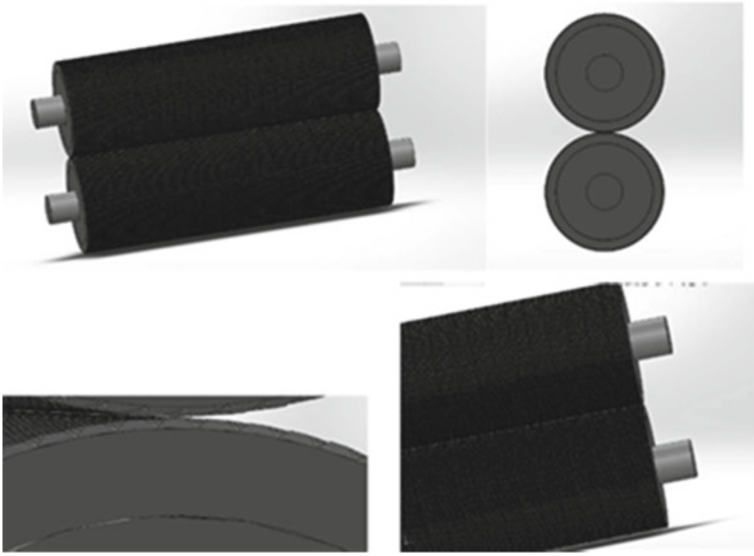


Fig. 4 CTC roller assembly

Roller segment. It has lower carbon content for better corrosive resistance (Design Guidelines for the selection and use of Stainless Steel, 1993).

5 Results and Discussion

Simulated stress profile, deformation, and temperature profile on both parent and scale-down model of CTC Roller Segment have been presented in Figs. 5, 6, 7, 8, 9 and 10.

Stress Analysis: The stress profile for an applied load on the roller segment can be observed from Figs. 5 and 6. It is seen that stress is low to moderate on the entire tooth, but it is high toward the middle point of shoulder length. The structure may fail at these points. It has been observed from the figures that the stress profiles are almost the same in both parent and scale-down models.

Deformation Analysis: Total deformation in the concentrated area of stress application is studied. Figures 7 and 8 represent the total deformation profile. The deformation is moderate in the area under observation. It increases toward the end of the helical path and is found to be high toward the last tooth. Deformation of both parent and scaled-down model is seen to be alike without any critical point.

Effect of Temperature: Taking room temperature of 25 °C during operation the temperature profile during the rotating condition is studied. There is an increase of

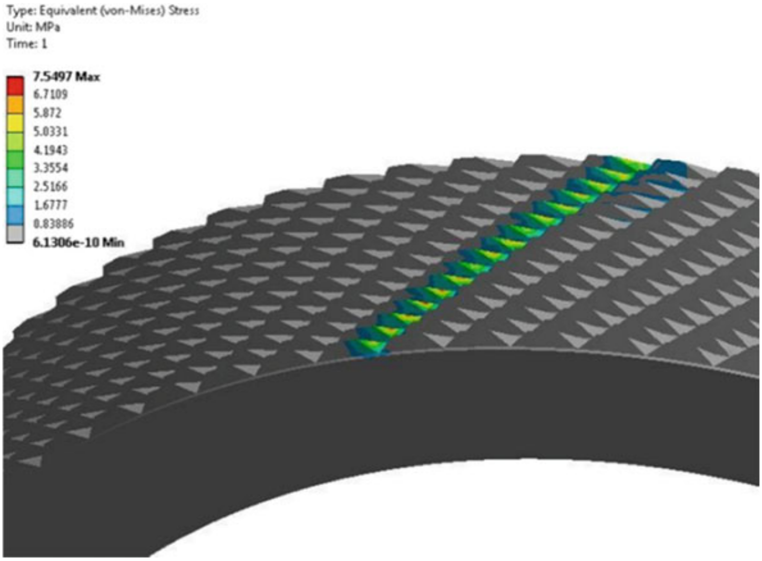


Fig. 5 Stress analysis of CTC roller segment

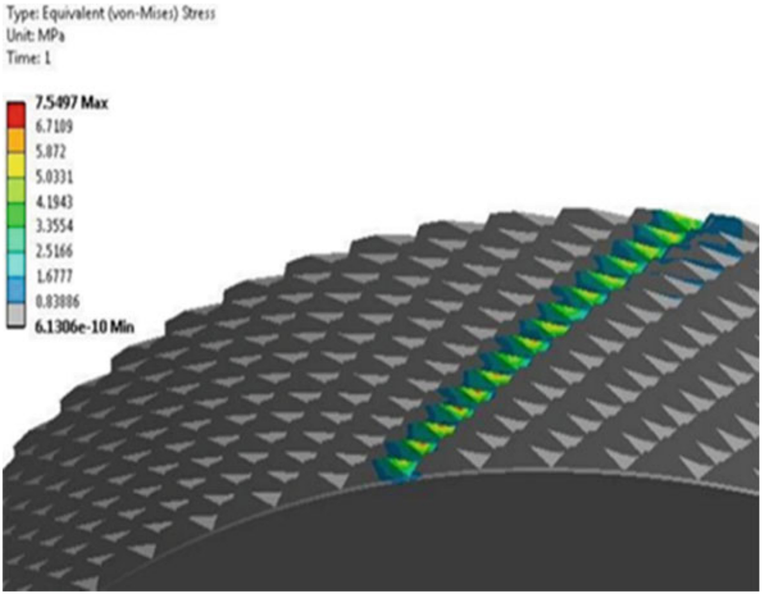


Fig. 6 Stress profile in scale-down model of CTC roller segment

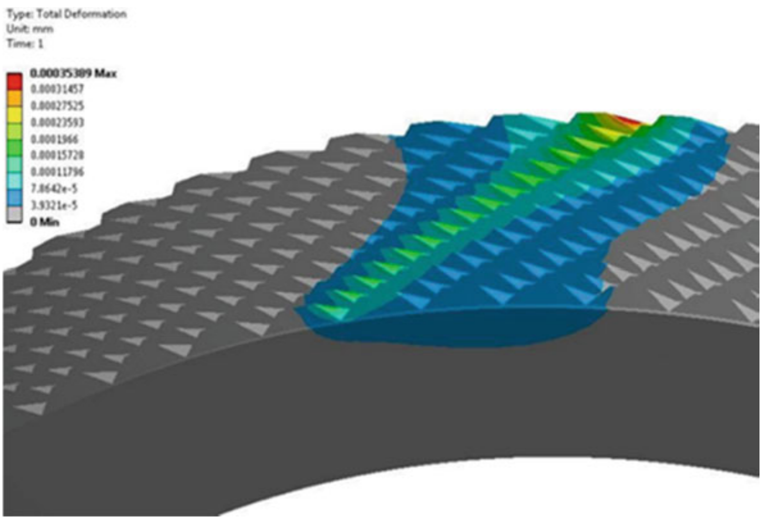


Fig. 7 Total deformation analysis of CTC roller segment

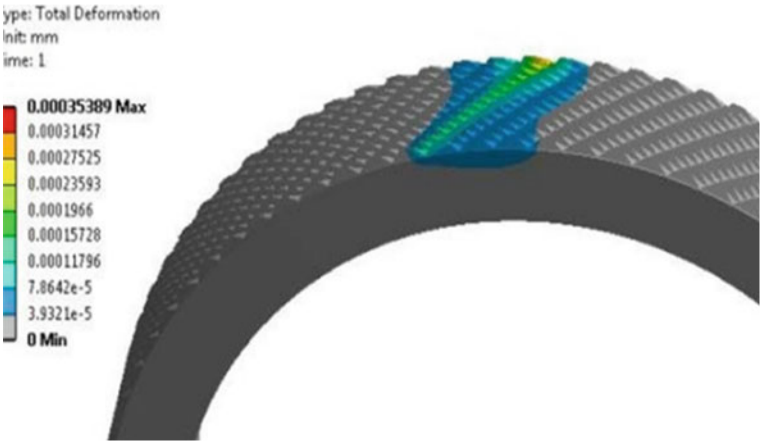


Fig. 8 Total deformation analysis in scale-down model of CTC roller segment

2–3 °C of temperature on the rolled leaves during cutting action in CTC Rollers. Figures 9 and 10 show the effect of temperature on the tooth profile of CTC Segment and scale-down model of CTC Segment, respectively. The temperature analysis on both parent and scaled-down models is observed to be the same and very minimum in both the cases.

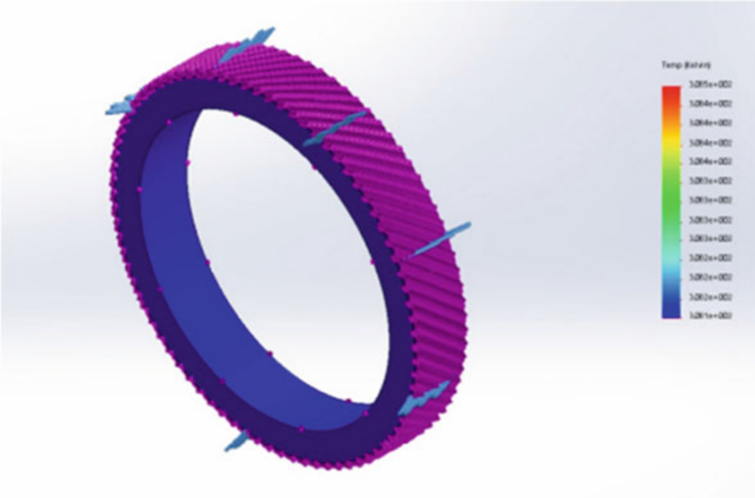


Fig. 9 Temperature profile on teeth of rotating CTC roller segment

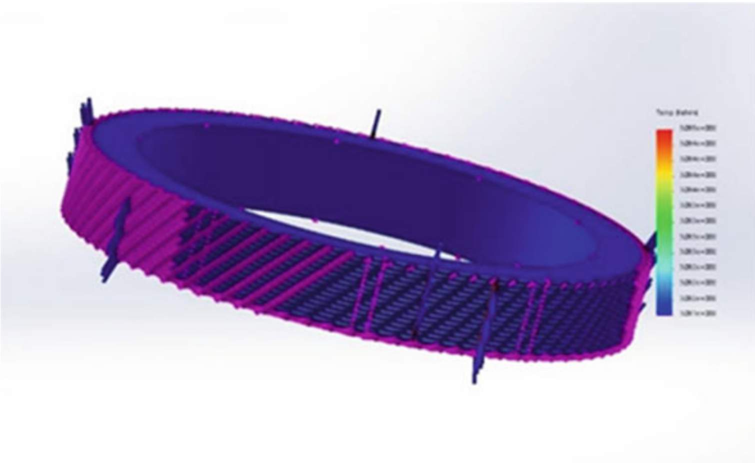


Fig. 10 Temperature profile on teeth scale-down model of CTC roller segment

6 Conclusions

Small tea growers occupy an important position in the economy of Assam. They have the potential to contribute to the generation of rural employment. But this sector faces many problems. The present condition of the small tea growers shows their dependency on Bought Leaf Factories and factories of other big Tea estates. There is a lack of operational infrastructure and absence of certain regulatory support which influences the income generated by these small tea growers. Thus, this paper aims to scale down the existing tea manufacturing unit.

In this study, proposed design of a scale-down version of CTC roller is discussed. Simulation results of both parent and scaled-down models are presented to study different characteristics. The analysis ensures that the CTC roller segment can be scaled down by a factor of 0.5 without affecting its performance characteristics.

References

Baruah P (2015) Problems of small tea growers. Soc Change Dev XII(1)

Bhamra A, Niazi Z (2016) Assam vision 2030 document—a review by development alternatives. Dev Altern

Clifford KW (1992) Tea cultivation to consumption. Springer

Datta U, Lanjewar RW, Balamurugan G, Banerjee AJ, Saha P, Sen S (2007) Development of automatic CTC roller chasing machine. In: 13th national conference on mechanism and machines, NaCoMM-2001. IISC, Bangalore

Ganguli P (2014) Small tea growers of Assam: theories, practices and challenges of an indigenous entrepreneurship. Int J Inf Futuristic Res 2(1):21–27

Lanjewar RW, Saha P, Datta U, Banerjee AJ, Jain S, Sen S (2008) Evaluation of machining parameters for turning of AISI 304. J Sci Ind Res 67(04):282–287

MoSPI (2018) State wise and item wise value of output from agriculture and allied sectors (2011–12 to 2015–16). Government of India, Ministry of Statistics and Programme Implementation

Rai N, Kumar V (2012) Role of science and technology in making rural India shine. IJRDMS 6(1)

Chapter 10
Dissolution Characteristics of Lac Dye

Nitish Kumar Tripathi, Baburaj A. Puthenveettil, and Abhijit P. Deshpande

1 Introduction

Lac is a natural resin of animal origin, the secretion of a tiny insect, *Laccifer lacca*, Kerr (Reshma et al. 2018). The resin obtained after processing the raw lac (stick lac) is a natural raw material for the manufacture of protective and decorative coating (Prasad et al. 2015) in the form of thin films, adhesives, and plastics with exceptional environmentally compatible properties, and is biodegradable. Lac is of profound economic importance in India (Yogi et al. 2016), since roughly 3–4 million tribal people, who constitute the socioeconomically weakest link of the Indian population, earn a subsidiary income from its cultivation (Yogi and Jaiswal 2014). India is the major producer of lac, accounting for more than 50% of the total world production. Due to this, any improvement in the processing of the lac has major social economic benefits (Chattopadhyay 2011).

The process of making seed lac, which is a semi processed material, from stick lac, involves several major steps, namely, crushing, winnowing, sieving, washing, drying, and grading. Stick lac is first crushed by roller crushers operated by either hand or power. Crushed lac is then winnowed to blow off lighter impurities. Sieving is then done, manually or with the help of power operated vibrating screens, to remove wood pieces, sand, and dirt (Sharma 2017). After these steps, the first phase of refining is done by washing with water, wherein water-soluble dye, vegetable glue, loose foreign substances, and dead insect parts are separated from the lac resin. Often, washing is done repeatedly using large amounts of water until the soluble dye and most of the impurities are removed. The lac, thus cleaned and refined, is spread on

N. K. Tripathi (✉) · B. A. Puthenveettil
Department of Applied Mechanics, Indian Institute of Technology Madras, Chennai, India
e-mail: apbraj@iitm.ac.in

A. P. Deshpande
Department of Chemical Engineering, Indian Institute of Technology Madras, Chennai, India

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_10

a large, clean, open air floor to dry. After drying, it is graded to get the commercial quality seed lac (Perveen et al. 2013).

We try to improve the washing process employed in GIRI MACS, a small-scale lac processing co-operative in Araku valley, near Vishakhapatnam, Andhra Pradesh, India. In their washing process, fresh water is continuously passed through the crushed stick lac while the lac is agitated in a horizontal drum using a rotating agitator. This process usually takes about two to three hours and 2000 L of water. Similar usage of water and power occur in most small-scale lac processing units. To improve such washing process, the mechanics of the dissolution of lac dye from the lac resin needs to be understood. We try to understand such dynamics in this study.

2 Material and Methods

2.1 Materials

The raw material for the washing experiments was pieces of solid lac obtained after crushing the stick lac and preliminary removal of wooden sand and dust parts, which was supplied by GIRI MACS.

2.2 Instruments and Chemicals

Shimadzu UV–VIS 1800 double-beam spectrophotometer, Precision electronic balance, Millipore deionized (DI) water, Cuvette, Magnetic Stirrer, and Laccaic acid from Sigma-Aldrich Co for calibration.

2.3 Procedure

We measure variation of the dye concentration in water with time by agitating stick lac in water as a function of various parameters of washing; the parameters include the agitation rate, the amount of stick lac, the amount of water, and the surface area of the granules of the stick lac. Twigs and other extraneous matter were first removed by handpicking, dusting, and sieving. The lac samples of different masses were taken and agitated with different rpm in different volumes of DI water. DI water volumes of V_w = 100, 200, and 300 ml at room temperature and masses of lac M_L = 0.5, 1.0, and 2.0 g, were used. Experiments with agitation rates of N = 500, 900, and 1500 rpm were conducted. The lac was then filtered with filter paper and dried with silica gel. The dried lac was kept in the oven for 30–45 min at a temperature of 40 °C to remove the remaining moisture after which the surface areas of the lac samples were measured by BET method. The washing was also carried out for lac samples that were first crushed for 5 and 20 s in a mixer grinder, maintaining the same procedures as mentioned above.

2.4 Determination of Concentration Using Spectrophotometer

During agitation of the lac samples in water, samples of water with dye dissolved in it were taken at various times (t) for measurement of the concentration of dye in water with time. Concentration of the dye in these samples were estimated from the measured absorbances of these samples using a UV–visible spectrophotometer with spectral region in the range 200–900 nm. The relation between absorbance (A) and concentration of dye (Cd) was obtained by calibrating the maximum absorbance obtained at a wavelength of 488 nm from known concentration of laccaic acid. The variation of absorbance at various concentrations of Laccaic acid in water with wavelength of light, used for calibration, is shown in Fig. 1. The calibration curve obtained was

$$A = 0.01525\,\mathrm{Cd}, \tag{1}$$

as shown in Fig. 2.

The absorbances of the dye solution samples, collected at various times while agitating the lac samples in water, were measured and then converted to concentrations of dye in water ($\mathrm{Cd_w}$) using the calibration relation (1), shown in Fig. 2. A

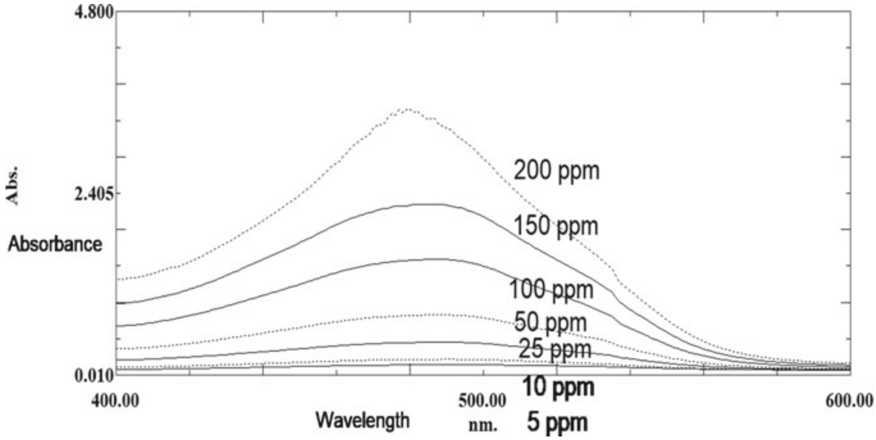


Fig. 1 Absorbance curves of various concentration of 200 ppm from top to 5 ppm of laccaic acid at lambda max 488 nm

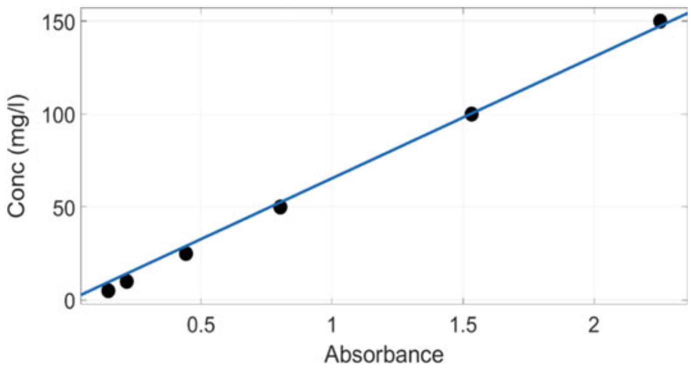


Fig. 2 Calibration curve of laccaic acid-o-, measured maximum absorbance of lactic acid at 488 nm at various Cd; $A = 0.01525 * \text{Cd}$

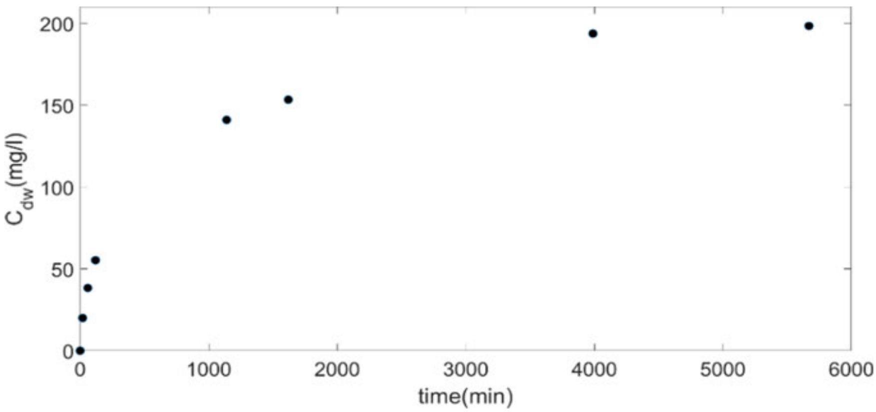


Fig. 3 Variation of the concentration of dye in water with time when a 2 g lac sample is agitated in 100 ml of water at 500 rpm

typical variation of (Cd_{w}) during the agitation of a 2 g sample of lac in $V_{\text{w}} = 100$ ml of water at 500 rpm is shown in Fig. 3.

3 Results and Discussion

An indicator of washing efficiency is the amount of dye remaining in the lac sample after a period of washing. We calculate the percentage of dye remaining in each lac sample as

$$C_{\text{dL}} = \frac{M_{\text{di}} M_{\text{L}} - C_{\text{dw}} V_{\text{w}}}{M_{\text{di}} M_{\text{L}}} \tag{2}$$

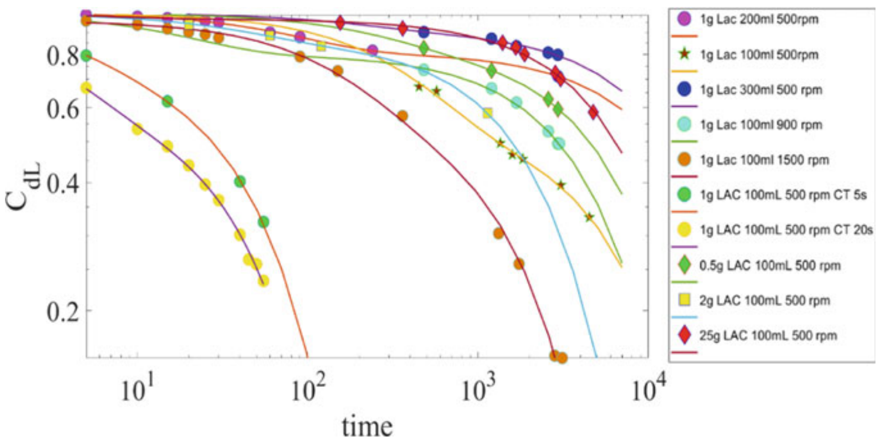


Fig. 4 Variation of C_{dL} with time for all the experiments; solid lines show the exponential curve fits of the form $A\mathrm{e}^{Bt} + C\mathrm{e}^{Dt}$

using the measured concentration of dye in water C_{dw}, where $M_{\mathrm{di}} = 16.87$ mg is the initial amount of dye in 1 g all the lac samples. M_{di} was found by repeatedly washing the lac sample, crushed into powder form, in several number of batches of fresh water, till no dye came out, with the dye concentration being measured in each batch.

Figure 4 shows the variation of C_{dL} with time for all the experiments conducted for various amounts of crushing of the lac sample, which results in various surface areas S_{L} of the lac samples, and for various M_{L}, V_{w}, and $\omega = \frac{2\pi N}{60}$. The solid lines in Fig. 4 are the curve fits of the form $A\mathrm{e}^{Bt} + C\mathrm{e}^{Dt}$ used to estimate t_{30} when data did not extend till t_{30}. From Fig. 4, we observe that t_{30}, the time taken till only 30% of the dye remains in the lac sample, i.e. time taken for C_{dL} to reach 0.3, decreases with increase in ω, V_{w} and S_{L}. This variation of t_{30} with ω, V_{w} and S_{L}, observable in Fig. 4, is plotted in Fig. 5, where the decreasing trends of t_{30} with ω, V_{w} and S_{L} can be clearly seen. The variation of t_{30} with increase in M_{L} is not so obvious since increase in M_{L} while increases the amount of dye to be removed from the lac and hence t_{30}, it also increases S_{L} which would in turn reduce t_{30}. Figure 5c shows that this variation is non-monotonic.

Inferring from these dependencies of t_{30} on M_{L}, S_{L}, V_{w}, and N, seen in Fig. 5, we now try to quantify these dependencies based on dimensional reasoning. We construct $t^* = t_{30}\,\omega$ as the dimensionless time taken for the concentration of dye in lac to reach 30% of its initial value. The other possible dimensionless combination that is in agreement with the expected variation of t_{30} with M_{L}, S_{L}, and V_{w} is a dimensionless washing parameter,

$$\zeta = \frac{C_{\mathrm{di}}\rho_{\mathrm{L}} S_{\mathrm{L}} v_{\mathrm{w}}^{1/3}}{M_{\mathrm{L}}} \tag{3}$$

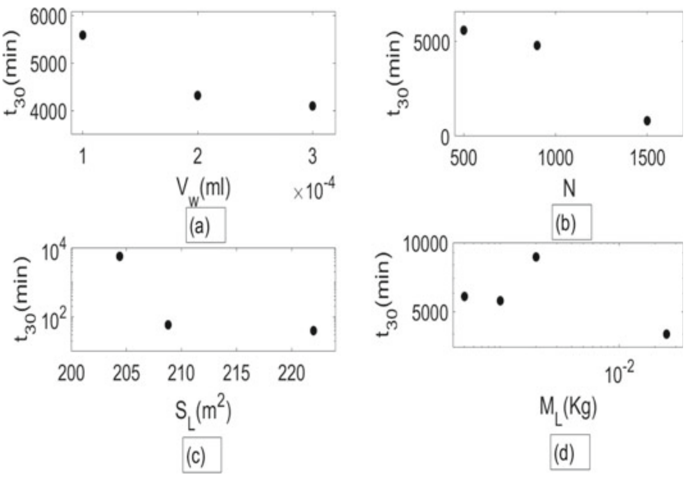


Fig. 5 Variation of t_{30} with V_{w} (**a**), ω (**b**), S_{L} (**c**), and M_{L} (**d**)

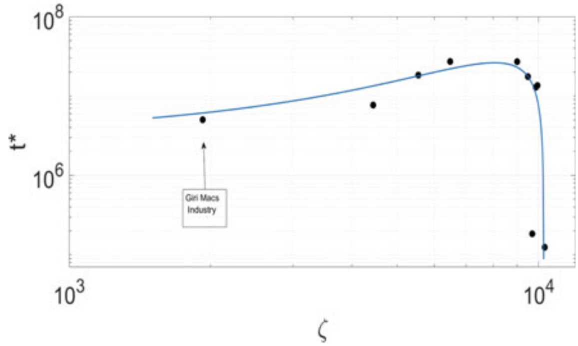


Fig. 6 The variation of dimensionless time for the concentration of dye in the lac to reach 30% of its initial value with the dimensionless washing parameter

Figure 6 shows the variation of t^* with ζ. All the data of t_{30} fall on to a single exponential curve $f(\zeta)$, where

$$f(\zeta) = (1.23\mathrm{e}+09)\mathrm{e}^{0.0004554\zeta} + (1.233\mathrm{e}+09)\mathrm{e}^{0.0004551\zeta} \quad (4)$$

Thus, the simple relation

$$t^* = f(\zeta) \quad (5)$$

could be used to estimate the time for the dye concentration in the lac samples to reach 30% of its initial value for different combinations of agitation rate, mass of lac sample, its surface area, and the volume of water. Figure 7 shows dimensionless washing time for the dye concentration in the lac sample to reach 50, 60, 65, and 70% of their initial value as a function of the dimensionless washing parameter

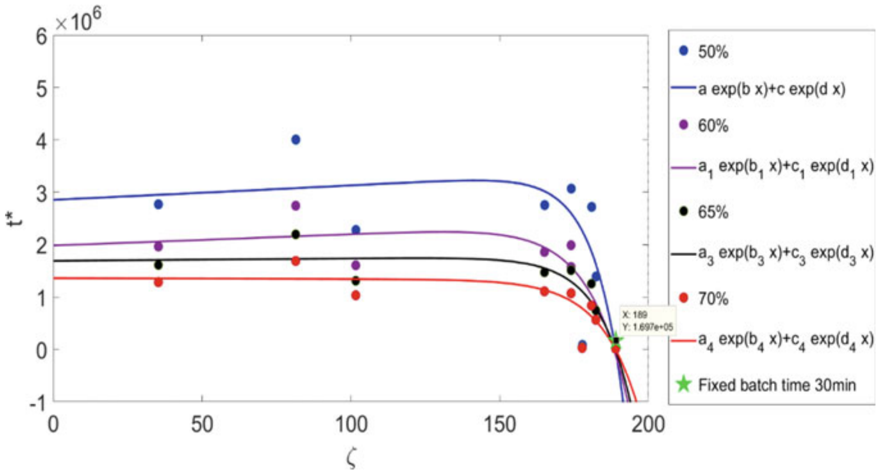


Fig. 7 The variation of t^* with ζ for various amount of dye in lac after washing

(3). The curves are similar in shape but shifted vertically upwards. The characteristic washing curves shown in Fig. 7 could now be used to convert the continuous washing process into a batch washing process, thereby effecting considerable savings in water consumption.

4 Conclusion

We studied the dissolution characteristics of lac dye from lac resin as a function of the agitation rate (ω), mass of the lac sample (M_L), the volume of water in which the agitation is done (V_w), and the surface area of the lac sample (S_L). We observed that the concentration of dye in water increases is an exponential manner resulting in an exponential decrease of dye mass in the lac sample. The value of mass of dye in the lac sample at any time was found to be decreasing function of ω, V_w, and S_L. These variations helped us to arrive at a relation for the time taken for 30% of the initial amount of dye to remain in the lac sample (t_{30}) as $\omega\, t_{30} = f(\zeta)$ where $\zeta = \frac{C_{d_i} \rho_L S_L v_w^{1/3}}{M_L}$ and f is a sum of exponential function. This relation can now be used to design interventions in the washing process so as to reduce the time and water usage in the washing process.

Acknowledgements We gratefully acknowledge the financial support of RuTAG IIT MADRAS. Experiments were conducted in the Environmental Engineering Laboratory of Chemical Engineering, IIT Madras; we thank Prof. R. Ravi Krishna for extending his laboratory facilities. We convey our gratitude to CCN Sahyog, Vishakhapatnam and GIRI MACS, Vishakhapatnam, for the information and material provided for this study.

References

Chattopadhyay S (2011) Introduction to lac and lac culture. BAU, Department of Forest Biology & Tree Improvement Faculty of Forestry, Ranchi

Perveen A, Jahan N, Abdul W, Alam MT (2013) Methods of processing of lac (*Laccifer lacca* Kerr) described in Unani system of medicine. Res J Pharm Sci 2(8):5–7. ISSN 2319-555X

Prasad N, Srivastava S, Siddique MZ, Sarkar PC, Ansari MF, Yadav SKS, Sharma SC, Thombare N (2015) Recent technologies at a glance. Technical bulletin No. 12/2015. ICAR—Indian Institute of Natural Resins and Gums, Ranchi, pp 1–35

Reshma BV, Manohar RN, Anaha VI (2018) A review on *Laccifer lacca.* World J Pharm Res 7(10):206–218

Sharma KK (2017) Lac crop harvesting and processing, chap 7

Yogi RK, Jaiswal AK (2014) Socio-economic characteristics of lac growers and host trees utilization pattern: a comparative study. Int J Usufructs Manag 15(2):37–46

Yogi RK, Singh RK, Bhattacharya A, Jaiswal AK, Kumar A (2016) Current scenario and new policy interventions in the lac sector. Jharkhand J Dev Manag Stud 14(1):6903–6917. XISS, Ranchi

Chapter 11
Innovative Technologies for Developing Rural Pottery Industry

Bhagavatheeswaran

1 Introduction

Pottery is one of the basic village industries, which had been sustaining the village economic since times immemorial. Large numbers of traditional potters are engaged in manufacturing traditional pottery products like earthen pots, pans, figurines, flower pots, garden pots, cook wares etc. Artisan pottery industry is as old as our civilization and legendry. The age of old traditional craft is found to be declining due to the lack of demand and hence the inadequate return. The industrial products out of metals, plastics etc. which are high quality attracted the public. The traditional pottery products users become less and hence less marketing of pottery products.

Before the advent of mechanized technology, every settled society was using some sort of pottery in their daily routine. However, the situation was gradually changed. High-tech utensils manufactured in metal, plastics and glassware introduced in the market. Hence the village pottery artisans were thrown out of business and forced to divert their skills in other fields. The village potters lacked the capability of developing innovative products, as demanded by the changing situation. Thus, the potters are severely affected by declining market for traditional products. This is the basic reason for potter families being economically very poor and living below poverty line.

Efforts were made to rejuvenate the traditional industry to some extend by government and non-government organization. Each organization is trying to intervene in the development of craft in their own ways. But nothing remarkable has been done in this direction. It is the prime necessity of all our concern to concentrate all our efforts to understand the problems and find out appropriate solutions and affect the outcome of the problems. Some spade work has been done here and there. But these activities could not catch the grip for a permanent development.

Bhagavatheeswaran (✉)
Centre for Social Development, Nagercoil, India
e-mail: csdbhagavathi@rediffmail.com

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_11

2 Limitation of Traditional Pottery

The traditional pottery making activities in the rural area of India have various limitations. All these limitations could be summarized as follows.

- The traditional pottery products are inferior in quality and look.
- Not meeting the modern requirements in terms of cooking and other utility.
- Energy consumption is high in comparison with other material vessels.
- Return from the industry is low and hence income level of pottery artisans is very low.
- Drudgery of production activity is high.
- Usage of obsolete machines and equipment.
- Limited fabrication methods and designs.
- Quantity of production is limited.

3 Innovations/Interventions Required

For upgrading the declining industry, it becomes essential to undertake the innovative approach in every steps of the production system. The possible innovation which could be undertaken has been listed out.

- Clay testing procedures—physical characters study needs to be initiated.
- For Clay processing technology, introduction of mechanical devices for cost effective processing of clay body preparation.
- Products requirement as per cooking habit of the consumers.
- Products fabrication technology needs to be introduced with the innovation of new machines for cost effective production.
- Products designing has to be undertaken for various types of utility and introduction of value addition and increase the product range.
- Efficient firing technology with designing of fuel efficient kilns for economy of the production.
- Business model development as a sustainable production enterprise.
- Packaging technology development as market promotional activities.

3.1 Clay Testing

It is essential to know the character of the clay. The physical characters of the clay are very important to understand the quality of the clay. Only after knowing the characters of the clay, the utility of the clay in the industry could be determined. To understand the characters same basic experimentations need to be conducted. Some of the physical characters need to be known are as follows.

- Shrinkage.
- Water absorption.
- Water of plasticity.
- Compressive strength.

Since the clay differs from sources to source it becomes necessary to find out the physical characters of the clay.

3.2 Clay Processing and Clay Body Preparation

Clay processing plays a vital role in determining the clay composition which we called as clay body preparation. The process of clay body preparation is achieved by undertaking clay processing methods. The clay body preparation method is essential to know the quality of the clay body. In general, there are three types of clay processing methods which are available. They are as follows.

- Wet processing
- Dry processing
- Combined process.

3.2.1 Wet Process

In wet process it is mainly done by adding required water in the clay lumps for clay body preparation. The dry clay lumps in small size were soaked in water. During this process all the ingredients needed for the clay body will be mixed beforehand and water is added with the dry clay lumps. The soaked clay mixer goes for the next operations. In the other method, clay slurry was prepared by the addition of excess water in a machine, sieved the slurry for getting fine granules of clay body in wet condition.

3.2.2 Dry Process

In this method the clay lump was broken into small pieces and dried in hot sun. When the clay lump is sufficiently dried, the lumps will be loaded in a machine to make fine powder. This fine powder is sieved to the required fineness mesh and utilized for further proposes.

3.2.3 Combined Process

Since drying of excess water takes time, the dry powder was added with the sieved clay slurry and soaked overnight. This soaked mixture was taken for further activities.

3.3 Factors Determined for Processing of Clay

The clay processing has been undertaken by considering the following purposes. The process depends on:

- The grain size required for products fabrication.
- The making temperature of the body.
- Quality of the clay available from the source.
- The fabrication techniques.

3.4 Machines Used for Clay Processing

There are different types of machines used for the processing clays. The processing techniques are determined as per the end products and the market value of the product.

Blunger

This machine is used for the clay processing by wet method. This is a cylindrical structure constructed by masonry work. A central shaft with a stirrer in the bottom is fixed. Whilst rotation when added with water and dry clay lumps, clay slurry was prepared. This clay slurry was sieved through the required mesh fineness and dried in settling tanks. This is a natural drying method. When the water is evaporated by sun, the semi-dried clay lumps were collected and utilized for next process.

Purpose of Blunger

- To remove stones, roots, pebbles etc.
- Homogeneous mixed of the ingredients.
- Cost effective clay slurry preparation.
- It detaches the clay from the impurities.
- Clay slurry as per our requirement can be prepared.

Ball Mill

This is a machine with cylindrical drum which rotates diagonally by mounted in two pedestals. It is erected on stand or pedestals on either side and rotates on axis. Inside the metallic drum there are fixed porcelain lining. Porcelain balls are used as a grinding media. The drum is loaded ¾ quantity of the inner capacity with material, balls and water. This machine was allowed to rotate for 24 h by an electric motor. The duration of the rotation depends upon the fineness of the clay slurry as per our requirement.

Purpose of Ball Mill

- Grinding the clay and other materials to fine mesh.
- Uniform mixing of the loaded materials.
- As per our requirement the batch can be determined.

Disintegrator

Disintegrator is used for powdering the dried clay lumps to fine mesh. This machine is a device which rotates in high speed and inside fitted with breakers. All these breakers are covered with a thick metal shield. Due to rotation the clay lump fed into the chamber got crushed and passes through a metal sieve of desired mesh fineness.

Purpose of Disintegrator

- Disintegrator produces huge quantity of clay powder with in short time.
- Desired fineness of dry clay powder is available by charging the mesh size.
- The machine is utilized for getting clay powder at minimum cost.

Wet Grinder

This is a machine used for grinding the clay mixture in wet condition. The soaked clay lumps have been ground to the required fineness by using metallic rollers. The moist clay was put between the rollers and squeezed to fine clay paste like thing. The rollers can be adjusted as per the requirement of the clay fineness.

Purpose of Wet Grinder

- Grinding of clay mixture is done by eliminating the manual labour.
- Clay body preparation time is saved.
- More quantity of clay body could be obtained in short period.

Pug Mill

Pug mill is used in pottery industry to get clay body kneaded with a required quantity of moisture. The appearance of the machine is similar to that of wet grinder with additional provisions for extruding the pugged clay from the machine. After the clay is being ground by using rollers, the kneaded clay was passed and pressed through a chamber with extruding arrangements fitted in the chamber. In the chamber the kneaded clay body was made homogeneous and comes out of the chamber through an outlet. The clay body comes out of the chamber through the outlet is cake like thing and with uniform moisture.

Purpose of Pug Mill

- Dual purpose is served. Grinding and kneading the clay body with controlled and uniform moisture of the clay body.
- By repeated pugging the fineness of the clay body can be increased.
- Pug mill eliminates drudgery of kneading operation and saves time.
- Desired quantity of clay body could be obtained.

3.5 Machines Used for Products Fabrication

There are different types of fabrication techniques and machines requested for those fabrication methods. Some of the important methods are as follows.

1. Throwing method—Electric potter's wheel
2. Jiggering method—Jigger and Jolly machine
3. Casting method—Plaster of Paris moulds
4. Pressing method—Hydraulic and electric press machine
5. Coiling method—Hand fabrication.

1. **Throwing method**

These are the common methods being practiced by most of the potters. For this method of fabrication special skill is needed to fabricate the products with the use of potter's wheel. Different types of wheels are available for the throwing purpose. Any types and shapes of circular form of articles could be fabricated by this method. Potters throwing wheel are available with different speed control.

2. **Jiggering method**

This is a method of preparing pottery products by a machine called Jigger and Jolly using plaster of Paris moulds. Beforehand we have to prepare the plaster of Paris working moulds by setting models of the products. By using this methods products of same size could be fabricated in a short time. For each and every type of products we have to prepare different working moulds. The moulds can be reused for 2/3 time a day after the removal of the fabricated products in the mould. This method is used in the industry for more volume of products fabrication. A semi-skilled worker can easily get trained and operate the machine for the fabrication of pottery products.

3. **Coping machine**

This is an advanced types of jiggering method by using specially designed machine called coping machine. This machine operates in a vertical form. Pottery products of very big size could be fabricated by using this machine. This machine could replace the manual working of the artisan and also eliminate the drudgery of operation.

4. **Pressing method**

Pressing is another method practiced for fabricating the products by using manual or mechanical methods by using plaster of Paris moulds or metallic dies used in a metal power press or hand press.

Manual method

Plaster of Paris moulds are used for fabricating the products. Prepared clay body was placed over the mould and by manually pressing the clay with the mould, the products are fabricated. Any shaped products of any size could be fabricated by this method.

Mechanical method

By using a press machine operated by electricity or by hydraulic system by using a metal dies, pottery products are fabricated. Though the initial cost is high, operation of product fabrication is easy by this method.

5. **Casting method**

Clay casting slip is prepared by using caustic soda and sodium silicate and by using plaster of Paris moulds, the pottery products are fabricated. The clay slurry was filled in the plaster of Paris mould, retains the slip in the mould to achieve the thickness and removes the excess of slurry from the mould, the article is formed.

6. **Coiling method**

This is a method of preparing the pottery products by using clay coiling. Clay coils are prepared, placed one above another and the gaps are joined manually and the shape of the pot is given. Any types and sized pots could be fabricated by using this method.

Firing technology

The fuel consumption in a pottery kiln is an important factor which determines the cast of the product. Different types of kilns are in use in the industry. They are

i. Up-draught kiln
ii. Down draught kiln
iii. Electric furnace
iv. Tunnel/continuous kiln

The firing of the pottery product is being determined according to the quantity of production, availability of the fuel, the temperature in which the product needs to be fired etc.

Further innovation envisaged

- Computerized products designing and decoration.
- Solar application in machine operations and firing purposes.
- Finding alternate fuel for kiln firing/machine operation.
- Designing mechanical devices for quality products fabrication.

Chapter 12
Integrated Framework for Technology Dissemination

James Rajanayagam

I sell here, Sir, what all the world desires to have – Power
—Mathew Boulton
Entrepreneur, Boulton-Watt Steam Engine

Not every technologist is fortunate to have a Boulton to lead a pivotal role in the technology dissemination journey as James Watt was. Boulton spearheaded an industrial revolution based on steam engines innovated by James Watt.

That was 240 years ago. They went through technological and business challenges for successful commercialization. The same challenges persist today for both technologists and entrepreneurs.

This paper looks at the existing frameworks for technology dissemination from academic institutions, at different stages of the technology dissemination process and finally presents an integrated framework with metrics for Key Success Factors (KSF) of the technology dissemination.

1 Background

Technology stock to achieve rural development and sustainable development goals (SDGs) from educational and research institutions grows every year due to growing interest by researchers on applied research for socially relevant causes. An indicator of this is the establishment of Centres of Development with focus on priority sectors like water, clean energy, environment, etc. in Universities to develop technologies that will solve global social problems. SDGs have played a role in developing and promoting innovative technologies to achieve the goals by 2030.

On the other hand, technology demand from rural users and entrepreneurs seems to be growing due to climate change, increasing population, depleting natural resources, etc. Voices of the beneficiaries of these technologies are increasingly heard and

J. Rajanayagam (✉)
Centre for Social Innovation and Entrepreneurship, IIT Madras, Chennai, India
e-mail: jraj0508@gmail.com

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_12

integrated into the new product development (NPD) process to match the offerings with the expectations or vice versa.

At the same time, a supply–demand gap always exists due to techno-socio-economic inequalities derived from the disconnect between suppliers and receivers, capability to access, use and benefit from technologies by the users, etc.

2 Context

This interplay of technology demand and supply is actively staged in the rural arena in the form of rural development with the help of rural entrepreneurs in front of an audience comprising of users and beneficiaries of the technologies.

In the context of developing world, where urban–rural divide is highly pronounced through economic inequality, infrastructure development, etc., rural development is given priority in terms of policies, innovations and infrastructure. According to Planning Commission of India, rural development connotes overall development of rural areas to promote the quality of lives. Hence, it is a multi-dimensional concept because quality of life depends, as determined through the Human Development Index, on the composite index of life expectancy, education and per capita income. The source of income in rural areas predominantly comes from agriculture and allied activities, cottage and artisan industries. Rural development is affected by challenges such as migration, underemployment and lack of infrastructure (Ilahi 2019).

Rural entrepreneurship is one of the agents to address these challenges. In a welfare state, the governments, whether be the local or the central, implement policies that are pro-poor with the objective to improve the lives of the vulnerable sections of the rural societies. Development sector, comprising of trusts, societies play a charitable role to address the immediate concerns and issues of the societies. Robinson (1991) concludes that non-governmental organizations (NGOs) registered some success in improving the incomes and consumption levels of the poor. However, the projects by NGOs suffer from lack of sustainability. In this context, rural entrepreneurship provides a sustainable means of problem-solving. Jayadatta (2017) defines rural entrepreneurship as emerging at village level which can take place in a variety of fields of endeavour such as industry, business, agriculture and act as a potent factor for overall economic development.

Whilst rural entrepreneurship brings many benefits, it faces many challenges as family, social, technological, financial and policy challenges (Patel et al. 2013). Meinhold et al. (2019), in her study of enterprises in Assam, India observes that individualistic approach to businesses, lack of technical and business skills, limited market knowledge act as constraints. Dutta (2020) opines that entrepreneurship may be promoted through a combination of business and technical skills, mentorship support and trust-based sales.

3 Literature Review of Frameworks for NPD and Allied Processes

Dhargalkar et al. (2016) identifies NPD approaches such as Quality Function Diagram, Linear Stage Gate and Ekman et al. (2006) identifies traditional engineering approaches to provide a framework for analysing the performance of the process. Based on their studies, universal framework and innovative product development are formulated. The frameworks are from the perspectives of the technologist. The aspects of entrepreneurship that involve commercialization come at the end of process. Challenges related to problem identification, lack of market information, inadequate funding are highlighted from the perspectives of technologists.

According to World Bank, scaling up means expanding, adapting and sustaining successful policies, programs or projects in different places and over time to reach a greater number of people. Hartmann et al. (2008) distinguishes three basic institutional approaches for scaling up development interventions: (i) hierarchical; (ii) individualistic; and (iii) relational; and amongst three organizational paths: (i) expansion; (ii) replication; and (iii) spontaneous diffusion. Technology commercialization is one of the approaches for expansion. It includes for-profit, non-profit, hybrid and charitable approaches with each bringing its own merits and de-merits. Challenges related to product engineering, fund-raising, distribution of the technology to the end-user, management of the supply chain at the front end and back end, servicing post-sales are addressed from the entrepreneur perspective.

Technology transfer is defined as transfer of a technology from one setting to another setting (Markert 1993). Johnson et al. (1997) clarified this as site of origin and place of use, thereby including the concerns of the user. Choi (2009) identifies education and training of the recipients, plan for the collaboration between the donor and the recipient as important elements of successful technology transfer. Other models are patent rights transfer model, long-term relationship models and combination of the two for the successful transfer (Harmon et al. 1997). In a patent rights transfer model, technologist develops the technology. The technology manager in a University identifies a potential entrepreneur through a formal search process and after negotiations upon the terms and conditions of a deal, transfers the intellectual property rights to him.

In a long-term relationship model, the technologist and the entrepreneur co-work to reach the goal of commercializing the technology. However, both these models present opportunities and challenges. Patent rights model is efficient in the sense that it advocates an assembly line approach of task oriented expertise to accomplish the required objectives. Challenges are entrepreneurs may not have the capability to address the technological issues as revealed through the market and user feedback. Long-term relationship model is built on the previous model, thereby eliminating the expertise limitation. But, on the flip side, it does not ensure that the expertise is shared or exchanged between the two parties.

To overcome these shortfalls, Choi (2009) proposes role-shifting model of technology transfer in which recipients become donors of technology in the future, leading to multiplier effect. This is built on both the former models, and yet at the same time, through rigorous training capacity building, the entrepreneur is enabled to become innovator.

In the context of rural entrepreneurship, technology benefits to solve the issues around the core priority sectors are addressed through a combination of the above three concepts of NPD, technology transfer and commercialization. It is complex and gigantic in nature, to imagine a rural entrepreneur to embark upon himself to integrate these concepts and take the technology for the benefit to him and the rural society. It is easy to think that the risks are equally borne by the technologist in the first two concepts. However, it is the entrepreneur that bears the maximum risks because of the flowing effects of the first two concepts. For instance, a faulty design input or user input may have led to the technology development in a wrong direction, but the entrepreneur may not be capable to resolve it by himself.

Technology dissemination from lab to the user passes through three distinct settings each with unique purposes, actors, goals, processes and process conditions. Through technology dissemination, three components pass through viz., physical structure which is the embodiment of the technology, knowledge, processes (Frey 1987). Hence, just as the processes are seamlessly inter-connected, it is expected that actors must be inter-connected, even though they have distinct and time-bound roles to play. They must be available for action as long as the technology serves its purpose.

As the frameworks for these different processes—NPD, technology transfer and technology commercialization provide the direction, metrics and tools to measure the success at each process, they are limited because they don't include the technology dissemination till the technology reaches and is used by the end-user. For instance, technology transfer may be successful but this may not ensure the success of commercialization. Similarly, commercialization may be successful but may not able to scale up through expansion or replication.

In the next section, an integrated framework to include the three distinct settings and process conditions is shown. Based on the process conditions, parameters are enumerated in a checklist to monitor the conditions in real time.

4 Integrated Framework for Technology Dissemination

This framework (refer Fig. 1) presents stages of technology dissemination from lab in a University or academic setting to field, main actors involved in each of the stages and processes, conditions and parameters that determine the conversion and efficiency. This framework adds another stage in the technology dissemination process, called user experience. User experience tells about the initial adoption, horizontal dissemination and conditions such as total user benefits. A successful user experience may encourage the capability at the grassroots level to produce future innovations.

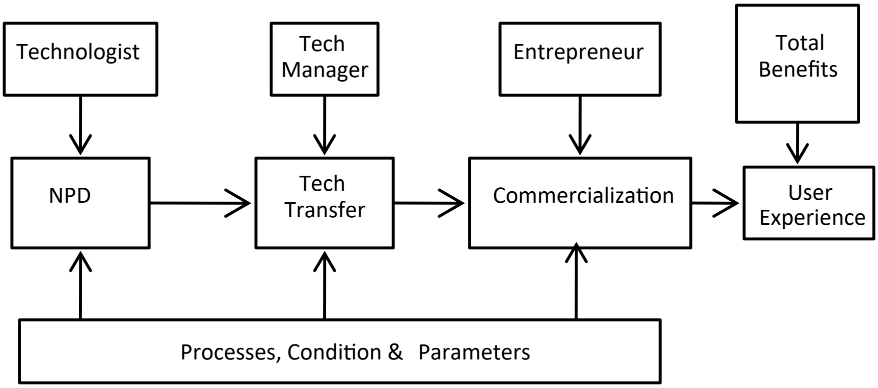


Fig. 1 Technology dissemination framework

The complexity of the transfer of technology from one setting to another is understood by breaking down the entire dissemination process into distinct stages. This framework includes user experience as an internal stage of the process instead of an external step or an effect of the technology because this stage is the sole purpose of the previous stages and the importance of this stage is understood from its role in successful horizontal propagation of technologies across the user base and its ability to spawn further innovations. Hence the dissemination is not to be seen as linear and bounded but is to be seen as a cyclical process.

The main actors include technologists, technology managers, entrepreneurs and users. In a University or government funded research lab setting, technologists are teaching faculty whose main objective is to share and generate subject knowledge, researchers who pursue studies. They may be individuals or as teams to achieve a goal. The team is very often floating during the life cycle of NPD process. When the project is completed, it is registered in the technology management office of the institution. Technology managers play different roles right from IP management, advertisement of technologies amongst industries. In the next stage, entrepreneurs bring the significant role through their access to knowledge of technology, market and users. Technology managers must be trained in the transfer process and should have inventions processing capability (Swamidass et al. 2009).

Within each stage, processes define tasks, activities, strategies to complete the activities and obtain results. All processes operate under conditions, which facilitate or make sure that processes operate. These conditions enable the flow of the components of the technology, ensure the mixture of the components in the right proportion and they remain cohesive. Such conditions may be classified broadly as organizational, financial, physical resources. Parameters may be leadership, funds, teamwork, networks, duration, etc. Each endeavour will require conditions and parameters and they are spread over a range, which has to be fine-tuned.

Figure 2 points the interconnectedness of the different stages through the fitness criteria, which acts as the conditions and parameters for the processes and provides the

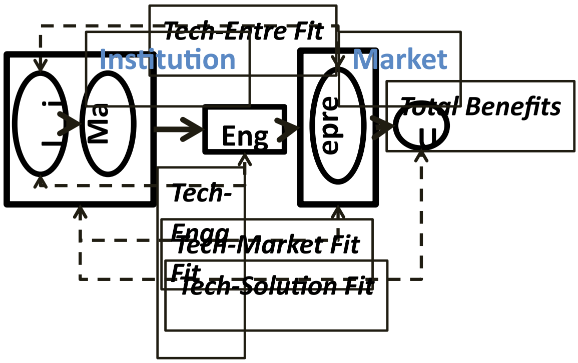


Fig. 2 Metrics for technology dissemination

checks and balances. The fitness criteria are not bounded by stages but cut across the boundaries to make sure the networks are connected and the flow of the technological components remains smooth and doesn't get frozen.

This framework attempts to group together four fitness criteria. The next section explains the fitness criteria and lists the elements of the criteria with parameters that operate in a range suited for the specific technologies.

4.1 Fitness Criteria

This framework proposes 5 fitness criteria. For each criterion, appropriate parameters are evolved. The parameters are developed based on the requirements of project, engineering, market and user experience. Each parameter is marked for its suitability against the three distinct components of the technology.

In Sect. 4.2. the parameters are defined in terms of their objectives, their role in the cohesion of the technological components and the flow of the same along the processes and stages and the corrective actions required in case of deviation. They are as follows.

(i) Technology Entrepreneur Fit

When the technology from a NPD process reaches the entrepreneur, the technology is available as a minimum viable product, few pilot trials and early user involvement. Therefore, it implies that the entrepreneur bears a tremendous responsibility, as much as that of the technologist, to take the technology to the end-user. The characteristics of rural entrepreneurs are risk-taking, innovative and ability to organize scarce resources to achieve the objectives of his pursuit. At the same time, he is constrained by, mainly, capital, new skills, labour and business skills to market the outputs. Hence, in the start-up language, the entrepreneur requires an incubation support consisting of early stage capital, mentoring and network formation.

Hence, this fitness criterion is important as the entrepreneur plays a significant role or a proxy role for the technologist in reaching the overall objective of the technology development project to solve the problems of the beneficiaries. This fitness criterion is also important because all but the first stage in the framework is critically dependent on this fitness.

(ii) Technology Solution Fit

From an academic perspective, researchers engage in NPD, primarily, with an objective to solve a specific problem that falls within their technology domain. Hence, in the ranking of fitness criteria, this fit will be the first one as the researchers work towards solving a specific problem and therefore, when the technology is developed, it will address the problem first.

This condition is necessary but not sufficient in the scheme of the framework. The fitness implies two parts of the coin. On one side is the precise statement of the problem, situation faced by the beneficiaries. On the other side is the solution formulated which is short-listed and selected from a world of possible solutions. The fitness criterion makes one aware of all the other possibilities, whether they are technological, socio-political, including the existing solutions, substitutes and their limitations.

As the first condition in the technology dissemination, this decides the start of the project. Checks and balances of this condition facilitate the steering of the project towards the goal in the right direction.

(iii) Technology Market Fit

This fit enables to compare the technology or the outputs of the technology with the existing similar products in the market or any substitutes that provide an equivalent of the value. The key metrics for the fit are claims and features. For a new technology, the claims shall ideally be disruptive or 3× over the nearest similar products or substitutes.

This condition applies to the last two stages, when the technology is, for the first time (except field trials which work under protected conditions) exposed to the harsh realities of the market. The application of this fitness criterion also informs that the technology is in the adolescent stages of its product life-cycle.

Moving away from the innovative dimension of the technology with respect to the problem, the technology is subjected to the competitive dimensions of the market such as cost of ownership, real and perceived value of the technology. This criterion evaluates the network characteristics of the value flow (derived from raw materials, actors and their motives in the supply chain) and brings with new decision-makers and influencers who have the ability to restrain or accelerate the flow of the technology in the technology dissemination process.

(iv) Technology Engineering Fit

When the technology comes out of the lab, it is a minimum viable product ready for further pilots. Before it goes into the market, it must be ready for engineering for production. The key metrics for this factor are affordability, accuracy and reliability. Affordability is the ability of the user to use it according to his needs. It may mean complete ownership or opportunity for rental ownership. Accuracy is the speed and quantity of the deliverable of the claim. Reliability is the ability to satisfy the needs and fulfil the claims above the confidence limits.

This criterion is from the perspective of users and the entrepreneur. For the users, this criterion tells about the user experience in terms of his interaction with the machine. When the user experience is closely associated with the machine and the technology, then it becomes an extension of man (Reuleaux 1963). This condition tells about the physical features, shapes and parts of the technology and their interactions with the users and how well the machine is optimally utilized to serve the needs of the users.

(v) Technology Total Benefits

The technology is naturally beneficial to the user community, which is necessary but not sufficient to fulfil the requirements of the user. The metric for this factor is the sum of inherent benefits that the technology (+) offers and the costs of breaking the lock-in from existing similar products, substitutes and practices (−).

This fitness criteria are important from three perspectives. One, it enables the user to adopt the technology by locking out of the existing practice or substitute. Second, it favours the horizontal dissemination across the user communities and bases. Third, the success of the technology spawns future innovations either at the user, entrepreneur or the technologist levels.

As explained in the previous fitness condition, the total benefits are evaluated by the 3As (accessibility, availability and affordability) across the three technological components. This condition, being the acid test for the entire project, right from problem realization, technology development, entrepreneurial abilities against the market forces, if not met, takes one to the initial stage to understand the process again from the beginning.

4.2 List of Parameters for Fitness Criteria

Bhuiyan (2011) identifies critical success factors for the NPD process are new product strategy, idea generation, screening and business analysis, development and testing. Sequeira (2004) concludes that the success of a technology for rural development depends on a number of parameters like technology selection, technology transfer and its implementation, political, socio-economic and the ethnic factors. Cuéllar-Gálvez et al. (2018) identifies lack of knowledge amongst small-scale farmers, risk aversion, paternalistic cultures, financial and institutional difficulties and geographical conditions are impediments to innovation adoption. Dutta (2020) opines that combining technical and business skills, sustained mentorship, trust-based sales approaches and agency building are factors for promoting entrepreneurship in rural areas. As per the framework in Fig. 1, NPD, rural entrepreneurship are part of the larger process and hence there is a need to cumulate the critical success factors (fitness criteria) and then list critical parameters for these criteria.

Table 1 Parameters and criticality

S. No	Parameter	Technology components		
		Physical structure	Knowledge	Process
1	*Technology entrepreneur fit*			
1.1	Subject alignment	✓	✓	✓
1.2	Goal alignment	✓	✓	✓
2	*Problem solution fit*			
2.1	Problem definition		✓	
2.2	Needs alignment		✓	
3	*Technology market fit*			
3.1	Competitive advantage	✓	✓	✓
3.2	Marketing	✓	✓	✓
3.3	Supply chain	✓	✓	
4	*Technology engineering fit*			
4.1	Engineering components	✓	✓	✓
4.2	Machine parameters	✓	✓	✓
4.3	Raw material availability	✓		✓
5	*User benefits*			
5.1	Accessibility	✓	✓	✓
5.2	Affordability	✓		
5.3	Availability	✓		

In this section, Table 1 brings together enterprises, institutions, market and the society and links through the fitness criteria to establish parameters for the monitoring and corrective actions.

Frey (1987) defines technology as an integration of three components—object, knowledge and process. Hence, when a technology is disseminated from one setting to another or many settings, it is imperative that all the components are held together, failing which the technology is prone to under-utilization or mis-utilization that might lead to undesirable results.

Hence, this paper attempts to breakdown the technology into its components and then tabulates them against the fitness criteria and their parameters. As can be seen from the table, all the components are required together for all the fitness criteria, however, it also informs that even some components are not shared with some of the actors, stages, etc., the entirety of the technology is not lost and they remain cohesive. For instance, in the technology solution fit, the physical structure may not be as critical as the knowledge and process components are. Similarly, in the user benefits criteria, affordability requires that the physical structure is owned or used by the users.

As the parameters are qualitative, it will be difficult to rank them against the components. The overall objective is to make sure all the components are passed on from setting to another across the stages of the technology dissemination. However, it may be said that all the parameters are derived from the user perspective. The ownership of all the parameters is not entirely dependent upon one actor, but it may be concluded that since the technologist initiated the process, the ownership rests with him.

5 Recommendations

Studies of technology dissemination, that starts in University settings with the objective to solve socially relevant issues and SDGs, by the framework of NPD alone, which considers technology transfer, commercialization and user experience as just one more step within it, is limited and inadequate to explain the successes, failures of technology adoption by end-users, because the framework of NPD does not include the different settings of the above-mentioned processes and each of them operate under different conditions.

Hence, this paper presented an integrated framework of technology dissemination. It also included user experience that explains the adoption behaviour and conditions under which horizontal dissemination amongst the user base happens and finally, builds the capability at the bottom (entrepreneur, user) for future innovations. This framework integrates all the settings from NPD, technology transfer, commercialization under the common themes of actors, processes, conditions and parameters.

Based on the framework, fitness criteria are developed to measure the progress and the performance of the processes. The criterion is designed to be robust to measure across different stages. Using the cross-process fitness criteria, parameters are selected from the available literature, that are technological, economical or organizational, and they are matched with the technological components, namely physical structure which is the embodiment of the technology, process and knowledge. The parameters measure the cohesiveness and fluidity of the technological components across processes and different settings.

The framework will be helpful to know the progress at any point of time by measuring the fitness criteria and the parameters. For instance, at a point, even if all the fitness criteria are satisfied except the entrepreneur-technologist fit against the parameter of goal alignment, then there is a possibility of mission drift and an alarm may be activated to correct this through the technology transfer process. Or if the user experience does not result in horizontal dissemination, then the technology solution fit or technology market may be activated to correct the problem or the parameters of 3As.

The framework could be taken up for further research through case studies, design new technology intervention projects. The framework advocates the premier role of knowledge in the technology and adequate documentation of both tacit and explicit knowledge created through the processes will be helpful to understand the gaps in the supply–demand gap of technological stock for rural development. Also, the parameters provided in the table are only indicative and further research into addition of parameters that are more robust could be researched.

6 Conclusion

One comes across questions in conferences and discussions with scientists on the causes for technology failures. The logic behind the query is assumed to be simplistic explanation is sufficient for the answer. However, it is not so. Without a holistic view of the processes, an answer and possibly reactive steps in the nature of policies, funding, product refinement with better features will only aggravate the situation.

References

Bhuiyan N (2011) A framework for successful new product development. J Ind Eng Manag 4(4):746–770

Choi HJ (2009) Technology transfer issues and a new technology transfer model. J Technol Stud 35(1):49–57

Cuéllar-Gálvez D et al (2018) A model to promote sustainable social change based on the scaling up of a high-impact technical innovation. J Sustain 10:4532

Dhargalkar K et al (2016) A universal new product development and upgradation framework. J Innov Entrep 5:27

Dutta S (2020) Promoting women's entrepreneurship in distribution of energy technologies: lessons from ENERGIA's WEE programme. IDS Bull Inst Dev Stud 51(1):71–90

Ekman S et al (2006) The need for a "new" innovative product development approach. In: International design conference—design 2006, Dubrovnik, 15–18 May 2006

Frey RE (1987) Is there a philosophy of technology? Paper presented at the 74th Mississippi Valley industrial teacher education conference, Chicago, IL

Harmon B et al (1997) Mapping the university technology transfer process. J Bus Ventur 12(6):423–434

Hartmann A et al (2008) Scaling up. A framework and lessons for development effectiveness from literature and practice. Brookings Global Economy and Development working paper series

http://www.quoteland.com/author/Matthew-Boulton-Quotes/1260/. Accessed 19 July 2020

Ilahi S (2019) Rural entrepreneurship: current scenario in India. Int J Sci Res 8(11)

Jayadatta S (2017) Major challenges and problems of rural entrepreneurship in India. IOSR J Bus Manag (IOSR-JBM) 19(9):35–44, Ver. II

Johnson SD et al (1997) Expanding the content base of technology education: technology transfer as a topic of study. J Technol Educ 8(2):35–49

Markert LR (1993) Contemporary technology: innovations, issues, and perspectives, chap 8. Goodheart-Willcox, South Holland, IL, pp 231–253

Meinhold K et al (2019) The processing of non-timber forest products through small and medium enterprises—a review of enabling and constraining factors. J For 2019

Patel B et al (2013) Rural entrepreneurship in India: challenges and problems. Int J Adv Res Comput Sci Manag Stud 1(2)

Reuleaux (1963) The kinematics of machinery: outlines of a theory of machines. Dover Publications

Robinson MA (1991) Evaluating the impact of NGOs in rural poverty alleviation: India country study

Sequeira AH (2004) Technology selection and management in rural areas: a case study
Swamidass PM et al (2009) Why university inventions rarely produce income? Bottlenecks in university technology transfer. J Technol Transf 34:343–363

Chapter 13
Community-Level Process-Design for the Extraction of Lac Resin and Dye

S. Namasivaya Naveen and Saumendra K. Bajpai

1 Introduction

India is a leading producer and exporter of lac products contributing approximately 50–60% to the world lac market with an annual production of 20,000 tons. The major lac producing states in India are Jharkhand, Chhattisgarh, and West Bengal. Lac is a resinous exudate secreted by the tiny insects called *Kerria lacca* on tree branches and consists of the three major components, which are the resin, wax, and dye (Hicks 1961). Depending on the various stages of refinement, the lac is categorized as stick lac, crude lac, seed lac, button lac, and shellac. The stick lac is crushed using a grinder to give crude lac, which is further washed and dried to produce seed lac. The button lac is obtained by melting seed-lac in a cloth filter and allowed to cool down in the shape of buttons with a diameter of around 8 cm. The market price for the different forms of lac is given in Table 1. Improving the lac cultivation and processing methods can benefit millions of tribal families, forest dwellers, and other sub-forest dwellers to earn money while residing in their native place (https://shodhganga.inflibnet.ac.in/handle/10603/121488).

Presently, the lac resin is extracted by traditional techniques, which involve heating the seed lac in a big cauldron and by continuous hot filtration using a tubular muslin cloth bag, passing only molten resin material which is then pressed and cooled to get flakes of resin called shellac (Das 2016; Sharma 2017). The cloth bag has a circumference of 25 cm and around 15–20 m long and this whole process employs around 3–4 people. This manual lac extraction method involves the use of water, which is scarce during the harvesting season, which falls in summer, and the laborers are also exposed to work under extreme temperatures and fumes.

Lac cultivators are forced to sell their crops in stick lac and crude lac stages due to the non-availability of processing tools for producing shellac at the community

S. Namasivaya Naveen · S. K. Bajpai (✉)
Department of Applied Mechanics, Indian Institute of Technology Madras, Chennai, India
e-mail: sbajpai@iitm.ac.in

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_13

Table 1 The market price of lac at different refining stages (www.ccnfortribes.org)

S. No.	Different forms of lac	Market price (Rs./kg)
1	Stick lac	140
2	Crude lac	270
3	Seed lac	290
4	Button lac	380
5	Shellac	650

level. Also, the modern methods of manufacturing shellac use steam for the melting process with seed lac as the starting material, which is out of reach at the community level. The beetle's body fluid contains the dye, which is soluble in sodium carbonate (Goswami et al. 2009). It is used as a food coloring agent, and the usefulness of lac dye is being explored in quantifying biomolecules (Ghosal et al. 2018; Bourtoom 2008). During the washing process, the lac dye dissolved in sodium carbonate is mostly let into agriculture fields as a fertilizer due to lesser capabilities and facilities in processing (Parry 1935). Lac resin finds its applications in coating wood for the final finish, metals, and also the floors (Cockeram and Levine 1961; Rossman 2009; Mills and White 1994). To provide value addition to the lac products and to ease the laborers working conditions, a single step lac resin extraction method with a one-step extended process for the extraction of lac dye is of much need.

In this study, the crude lac was first washed with sodium carbonate to soften the resin for removing impurities such as small twigs and trapped insects. By washing with sodium carbonate, the lac dye gets dissolved and by employing a titration-based method using oxalic acid, the pure lac dye can be obtained. The lac resin was further extruded using a modified syringe pump with a muslin cloth filter for further purification of the lac resin. The filtered resin is loaded into the mini extruder assembly chamber and extruded using a cloth filter. Besides, the solubility of the lac resin is checked in IPA for coating applications. This primary research provides a foundation for developing a single step extraction method for lac resin and value addition of other lac products, which will benefit the communities involved in lac cultivation and processing.

2 Materials and Methods

2.1 Materials

Crude lac was supplied by the Sahayog community co-ordination network, India. Sodium carbonate anhydrous (Na_2CO_3, product number S0156) and isopropyl alcohol ($(CH_3)_2CHOH$, product number UN1219) were purchased from Rankem chemicals, India. Oxalic acid ($C_2H_2O_4.2H_2O$) was procured from Akshar chemicals, India. The chemicals used in the study are all of the reagent grade and were used without any further purification.

2.2 Pre-refining of Lac

The crude lac was obtained post crushing of the stick lac and mainly consists of the lac resin, wax, lac dye, and other impurities. To dissolve the lac dye and to remove the impurities, the crude lac (10 g) was subjected to 0.04 M sodium carbonate wash with stirring at 80 °C for 1 h at 500 rpm in a magnetic stirrer with hot plate. The schematic diagram showing the washing process involved in the pre-refining stage of lac resin is shown in Fig. 1. The sodium carbonate dissolves the lac dye, and the other impurities are removed. Lac resin obtained after three washes should be free from lac dye and other contaminants.

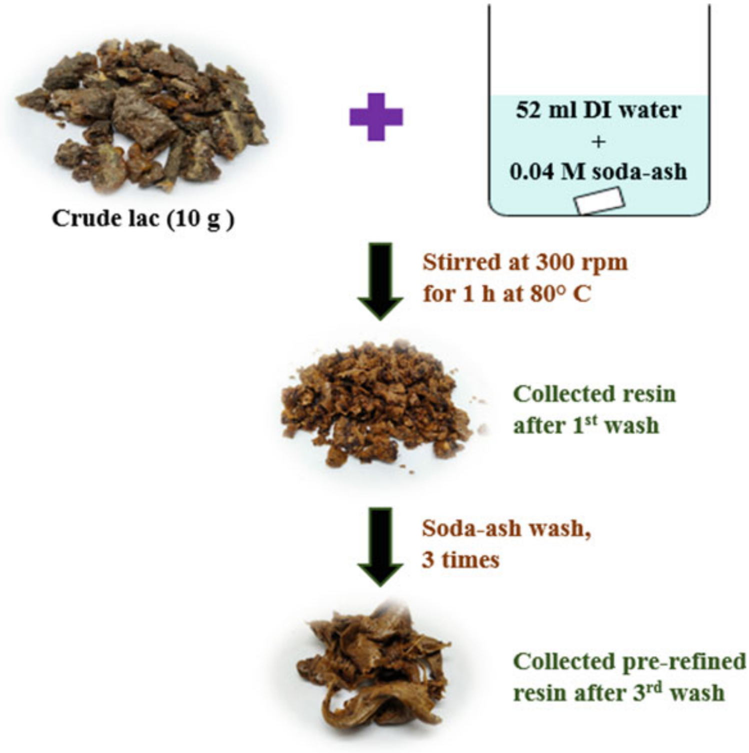
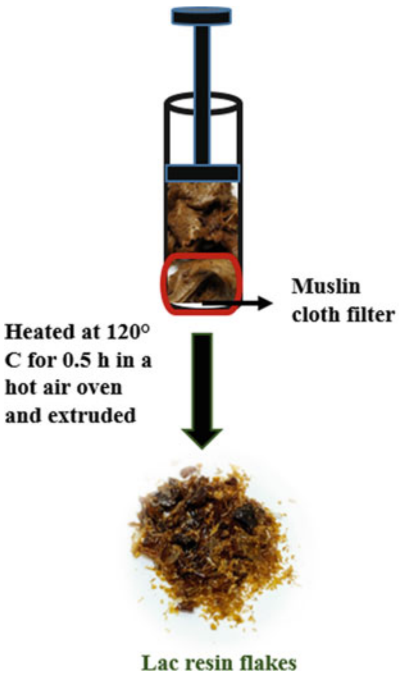


Fig. 1 Schematic diagram showing the steps involved in the pre-refining of lac resin

2.3 *Extrusion of Lac Resin Post Washing—Testing for Filtration*

To further remove the impurities present in the resin after pre-refinement, an extrusion-based setup was designed to filter the impurities. The schematic diagram showing the hot extrusion process and the modified extruder setup with applied pressure conditions for extrusion is given in Fig. 2. A syringe pump was modified for lac resin extrusion and the end of the syringe pump was covered with a muslin cloth which acts as a filter. The resin collected at the end of pre-refinement is filled in the syringe pump, and the entire setup was placed in the hot air oven at 120 °C for 0.5 h and then immediately extruded to get the final resin product. Before the resin gets solidified, it was compressed to form thin resin sheets which can further be crushed to get flakes of resin. From the extrusion set-up, the flowability of the molten resin was determined for two pressure conditions.



Syringe pump extruder dimensions and parameters

Extruder dimensions	Force applied	Pressure conditions
Radius = 1 cm	4.9 N	1 kPa
Height = 6.5 cm		No-pressure

Fig. 2 Schematic diagram representing the syringe pump hot extrusion setup and extrusion parameters

2.4 Isolation of Lac Dye

Firstly, 100 ml of the dye solution dissolved in sodium carbonate was titrated with 0.5 M of oxalic acid until a color change from purple to orange was observed. The sodium oxalate precipitate formed as the result of the reaction between sodium carbonate and oxalic acid gets settled at the bottom. The supernatant solution consisting of the lac dye was collected and dried in a hot air oven at 60 °C for 12 h to get lac dye granules. A schematic diagram showing various steps in the isolation of lac dye is given in Fig. 3.

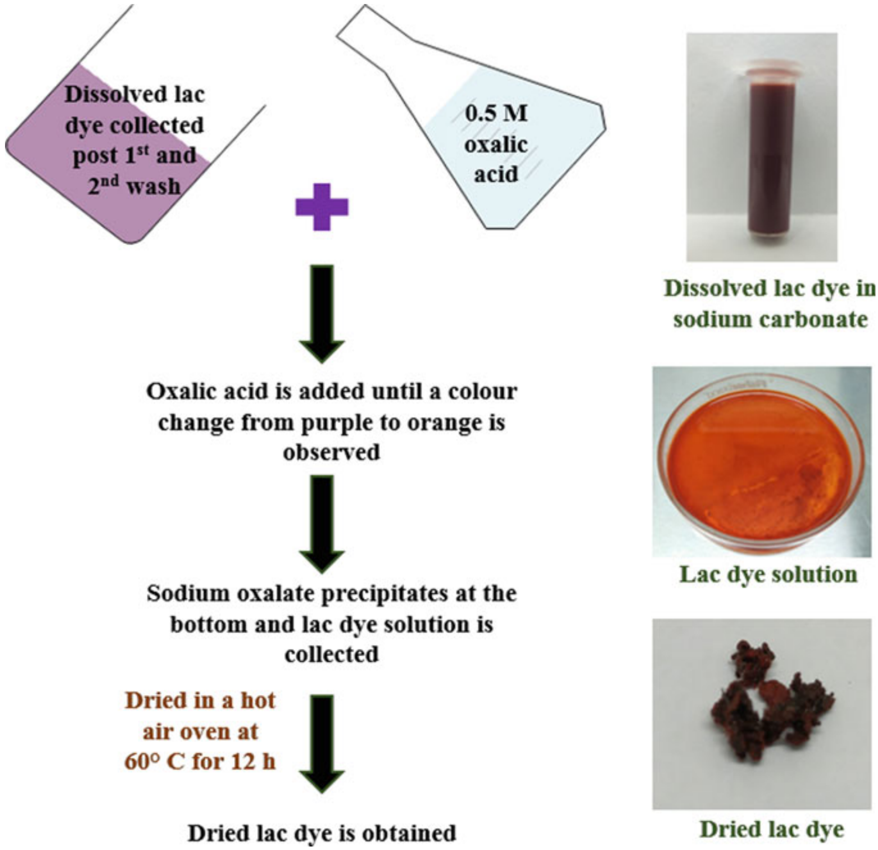


Fig. 3 Schematic diagram displaying the process involved in the isolation of lac dye

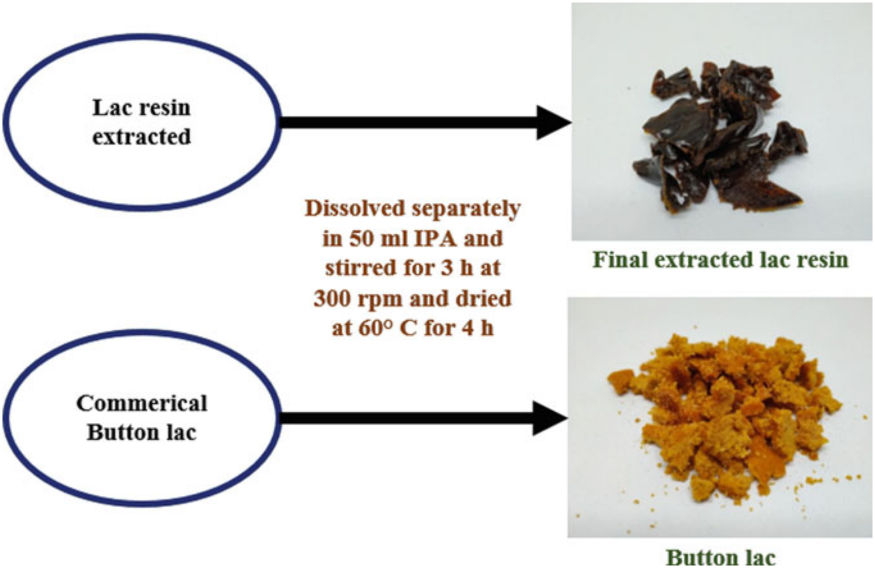


Fig. 4 Schematic diagram showing the process involved in checking the solubility of the extracted and button lac resin

2.5 *Solubility of the Extracted Lac Resin*

After the extrusion process, the collected lac resin was tested for its solubility in isopropyl alcohol (IPA). For coating applications, the solubility of the resin in volatile solvents is very much important. Also, the impurities can further be removed by dissolving the lac resin in IPA. The resin with an initial weight of 9.2 g was added to 50 ml of IPA and stirred using a magnetic stirrer at 200 rpm for 3 h. Then the dissolved resin in IPA was filtered using a nylon mesh and dried in a hot air oven at 60 °C for 4 h. A schematic diagram explaining the steps in checking the solubility of the final resin and button lac is shown in Fig. 4.

2.6 *Lac Mini Extruder Design and Assembly*

In order to increase the production capacity of the resin, a lac mini extruder design was proposed and fabricated. The schematic diagram of the lac extruder setup and assembly with the following components is provided in Fig. 5a, b, and c.

The lac mini extruder consists of an extruder chamber for filling the sodium carbonate washed resin and the charcoal was filled in the sides of the chamber and heated. Charcoal was used as the fuel due to its local availability and for decreasing the electricity consumption. The melted resin passes through the advancing filter scheme

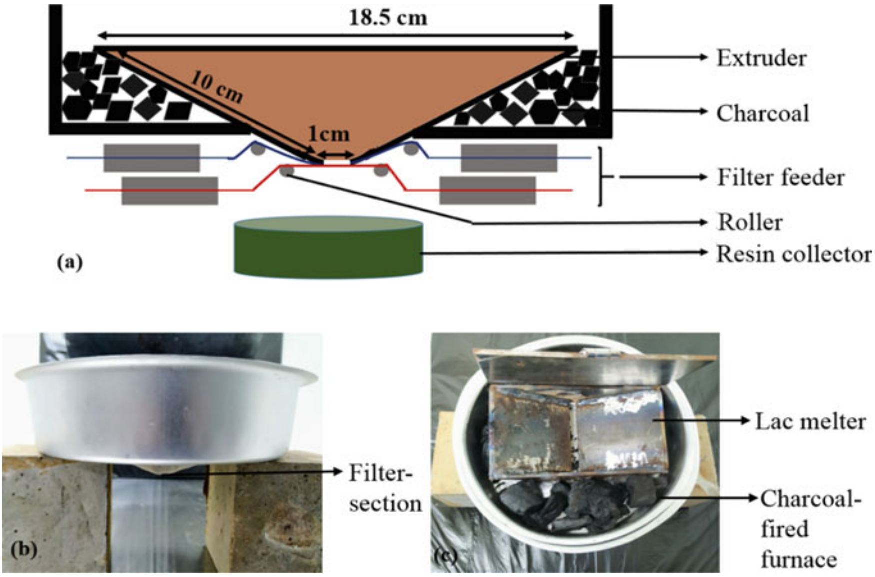


Fig. 5 **a** Schematic diagram explaining the design of lac mini extruder setup, **b** lac mini extruder assembly—side view, and **c** lac mini extruder assembly—top view

provided at the bottom exit of the extruder chamber. Two rollers are provided for feeding the muslin cloth filter with a collector vessel for storing the filtered resin.

3 Results and Discussion

3.1 Extraction of Lac Resin

In the process of lac extraction, the weight of the resin after each wash was noted, and for each consecutive wash, the weight was found to be decreasing due to the removal of impurities. The addition of sodium carbonate with stirring and heating at 80 °C caused intrinsic swelling of the organic and plant matter, enhancing the transport. Mainly, the wood and insect debris float to the top, and the resin remains at the bottom. The collected resin is subjected to three more washes for further purification and collection of lac dye. The lac resin at different processing stages is shown in Fig. 6a, b, and d. The weight of the resin following each wash for a starting material of 10 g crude lac is given in Table 2.

After washing process, the lac resin collected was still containing some impurities and was further extruded through a syringe pump with a muslin cloth filter for removal of contaminants and optimization of filtration conditions. It was found from this preliminary investigation that the viscosity of the molten lac at 120 °C was low, and

Fig. 6 **a** Crude lac, **b** collected lac resin post first wash, **c** extruded lac resin dissolved in IPA, dried, **d** collected lac resin post third wash, **e** final lac resin product post washing and extrusion, and **f** commercial button lac dissolved in IPA and dried

Table 2 Resin weight post wash cycle

Wash cycle	Cycle 1	Cycle 2	Cycle 3
Resin weight (g)—post each wash	9.8	9.4	9.2

the resin was able to flow through the extruder without any application of pressure. This finding provided valuable inputs for extrusion using the mini extruder. Also, the need to pressurize the mini extruder chamber was removed. The lac resin obtained after extrusion using syringe pump was very minimal and thus the lac mini extruder was proposed. The lac resin collected post three washes was filled in the extruder and heated using the charcoal-fired furnace to melt the resin. Post extrusion, the resin was pressed immediately in the form of sheets which were further crushed to get resin flakes and the final weight of the resin post extrusion was weighed to be 9.2 g. The final resin product after washing and extrusion is shown in the Fig. 6e.

3.2 *Solubility of the Extracted Resin and Button Lac*

For comparison, the button lac available in the market was dissolved in IPA, the initial and the final weights of the button lac after dissolving in IPA were found to be 9.2 g and 9.1 g. The final lac resin obtained after extrusion had an initial and final weight of 9.2 g. This shows that the final resin flakes were free of impurities. The extruded and commercial button lac after dissolving in IPA is shown in Fig. 6c and f. The solubility of the lac resin is useful for various coating applications as it provides a

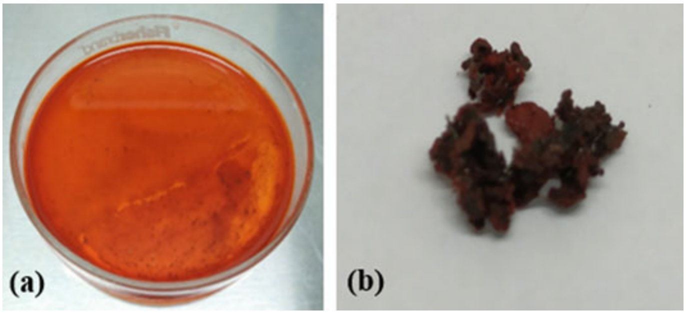


Fig. 7 **a** Lac dye solution, and **b** dried lac dye

glossy finish and thin-film forming coating on various objects such as wood, metals, and frames (Derry 2012; Sutherland 2010).

3.3 Preparation of Lac Dye

Lac dye dissolved in the sodium carbonate solution collected post first and second wash was used for further lac dye extraction as a result of the lac dye getting dissolved mostly in the first two washes itself. With the addition of oxalic acid, there is a color change from purple to orange. Oxalic acid reacts with sodium carbonate to form sodium oxalate, which then precipitates and starts settling at the bottom. Then, the supernatant solution containing the lac dye was collected as shown in Fig. 7a and dried in a hot air oven. The lac dye was completely soluble in water and the final dried lac dye is displayed in the Fig. 7b. For a starting material of 10 g crude lac, the dye yield was approximately 0.1 g.

3.4 Yield, Material, and Energy Consumption

Power consumption calculations for the pre-refining of lac resin and dye preparation are given in Table 3. The total consumables used, energy consumption, and yield for 1 kg crude are listed in Table 4. For a starting material of 1 kg crude lac, the lac resin and dye yield was 920 g and 9.4 g, respectively.

4 Conclusion

This study provides valuable input on the complete extraction of lac resin and lac dye, which is a source of income for many tribal families and forest dwellers. The

Table 3 Power consumption calculations

Stage	Process	Device wattage (W)	Usage in hours	Total power consumption (kWh)	Total power consumption for 1 kg crude lac (kWh)
Pre-refining of lac resin (per 100 g batch)	Stirring and heating	650	6	3.9	39
	Drying	1200	3	3.6	36
Lac dye preparation	Drying	1200	12	14.4	14.4
Total					89.4

Table 4 Consumption and yield

S. No.	Consumables and yield (For 1 kg crude lac)	Quantity
1	Water	15.6 L
2	Sodium carbonate	4 g
3	Power consumption (stirring and heating)	89.4 kWh
4	Lac resin yield	920 g
5	Lac dye yield	9.4 g

primary research on lac resin and dye is crucial in developing a single-step extraction of lac resin for improving laborers working conditions and increasing their income by value addition of lac products. The key limitation of this study is that our lab-scale design yields less than 10 g of lac resin and further optimization of soda-ash based washing needs to be explored. In the future, the characterization of the produced lac resin flakes and dye has to be performed, and a working prototype of the provided design with advancing filter scheme has to be developed for large-scale production of lac resin products.

Acknowledgements We thank the Indian Institute of Technology, Madras, and RuTAG, IIT Madras for funding (ICS1819047RuTGSAUM). We are thankful to Sahayog community CCN, Vishakapatnam, Andhra Pradesh for field assistance and inputs.

References

Bourtoom T (2008) Edible films and coatings: characteristics and properties. Int Food Res J 15(3):237–248

Cockeram H, Levine S (1961) The physical and chemical properties of shellac. J Soc Cosmet Chem 12(6):316–323

Das A (2016) Economics of lac cultivation in district Kanker of Chhattisgarh. http://krishikosh.egranth.ac.in/handle/1/5810001894. Last accessed 22 June 2020

Derry J (2012) Investigating shellac: documenting the process, defining the product: a study on the processing methods of shellac, and the analysis of selected physical and chemical characteristics. http://urn.nb.no/URN:NBN:no-33276. Last accessed 22 June 2020

Ghosal S, Sharma KK, Singh AK, Singh BP (2018) Recent advances in lac production technologies. http://krishi.icar.gov.in/jspui/handle/123456789/12076. Last accessed 22 June 2020

Goswami DN, Prasad N, Baboo B, Kumar KK, Ansari MF (2009) Degradation of lac with storage and a simple method to check the same. Pigm Resin Technol

Hicks E (1961) Shellac its origin and applications. Chemical publishing Co., New York

Mandal JP A study of the problems and prospects of lac industry in the Purulia district of West Bengal. https://shodhganga.inflibnet.ac.in/handle/10603/121488. Last accessed 22 June 2020

Market price of lac in India during the year 2019, provided by Sahayog CCN. www.ccnfortribes.org.

Mills JS, White R (1994) The organic chemistry of museum objects. Buttersworth, London, Oxford

Parry EJ (1935) Shellac: its production, manufacture, chemistry, analysis, commerce and uses. Sir Isaac Pitman & Sons, Ltd., London, p 151

Rossman JM (2009) Commercial manufacture of edible films. In: Edible films and coatings for food applications. Springer science and business media, pp 367–390

Sharma K (2017) Lac crop harvesting and processing. In: Industrial entomology. Springer, Singapore, pp 181–196

Sutherland K (2010) Bleached shellac picture varnishes: characterization and case studies. J Inst Conserv 33(2):129–145

Part II
Rural Water Resources

Chapter 14
Understanding Declining Storage Capacity of Tank Cascade System of Madurai: Potential for Better Water Management for Rural, Peri-Urban, and Urban Catchments

Aman Srivastava and Pennan Chinnasamy

1 Introduction

Water availability for domestic water demand (both in urban and rural settings) and agricultural water demands to sustain agrarian practices continues to be the foremost priority in India (Sawkar et al. 2018). In order to fulfill the water demand of the numerous water-consuming sectors, India essentially depends on its utilizable surface and groundwater resources which epitomizes merely 4% of the global renewable water resources (Dhawan 2017). Of the total 4000 km^3 of rainfall received annually, 1953 km^3 of the water is available as surface water resources while the utilizable surface water resources have been estimated to be 690 km^3 (MoWR 1999, 2017; Planning Commission 2008). The minimum storage volume required to store the utilizable water resources has been estimated to be 460 km^3, however, the present storage capacity, available in India, is merely 253 km^3 (Subramanya 2013; Srivastava and Chinnasamy 2021a). Nevertheless, apart from limited storage capacities, issues associated with the high spatio-temporal inconsistency in water availability exists. More than 40% of India's land falls under the semi-arid category receiving significantly less rainfall ranging between 500 and 1000 mm, such as the parts of Rajasthan, Gujarat, and leeward side of Western Ghats (Ghosh and Srinivasan 2016; Pai et al. 2017). Whereas, parts of Western Ghats (on the West coast of India) and North-Eastern regions receive an annual rainfall of more than 4000 mm. Consequently, short rainy seasons and long dry season lead to anomalies causing extreme

A. Srivastava (✉) · P. Chinnasamy
Centre for Technology Alternatives for Rural Areas (CTARA), Indian Institute of Technology Bombay, Mumbai, India
e-mail: amansrivastava1397@gmail.com

P. Chinnasamy
Rural Data Research and Analysis (RuDRA) Lab, Indian Institute of Technology Bombay, Mumbai, India

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_14

events such as floods and droughts (Mujumdar 2020). One of the reasons attributed to the seasonal change in the weather in India is given to the recent impacts of climate change vulnerabilities. One of the major impacts of climate change is observed in the erratic rainfall pattern of the summer monsoon (also called South-West monsoon) (Khadke and Pattnaik 2021). In India, about 33% of the cropped area receives rainfall of less than 750 mm while most parts of peninsular, Central, and North-West India receive rainfall below 1000 mm (Subramanya 2013). These regions are most vulnerable to drought if in case, summer monsoon plays truant. Despite the fact that India receives a normal annual rainfall of 1180 mm, water mismanagement and misuse has adversely affected the agricultural productivity and wellbeing of millions of people.

The Indian monsoon system and associated seasonal anomalies have necessitated the creation of rainwater harvesting structures to hold rainwater (Vyas 2020). Surface water conservation has become a key adaption strategy for any system that maneuvers to reduce the impact of the water crisis (Sawkar et al. 2018). Intending to buffer the influences of rising issues due to climate change, the Indian government is gradually shifting toward adopting traditional water conservation systems and institutional frameworks (Sawkar et al. 2018). Given that these strategies are simple and eco-accommodating, the revival of such storage structures can result in a more decentralized way of water management at the local scale (Reddy et al. 2018). India has been witnessing the impacts of droughts and floods since ancient times. Therefore, the ancestors, by their experiences, continued to build structures to catch, hold, and store rainwater during the monsoon period as a source to make the use of during the non-monsoon period (Satishkumar et al. 2017). These traditional practices, though less prevalent in modern times, are still in use and efficient. One such framework of ancient water management is the tank cascade systems (*TCS*). A tank is an earthen structure (bund) constructed across a stream, holding the stream water reaching toward it from its catchment (tank water spread area) and releasing surplus water of the stream from the weir located at extreme end(s) of the bund (Narayanamoorthy 2007; Neelakantan et al. 2017; Palanisami and Meinzen-Dick 2001). Unlike ponds, reservoirs, or lakes, a tank has one or two surplus weirs, waterhole at inlets, sluices, etc. In general, a *TCS* is defined as the connected series of small, medium, and large tanks organized from a higher elevation to lower elevation in an effort to channelize gravity flow along with the series (Geekiyanage and Pushpakumara 2013).

A *TCS* represents a more than 2000 years old surface water civilization developed ingeniously by the rulers, local chieftains, and philanthropists in association with rural communities, especially in the regions experiencing intense monsoons for few weeks followed by long droughts. The *TCS* was considered the common pool resource that could be accessed by all for multiple purposes. The principal behind *TCS* was to make the use and reuse of the water by conveying, storing, and utilizing water over the surface at a micro- (or meso-) scale (Srivastava and Chinnasamy 2021; Srivastava and Chinnasamy 2023). In order to ensure the sustainability of *TCS* in ancient times, elected representatives from Gram Sabhas (village-level assembly in India) had considered utilizing revenue generation from *TCS* for its maintenance. Apart from the purposes of balancing the mico-climatic conditions, *TCS* was primarily used as an irrigation source for the command area at its downstream.

Nevertheless, when the decentralized management of *TCS* became centralized, there was no revenue (or resources) left for further management of *TCS*. The first impact of this governance system was on the village economy, as the primary livelihood of the farmers crashed. The *TCS*, in general, has deteriorated since the colonial period because of redundant interventions by the state and changing socio-economic and political conditions, especially when it comes to the governance on a rural scale. At the time of independence, these tanks were irrigating more than 3.6 million hectares (Mha) (~17%) of the command area which was subsequently reduced to 1.7 Mha (2.5%) by 2014–2015 (Reddy et al. 2018; CWC 2015). There are diverse social, economic, physical, and institutional reasons identified by the literature regarding the degeneration of *TCS* (Reddy et al. 2018; Palanisami and Meinzen-Dick 2001; Kumara and Kumar 2019; Palanisami 2006; Palanisami et al. 2010; Sakthivadivel et al. 2004; Sakthivadivel and Shah 2019). A few of the chief reasons included increasing population density, a decline in community-based technology, the rapid spread of tube-well technology, and an unsustainable system for development and modernization. Currently, there are about 208,000 tanks in India of which, nearly 120,000 tanks (~58%) are located in the Southern peninsular states such as Tamil Nadu, Karnataka, Andhra Pradesh, and Telangana State (Sakthivadivel and Shah 2019). Furthermore, to explore these *TCS*, it becomes essential to conduct evidence-based research to study the regional hydrological conditions and the grounded institutional capabilities available in the recent decade for the maintenance of these structures. This study presents a case of cascading tanks from the city of Madurai, India.

Historically, the tanks have been a primary water source for the people of Madurai, a South-Indian city in the Tamil Nadu state of India (Amarnath and Raja 2006). Madurai is considered one of the oldest cities in Tamil Nadu located on the bank of the Vaigai River. The city has been categorized under a semi-arid region with subtropical climatic conditions (Sundaresan et al. 2017). As the Tamil Nadu state shares its boundary with Kerala, which is bordered by the Western Ghats, the summer monsoon is mostly hindered to the entire state. As a result of which, the state is predominantly dependent on the post-monsoon season (North–East monsoon) for meeting its water demands. However, the rainfall during the post-monsoon season has been recorded to be highly fluctuating and erratic. It resulted in recurring events of droughts and floods since ancient times. This has been considered one of the plausible reasons why the Vaigai River turned seasonal (Nagalapalli et al. 2019). Similar are the conditions in Madurai city (Roy and Kumari 2019). The city has a river, Vaigai, which however remains dry for most of the year. As a consequence, the residents, especially in the urban and peri-urban belts, are receiving irregular municipal water supply. In addition, the city has witnessed 13 events of drought in the last five decades, recurring every 3 to 7 years (Surendran et al. 2017). Apart from climate, the city has undergone rapid expansion since the 1990s. At the same time, the population, which is currently 2.7 million, has also doubled in the last 25 years. All these vicissitudes are resulting in abrupt changes to the land use land cover (*LULC*) pattern bringing significant alternations to hydrological cycles (Thummala et al. 2019). The most visible impacts are increased surface runoff and decreased groundwater percolation (Jacob et al. 2016). Consequently, the first prey to the impacts of this rapid urbanization, apart from the Vaigai River, is the elegant system of the Vandiyur tank cascade system (*VTCS*) of Madurai city. From the field investigation, it was identified that the interconnected system tanks under *VTCS* were designed to function as an irrigation tanks. Nevertheless, the irrigation tanks, in recent decades, were not considered a reliable irrigation source by the farmers. This was for the reason that the tanks, due to anthropogenic stressors, and climate change, turned rain-dependent and unable to serve irrigation during the non-monsoon period. To increase understanding of the regional hydrology of Madurai city from the perspective of using ancient water harvesting systems, this study, for the first time, will comprehensively consider the influence of the rainfall-runoff process, water variability in *VTCS*, agricultural pattern, and decentralized approaches by the local institutions on available water resources and its management.

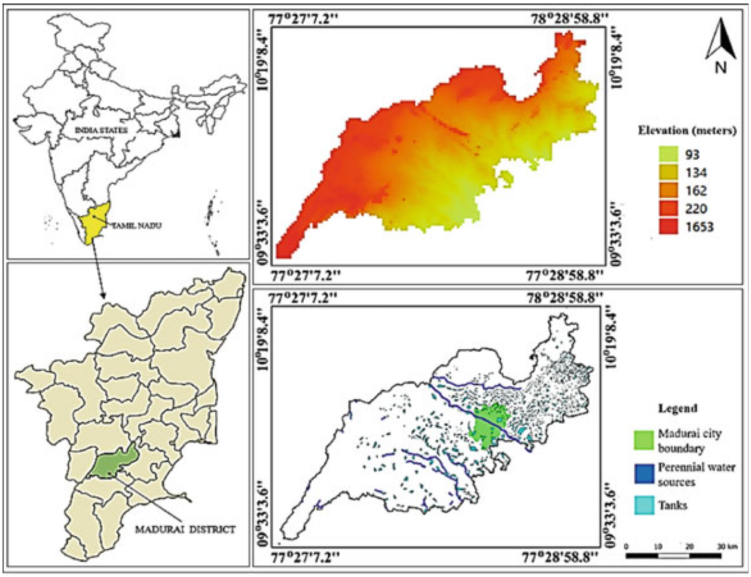
1.1 Study Objectives

The primary objective of this paper is to better understand the physical drivers that impact the efficiency and storage of the Vandiyur tank cascade system (*VTCS*). Secondary objectives include investigating administrative challenges (if any) that impact *VTCS*, and to document long-term hydroclimatic and land use changes in the *VTCS* catchment area, which can aid in understanding the supply–demand scenario, especially in the context of tank-fed based agricultural practices.

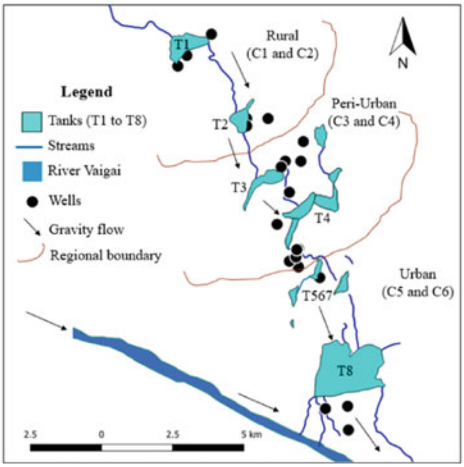
2 Methods

2.1 Study Site

Madurai city is part of the Madurai corporation and represents the administrative headquarter of the Madurai district in the Indian state of Tamil Nadu (Fig. 1). Being the second-largest in terms of area and third largest in terms of population in the state (population of 2,578,201), the archaeological findings suggest that the district is more than 2500 years old and has continuously inhabited for the last two millennia (Lewandowski 1977; Srivastava and Chinnasamy 2022; http://www.maduraicorporation.co.in/population.html). Madurai city, which is also known as the cultural capital of the state, is located between 9.93° N and 78.12° E with an average elevation of 101 m above mean sea level. The city covers an area of 109 km^2 and is situated on the bank of the river Vaigai having flat and fertile plains. The topography moderately increases in North (N), East (E), and West (W) directions but not in South (S). In general, a gently sloping terrain is observed from N–W to the S–E direction, as evident from the digital elevation map shown in the insets of Fig. 1a. As there are no hills in the region, the city experiences roughly steady-state meteorological conditions.



(a). Location of study site in Madurai district, Tamil Nadu, India. Inset shows the location of Madurai in India and the Digital Elevation Model (DEM) of Madurai



(b). Location of Vandiyur tank cascade system (*VTCS*) in Madurai city showing catchments (C), system tanks (*T*), wells (*W*), and surplus streams interconnecting the *VTCS*

Fig.1 Study site. **a** Location of study site in Madurai district, Tamil Nadu, India. Inset shows the location of Madurai in India and the digital elevation model (DEM) of Madurai. **b** Location of Vandiyur tank cascade system (*VTCS*) in Madurai city showing catchments (C), system tanks (*T*), wells (*W*), and surplus streams interconnecting the *VTCS*

However, as the Tamil Nadu state is located in the semi-arid climatic zone, the city, at the same time, also experiences a dry-summer subtropical climate (CGWB 2010, 2014a, b). The temperature ranges from 15 °C to 41 °C while the relative humidity ranges from 45 to 85% in the Madurai district (Surendran et al. 2017).

The study site, *VTCS* is located in Madurai city and it extends from a village named Vandiyur located in Madurai-urban on the left bank of the river Vaigai to the village Kulamangalam in the Madurai-rural region (Fig. 1b). The study site has been categorized into six catchments (*C*) where each one is representative of at least a system tank (*T*) of *VTCS*, wells (*W*), and agricultural land apart from human settlement. These catchments are further classified into three types based on their developmental settings. The villages Kulamangalam (*C*1) and Veerapandi (*C*2) are classified under Madurai-rural each having the tanks *T*1 and *T*2, Thiruppalai (*C*3) and Siruvour (*C*4) are classified under Madurai-peri-urban each having the tanks *T*3 and *T*4, and Kosakulam-Parsurampatti-Kodikulam (*KPK—C*5) and Vandiyur (*C*6) are classified under Madurai-urban each having the tanks *T*567 and *T*8. There is a total of 22 wells (*W*1 to *W*22) located in the vicinity of *VTCS*. There is a gentle slope from *C*1 to *C*6 due to which, gravity flow is observed from *T*1 to *T*8 in *VTCS*, wherein the surplus runoff from one tank recharges the next tank at the downstream, and thus the catchments are interconnected, as shown in Fig. 1b.

2.2 Fieldwork and Data Collection

The present study encompasses both field (primary data collection) and technical (secondary data analysis) aspects, including both quantitative (data-based) and qualitative (survey-based) research methods. The primary and secondary data on the water resources were collected from the offices of Gram Panchayat (*GP*; village-level governance body in India), Zilla Parishad (*ZP*; district councils in India), Public Works Department (*PWD*), India Meteorological Department (*IMD*), *DHAN* (Development of Human Action; a grassroots level not-for-profit organization) Foundation, and published works of literature. Participatory appraisal activities with Sarpanch (village head or *Talaivar*), Gram Sevak (village development officer), members of *GP*, teachers from the *ZP* schools, staff from *DHAN* Foundation, and local villagers/citizens along with household surveys were conducted. The study period for the present research was between 2002 and 2018. The data on remote sensing studies prior to 2002 were unavailable. The aforementioned field experimentations and site surveys were conducted between 2018 and 2020 to validate the findings from remote sensing studies.

2.3 Rainfall Data

According to *IMD*, the four seasons in India are classified as winter season from January to February, summer season (also called as pre-monsoon season) from March to May, South–West (S–W) monsoon season (also called as monsoon season) from June to September, and North–East (N–E) monsoon season (also called as post-monsoon season) from October to December (Viswanath et al. 2020). The rainfall data for the Madurai district for the last 50 years (since 1969) were obtained from the India Meteorological Department (*IMD*) website (https://mausam.imd.gov.in/imd_latest/contents/rainfall_statistics_3.php). The data was used in calculating normal rainfall (based on the average rainfall between 1969 and 2018) while the rainfall received during the study period was considered as the actual rainfall. Percentage departure (deficiency) was estimated by comparative analysis between normal and actual rainfall magnitude for the study period, using the following equation:

$$\text{PercentageDeparture} = \frac{\text{ActualRainfall} - \text{NormalRainfall}}{\text{NormalRainfall}} \times 100$$

2.4 Google Earth Satellite Data

The assessment of the urbanization trend in Madurai city was based on Google Earth satellite data. The satellite images were obtained using Google Earth Pro archives for the years 2002 and 2018. The catchment boundaries were prepared using Google Earth Pro, as shown in Fig. 4. Each catchment consisted of at least one tank whose surplus water release became the recharge stream for the next catchment downstream. The satellite images were further analyzed to develop precise land use land cover (*LULC*) classifications. This included three types of land covers viz., agriculture, barren land, and forest (non-urbanized cover), tanks and surface recharge streams (surface water storage cover), and built-up regions (urbanized cover consisting of buildings, residential houses, playgrounds, and related concrete covers).

2.5 Runoff Estimations

The runoff was estimated using the curve numbers (*CN*) technique, developed by Soil Conservation Services (SCS) (Boughton 1989). In the determination of *CN* for the present study side, the type of soil and the type of land use within catchments were identified for 2002 and 2018 ground conditions. Based on the field investigations, the study considered hydrological soil classification group-C for the soils of the *VTCS* region, which is characterized by moderately high runoff potential. The antecedent moisture condition type-II was considered for the study that is characterized by the average of both dry and wet soil conditions (Mishra and Singh 2013; Srivastava and Chinnasamy 2021b). Against each catchment, weighted *CN* (based on the different land uses) was calculated. As the study site underwent a drastic change in *LULC* (Sect. 3.2) during the study period, a comparative analysis between *CN* for 2002 and *CN* for 2018 was conducted for understanding the influence of surface runoff across *VTCS*.

2.6 Tank Storage Estimations

The surface area of the tank was obtained during *LULC* studies and the volume estimation was based on the average depth to full-tank level (*FTL*) of these structures. The data on the total volume of the tank was obtained from the district *PWD* office, while the actual volume was obtained by site survey of tanks. The field surveys were conducted inside the tanks during the summer of 2019 (when the tank water spread area was completely dry) in multiple phases. *GPS*—(Global Position System) Essential tool was used to identify the mean sea level of all the points recorded while traversing in N–S, E–W, NW–SE, and NE–SW directions.

3 Results and Discussions

The present section has been broadly classified into four categories viz., (1) analysis of rainfall trend, (2) changes in *LULC* pattern, (3) analysis of runoff across catchments, (4) understanding high water variability in systems tanks and associated impacts over the functionalities of *VTCS*, such as tank irrigation for sustaining the agricultural practices in non-monsoon or summer seasons, and (5) discussion on the administrative challenges that impact *VTCS*.

3.1 Rainfall Analysis

The seasonal rainfall analysis of the Madurai district is shown in Fig. 2. It is evident that the N–E monsoon is the major season contributing water to the study site which is 45% followed by the S–W monsoon which contributes 36%. The summer season, having a highly erratic rainfall pattern, contributes 16% as rain, while the winter is limited to 3%. By comparing normal seasonal rainfall (1969–2018) with actual seasonal rainfall (2002–2018), results indicated that overall, there was a reduction in the N–E monsoon rainfall by 11.2% and S–W monsoon rainfall by 10.6%. An increase of 22% of the summer rainfall was recorded, however, the field investigation conflictingly revealed that the contribution of this rainfall was insignificant to both agriculture and *VTCS*. It was attributed to the fact that the rainfall during summer

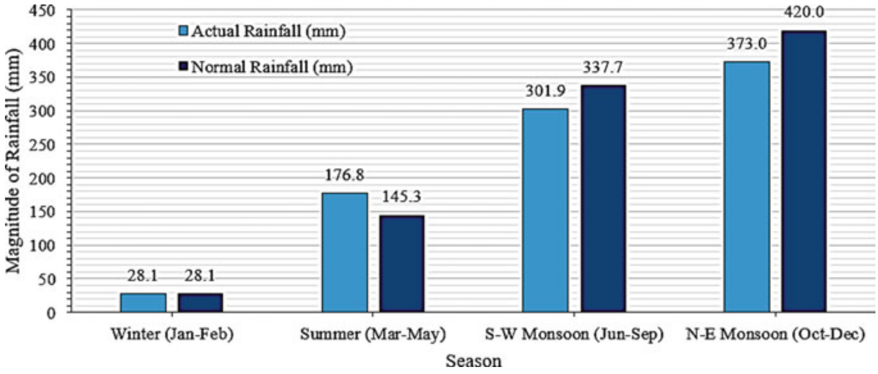


Fig. 2 Comparative analysis of seasonally normal rainfall (between 1969 and 2018) and actual rainfall (between 2002 and 2018) in Madurai district

was essentially received in the catchment post-mid-May. As a result of which, the large magnitude of rainfall in a short span resulted in higher surface runoff from the catchments. Furthermore, rainfall during the S–W monsoon season in the entire Tamil Nadu state has been recorded to be highly erratic, stormy, unpredictable, and largely unreliable, especially for rain-fed agricultural practices (Varadan et al. 2017).

The comparative analysis between average annual normal and actual annual rainfall is shown in Fig. 3. The normal rainfall in the Madurai district was obtained as 931 mm. Nevertheless, the last couple of decades were observed with a higher percentage departure in the actual rainfall from normal. Averagely, the percentage deficiency in the rainfall between the study period was 22% while the percentage surplus was recorded at 59.5%. But the period of percentage surplus was limited and observed exceedingly fluctuating. As it was apparent that across 17 years of the

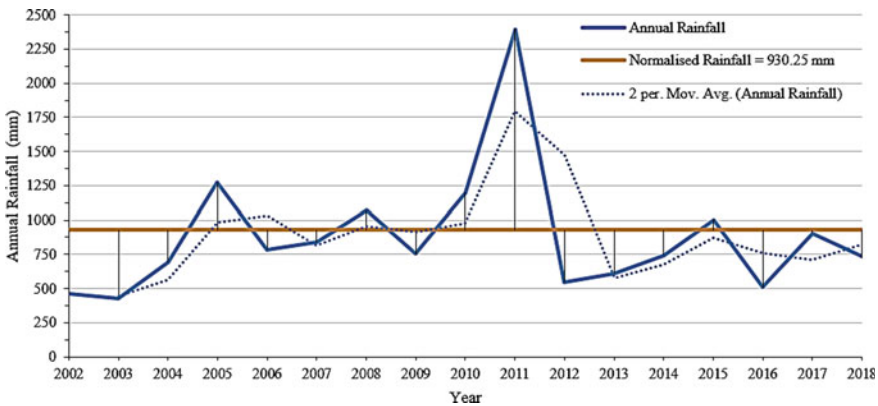


Fig. 3 Comparative analysis of annual average normal rainfall (between 1969 and 2018) and actual rainfall (between 2002 and 2018) in Madurai district

study period, the percentage deficiency in rainfall was observed 12 times while the percentage surplus was limited to five. The recent decade (since 2012) was observed to be critical, concerning the percentage departure of the rainfall, which was recorded as high as 45% (maximum) in the past seven years. The period between 2015 and 2017 was declared drought in the entire Tamil Nadu state (Santhanam et al. 2020). As a consequence, the agricultural activities remained abandoned consecutively for three years (2015–2017). This happened for the reason that most of the agricultural land was either rain-fed or tank-fed in Madurai city. For a couple of decades, the tanks were observed to be dependent on rain as a result of which the reliability of the tanks for irrigation was identified to be futile.

3.2 *Land Use Land Cover (*LULC*) Analysis*

Results from areal imagery analysis (Fig. 4) showed a rapid increase in the urban area, up to 300%, between 2002 and 2018 in peri-urban and urban Madurai. Results also indicated that the Vandiyur tank (*T*8) reduced in size, as the tank had a water spread area of 690 acres, irrigating a command area of more than 1000 acres withholding a storage capacity of 107 million cubic feet in the 1990s had shrunk to 71 million cubic feet by 2018. The command area had reduced to 100 acres and water spread had reduced to 572 acres. The primary reason behind the decline was the conversion of the command area into human settlement via encroachments. Currently, there are about 90 acres of the command area irrigated using *T*8. The cover of the urbanized area was recorded highest for *C*6 followed by *C*3. The urbanized cover was found

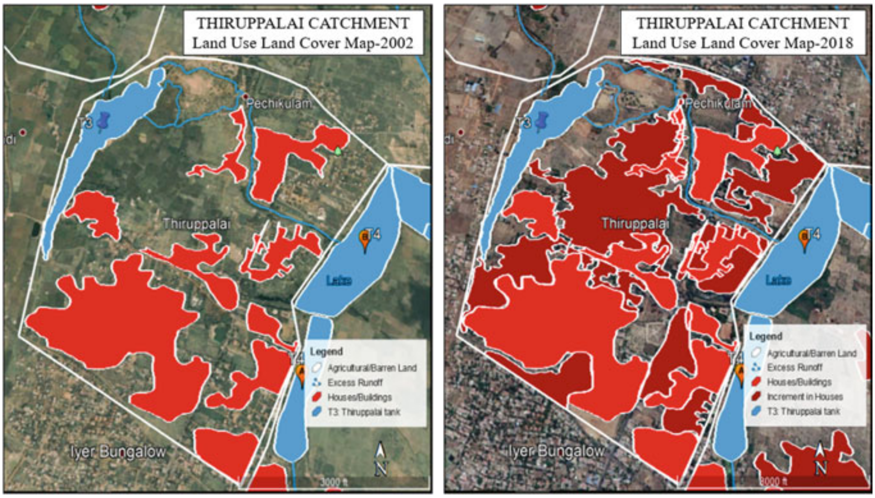


Fig. 4 Comparison of built-up cover between 2002 and 2018 in Thiruppalai catchment (*C*3) at Madurai city

in less than 5% of the entire rural catchments ($C1$ and $C2$) (Fig. 5). In general, an increasing trend was observed in the urbanization from rural (least) to peri-urban and further to urban catchments across the study site.

Another classification of the land use considered for the present study was the agricultural cover. Agricultural practices were considered one of the primary livelihood practices in rural catchments ($C1$ and $C2$). As evident from Fig. 6, apart from rural, Vandiyur ($C6$) was the only urban catchment practicing agriculture while the

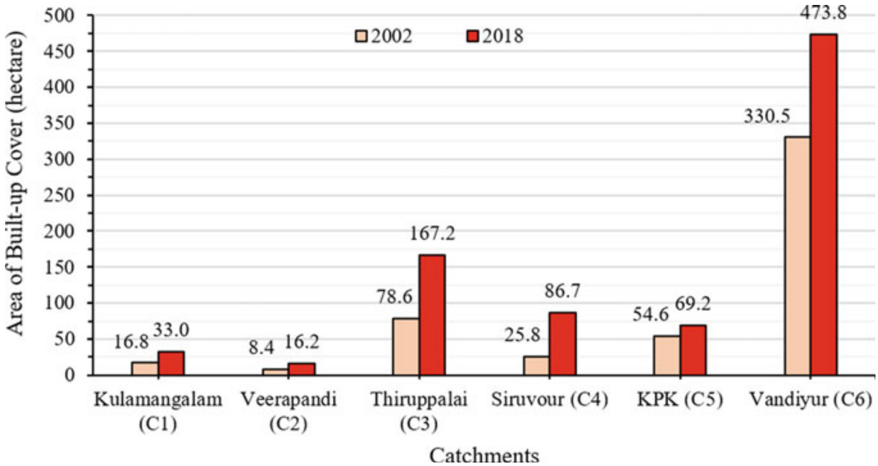


Fig. 5 Change in built-up cover between 2002 and 2018 across Vandiyur tank cascade system (*VTCS*) in Madurai city

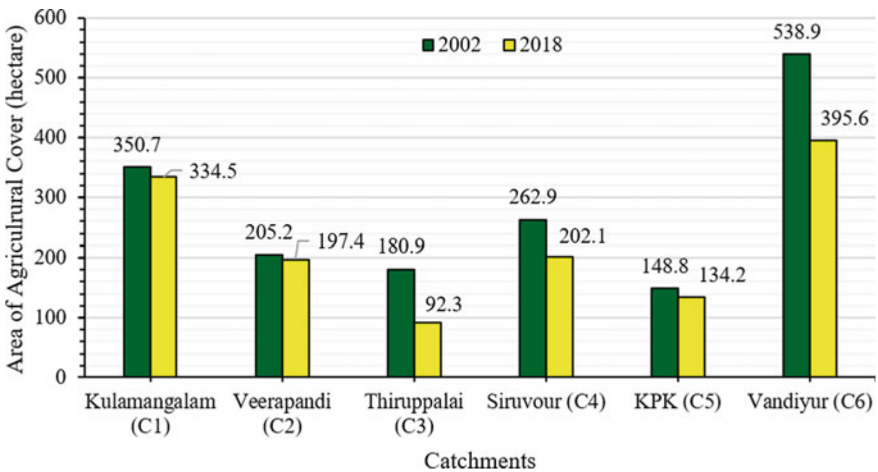


Fig. 6 Change in agricultural land cover between 2002 and 2018 across Vandiyur tank cascade system (*VTCS*) in Madurai city

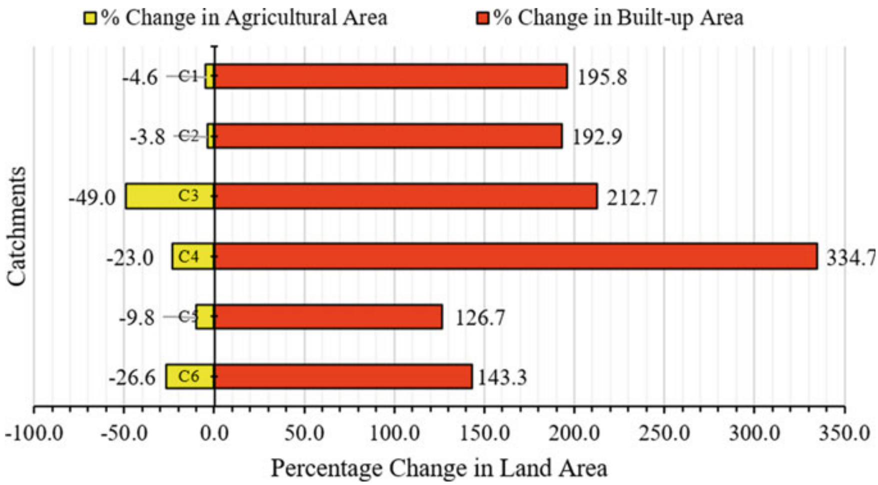


Fig. 7 Percentage change in agricultural and built-up cover between 2002 and 2018 across Vandiyur tank cascade system (*VTCS*) in Madurai city

agricultural practices in *C*3, *C*4, and *C*5 were observed recessive. In the case of later, these abandoned lands of agriculture underwent rapid encroachment due to the expansion of the Madurai city from urban to peri-urban belts. Tanks served as a primary source of irrigation in *C*1, *C*2, and *C*6, apart from seasonal rainfall and canal water supply from the Periyar and Sathaiyar dams located upstream of *C*1. In general, a decrease in the agricultural land cover was observed between 2002 and 2018 by approximately 56 ha across the study site. The general trend of agricultural land cover was observed decreasing from urban (highest) to peri-urban to further rural catchments.

The percentage change in the *LULC* across six interconnected catchments in Madurai city is summarized in Fig. 7. The highest percentage increment in the urbanized cover was recorded to be more than 330% in Siruvour catchment (*C*4) followed by Thiruppalai (*C*3) with an increment of more than 210%. Both *C*3 and *C*4 are located in the peri-urban region. The reason behind the rapid urbanization in the peri-urban region was attributed to its location and feasibility for expansion. The *C*6 was close to its urbanization saturation, concerning the land area availability. Therefore, the expansion of the city was happening through *C*3 and *C*4 which are located next (at the upstream) to the Vandiyur, and at the same time, was approaching rural areas. Also, the agricultural activities were becoming limited due to rain-fed based farming practices and unreliable irrigation water supply from the silted (unmanaged) tanks. This resulted in the rapid conversion of the agricultural land (command area) into non-agricultural land. The highest decrement in the percentage cover of the non-urbanized region was recorded in *C*3 (49%). Whereas, *C*6 ranked second with a 27% decrement followed by *C*4 with a 23% decrement in the non-urbanized region. This newly available land was accommodating the expansion of the urbanizing cover of the city.

Results further indicated that the rural catchments had been least affected due to urbanization primarily due to two reasons. Firstly, the villagers were actively participating in tank-fed-based agricultural development. Villages had formed their water user associations (*WUAs*) headed by Sarpanch (*Talaivar*). The second reason could be that the villages were located far from the urban region and hence were not much influenced by the impact of urbanization. Overall, the non-urbanized cover had reduced in all the catchments since 2002 by 20% and the urbanized cover had increased across all the catchments since 2002 averagely by 150 to 300%. Saravanabavan et al. (2019) also identified the built-up cover (43% of the entire Madurai city) to be the most dominating land use land cover classification, followed by fallow land (20%), cropland (14%), and tank water spread area (13%). The study on LULC change by Kundu et al. (2018) indicated the decline in the non-urbanized area (by 24%) whereas, the built-up area increased by more than 200% in the entire Madurai city between 2001 and 2018.

3.3 Analysis of Runoff Across Catchments

The study of the assigned curve number for each land use classification provided data on the percentage surface runoff of the total rainfall received for each catchment in the study region. The temporal change in *LULC* resulted in an increment in the curve number, leading to an increment in the runoff across all catchments (Fig. 8). The greatest percentage increase in the runoff was recorded in peri-urban catchments

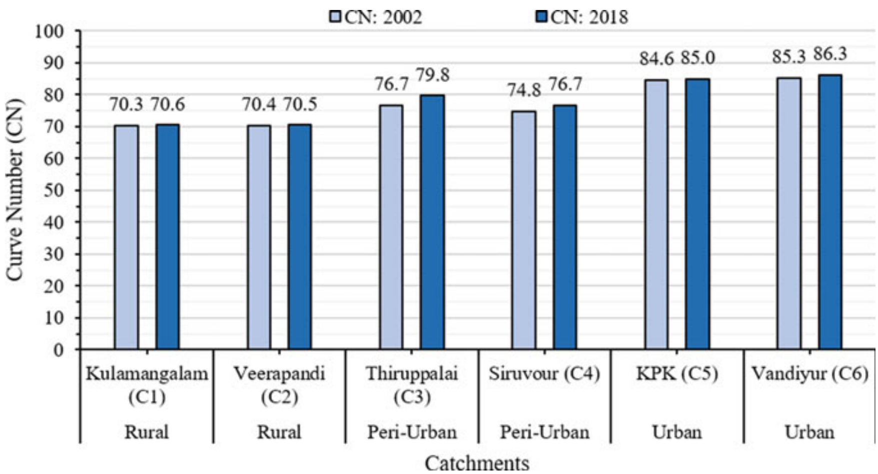


Fig. 8 Change in Curve Number (*CN*) between 2002 and 2018 across Vandiyur tank cascade system (*VTCS*) in Madurai city

(2.5 to 4%) followed by urban catchments (0.5 to 1.5%), while the least increase in the runoff was observed in the rural areas (0.1 to 0.4%) across the study period. This can be attributed to the fact that the rural area underwent the least urbanization due to which, the runoff remains rather unaffected. While the opposite is scenarios at peri-urban catchments. As discussed in Sect. 3.2, the urban region was already saturated in terms of built-up cover and therefore, the city is expanding via the peri-urban region. As a result, most abrupt changes to *LULC* happened in the peri-urban region thereby resulting in the highest percentage increase in runoff across *VTCS*.

The highest runoff was recorded from $C6$ (>86%) in 2018 followed by $C5$ having 85% of surface runoff. Both the catchments were located in the urban region of Madurai city. The least surface runoff was recorded in rural areas ($C1$ and $C2$ with having ~70% runoff), followed by a peri-urban region ($C3$ and $C4$) with a variation of 75 to 80%. Consequently, rural areas had more provision for groundwater recharge, whereas the increasing impervious cover was resulting in higher surface runoff from the catchments (as evident from $C5$ and $C6$). As a result of erratic rainfall patterns, rapid urbanization, and increased surface runoff, the discharge into the *VTCS* decreased, which led to a decrease in the natural recharge of groundwater in the areas adjoining the tanks. The direct impact was observed in agricultural productivity.

*3.4 Status of Vandiyur Tank Cascade System (*VTCS*)*

The *VTCS* fundamentally consisted of four connected series (chain) with 21 tanks in total and having Vandiyur tank ($T8$) as a common. One of the series ($T1$ to $T8$) from village Kulamangalam ($C1$) to Vandiyur ($C6$), which is the longest and has its tank in all three developmental settings viz., rural, peri-urban, and urban, was investigated for the present study. Vandiyur tank was the largest tank in *VTCS* (refer to Fig. 1b), located close to the plains of the Vaigai river. In the study area, the human settlements were observed expanding (refer to Sect. 3.2) from the Vandiyur basin toward the North. Therefore, the influence of the expansion was apparently visible in peri-urban catchments. At the same time, agricultural practices had been observed to be more consistent in rural catchments, which gradually decreased in the South. As a result, the system tanks of *VTCS* had been found to function differently across the study sites. Mostly it was governed by the degree of urbanization, tank-based irrigation, administration under which the tank was located (Panchayat or Municipal Corporation or *PWD*), and the local communities' involvement in the maintenance of the *VTCS*.

The field investigation of *VTCS* was conducted in each system tank the determination of the actual volume in 2019. It was remarkably noticed from the site surveys that the peri-urban and urban tanks were receiving the discharge of sewage via pipe outlets opened into the tanks from the nearby human settlement zones (Fig. 9). To differentiate the filled-part of urban tanks from rural tanks, this study, instead of calling filled-part silt in general, called it muck (sewage waste). Conversely, rural tanks were found with silt instead of muck, however, the issue of open defecation

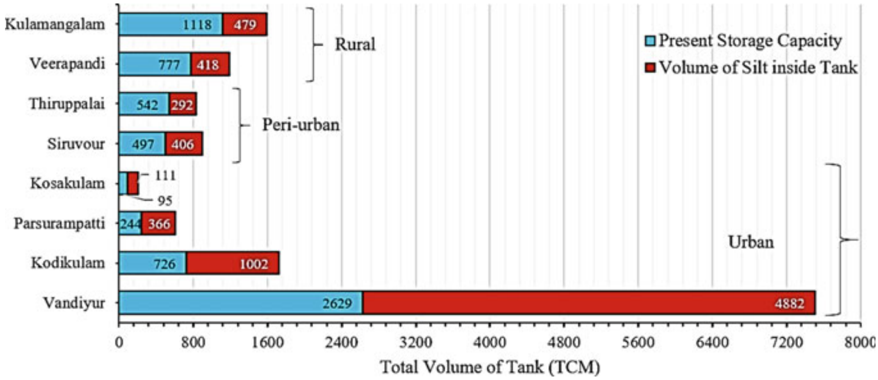


Fig. 9 Status of silt storage in the units of thousand cubic meters (*TCM*) across Vandiyur tank cascade system (*VTCS*) in 2019–2020 at Madurai city

persisted in the rural catchments. The volume of the silt/muck inside the tank was estimated by the difference between the total volume of the tank and the actual volume determined through site surveys. Largely, results indicated that 30 to 70% of the total tank volume was filled (either with silt or muck). As evident from Fig. 9, the rural tanks were found less filled (30 to 35%) than peri-urban tanks (35 to 45%) and urban tanks (54 to 65%).

The percentage volume filled in the tanks was observed to increase from rural to urban tanks. This, for the reason, was attributed to three facts. One, agricultural practices in rural regions make the continuous use of tanks for irrigation, whereas, the tanks in peri-urban and urban were mostly left unused and unmaintained. Therefore, rural tanks kept a check over the siltation process. Two, as the geological set-up of the study site, influences gravity flow within *VTCS*, hydrologically, more surplus runoff from tanks (as surplus streams originating from tank's weir) and catchment runoff (either from command area or urbanized land) were occurring from rural to urban catchments. Consequently, the deposition of silt in peri-urban and urban tanks from rural tanks/catchments was observed to increase at each tank level (from rural to urban). Third, community-level engagement at rural catchments by *DHAN* Foundation regarding decentralized management of tanks for irrigation and livestock management purposes promoted villagers to conduct, annually, the desiltation program inside tanks. However, similar approaches at peri-urban and urban catchments were observed limited.

Yet in another investigation regarding seasonal water availability, *VTCS* was observed undergoing high spatial and temporal variation in water storage. Figure 10 shows maximum (% departure > 0%) and minimum scenarios (% departure < 0%) of water availability inside tanks across four seasons viz., winter, summer, S–W monsoon, and N–E monsoon across the study period. The N–E monsoon season recorded the highest availability of water in a year (Fig. 10d). During this season, the maximum water availability across *VTCS* was observed at 100% while the minimum water availability varies between 20 and 30% of the actual volume of the tanks.

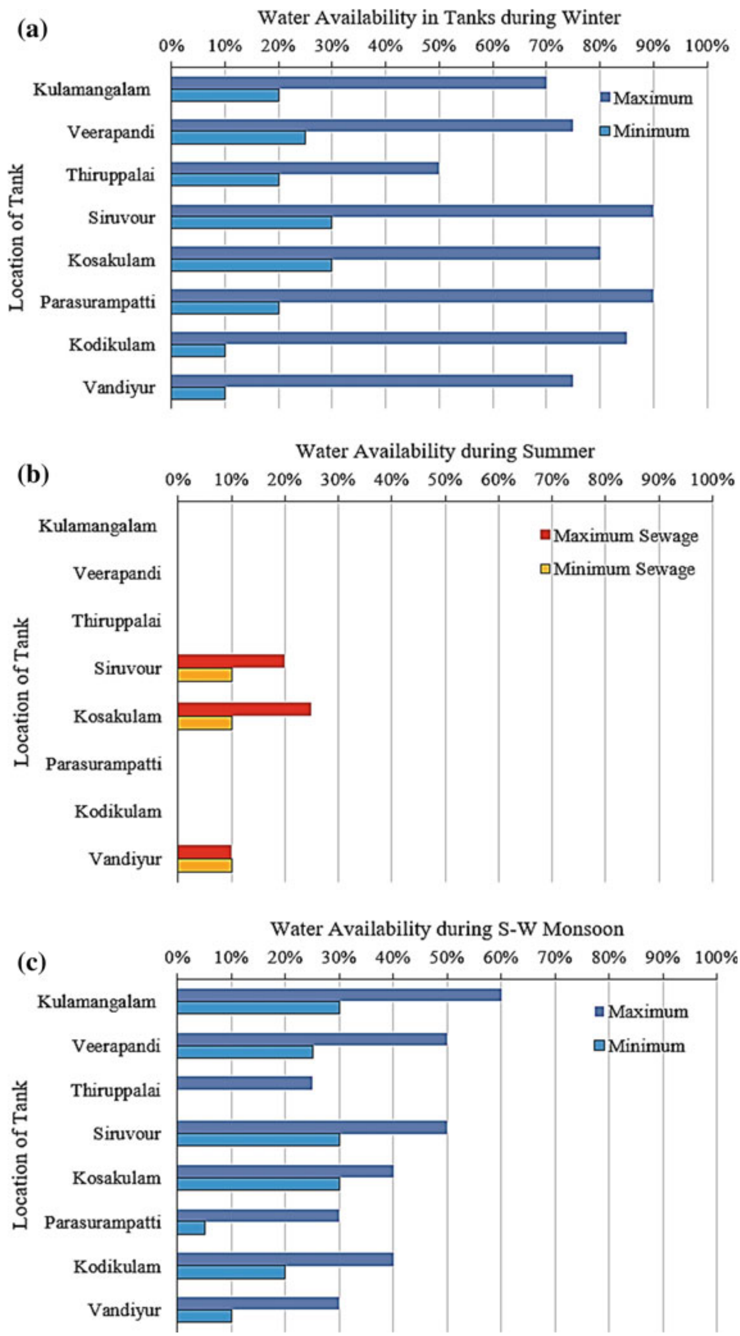


Fig. 10 Average seasonal water availability in system tanks (expressed in percentage of actual volume) of the Vandiyur tank cascade system (*VTCS*) for the study period between 2002 and 2018 in the seasons of **a** winter, **b** summer, **c** S–W monsoon, and **d** N–E monsoon

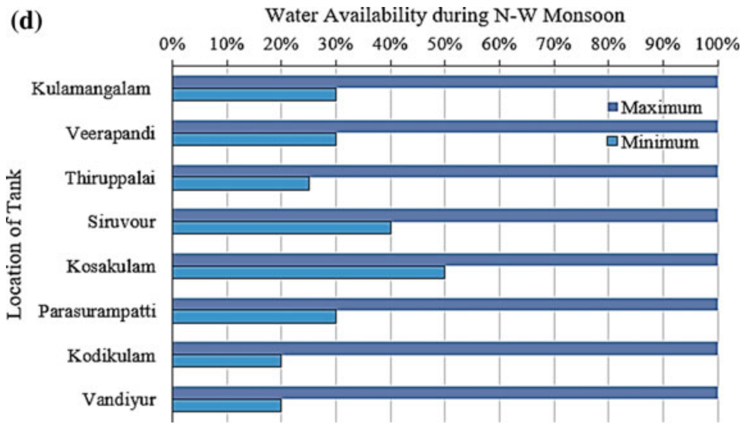


Fig. 10 (continued)

Following this, the winter season recorded the second-largest water availability across *VTCS* (Fig. 10a) and was approximately 30% higher than the S–W monsoon season (Fig. 10c). During winter, the minimum water availability varies from 10 to 30% while the maximum varies from 50 to 90%. While the least water availability was recorded during summer (Fig. 10b). Under both maximum and minimum water scenarios, the *VTCS* as a whole remained dry for the entire summer season. Furthermore, instead of rainwater, sewage water was observed in *T*4, *T*5, and *T*8.

In general, limited attempts were made to understand the efficiency of these tanks, and thus, the application of *VTCS* in meeting irrigation demand remained challenging. Lack of a holistic understanding of processes that impact the functioning of tanks (such as erratic rainfall patterns, changing *LULC*, and increasing surface runoff) and the absence of dedicated capacity to manage tanks (such as water user associations) had been key reasons for the dismal performance.

3.5 Challenges and Way Forward in VTCS Management of VTCS

The field investigation based on the actual volume of tanks versus the volume of silt/muck and spatio-temporal variability of the water across tanks indicated that *VTCS* could not be used to its optimum efficiency, due to management challenges. Furthermore, a few tanks were observed as a source of sewage and solid waste disposal (refer to Fig. 10b). The lack of ownership and management of the tanks could have increased sedimentation load inside the tank spread area. As a consequence, the actual potential of the tank was reduced by 30 to 70%, which subsequently reduced the number of cropping seasons from previously two or three seasons to one. Hence, the study further investigated the institutional frameworks and local community involvement in the maintenance of the tanks.

In *VTCS*, out of the eight tanks studied, six tanks (*T*3 to *T*8) were under the control of the Madurai's *PWD*, as they were located in the corporation boundary, while the remaining two tanks (*T*1 and *T*2) were under the control of Panchayat. In the case of urban tanks, Walker's Club and Gomathipuram Association were the two active water user associations (*WUA*) observed maintaining the Vandiyur tank (*T*8). Although for the remaining tanks, no such *WUAs* were observed, and hence, these tanks (*T*3 to *T*7) mostly remained unmaintained. While in the case of rural tanks, *DHAN* Foundation's Vayalagam Tank-fed Agriculture Development Program in Madurai was observed actively operating since 1992 (https://www.dhan.org/vayalagam/). They have been working on the revival, restoration, and rehabilitation of the village tanks under Panchayat intending to promote community governance in water resources. Several attempts of revival and desiltation of both urban and rural tanks had taken in the past, but due to the lack of both ownership and maintenance, these structures remained silted (Chinnasamy and Srivastava 2021; Sundaresan et al. 2017; Srivastava and Chinnasamy 2021; Jacob et al. 2016).

Therefore, the study urges the Madurai administration to pilot test *VTCS* for its support to influence micro-climatic parameters, groundwater recharge, biodiversity, and its potential to check siltation, floods, and drought across one or two catchments by reviving and rehabilitating the structure and tank spread area. If the pilot tests are successful in increasing the net surface and groundwater storage, the revival and rehabilitation methodology can be introduced to all the 21 tanks in *VTCS*. This will certainly increase the storage of S–W and N–E monsoon water, which is crucial and necessary to mitigate future irrigation water crises. The current study results will increase the understanding of the current water depletion across Madurai city, and the storage available in the *VTCS* that can be recharged either through the surplus tank runoff or catchment runoff or both apart from the rain. This can allow *VTCS* to remain functional even during non-monsoon seasons, particularly during the peak summer. Furthermore, considering the digitalization-based smart planning of water resources, online web applications for surface-water and groundwater budgeting can be developed at rural, peri-urban, and urban scales (Srivastava et al. 2021; Srivastava et al. 2022) Such attempts can allow easy dissemination of local information on water balance for surface water storage structures (VTCS in specific) at real-time.

4 Conclusions

Under ongoing climate change impacts and increasing rural and urban water stress, there are huge investments (some as loans) and incurred costs for developing water infrastructures in India. With a spree of water infrastructure projects designed, attempts to revive traditional and historic water infrastructures are limited. Such is the case in the Madurai city of South India, where tank cascade systems (especially the Vandiyur tank cascade system (*VTCS*)) have been poorly managed. Limited attempts have been made to understand the efficiency of these tanks, and thus revival efforts are futile. Lack of a holistic understanding of processes that impact the functioning of tanks and the absence of dedicated capacity to manage tanks have been key reasons for the dismal performance.

This study, for the first time, identified long-term physical drivers that impacted the storage potential of *VTCS* and also document the administrative constraints that prevent the management of *VTCS*. On the climate change front, long-term rainfall data indicate a shifting pattern of dominant rainfall seasons and also found that the concentration of rainfall events has increased, which has led to increased flash runoff events and floods. Along with the changing rainfall patterns, long-term land use land cover change analysis indicated that there is a considerable increase in the urbanization of land in the *VTCS* catchment area, which has influenced the soil erosion and sediment loading potential. Due to the aforementioned change in rainfall and unsustainable *LULC* patterns, results indicated an increase in sediment loading in the Vaigai River which led to increased sedimentation in the *VTCS* system. This sedimentation has decreased the storage potential of the *VTCS* from 30 to 70% between 2002 and 2019. As a result, even though *VTCS*'s original storage potential can satisfy the water demands of the catchment area, with high sedimentation there is a reduced water storage scenario, which led to the ongoing water supply stress in the region. It was also understood, via surveys with *DHAN* Foundation, a grassroots level not-for-profit organization in Madurai, that there was no dedicated government agency to maintain the *VTCS*, with only *NGOs* working on them. Therefore, even though the historic and traditional water storage infrastructure exists, lack of understanding of process drivers and improper management have led to decreased water and socio-economic stress.

To conclude, traditional water harvesting structures have the potential to ease the water stress in the current scenario, and methods to understand the issues with traditional water infrastructure exist. However, without appropriate public and government participation and policies, the revival of this traditional infrastructure is challenging. Therefore, rather than investing in new water infrastructure, this study urges a collaborative effort from policymakers and government agencies in understanding long-term impacts on tanks and encourages periodic maintenance and management of traditional water infrastructures that can aid sustainable water development in India.

Acknowledgements Authors thank the Ministry of Rural Development (*MoRD*), Government of India, New Delhi, and Centre for Technology Alternatives for Rural Areas (*CTARA*) from the Indian Institute of Technology (*IIT*) Bombay, India for providing a fellowship platform to conduct this work. Authors acknowledge the financial support received from the Centre for Urban Water Resources (*CURE*) from *DHAN* Foundation—Madurai, India, and *CTARA* from *IIT* Bombay, India for facilitating field visits as well as to present this work at the 2nd International Conference on Rural Technology Development and Delivery (RTDD 2020) organized at *IIT* Madras, India. Thanks are due to officials of *DHAN* Foundation viz., Mr. Elamuhil (Water Resources Engineer) and Lokesh Sinram (Environmentalist), Mr. N. Venkatesan (Program Manager—Human Resource), Mr. V. Venkatesan (Chief Executive Officer—Vayalagam), Mr. Arumugam Gurunathan (Director—The DHAN Academy), and Mr. M. P. Vasimalai (Executive Director—DHAN), and all the participants, farmers, village people, Panchayats, and *PWD* officials from Madurai city.

References

Amarnath JS, Raja PK (2006) An economic analysis of tank rehabilitation in Madurai district of Tamil Nadu. Agric Econ Res Rev 19(1):187–194. https://doi.org/10.22004/ag.econ.57757

Boughton WC (1989) A review of the USDA SCS curve number method. Soil Res 27(3):511–523. https://doi.org/10.1071/SR9890511

CGWB (2010) A report on Madurai district. Central Ground Water Board (CGWB), Ministry of Water Resources, New Delhi, India

CGWB (2014a) Ground water year book—2013–2014a. Central Ground Water Board (CGWB), Ministry of Water Resources, New Delhi, India

CGWB (2014b) Dynamic groundwater resources. Central Ground Water Board (CGWB), Ministry of Water Resources, New Delhi, India

CWC (2015) Report on water and related statistics. Information System Organisation, Water, Central Water Commission, Government of India. http://cwc.gov.in/sites/default/files/water-related-statistics-2015.pdf. Last accessed 17 July 2020

Chinnasamy P, & Srivastava A (2021) Revival of traditional cascade tanks for achieving climate resilience in drylands of South India. Frontiers in Water. 3:35

Dhawan V (2017) Water and agriculture in India. In: Background paper for the South Asia expert panel during the global forum for food and agriculture (GFFA), pp 3–24. https://www.oav.de/fileadmin/user_upload/5_Publikationen/5_Studien/170118_Study_Water_Agriculture_India.pdf. Last accessed 17 July 2020

Geekiyanage N, Pushpakumara DK (2013) Ecology of ancient tank cascade systems in Island Sri Lanka. J Mar Island Cultures 2(2):93–101. https://doi.org/10.1016/j.imic.2013.11.001

Ghosh S, Srinivasan K (2016) Analysis of spatio-temporal characteristics and regional frequency of droughts in the southern peninsula of India. Water Resour Manage 30(11):3879–3898. https://doi.org/10.1007/s11269-016-1396-5

IMD—India Meteorological Department, Ministry of Earth Sciences, Government of India, Homepage. https://mausam.imd.gov.in/imd_latest/contents/rainfall_statistics_3.php. Last accessed 17 July 2020

Jacob N, Jaryal A, Gurunathan A (2016) Environmental isotope investigation to understand the groundwater recharge from irrigation tanks in Thirumal area, Madurai. In: Raju N (ed) Geostatistical and geospatial approaches for the characterization of natural resources in the environment. Springer, Cham, pp 285–291. https://doi.org/10.1007/978-3-319-18663-4_44

Khadke L, Pattnaik S (2021) Impact of initial conditions and cloud parameterization on the heavy rainfall event of Kerala (2018). Model Earth Syst Environ. https://doi.org/10.1007/s40808-020-01073-5

Kumara TM, Kumar S (2019) Dynamics of community based tank irrigation systems in India: a case study of Andhra Pradesh. Indian J Extension Educ 55(4):116–121. https://www.indianjournals.com/ijor.aspx?target=ijor:ijee3&volume=55&issue=4&article=021. Last accessed 17 July 2020

Kundu D, Pandey A, Sharma P, Bhusan S, Mondal B, Lahiri B, Sharma TC, Vijh S (2018) India: national urban policies and city profiles for Delhi and Madurai. Research Report, National Institute of Urban Affairs. Pub. GCRF Centre for Sustainable, Health and Learning Cities and Neighbourhoods (SHLC)

Lewandowski SJ (1977) Changing form and function in the ceremonial and the colonial port city in India: an historical analysis of Madurai and Madras. Mod Asian Stud 11(2):183–212. https://www.jstor.org/stable/311548

Madurai Corporation, Homepage. http://www.maduraicorporation.co.in/population.html. Last accessed 17 July 2020

Mishra SK, Singh VP (2013) Soil conservation service curve number (SCS-CN) methodology, vol 42. Water Science and Technology Library, Springer Science and Business Media

MoWR (1999) Report of the national commission for integrated water resources development. Ministry of Water Resources (MoWR), Government of India, New Delhi

MoWR (2017) Report on the impact of climate change on water resources. Ministry of Water Resources (MoWR), Government of India, New Delhi. http://www.indiaenvironmentportal.org.in/files/file/Impact%20of%20Climate%20Change%20on%20Water%20Resources.pdf. Last accessed 17 July 2020

Mujumdar M (2020) Droughts and floods. In: Krishnan R, Sanjay J, Gnanaseelan C, Mujumdar M, Kulkarni A, Chakraborty S (eds) Assessment of climate change over the Indian region. Springer, Singapore, pp 117–147. https://doi.org/10.1007/978-981-15-4327-2_6

Nagalapalli S, Kundu A, Mall RK, Thattai D, Rangarajan S (2019) An appraisal of flood events using IMD, CRU, and CCSM4-derived meteorological data sets over the Vaigai river basin, Tamil Nadu (India). Sustain Water Resour Manage 5(4):1731–1744. https://doi.org/10.1007/s40899-019-00325-2

Narayanamoorthy A (2007) Tank irrigation in India: a time series analysis. Water Policy 9(2):193–216. https://doi.org/10.2166/wp.2006.063

Neelakantan TR, Suribabu CR, Selvakumar R (2017) Opportunity to restore irrigation tanks in the Cauvery delta by mining and deepening. Environ Dev Sustain 19(4):1463–1472. https://doi.org/10.1007/s10668-016-9814-7

Pai DS, Guhathakurta P, Kulkarni A, Rajeevan MN (2017) Variability of meteorological droughts over India. In: Rajeevan M, Nayak S (eds) Observed climate variability and change over the Indian region. Springer, Singapore, pp 73–87. https://doi.org/10.1007/978-981-10-2531-0_5

Palanisami K (2006) Sustainable management of tank irrigation systems in India. J Dev Sustain Agric 1(1):34–40. https://doi.org/10.11178/jdsa.1.34

Palanisami K, Meinzen-Dick R, Giordano M (2010) Climate change and water supplies: options for sustaining tank irrigation potential in India. Econ Polit Weekly 45(26/27):183–190. https://www.jstor.org/stable/40736699

Palanisami K, Meinzen-Dick R (2001) Tank performance and multiple uses in Tamil Nadu, South India. Irrig Drainage Syst 15:173–195. https://doi.org/10.1023/A:1012927722965

Planning Commission (2008) Eleventh five-year plan (2007–2012): agriculture, rural development, industry, services, and physical infrastructure. Gov India 3:43–64. https://niti.gov.in/planningcommission.gov.in/docs/plans/mta/11th_mta/chapterwise/Comp_mta11th.pdf. Last accessed 17 July 2020

Reddy VR, Reddy MS, Palanisami K (2018) Tank rehabilitation in India: review of experiences and strategies. Agric Water Manag 209:32–43. https://doi.org/10.1016/j.agwat.2018.07.013

Roy D, Kumari S (2019) Social actors in traditional tank rehabilitation: a case study of Tamil Nadu (India). Sustain Water Resour Manage 5(2):587–597. https://doi.org/10.1007/s40899-018-0221-0

Sakthivadivel R, Shah M (2019) Will Kudimaramathu make communities think tanks again? A study of tanks in transit, coping mechanism of communities and government action, vol 6. International Water Management Institute (IWMI), Sri-Lanka

Sakthivadivel R, Gomathinayagam P, Shah T (2004) Rejuvenating irrigation tanks through local institutions. Econ Polit Weekly 39(31):3521–3526. https://www.jstor.org/stable/4415350

Santhanam K, Abraham M, Mishra AK (2020) Productivity improvement of wasteland in drought-prone, over drafted and rocky terrain watershed: a case study of upper Thurinjalar watershed in Ponnaiyar basin Tamil Nadu, India. Natl Acad Sci Lett 43(5):439–442. https://doi.org/10.1007/s40009-020-00882-7

Saravanabavan V, Balaji D, Preethi S (2019) Identification of dengue risk zone: a geo-medical study on Madurai city. GeoJournal 84(4):1073–1087. https://doi.org/10.1007/s10708-018-9909-9

Satishkumar U, Dasog GS, Balakrishnan P, Ramaswamy K (2017) Assessment of sedimentation rate in rain-fed irrigation tank systems under different agro-climatic zones in Karnataka, India. Agric Res 6(1):47–56. https://doi.org/10.1007/s40003-016-0237-3

Sawkar RH, Joshi M, Swaminath MH, Guruprasad G (2018) Government of India policy of fixing minimum support price for agriculture products in relation to water resources of peninsular India. J Geol Soc India 92(4):389–392. https://doi.org/10.1007/s12594-018-1032-5

Srivastava A, Chinnasamy P (2021) Water management using traditional tank cascade systems: a case study of semi-arid region of Southern India. SN Appl Sci. 3:281. https://doi.org/10.1007/s42452-021-04232-0

Srivastava A, Chinnasamy P (2021a) Developing village-level water management plans against extreme climatic events in Maharashtra (India)—a case study approach. In: Vaseashta A, Maftei C (eds) Water safety, security and sustainability. Advanced Sciences and Technologies for Security Applications. Springer, Cham. pp 615-635. https://doi.org/10.1007/978-3-030-76008-3_27

Srivastava A, Chinnasamy P (2021b) Investigating impact of land-use and land cover changes on hydro-ecological balance using GIS: insights from IIT Bombay, India. SN Appl Sci 3:343. https://doi.org/10.1007/s42452-021-04328-7

Srivastava A, Chinnasamy P (2022) Assessing groundwater depletion in southern India as a function of urbanization and change in hydrology: a threat to tank irrigation in Madurai city. In: Kolathayar S, Mondal A, Chian SC (eds) Climate change and water security. Springer, Singapore. Lect Notes in Civil Eng 178:293–308. https://doi.org/10.1007/978-981-16-5501-2_24

Srivastava A, Chinnasamy P (2023) Tank cascade system in southern India as a traditional surface water infrastructure: a review. In: S. Chigullapalli et al. (eds.), Rural technology development and delivery. Des Sci Innovation. https://doi.org/10.1007/978-981-19-2312-8_15

Srivastava A, Khadke L, Chinnasamy P (2021) Web application tool for assessing groundwater sustainability—a case study in rural-Maharashtra, India. In: Vaseashta A, Maftei C (eds) Water safety, security and sustainability. Adv Sci Technol Secur Appl. Springer, Cham. pp 637–659. https://doi.org/10.1007/978-3-030-76008-3_28

Srivastava A, Khadke L, Chinnasamy P (2022) Developing a web application-based water budget calculator: attaining water security in rural-Nashik, India. In: Kolathayar S, Mondal A, Chian SC (eds) Climate change and water security. Springer, Singapore. Lect Notes in Civil Eng 178:473–492. https://doi.org/10.1007/978-981-16-5501-2_37

Subramanya K (2013) Engineering hydrology. McGraw-Hill, Delhi, India

Sundaresan J, Allen A, Johnson C (2017) Reading urban futures through their blue infrastructure: wetland networks in Bangalore and Madurai, India. In: Bell S, Allen A, Hofmann P, Teh TH (eds) Urban water trajectories, vol 6. Springer, Cham, pp 35–50. https://doi.org/10.1007/978-3-319-42686-0_3

Surendran U, Kumar V, Ramasubramoniam S, Raja P (2017) Development of drought indices for semi-arid region using drought indices calculator (DrinC)—a case study from Madurai district, a semi-arid region in India. Water Resour Manage 31(11):3593–3605. https://doi.org/10.1007/s11269-017-1687-5

Thummala N, Madhuri M, Srinivas E, Rao AN, Mariappan VN (2019) GIS technology for assessment of urban green cover area of Madurai corporation in Tamil Nadu. In: Rao P, Rao K, Kubo S (eds) Proceedings of international conference on remote sensing for disaster management. Springer Series in Geomechanics and Geoengineering, Springer, Cham, pp 25–31. https://doi.org/10.1007/978-3-319-77276-9_3

Varadan RJ, Kumar P, Jha GK, Pal S, Singh R (2017) An exploratory study on occurrence and impact of climate change on agriculture in Tamil Nadu, India. Theor Appl Climatol 127(3):993–1010. https://doi.org/10.1007/s00704-015-1682-9

Viswanath NM, Ramachandran S, Reganti HR (2020) Modeling and predicting the patterns of seasonal rainfall in Tamil Nadu, India 1951–2017: an UCM approach. Arab J Geosci 13(5):226. https://doi.org/10.1007/s12517-020-5216-0

Vyas K (2020) Big data mining on rainfall data. In: Kotecha K, Piuri V, Shah H, Patel R (eds) Data science and intelligent applications, vol 58. Springer, Singapore, pp 99–104. https://doi.org/10.1007/978-981-15-4474-3_10

Chapter 15
Tank Cascade System in Southern India as a Traditional Surface Water Infrastructure: A Review

Aman Srivastava and Pennan Chinnasamy

1 Introduction

South India, a peninsula in the shape of an upturned triangle in the Indian subcontinent, is located between 8° 19′ N to 21° 16′ N latitude and 72° 56′ E to 82° 18′ E longitude. South India is bounded by Satpura and Vindhya ranges in the North, the Indian Ocean in the South, Sri Lanka in the South-East, the Bay of Bengal in the East, and the Arabian Sea in the West (Fig. 1). South India previously consisted of four states viz., Andhra Pradesh, Karnataka, Kerala, and Tamil Nadu, and two union territories viz., Lakshadweep and Puducherry. While Telangana, the 28th state of the Union of India and the 5th state of South India was created from Andhra Pradesh in 2014. Literature prior to 2014 analyzed South India with a consideration of four states (Jain and Dannenberg 2018). The neighboring states in South India include Maharashtra, Goa, Chattisgarh, and Odisha. Deccan plateau is the major geographic characteristic of South India. Satpura ranges define the Northern spur of the Deccan plateau while the Western Ghats define the Western spur (Vasu et al. 2017). The Western Ghats continue South via the Karnataka coast and terminate at Nilgiri mountains which is an Eastern extension of the Western Ghats. Nilgiri Mountains run along the border of Tamil Nadu with Northern Kerala and Karnataka and continue till the low-lying hills of the Eastern Ghats, located at the Western border of Tamil Nadu and Andhra Pradesh. In general, Karnataka, Tamil Nadu, and Maharashtra cover the major portion of the Deccan plateau that slopes down gently

A. Srivastava (✉) · P. Chinnasamy
Centre for Technology Alternatives for Rural Areas (CTARA), Indian Institute of Technology Bombay, Mumbai, India
e-mail: amansrivastava1397@gmail.com

P. Chinnasamy
Rural Data Research and Analysis (RuDRA) Lab, Indian Institute of Technology Bombay, Mumbai, India

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_15

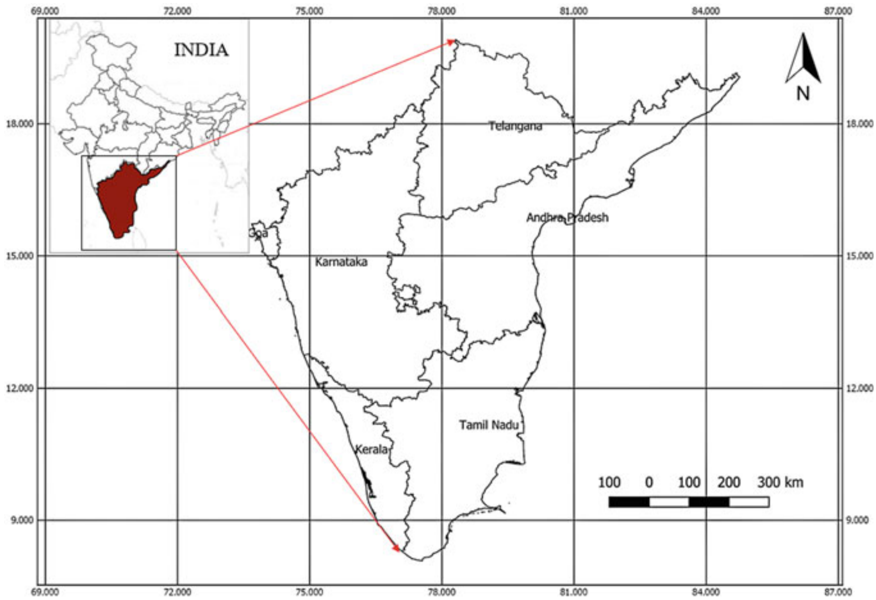


Fig. 1 Location of South India in Indian sub-continent. *Source* QGIS

from the Western Ghats (having an average elevation of 500–1200 m) to the East coast (having a detached hill of average elevation of about 700 m) (UNESCO 2020).

Climate-wise, South India experiences a hot-humid and mostly semi-arid tropical climate with an average annual rainfall of 750 mm (Kodirekkala 2018). In addition, there exists a high spatio-temporal variation in the rainfall pattern. The region around the Western Ghats receives more than 4000 mm of annual rainfall that gradually decreases to 600 mm toward the Eastern Ghats (Mishra and Nagaraju 2019; Khadke and Pattnaik 2021). South-West monsoon also called summer monsoon (June to September) is the major source of rainwater in Kerala, Karnataka, Telangana, and the part of Andhra Pradesh contributing nearly 90% of the total rainfall. Whereas, in the case of Tamil Nadu and South-East Andhra Pradesh, the North-East monsoon also called post-monsoon (October to December) is the major source of rainwater contributing about 47% of the total rainfall (Bal et al. 2016; Murthy et al. 2019). This anomaly is attributed to the fact that the Western Ghats hinder the South-Westerly winds as a result of which South-West monsoon striking in the Southern part of Kerala, advances further to Karnataka shadowing Tamil Nadu and South-East Andhra Pradesh. But during the post-monsoon season, South-West monsoon retreats due to which, the North-Easterly flow of air carrying moisture from the low-pressure region of Bay of Bengal strikes the East coast of the Southern peninsular region, especially Tamil Nadu, which not only causes intense rainfall but attracts cyclones formed in the Bay causing damages to life and property. Apart from rainfall, the river is yet the other source of water in South India. The major drainage basin includes the Godavari, Krishna, and Cauveri, located between Western and Eastern Ghats. Nevertheless, these basins, unlike the perennial rivers of Northern India, are seasonal and rainfed. As a consequence of climate change vulnerabilities and rapid land-use transformations,events such as erratic rainfall patterns, high spatio-temporal variabilities in the available water resources, and extreme events such as droughts and floods have becomes cyclic and recurrent in South, West, and Central India (Anil and Ramesh 2017; Chakrabarti et al. 2015; Srivastava and Chinnasamy 2021b; Srivastava et al. 2021). In general, the shorter monsoon season and longer dry season in South India necessitated the creation of surface water storage structures with an intent to hold the rainwater of monsoon (buffering impacts of intense flooding) and use-reuse of stored water during non-monsoon (dry) periods (retarding negative consequence of droughts) (Ghosh and Srinivasan 2016; Guhathakurta 2015; Guhathakurta et al. 2017). One of the traditional structures, in this context, is the tank cascade systems (*TCS*), ingeniously developed by the local rulers through a public-participatory approach. This structure was created as a result of the extraordinary engineering and managerial-social skills of the rulers, philanthropists, and local communities (https://www.dhan.org/vayalagam/).

The *TCS* continued to provide ecological services for several centuries due to its institutional arrangements where the benevolent local rulers with their communities (beneficiaries) participated in building, expanding, and maintaining the *TCS* (decentralized way of tank management). However, the degradation of *TCS* started with the colonization of India in the early nineteenth century due to the shift in the policy attributing water as the estate property. Consequently, *TCS* became the source of revenue generation during the British period, rather than a protective source, collapsing the institutional arrangements, and disrupting the local livelihoods (Mosse 1997; Shah 2008). Even after the post-independent period, the decline of the tank irrigation practices continued until the 1980s when the South Indian States in association with Central Government started realizing the significance of the tanks in establishing rural economies across the nation (Narayanamoorthy 2007; Reddy et al. 2018).

1.1 Study Objectives

The primary objective of this study is to provide a detailed review of the tank cascade system (*TCS*) in Southern peninsular India, to assess the extent and significance of *TCS* in the environment and economy, and to identify the key impacts of *TCS* and current challenges. Secondary objectives include identifying potential revival mechanisms for *TCS* and assessing different revival, restoration, and rehabilitation programs conducted for *TCS* across South India. This paper is an attempt to explore the variations in *TCS* across the Southern peninsular regions and draw lessons from the historical development of *TCS* across South Indian states.

2 Tank Cascade Systems: A Centuries-Old Technology

In South India, there are broadly two seasons viz., a relatively dry season (summer) from March to mid-June and the rainy season (principal monsoon) from October to December. The dry season is mostly plagued by the recurrent and considerable duration of droughts while the rainy season is usually accompanied by seasonal flooding (Guhathakurta 2015; Guhathakurta et al. 2017). For decades, the farmers have only been able to cultivate during the rainy season due to water shortages in the dry season. More than 80% of South India lies in the semi-arid dry zone and is prone to the issues of water scarcity (Bharucha 2016; Vinke et al. 2017). Furthermore, the topography was observed undulating with hard subsurface warranting surface water storage. As a consequence, the level of groundwater lowered due to low water retention by the soils aggravating water stress to agriculture and wildlife (Panda et al. 2017). To combat these issues in South India, over 2400 years ago, flourished one of the finest hydraulic civilizations of the world referred to as tank cascade systems (*TCS*). The ancient kings developed the sophisticated network of small tanks connected by canals or natural streams to a large reservoir that collected and redistributed rainwater the land received (Shah 2011). The tanks were built in a cascading system (*TCS*) using the natural inclination of the topography of the land. The communities were mandated to maintain *TCS* by the king's order. Due to this, *TCS* remained functional for several centuries, of which, few of them are still functional. "Let not a single drop of water go waste into the sea without benefiting the world," said King Parakramabahu in the twelfth century AD was the reusing principle behind the *TCS* (Aubriot and Prabhakar 2011; Geekiyanage and Pushpakumara 2013).

A tank is defined as a water-holding structure enclosed by an earthen bund constructed across the surface stream so as to hold and regulate the catchment runoff/rain. A tank is further classified as system tank if there exist supplementary sources of water to the tank apart from rainfall such as rivers, catchment runoff, connecting streams, surplus flow from upstream tanks, etc. Wherein, if the tank is rainfed, it is classified as non-system tank or rainfed tank (https://www.dhan.org/vayalagam/). In South India, most of the tanks constructed are observed interconnected with upstream and downstream tanks and thus mostly identified as system tanks. In general, an individual tank with its catchment, water spread, and command area is an integral part of a watershed within which it is situated. A tank in the *TCS* is not a distinct individual unit that can work independently, but rather it is connected to many other tanks and components which cannot function properly. Bound together in a certain hydraulic pattern, the entire set of tanks functions as a single unit. A cascade of tanks forms a micro-watershed by itself as the tanks are interlinked, often by a common stream or by the surplus water of an upstream tank recharging a downstream tank (Kayastha 2011; Srivastava and Chinnasamy 2021a). An existing tank or cascading tank within a catchment or watershed captures the rainwater runoff and conserves it for later use, which would otherwise flow down the gullies and streams and mostly get evaporated or otherwise dissipated (Fig. 2). These catchments or micro-watersheds, if delineated, will extend in the range of 13–26 km^2 with an

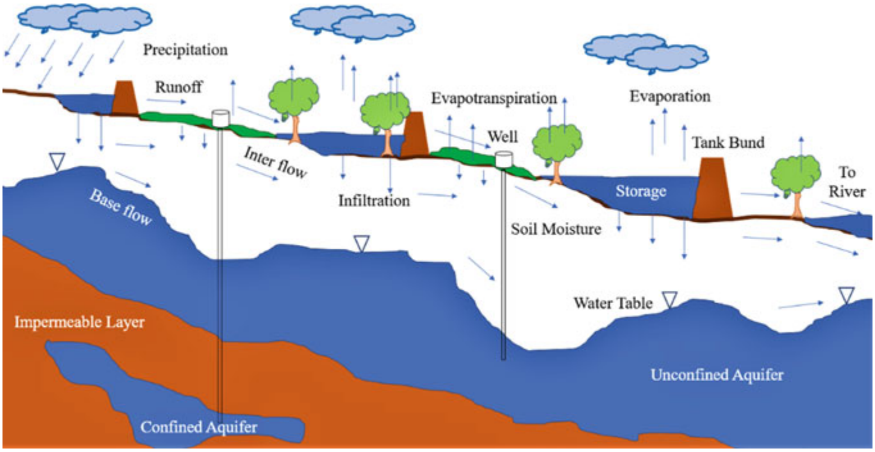


Fig. 2 Schematic representation (in elevation) of a small tank cascade system (*TCS*)

average of 20 km^2. Essentially the tanks or village tanks were developed as an alternative source for irrigation intending to overcome the difficulties faced by the then farmers practicing rainfed-based agriculture and to ensure irrigation sources/supply even during the non-monsoon period (Urfi 2017; Srivastava and Chinnasamy 2021c). The main goal of the *TCS* was to save and reuse the water allowing cultivation in both the seasons across the dry zones. Tank, paddy field, watersheds, canals, and natural ecosystem, were perfectly interlaced. Apart from irrigation, the tanks were employed for diverse uses such as domestic water supply, livestock management, influencing micro-climatic parameters such as evaporation, temperature, humidity, heat balance, soil moisture, vegetation, groundwater, etc. that comprehensively influenced the hydrological cycle thereby water balance within its catchment or micro-watershed boundaries. For small watersheds, the natural hydrological cycle of the *TCS* was kept through the soil, vegetation, and atmosphere keeping it more accountable to nature and the environment (Geekiyanage and Pushpakumara 2013; Reddy and Behera 2009).

Ancient kings were visionaries as their design for *TCS* kept the perfect ecological balance with the environment. The design of the tanks was influenced by the Buddhist belief that humans need to live in harmony with nature. So, the *TCS* was based on the culture of sharing, community ownership, and the respective natural course of water and animal life (Sakurai and Palanisami 2001). The water utilized in upper tanks again is reutilized in the downstream tanks, and specific areas of the tanks were dedicated to wild animals like the endangered ancient elephants, birds, and many other species from the nearby forest (Ariza-Montobbio et al. 2007). The formation of the *TCS* requires a landscape where water drains naturally in a branched or dendritic pattern. The *TCS* is formed by building tanks crossing the natural streams. Tanks along with their components are carefully designed and exceptionally well-constructed for efficient water management covering all the seasons. Each tank in the given *TCS* has organized geographical and functional features that harmonize with the environment and are essential for water conservation and management. These functional components of the tank serve a specific purpose (Palanisami 2006). Their function can be explained by modern science even though they were designed several centuries ago. The *TCS* has four main functions viz., first, it functions to capture water during the monsoon minimizing the flood; second, it stored rainwater over the surface and below the ground enhancing the water security. Third, tanks in *TCS* allows the use and reuse of water; and fourth, they help in mitigating the drought effects in dry zone where water shortage is acute. The *TCS* was perfectly adapted to cope with the climate of South India, characterized by recurrent droughts and floods (Bebermeier et al. 2017).

The *TCS* consisted of several components each of which serves a specific purpose so as to ensure good quality water is supplied throughout the year in adequate quantities (Narayanamoorthy and Jothi 2019). There are differences in the number of components present in the *TCS* depending upon the landscape position and utility of the tanks. In a system, the first set of components has been designed to improve the quality of the water entering the tank from the catchment by a series of filtering systems (Fig. 3). In forest tanks, water holds, (bunds) located in the catchment of the tank, retain dead leaves, mud or sediments, and other debris. Next, before the tank water spread area, is a grass cover (filter), located between the catchment and the high

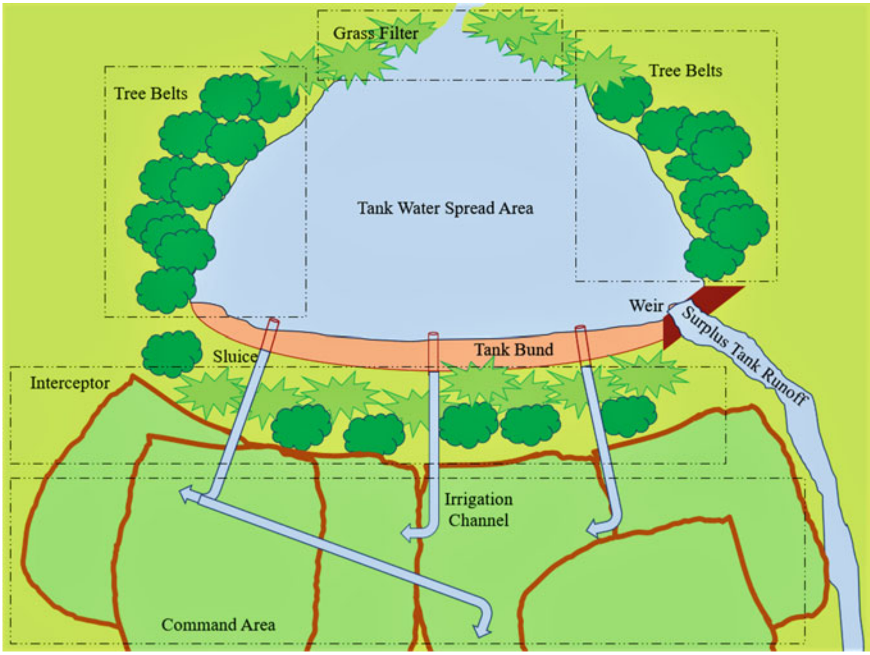


Fig. 3 Schematic representation (plan view) of a tank and its components. Adapted from Geekiyanage and Pushpakumara (2013)

flood level for purifying the water by holding the granules of the Earth and sediments. This is very similar to the preliminary treatment step in the modern wastewater treatment system. Further, this clean water enters the system for human consumption and agriculture. The water stored in the tank is protected from evaporation by tree belts naturally growing along either side of the uppermost area of each tank. They act as a windshield and minimize the contact of the water surface, thus the evaporation. At the same time, the stored water inside the tank spread area, through their percolating behavior, becomes a potential recharge source for groundwater (Massuel et al. 2014). The interceptor is a thick strip of vegetation located between the tank bund and the paddy field. Thus, functions to retain the saline water seeping from the tanks. Various plants having salt observing characteristics are found in the interceptor which helps to reduce the salinity of the water seeping from the bund before it reaches the paddy field. In addition, the interceptor minimizes seepage losses from the tank by raising the downstream water table. Irrigation water used for cultivation is to be disposed of through a drainage canal. Common drainage is used for this purpose. This ensures the prevention of salt accumulation in the paddy field. A salt-affected soil does not produce a good yield. In addition to their main function, the tree belt and interceptor also contribute to the stability of the tank ecosystem. They also function as nature reserves where a rich assemblage of biodiversity is formed which in turn provides multiple benefits to the community (Geekiyanage and Pushpakumara 2013; Meter et al. 2015).

3 Challenges to Tank Cascade Systems

Water management strategies in South India, as a whole, involved the local community, participating actively in tank building and maintenance. However, since the colonial period, the maintenance and management practices introduced by the estate undermined the importance of community participation (Mosse 1999). The tank ecosystem has not been properly maintained. The ancient tanks' designs and construction sophistication were poorly understood by modern engineers and major key features were dropped in the colonial era. There was also a poor understanding of the tank components, for example, forest tanks that were supposed to function as filters were wrongly used for irrigation. The *TCS* was neglected and abandoned due to which two major groups suffered viz., fishing and farming communities. The environment surrounding almost every tank deteriorated tragically. Trees growing naturally in the tree belts in the upland areas of the tank area were filled indiscriminately. As a result, the environment became deprived of birds and insects owing to the destruction of vegetation. In addition, colonization promoted mal-irrigation technologies, economic globalization, and fundamental changes in social and cultural values. The consequence was that a large number of tanks become ineffective or in some cases defunct, as a result of which the area under tank irrigation declined, and the local ecosystem deteriorated (Bitterman et al. 2016; Kumar et al. 2016). Subsequently, the degradation of the tanks continued even after the independence of India.

The government, both at the state and the center, inherited the same policy framed during British India that most water rights belong to the government. The interest of the local communities, due to the policy preventing community involvement in the maintenance and management of *TCS*, declined (Reddy et al. 2018; Nagarajan 2013). The impact of this fact was reflected in the tank irrigation practices and associated groundwater rechrage patterns. The declining of TCS can be better understood by referring to the evidence-based case studies from across Southern India (Srivastava and Chinnasamy 2022, 2023). For instance, in the 1950s, the three major sources of irrigation viz., tanks, canals, and groundwater (through wells) covered a command area of 38%, 36%, and 24%, respectively. Conversely, by 2000, the tank irrigated area reduced to 18% (ADB 2006).

In recent decades, climate change vulnerabilities are exposing South India to higher temperatures, heavy and more irregular rainfall, and longer droughts and most of the *TCS* are in disrepair. Due to this, reduced inflow to the tanks was observed resulting in high variation in water availability (Dhanya and Ramachandran 2016). One of the studies by the Asian Development Bank showed that the rainfall fluctuations and tank irrigated area followed a similar trend between 1960 and 1980 and were found highly correlated (ADB 2006). Due to this, the lack of rainfall for a certain period caused poor tank irrigation thereby reducing irrigated area while higher rainfall caused the greater irrigated area. Tanks turned rainfed and their functionalities became unreliable. However, post-1980s, it was observed that despite receiving higher rainfall, the tank irrigated area decreased. This happened due to the advancement of alternative sources of irrigation such as canal water supply, groundwater irrigation, etc. The development of well-irrigation technology during the green revolution (in the early 1970s) prompted communities to shift toward individual-based technology (use of diesel or electric pumps, tube-wells, and borewells). It was observed that the use of the alternative sources such as canals experienced a two-fold rise in the command area accounting for 39% irrigation potential while a more than five-fold rise in the command area irrigated by groundwater sources was observed, accounting for 47% irrigation potential between 1952 and 2000 (Fig. 4). On average, a rise in an irrigated area using alternative sources was one million hectares (ha) per year though tank irrigated area was gradually observed to decrease (ADB 2006; Janakarajan and Moench 2006; Narayanamoorthy 2011).

There are many more explanations as to how the tank irrigation declined as a result of limited inflow into the tank catchment. A few of the major reasons included silting of feeder channels, the encroachment of supply channels and tank beds, rapid urbanization causing abrupt land use/land cover changes in urban regions, unplanned watershed development cutting off the water inflow to the *TCS*, sand mining of supply channels, poor maintenance of structural components of *TCS*, and rural infrastructure development interfering with the natural inflows. The fundamental impact of the poor inflow into the tank resulted in tank sedimentation. Upland farming practices including shifting cultivation without augmenting appropriate soil conservation measures are one of the other causes. The runoff water from the upper catchments of the tanks brought loosened soil as sediments and resulted in tank sedimentation. Sedimented tanks hold less water with reduced key tank functions such as flood

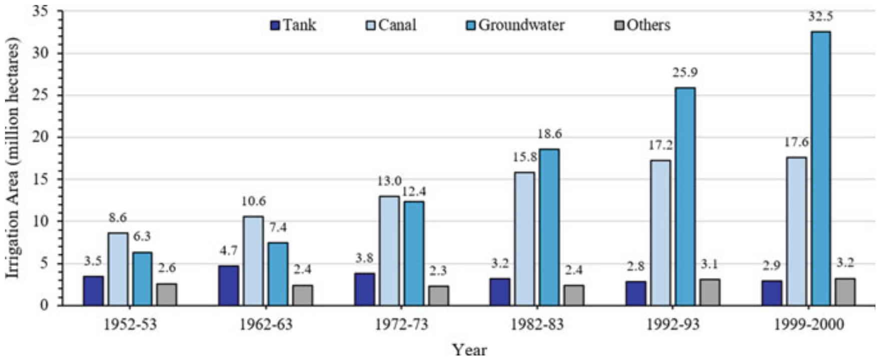


Fig. 4 Comparative analysis of different irrigation sources in the post-Independent India. *Source* Water and related statistics, Central Water Commission (2010)

control, groundwater recharge, water supply, and drought mitigation. Over the years, the tanks dry up completely and the paddy field becomes abandoned land (Morrison 2019; Narayanamoorthy and Suresh 2016; Srinivasan et al. 2013; Sundaresan et al. 2017).

4 Status of Tank Cascade Systems in South India

A similar trend of tank degeneration, as discussed in the previous section, was observed across South Indian states. Although there were the decline and decay of the major *TCS* in the dry zone of South India from colonial rule onwards, these cascading tanks continued in varying degrees of operation. Following independence in 1947, the responsibility for maintaining the minor irrigation schemes (tank management) was taken over by the minor irrigation department under State and Central governments. They were entrusted with the responsibility of maintaining all village-level irrigation schemes. With this change, the participation of the communities in the tank maintenance decreased, and the community became dependent on the state government for tank operation and maintenance. The major impact was observed on the primary livelihood activities of the farmers and rural communities in South India that collapsed as a result of the ignorance of *TCS* (Jayatilaka et al. 2001; Sakthivadivel et al. 2004). Until the 1980s, very little or no attention was paid to *TCS* as a whole but only to the individual tanks. Farmers had to face unforeseen problems owing to the construction and restoration of single tanks in isolation ignoring the interconnective nature in functionalities of the cascade system (Reddy et al. 2018).

In India, the number of tanks and ponds has been reported to vary between 200,000 and 350,000 (ADB 2006). Although the number of tanks from other sources has been reported to be 208,000, of this, more than 60% (159,000) of the tanks are located in South India (Reddy et al. 2018; Aubriot and Prabhakar 2011).

Of the South Indian states, Telangana has the highest number of tanks, which is 55,837 (Mission Kakatiya 2020). Andhra Pradesh is having 39,031 tanks (APCTMP 2020) and similar is the number of tanks in Tamil Nadu, which is about 39,000 tanks (Nasir and Selvakumar 2021). Kerala has about 5000 temples, each one in most instances having a sacred tank (Maya 2003), while about 3534 tanks are located in Karnataka (https://www.thehindubusinessline.com/news/national/Over-70-minor-irrigation-tanks-in-Karnataka-dry/article20479663.ece). Even in the union territory like Puducherry, there are, in total, 83 tanks. Altogether, these 159,000 tanks serve more than 65,000 villages in Southern India (Aubriot and Prabhakar 2011). However, the use of the *TCS* was observed to decline since the 1960s (Fig. 4). In 2000–2001, about 35% of the tanks in South India were observed in use in India while the tanks not in use increased from about 20,000 to 40,000 between 2000–2001 and 2010–2011. In the case of the number of tanks in use, between 1986 and 2007, the number of functional tanks reduced from 210,000 to 160,000 in South India while at all India levels, an increasing trend in the number of functional tanks was recorded during the same period (Fig. 5). This can be attributed to the watershed development programs which initiated in the post-1990s across India. Nevertheless, the decreasing trend in the tanks in South India reflected that the rehabilitation programs for tanks including watershed development were limited.

In the case of the percentage contribution of tank irrigation compared to other irrigation sources such as canals and wells, a decreasing trend is observed since the 1970s (Fig. 6). In South India, tank irrigation remained a predominant source since the independence of India. However, its contribution to yield was recorded at 27% in 1972 which was subsequently reduced to a mere 8% in 2014. A similar trend was

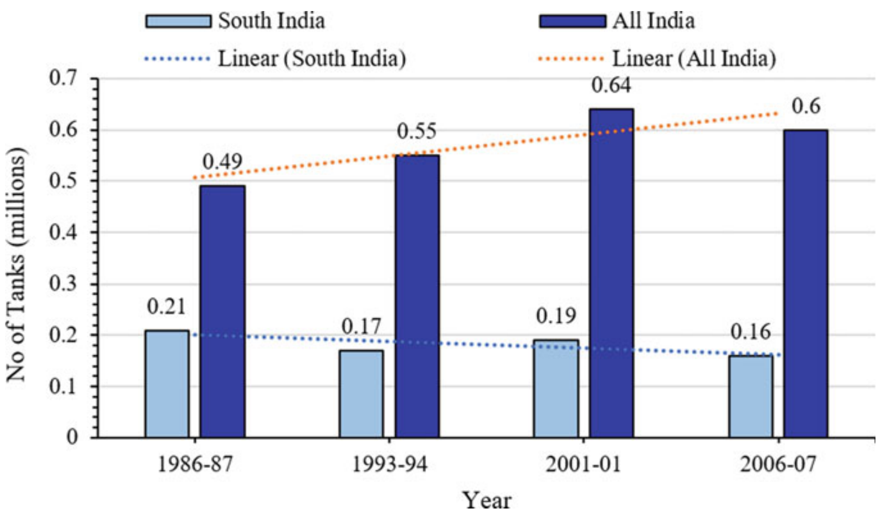


Fig. 5 Comparative analysis of the number of tanks in South India with all India between 1986 and 2007. *Source* Government of India (different years), Compiled from minor irrigation census, Ministry of Water Resources

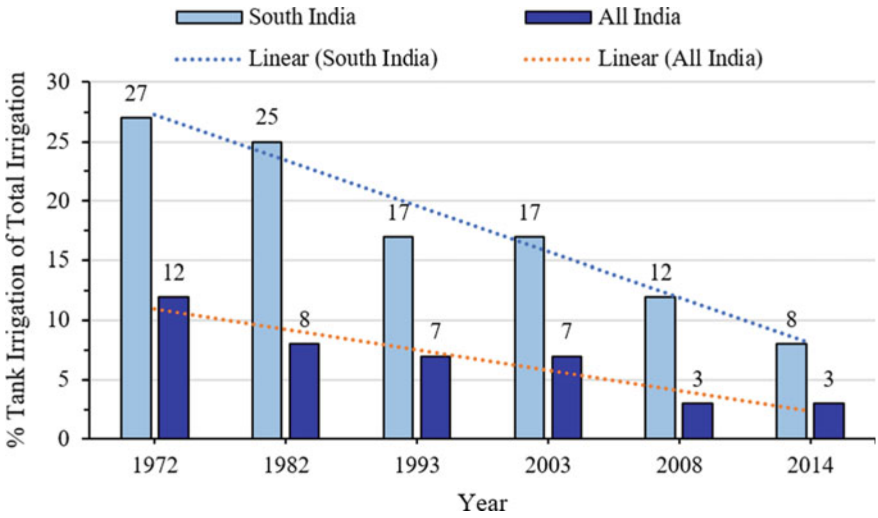


Fig. 6 Comparative analysis of the contribution of tank irrigation to all irrigation sources used in South India with all India between 1972 and 2014. *Source* Government of India (different years), Compiled from Minor Irrigation Census, Ministry of Water Resources

observed at all India level tank irrigation contributions in agriculture. Tank irrigation deteriorated at the advent of well-irrigation due to advancements in groundwater extraction technology since the green revolution of the 1970s that consequently reduced the tank irrigation contribution from 12% in 1972 to 3% in 2014 across India.

The unforeseen impact due to the degeneration of tank irrigation across both South India and India as a whole was reflected in the tank irrigated area (Fig. 7). The share under tank irrigation has steadily declined in South India by 56% (from 2,170,000 to 960,000 ha) and 54% in India between 1972 and 2014. Furthermore, comparing the share of the landholding under tank irrigation in South India with all India, the tank irrigated area has declined from 58% in 1972 to 45.5% by 2003. Although a rise in the landholding was observed between 2003 and 2008, as a result of which, the landholding under tank irrigation further increased to 56% in 2014. This was attributed to the rehabilitation programs for *TCS* across South Indian states.

In general, tank irrigation holds relatively greater significance across South Indian states where about 35% of the tanks, in use, irrigate more than 50% of the command area. Nonetheless, the tank irrigation practices as a whole have drastically deteriorated given the rising alternatives to tank irrigation in view of canals and wells. Therefore, more attention has been given to the South Indian states since the 1980s in terms of reviving and rehabilitating the cascading network of tanks with an intent to restore its primary functionalities (Reddy et al. 2018; Chinnasamy and Srivastava 2021).

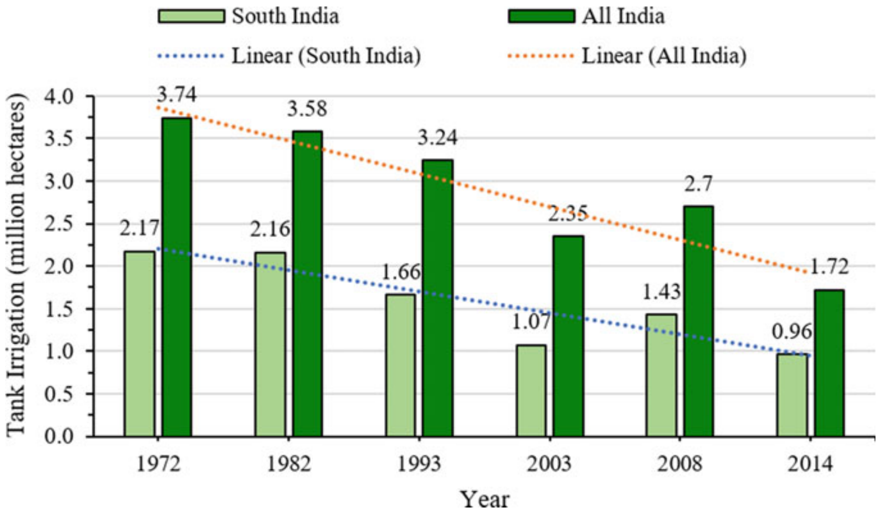


Fig. 7 Comparative analysis of tank irrigated area in South India with all India between 1972 and 2014. *Source* Government of India (different years), Compiled from Minor Irrigation Census, Ministry of Water Resources

5 Tank Rehabilitation Programs for Sustainable Management

Tank rehabilitation initiatives, in the post-independent period, were much needed in the context given the economic angle and community-based common-property resources management. Structural and functional repairing of tanks such as desiltation of tank water spread area, laying filter and rip-rap, creating additional volume for dead storage, reconstruction of totally damaged sluices, eradication of weeds/water invasive plants species, strengthening the tank bunds, the selective lining of channels, and repairing surplus weirs and canal structures are few of the integral and urgent interventions required while rehabilitating tanks (Reddy et al. 2018; Palanisami et al. 2010). Concurrently, it was also concluded in several research studies that the incurred cost in the tank restoration works was outweighed by the benefits and restored functionalities of the tanks. Furthermore, the tank size estimated based on tank water spread area and tank irrigation area was found proportional to the benefits obtained after restoring such tanks (Reddy and Behera 2009; Palanisami 2006). Apart from the capital investments in tanks, the scheme under the participatory irrigation management (*PIM*), adopted by many state governments, such as the command area development (*CAD*) program initiated in 1974, provided scopes to increase water use efficiencies from surface water storage by generating additional water storage, bringing consistency in availability of water for direct irrigation supply, replenishing groundwater, and mobilizing co-management (http://mowr.gov.in/programmes/cadwm-programme-background; Poddar et al. 2011; Shamiyulla 2010). Due to the shift from traditional tank irrigation to well-irrigation post-1970s, the demand for groundwater recharge through surface storage structures (*TCS*) to allow extraction even during non-monsoon seasons became an essential requirement. In fact, the groundwater recharge aspects of the *TCS* were later become one of the pressing reasons governing the designs for tank rehabilitation programs. Therefore, it was highlighted that the rehabilitation program, in the long run, would be addressing fundamental issues such as collapsed primary livelihood opportunities for local communities, food insecurity, and regional and ecological imbalances across South India (Reddy et al. 2018).

The tank rehabilitation and modernization programs across Southern India started during the early 1980s. South India as a whole and states like Tamil Nadu, Karnataka, and Andhra Pradesh along with Maharashtra, Rajasthan, and Odisha are a few of the pioneering states with regard to implementing tank rehabilitation programs. Bilateral agencies such as the European Economic Community (*EEC*), World Bank, Asian Development Bank, and National Bank for Agriculture and Rural Development (*NABARD*) provided financial assistance for tank rehabilitation in these states. In addition, the government of Tamil Nadu and Karnataka carried out rehabilitation either through their own budgets or in collaboration with local non-government organizations (*NGOs*). Few of these *NGOs* actively working with the state governments are the Development of Human Action (*DHAN*) Foundation in Tamil Nadu and Andhra Pradesh, Gram Vikas (*GV*), and Institute for Youth Development (*IYD*) in Karnataka, Palmyra in Pondicherry, and Society for Promotion of Wasteland Development (*SPWD*) across various states (Reddy et al. 2018; ADB 2006).

The Government of India in 1984, signed an agreement with *EEC* for the rehabilitation project on modernizing 150 tanks across Tamil Nadu with a command area ranging from 100 to 200 ha (averaging 125 ha/tank) covering 3.8% of the command area. The completion of the phase-1 in 1989 rehabilitated 205 tanks having a total command area of 27,217 ha while phase-2 rehabilitated further 150 tanks covering 20,300 ha by 1996. Yet in another program, Rural Infrastructure Development Fund (*RIDF*) under *NABARD* rehabilitated 65 and 44 tanks in two phases. Later a 7-year long Water Resources Consolidation Project (*WRCP*) was initiated with assistance from the World Bank that aimed to cover the entire Tamil Nadu state for the rehabilitation of the remaining tanks. This project covered 620 tanks in Palar, Vaigai, and Thamiravaruni basins. In general, under different rehabilitation programs initiated in Tamil Nadu, more than 11,000 tanks have been rehabilitated. With the completion of each program, the learning made was used as input in revising the *EEC* model (Reddy et al. 2018; ADB 2006).

The Tank Rehabilitation Project in Pondicherry (*TRPP*) with a revised *EEC* model was proposed in 1999. All the 83 tanks of the territory were considered that were inclusive cascading tanks and system tanks. For the rehabilitation works, *NGOs* were given the task to form the Tank Associations (*TAs*) representing the village communities. The purpose of *TAs* was to approve the estimates prepared by Public Works Department (*PWD*). Of the total budget, *TAs* were mandated to contribute 12.5% which was chiefly used in the desiltation works under tank rehabilitation. Besides this, self-help groups (*SHGs*) were involved in support services and income generation activities such as fishing, tree plantations, etc. and one *NGO* was assigned to look after the tanks. Due to the rigidity in the schedule for the completion of the works and its implementation by involving several organizations together, the *TRPP* model faced consequences in terms of delay, resulting in incomplete works. As a result of this weakness in the model, the capacity building of *TAs* within the project period became challenging. In addition, an *NGO* in Pondicherry called Palmyra was also observed in similar programs where tank rehabilitation was made with the assistance of the Indo-Canadian Environment Facility (Reddy et al. 2018; ADB 2006).

The tank rehabilitation in Karnataka was handled by the Department of Minor Irrigation (*DIM*) since 1997, which focused on the tanks having a command area between 40 and 2000 ha. The tanks with command area of < 40 ha were handled by Gram Panchayat (village-level elected governance body), while > 2000 ha was under the control of the department of medium and major irrigation works. In 2002, the government of Karnataka decided to rehabilitate 2000 minor tanks on a pilot basis under Karnataka Community-Based Tank Rehabilitation Project (*KCBTRP*). In this initiative, a separate and autonomous society called Jala Samvardhane Yojna Sangha (*JSYS*) was formed. The purpose of the society was to catalyze the implementation of the World Bank projects by influencing community participation. The interventions provided technical and operational skills to the communities associated with the Sangha through the hands-on training program and field visits. Besides *JSYS*, Institute for Youth Development (*IYD*) instituted in 1978, was actively involved in promoting youths in the tank rehabilitation measures. Their model was based on both the inputs from farmers and donor agencies. The farming community contributed 30% of the cost of the tank rehabilitation works while 70% was ensured by *IYD* from agencies such as the Council for Advancement of People's Action and Rural Technology (*CAPART*). Yet another rural development *NGO*, Gram Vikas (*GV*), was initiated in the early 1990s in the Kolar district of Karnataka regarding tank rehabilitation. The *GV* majorly focused on providing small cash subsidies and loans to poor and marginal landholders who applied desilted earth from tanks as manure. The participatory approach was considered for the programs with assistance from *SHGs* and in presence of a Dalit (backward caste) population (Reddy et al. 2018; ADB 2006).

Andhra Pradesh and Telangana State Community-Based Tank Management Project, funded by World Bank, was initiated in 2007 and completed in 2016. The development objectives of the project were to improve the management of *TCS* and to improve agricultural productivity using *TCS*. The assessment report by the Independent Evaluation Group (*IEG*) highlighted that the project addressed support services for agriculture, livestock, and fisheries through institutional strengthening for water user associations (*WUAs*) who were also involved in participatory groundwater management. Results indicated that about 975 tanks in Andhra Pradesh and 1182 tanks in Telangana irrigated 122,116 and 131,214 ha, respectively, and covered 605,502 beneficiaries including 42,000 farmers, were rehabilitated across 10 years. By the end of the project, 1791 tanks were handed over to *WUAs* for operation and maintenance. Due to the improved water availability in *TCS*, an additional 63,740 ha was brought in to complete tank irrigation (Samantaray 2014, 2016).

The government of Telangana State initiated its flagship program, Mission Kakatiya in 2014, intending to replenish groundwater and rejuvenate the rural economy by reducing power consumption in the farm sector, getting higher yields, and spurring the growth of livestock. Based on the site survey conducted by the irrigation department, 46,531 minor tanks were identified across the state where rehabilitation was much-needed. The department further planned to restore and rehabilitate all the 46,531 tanks in the five years to bring 450,000 ha of the barren land into command. It was decided to restore 9306 tanks (20% of the total tanks) every year, in a phased manner. By 2017, rehabilitation of about 5000 tanks was completed while nearly 20,000 tanks remained in progress. The study conducted by the International Crops Research Institute for the Semi-arid Tropics (*ICRISAT*) found that the application of the silt (obtained after the desiltation of the tanks) on the agricultural land resulted in saving Indian Rupee (INR) 2500 to INR 3750 on chemical pesticides and fertilizers. In the case of cotton cultivation, the application of silt resulted in increased yield by 1000 kg/ha (Reddy et al. 2018; Mission Kakatiya 2015, 2018).

To summarize, tank rehabilitation programs conducted across South India lacks a holistic approach, as a result of which, the long-term sustainability of these programs remains unaddressed. This could be attributed to the lack of follow-up budgetary provisions and maintenance activities in programs. Although the projects of the Asian Development Bank, World Bank, etc. accounted for structural repair of the tanks, command area development, and engaging local communities by developing associations, integrated watershed management appeared as a future scope in *TCS* management. One of the common features observed across all interventions was the involvement of the local communities (beneficiaries). The capacity building for *TCS* could not be imagined without collective actions, in the presence of both, the government departments in assistance with bilateral agencies; and local communities with Gram Panchayat/local administrative bodies. One of the most common structural interventions made in *TCS* was the desiltation of the tanks. The resultant silt, in turn, provided more or less the benefits to the entire South India. The studies indicated that the application of the silt in farms improved the yield by 20 to 40% while the use of chemicals in farming reduced by 50 to 60% compared to earlier years. In general, the tank rehabilitation programs improved the functionality of tanks, increased agricultural productivity and livestock production, lowered spatio-temporal variation in the water availability, and replenished the groundwater table. In fact, the lining of the drainage and canals improved water-saving by 21%. This has benefited directly or indirectly the households owning land as well as poor and marginal farmers including landless laborers (Reddy and Behera 2009). However, this study further recommends bringing sustainable approaches while designing tank rehabilitation programs so as to facilitate the functionalities and management of *TCS* even after the completion of the program. One such attempt could be to introduce the user-friendly surface-water and groundwater budget estimators at rural scales, which can provide water balance information on tank storage to local masses for smart planning (Srivastava et al. 2021, 2022).

6 Conclusions

Climate change vulnerabilities and anthropogenic stressors, in the twenty-first century, have led to the issues of sustainability in terms of water management, specifically in South India. Nevertheless, the traditional water harvesting structures, though not prevalent in modern times, have challenged the extreme weather events. One of these structures is the tank cascade system (*TCS*) which forms the major part of South India's surface water civilization. While traditional tanks have been widely used for multiple purposes, documentation on tanks and challenges could aid better management. This review thus aimed at documenting the successes and challenges of tanks in Southern peninsular regions of India. The review found that the *TCS* which was ingeniously designed and built around 2000 years ago, is globally regarded as one of the most efficient water management systems. In addition, it is considered as the emblem of the extraordinary engineering, managerial, and social skills of the ancient kings, philanthropists, and local communities. The *TCS* remained functional for centuries across dry regions of South India. The reason accredited was the community-based participatory approach to building and maintaining tanks and a decentralized way of governing tank management by the local institutions. The *TCS* networks were established in the way to get the maximum benefits of the North-East monsoon rains in the semi-arid regions experiencing long droughts. One of the critical functions of the *TCS* was the recycling of the water in each tank of cascades thereby maintaining an ecological balance between subsurface, surface, and atmospheric hydrogeological and meteorological components.

The review further indicated that even though the traditional tanks were very successful for centuries, improper management has challenged the even existence of such structures. After colonization, widespread recognition was formed that the *TCS* was on a decline which continued even after the independence of India. The decline was attributed to both in terms of relative importance of tank irrigation practices and declining tank irrigated areas. One of the chief reasons acclaimed was the change in the policy that the water is the property of the state (government). As a consequence, the participatory approach to tank maintenance degraded leading to poor tank management causing its structural and functional deformities. Besides this, the development of the individual-based well-irrigation technology, during post green revolution period (around 1970s), further added to the distress of *TCS*. One of the most pressing recommendations, after the independence, was the revival, restoration, and rehabilitation of the *TCS*. By the beginning of the 1980s, the government of India started realizing the significance of the *TCS* as a sustainable way of dry land water management. Several rehabilitation programs in association with bilateral agencies were implemented since then across South India. The review identified that most of the rehabilitation programs, in the long run, remained futile, as not much consideration was paid to the holistic development of tanks and the continuation of tank management aspects after the completion of the programs. The review suggests that ownership and documentation of the impacts of these structures can increase the accountability and sustainability of the rehabilitation programs and sensitize the locals to preserving these traditional water infrastructures. Further, rehabilitation programs with a focus on maximizing the overall productivity of the *TCS* can improve the primary livelihood of the local communities, especially in the semi-arid villages of South India.

Acknowledgements Authors thank the Ministry of Rural Development (*MoRD*), Government of India, New Delhi, and Centre for Technology Alternatives for Rural Areas (*CTARA*) from the Indian Institute of Technology (*IIT*) Bombay, India for providing a fellowship platform to conduct this work. Authors acknowledge the financial support received from the Centre for Urban Water Resources (*CURE*) from *DHAN* Foundation—Madurai, India, and *CTARA* from *IIT* Bombay, India for facilitating field visits as well as to present this work at the 2nd International Conference on Rural Technology Development and Delivery (RTDD 2020) organized at *IIT* Madras, India. Thanks are due to officials of DHAN Foundation viz., Mr. Elamuhil (Water Resources Engineer) and Lokesh Sinram (Environmentalist), Mr. N. Venkatesan (Program Manager—Human Resource), and Mr. V. Venkatesan (Chief Executive Officer—Vayalagam), Mr. Arumugam Gurunathan (Director—The DHAN Academy), and Mr. M. P. Vasimalai (Executive Director—DHAN), and all the participants, farmers, village people, Panchayats, and PWD officials from Madurai city.

References

ADB (2006) Rehabilitation and management of tanks in India: a study of select states. Publication Stock, No. 122605, Asian Development Bank, Philippines

Anil AP, Ramesh H (2017) Analysis of climate trend and effect of land use land cover change on Harangi streamflow, South India: a case study. Sustain Water Resour Manage 3(3):257–267. https://doi.org/10.1007/s40899-017-0088-5

APCTMP—Andhra Pradesh community-based tank management project. Homepage, http://www.apmitanks.in/#:~:text=Message%20of%20Minor%20Irrigation%20Minister,....%20%C2%BB%C2%BB%C2%BB. Last accessed 31 July 2020

Ariza-Montobbio P, Galán E, Serrano Tovar T, Reyes-García V (2007) Water tanks as ecosystems. Local ecosystemic perception for integral management of water tanks in Tamil Nadu, South India. Perifèria: revista de recerca i formació en antropologia. https://www.raco.cat/index.php/Periferia/article/view/146580

Aubriot O, Prabhakar PI (2011) Water institutions and the 'revival' of tanks in South India: what is at stake locally? Water Altern 4(3):325–346. https://www.researchgate.net/publication/262176720_Water_Institutions_and_the_%27Revival%27_of_Tanks_in_South_India_What_Is_at_Stake_Locally. Last accessed 31 July 2020

Bal PK, Ramachandran A, Geetha R, Bhaskaran B, Thirumurugan P, Indumathi J, Jayanthi N (2016) Climate change projections for Tamil Nadu, India: deriving high-resolution climate data by a downscaling approach using PRECIS. Theoret Appl Climatol 123(3–4):523–535. https://doi.org/10.1007/s00704-014-1367-9

Bebermeier W, Meister J, Withanachchi CR, Middelhaufe I, Schütt B (2017) Tank cascade systems as a sustainable measure of watershed management in South Asia. Water 9(3):231. https://doi.org/10.3390/w9030231

Bharucha ZP (2016) On the climate of scarcity and crisis in the rainfed drylands of India. In: Ioris A (ed) Agriculture, environment and development. Palgrave Macmillan, Cham, pp 91–121. https://doi.org/10.1007/978-3-319-32255-1_4

Bitterman P, Tate E, Van Meter KJ, Basu NB (2016) Water security and rainwater harvesting: a conceptual framework and candidate indicators. Appl Geogr 76:75–84. https://doi.org/10.1016/j.apgeog.2016.09.013

CADWM—Command area development and water management programme. Homepage, http://mowr.gov.in/programmes/cadwm-programme-background. Last accessed 31 July 2020
Chakrabarti R, Hertz NL, Kabisch S, Reil A, Wolf T (2015) Addressing climate change impacts through community-level water management: case studies from the south-eastern coastal region of India. In: Shrestha S, Anal A, Salam P, van der Valk M (eds) Managing water resources under climate uncertainty. Springer Water. Springer, Cham, pp 291–317. https://doi.org/10.1007/978-3-319-10467-6_14
Chinnasamy P, Srivastava A (2021) Revival of traditional cascade tanks for achieving climate resilience in drylands of South India. Front Water 3:35
CWC—Central Water Commission (2010) Water and related statistics, information system organisation, Water Planning and Projects Wing, Central Water Commission, Government of India, New Delhi
DHAN Vayalgam Foundation Homepage. https://www.dhan.org/vayalagam/. Last accessed 31 July 2020
Dhanya P, Ramachandran A (2016) Farmers' perceptions of climate change and the proposed agriculture adaptation strategies in a semi arid region of south India. J Integr Environ Sci 13(1):1–8. https://doi.org/10.1080/1943815X.2015.1062031
Geekiyanage N, Pushpakumara DK (2013) Ecology of ancient tank cascade systems in Island Sri Lanka. J Marine Island Cultures 2(2):93–101. https://doi.org/10.1016/j.imic.2013.11.001
Ghosh S, Srinivasan K (2016) Analysis of spatio-temporal characteristics and regional frequency of droughts in the southern peninsula of India. Water Resour Manage 30(11):3879–3898. https://doi.org/10.1007/s11269-016-1396-5
Guhathakurta P (2015) Observational analysis of heavy rainfall during southwest monsoon over India. In: Ray K, Mohapatra M, Bandyopadhyay B, Rathore L (eds) High-Impact weather events over the SAARC region. Springer, Cham, pp 207–227. https://doi.org/10.1007/978-3-319-10217-7_14
Guhathakurta P, Menon P, Inkane PM, Krishnan U, Sable ST (2017) Trends and variability of meteorological drought over the districts of India using standardized precipitation index. J Earth Syst Sci 126(8):1–8. https://doi.org/10.1007/s12040-017-0896-x
Jain A, Dannenberg S (2018) The future of water use: scenarios for water management in Telangana—strengthening local governance in the minor irrigation sector. In: Peperhove R, Steinmüller K, Dienel HL (eds) Envisioning uncertain futures. Zukunft und Forschung. Springer VS, Wiesbaden, pp 133–141. https://doi.org/10.1007/978-3-658-25074-4_8
Janakarajan S, Moench M (2006) Are wells a potential threat to farmers' well-being? Case of deteriorating groundwater irrigation in Tamil Nadu. Econ Polit Weekly 41(37):3977–3987. https://www.jstor.org/stable/4418705
Jayatilaka CJ, Sakthivadivel R, Shinogi Y, Makin IW, Witharana P (2001) Predicting water availability in irrigation tank cascade systems: the cascade water balance model, vol 48. International Irrigation Management Institute, Sri-Lanka
Kayastha RB (2011) Cascade system. In: Singh VP, Singh P, Haritashya UK (eds) Encyclopedia of snow, ice and glaciers. Encyclopedia of Earth Sciences Series. Springer, Dordrecht. https://doi.org/10.1007/978-90-481-2642-2_53
Khadke L, Pattnaik S (2021) Impact of initial conditions and cloud parameterization on the heavy rainfall event of Kerala (2018). Model Earth Syst Environ. https://doi.org/10.1007/s40808-020-01073-5
KMID—Karanataka minor irrigation department news flashed on The Hindu. Homepage, https://www.thehindubusinessline.com/news/national/Over-70-minor-irrigation-tanks-in-Karnataka-dry/article20479663.ece. Last accessed 31 July 2020
Kodirekkala KR (2018) Cultural adaptation to climate change among indigenous people of South India. Clim Change 147(1):299–312. https://doi.org/10.1007/s10584-017-2116-8
Kumar MD, Bassi N, Kishan KS, Chattopadhyay S, Ganguly A (2016) Rejuvenating tanks in Telangana. Econ Polit Week 51(34):30–34. https://www.epw.in/journal/2016/34/commentary/rejuvenating-tanksin-telangana.html. Last accessed 31 July 2020

Massuel S, Perrin J, Mascre C, Mohamed W, Boisson A, Ahmed S (2014) Managed aquifer recharge in South India: what to expect from small percolation tanks in hard rock? J Hydrol 512:157–167. https://doi.org/10.1016/j.jhydrol.2014.02.062

Maya S (2003) Temple tanks-the ancient water harvesting systems of Kerala and their multifarious roles. Indian J Tradit Knowl 2(3):224–229. http://hdl.handle.net/123456789/25926

Mishra AK, Nagaraju V (2019) Space-based monitoring of severe flooding of a southern state in India during south-west monsoon season of 2018. Nat Hazards 97(2):949–953. https://doi.org/10.1007/s11069-019-03673-6

Mission Kakatiya, Government of Telangana (2015) Homepage, https://missionkakatiya.cgg.gov.in/homemission. Last accessed 31 July 2020

Mission Kakatiya (2018) Homepage, https://tweb.telangana.gov.in/initiatives/mission-kakatiya/. Last accessed 31 July 2020

Mission Kakatiya (2020) Homepage, https://www.telangana.gov.in/Pages/News/PromotedNews/MissionKakatiya.aspx. Last accessed 31 July 2020

Morrison KD (2019) Water in South India and Sri Lanka: agriculture, irrigation, politics, and purity. In: Yasuda Y, Scarborough V (eds) History of water and civilization, vol 7. UNESCO, pp 1–53. https://www.academia.edu/download/48522809/morrison_UNESCO_manuscript_in_press.pdf. Last accessed 31 July 2020

Mosse D (1997) The symbolic making of a common property resource: history, ecology and locality in a tank-irrigated landscape in south India. Dev Chang 28(3):467–504. https://doi.org/10.1111/1467-7660.00051

Mosse D (1999) Colonial and contemporary ideologies of 'community management': the case of tank irrigation development in South India. Mod Asian Stud 33(2):303–338. https://www.jstor.org/stable/313170

Murthy KN, Reddy TA, Kumar KV (2019) A UCM approach for forecasting the seasonal rainfall patterns in Coastal Andhra Pradesh, India 1901–2017. Pure Appl Geophys 177:5551–5565. https://doi.org/10.1007/s00024-019-02236-x

Nagarajan R (2013) Tank rehabilitation index for prioritization of lakes in semi arid regions—geospatial approach. Int J Geomatics Geosci 3(3):525. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.449.2396&rep=rep1&type=pdf. Last accessed 31 July 2020

Narayanamoorthy A (2007) Tank irrigation in India: a time series analysis. Water Policy 9(2):193–216. https://doi.org/10.2166/wp.2006.063

Narayanamoorthy A (2011) Development and composition of irrigation in India: temporal trends and regional patterns. Irrig Drain 60(4):431–445. https://doi.org/10.1002/ird.593

Narayanamoorthy A, Jothi P (2019) Water saving and productivity benefits of SRI: a study of tank, canal and groundwater irrigated settings in South India. Water Policy 21(1):162–177. https://doi.org/10.2166/wp.2018.199

Narayanamoorthy A, Suresh R (2016) Does Urbanisation affect tank irrigation development in Tamil Nadu? A macro-level analysis. Rev Dev Change 21(2):11–34. https://doi.org/10.1177/0972266120160202

Nasir N, Selvakumar R (2021) Estimating the loss of water spread area in tanks using remote sensing and GIS techniques in Ambuliyar sub-basin, Tamilnadu. In: Ramanagopal S, Gali M, Venkataraman K (eds) Sustainable practices and innovations in civil engineering. Lecture notes in civil engineering, vol 79. Springer, Singapore, pp 227–237. https://doi.org/10.1007/978-981-15-5101-7_23

Palanisami K (2006) Sustainable management of tank irrigation systems in India. J Dev Sustain Agric 1(1):34–40. https://doi.org/10.11178/jdsa.1.34

Palanisami K, Meinzen-Dick R, Giordano M (2010) Climate change and water supplies: options for sustaining tank irrigation potential in India. Econ Polit Weekly 45(26):183–190. https://www.jstor.org/stable/40736699

Panda B, Chidambaram S, Ganesh N (2017) An attempt to understand the subsurface variation along the mountain front and riparian region through geophysics technique in South India. Model Earth Syst Environ 3(2):783–797. https://doi.org/10.1007/s40808-017-0334-8

Poddar R, Qureshi ME, Syme G (2011) Comparing irrigation management reforms in Australia and India—a special reference to participatory irrigation management. Irrig Drain 60(2):139–150. https://doi.org/10.1002/ird.551

Reddy VR, Behera B (2009) The economic and ecological impacts of tank restoration in South India. Eur J Dev Res 21(1):112–136. https://doi.org/10.1057/ejdr.2008.12

Reddy VR, Reddy MS, Palanisami K (2018) Tank rehabilitation in India: review of experiences and strategies. Agric Water Manag 209:32–43. https://doi.org/10.1016/j.agwat.2018.07.013

Sakthivadivel R, Gomathinayagam P, Shah T (2004) Rejuvenating irrigation tanks through local institutions. Econ Polit Weekly 39(31):3521–3526. https://www.jstor.org/stable/4415350

Sakurai T, Palanisami K (2001) Tank irrigation management as a local common property: the case of Tamil Nadu, India. Agric Econ 25(2–3):273–283. https://doi.org/10.1111/j.1574-0862.2001.tb00207.x

Samantaray R (2014) India-IN Andhra Pradesh community-based tank management. Project: P100789-Implementation Status Results Report: Sequence 17, pp 1–1. The World Bank. http://documents.worldbank.org/curated/en/872791469731243165/India-IN-Andhra-Pradesh-and-Telangana-State-Community-Based-Tank-Management-P100789-Implementation-Status-Results-Report-Sequence-21. Last accessed 31 July 2020

Samantaray R (2016) India in Andhra Pradesh and Telangana state community-based tank management: P100789-Implementation Status Results Report: Sequence 20, No. ISR24040, pp 1–1. The World Bank. https://ieg.worldbankgroup.org/sites/default/files/Data/reports/ppar_indiaandhrapradesh.pdf. Last accessed 31 July 2020

Shah E (2008) Telling otherwise: a historical anthropology of tank irrigation technology in South India. Technol Cult 49(3):652–674. https://www.jstor.org/stable/40061431

Shah T (2011) Past, present and the future of canal irrigation in India. India infrastructure Report, pp 70–87. http://www.rimisp.org/wp-content/uploads/2010/05/Paper_Tushaar_Shah-4.pdf. Last accessed 31 July 2020

Shamiyulla N (2010) Participatory irrigation management (PIM) in the context of future of irrigation in India. Asian J Dev Matters 4(1):18–27. http://indianjournals.com/ijor.aspx?target=ijor:ajdm&volume=4&issue=1&article=003

Srinivasan V, Seto KC, Emerson R, Gorelick SM (2013) The impact of urbanization on water vulnerability: a coupled human–environment system approach for Chennai, India. Global Environ Change 23(1):229–239. https://doi.org/10.1016/j.gloenvcha.2012.10.002

Srivastava A, Chinnasamy P (2021a) Water management using traditional tank cascade systems: a case study of semi-arid region of Southern India. SN Appl Sci. 3:281. https://doi.org/10.1007/s42452-021-04232-0

Srivastava A, Chinnasamy P (2021b) Investigating impact of land-use and land cover changes on hydro-ecological balance using GIS: insights from IIT Bombay, India. SN Appl Sci. 3:343. https://doi.org/10.1007/s42452-021-04328-7

Srivastava A, Chinnasamy P (2021c) Developing village-level water management plans against extreme climatic events in Maharashtra (India)—a case study approach. In: Vaseashta A, Maftei C (eds) Water safety, security and sustainability. Advanced sciences and technologies for security applications. Springer, Cham. pp 615–635. https://doi.org/10.1007/978-3-030-76008-3_27

Srivastava A, Chinnasamy P (2022) Assessing groundwater depletion in southern India as a function of urbanization and change in hydrology: a threat to tank irrigation in Madurai city. In: Kolathayar S, Mondal A, Chian SC (eds) Climate change and water security. Lecture notes in civil engineering, vol 178. Springer, Singapore. pp 293–308. https://doi.org/10.1007/978-981-16-5501-2_24

Srivastava A, Chinnasamy P (2023) Understanding declining storage capacity of tank cascade system of Madurai: potential for better water management for rural, peri-urban, and urban catchments. In: Chigullapalli S et al (eds) Rural technology development and delivery. Design science and innovation. https://doi.org/10.1007/978-981-19-2312-8_14

Srivastava A, Khadke L, Chinnasamy P (2021) Web application tool for assessing groundwater sustainability—a case study in rural-Maharashtra, India. In: Vaseashta A, Maftei C (eds) Water safety, security and sustainability. Advanced sciences and technologies for security applications. Springer, Cham. pp 637–659. https://doi.org/10.1007/978-3-030-76008-3_28

Srivastava A, Khadke L, Chinnasamy P (2022) Developing a web application-based water budget calculator: attaining water security in rural-Nashik, India. In: Kolathayar S, Mondal A, Chian SC (eds) Climate change and water security. Lecture notes in civil engineering, vol 178. Springer, Singapore. pp 473–492. https://doi.org/10.1007/978-981-16-5501-2_37

Sundaresan J, Allen A, Johnson C (2017) Reading urban futures through their blue infrastructure: wetland networks in Bangalore and Madurai, India. In: Bell S, Allen A, Hofmann P, Teh TH (eds) Urban water trajectories, vol 6. Springer, Cham, pp 35–50. https://doi.org/10.1007/978-3-319-42686-0_3

UNESCO, About world heritage: Western Ghats. Homepage, https://whc.unesco.org/en/list/1342/. Last accessed 31 July 2020

Urfi AJ (2017) Values associated with village tanks and some instances of enviro-legal activism for wetland conservation. In: Prusty B, Chandra R, Azeez P (eds) Wetland science. Springer, New Delhi, pp 563–573. https://doi.org/10.1007/978-81-322-3715-0_29

Van Meter KJ, Basu NB, McLaughlin DL, Steiff M (2015) The socio-ecohydrology of rainwater harvesting in India: understanding water storage and release dynamics at tank and catchment scales. Hydrol Earth Syst Sci Discuss 12(11):12121–12165. https://doi.org/10.5194/hessd-12-12121-2015

Vasu D, Singh SK, Tiwary P, Sahu N, Ray SK, Butte P, Duraisami VP (2017) Influence of geochemical processes on hydrochemistry and irrigation suitability of groundwater in part of semi-arid Deccan Plateau, India. Appl Water Sci 7(7):3803–3815. https://doi.org/10.1007/s13201-017-0528-2

Vinke K, Martin MA, Adams S, Baarsch F, Bondeau A, Coumou D et al (2017) Climatic risks and impacts in South Asia: extremes of water scarcity and excess. Reg Environ Change 17(6):1569–1583. https://doi.org/10.1007/s10113-015-0924-9

Part III
Rural Energy Systems

Chapter 16
Development of Cold Storage Powered by Pico Hydropower

R. P. Saini, S. K. Singal, Imtiyaz Ali, and Yogeshwar Kumar

1 Introduction

In Himalayan regions agriculture is a very significant part of the economy (Sati 2005). Farmers have few means to preserve their crops which are not sufficient for long-terms storage and preservations. It was surveyed that storage of perishable goods, locally developed and imported goods from different areas is a common problem in hill areas. Based on the information obtained from local people about the vegetables and fruits production and share of waste in communities of different district in the states of Himachal and Uttarakhand, it was observed that the wastage of locally grown fruits and vegetables due to non-existence of appropriate cold storage facilities vary from 10 to 50%. As a result, farmers sell most of their fruits and vegetables to market immediately at down prices due to absence of proper storage and preserving facilities.

In addition, the Himalayan region and mountain areas of the country are endowed with natural water falls, streams and rivers flowing down the hills. These water resources provide immense opportunities for generation of small hydropower for infrastructural development and creating new and additional livelihoods for the local people (Kaunda et al. 2012).

2 Cold Storage-A Case Study

In order to design and promote a solution and empowering farmers for better preservation of their crops, a low-cost cold storage unit is designed and developed by RuTAG,

R. P. Saini (✉) · S. K. Singal · I. Ali
HRED, IIT Roorkee, Roorkee, India
e-mail: rp.saini@hre.iitr.ac.in

Y. Kumar
Jansamarth NGO, New Delhi, India

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_16

IIT Roorkee. This storage may be helpful to farmers and ultimately improving their profit potential and the living standards. In most of the rural mountain areas, lot of hydropower potential exist in small scale. A Pico hydropower plants can be used as to provide the power and energizing a chain of cold storage units to develop the required facilities for storage of off-season vegetable and fruits (Kapoor 2013). The integration of micro hydropower with cold storage is economically viable and feasible.

2.1 Data Collection and Analysis

Based on collected data from site, an estimation of fruits and vegetables production and share of waste in communities of different district in the states of Himachal and Uttarakhand have been made. Percentages waste with respect to total annual wastage in the state of Uttarakhand and Himachal are shown in Fig. 1.

To estimate the vegetables and fruits production in the states of Himachal and Uttarakhand, data has been collected and is given in Table 1. It is observed that the wastage of locally grown fruits and vegetables due to non-existence of appropriate cold storage facilities vary from 10 to 50%.

In view of demand utilizing resources of Pico hydropower for integration with cold storage, a survey was carried out to access the power, discharge and head at a site. Based on the data obtained, the possibility of establishing power unit for power generation to run the cold storage plant was found to be suitable as shown in Fig. 2.

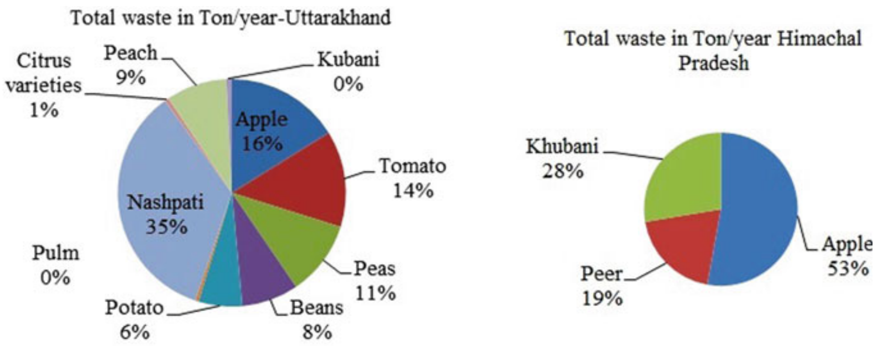


Fig. 1 Percentage waste for fruits and vegetable

Table 1 Estimate of fruits and vegetables in Himachal and Uttarakhand

Production Area	Fruit/vegetable	Production (ton/year) for preserving	Wastage (%)	Period of production	Temp °C for preservation
Uttarakhand					
Uttarkashi (Nogaav, Purola block) Almora, Bageshwar (Hawalbag, Garud, Someshwar, Berinagghati, Kapkot block) Nainital (Ramgarh, Ramnagar, Bhawali) Chamoli (JoshimathDasoli, Pipalkoti block, Devaal, Ghat etc.)	Apple	3000–3500	25–30	July–Nov	4–10
	Tomato	2500–3000	25–30	May–Oct	12
	Peas	2500–3000	15–20	Aug–Oct, Mar–June	0
	Beans	1000–1200	15–20	May–June	11–15
	Potato	2000–2500	10–15	Aug–Nov	7–10
	Pulm	50–100	25–30	May–July	10–13
	Peer (Nashpati)	3000–4000	40–50	Aug–Sept	0
	Citrus varieties (Malta, Nibu)	90–150	20–25	Oct–Nov	0–2
	Peach (Aadu)	1500–2000	25–30	Aug–Dec	0
	Apricot (Khubani)	50–100	25–30	May–July	0
Himachal Pradesh					
Shimla, Kullu, Sirmour, Mandi	Apple	4500–5000	25–30	July–Nov	4–10
	Peer	1500–2000	25–30	Aug–Sept	0
	Khubani	2000–3000	25–30	May–July	0

Fig. 2 Survey for civil works of Pico hydro-based cold storage

2.2 Energy Requirement for Cold Storage

Based on the survey and discussion with the local people and NGOs, it is found that nearly 50 houses in the nearby of selected village which were getting power from

Table 2 Assessment of load and energy consumption of the village

LEDs	Assessed load	Supply hours	Energy consumption per day
	$6 \times 10 \times 50 = 3000$ W or 3.00 kW	6 h Early sunset time and common life settles down around 21:00 h	1.50×6 kWh = 9.00 kWh
Cold storage unit	Assessed load: 2.64 kW	24 h	2.64×24 kWh = 63.36 kWh
Public lighting	Assessed load 18×20 W = 0.36 kW	5 h – Number of light points: Upto 20 – Load: 18 watts CFL	0.36×5 kWh = 1.8 kWh

the grid. The grid is not reliable and not sufficient to fulfill the needs of the village. The assessed load/supply per hours and energy consumption are given in Table 2.

3 Design Analysis-Pico Hydro-Based Cold Storage

Based on site collected data and power requirement for cold storage, Pico hydropower and cold storage unit were designed. It comprises of power channel, forebay tank, power room and cold storage chamber. The civil works for Pico hydropower were designed based on the power consumption of storage unit. Water is diverted from the river via weir and transferred to the forebay tank through power channel. Water from the forebay tank is transferred to the turbine with a pressurized penstock. Turbine with generator and other accessories mounted in the power room. Water imparts its energy to the turbine shaft and exits from the turbine through the tail race. Generated electricity is used to power the cold storage via a transmission line which is about 500 m away from the power house building. The layout and design of power house along with cold storage unit are shown in Figs. 3, 4 and 5.

4 Experimental Analysis

4.1 Cold Storage Specifications and Site Parameters

In order to utilize the Pico hydropower in rural areas for cold storage applications, a survey was conducted to estimate the share of waste of locally grown food. The discharge passing in the river Barni in the district of Uttarkashi was also measured. On the basis of the collected data, cooling temperature required for preserving goods,

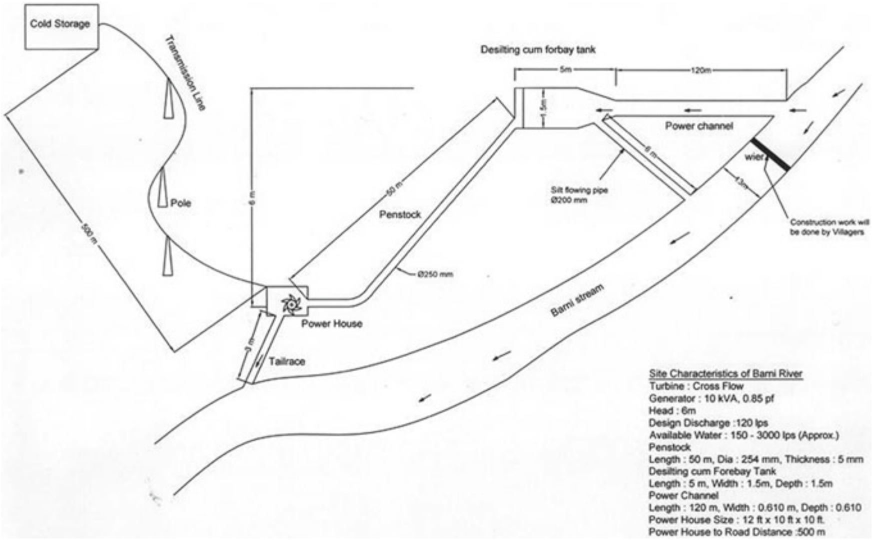


Fig. 3 Layout of Pico hydropower-based cold storage

space and power required for cold storage unit were calculated and are given in Table 3.

4.2 Experimental Setup

A portable cold storage chamber for 1.5 tons capacity was designed and developed. The complete unit was tested in the laboratory in HRED, IIT Roorkee. The outcome of the cold storage unit is monitored at constant head and discharge.

The experimental investigations are carried out on an experimental set up of a cross flow turbine with cold storage developed and fabricated at HRED, IIT Roorkee. A cross flow turbine with the water discharge of 100 lps and head 6.5 m has been taken under the present study. The experimental set up have two mixed flow type service pumps to pump water at high pressure to provide the required head and flow. These two mixed flow pumps joined with the sump tank through which water is supplied with high pressure to cross flow turbine. Water is supplied via an elbow shape draft tube joined with outlet of turbine after allowing motion to cross flow vane. Water recycled back to the sump through the channel and again used to power the turbine. Figures 6 and 7 show the photograph of the experimental test rig in the laboratory and the cold storage unit respectively.

The RPM, discharge and head are measured with the help of digital tachometer, ultrasonic flow meter and digital pressure gauge, respectively. A resistive load using cold storage is applied on the generator. A voltmeter attached in the panel is used to

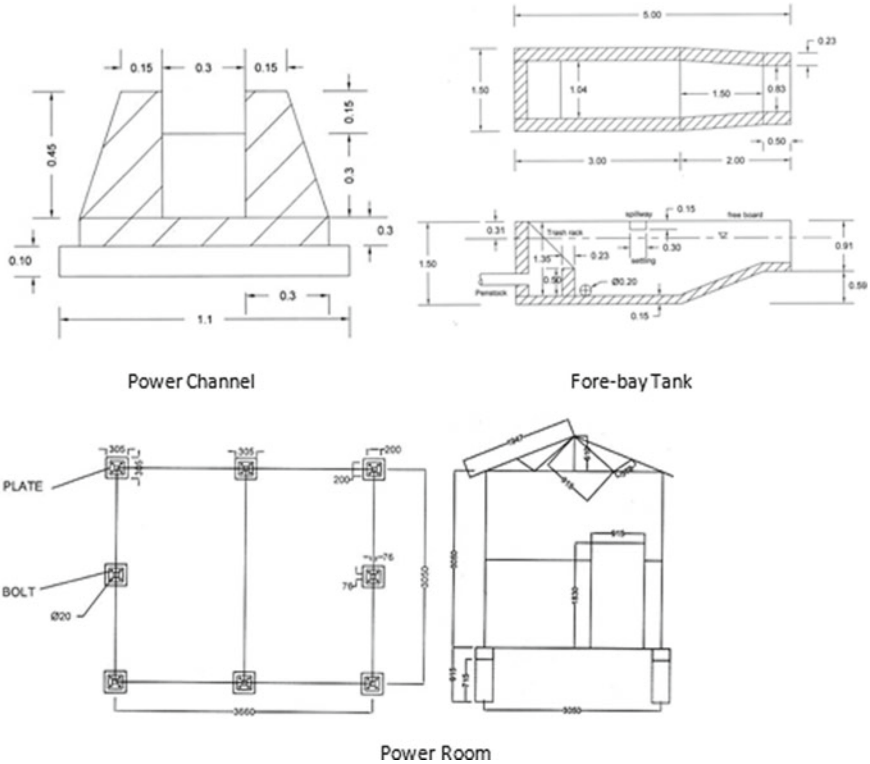


Fig. 4 Schematic of Pico hydropower components

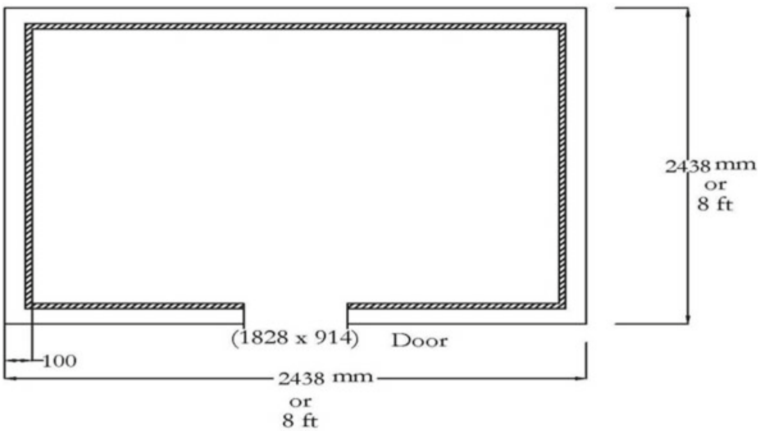


Fig. 5 Schematic of cold storage

Table 3 Parameter details of cold storage and Pico hydro site

S. No	Parameter name	Value
1	Dimension of chamber	2438 mm × 2438 mm × 2438 mm
2	Door size standard swing door	1828 mm (h) × 914 mm (w)
3	Thickness of insulation (polyurethane)	100 mm
4	Temperature control	0 °C
5	Ambient temperature (maximum)	42 °C
6	Type of compressor/company condensing unit	Reciprocating
7	Refrigerant gas work	R22
8	Capacity of machine	10,000 BTU/h
9	Starting current	10–11 Amp
10	Running current	Amp
11	Power required	1.92 kW
12	Gross head	10.0 m
13	Minimum discharge	150 lps
14	Maximum discharge	3000 lps (estimated)
15	Capacity of cold storage	3000 kg

Fig. 6 Photograph of experimental test rig at HRED IIT Roorkee

Fig. 7 Photograph of cold storage unit

measure the voltage of generator as desired voltage should be maintained throughout the experimentations. The power generated by generator connected to turbine is measured using energy meter. The instruments used under the present work are shown in Fig. 8.

4.3 Experimental Procedure

Two service pumps have used to supply the desired discharge during the operation of Turbine. The flow rate to the turbine is varied by using a valve connected at the inlet of pump. The pressure head at the turbine inlet is measured by using a pressure gauge. Whereas, the flow rate of water is measured by using ultrasonic flow meter. The turbine and synchronous generator are connected with each other with the help of belt and pulley arrangement. The generator is connected to resistive load panel and cold storage as a load. A wattmeter (energy meter) is also to measure the output of generator. Thereafter, the valve is gradually opened and the water is allowed to enter into turbine. The readings of pressure gauge and flow meter are recorded after starting the rotation of turbine. The turbine is allowed to rotate at high speed with the help of valve and the load on the generator is provided through switching the cold storage. The flow and load are adjusted to maintain the 1500 rpm

Fig. 8 Photographs of various instrumentations used during experimentations

of the generator. The reading of the pressure gauge (head), flow meter (discharge), loads and wattmeter were recorded. On adjusting the valve corresponding to constant head and discharge, readings were taken by varying the temperature for testing the cold storage unit. Power consumption is found to be reduced with reducing the cold storage temperature.

4.4 Data Conversion

For a given pump inlet pressure (P_i), the head acting on the turbine was calculated as;

$$H = 10 P_i\, m$$

Input Power (P_1) and output power of turbine (P_2) were computed using the following expression;

$$P_1 = Q\mathrm{gH}\,\mathrm{kW}$$
$$P_2 = G_0/\eta_\mathrm{g}\,\mathrm{kW}$$

where, Q is the discharge in m^3/s, H is head in m and g is the gravitational acceleration which is equal to 9.81 m/s^2. G_o is the wattmeter reading or the generator output and η_g is generator efficiency.

Efficiency, $\eta_{turbine}$ of turbine was calculated as;

$$\eta_{turbine} = P_2/P_1$$

As it is common that if heat load of the cold storage is (Q) and desired preserve temperature T_1 and ambient temperature T_2 then coefficient of performance of plant can be calculated as;

$$\text{C.O.P} = T_1/(T_2 - T_1)$$

The power consumed by the cold storage is;

$$P_{coldstorage} = \text{Heat Load/C.O.P}$$

5 Experimental Analysis-Power Consumption by Cold Storage

Under the present study, the results are obtained corresponding to constant head and discharge of 6.5 m and 100 lps respectively. The Pico hydro generating unit can produce sufficient power to fulfill the energy required by cold storage unit. Initially, the power required to start the cold storage unit is high. However, the power consumed to maintain the temperature is significantly reduced as the storage attains the desired temperature. The power consumption is found to be reduced on further decrease in the operating temperature of cold storage temperature. The variation of power with respect to temperature is shown in Fig. 9.

The data collected during testing of cold storage at constant head 6.5 m and100 lps discharge are given in Table 5 and 6.

Based on the experimental result, it is observed that power consumption of the cold storage is found to be decreased with decrease in cold storage temperature. The power consumed in initial stage (cold storage temperature is 28°) is 2.2 kW, whereas it consumes 19 kW after attaining the temperature of 4 °C in cold storage unit to preserve the vegetable and fruits.

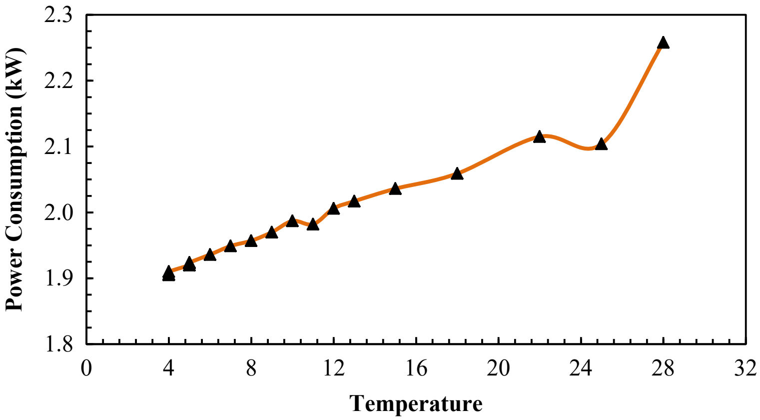


Fig. 9 Power consumption decrease with decreasing temperature

Table 5 Test results of pico hydropower generating unit at constant head and discharge

S. No	Speed (RPM)	Frequency (Hz)	Voltage (Volt)	Current (Amp)	Input power (W)	Output power (W)
1	1476	49.4	236	10	6370	2364
2	1480	49.5	237	10	6370	2370
3	1481	49.8	237	10.5	6370	2491
4	1482	49.8	237	11	6370	2610
5	1484	49.9	237	11	6370	2612
6	1483	50	237	11	6370	2612
7	1484	49.9	237	11	6370	2612
8	1483	50	237	11	6370	2612
9	1482	50	237	11	6370	2613
10	1483	50	237	11	6370	2613

6 Installation of Pico Hydropower-Based Cold Storage

As per site conditions and requirement, power channel, forebay tank, power house room and installation of penstock were constructed. The channel was constructed to get the water from diversion weir and diverted to forebay tank through a 120 m long power channel. Water from forebay carried to the power house to run hydraulic turbine through pressurized penstock pipe of 75 m long. The penstock pipe is made of mild steel.

Table 6 Test results for power consumption by cold storage unit

S. No	Voltage (Volt)	Current (Amp)	Frequency (Hz)	Temperature (°C)	Power consumption (W)
1	231	9.76	47.6	28	2258
2	232	9.07	49.2	25	2104
3	232	9.12	49	22	2115
4	232	8.85	49.3	18	2059
5	232	8.76	49.3	15	2036
6	233	8.65	49.4	13	2017
7	233	8.61	49.4	12	2006
8	232	8.54	49.4	11	1982
9	233	8.52	49.4	10	1987
10	233	8.38	49.4	8	1957
11	233	8.29	49.4	6	1936
12	233	8.17	49.4	4	1910

6.1 Diversion Weir and Intake

A diversion structure is essential across the nallah for diverting the water for power generation. The nallah bed consists of pebbles, gravels and boulders. Such weirs are suited for mountainous streams as they do not much interfere with the regime of the streams. Weir was constructed in full width of stream to avoid any restriction to flow that could cause an afflux as shown in Fig. 10.

6.2 Power Channel

The water from diversion weir was transferred to desilting tank through 120 m long rectangular power channel. The photograph of the power channel is shown in Fig. 11.

6.3 Construction of Desilting-Cum-Forebay Tank

As per site conditions and requirement, a desilting-cum-forebay tank was constructed. The existing desilting-cum-forebay tank is designed to remove the silt efficiently. Desilting tank comprises of a concrete rectangular tank of 2.0 m width and 5.0 m length. The desilting-cum-forebay tank for power generation is designed for a discharge of 0.140m^3/s. A valve is provided to flush the flushing from the desilting tank. The silt-ridden water is discharged back into the nallah. A free board of 0.30 m

Fig. 10 Diversion weir and intake

is provided at desilting tank. The photograph of desilting-cum-forebay tank is shown in Fig. 12.

Water from forebay was transferred to the power house to run the turbine through pressurized penstock having 250 mm diameter.

6.4 Power House Building

Power house building is a housing for turbine, generating units, auxiliary equipment, control panels and also provides suitable outlet for tail water discharge. Under the present project, power house building is designed with the size 10.0 ft × 8.0 ft × 10.0 ft. The designed house accommodates 1 number of turbine generating unit having a capacity of 5 kW, control panels, auxiliary equipment as shown in Fig. 13. Walls of the building were made of brick with plaster. Figure 14 shows the photographs turbine installation in power house building.

Fig. 11 Power channel

6.5 Cold Storage

Cold storage is used for preserving the fruits and vegetable for a long period at desired temperature to reduce the risk of damage and to extend the time for use. The cold storage unit is designed with a capacity to store 3000–4000 kg fruits and vegetable. The cold storage unit is shown in Fig. 15.

The cold storage unit is made up of 2 chambers having total capacity of 3 tons. It is insulated with polyurethane of 100 mm thickness. The cold storage unit also contains a reciprocating compressor. This unit requires starting current of 10 to 11 amp, whereas, 7 to 8 amp of running current. The total power of 2.64 kW is consumed to preserve the fruits and vegetables at 0 °C when the ambient temperature is 42 °C.

7 Results and Discussions

The design, construction and installation of pico hydro-based cold storage was carried out on the river bernigad at Berni village in district Uttarkashi of the state Uttarakhand.

Fig. 12 Desilting-cum-forebaytank

Water is diverted from the river to the forebay tank through the power channel and water from the forebay tank is transported to the turbine via a penstock. Water at 10-m head and discharge with 140 lps recorded by the pressure gauge and flow meter. Turbine shaft connected with the alternator through the belt rotates the generator. The plant generates a power of 5.0 kW which is used to power the cold storage. It was observed that out of 5, 1.9 kW power was consumed by the cold storage and the remaining power can be used for other utility. The photograph of the designed Pico hydro-based cold storage unit is shown in Fig. 16. The power developed by the pico hydro plant will utilize for domestic purposes if it is not required by the cold storage unit or the unit cuts off when the set-temperature is reached. The same has now been included in the revised manuscript.

Fig. 13 Power house building

Fig. 14 Installation of turbine and generator

Fig. 15 Installation of cold storage

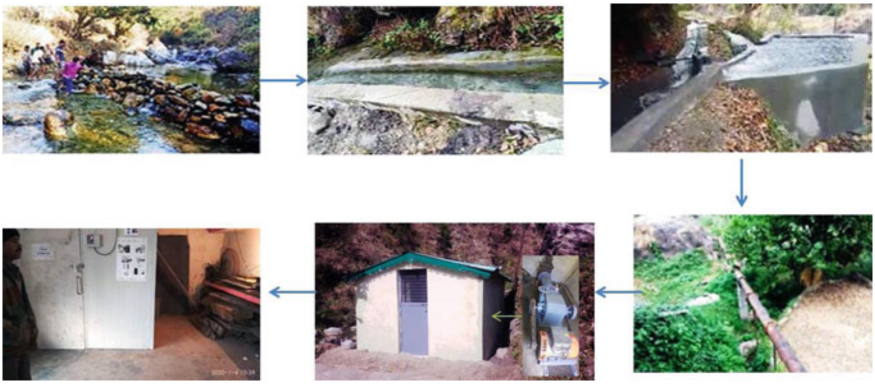


Fig. 16 Photograph of Pico hydro-based cold storage unit installed

8 Conclusions

In order to harness the hydropower available and to use the generation for cold storage, a site on the river Barnigad located near the village Barni, block Naugaon in Uttarkashi district of Uttarakhand state was selected. Based on the site visit and survey conducted, it is found that the sufficient flow of water is available in the river throughout the year for irrigation and for other uses. In order to utilize the available head and discharge, a low-cost cold storage unit powered by pico hydro plant was designed, developed and successfully installed and tested in the field to preserve the fruits and vegetable and extend their life. Under this cold storage unit, farmers can save upto 30% of their fruits and vegetables. This technology is useful in the un-electrified hilly areas of Uttarakhand and Himachal Pradesh.

References

Kapoor R (2013) Pico power: a boon for rural electrification. Adv Electr Electr Eng 3(7):865–872 (2013). ISSN 2231-1297

Kaunda CS, Kimambo CZ, Nielsen TK (2012) Hydropower in the context of sustainable energy supply: a review of technologies and challenges. ISRN Renew Energy: 2012

Sati VPJ (2005) Systems of agriculture farming in the Uttranchal Himalaya, India. J Mt Sci 2:76

Chapter 17
Steady-State Analytical Modeling of Cookstove Insulation for Improving Efficiency

Aniket Hulage, Deepak Marla, Upendra Bhandarkar, and Vijay Honkalaskar

1 Introduction

More than one-third of the world's population depends on solid biomass fuel like wood, charcoal, animal dung (Fullerton et al. 2008). In India, more than two-thirds of households depend on fuel mentioned above. Even with an increasing number of families adopting cleaner non-smoking efficient stoves, the usage of traditional cookstoves is still a significant occurrence. For the rural sector people at the bottom of the economic pyramid, in the Indian context, there are lot of drudgeries involved in fuel fetching for conventional cookstove. Rural women have to travel 5–6 km per every 2–3 days on challenging uneven terrain (Honkalaskar et al. 2013). Additionally, in the rural sector, where there is no provision of the chimney in the house to vent the smoke outside or not at all any control on smoke production, traditional cookstoves stand as a significant risk to health for women, children, and environment. Nearly 3.8 million deaths per year are there due to direct exposure to in-house air pollution from stroke, heart disease, chronic obstructive pulmonary disease, and lung cáncer (Kongre and Katarkar 2017). Various toxic products in smoke like carbon monoxide, carbon dioxide, nitrogen oxides ($NO_{x)}$, sulfur oxides ($SO_{x)}$, benzene, benzopyrene, formaldehyde lead to acute respiratory infections, chronic lung cancers, eye problems, low birth rate, and many more others About 1.6 million deaths of women and children per year are due to indoor air pollution (WHO-Fact sheet no. 292 2005). Thus we have to design a thermally efficient, affordable, healthy, lightweight, durable, and

A. Hulage (✉)
Thermal and Fluids Engineering Specialization, Mechanical Engineering, IIT Bombay, Mumbai, India
e-mail: aniketsadashivhulage@gmail.com

D. Marla · U. Bhandarkar
Mechanical Engineering, IIT Bombay, Mumbai, India

V. Honkalaskar
IIT Bombay, Mumbai, India

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_17

compact cookstove as compared to a traditional one for the people at the BoEP, in all countries across the world. Increased efficiency reduces fuel consumption; consequently, the drudgery involved in fuel fetching activity. Hence, the steady-state analytical model of cookstove insulation is developed. Trapped heat increases the mean temperature of heat addition inside the hearth (combustión chamber of Wood), thus forcing carbón monoxide to convert into carbón dioxide, making the cookstove more healthy.

2 Materials and Methods

Poor and incomplete combustion of wood in inefficient cookstoves produces harmful emissions. One of the most efficient ways to increase thermal efficiency is by providing insulation to the stove Wall. For insulators, there are three variables. The insulator is governed by 1. Insulation Thickness (m) 2. Thermal Conductivity (W/mK) 3. Emissivity. Approach of modeling is to divide the cookstove wall into layers and then apply the thermal network technique to find equivalent heat transfer coefficient and equivalent thermal diffusivity and solve the thermo-chemical model for cookstove versions (normal cookstove, cookstove with twisted tape, cookstove with grate). Assumptions are: The temperature of an inner surface of the stove body remains constant throughout the cookstove operation period (steady-state) and is uniform throughout the surface.

Heat loss to the surrounding (W) is given by

$$\dot{Q}_{\text{surr}} = U_{\text{equivalent}} A_{\text{out}} (T_{\text{w}} - T_{\text{amb}}) \tag{1}$$

Heat loss to the stove Wall (W) is given by

$$\dot{Q}_{\text{wabs}} = 2 K_{\text{st}} A_{\text{w}} (T_{\text{w}} - T_{\text{amb}}) \left(\frac{1}{\pi \alpha_{\text{equivalent}} t} \right)^{0.5} \tag{2}$$

For the body to be treated as semi-infinite medium, criteria is given by

$$\frac{L}{2\sqrt{\alpha t}} \geq 0.5 \tag{3}$$

Wall stove body, satisfy the above criteria of Eq. (3), while insulation layer materials don't. So only the cookstove wall can be treated as the semi-infinite médium while the insulation layer can't. Consider the most general insulation case with a circuit diagram, as shown in Fig. 1. For the cookstove with insulation, $U_{\text{equivalent}}$: equivalent heat transfer coefficient (W/m^{2}K) is given by,

$U_{\text{equivalent}}$

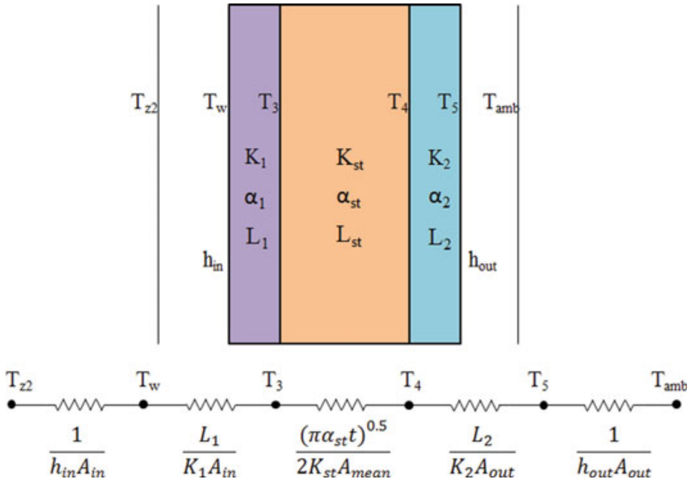


Fig. 1 Insulation circuit diagram

$$= \left[\frac{A_{\text{mean}}}{h_{\text{in}} A_{\text{in}}} + \frac{L_1 A_{\text{mean}}}{K_1 A_{\text{in}}} + \frac{(\pi \alpha_{\text{st}} t)^{0.5}}{2K_{\text{st}}} + \frac{L_2 A_{\text{mean}}}{K_2 A_{\text{out}}} + \frac{A_{\text{mean}}}{h_{\text{out}} A_{\text{out}}}\right] \tag{4}$$

$\alpha_{\text{equivalent}}$: equivalent thermal diffusivity (m^2/s) is given by,

$$\alpha_{\text{equivalent}} = \left[\frac{2L_1 A_{\text{mean}}}{K_1 A_{\text{in}}} \frac{K_{st}}{(\pi t)^{0.5}} + \frac{2L_2 A_{\text{mean}}}{K_2 A_{\text{out}}} \frac{K_{\text{st}}}{(\pi t)^{0.5}} + \alpha_{\text{st}}^{0.5}\right]^2 \tag{5}$$

Using the values of $\alpha_{\text{equivalent}}$ and $U_{\text{equivalent}}$, heat loss to surrounding, stove wall, and floor are calculated. These values are used in the seven equation system of the steady-state analytical thermo-chemical model of cookstove. These equations are non-linear equations, solved in Matlab code using fsolve command (Honkalaskar 2014). After simulations, thermal performance parameters are evaluated. Thermal performance parameters are input power, thermal efficiency, heat transfer coefficient, fuel-burning rate, carbon monoxide-carbon dioxide ratio, excess air ratio, specific fuel consumption, stove wall efficiency.

3 Results and Discussion

Graphs of variation in the thermal efficiency with respect to insulation variables for different cookstove versions and variants can be seen in Fig. 2.

If heat flow is reduced, then, entropy rate generation will decrease and in the language of thermodynamics, available energy increases, making the system more

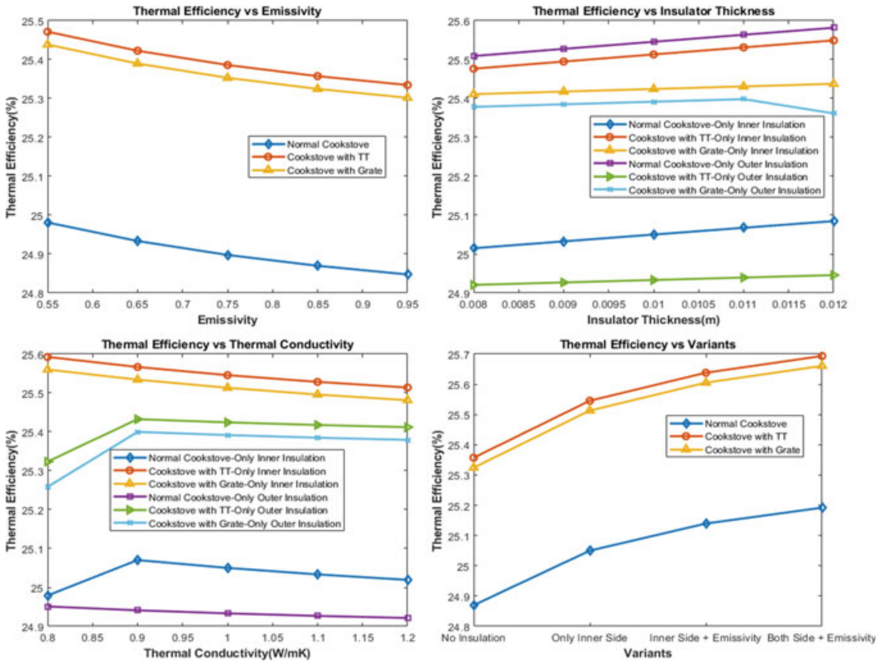


Fig. 2 Variation of thermal efficiency versus insulation variables

reversible thus high thermal efficiency. Similar graphs can be plotted for other thermal performance parameters.

4 Conclusion

Analytical model of cookstove insulation is successfully developed. The thermal efficiency of cookstove does increase, also making the cookstove healthier after the insulations to a wall, but increasing insulation has certain limitations too. Some thermal performance parameters like exhaust gas energy and heat transfer coefficient oppose some of these insulation variables (as shown in Table 1) to limit the performance. Outer insulation is having maximum impact on cookstove performance in comparison with inner insulation. The thermal conductivity of insulation plays a central role in deciding the performance of the system (Table 2).

Table 1 Insulation variable and opposing thermal performance parameters

Insulation parameter (should be)	Opposing thermal performance parameters				
	Exit energy	Heat transfer coefficient	CO/CO_2 ratio	Thermal efficiency	SFC
An emissivity of inner material = minimum					
Insulation thickness of inner material = maximum	Yes	Yes			
Insulation thickness of outer material = maximum			Yes	Yes	Yes
Thermal conductivity of inner material = minimum	Yes	Yes			
Thermal conductivity of outer material = minimum	Yes	Yes			

Table 2 Individual effect (trend) of insulation parameters on cookstove parameters

Parameter	1. Input power	2. Thermal efficiency	3. Stove wall energy	4. Exit energy	5. Heat transfer coefficient
ε reduction	Increase	Increase	Decrease	Increase	Decrease
L_1 increase	Increase	Increase	Decrease	Increase	Decrease
L_2 increase	Increase	Optimum value	Decrease	Optimum value	Optimum value
K_1 increase	Decrease	Optimum value	Increase	Optimum value	Optimum value
K_2 Increase	Optimum value	Optimum value	Increase	Optimum value	Optimum value
	6.CO/CO_2 ratio	7. Excess air	8. Wall temperature	9. Char burn rate	10. Specific fuel consumption
ε reduction	Decrease	Decrease	Decrease	Decrease	Decrease
L_1 increase	Decrease	Decrease	Decrease	Increase	Increase
L_2 increase	Optimum value	Decrease	Decrease	Increase	Optimum value
K_1 increase	Optimum value	Increase	Increase	Decrease	Optimum value
K_2 increase	Optimum value	Optimum value	Increase	Optimum value	Optimum value

References

Fullerton DG, Bruce N, Gordon SB (2008) Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. Trans Roy Soc Trop Med Hyg 102(9):843–851
Honkalaskar VH (2014) Ph.D. thesis, IIT Bombay
Honkalaskar VH, Bhandarkar UV, Sohoni M (2013) Development of a fuel efficient cookstove through a participatory bottom-up approach. Energy Sustain Soc 3:16
Kongre S, Katarkar S (2017) Thermal analysis of cookstove (cookstove) used for cooking purpose. Environ Manage 39:534–544
WHO (2005) Indoor air pollution and health-Fact Sheet No-292

Part IV
Rural Landscapes/Rural Environment

Chapter 18
History of Indian Sanitation and Paradigm Shift Required for Rural Sanitation

N. Chandana and Bakul Rao

1 Indian Sanitation Journey

In the world, every year millions of people die because of water-borne diseases which could be partially attributed to lack/ non-functioning of sanitation systems (McGill et al. 2019; Freeman et al. 2017), mainly in developing countries (Burkitt 1973; Richard et al. 1983). India has a long history of sanitation issues (i.e., open defecation, lack of sanitation service chain, etc.) and this paper focuses on sanitation strategies undertaken by independent India to overcome the hurdles in achieving proper sanitation. The literature review was carried out by searching keywords in online search engines for data collection and the details of each scheme were downloaded from the respective websites, and hard copies available with government offices were also reviewed and data were collected and analyzed. The critical appraisal of Indian sanitation policies from post-independence to the current era of ODF, India reveals that the journey can be divided into three important sanitation eras as shown in Fig. 1.

The first era is the water supply coverage era (1947–1980) also named as the stationary phase of the Indian sanitation sector. In this period, water has a direct impact on people was given more importance than sanitation. The second era is called the eradication of OD era (1980–2008) also referred to as the lag phase of Indian sanitation. The 1981–1990 decade is declared as an international drinking water supply and sanitation (WS&S) decade by 34th world health assembly, which influenced India to take separate sanitation programs. During this time, massive subsidies were provided by GoI, assuming that toilets were not affordable for the poor and rural people. Finally, the third era is called as sanitation coverage era

N. Chandana (✉) · B. Rao
Centre for Technology Alternatives for Rural Areas, Indian Institute of Technology Bombay, Mumbai 400076, India
e-mail: chandana2n@gmail.com

B. Rao
e-mail: bakulrao@iitb.ac.in

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_18

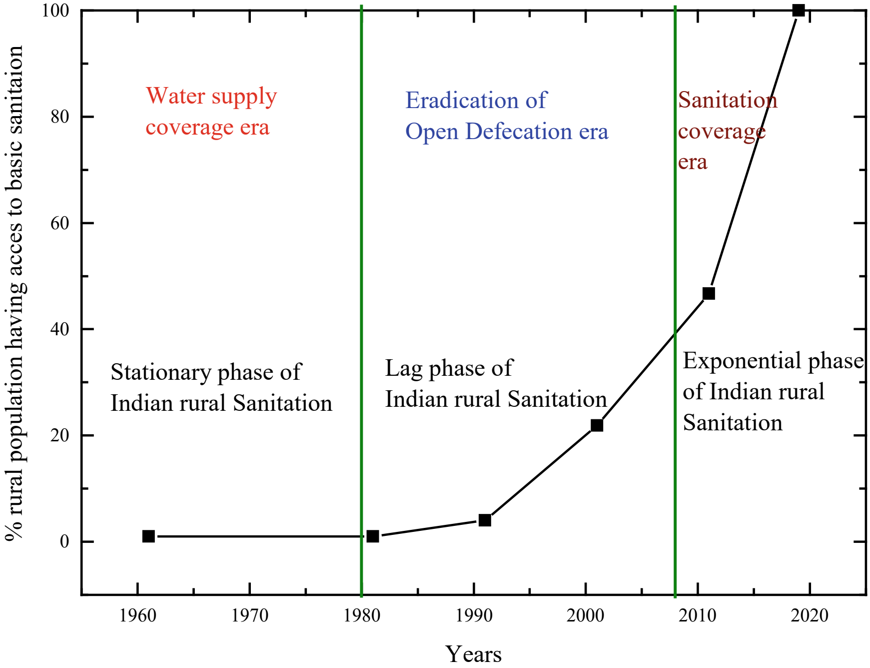


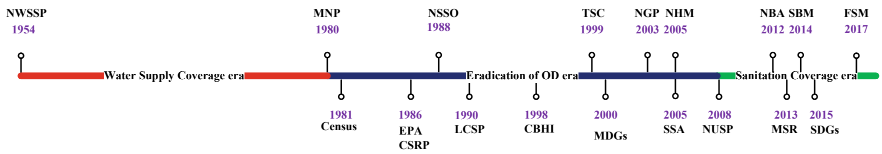
Fig. 1 Rural populations have access to basic sanitation

(2008–2019) also called as an exponential phase of Indian sanitation. During this period, though the drinking water coverage increased in India, health issues of the poor have not bettered (WHO 2018). According to WHO (2008), human social and economic development and well-being are dependent on basic sanitation (WHO 2006a). Considering the importance of sanitation in the development of poor nations, 2008 was declared as the International Year of Sanitation (WHO 1981). During this time period, the construction of toilets by the government is considered a solution to sanitation problems, and millions of toilets are constructed in India. The important events in India's sanitation history from 1954 are as shown in Fig. 2.

2 Eras of Indian Sanitation

2.1 Water Supply Coverage Era (1947–1980): The Stationary Phase of Indian Rural Sanitation

The Bhore Committee report (1944) emphasized that the essential condition for promoting good health was to develop a sanitary conscience in the community. The country's five-year plans kept Bhore committee recommendations as to the



NWSSP	National Water Supply and Sanitation Programme
MNP	Minimum Need Programme
EPA	Environmental Protection Act
CSRP	Centrally Sponsored Rural Sanitation Programme
NSSO	National Sample Survey Organization
LCSP	Low-Cost Sanitation programme
CBHI	Central Bureau of health intelligence
TSC	Total Sanitation Campaign
MDGs	Millennium Development Goals
NGP	Nirmal Gram Puraskar
SSA	Sampoorna Swachhtha Andolana scheme
NHM	National Health Mission
NUSP	National Urban Sanitation Policy
NBA	Nirmal Bharath Abhiyan
MSR	Prohibition of Employment as Manual Scavengers and their Rehabilitation Act
SBM	Swacch Bharath Mission
SDGs	Sustainable Development Goals
FSM	Prima of faecal sludge management

Fig. 2 Timeline of independent Indian sanitation strategy

guidelines in the development of India. In the first plan (1951–1956), GoI provided ₹ 240 million to the states for WS and S (Planning Commission 1950). The WS and S program was developed by the GoI, under which ₹ 120 million as loans for urban WS schemes, and a grant of ₹ 60 million was sanctioned for rural WS schemes. In the second plan (1956–1961), the total investment of 1057.0 million was sanctioned in WS&S (Planning Commission 1956). The grant distribution was ₹ 530 million for urban WS&S, ₹ 280 million for rural WS, and a particular provision of ₹ 100 million for urban areas was provided by GoI. In 1961, the health survey and planning committee reported that, from 1951–1961, 244 urban WS schemes and 65 urban sewerage schemes (mainly in top cities like Bombay and Mysore) were established by GoI with a total budget of ₹ 680 million as shown in Fig. 3. In rural India, 228 WS schemes (i.e., 134 in the 1st five plans and 94 in the 2nd five-year plan) were approved and no sanitation schemes were approved (Lakshmanaswami 1961). As shown in Fig. 3, no of schemes and budget allocation for urban areas are higher than in rural, and water being the basic need of humans, it is always given primary importance both in rural and urban areas. In addition, sanitation schemes were less for urban areas and not available for rural areas during 1950–1960, as shown in Fig. 3.

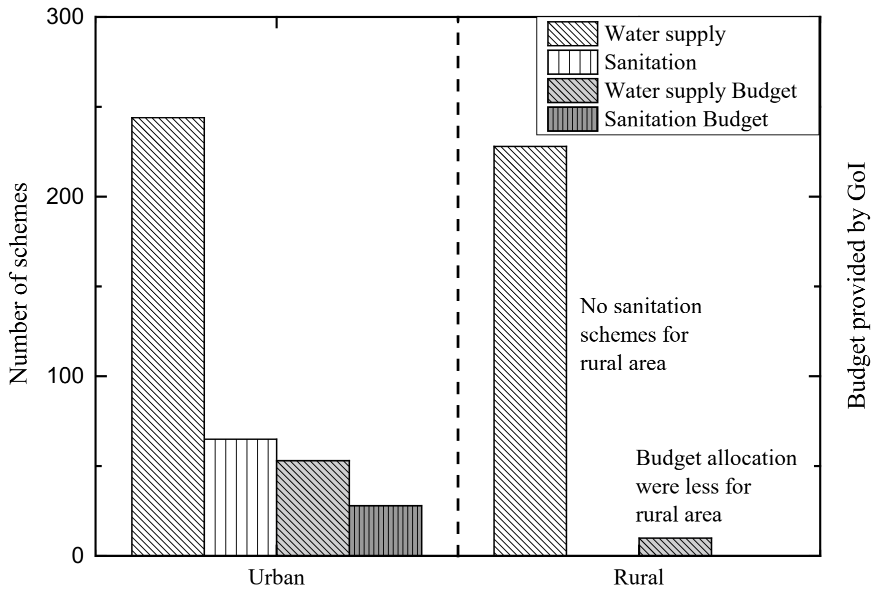


Fig. 3 Number of schemes provided for water and sanitation during 1950–60

The above evidence indicates that rural sanitation was not considered a priority issue during this era. This could be due to the fact that during post-independence, increasing agricultural production was given most priority thus WS has been considered over sanitation. Though sanitation and water schemes were implemented by the policymakers, especially for urban areas, according to the 1961 census, in urban areas 75% lack protected WS and 85% lack sewerage system amenities. Until the third plan (1961–1966), the community development program had WS&S as a component. The third five-year plan indicated that waste from urban areas needed to be addressed properly and hence a separate department called the "housing and urban and rural planning" department was formed which invested ₹1006.0 million in WS&S (Planning Commission 1961).

In the fourth plan (1969–1974), about 1.2 million sanitary wells and hand-pumps were constructed and 17,000 villages had piped WS (Planning Commission 1969). Further, in the fourth plan, an investment of ₹ 4050 million was made in WS&S in Regional Development, Housing, and WS department. During 1951–74, a total of ₹ 8550 million were invested in WS&S facilities in urban areas.

In the fifth plan (1974–1978), Minimum Need Program (MNP) was launched and it is the first program that defined poverty as not only about food, shelter, and clothing but also related to the quality of life. Based on the sixth plan (1980–1985) report, about 1.84 lakh villages had benefited from MNP. The sixth plan report also highlighted that almost 98% of the rural households did not have any latrines, as shown in Fig. 1. Thus, in this era, both urban and rural areas were lacking basic sanitation facilities, and WS was given more priority in this era.

2.2 Eradication of Open Defecation Era (1980–2008) of Indian Sanitation

In 1980, based on the severity of the deaths due to unhygienic conditions in the world, the 34th world health assembly declared 1981–1990 as an international drinking WS&S decade to improve the hygiene conditions in the world (WHO (World Health Organisation) 1981). In India, however, the evaluation reports indicated that the progress made on WS and basic sanitation was not satisfactory. By March 1980, about 36% (200,000 out of 557,137 (Bureau 1981)) villages with 160 million population were lacking WS facilities. In this context, in the sixth plan (1980–1985), GoI with decided to provide 100% WS to the entire population, and partial (i.e., 80% urban and 25% rural) population with sanitation facilities by the 1990 (Planning commission 1992). In addition, the sixth plan revised MNP by increasing the funds of rural WS&S from 3810 million to 15,440 million (Planning Commission 1980). The sixth plan provided a ₹ 39,220.2 million (i.e., ₹ 33,078.0 million in the state sector and ₹ 6142.2 million in the central sector) for WS&S (Planning Commission 1985) schemes, with the provision of drinking water as a main agends. The census of 1981 declared that sanitation coverage in rural India is only 1%, and in urban India, only 198 towns had sewerage facilities (Planning Commission 1985). During this era, low-cost sanitation techniques were implemented in urban slums and in 110 towns, United Nations Development Program (UNDP) promoted the water-seal latrines installation in seven states (viz., Maharashtra, Rajasthan, Assam, Bihar, Uttar Pradesh, Gujarat, and Tamil Nadu).

The seventh plan (1985–1990), sanctioned ₹ 40 million, especially for rural sanitation (Planning Commission 1992, 1985). In addition, the development of women and children in rural areas (DWCRA) program also emphasized the importance of sanitation in rural areas to protect women's dignity. However, with all these efforts by GoI, in 1985, only 28% and 73% of the urban population had proper sanitation and safe water, respectively (Planning Commission 1992). To improve the sanitation status in rural India, the United Nations and other external agencies influenced India to distinguish the sanitation sector from the water sector. Centrally sponsored Rural Sanitation Program (CRSP) was started in 1986 under the Ministry of Rural Development to provide good quality of life to rural people (Asthana 1997; Brij 2012). Massive subsidies were provided under CRSP, assuming that toilets are not affordable to the poor. However, in 1988, a survey conducted by the National Sample Survey Organization (NSSO) reported that even with subsidies, 81% in the rural areas and 35% in urban areas lacked sanitation facilities, 83% in rural and 26% in urban followed OD, which indicate that subsidiaries were either not reaching the people or subsidies were not being availed.

The CRSP introduced a low-cost sanitation program (LCSP) in 1990, for the liberation of scavengers from the manual sector. LCSP mainly concentrated on eliminating the inhuman practices in the sanitation chain (i.e., carrying night soil), and to rehabilitate scavengers. The eighth plan (1992–1997) provisioned ₹1500 million for

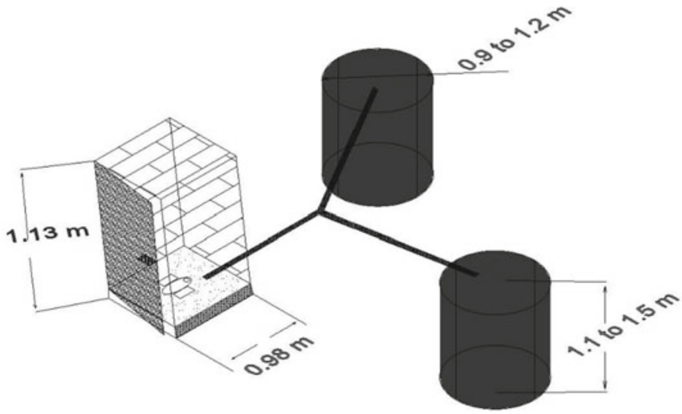


Fig. 4 UNDP design for two pits pour-flush latrine

LCSP, to meet the objective of conversion of dry latrines units into low-cost pour-flush sanitary latrines for the liberation of manual scavengers (Planning Commission 1992). In LCSP, a standard UNDP design for two pits pour-flush latrine as shown in Fig. 4 (i.e., superstructure size of 1.13 m × 0.98 m and pit size varies from 0.9 m diameter to 1.2 m diameter and from 1.15 m depth to 1.5 m depth) was recommended.

Though the central government provided funding by various means for reaching the sanitation target, the following reasons resulted in GoI being unable to achieve the sanitation target:

(i) benefits not reaching the targeted people (i.e., above poverty line people installed the pour-flush latrines due to their upper hand in the society),
(ii) inadequate or not available for the superstructure (i.e., only ₹2500 was provided by the government, which was not sufficient for the construction of both super and substructure),
(iii) the recommended technology was often unsuitable because of improper design of superstructure (i.e., 70 to 80% of people complained that the cubicles were dark and small to be used (Planning Commission 1992, 1985, 1997)) and
(iv) lack of technical knowledge (i.e., the diameter of pits found to be constant in all cases at 0.9 m made of standardized cement rings instead of a honeycomb brick wall. Less distance between pits, lack of knowledge on maintaining pits, and entry of rainwater into the pits (Ministry of Urban Development 1990))

As per the planning commission report in 1988, rural sanitation coverage was increased to 4% due to Central Rural Sanitation Program in 1986 (Planning Commission 1997). As per the 1991 census, less than 10% of rural households had sanitation facilities, as shown in Fig. 1. Whereas in the urban areas, 400,000 manual scavengers in 3117 towns were cleaning 5.4 million dry latrines.

All the above programs with the aim to develop the rural areas worked on the philosophy that providing drinking water to people will improve their health and wealth of people. Hence in this era, drinking water was given more priority (i.e.,

₹132,450.0 million were sponsored for Rural WS Program, whereas ₹ 9550.0 million for rural sanitation program in the eighth plan). However, in 1998–99, the Central Bureau of Health Intelligence (CBHI) in the Ministry of Health and Family Welfare reported that 30 million people in India suffer from sanitation issues and five out of ten children between the age of 1–4 years are suspected of dangerous fatal diseases due to human excreta contamination in water. This report showed that it is not about the quantity of drinking water to be provided; also, about the quality of drinking water, which was directly related to sanitation.

To improve that sanitation conditions in rural India, in 1999, CRSP came up with a community-led, people-centered, demand-driven, and incentive-based model in the name of the Total Sanitation Campaign (TSC) to eliminate open defecation (Hueso and Bell 2013). Further, in September 2000, India signed the United Nations millennium declaration, committing to eradicating extreme poverty in all its forms by 2015, in which one target was the provision of access to basic sanitation. Millennium Development Goals (MDGs) target was to provide 50% of the rural population with sanitation facilities by 2015. For this, GoI under TSC kept the target to achieve 100% sanitation coverage by the end of 2012 (Planning Commission 2002, 2007). Innovative awards like Nirmal Gram Puraskar (clean village award scheme) were introduced in 2003, to encourage a competitive environment for cleanliness, and the Sampoorna Swachhtha Andolana scheme in 2005 was started under the TSC. By 2007, TSC has built 3.5 million household toilets, 41,000 school toilets, and 1,700 women's complexes. However, according to 2001 census data, only 36.4% of the population had sanitary latrines and 21.9% of the rural population had latrines.

According to the Planning Commission report of 2007, the main constraints of TSC and LCSP programs were.

(i) the absence of subsidy for superstructure portion,
(ii) non-availability of sufficient space for the construction of twin pits, and,
(iii) poor loan recovery from the individual.

Further, the award schemes were successful in creating a competitive nature, but were not successful in the long term, as people started neglecting them, after receiving the award. A study in 2008 by UNICEF revealed that 76% of households in the villages which have been awarded Nirmal Gram Puraskar were still defecating in the open and only six of the 162 Nirmal Gram Puraskar villages had sustained its status (Planning Commission 2002). Ministry of Drinking Water and Sanitation, 2010, found that low incentives provided by TSC led to poor quality of toilet construction and unfinished toilets (Planning Commission 2007), and also limited involvement of panchayat to raise awareness and assist TSC (Planning Commission 2002) were are the key factors for non-usage of sanitation facilities.

2.3 Sanitation Coverage Era (2008–2019)-Exponential Phase of Indian Rural Sanitation

Though the objective of LCSP was to eradicate manual scavengers in the sanitation sector, however, its standard design of twin pit latrines had again made the necessity of manual scavenging when pits were full. It could be because, in the honeycomb structure, water gets infiltrated into the ground, thus leaving thick sludge, which cannot be removed by vacuum, leading to the use of manual labor for it. Even though the number of people without drinking water dropped below one billion (JMP 2008) in the world, the health issues of people did not decrease. This indicated to the world that, sanitation conscience of people is critical to improving the health and relative wealth of people. In this regard, the United Nations general assembly declared 2008 as the International Year of Sanitation by understanding the importance of sanitation in maintaining the health of people. In 2006, WHO/ UNICEF Joint Monitoring Program (JMP) for WS&S estimates that around 0.6 billion people in India are still following open defecation, as shown in Table. 1 (Planning Commission 2007). It also reported that WS was increasing in India as indicated in Table. 1, than sanitation coverage.

In 2008, National Urban Sanitation Policy (NUSP) was formed by the Ministry of Urban Development safe collection, safe transportation, safe disposal, and treatment

Table. 1 Drinking water and sanitation coverage of India by WHO/UNICEF Joint Monitoring Program (JMP)

	Urban			Rural			Total		
Year	Piped	Other	UN	Piped	Other	UN	Piped	Other	UN
Drinking water coverage (%)									
2017	68	28	3	32	60	7	44	50	6
2006	49	47	4	10	76	14	21	68	11
2000	74	21	5	33	47	18	44	40	14
1990	52	38	10	7	58	35	18	53	29
	Urban			Rural			Total		
Year	IMP	OD	UN	IMP	OD	UN	IMP	OD	UN
Sanitation coverage (%)									
2017		5	2		36	3		26	2
2006	52	18	8	18	74	3	28	58	4
2000		27	8		90	5		73	6
1990	44	28	10	1	89	6	5	8	73

Piped—Piped into dwelling, yard, or plot; Other—Other improved; *UN*—Unimproved; *OD*—open defecation; *IMP*—improved; (JMP 2008; JMP (Joint Monitoring Program) 2019); Improved water supply: Piped water, protected dug well, community RO plant, public tap, tube well, protected spring. Improved sanitation: Onsite sanitation technologies with flush systems, ventilated improved pit (VIP), composting toilet, pit latrine with slab of human excreta. NUSP aims at the development of citywide sanitation plans, to convert the cities into 100% open defecation free, and is the first policy that spoke on the collection and transportation of human waste. The 2011 census reported that 32.7% of urban population are having piped sewer systems, whereas 12.6% still defecate in the open (Planning Commission 2012). In 2012 NSSO reported that 43.4% of households (i.e., 59.4% rural and 8.8% urban) have no access to sanitation.

Further, India could not achieve the sanitation target that was included in the MDGs. Hence subsequent Sustainable Development Goals (SDGs) were signed to eliminate OD and by 2030 entire population should have sanitation (Novotny 2018). To achieve these targets and accelerate sanitation coverage, in 2012, Nirmal Bharat Abhiyan (NBA), under the Ministry of Drinking Water and Sanitation, was formed. The NBA target was to attain 100% sanitary facilities in entire rural India by 2022 (JMP 2008). Funds were diverted for information, education, and communication (IEC), and also this policy encouraged subsidies after attaining ODF status. Access to safe sanitation is a crucial mechanism to reducing child and infant mortality (adverse health outcomes associated with diarrheal disease), to safeguard women's dignity, and to reduce poverty levels. In this regard, different external agenesis, acts, and the direct and indirect program, as shown in Fig. 5 were determined to achieve sustainable sanitation in India.

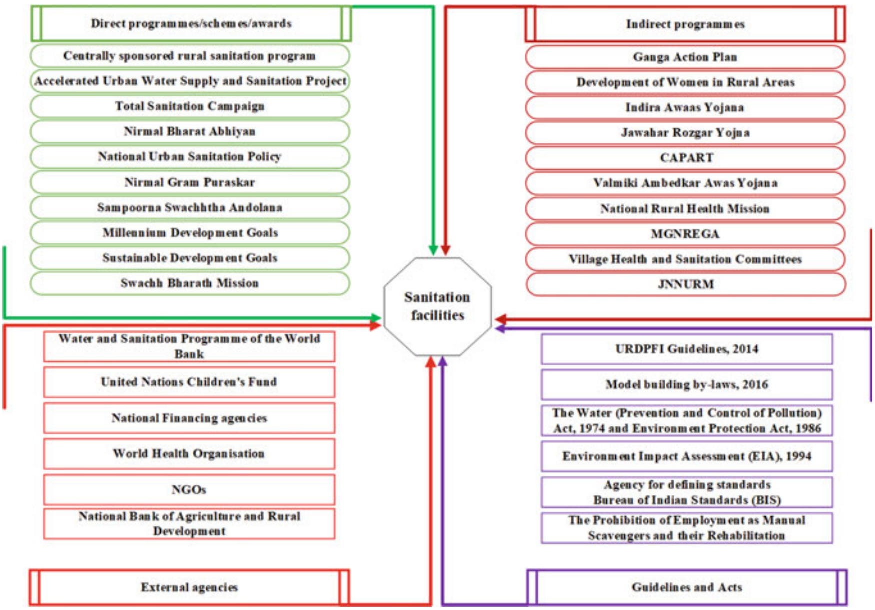


Fig. 5 External agencies, acts, the direct and indirect programs determined to achieve sustainable sanitation in India. *Note* NGO-Non = Government Organizations; CAPART- Council for Advancement of People's Action and Rural technology; MGNREGA- The Mahatma Gandhi National Rural Employment Guarantee Act; JNNURM-Jawaharlal Nehru National Urban Renewal Mission

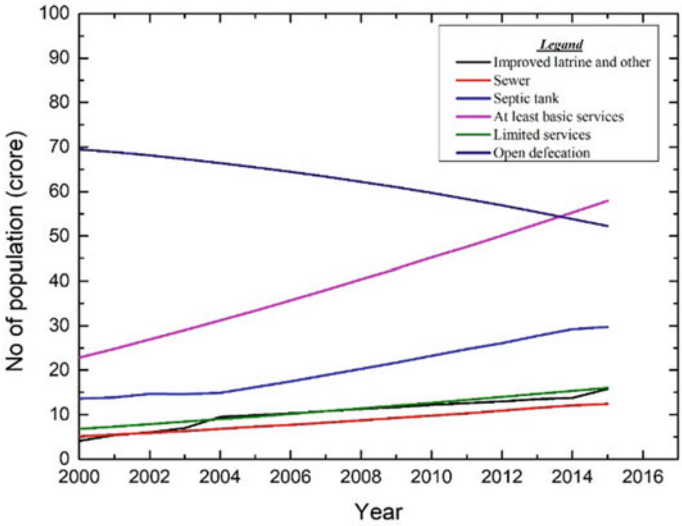


Fig. 6 Population having access to sanitation system in crore in India by WHO-UNICEF-JMP

Further, in 2013 "the prohibition of employment as manual scavengers and their rehabilitation" act was bought into action, which emphasized the usage of the safe truck-based emptying system for Fecal Sludge, FS, (i.e., human excreta after decomposition in onsite sanitation technologies). As shown in Fig. 6, sanitation facilities in India were increasing gradually till 2014.

Grasping the importance of sanitation and emergency condition in India, GoI targeted to achieve Swachh Bharat by October 2, 2019, by formulating Swachh Bharat Mission (SBM) as a tribute to the 150th birth anniversary of Mahatma Gandhi. SBM has two wings (i) SBM Gramin, under the Ministry of Drinking Water and Sanitation, and (ii) SBM Urban, under the Ministry of Housing and Urban Affairs (SBM (Swachh Bharat Mission) Gramin 2017a). In 2016, the National Family Health Survey (NFHS) reported that improved sanitation in rural India is only 36.7% (NFHS (National Family Health Survey) 2015). SBM claims 102,867,271 toilets have been built since 2014, as shown in Fig. 7, and also to ensure the long term sustainability of these toilets, the second phase of mission saying ODF^{+} was introduced in 2019. It can be observed from Fig. 7 that the toilets building has been exponentially increased during the year 2015 to 2019. In addition, the cumulative values have been increased to greater than 100 million by 2019.

Unlike previous Indian sanitation programs, SBM-G had partnerships with state governments, district administrations, development partners, school teachers to emphasize sanitation, and different level administrative systems, as shown in Fig. 8. In addition, SBM kept its processing of the documents accelerated and its monitoring system strict with the aid of technologies like the internet. Mass media was used for IEC in this scheme, leading to improving the sanitation facilities in India. Further,

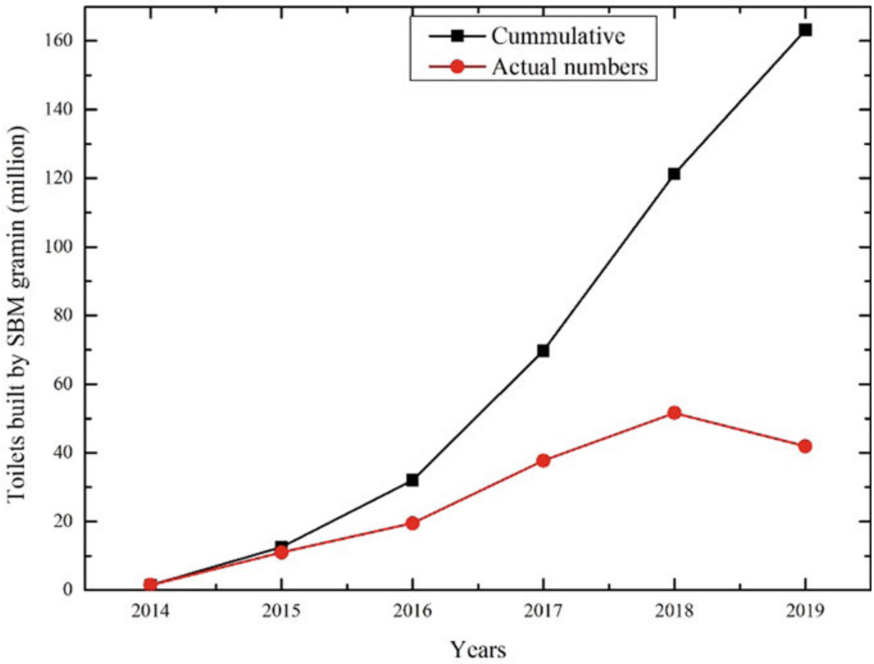
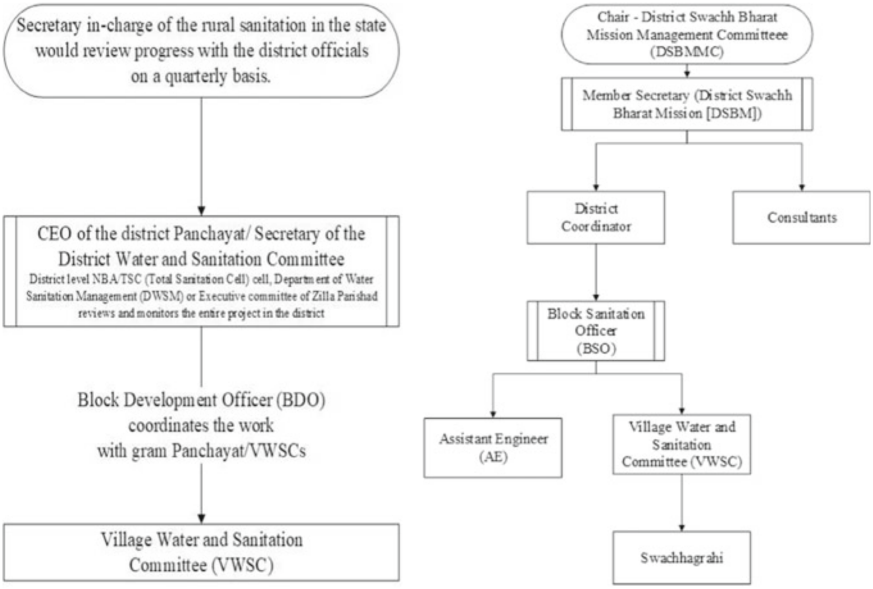


Fig. 7 Toilet coverage by SBM Gramin from 2014 to 2019

competitive scoring of sanitation was made at each administrative level to encourage sanitation implementation.

At present, in India, two types of sanitation systems exist, i.e., (i) Onsite Sanitation System (OSS), generally for rural areas, and (ii) capital-intensive conventional sewerage system for big cities. In India, around 70% of the sanitation system is OSS, which does not have proper management of FS (WHO 1992). As per the rules of SBM, toilets that have access to sewerage system within 30 m can build only the superstructure and connect to sewer, while where there is no sewerage system within 30 m an onsite treatment needed to be constructed. However, only 32.7% of households with a toilet facility are connected to an underground sewage network (census, 2011). Thus, approximately 55 million toilets have an OSS (Bhitush et al. 2017).

As per SBM, the OSS recommended is the double pit latrine, as shown in Fig. 9 (SBM 2016; SBM 2017b), and the structure of the pits is to be built like a honeycomb. Thus the wastewater and gas can be absorbed by the soil while the remaining bricklayers can be cemented permanently. The double pit OSS proposed by SBM claims to have the ability to degrade the excreta and efficiency to convert the excreta into manure. When one pit gets filled, it should be closed, allowing waste to get converted to manure, and the second pit should be used.



(a) NBA (b)- SBM-G

Fig. 8 The administrative structure of the NBA and SBM-G

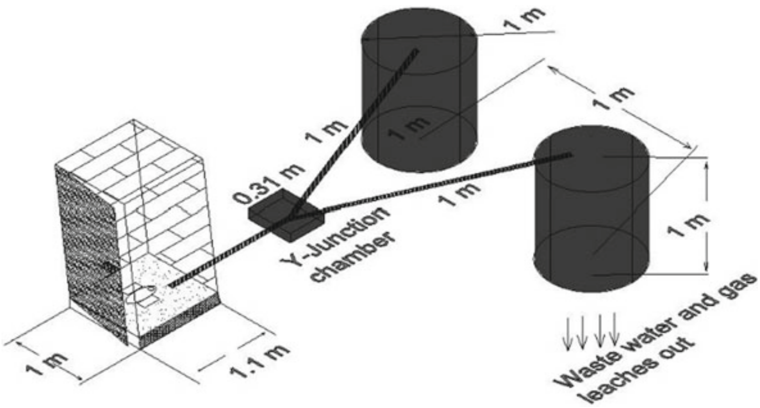


Fig. 9 Technicalities of twin pit for the pour-flush toilet by SBM

Though SBM has shown tremendous work in the elimination of OD, the behavioral reasons and technical aspects, however, may lead to the unsuitability of its efforts, such as.

- In villages, people have social norms (assumptions, traditions, etc.) that may discourage people from using toilets, and in a few parts of India, it is still believed that toilets are for women.
- People not using the toilet due to fear of the pits getting filled up quickly, foul smell, toilet getting dirty, or simply to avoid toilet cleaning (SBM 2017b).
- The desludging cost to poor households in developing countries estimated to be a major part of their annual income (JMP 2008). The financial burden of emptying the OSS has led to environmental pollution by not emptying the OSS or unscientific way of disposal of FS (WHO 2017). India stands 4th in the world for not emptying the OSS facilities, i.e., around 93% (JMP 2019).
- Based on USEPA guidelines for FS generation, the OSS in India currently can produce 56 million m^3 of FS/year and by end of 2020, it could soar up to 1 billion m^3, making the disposal of FS a major task for government.
- SBM suggests 1–1.5 L of water to be added per usage of the toilet for the proper functioning of double pit toilets (SBM 2017b), however, in most of India usage of the recommended volume of water is not practiced leading to difficulty in long term suitability of these pits.

National Policy on Fecal Sludge and Septage Management was published in 2017, emphasizing the safe practices and rules to be followed for truck-based services. However, this document did not cover the existing practices and their improvising on them. FS has a high concentration (10–100 times) of toxic pollutants compared to wastewater (Doulaye and Martin 2014); hence a proper disposal method needs to be explored. Further, as double pit toilets are a honeycomb, the manure which will be produced in the double pit latrines will be thick and cannot be vacuumed out, thus leading to the practice of manual scavenging in the sector, thus questioning the whole philosophy of eradication of manual labor in the sanitation sector.

3 The Way forward- Paradigm Shift Required for Rural Areas

India has undergone an interesting journey of sanitation coverage from 1% rural sanitation coverage to maximum toilet construction by 2019. Predominantly SBM Gramin has constructed 180 million toilets in India from 2014 to 2019. However, these toilets lack the required management systems for the collection, emptying, transportation, and safe disposal of the Fecal Sludge FS (i.e., human excreta after decomposition in onsite sanitation technologies). By realizing the importance of FS Management, MoUD has published prima on Fecal Sludge Management (FSM), in 2017. However, this document did not cover the (i) number of existing unsanitary sanitation technologies (i.e., Pit latrines, bucket latrines, ventilated improved pit), (ii) existing unscientific practices (like disposal of FS into rural agricultural lands), (iii) nonexistence of the FS treatments in India, and (iv) also appropriate design required currently for Indian condition (which depends on physical, chemical, and biological characteristics of FS produced). Further, the implementation of FSM is dependent on the decision of local bodies as per the 74th Constitutional Amendment Act. The present sanitation policy currently focuses on a subsidy-based approach to operationalizing a sanitation system; however, it is important to develop a model with a self-driven approach or even a profitable approach for sustainable sanitation systems in rural India.

From the critical analysis of the Indian sanitation's journey, the parameters which play a crucial role in sustaining the sanitation system in India are:

(i) The award schemes (i.e., Nirmal Gram Puraskar) were successful in creating a competitive nature but were not successful in the long term, as people started neglecting them, after receiving the award. Thus, strict enforcement of the by-laws is required and monitoring of the onsite sanitation structures built. Administrative areas that declared themselves as "open defecation free" should maintain the sanitation system and also follow strict rules regarding the OSS construction.

(ii) Pit latrines, bucket latrines, ventilated improved pit, biogas latrine, and composting latrines produce thick FS, which cannot be emptied using vacuum pumps. Thus, Manual scavenging has become an integral part of the sustenance of the sanitation chain. Converting unsanitary toilets to septic tanks can help in the eradication of manual scavenging in the sanitation sector.

(iii) According to WHO, 3000 L of FS gets accumulated per household, thus, 56 million m^3 of FS will be produced in a year, and by 2020, it soars up to 1 billion m^3, making the disposal of FS a major task for the government. Managing a proper collection, transportation, treatment, and disposal of FS is a need of Indian sanitation. As FSM is a relatively new field, lack of scientific understanding of the chemical-physical-biological-mineralogical characteristics of the FS has hindered innovation in the collection, transportation, and treatment of FS. Although the primary goal of the FSM is a public and environmental health, the sustainability of FSM depends on designing the treatment facilities and the end-use of treated FS produced (Chandana and Rao 2021). The main challenges and constraints in the design of FSM in India are (i) lack of technical knowledge on rate of degradation of fecal matter in different OSS, characteristics of FS, and treatment options of FS, (ii) lack of planning in OSS and its access and (iii) lack of innovation required for emptying, collection, transportation, and treatment of FS (Chandana and Rao 2020). The need of the hour for Indian sanitation is the extensive experimental investigation on the holistic characterization of FS samples from different OSS from different parts of India, followed by the development of appropriate solutions for desludging, collection, and FS treatment.

References

Asthana AN (1997) Where the water is free but the buckets are empty: demand analysis of drinking water in rural India. Open Econ Rev 8(2):137–149

Bhitush L, Amrita B, Mahreen M, Uday B (2017) Septage management, a practitioner's guide. In: Parrey AA (ed) Centre for science and environment

Brij P (2012) Five year plans and rural water supply in India: a critical analysis. Dev Country Stud 2(3). ISSN 2225-0565

Burkitt DP (1973) Some diseases characteristic of modern western civilization. BMJ 1(5854):274–278. https://doi.org/10.1136/bmj.1.5848.274

Census Bureau (1981) A hand book of population statistics New Delhi

Chandana N, Rao B (2020) Status of sustainable sanitation chain in rural, semi-urban, and urban regions: a case study of Maharashtra, India. J Water Sanitation Hyg Dev. https://doi.org/10.2166/washdev.2020.020

Chandana N, Rao B (2021) Evaluating the physicochemical, nutrient, and pathogenic characteristics of fecal sludge for fertilizer application: case from Vadgaon Maval, Maharashtra, India. J Environ Eng 147(3). https://doi.org/10.1061/(asce)ee.1943-7870.0001854

Doulaye K, Martin S (2014) Low-cost options for treating faecal sludges (FS) in developing countries- challenges and performance. In: IWA specialist group conference on wetlands systems for water pollution control. Avignon, France

Freeman MC, Garn JV, Sclar GD, Boisson S, Medlicott K, Alexander KT, Penakalapati G, Anderson D, Mahtani AG, Grimes JET, Rehfuess EA, Clasen TF (2017) The impact of sanitation on infectious disease and nutritional status: a systematic review and meta-analysis. Int J Hyg Environ Health 220(6):928–949. https://doi.org/10.1016/j.ijheh.2017.05.007

Hueso A, Bell B (2013) An untold story of policy failure: the total sanitation campaign in India. Water Policy 15(6):1001–1017. https://doi.org/10.2166/wp.2013.032

JMP (Joint Monitoring program) (2019) Progress on household drinking water, sanitation and hygiene I. JMP, USA

JMP (Joint Monitoring program) (2008) Progress on drinking water and sanitation. In: Joint monitoring programme for water supply and sanitation 2008. JMP, USA

Lakshmanaswami M (1961) Report of the health survey and planning committee. Government of India Ministry of Health

McGill BM, Altchenko Y, Hamilton SK, Kenabatho PK, Sylvester SR, Villholth KG (2019) Complex interactions between climate change, sanitation, and groundwater quality: a case study from Ramotswa, Botswana. Hydrogeol J 27(3):997–1015. https://doi.org/10.1007/s10040-018-1901-4

Ministry of Urban Development (1990) Evaluation study of lowcost sanitation program, Human Settlement Management Institute, New Delhi, India

NFHS (National Family Health Survey) (2015) India fact sheet National family health survey-4. Ministry of Health and Family Welfare, Mumbai, India

Novotný J, Hasman J, Lepič M (2018) Contextual factors and motivations affecting rural community sanitation in low- and middle-income countries: a systematic review. Int J Hygiene Environ Health **221**(2):121–133. https://doi.org/10.1016/j.ijheh.2017.10.018

Planning Commission (1950) First Five Year Plan, New Delhi: Government of India

Planning Commission (1956) Second Five Year Plan. Government of India, New Delhi

Planning Commission (1961) Third five-year plan. Government of India, New Delhi

Planning Commission (1969) Fourth five-year plan. Government of India, New Delhi

Planning Commission (1980) Sixth five year plan. Government of India, New Delhi

Planning Commission (1985) Seventh five-year plan. Government of India, New Delhi

Planning Commission (1992) Eighth five-year plan. Government of India, New Delhi

Planning Commission (1997) Ninth five-year plan. Government of India, New Delhi

Planning Commission (2002) Tenth five-year plan. Government of India, New Delhi

Planning Commission (2007) Eleventh five year plan. Government of India, New Delhi

Planning Commission (2012) Twelfth five-year plan. Government of India, New Delhi

Richard GF, David JB, Hemda G, Dancan M (1983) Sanitation and disease health aspects of excreta and wastewater management. Wiley, Washington
SBM (Swachh Bharat Mission) Gramin (2017a) Guidelines for Swachh Bharat Mission (Gramin): Ministry of Drinking Water and Sanitation
SBM (Swachh Bharat Mission) Gramin (2017b) Development manual for district level-level functionaries: Ministry of Drinking Water and Sanitation
SBM (Swachh Bharat Mission) Urban (2016) Guidelines for Septage Management in Maharashtra: Swachh Maharashtra Mission (Urban)
WHO (World Health Organisation) (1981) Resolution of world health Assembly. Thirty-Fourth World Health Assembly, Geneva
WHO (World Health Organisation) (1992) A guide to the development of on-site sanitation. WHO, Washington
WHO (World Health Organisation) (2018) Guidelines on sanitation and Health. WHO, Washington
WHO (World Health Organisation) (2017) Progress on drinking water, sanitation and hygiene. WHO
WHO (World Health Organisation) (2006a) WHO guidelines for the safe use of wastewater and greywater: volume I-Police and regulatory aspect. WHO, Washington

Chapter 19
Evaluation of Shyama Prasad Mukherji Rurban Mission

Check for updates

Satish Dulla and Bakul Rao

1 Background

India has 66% of its population living in rural areas (Data Bank 2019), which were called 'Souls of India' by Mahatma Gandhi, but a decline of 18% population was observed in these areas over the past 100 years (Sekhar and Padmaja 2013). The main reason behind this decline was the migration from rural areas to urban areas in search of a better lifestyle and the driving force was the difference in facilities and opportunities between these areas. To tackle this problem, the Government of India (GoI) came up with the concept of regional development, which had existed since the first five-year plan. A regional development plan evaluates the area's potential, involves local people in plan formulation and implementation, makes optimum and judicious use of regional resources, thereby plans to remove the regional backwardness by meeting the regional aspirations and demands (Kumar and Rahaman 2016). Provision of Urban Amenities in Rural Areas (PURA), Sansad Adarsh Gram Yojana (SAGY) were some of India's popular schemes in the context of regional development and focused on rural areas. Shyama Prasad Mukherji Rurban Mission (SPMRM) is one such mission that was started in 2016 by the Government of India, intending to stimulate local economic development, enhance basic services by creating well-planned Rurban clusters (Shyama Prasad Mukherji Rurban Mission 2020). The word 'Rurban' combines two words, rural and urban, which signify the urban–rural continuum. This study aims to identify confounding factors in the selection criteria and this mission's planning process in developing Rurban clusters. In turn, it explores the scope for intervention in the scheme to achieve the objectives.

S. Dulla · B. Rao (✉)
Centre for Technology Alternatives for Rural Areas, IIT Bombay, Mumbai, India
e-mail: bakulrao@iitb.ac.in

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_19

2 Shyama Prasad Mukherji Rurban Mission (SPMRM)

SPMRM is a classic example of government schemes that prefers integrated development planning. This mission's objective is to stimulate local economic development in the selected potential regions (Rurban Clusters) of rural areas. SPMRM's target was to form 300 Rurban clusters by 2021 in three phases, but only 296 clusters were allocated till now (SPMRM 2020a). The proceedings between state and central government throughout the mission are shown in a flow chart, Fig. 1. The framework of the mission was studied and made the following insights at each stage of the mission.

2.1 Categorization of Rurban Clusters

The mission starts with categorizing regions into tribal and non-tribal, based on Article 366 (25) of the Indian constitution. Article 366 (25) emerged by taking all the considerations from the erstwhile Article 342 in verbatim (GoI 2020). Article 342 was included in the Constitution of India in 1949, which entitled the presidents of the states or union territories to specify the tribes or tribal communities that fall under the scheduled tribes at their discretion. So, the decision of categorization was subjective and depended upon the local prevailing conditions at that time. The

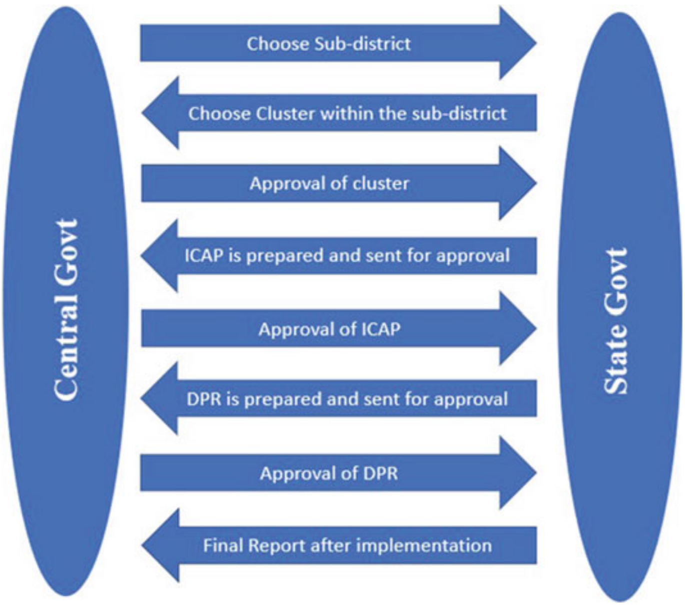


Fig. 1 The proceedings in the Rurban mission

same categorization may not be appropriate in the present context as the socio-economic conditions have changed over the past 70 years. In turn, it influences cluster development because the selection criteria and funding for the cluster vary with the category of the cluster (FOI 2020).

2.2 Selection of Rurban Clusters

As per the target, 200 non-tribal clusters and 100 tribal clusters put together 300 Rurban clusters were to be developed. Non-tribal clusters were selected from plain and coastal areas, which had a population from 25000 to 50000. Whereas tribal clusters were selected from desert and hilly areas, which had a population from 15000 to 25000 (FOI 2020). The Framework of Implementation (FoI) of SPMRM gave the factors and corresponding weights at central and state levels in the selection criteria of a cluster, shown in Table 1.

It was observed that the factors vary widely between state and central levels in non-tribal clusters, but they were almost the same in the case of tribal clusters. The Rurban mission promoted schemes like Pradhan Mantri Jan Dhan Yojana (PMJDY) and Swachh Bharat Mission (SBM Grameen) by assigning 10 and 5% weight in the non- tribal cluster selection at the state level. However, the preference of these two schemes over others was not explained. The guidelines were prepared at the central level and the states were given the freedom to modify the current factors or choose additional factors not crossing 20% weight in the cluster selection criteria. Since the states have a better idea of local conditions and are more liable for regional development, they can be given more freedom in cluster selection to develop better options for Rurban clusters.

2.3 Funding for Rurban Clusters

The funding of Rurban clusters was divided into two parts, i.e., through the convergence of fund sources and critical gap funding.

The convergence of existing fund sources. All the funds through centrally sponsored, central and state govt schemes, corporate social responsibility, etc., which can be used for the cluster development, were merged and tallied with the requirement while preparing the regional development plan. Each Rurban cluster must prepare an Integrated Cluster Action Plan (ICAP), which should justify that funds through convergence can meet 70% of the project capital (FOI 2020).

Critical Gap Funding (CGF). The difference between the required fund and the available fund through convergence is called a critical gap. This gap can be filled up through CGF, which is a unique feature of this scheme SPMRM. The remaining 30% of the project capital can be funded under CGF, which is limited to 15 crores for tribal

Table 1 Weight distribution in the cluster selection procedure at the state and central level

	Non-tribal cluster		Tribal Cluster	
Central Level	35%	Decadal growth in rural population	25%	Decadal growth in tribal population
	35%	Decadal growth in non-farm workforce participation	15%	Decadal growth in non-farm workforce participation
	10%	Presence of economic clusters	20%	Current tribal literacy rate
	10%	Presence of places of tourism and pilgrimage significance	25%	Decadal growth in rural population
	10%	Proximity to transport corridors	15%	Presence of economic clusters
State Level	20%	Decadal growth in rural population	35%	Decadal growth in tribal population
	20%	The rise in land values	35%	Growth in tribal literacy rates
	20%	Decadal growth in non-farm workforce participation	30%	Decadal growth in non-farm Workforce participation
	20%	Percentage enrollment of girls in secondary schools		
	10%	Percentage households with bank accounts under Pradhan Mantri Jan Dhan Yojana (PMJDY)		
	05%	Performance in Swachh Bharat Mission (SBM Grameen)		
	05%	Good governance initiatives by Gram Panchayats		

Source Framework of Implementation (FoI), SPMRM, Ministry of Rural Development India

and 30 crores for non-tribal clusters. The difference in the population considered, i.e., 15000–25000 in tribal and 25000–50000 in non-tribal clusters, is the base for CGF limits (FOI 2020). However, the cost of basic and social amenities that account for a significant part of the investment depends on topography, climate, water availability, population density and many more factors along with the population. In many cases, tribal clusters need basic and social amenities, which imply that they require more funds than non-tribal clusters.

2.4 Integrated Cluster Action Plan (ICAP)

ICAP is the base for the release of CGF's first installment. It consists of two components: (i) Socio-economic and infrastructure planning, (ii) Initiation of spatial planning (FOI 2020). ICAP guides the development of the Rurban cluster by defining the following.

(a) Strategy and vision for the clusters
(b) Outcomes desired in each cluster
(c) Critical gap funding for each cluster
(d) Resource mobilization methods
(e) Draft notification for declaring the cluster as a planning area.

The cluster needs are to be listed and categorized into basic, social, economic and digital amenities. They are prioritized based on the principle of saturation while preparing the ICAP. It is adopted based on a common assumption that the bottom layer's existence supports the upper layer, i.e., basic amenities are necessary to support others (SPMRM 2020b). The comparative analysis of six ICAPs from Maharashtra based on the City and Industrial Development Corporation of Maharashtra (CIDCO) data to check the clusters' preferences showed that every cluster had its priorities (Fig. 2). Jogeshwari gave a high preference for social amenities, whereas Kasatwadi looks for more economic activities. There might be an intense need for economic activities than basic and social amenities in some clusters. Hence, the assumption of the principle of saturation doesn't fit all the contexts as per the current study.

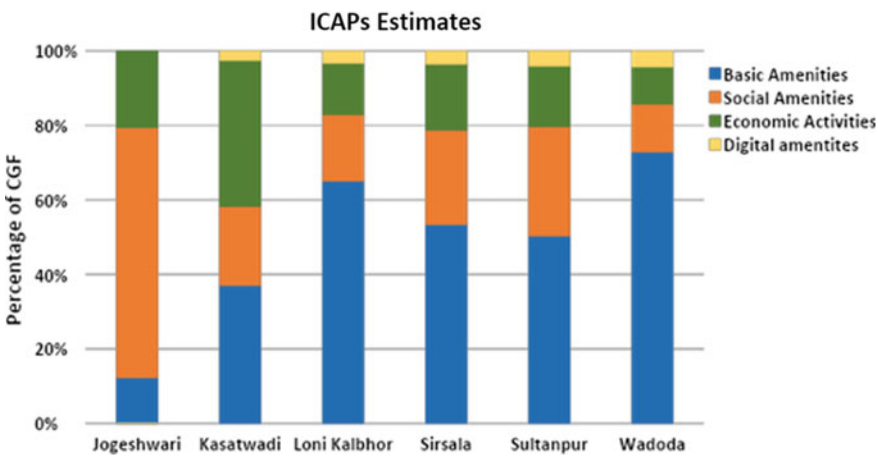


Fig. 2 Comparative analysis of 6 ICAPs' estimates

3 Spatial Distribution of Rurban Clusters

Spatial distribution is the representation of a phenomenon across the earth's surface. A graphical display of spatial distribution is a fine tool to summarize raw data. This study analyzed the spatial distribution of 296 Rurban clusters in India. There are two types of Rurban clusters (tribal and non-tribal) spread across 28 states and 8 union territories allocated in three phases, i.e., 100 clusters in each phase (SPMRM 2020a). Here, phase represents three years, i.e., one year for cluster allocation and planning and two years for the implementation, which overlaps with the next consecutive phase's cluster allocation and planning. The following bar graph (Fig. 3) shows the cluster distribution in which each bar is a composite of six parts, i.e., three phases in tribal and non-tribal clusters.

Maharashtra got the highest number, i.e., 20 Rurban clusters, which had an equal share of tribal and non-tribal clusters. Madhya Pradesh and Uttar Pradesh occupied the next place and had a greater share of tribal clusters and non-tribal clusters. All the union territories got a non-tribal cluster at least and Kerala, Tamil Nadu, Bihar, Haryana, Punjab, Sikkim and union territories were allocated no tribal cluster. Simultaneously, more tribal clusters were observed in Maharashtra, Madhya Pradesh, Chhattisgarh, Gujarat, Jharkhand and Odisha. The same data is presented on a map (Fig. 4) showing the clusters' geographical locations for more inferences.

Tribal clusters are mostly concentrated in the central part of India. A particular pattern is observed in their distribution extending from Gujrat toward Assam. A belt of non-tribal clusters is observed starting from Punjab toward West Bengal along the

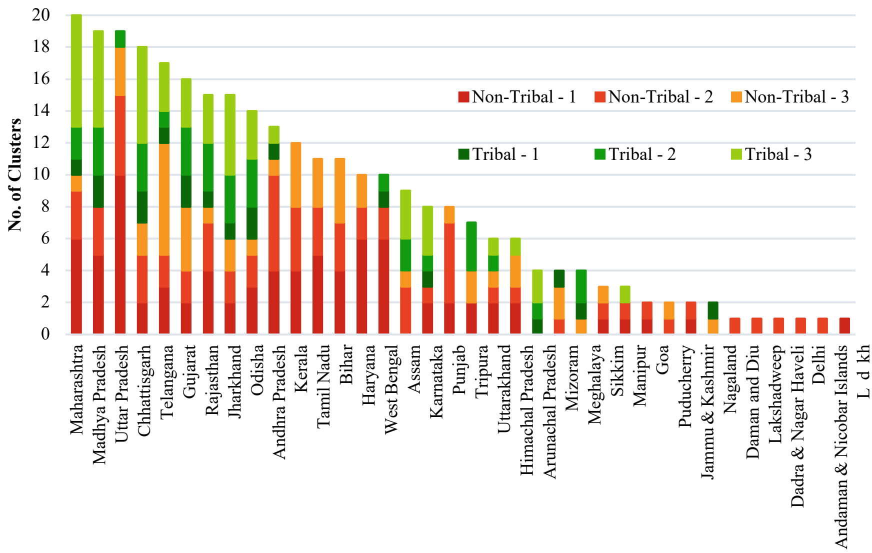


Fig. 3 Rurban clusters' distribution

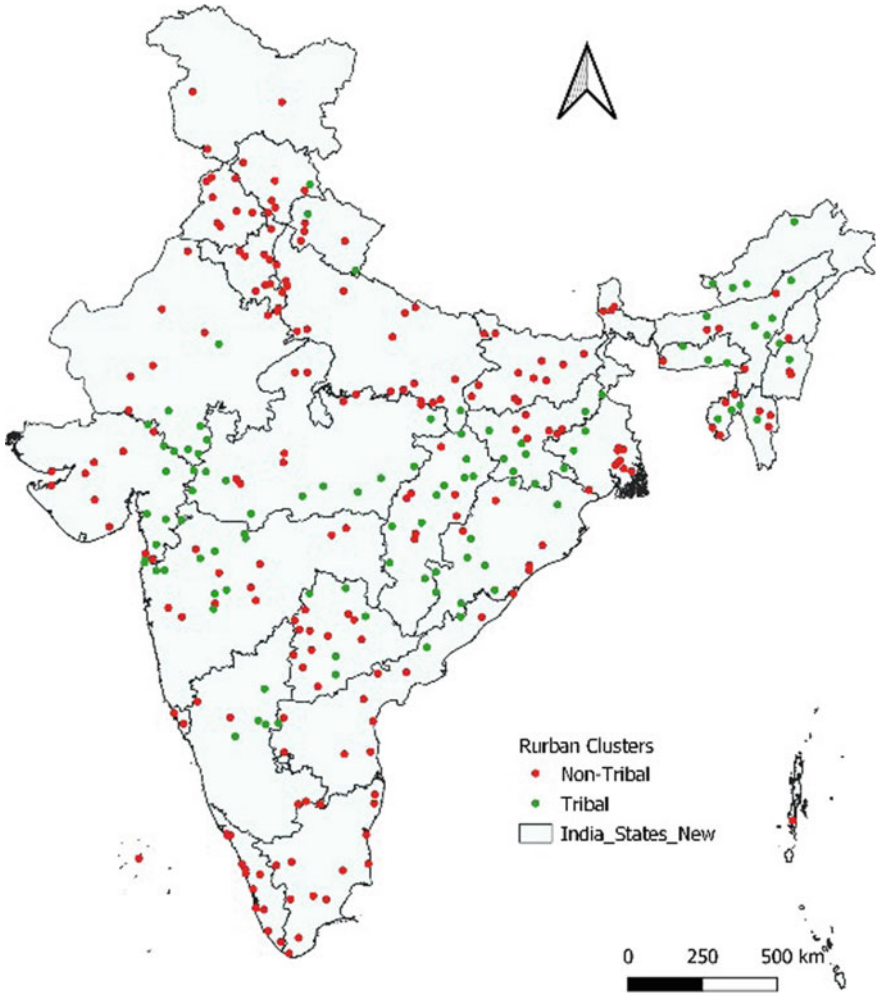


Fig. 4 Tribal and non-tribal clusters' distribution

river Ganga. Similarly, another group of non-tribal clusters is observed from Kerala toward Telangana.

3.1 Rurban Clusters and Scheduled Districts

The Ministry of Tribal Affairs has scheduled 177 districts as Tribal districts in India, which account for more than 50% Indian tribal population. These 177 districts were grouped into three categories according to the priority in attention. That means the

Ministry will concentrate on priority one districts first and so on (GoI 2020). When plotted on a map, these scheduled districts gave a similar pattern as that of Rurban tribal clusters. So, tribal clusters' locations are overlaid on the scheduled districts' map (Fig. 5).

It was found that 68% of the tribal clusters were located in the 177 scheduled tribal districts and 50% of the remaining 32% tribal clusters were located nearby scheduled tribal districts. It was because demographics were given high priority in both the tribal clusters and scheduled district allocation. So, tribal clusters fell in line with the scheduled tribal districts and the forest cover, which was an additional advantage for the regional development. No tribal cluster was allotted to some states because the number of clusters was limited and they were allotted based on the ranking given in Table 1. The remaining states also had the potential regions which

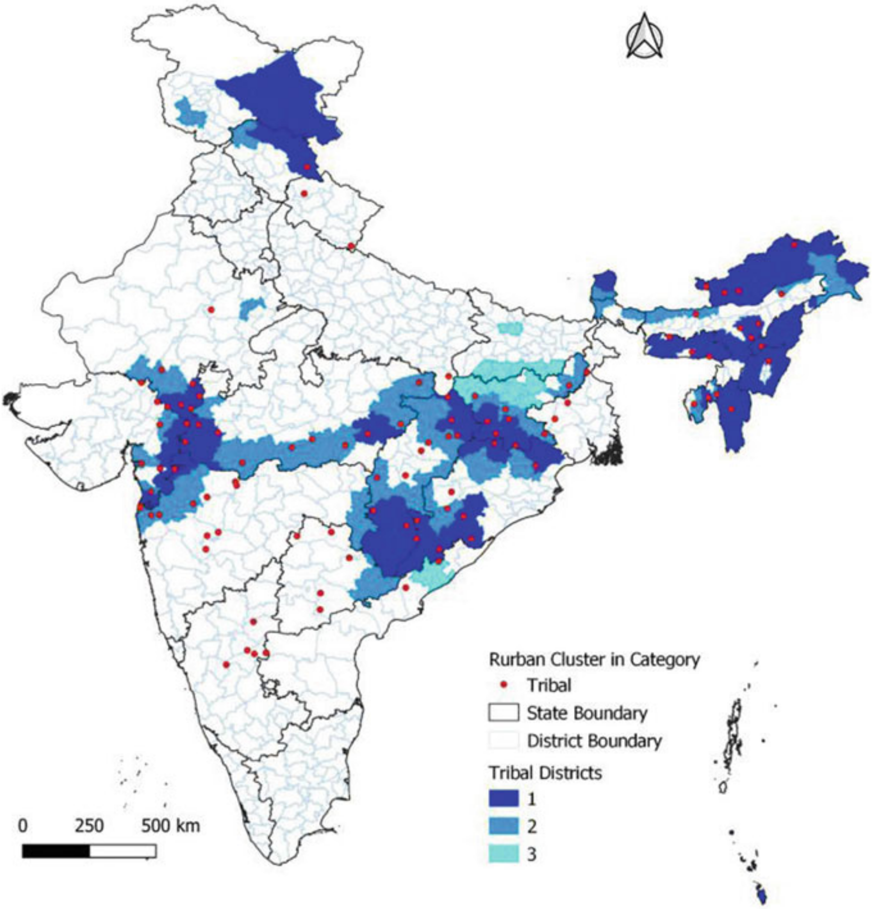


Fig. 5 Tribal clusters and scheduled tribal districts

were qualified to become the Rurban cluster, but they had to wait for their turn as per ranking.

4 Conclusion

SPMRM is a popular scheme with the regional development concept whose target was to create 300 Rurban clusters. This study evaluated SPMRM in aspects like the categorization, selection, funding, ICAP preparation and spatial distribution of clusters and pointed out the concerning confounding factors in each aspect. It was found that the categorization was done based on age-old subjective ideas that affect the selection and funding of the cluster. Existing selection criteria highlighted schemes like PMJDY, SBM Grameen without stating a valid reason and provide conditional freedom to the states, i.e., states can modify or include more factors limited to 20% weight. Classification and selection of Rurban clusters should be made based on the current condition and the latest data. Bias can be reduced by considering relevant factors and allocating corresponding weights to them in the cluster selection process. States should be given more freedom in terms of manipulating the weights in the best possible way. Sufficient funds should be allocated to avoid discrepancies in the implementation, and the funding for the tribal clusters should be increased by adopting more factors into consideration rather than demographics alone. Prioritization can be left to local authorities instead of one defined path for all. Such that most appropriate plan can be prepared, which would result in effective implementation and achieve the expected goals and objectives in stipulated time. The tribal clusters' distribution followed the scheduled tribal districts announced by the Ministry of Tribal Affairs, an added advantage for the scheduled tribal districts in regional development through convergence.

Acknowledgements I am grateful to the Ministry of Rural Development (MoRD), Government of India for supporting this research with a fellowship.

References

Data Bank (2019) World Bank. https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?namedesc=false. Last Accessed in 2019

GoI (2020) Annual Report 2018–19, Ministry of Tribal Affairs. https://tribal.nic.in/Statistics.aspx. Last Accessed 27 June 2020

Kumar P, Rahaman S (2016) Pre and post regional development scenario in India. Urban Reg Stud Contemp India 3(1):1–10

Sekhar SC, Padmaja R (2013) Rural demographics of India. Indian J Indus Relat 49(1):157–165

Shyama Prasad Mukherji Rurban Mission, Ministry of Rural Development, GoI. Homepage. http://Rurban.gov.in/. Last Accessed 25 Feb 2020

SPMRM (2020a) Management Information System, GoI. http://Rurban.gov.in/index.php/login/in-dex. Last Accessed 25 Feb 2020a

SPMRM (2020b) Rural Development and Panchayat Raj Department, Government of Maharashtra. https://rdd.maharashtra.gov.in/en/shyama-prasad-mukherjee-campaign. Last Accessed 9 July 2020b

The Framework of Implementation (FOI) (2020) SPMRM, GoI. http://Rurban.gov.in/in-dex.php/Public_home/framework. Last Accessed 25 Feb 2020

Chapter 20
A Multi-criteria Based Analysis for Prioritization of Solid Waste Treatment Methods for Rural Areas

Pawle Md. Umar Ravish and Ajaykumar R. Kambekar

1 Introduction

The entire world is living in an unprecedented era of human, technological, and economic development. With trade and commerce reaching unparalleled heights due to globalization, not only it has made countries more prosperous but also it has drastically improved the living standards of people in the developed as well as the developing countries. All these activities have resulted in the generation of tremendous amount of municipal solid waste. Municipal solid waste generally refers to the waste collected by municipalities or other local authorities which typically comprises household waste, commercial waste, institutional waste, and waste generated from public places. It has been estimated that about 2.01 billion tons of municipal solid waste were generated in 2016 worldwide, with at least 33% of it not managed in an environmentally safe manner; and under business-as-usual scenario, it is expected that this municipal solid waste generation will reach 3.40 billion tons by 2050 (Kaza et al. 2050; Pipatti et al. 2006).

India is the second-most populous country in the world after China; about 17.7% of world's population lives in India, i.e., 1 out of every six people is an Indian (United Nations 2019). In 2011, the total population of the country was 1210.2 million, out of which 833.1 million (68.85%) lived in 0.64 million villages and only 377.1 million (31.15%) lived in cities. Interestingly, the share of rural population in the total population is decreasing gradually. The percentage of rural population was 82.7% in the first census of 1951 which has declined to 68.85% in 2011. On the other hand, India's urban population share was 17.3% in 1951 which has increased to 31.15% in 2011 (Census of India 2011). This increase in urban population is mainly attributed

P. Md. Umar Ravish
Sardar Patel College of Engineering, Mumbai, India

A. R. Kambekar (✉)
Department of Civil Engineering, Sardar Patel College of Engineering, Mumbai, India
e-mail: a_kambekar@spce.ac.in

S. Chigullapalli et al. (eds.), *Rural Technology Development and Delivery*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-2312-8_20

to the migration of rural people to urban areas in search of employment, better infrastructure facilities, healthy lifestyle, etc. (Bhavita and Malek 2018). The rapid and unfair growth in urban areas, along with inadequate provision of basic sanitation infrastructure, has distressed many Indian cities in solid waste management and other such public services (Annepu 2012).

With regards to municipal solid waste, estimations suggest that about 1.5 Lakhs Tons per Day (54.75 Million Tons per Year) of solid waste is generated in urban India, and the per capita solid waste generation ranges from 0.20 to 0.6 kg/day in major cities. Also, the waste collection efficiency is between 70 and 90% in major metro cities whereas it is below 50% in several smaller cities. In 2014–15, out of the total MSW, approximately 117,644 TPD (80%) was collected, while only 32,871 TPD (22%) was processed or treated (Central Public Health and Environmental Engineering Organisation (CPHEEO) 2016a). A study by The Energy and Resources Institute (TERI) suggests that by 2047 solid waste generation in Indian cities will increase to 260 Million Tons per Year, which is five times the present value. It has also been estimated that the annual rate of increase in solid waste generation in Indian cities would be about 5% per annum. Present way of municipal solid waste management in Indian cities is largely ill-functioned which has led to degradation of the environment and resulted in poor quality of life (Central Public Health and Environmental Engineering Organisation (CPHEEO) 2016b).

In rural India, due to high population, growing consumerism, changing food habits, increasing use of plastics, packaging, and use and throw items, etc. the management of solid waste generated from rural households is increasingly becoming an issue of serious concern with regards to health and environment. In rural areas, this aspect has mostly been neglected due to lack of proper infrastructure, unavailability of sustainable technology at household or community level, lack of adequate O&M infrastructure, and awareness of common people (Ministry of Drinking Water and Sanitation Government of India 2015). Though solid waste generated in rural areas is predominantly organic and biodegradable and is of the order of 0.3–0.4 Million Metric Tons per Day, it is becoming a major problem as the waste generated is not segregated in-situ and also there are no proper solid and liquid waste management systems existing in these areas (Ramesh and SivaRam 2016). This has led to the spread of vector-borne diseases such as diarrhea, malaria, polio, dengue, cholera, typhoid, and other water-borne infections such as schistosomiasis. About 88% of the total disease load is due to lack of clean water and sanitation and the improper solid and liquid waste management (Ministry of Rural Development xxxx). It is quite evident that the problem of municipal solid waste management (MSWM) has emerged as a big challenge in the urban as well as the rural areas in India.

Realizing the need for a massive sanitation drive to tackle solid and liquid waste problems at the national, regional, and local levels, the Government of India launched the Swachh Bharat Mission (SBM) on October 2, 2014, with the vision of a cleaner India. It is one of biggest ever drives undertaken in the country to accelerate efforts to achieve universal sanitation and to put focus on improving cleanliness and sanitation. This mission incorporates both rural and urban components separately as: Swachh Bharat Mission (Gramin) and Swachh Bharat Mission (Urban). The overall objective of Swachh Bharat Mission (Gramin) is to promote cleanliness and accelerate sanitation coverage in rural areas by motivating village people and administration bodies and encouraging them to undertake cost-effective and appropriate technologies for ecologically safe and sustainable sanitation (Guidelines for Swachh Bharat Mission (Gramin) 2018). In order to scale down the load on the urban solid waste treatment infrastructure and also to handle the rural solid waste in a responsible manner thereby providing healthy lifestyle along with maintaining the ecological and environmental balance, it is imperative to provide an efficient and fully functional solid waste management system in rural areas itself.

Solid waste management (SWM) includes all activities that seek to minimize health, environmental, and aesthetic impacts of solid waste (Zhu et al. 2008). An effective functional waste management system comprises six elements: (a) waste generation; (b) waste handling and sorting, storage, and processing at the source; (c) collection; (d) sorting, processing, and transformation; (e) transfer and transport; and (f) disposal (Manual on Municipal Solid Waste Management 2000). Each of these elements has its own characteristics and requires different levels of planning and decision-making to make the entire management process effective. However, selection of an efficient and appropriate solid waste treatment method for a particular area is one of the important considerations for the success of a waste management system. Selection of a wrong waste treatment method can lead to the failure of entire waste management system, apart from economic and environmental losses (Selection Criteria for Waste Processing Technologies 2016). Hence this study focuses only on the decision-making problem related to selection of a solid waste treatment method for a village.

A large number of solid waste treatment methods are available worldwide. Selection of an appropriate technology for an area is an onerous task as decision-makers have to trade-off between a pool of conflicting economic, environmental, social, and technical criteria. Hence in modern challenging environment, decision-makers often need fast and effective tools to quickly model and optimize several decision alternatives and then compare them according to various preconditions or performance criteria (Vučijak et al. 2016). In recent decades Multi-Criteria Decision Analysis, a branch of operations research, has emerged as an important and convenient tool to support decision-makers in finding optimal results for complex decision-making problems involving various indicators, conflicting objectives, and criteria (Kumar et al. 2017). A large number of MCDA techniques and approaches have been developed over the years with the purpose of improving the quality of decisions by creating the development more efficient, rational, and explicit; and each one has its own merits and demerits (Mardani et al. 2015). The ability of MCDM to handle complex and controversial information, which forms the basis of a decision-making process and then to integrate it with human aspirations by involving multiple stakeholders, has attracted the applications of MCDA in the field of environmental decision-making as well (Kiker et al. 2005).

2 Literature Review

According to Belton and Stewart (Valerie and Stewart 2002), "MCDA is an umbrella term used to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter". Multi-Criteria Decision Analysis (MCDA) serves as an aid to decision-making by disintegrating the decision-making problem into manageable fragments to make judgments based on relevant data and then reassembling these fragments to have a logical and rational solution to the problem (Analysis 2009). In recent years MCDA has become a very fertile and popular branch of the Operational Research, with an ever-increasing application to a very diverse set of problem scenarios (Bruno and Genovese 2018). MCDA is a discipline that has a wide range of applications in mathematics, management, informatics, psychology, social science, economics, etc. It has flourished in all areas where a significant tactical or strategic decision is to be made depending on the time perspective of the consequences (Alessio and Nemery 2013).

Several review studies have been conducted pertaining to application of MCDA in solving environmental problems which help in knowing the suitability of a particular MCDA technique. Achillas et al. (Achillas et al. 2013) presented an extensive review of the literature on MCDA in waste management problems. Research papers were classified based on waste stream assessed, date of publication, MCDA method used and the specific topic addressed. It was found out that AHP and ELECTRE are mostly used in both location and strategy problems, whereas PROMETHEE is mostly preferred in identifying optimal waste management alternative strategies. Apart from this, it was also found that the concept of sustainable waste management is gaining importance in recent compromising models.

Huang et al. (2011) reviewed past studies in the field of multi-criteria decision-making in environmental science, conducted from 1990 to 2010. The study showed that the number of MCDA papers published in the environmental field has grown significantly during these two decades. A total of 312 papers were reviewed and it was found that AHP is the most commonly used MCDA technique. AHP/ANP was used in 48% of the papers followed by MAUT (16%) and Outranking methods (13%). It was also observed that AHP is widely used, at 80%, in spatial/GIS papers. However, in air quality/emissions studies, PROMETHEE is used more widely than AHP.

Similar study was conducted by Soltani et al. (2015) in which applications of MCDA in solving MSWM problems specifically were reviewed. A total of 68 studies were reviewed to analyze the trend in MSWM problems with multiple stakeholders. It was found that 38% of reviewed studies involved multiple stakeholders in decision-making process. Stakeholders were involved to assign criteria weights in majority of the studies while in few studies only stakeholders evaluated alternatives on their own. Most of the studies combined various MCDA methods with other popular decision-making tools. AHP and Graphical Information System (GIS) is one of the most popular combinations used in the reviewed papers. This study also showed that AHP (65%) is the dominant technique used in solving MSWM problems while PROMETHEE is an emerging method.

MCDA has been applied to address different types of solid waste management problems in urban as well as rural areas. Since the amount of waste generated in urban areas is large it requires a robust waste management strategy that can lead to safe disposal of solid waste. In the study carried out by Madadian et al. (2013), AHP method has been applied to select the best urban waste management strategy for Tabriz city in Iran. Four waste management strategies comprised of several solid waste treatment practices such as Source Separation (SS), Biological and Mechanical Treatment (BMT), Refused Derived Fuel (RDF), Incineration and Landfilling were evaluated based on eight criteria. The findings of the research showed that the strategy comprising SS, Compost production, BMT, RDF, and Lanfilling is the best one for urban waste management. Antonopoulos et al. (2014) examined three treatment alternatives viz. mechanical–biological aerobic treatment without RDF energy recovery, mechanical–biological anaerobic treatment, and incineration with energy recovery, in the capacity range of 70–90 kT, for solid waste treatment of a medium-sized town using AHP. The alternatives were compared based on their environmental, social, and economic performance and it was found that for such an area Incineration with energy recovery would be the most suitable option. Jovanovic et al. (2016) applied SAW and TOPSIS methods to choose the optimal municipal solid waste (MSW) management system for Kragujevac city in Republic of Serbia.

Due to growing health and environmental concerns, it has become essential to treat the solid waste scientifically in rural areas as well. It is crucial to choose the most appropriate treatment method depending on the local conditions of the village. MCDA has the advantage of involving several qualitative and quantitative factors in the assessment process which guides the selection of a particular treatment method. This has been highlighted in the study conducted by Alfons and Padmi (2018). In the study, a multi-criteria approach has been adopted for selecting the most solid waste management approach for rural areas in Indonesia. A four-level AHP hierarchy was modeled comprising of a goal, five general criteria, 20 sub-criteria, and three alternatives. The results highlighted the importance of integrated solid waste management in rural areas as integrated treatment facility initiated by household-scale waste handlings was reported to be the most optimal solid waste management concept.

One of the key features of MCDA is that it can be combined with other decision-making systems such as Life Cycle Assessment (LCA) or with some spatial analysis tool such as GIS. One of the shortcomings of LCA is that it does not take into account the economic and social factors. Kermani et al. (2014) highlighted this shortcoming of LCA and combined it with TOPSIS to find out the optimum urban waste management system for a city generating 1000 Tons/day of waste having high organic content. Aguilar et al. (2018) in their study presented a multi-criteria-based methodology for the emplacement of solid waste management infrastructure with the help of spatial analysis tools available in the GIS software. The study highlighted the use of multi-criteria evaluation technique AHP along with GIS, which helped in taking into account several criteria while reducing time and cost in decision-making. Jaiswal et al. (2018) carried out a suitability analysis for waste disposal site selection for a urban area using geospatial multi-criteria decision-making. GIS software along with AHP based Weighted Linear Combination and TOPSIS was used which generated sophisticated spatial outputs which were quite accurate, practical as well as visually appealing to the decision-makers. It was mentioned that such types of scientific approaches lead to more efficient planning.

Regional features play an important role in the decision-making process of solid waste management problems. These features vary from country to country and also from region to region within a country. Therefore by using the regional features in establishing the criteria for assessment of alternatives, this study highlights the application of MCDA to find most suitable solid waste treatment method for a rural area.

3 Materials and Methodology

3.1 Problem Definition

In this study three most commonly used solid waste treatment methods sought to be feasible at rural level viz. Anaerobic Digestion (AD), Vermicomposting (VC), and Windrow Composting (WC) are compared and ranked using Analytic Hierarchy Process (AHP) since it is one of the simplest and most widely used MCDA techniques. The alternatives are evaluated against ten criteria to find the final priorities. In AHP, the final priorities of alternatives can be determined by adopting two different modes: Distributive mode and Ideal mode. In this study also, the final priorities are determined using both the modes. A sensitivity analysis has been done in the end to check the robustness of the results obtained from the decision-making process. The methodology adopted for the study is shown in Fig. 1.

3.2 Study Area

Palsoli village (19.3639 °N, 73.2773 °E), located in Shahapur Tehsil of Thane district in Maharashtra is selected as the study area. It is approximately situated 30 km away from sub-district headquarters of Shahpur and about 70 km away from district headquarter. The nearest railway station is Vasind. It is about 5.4 km away from this village. The village location is shown in Fig. 2. Several site visits were done to know about the existing solid waste management practices in the village. From the visits, it was found out that there was no proper system of solid waste collection, transportation, and disposal in the village. The solid waste was neither treated at individual level nor at village level. People were either simply dumping or burning the solid waste. Therefore this study had been undertaken to provide a suitable solid

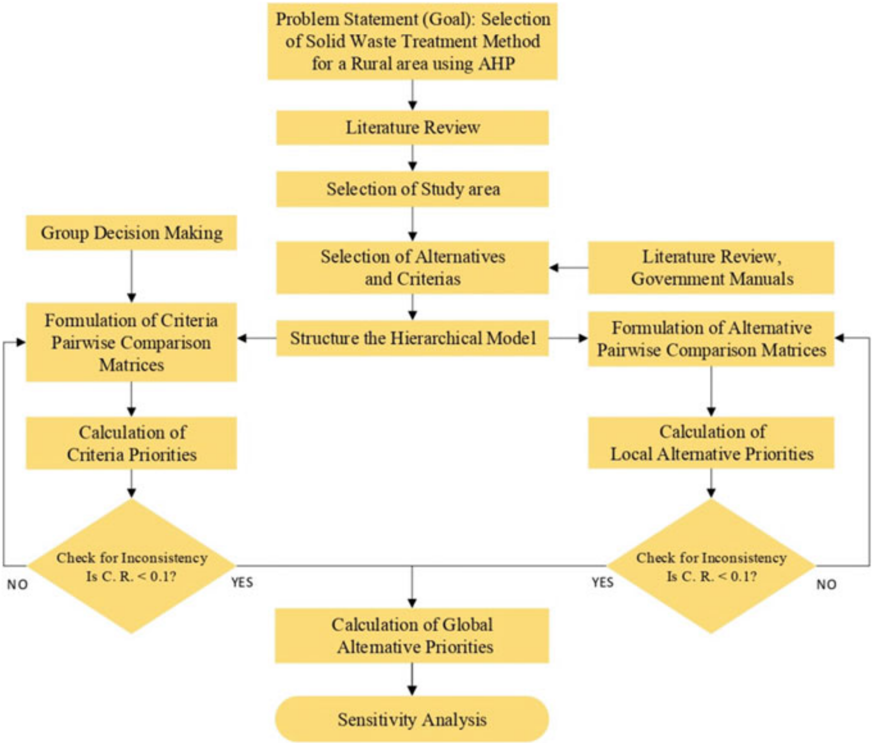


Fig. 1 Study methodology flowchart

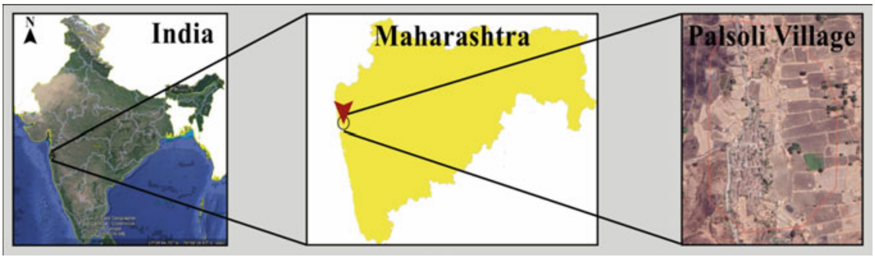


Fig. 2 Palsoli village. *Source* Google Earth

waste treatment method for the village which will help the local authorities to develop and implement a sustainable solid waste management system in the village.

3.3 About Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process is a theory of relative measurement which was developed by Saaty during 1971–75 (Saaty 1987). It is a comprehensive framework which is designed to make multi-objective, multi-criterion, and multi-actor decisions involving finite number of alternatives (Harker and Vargas 1987). It reduces a multi-dimensional problem into a one-dimensional one and determines decisions by a vector of priorities which gives an ordering of the different possible outcomes (Saaty 2006). There are three major concepts behind AHP: analytic, hierarchy, and process, as described by Harker (1989). Analytics refers to the use of numbers and mathematical/logical reasoning involved in the AHP; Hierarchy refers to the structuring of decision problems into levels based on one's understanding of the problem. By breaking the problem into various levels, the decision-maker can easily focus on smaller sets of decisions, and the Process term signifies the natural process of decision-making which involves decision-makers' meetings, debating, revision of priorities, etc. AHP is based on a set of axioms that provide the theoretical basis for the method. These axioms are given by Saaty and Kułakowski (2016) and are briefly described below:

- **Axiom 1**: Reciprocal Judgments—The pairwise comparison matrix is formed based on this axiom. As per this axiom, if an element of a comparison matrix (A) belonging to ith row and jth column is given as a_{ij} then the element belonging to jth row and ith column a_{ji} is given as, $a_{ji} = 1/a_{ij}$. This results in the formation of a positive reciprocal matrix.
- **Axiom 2**: Homogenous Elements—According to this axiom elements present in a particular level of hierarchy must be comparable. Infinite preferences are not allowed when comparing alternatives or criteria.
- **Axiom 3**: Hierarchic or feedback dependence structure—This axiom sets the basis for the formulation of a decision problem into a hierarchy. A set of elements in a particular level are to be compared with respect to an element in the immediate next higher level.
- **Axiom 4**: Rank order expectations—All the criteria and alternatives which are significant in solving the decision problem must be included in the hierarchy. Addition or deletion of any criteria or alternative should be avoided as this could give different order of ranking.

Due to its ability to solve a complex decision-making problem hierarchically, and quantify intangible criteria, AHP is one of the most widely used MCDA methods and has been used extensively where the evaluation of alternatives is mostly subjective (Tarmudi et al. 2010; Emrouznejad and Marra 2017). The steps involved in AHP as given by Saaty (1994) are enlisted below:

- **Step 1**: Problem Definition.
- **Step 2**: Structure the decision problem into a hierarchical model by establishing goals, criteria, and alternatives and showing their relationships.
- **Step 3**: Formulate pairwise comparison matrices and check for consistency ratio.

- **Step 4**: Determine criteria weights and local alternative weights.
- **Step 5**: Synthesize these results to determine global alternative weights and obtain the ranking of alternatives.
- **Step 6**: Perform sensitivity analysis.

The problem definition step has already been covered in Sect. 3.1. In the subsequent sections, the above steps have been described briefly and applied to the case study.

3.4 Structure the Decision Problem into a Hierarchical Model by Establishing Goals, Alternatives, and Criteria

The hierarchy disintegrates the decision problem into various levels with homogenous elements such as goal, criteria, sub-criteria, and alternatives occupying a specific level in the model. Elements that have a global character, i.e., goal, can be placed at the top level of the hierarchy, followed by a criterion level, then a sub-criteria level (if any), and finally the alternatives at the bottom. The purpose of forming this hierarchy is twofold: (i) It gives overall view of the relationships between these elements and (ii) It helps the decision-maker check whether the issues in each level are of the same order of magnitude, so that comparison can be made only between homogenous elements (Saaty 1990).

Selection of Alternatives

A wide range of methods is available to treat municipal solid waste with each method having its own merits and demerits. Out of the feasible options available for rural areas, three methods viz. Anaerobic Digestion (AD), Vermicomposting (VC), and Windrow Composting (WC) are selected as alternatives for this study. The alternatives are briefly described in the subsequent paragraphs:

Anaerobic Digestion/Biomethanatiom

Anaerobic digestion, also known as Biomethanation, consists of anaerobic digestion of organic matter present in the solid waste by microorganisms that break down the biodegradable material in the absence of oxygen. In this method, there is considerable amount of volume and mass reduction of the input material. The decomposition of the waste mass by microbial activity results in the generation of an odorless and colorless biogas which mainly comprises 55–60% methane and 30–40% carbon dioxide (CO_2). The biogas has high energy value and hence can be used either for cooking/heating applications or for the generation of electricity. The nutrient-rich sludge obtained from anaerobic digestion can be used as manure-based on its composition. Due to the high organic content of the rural solid waste, this method can be considered a viable option for solid waste treatment (Varma 2012; Gupta et al. 2015; Sharholy et al. 2008; Government of India 2016).

Vermicomposting

Vermicomposting is the process of decomposing the biodegradable fraction of solid waste with the help of particular species of earthworms. The end result of the process is the production of vermicompost which is a nutrient-rich, natural fertilizer and soil conditioner. The earthworm species that are efficient in conversion of waste are Pheretima elongate, Eisenia fetida, Lampito mauritii, Perionyx excavatus, Lumbricus rubellus, Eudrilus eugeniae, etc. When compared with normal composting, vermicompost is richer in plant nutrients and has better market price. Along with this, sale of worms can also bring additional revenue. Vermicomposting is typically suited for managing smaller waste quantities. Also the ideal feedstock for vermicomposting is vegetable market waste, kitchen and garden waste, cow dung and agricultural waste which make this technique suitable for rural areas (Varma 2012; Gupta et al. 2015; Sharholy et al. 2008; Government of India 2016).

Windrow Composting

Windrow composting process consists of placing the pre-sorted solid waste in long narrow piles called windrows. The windrows are turned on a regular basis for mixing of composting materials and enhancing the passive aeration process. The size, shape, and spacing of windrows depend on the equipment used for the turning operation. Since waste generated is not huge in rural areas and also due to financial constraints, manual labor can also be used for windrows in place of machinery. At the end of one composting cycle, the finished product is dark brown in color with an earthy smell, fragile, and rich in organic matter content and nutrients, which can be used as manure (Government of India 2016).

Selection of Criteria

The MCDA problem of solid waste treatment methods involves a set of finite number of criteria which govern the prioritization of the alternatives. These criteria are either quantitative or qualitative in nature. Quantitative criteria are objective criteria based on cardinal scales whereas qualitative criteria are subjective criteria based on ordinal scales. In case of subjective criteria, the performance of alternatives has been measured using a five point rating scale of worst, poor, good, very good, and best corresponding to numerical values of 1, 2, 3, 4, and five respectively. In MCDM criteria are also classified as Benefit criteria or Cost Criteria. Benefit criteria are the ones which are to be maximized, i.e., more the performance value of an alternative for the criteria, more will be its priority whereas a cost criteria are the ones which are to be minimized, i.e., lesser the performance value of an alternative for the criteria, more will be its priority. Based on the literature review, ten criteria have been selected which are broadly categorized into four groups: economic, technical, environmental, and social.

Economic criteria represent the cost aspect of the treatment methods. The economic criteria considered in this study are construction cost and annual operation cost. Construction cost is the cost incurred in the construction of the main treatment plant. Annual operation cost includes the salaries of employees, electricity charges, etc. Technical criteria represent the technical information about the treatment methods. Three technical criteria selected for this study are Land requirement, Cycle Time, and End product benefits. Land requirement is the area of land required for the main treatment plant alone. Cycle Time is the time required for conversion of solid waste into a beneficial end product. End product benefits indicate the types of beneficial products obtained after the completion of cycle time of the treatment method. Environmental criteria represent the threats and harmful effects of a treatment method on the environment and on the health of local people. The environmental criteria considered in this study are Fly nuisance, Odor problems, and Leachate problems. Fly nuisance is the aesthetic trouble caused because of presence of birds, flies, etc. over the waste. Odor problem is one of the serious threats to human health since in certain treatment methods various types of gases are evolved which may cause several diseases. Leachate is the byproduct of solid waste treatment which contaminates the soil as well as the groundwater thereby degrading the environment. Social criteria include the attitude of people toward a particular treatment method. Public acceptance and Employability are the two social criteria selected for this study. Public acceptance indicates the interest of local people in the acceptance of a treatment method. Employability indicated the number of job opportunities created due to the adoption of a treatment method. Table 1 gives information about the criteria used in this study. The technical specifications or the performance values of all the alternatives with respect to each criteria are summarized in Table 2.

The hierarchy model for selecting the best solid waste treatment method is shown in Fig. 3. The model comprises three levels with the goal of the decision-making problem at the top level, followed by the 10 criteria at the intermediate level, and finally the three alternatives at the bottom-most level. All the three alternatives are linked to each criteria and all the 10 criteria are linked to the goal of the problem.

Table 1 Criteria information

General criteria	Specific criteria	Notation	Units/scale	Benefit (B)/cost (C)
Economic	Construction cost	C1	INR	C
	Operation cost	C2	INR	C
Technical	Land requirement	C3	sq. m	C
	Cycle time	C4	Days	C
	End product benefits	C5	5 point scale	B
Environmental	Fly nuisance	C6	5 point scale	C
	Odor problem	C7	5 point scale	C
	Leachate problem	C8	5 point scale	C
Social	Public acceptance	C9	5 point scale	B
	Employability	C10	5 point scale	B

Table 2 Technical specifications of alternatives with respect to each criteria

Alternatives / Criteria	Anaerobic digestion (AD)	Vermicomposting (VC)	Windrow composting (WC)
C1	22,09,000[a]	26,83,230[a]	25,98,030[a]
C2	3,88,080[b]	4,33,705[b]	3,88,080[b]
C3	265	654	688
C4	40	75	50
C5	Best (5)	Good (3)	Good (3)
C6	Best (5)	Best (5)	Worst (1)
C7	Poor (2)	Best (5)	Poor (2)
C8	Poor (2)	Best (5)	Good (3)
C9	Poor (2)	Best (5)	Worst (1)
C10	Good (3)	Good (3)	Good (3)

Note
[a]Construction cost is calculated for treatment plant of capacity 0.5TPD and has been calculated using State Schedule of Rates 2019–20, PWD, Government of Maharashtra (2019)
[b]The salaries for employees have been taken from https://paycheck.in and price of earthworms have been taken from https://www.indiamart.com/. Minimum and Wage (2020), Eathworms and for Composting (2020)

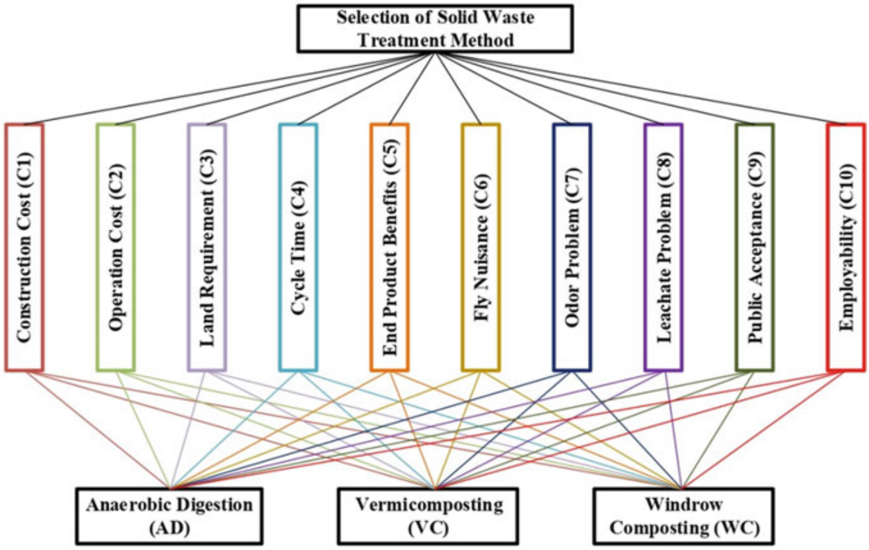


Fig. 3 AHP hierarchy for selection of SWT method

3.5 Formulation of Pairwise Comparison Matrices

Making pairwise comparison lies at the heart of AHP. The manner in which elements of different levels are compared is based on the principle as given by Saaty (2008): The elements of lower level are compared with respect to each element in its immediate upper level only. This indicates that in a three-level hierarchy, all the alternatives lying in the bottom-most level will be compared with respect to each criteria lying in the immediate level above. Similarly, all the criteria will be compared with respect to the goal of the problem. A judgment or comparison is the numerical value expressing relationship between two elements that share a common judgment-making aspect. These pairwise comparisons are made with the help of a fundamental scale of absolute numbers known as Saaty's scale given by Saaty (2008) which is shown in Table 3. Each judgment reflects the importance of one element with respect to another element with which it is compared (Fig. 4).

The judgments can be made either by an individual decision-maker or group of decision-makers. The set of pairwise judgments is represented in a square matrix called the Pairwise Comparison Matrix or Judgmental Matrix (A). The order of matrix A, represented as n, will be equal to the number of elements present in a level

Table 3 Saaty's fundamental scale of absolute numbers (Saaty 2008)

Intensity of importance	Explanation
1	Element *A* and *B* are of equal importance
3	Element *A* is more moderately important than *B*
5	Element *A* is strong important than *B*
7	Element *A* is very strong or demonstrated more important than *B*
9	Element *A* is extremely more important than *B*
2 or 4 or 6 or 8	Indicates intermediate importance between 1 and 3, 3 and 5, 5 and 7, 7 and 9, i.e., Weak or slight, Moderate plus, Strong plus, and Very, very strong importance, respectively
1.1–1.9	If the importance of elements is very close to each other

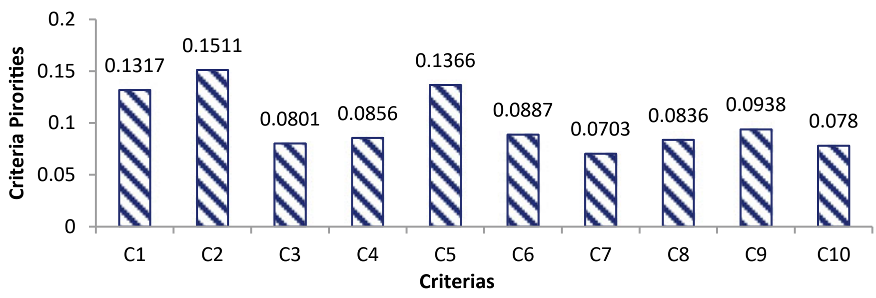


Fig. 4 Graph of criteria weights

of hierarchy. The judgmental value of ith row and jth column is denoted as a_{ij}. The entire matrix A is filled based on axiom 1. Hence the total number of comparisons to be made to fill the judgmental matrix is $\{[n \times (n - 1)]/2\}$.

Pairwise Comparison Matrix or Judgmental Matrix (A)

$$= \begin{bmatrix} a_{11} & \ldots\ldots & & a_{1n} \\ \vdots & \ddots & \cdots & \vdots \\ \vdots & \cdots & \ddots & \vdots \\ a_{n1} & \ldots\ldots & & a_{nn} \end{bmatrix}_{n \times n}$$

Since the case study involves three alternatives and 10 criteria, 10 judgmental matrices would be formulated with alternatives as to the elements for comparison with respect to each criteria; and one judgmental matrix would be formulated with criteria as the elements for comparison with respect to the goal. Hence a total of 11 judgmental matrices will be formed. In the study, the criteria judgmental matrix and hence criteria weights have been obtained using group judgment-making process. A group of 10 decision-makers was formed comprising of academia professionals, industry experts, and local administrative heads. The pairwise comparisons were collected and aggregated through AHP Online System (AHP-OS) (Goepel 2018). However, since filling up these matrices is a time-consuming task, the alternative judgmental matrices were filled by authors alone based on the technical specifications.

3.6 Calculation of Criteria and Local Alternative Weights

Once the pairwise comparison matrices are formed, the next step is to calculate the priorities (weights) of criteria with respect to goal and alternative weights with respect to each criterion, also called the local alternative weights. This leads to the formation of respective priority vectors. The priority vectors are found using column normalization method (Saaty and Hu 1998). First, normalized values (r_{ij}) of all the performance values in a matrix are calculated using Eq. (1) and then simple arithmetic mean is taken along the row using Eq. (2) to get the priority (w_i).

$$r_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{1}$$

$$w_i = \frac{\sum_{j=1}^{n} r_{ij}}{n} \tag{2}$$

where n is the order of the square matrix; i is the row number; and j is the column number. The criteria priority vector is denoted as $W = (w_1, w_2, \ldots, w_p)^T$, where w_1, w_2, …, w_p are the criteria priorities or weights and p is the total number of criteria.

The local priority vector of alternatives for a criteria C_q is given as $L_q = (L_{1q}, L_{2q}, \ldots, L_{mq})^T$, where $L_{1q}, L_{2q}, \ldots, L_{mq}$ are the local alternative priorities or weights, m is the total number of alternatives and q is the criteria number. Hence for p number of criteria there will be p number of local priority vectors formed. The local alternative priorities in the priority vector can be represented in two modes: (i) Distributive mode and (ii) Ideal mode. In distributive mode, the priorities of alternatives for each criterion are kept in the same form as obtained after using Eqs. (1) and (2). In Ideal mode, the priorities of the alternatives for each criterion are divided by the largest value among them. The Ideal mode eliminates the problem of rank reversal which exists in distributive mode, which may occur due to addition or deletion of an alternative (Saaty and Hu 1998). In this study, the local alternative priorities have been used in both the modes to determine the global alternative priorities.

3.6.1 Check for Consistency

Once the priority vectors are determined for respective pairwise comparison matrices, a crucial step in AHP is to check the consistency of judgmental matrix. Consistency is the correctness of pairwise comparisons. A matrix is said to be consistent when $a_{ik} = a_{ij} \times a_{jk}$ for i, j, and $k = 1, 2, \ldots, n$. However, inconsistency is inevitable in judgments, especially when number of elements to be compared is more. In AHP an inconsistency of lower order of magnitude of 10% is considered a tolerable error. Saaty proposed an eigenvalue approach to measuring the level of inconsistency in a pairwise comparison matrix. According to this approach, a consistent pairwise comparison matrix A of order n will have its principal eigenvalue equal to the order of matrix n. However, when the matrix is inconsistent, the principal eigenvalue will always be more than equal to n. This principle eigenvalue is denoted as $\lambda_{\max}$. The difference between $\lambda_{\max}$ and n measures the deviation of the judgments from the consistent approximation. This difference is used in the formation of a Consistency Ratio (C.R.) which indicates level of inconsistency of the matrix. The Consistency Ratio (C.R.) is given by:

$$C.R. = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{3}$$

where CI is the Consistency Index and RI is the average Random consistency Index. The Consistency Index (CI) is given by $(\lambda_{\max} - n)/(n - 1)$. The average Random Consistency Index (RI) value is obtained from Table 4 based on the order of the matrix, as given by Saaty. The principal eigenvalue is obtained by solving the linear

Table 4 R. I. Values based on order of matrix (n) (Saaty 1994)

n	1	2	3	4	5	6	7	8	9	10
R. I	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

algebra problem of $A \times w = \lambda_{\max} \times w$, where A is the judgment matrix and w is the respective priority vector. The value of $\lambda_{\max}$ is calculated as:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{A \times w}{w_i} \tag{4}$$

where w_i is the criteria weight. The value of Consistency Ratio (C. R.) must be less than 10%. If this value is not less than 10% then the decision-maker needs to revise the judgments and find the priority vectors again.

3.7 Calculation of Global Alternative Weights

After the inconsistencies in criteria priority vectors and local alternative priority vectors are found to be within permissible limits, the local alternative priority vectors are synthesized to find the global alternative priority vector by combining all the local alternative weights in one matrix and multiplying that matrix with the criteria weights. The global alternative priority vector is represented as $G = (g_1, g_2, \ldots, g_m)^{\mathrm{T}}$, where $g_1, g_2, \ldots, g_m$ is the global alternative weights. The global alternative priority vector is determined as follows:

$$G = \begin{bmatrix} g_1 \\ g_2 \\ \cdots \\ g_m \end{bmatrix}_{m\times 1} = \begin{bmatrix} L_{11} & L_{12} & \cdots & L_{1p} \\ L_{21} & L_{22} & \cdots & L_{2p} \\ \cdots & \cdots & \cdots & \cdots \\ L_{m1} & L_{m2} & \cdots & L_{mp} \end{bmatrix}_{m\times p} \times \begin{bmatrix} w_1 \\ w_2 \\ \cdots \\ w_p \end{bmatrix}_{p\times 1} \tag{5}$$

The ranking of alternatives is obtained based on the global alternative weights. The alternatives are ranked in the decreasing order of their weights. The alternative having the highest weight is ranked first and is considered the most suitable solution while the alternative having the lowest weight is be ranked last and is considered the least suitable solution.

3.8 Sensitivity Analysis

According to Dantzig (1963), “Sensitivity analysis is a fundamental concept in the effective use and implementation of quantitative decision models, whose purpose is to assess the stability of an optimal solution under changes in the parameters”. The goal of sensitivity analysis is to determine the robustness of the results obtained through decision-making process by examining the effect on the ranking of the alternatives by modifying the criteria weights (Babalola 2015). The advantage of sensitivity analysis can hardly be overlooked in applications of MCDM techniques to real-life problems as it helps the decision-maker to effectively focus more on the sensitive parts of a given MCDM problem (Triantaphyllou and Sánchez 1997). In this study, sensitivity analysis is carried out by taking different scenarios into consideration. In each scenario, the criteria weights are varied to check for variation in the final rankings of the alternatives. Based on the ranking of the criteria priorities obtained from the group decision-making results, six scenarios have been established which are described below:

- **Scenario 1**: The topmost criteria have been assigned criteria weight of 1.000 and all remaining criteria have been assigned criteria weight of 0.000.
- **Scenario 2**: The top two criteria have been assigned criteria weight of 0.500 and all remaining criteria have been assigned criteria weight 0.000.
- **Scenario 3**: The top four criteria have been assigned criteria weight of 0.250 and all remaining criteria have been assigned criteria weight of 0.000.
- **Scenario 4**: The top five criteria have been assigned criteria weight of 0.200 and all remaining criteria have been assigned criteria weight of 0.000.
- **Scenario 5**: The top eight criteria have been assigned criteria weight of 0.125 and all remaining criteria have been assigned criteria weight of 0.000.
- **Scenario 6**: All criteria have been assigned equal criteria weight of 0.100.

4 Results and Discussions

4.1 Criteria Priorities and Local Alternative Priorities

The result of group decision-making process for the calculation of criteria weights is shown in Table 5. The graphical representation of criteria weights is shown in Fig. 5.

The economic criterion of Operation Cost (C2) has been considered the most important criteria by the group in the selection of most suitable SWT method and has the highest priority of 0.1511. It is followed by End Product Benefits (C5) and Construction Cost (C1) having priorities of 0.1366 and 0.1317, respectively. On the other hand, Odor Problem (C7), an environmental criterion, has the least priority of 0.0703. However, this is not the case with other environmental criteria of Fly nuisance (C6). It has a priority of 0.0887 and ranks fifth in the list whereas Leachate Problem (C8) ranks seventh in the entire list. Public Acceptance (C9) which is a social criterion has been considered the fourth most important criteria in determination of alternative priorities whereas Employability (C10) has been ranked last but one in

Table 5 Criteria priorities

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Priorities	0.1317	0.1511	0.0801	0.0856	0.1366	0.0887	0.0703	0.0836	0.0938	0.078

C. R. = 0.0271

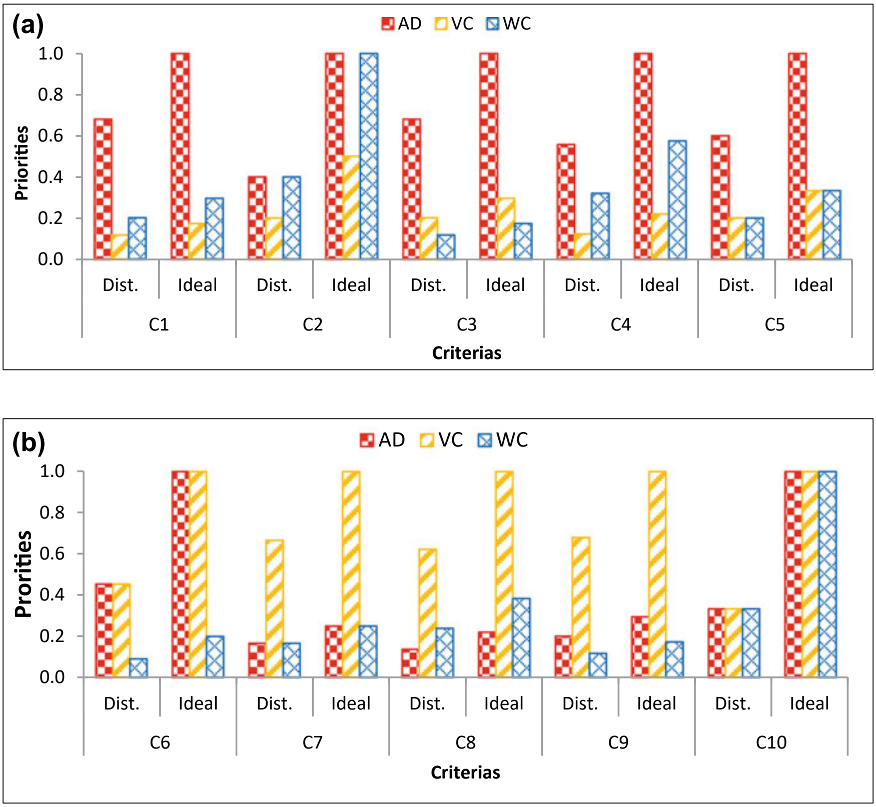


Fig. 5 **a** Comparison graph of Local alternative priorities in distributive and ideal mode for criteria C1 to C5. **b** Comparison graph of local alternative priorities in distributive and ideal mode for criteria C6 to C10

the list. Cycle Time (C4) and Land Requirement (C3), both technical criteria, have been considered of moderate importance as they have been ranked sixth and eighth on the list. The Consistency Ratio (C. R.) of the pairwise comparisons of entire group is 0.0271 which is less than 0.1 and hence these criteria priorities have been used to find the final rankings of the alternatives.

The pairwise comparison matrices for alternatives with respect to each criterion are shown in Tables 6 and 7. All the comparison matrices have C. R. less than 0.1 which indicates that the inconsistencies are within the acceptable limits.

Tables 8 and 9 show the local alternative priorities with respect to each criterion in distributive mode and ideal mode, respectively. Based on technical specification of alternatives with respect to each criterion, the preferences of local alternative priorities are also obtained in the same manner. For all the cost criteria, alternatives having minimum performance value have the highest priority whereas, for all the benefit criteria, alternatives having maximum performance value have the highest priority. The ideal mode gives a much better understanding of the preferences when

Table 6 Pairwise comparison of alternatives with respect to criteria C1 to C5

Ct	C1			C2			C3			C4			C5		
Alt	AD	VC	WC	AD	VC	WC	AD	VC	WC	AD	VC	WC	AD	VC	WC
AD	1	5	4	1	2	1	1	4	5	1	4	2	1	3	3
VC	1/5	1	1/2	1/2	1	1/2	1/4	1	2	1/4	1	1/3	1/3	1	1
WC	1/4	2	1	1	2	1	1/5	1/2	1	1/2	3	1	1/3	1	1
	C.R. = 0.0238			C.R. = 0.0000			C.R. = 0.0238			C.R. = 0.0176			C.R. = 0.0000		

Table 7 Pairwise comparison of alternatives with respect to criteria C6 to C10

Ct	C6			C7			C8			C9			C10		
Alt	AD	VC	WC	AD	VC	WC	AD	VC	WC	AD	VC	WC	AD	VC	WC
AD	1	1	5	1	1/4	1	1	1/4	1/2	1	1/4	2	1	1	1
VC	1	1	5	4	1	4	4	1	3	4	1	5	1	1	1
WC	1/5	1/5	1	1	1/4	1	2	1/3	1	1/2	1/5	1	1	1	1
	C.R. = 0.0000			C.R. = 0.0000			C.R. = 0.0176			C.R. = 0.0238			C.R. = 0.0000		

Table 8 Local alternative priorities with respect to each criterion in distributive mode

Crit Alt	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
AD	0.6806	0.4000	0.6806	0.5571	0.6000	0.4545	0.1667	0.1373	0.2014	0.3333
VC	0.1179	0.2000	0.2014	0.1226	0.2000	0.4545	0.6667	0.6232	0.6806	0.3333
WC	0.2014	0.4000	0.1179	0.3202	0.2000	0.0909	0.1667	0.2395	0.1179	0.3333

Table 9 Local alternative priorities with respect to each criterion in ideal mode

Crit Alt	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
AD	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.2500	0.2203	0.2959	1.0000
VC	0.1733	0.5000	0.2959	0.2201	0.3333	1.0000	1.0000	1.0000	1.0000	1.0000
WC	0.2959	1.0000	0.1733	0.5748	0.3333	0.2000	0.2500	0.3843	0.1733	1.0000

compared to distributive mode since the best value will always have priority 1 and the subsequent values will have priorities less than 1. Figure 5a, b shows the comparison of local alternative priorities in Distributive and Ideal mode for Criteria C1 to C5 and Criteria C6 to C10, respectively. Since criteria C1 is cost criteria and Anaerobic Digestion (AD) has the least cost of construction it has the highest priority with respect to criteria C1 whereas Vermicomposting (VC) has the highest cost of construction has the least priority with respect to criteria C1. Anaerobic Digestion (AD) has the highest priority for criteria C2, C3, C4, and C6. For other cost criteria

Table 10 Global Alternative Priorities and Preference for both the modes

Mode	Alternatives			Preference
	AD	VC	WC	
Distributive	0.4427	0.3288	0.2280	AC ≻ VC ≻ WC
Ideal	1.0000	0.7367	0.5645	AC ≻ VC ≻ WC

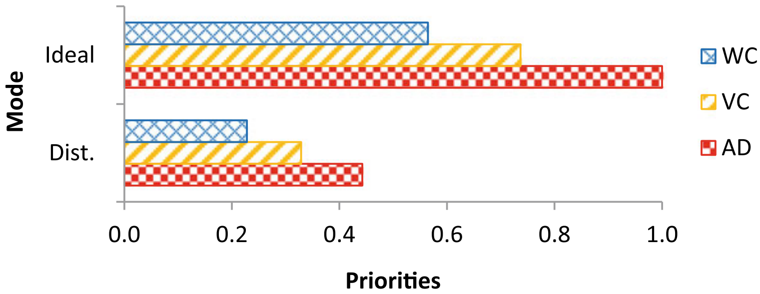


Fig. 6 Comparison graph of global alternative priorities

C7 and C8, vermicomposting has the least performance value and hence has the highest priority. For Benefit criteria C5, since Anaerobic Digestion (AD) has the highest performance value, it also has the highest priority. Similarly for criteria C9, Vermicomposting (VC) has the highest priority. Since the performance value of each alternative is same for C10, all the alternatives have same priority.

4.2 Global Alternative Priorities

The global alternative priorities obtained after multiplying the criteria weights with local alternative priorities are shown in Table 10. The priorities have been found separately for both distributive mode and ideal mode. In both the modes, Anaerobic Digestion (AD) has the highest priority while Windrow composting (WC) has the least priority. Vermicomposting (VC) ranks second in both the modes. Figure 6 shows the global alternative priorities as obtained in both the modes.

4.3 Sensitivity Analysis

To check the robustness of the results obtained using AHP, a sensitivity analysis has been performed by adopting a scenario-based approach. Six different scenarios have been constituted in which the criteria weights have been varied to check the variation in the final preferences of the alternatives. The assignment of priorities to criteria in each scenario is done as per the explanation in Sect. 3.8. Table 11 shows criteria priorities for different scenarios. The result of sensitivity analysis for distributive and ideal mode is shown in Fig. 7a, b and is explained in subsequent paragraphs.

The final preference of alternatives is same for both the modes for each scenario. Also for each scenario in both the modes, Anaerobic Digestion (AD) has the highest priority which is the same as for the group decision-making process. Only for scenarios S1 and S2, the final preference of Vermicomposting (VC) and Windrow Composting (WC) is different from the final preference of group decision-making process. For both these scenarios, WC has more preference than VC. The reason for such variation is the assignment of criteria weights of 1.000 and 0.500 to criteria C2

Table 11 Criteria weights for different scenarios

Scenario / Criteria	Group criteria weights	S1	S2	S3	S4	S5	S6
C1	0.1317	0.000	0.000	0.250	0.200	0.125	0.100
C2	0.1511	1.000	0.500	0.250	0.200	0.125	0.100
C3	0.0801	0.000	0.000	0.000	0.000	0.125	0.100
C4	0.0856	0.000	0.000	0.000	0.000	0.125	0.100
C5	0.1366	0.000	0.500	0.250	0.200	0.125	0.100
C6	0.0887	0.000	0.000	0.000	0.200	0.125	0.100
C7	0.0703	0.000	0.000	0.000	0.000	0.000	0.100
C8	0.0836	0.000	0.000	0.000	0.000	0.125	0.100
C9	0.0938	0.000	0.000	0.250	0.200	0.125	0.100
C10	0.0780	0.000	0.000	0.000	0.000	0.000	0.100

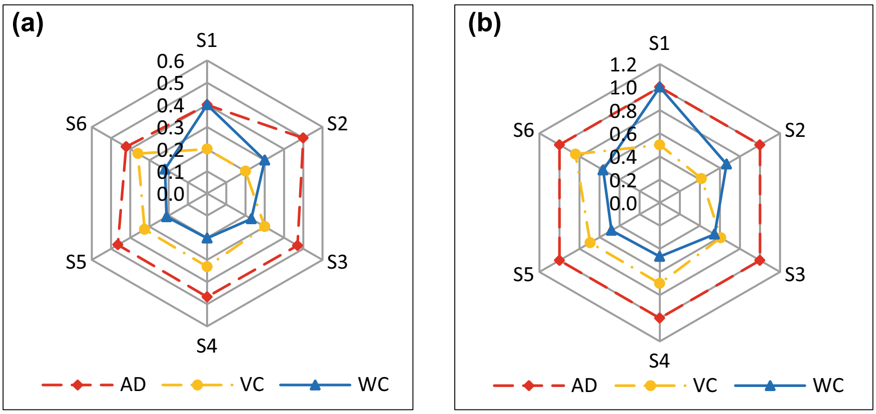


Fig. 7 **a**, **b** Global alternative priorities for different scenarios in distributive mode and ideal mode, respectively

for which the performance value of WC is better than VC. But as the number of non-zero criteria increased in remaining four scenarios S3, S4, S5, and S6 the preference of alternatives appeared exactly same as that for the group decision-making process. Hence the robustness of the decision-making process undertaken is well verified.

5 Conclusion

The problem of solid waste management is increasing day by day in the rural areas due to the growing consumerism, changing lifestyles, etc. Due to this, the need for an effective solid waste management (SWM) system in rural areas can hardly be overlooked. It is crucial to select the most suitable solid waste treatment method for efficient functioning of SWM system. But due to the availability of large number of treatment methods and the involvement of large number of criteria in selecting the most suitable option for a particular area, the decision-making problem becomes challenging. In recent decades, MCDM has emerged as a convenient tool to overcome such challenges in decision-making process. Many MCDM techniques have been developed with each one having its own merits and demerits. AHP is one of the MCDM techniques which is simple to use and hence has been widely used to solve decision-making problems across disciplines including environmental problems. This study highlighted the application of AHP in the selection of the most suitable solid waste treatment method in the context of rural areas. From the application of AHP it has been found that Operation Cost is the most important criterion in the selection of alternatives and the most suitable method for the study area among the options selected is Anaerobic Digestion. Vermicomposting emerged as the second-most suitable option followed by Windrow Composting. A sensitivity analysis has been performed to check the robustness of the decision-making process. From the analysis, it has been found that the most suitable solid waste treatment method for the study area is Anaerobic Digestion only even after the alteration of criteria weights. Hence the robustness of the decision-making process is well verified.

Acknowledgements The authors express their gratitude to TEQIP III of Sardar Patel College of Engineering for providing all the necessary funds during the entire duration of this study.

References

Achillas C, Moussiopoulos N, Karagiannidis A, Banias G, Perkoulidis G (2013) The use of multi-criteria decision analysis to tackle waste management problems: a literature review. Waste Manage Res 31(2):115–129. https://doi.org/10.1177/0734242X12470203

Annepu RK (2012) Sustainable solid waste management in India. M.Sc. thesis. Earth Engineering Center, Columbia University, New York

Alessio I, Nemery P (2013) Multi-criteria decision analysis: methods and software, 1st edn. Wiley, West Sussex

Antonopoulos IS, Perkoulidis G, Logothetis D, Karkanias C (2014) Ranking municipal solid waste treatment alternatives considering sustainability criteria using the analytical hierarchical process tool. Resour Conserv Recycl 86:149–159. https://doi.org/10.1016/j.resconrec.2014.03.002
Alfons AB, Padmi T (2018) Multi-criteria analysis for selecting solid waste management concept case study: rural areas in Sentani Lake Region, Jayapura. Indonesian J Urban Environ Technol 2(1):88–101. https://doi.org/10.25105/urbanenvirotech.v2i1.3557
Araiza Aguilar JA, Nájera Aguilar HA, Gutiérrez Hernandez RF, Rojas Valencia MN (2018) Emplacement of solid waste management infrastructure for the Frailesca Region, Chiapas, México, using GIS tools. Egypt J Remote Sens Space Sci 21(3):391–399. https://doi.org/10.1016/j.ejrs.2018.01.004
Babalola MA (2015) A multi-criteria decision analysis of waste treatment options for food and biodegradable waste management in Japan. Environments 2(4):471–488. https://doi.org/10.3390/environments2040471
Bhavita S, Malek SS (2018) A recapitulation on exigency of smart villages in Indian ambience. Int J Adv Eng Res Dev 5(03):1–8. https://doi.org/10.21090/ijaerd.nace19
Bruno G, Genovese A (2018) Multi-criteria decision-making: advances in theory and applications—an introduction to the special issue. Soft Comput 22(22):7313–7314. https://doi.org/10.1007/s00500-018-3531-0
Census of India (2011) Provisional population totals. Office of the Registrar General and Census Commissioner, New Delhi. https://censusindia.gov.in/2011-prov-results/paper2/data_files/india/paper2_1.pdf
Central Public Health and Environmental Engineering Organisation (CPHEEO) (2016) Municipal solid waste management manual, part III. Ministry of Urban Development, Government of India, New Delhi. http://cpheeo.gov.in/upload/uploadfiles/files/Part3.pdf
Central Public Health and Environmental Engineering Organisation (CPHEEO) (2016) Municipal solid waste management manual, part I. Ministry of Urban Development, Government of India, New Delhi (2016). http://cpheeo.gov.in/upload/uploadfiles/files/Part1(1).pdf
Central Public Health and Environmental Engineering Organisation (CPHEEO) (2000) Manual on municipal solid waste management. Ministry of Urban Development, Government of India, New Delhi
Central Pollution Control Board (CPCB) (2016) Selection criteria for waste processing technologies. Ministry of Environment, Forest and Climate Change, Government of India, New Delhi. http://cpcb.nic.in/SW_treatment_Technologies.pdf
Central Public Health and Environmental Engineering Organization (CPHEEO) (2016) Municipal solid waste management manual, part II. Ministry of Urban Development, Government of India, New Delhi. http://cpheeo.gov.in/upload/uploadfiles/files/Part2.pdf
Dantzig GB (1963) Linear programming and extensions. RAND Corporation, Santa Monica, CA. https://www.rand.org/pubs/reports/R366.html
Emrouznejad A, Marra M (2017) The state of the art development of AHP (1979–2017): a literature review with a social network analysis. Int J Prod Res 55(22):6653–6675. https://doi.org/10.1080/00207543.2017.1334976
Goepel KD (2018) Implementation of an online software tool for the analytic hierarchy process (AHP-OS). Int J Anal Hierarchy Process 10(3):469–487. https://doi.org/10.13033/ijahp.v10i3.590
Government of India, Solid and liquid management in rural areas: a technical note. Department of Drinking Water Supply, Ministry of Rural Development, New Delhi. https://swachhbharatmission.gov.in/sbmcms/writereaddata/images/pdf/technical-notes-manuals/SLWM-in-Rural-Areas-Technical-Note.pdf
Guidelines for Swachh Bharat Mission (Gramin) (2018) Ministry of Drinking Water and Sanitation, Government of India, New Delhi. https://jalshakti-ddws.gov.in/sites/default/files/SBM(G)_Guidelines.pdf
Gupta N, Yadav KK, Kumar V (2015) A review on current status of municipal solid waste management in India. J Environ Sci 37:206–217. https://doi.org/10.1016/j.jes.2015.01.034

Harker PT, Vargas LG (1987) Theory of ratio scale estimation: Saaty's analytic hierarchy process. Manage Sci 33(1):1383–1403. https://doi.org/10.1287/mnsc.33.11.1383

Harker PT (1989) The art and science of decision making: the analytic hierarchy process. In: Golden BL, Wasil EA, Harker PT (eds) The analytic hierarchy process. Springer, Heidelberg, pp 3–36. https://doi.org/10.1007/978-3-642-50244-6_2

Huang IB, Keisler J, Linkov I (2011) Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends. Sci Total Environ 409(19):3578–3594. https://doi.org/10.1016/j.scitotenv.2011.06.022

Indiamart Live Eathworms for composting. https://www.indiamart.com/proddetail/vermiculture-earthworm-11265286812.html. Last Accessed 12 July 2020

Jaiswal AK, Satheesh TA, Pandey K, Kumar P, Saran S (2018) Geospatial multi-criteria decision based site suitability analysis for solid waste disposal using topsis algorithm. ISPRS Ann Photogramm Remote Sens Spatial Inf Sci 4(5):431–438. https://doi.org/10.5194/isprs-annals-IV-5-431-2018

Jovanovic S, Savic S, Jovicic N, Boskovic G, Djordjevic Z (2016) Using multi-criteria decision making for selection of the optimal strategy for municipal solid waste management. Waste Manage Res 34(9):884–895. https://doi.org/10.1177/0734242X16654753

Kaza S, Yao L, Bhada-Tata P, Van Woerden FV (2018) What a waste 2.0: a global snapshot of solid waste management to 2050. Urban Development Series. World Bank, Washington. https://doi.org/10.1596/978-1-4648-1329-0

Kermani M, Nouri J, Omrani GA, Arjmandi R (2014) Comparison of solid waste management scenarios based on life cycle analysis and multi-criteria decision making (case study: Isfahan City). Iran J Sci Technol (Sci) 38(3):257–64. https://doi.org/10.22099/ijsts.2014.2271

Kumar A, Sah B, Singh AR, Deng Y, He X, Kumar P, Bansal RC (2017) A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. Renew Sustain Energy Rev 69:596–609. https://doi.org/10.1016/j.rser.2016.11.191

Kiker GA, Bridges TS, Varghese A, Seager TP, Linkov I (2005) Application of multicriteria decision analysis in environmental decision making. Integr Environ Assess Manag 1(2):95–108. https://doi.org/10.1897/IEAM_2004a-015.1

Madadian E, Amiri L, Abdoli MA (2013) Application of analytic hierarchy process and multicriteria decision analysis on waste management: a case study in Iran. Environ Prog Sustain Energy 32(3):810–817. https://doi.org/10.1002/ep.11695

Maharashtra Gram Panchayat Minimum Wage. https://paycheck.in/salary/minimumwages/18640-maharashtra/18851-gram-panchayat. Last Accessed 12 July 2020

Mardani A, Jusoh A, Nor KMD, Khalifah Z, Zakwan N, Valipour A (2015) Multiple criteria decision-making techniques and their applications—a review of the literature from 2000 to 2014. Econo Res Ekonomska Istraživanja 28(1):516–571. https://doi.org/10.1080/1331677X.2015.1075139

Ministry of Drinking Water and Sanitation Government of India, New Delhi (2015) Technological options for solid and liquid waste management in rural areas. https://www.susana.org/_resources/documents/default/3-2322-7-1442317620.pdf

Multi-criteria analysis: a manual (2009) Department for Communities and Local Government, London. http://www.communities.gov.uk/documents/corporate/pdf/1132618.pdf

Pipatti R, Sharma C, Yamada M (2006) Chapter 2: Waste generation, composition and management data. IPCC Guidelines for National Greenhouse Gas Inventories, Kanagawa. https://www.ipccnggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_2_Ch2_Waste_Data.pdf

Public Works Department (PWD) (2019) State schedule of rates 2019–20. Government of Maharashtra, Mumbai

Ramesh R, SivaRam P (2016) Solid waste management in rural areas: a step-by-step guide for Gram Panchayats. Centre for Rural Infrastructure (CRI), National Institute of Rural Development and Panchayati Raj (NIRD&PR), Hyderabad. http://nirdpr.org.in/nird_docs/sb/doc5.pdf

Saaty RW (1987) The analytic hierarchy process-what it is and how it is used. Math Modell 9(3–5):161–176. https://doi.org/10.1016/0270-0255(87)90473-8

Saaty TL (2006) The analytic network process. Archive of SID. Network 1(1):1–26. http://www.springerlink.com/index/p9r45787g7u914n9.pdf

Saaty T, Kułakowski K (2016) Axioms of the analytic hierarchy process (AHP) and its generalization to dependence and feedback: the analytic network process (ANP), pp 1–12. http://arxiv.org/abs/1605.05777

Saaty TL (1994) How to make a decision: the analytic hierarchy process. INFORMS J Appl Anal 24(6):19–43. https://doi.org/10.1287/inte.24.6.19

Saaty TL (1990) How to make a decision: The analytic hierarchy process. Eur J Oper Res 48(1):9–26. https://doi.org/10.1016/0377-2217(90)90057-I

Saaty TL, Hu G (1998) Ranking by eigenvector versus other methods in the analytic hierarchy process. Appl Math Lett 11(4):121–125. https://doi.org/10.1016/S0893-9659(98)00068-8

Saaty TL (2008) Decision making with the analytic hierarchy process. Int J Serv Sci 1(1):83–98

Sharholy M, Ahmad K, Mahmood G, Trivedi RC (2008) Municipal solid waste management in Indian cities—a review. Waste Manage 28(2):459–467. https://doi.org/10.1016/j.wasman.2007.02.008

Soltani A, Hewage K, Reza B, Sadiq R (2015) Multiple stakeholders in multi-criteria decision-making in the context of municipal solid waste management: a review. Waste Manage 35:318–328. https://doi.org/10.1016/j.wasman.2014.09.010

Tarmudi Z, Abdullah ML, Tap AOM (2010) Evaluating municipal solid waste disposal options by AHP-based linguistic variable weight. Matematika 26(1):1–14. https://doi.org/10.11113/MATEMATIKA.V26.N.554

Triantaphyllou E, Sánchez A (1997) A sensitivity analysis approach for some deterministic multi-criteria decision-making methods. Decis Sci 28(1):151–194. https://doi.org/10.1111/j.1540-5915.1997.tb01306.x

United Nations (2019) World population prospects 2019, Online edn, Rev 1. Population Division, Department of Economic and Social Affairs. Retrieved from: https://population.un.org/wpp/Download/Standard/Population/

Varma RA (2012) Technology options for treatment of municipal solid

Vučijak B, Kurtagić SM, Silajdžić I (2016) Multicriteria decision making in selecting best solid waste management scenario: a municipal case study from Bosnia and Herzegovina. J Clean Prod 130:166–174. https://doi.org/10.1016/j.jclepro.2015.11.030

Valerie B, Stewart TJ (2002) Multiple criteria decision analysis: an integrated approach. Springer, Boston. https://doi.org/10.1007/978-1-4615-1495-4

Zhu D, Asnani PU, Zurbrügg C, Anapolsky S, Mani S (2008) Improving municipal solid waste management in India : a sourcebook for policy makers. World Bank Institute Resources. World Bank, Washington. https://doi.org/10.1596/978-0-8213-7361-3