Research Paper

Status of sustainable sanitation chain in rural, semi-urban, and urban regions: a case study of Maharashtra, India

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ABSTRACT

Since 2014, the Government of India has constructed millions of toilets with onsite containment technology (OCT) (i.e., pit latrines and septic tanks). In this study, a detailed analysis of the toilets built, people’s awareness about the existing sanitation system, and faecal sludge management (FSM) in rural, semi-urban, and urban areas of Maharashtra, India was done by carrying out a household (HH) survey and interviews with stakeholders. In the surveyed areas, open defaecation (OD) has been eliminated and an individual HH toilet with OCT is the most common sanitation available. The rural area has no FSM facilities. The semi-urban area has a very little faecal sludge (FS) collection by private agencies, while the urban area has a government-aided FS collection system. However, the semi-urban and urban areas have no disposal or treatment facility for the FS collected. In the urban area, irregular emptying of FS has triggered 7% of the HHs to practise OD and 29% of the HHs use manual labour for emptying the OCT. This study can help practitioners, government agencies, and non-governmental organisations to understand the ground reality for establishing/modify FSM rules and regulations for Indian conditions.

Key words | developing countries, faecal sludge, faecal sludge management, household survey

HIGHLIGHTS

● The paper highlights the status of sanitation in three different geographical areas of Maharashtra, India by carrying out a 100% household (HH) survey and interviews with stakeholders.

● These case studies show that the efforts to eradicate OD and control water pollution by the Government of India will not be successful without FSM. Thus, efficient FSM is the need of the hour for India at different levels of urbanisation.

INTRODUCTION

One of the major contributors to water pollution is the mixing of human waste with freshwater, especially where there is a lack of/non-functioning sewage treatment systems (Graham & Polizzotto 2013). Around 3.4 million people die of water-borne diseases every year worldwide (UNDP 2004; Novotny et al. 2018; Faitli et al. 2019). In 2012, the WHO–UNICEF Joint Monitoring Program declared that India contributes to 60% of the world’s open defaecation (OD), which is linked to child stunting, infant mortality, and other health concerns (UNDP 2004). To address this situation, India has launched many schemes to eliminate OD including the Swachh Bharat Mission (SBM), a sanitation programme...
started in 2014 in which more than 100 million toilets with onsite containment technologies (OCTs) were constructed in an effort towards achieving the sixth Sustainable Development Goal, of ensuring safe sanitation (Bhitush et al. 2017).

Previous studies, both before and during SBM, have noted that people do not use toilets due to unfinished infrastructures of the toilets, culturally ingrained behavioural barriers towards the use of latrines, and flawed monitoring (Hueso & Bell 2013; Routray et al. 2015). Flawed monitoring means that faecal sludge (FS) is not adequately emptied from OCT, thus leading to overflow of toilets, which results in their inutility. Sludge that accumulates in the OCT, termed faecal sludge, can, if improperly managed, spread pathogens causing typhoid, cholera, diarrheal diseases, amoebic dysentery, and other virulent diseases (Burkitt et al. 1972). Studies (CSE 2011; Krithika et al. 2017; O’Reilly et al. 2017; Barani et al. 2018; Prasad & Ray 2019) have indicated that FS collection, transportation, treatment, and safe disposal are crucial steps to stop water pollution caused by human waste and achieve complete sanitation in urban India. According to Hueso & Bell (2013), the average desludging time of an OCT in India should be 2–3 years (Hueso & Bell 2013). However, the financial burden of emptying an OCT is high and has led to inhumane practices such as manual scavenging or emptying avoidance.

The National Commission for Safai Karamcharis reported that since 2017, at least one Indian worker had died every 5 days during the cleaning of sewers or septic tanks (PUDR 2019). To help solve this problem, Mehta et al. (2019) observed that scheduled desludging is the best option for Indian urban areas such as Wai and Sinnar in Maharashtra (Mehta et al. 2019). Contrary to scheduled desludging, some studies (Routray et al. 2015; Hammer & Spear 2016; Coffey et al. 2017; Crocker et al. 2017; Novotny et al. 2018; Prasad & Ray 2019) have proposed that increasing people’s awareness on the importance of emptying the OCT and government monitoring are the best solutions for a sustainable sanitation chain. The current policies focus on the subsidy-based approach to solve sanitation problems in India. However, developing a model with a self-driven or even profitable approach for a sustainable sanitation system is crucial in developing countries such as India (Mehta et al. 2019). Additionally, studies (Routray et al. 2015; Hammer & Spear 2016; Coffey et al. 2017; Crocker et al. 2017; Novotny et al. 2018; Prasad & Ray 2019) have concentrated mainly on the urban area, whereas the majority of households (HHs) with OCTs are in rural and semi-urban India. The 74th Constitutional Amendment Act of 1992 reformed the sanitation sector by transferring its management from state to local bodies. However, data about the types of toilets available, HH preference for sanitation technologies in rural and semi-urban areas are still missing in the literature due to the lack of importance given to the sanitation sector in rural and semi-urban India.

The present study focuses on understanding the government’s claim about OD-free cities and villages, people’s awareness about the sanitation chain, sanitation systems available, and the fate of FS produced onsite by considering the following areas: (i) rural area (Katavi village, Maharashtra, India), (ii) semi-urban area (Vadgaon Maval, Maharashtra, India), and (iii) urban area (Faizpur city, Maharashtra, India). This novel study considered different geographic areas in Maharashtra, India based on population density and urbanisation to assess the current status of faecal sludge management (FSM) in India. This study can help practitioners, government agencies, and NGOs to create regulations for developing rural areas.

STUDY AREA AND METHODOLOGY

Maharashtra has not shown any improvement in the SDG score as per India’s NIT Aayog from 2018 to 2019 and also ranked in top 3 states which produces most waste, thus this state is selected as study area (Pandey & Sengupta 2020). The socioeconomic demographic characteristics of the three areas selected for this study within Maharashtra are presented in Table 1 and in Figure 1. The first area was Katavi village, a rural area in Maval Taluka of Pune District in Maharashtra located at 18.7486’N 73.641’E. It is a prosperous village with a predominant Maratha population and an abundant water supply. The second area was Vadgaon Maval, a semi-urban area in Maval Taluka of Pune District in Maharashtra located at 18.7486’N 73.641’E. The place was declared a Notified Area Council (a rural area in the transition to an urban area) on 3 February 2018 by the government of Maharashtra. Vadgaon Maval
is located close to the metropolitan city of Pune, and, as illustrated in Table 1, 67% of the total HHs consisted of people who migrated to this semi-urban area in the last 15 years, indicating its rapid development.

The third area was Faizpur, a city municipal council in the Jalgaon district of Maharashtra located at 21.17°N 75.85°E. Faizpur is one of the oldest municipal councils, notified as a town in 1889, and is not located in the vicinity of any metropolitan city. The growth of this place is almost saturated as presented in Table 1; only 29% of the total HHs consisted of a migrated population.

To understand the sustainable sanitation chain, an integrated approach consisting of planning, management, and technology is required. To analyse the sanitation chain status, a mixed research method as explained below was used. The research methodology of this study consisted of data collection through document analysis, identification of stakeholders, and conducting interviews by using social science research methodologies, direct observations and estimations. As no data pertaining to the study objectives were available with the government, a structured questionnaire (Supplementary material, Appendix-I) was prepared by using an open data collection android application called Kobo Collect Toolbox for assisting the survey. A census of all HHs was conducted from February 2019 to August 2019. As illustrated in Table 1, the sample sizes of the rural, semi-urban, and urban areas were 126, 3,800, and 4,536 HHs, respectively. Furthermore, government bodies, desludging agencies (involved in FS collection and disposals), and farmers (who were using FS directly as fertilizer) were interviewed to understand the issues faced by them. According to the 2018, sanitation and health guidelines by WHO, the sanitation service chain consists of toilets, containment storage or onsite treatment, conveyance, treatment, and end-use or disposal. Studies (CSE 2011; NUSP 2013; CPHEEO 2012; Mehta et al. 2019) have considered FS collection, transportation, treatment, and safe disposal as a standard component for FSM evaluation. However, in India, the other challenges that need to be considered are manual scavengers, and FS variations due to various types of latrines. To understand the Indian FSM system, analysis was divided into components based on the class of toilets and sanitation chain available; the existing OCTs; and the method used for emptying, transportation, treatment, and safe disposal. The obtained data were cleaned and analysed using confirmatory data analysis with respect to the objectives, and the FSM system was analysed using the excreta flow diagram or shit flow diagram (SFD) tool.

### RESULTS AND DISCUSSION

#### Surveyed rural area – Katavi

Of the 628 people residing in 126 HHs in Katavi village, only 4 HHs claimed to have an agrarian livelihood, whereas the other HHs were mainly dependent on the business. All HHs in this rural area have private water supply mainly through bore wells, indicating the presence of surplus water for domestic purposes. The development of the rural area was dynamic as 27% of the HHs migrated into the area within the past 5 years, due to its proximity to Pune.

| Name         | Rural area | Semi-urban area | Urban area |
|--------------|------------|-----------------|------------|
| Population   | 638        | 14,595          | 22,342     |
| Migration rate| High       | High            | Low        |
| Number of HHs| 126        | 3,800           | 4,536      |
| % Pucca HHs | 98         | 94              | 59         |
| % HHs staying in own house | 63 | 53 | 83 |
| Major livelihood | Own business | Private company employees | Daily wage works |
| % Social class | General | 67 | 55 | 29 |
| SC/ST | 13 | 20 | 17 |
| OBC | 10 | 15 | 44 |
| % Residing in place >15 years | 44 | 33 | 71 |
| % BPL | 20 | 39 | 25 |
| Water supply/week | 7 days | 7 days | 4 days |
| Water body | Indrayani river | Indrayani river | Suki river |
| % Private taps and borewells | 80 | 81 | 75 |

*Pucca HH (masonry HH); ST, scheduled cast; SC, scheduled tribes; OBC, other backward castes; BPL, below poverty line.
As illustrated in Figure 2, 98% of OD was eliminated in this rural area mainly due to the emphasis of Indian government schemes on building of toilets. In total, 23% of the HHs were connected to community toilets (CTs), i.e., toilets serving more than 3 HHs and shared toilets (ShTs), i.e., toilets serving 2 or 3 HHs, and remaining 75% of the HHs were connected to individual household toilets (IHHTs), i.e., toilets serving households with less than 3 HHs. Additionally, 8% of the HHs claimed to empty their OCTs, while 58% of the HHs claimed to be satisfied with the emptying process.
connected to individual HH toilets (IHHTs). The surveyed rural area had no sewerage system and was dependent on the OCT. As depicted in Figure 2, approximately 43% of the IHHTs were not connected to pits or sewers in this rural area; the excreta flushed from toilets were directly discharged into agricultural fields, indicating the high risk of diseases by faecal coliform bacteria. Only 50% of the IHHTs were connected to a septic tank, and no HH had knowledge of the size of it. Additionally, only 8% of the HHs claimed to empty their OCTs, whereas the remaining 92% of the HHs with IHHTs had not emptied their tanks because they were not filled or because people were unaware of the need for emptying. The tanks were not being filled because either the tank size was bigger than that required to serve the need of the family or the tanks were not waterproof, leading to the percolation of wastewater into the ground like a soak pit, leading to groundwater pollution. This leaching could cause disease transmission infection among the villagers, considering that groundwater is used as the main source of water.

It was interesting to find that the surveyed rural area did not have an emptying facility of its own, although 8% of the HHs claimed to empty their OCTs. Upon investigation, it was understood that these HHs were above the poverty line and hired an emptying vehicle, from the nearby urban area which charged ₹1,200–₹2,200 (16–30$) per OCT as per volume. FSM facilities such as collection, transportation, and treatment or disposal facilities were not found in this rural area. Thus, this underlines the need for a strict policy regulation for rural areas to ensure that sanitation becomes a basic right of the poor.

Surveyed semi-urban area – Vadgaon Maval

Vadgaon Maval was established as a NAC on 3 February 2018 and has a population of 15,466 distributed among 3,800 HHs. The major problem in this semi-urban (the village in transition) area was the high number of migrants from the surrounding rural area. In total, 48% of the HHs are migrants (people who migrated to Vadgaon Maval in the past 5 or less years), which indicates the informal type of settlements and unplanned development. As regards water scarcity, the area has plenty of water as it is located on the banks of the Indrayani river.

OD and manual scavenging practices were not found in this semi-urban area (Figure 3). In total, 79% of the HHs were connected with IHHTs and the remaining were connected with CTs and ShTs. While the majority of the semi-urban area had no sewer network, recently constructed community buildings were provided with sewer systems that lead to open or huge underground tanks. As illustrated in Figure 3, the major sanitation system was the OCT referred to as the septic tanks. Only 6% of the HHs knew about the exact size and depth of the OCT.

Only 9% of the HHs with OCT in this area had emptied the FS, indicating the need for creating awareness and
encouraging the local government’s involvement in providing an improved FSM facility. The reasons for not emptying the OCT similar to the surveyed rural area were that the ‘pit was not full’ and that they were unaware that the pits need to be emptied. The FS desludging or emptying, collection, and disposal were conducted by a private agency, and a qualitative survey was conducted to understand the practices and difficulties faced by the agency. The FS collection was performed using truck-mounted vacuum tankers (honey suckers) of 3,000-L capacity, as depicted in Figure 4(a). The private agency is a demand-based company, and the workers are not trained about safety and cleanliness. During the survey, the HHs claimed that desludging was performed by NAC-authorised vehicles and the cost of which varied between ₹1,000 and ₹15,000 (13–200$). However, an interview with the desludging agency revealed that they gave a newspaper advertisement and were not authorised by the NAC body. The desludging agency claimed to collect only ₹1,000–₹2,000 (13–27$) from each HH. Thus, proper regulations and monitoring are required in safe desludging and monitoring the price of emptying so that people are encouraged to empty the FS periodically.

Additionally, 4% of the HHs claimed that desludging was performed through manual emptying 10 years ago, and the cost of desludging was between ₹500 and ₹1,500 (7–20$). Further investigation revealed that the person who used to perform manual desludging 10 years ago had passed away. In 2013, the Government of India enacted the Prohibition of Employment as Manual Scavengers and their Rehabilitation Act, which strictly prohibits manual scavenging (people who remove excreta) and helps in the rehabilitation of manual scavengers. Thus, the inhumane practice of manual emptying of FS in the semi-urban area had mainly stopped because of no successor in the field, rather than any other interventions. The FS was disposed directly into a nearby paddy field as shown in Figure 4(b) and 4(c). An interview with the owners of the paddy field revealed that the application of FS as a soil conditioner increased the fertility of soil by threefold compared with other untreated soils. However, direct FS disposal into a farm can cause serious faecal coliform contamination of soil, water, and food (Graham & Polizzotto 2013; Lalander et al. 2013). In addition, surveyed semi-urban area is famous for its rice cultivation, especially the ‘Indrayani’ variety of rice. In this case, as FS is disposed directly into paddy field, the potential for faecal coliform transmission into food need to be studied.

The surveyed urban area – Faizpur

Faizpur municipal council has a population of 22,342 staying in 4,536 HHs and being an old city, the area has almost reached its capacity for growth, and its water source is the Suki river. Only 59% of the HHs were pucca (designed to be solid or permanent) buildings, whereas the remaining 41% resided in slums and urban encroachments. The major livelihood of people in the area is daily wage work.

As depicted in Figure 5, 69% of HHs had IHHTs and other HHs depended mainly on CTs and ShTs. Approximately 7% of the HHs were practising OD, despite having CTs. Investigation revealed that these HHs were provided

![Figure 4](http://iwaponline.com/washdev/article-pdf/11/1/112/876787/washdev0110112.pdf)
with CTs, but due to the improper maintenance of toilets and irregular emptying of FS, the toilet got blocked and became unhygienic, triggering the HHs to practise OD. The surveyed urban area indicates that building toilets without FSM are a temporary solution to eliminate OD, emphasising the paradigm shift required from building toilets to providing a sustainable sanitation system. Currently, 98% of the IHHTs are connected to an OCT in this area of which 90% are septic tanks. Furthermore, 29% of the HHs were aware of the size of their OCT, which reflects better awareness compared with the surveyed rural and semi-urban areas. In the surveyed urban area, a municipality-authorised desludging honey sucker vehicle with a capacity of 3,000 L was used; however, the cost of desludging, safe handling of FS collection, and disposal were not monitored by the municipal council. Only 9% of the HHs claimed to empty their OCT using both the manual and mechanical modes for emptying.

The HHs in this area paid ₹1,000-₹4,000 (13–54$) for emptying an OCT by using a machine and ₹100-₹800 (1.3–11$) for manual emptying. Furthermore, 29% of the OCT were emptied by manual labourers because it is more efficient and cheaper than the other means. This indicates that an increasing number of toilets without proper FSM monitoring and regulations may lead to the re-emergence of inhumane practices such as manual scavenging. Due to the lack of FS treatment or disposal facility in the surveyed urban area, FS was dumped into farmland or solid waste dumping grounds.

**Comparison of FSM in the surveyed rural, semi-urban, and urban areas**

This section attempts to explain the existing scenario in India at each stage of the sanitation service chain by considering the surveyed areas with a different population and density (as shown in Figure 6). The type of toilets has an influence on FS characteristics, that is, the FS from the community and public toilets is not biologically stable (as the technology is desludged frequently), while the FS from the IHHTs is biologically stable and has uniform characteristics. Therefore, in this study, the understanding of the existing toilet class and its OCT is considered as the first step in FSM. In all the surveyed areas, the HH claims that the major class of toilets was the IHHT which was connected to septic tanks. However, these septic tanks were only containers, a few of which had baffles. Usually, the septic tanks were square shaped with or without compartments based on the availability of space and financial status of the user (they did not meet the Indian standard norms for septic tanks – IS 2740), leading to less efficient degradation of excreta. The use of non-standard technologies could be due to the fact that there is no enforcement of standards by governing bodies while approving building plans and that local toilet
builders were untrained in the construction of standard septic tanks. In the surveyed urban area, toilet blockages and unhygienic conditions prevailed due to the improper maintenance of toilets and irregular emptying of FS, triggering OD. Thus, the lack of FSM can trigger OD, eventually wasting all the efforts of sanitation schemes.

**Emptying and transportation**

As shown in Figure 6, the surveyed rural area had no basic FSM facility (FS collection, transportation, and disposal), the semi-urban area had very little (~9%) collection of FS by private agencies, and the surveyed urban area had FS collection by the government-contracted service provider. HHs were responsible for the capital and maintenance costs of their sanitation technology. However, in all the surveyed areas, less than 10% of HHs claimed to empty their onsite sanitation technology, and when asked about the frequency of emptying, a majority of the respondents answered with ‘whenever the tank gets filled’, indicating that serious efforts are required in creating awareness and implementing stringent regulations and its enforcement for FSM. Additionally, a lack of desludging can lead to malfunctioning of OCT and clogging, which may trigger OD. When the OCT overflows, it may cause ground and surface water pollution. Moreover, the semi-urban and urban areas had an unregulated private sector for desludging, and the charges for the emptying services were demand-based and different for different stakeholders such as HHs, residential colonies, commercial establishments, institutions, toilet complexes, and offices. The desludging cost is a major part of the annual income of poor HHs in developing countries. The financial burden of FS emptying has led to environmental pollution by either non-emptying the OCT or the unscientific way of FS disposal. In this regard, we attempted to understand the effect of financial stability (income level of the HH) on the maintenance of sanitation (emptying the OCT) by dividing the interviewees into the following two classes: (i) below poverty line (BPL) (low-income level) and (ii) above poverty line (APL) (high-income level).
Figure 7(a) illustrates that in both the urban and semi-urban areas, ShTs are utilised and OD is practised more by the BPL than the APL HHs. Figure 7(b) illustrates that both BPL and APL HHs in the urban and semi-urban areas empty their OCTs when they are full, and people’s awareness of regular emptying does not depend on the HH income level.

Previous studies (Centre 2013; Srinivas et al. 2017; Mehta et al. 2019) have claimed that unauthorised desludgers in India often charge high user fees (₹3,051–₹5,340/41–71$). In the present study, the cost for emptying per OCT was found to be ₹1,200–₹2,200 (16–30$) in the rural area, ₹1,000–₹15,000 (13–200$) in the semi-urban area, and ₹1,000–₹4,000 (13–54$) in the urban area. The cost of emptying service depends on the quantity of FS to be removed and the distance from the HH to the disposal point. The cost paid by the HH based on their income level is illustrated in Figure 8. In the semi-urban area, the BPL HHs claimed to pay less than ₹500 (7$), whereas APL HHs claim to pay higher than ₹500 (7$) for emptying the OCTs were paid only by the APL HHs for emptying the OCT (Figure 8(a)). Similarly, all the charges were claimed to be paid by the APL HHs in the urban area. This indicates that the BPL HHs may never empty their OCT or may also stop using toilets to avoid the financial

![Diagram](http://iwaponline.com/washdev/article-pdf/11/1/112/876767/washdev0110112.pdf)
burden of emptying. In this regard, the local government should design a sanitation tax to be added to each property based on their income levels, and a performance-linked annuity contract should be signed with the private desludging companies (Mehta et al. 2019).

A survey with the desludging agency revealed that the scarcity of cleaning orders and the poor condition of the road in the rainy season compel agencies to avoid any cleaning. This indicates that FS is mainly collected during summer in the semi-urban area, increasing the load on FS treatment in this period. However, Bassan et al. (2013) reported that a high number of HHs request emptying in the rainy season in Ouagadougou, Burkina Faso, which is concurrent with the findings of Krithika et al. (2011) in Chennai, India. The observed variation in the FS collection load and treatment system for different places maybe because Chennai and Ouagadougou are urban areas where waterlogging are common in the rainy season. Problems such as lack of infrastructure observed in the surveyed areas make it impossible to provide service in the rainy season (Bassan et al. 2013). Hence, an appropriate FS treatment design should be prepared based on the understanding of local collection efficiency, local practices, seasonal variation in FS load, and people’s awareness (Barani et al. 2018).

FS disposal or treatment

The surveyed rural, semi-urban, and urban areas had no treatment or disposal facility. The interviews with the desludging agency revealed the following disposal practices. If the collected FS had too much scum (mainly used sanitary napkins, contraceptive materials and plastics), which usually came from public toilets, they dumped the FS in open drains or on barren sites; otherwise, the FS was dumped into agricultural lands, mainly in paddy fields. These practices can be reduced through continuous awareness campaigning, the involvement of the HHs, and implementation of strict regulations by the government (fines on manual emptying, unsafe management of FS, and illegal dumping). Design of an effective FS emptying service, a training programme on safety, and licensing of truck drivers for the collection system has to be implemented and a policy focussing on the rebuilding of OCTs to septic tanks needs to be emphasised by local government bodies.

Analysis of FSM in the surveyed areas by using the excreta flow diagram or SFD

In 2008, the National Urban Sanitation Policy was formulated by the Ministry of Urban Development mandating...
Figure 9  | Excreta flow diagram analysis of (a) surveyed rural, (b) semi-urban, and (c) urban areas. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/washdev.2020.020. (continued)
the safe collection, transportation, and disposal of human excreta from Indian urban areas. In this regard, the Centre for Science and Environment, India (a non-profit public interest research and advocacy organisation working on the water and sanitation sector) has started encouraging the use of the excreta flow diagram or SFD as a tool for understanding sanitation in India. The SFD is a tool to readily visualise, understand, and communicate how excreta physically flow through the point of defaecation to disposal or end-use. It includes a qualitative assessment of FSM along the service delivery pathway, namely, containment, emptying, transportation, treatment, and end-use (SFD 2018). In this study, a comprehensive SFD analysis (which includes stakeholder engagement and systematic primary data collection) was conducted by using the SFD Graphic Generator (SuSanA platform). Green arrows moving from the left to right in the graph represent excreta that are safely managed and moved along the sanitation service chain, whereas red arrows turning towards the bottom of the graph represent excreta that are not safely managed and discharged into the environment. The width of each arrow is proportional to the percentage of the population whose excreta contribute to that flow. In Figure 9(a) and 9(b), the SFDs of the surveyed rural and semi-urban areas indicate that FS was safely contained in only 7 and 4% cases, respectively, whereas it was not safely contained in 93 and 96% cases, respectively. Thus, this indicates the severity of water pollution in these study areas, where groundwater is the main source of water. One of the limitations of SFD analysis for rural or semi-urban India is the unavailability of data on size, shape, and effectiveness of OCT. Figure 9(c) illustrates that the SFD of the urban area indicates zero safe FS containment, signifying the worst FSM.

All the SFDs demonstrated that the majority of OCTs were not emptied, indicating FS flowing into the environment without treatment. The surveyed rural area has mostly toilets directly letting excreta into the environment. Furthermore, typical septic tank vacuum tankers are usually not powerful enough to empty pit latrines. Thus, the treatment of human waste at the source by using onsite sanitation technologies...
such as microbial fuel cell latrines, composting latrines and septic tanks (Knoop et al. 2013; Butler et al. 2014) with proper collection and treatment of FS can make the unsafe FS safe, thus protecting the environment. Whereas in semi-urban and urban area where the FS collection system is already existing, a centralised FS treatment technology, such as (i) unplanted drying beds (Doulaye & Martin 2004; Cofie et al. 2006), (ii) planted drying beds/constructed wetlands (Doulaye & Martin 2004), (iii) settling/thickening ponds (WHO 2018), (iv) anaerobic ponds (WHO 2018), and (v) co-composting (Kone et al. 2007), can be designed to allow safe handling of FS; this can help in the circular economy. Furthermore, urban areas, where latrines are connected to sewer systems, should have a community-based decentralised system for better management.

CONCLUSION

The paper highlights the status of sanitation in three different geographical areas of Maharashtra, India. These case studies show that the efforts to eradicate OD and control water pollution by the government of India will not be successful without proper FSM. As the level of urbanisation increases, OD (despite the presence of toilets), inhumane practices such as manual scavenging, and unsafe FSM also increase. In the surveyed rural, semi-urban, and urban areas, people’s awareness of onsite sanitation management was insufficient. Challenges with respect to sanitation infrastructure are not only lack of sewer lines but also appropriate collection and transportation of FS generated onsite. Further, for the effective operation of FS treatment, local preference about OCT emptying time of the year is an important parameter to be considered while designing the FSM. Thus, efficient FSM is a pressing need for India at all levels of urbanisation.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

Barani, V., Hegarty-Craver, M., Rosario, P., Madhavan, P., Perumal, P., Sasidaran, S., Basil, M., Raj, A., Berg, A. B., Stowell, A., Heaton, C. & Grego, S. 2018 Characterization of fecal sludge as biomass feedstock in the southern Indian state of Tamil Nadu. Gates Open Research 2. https://doi.org/10.12688/gatesopenres.12870.1.

Bassan, M., Tchonda, T., Yiougo, L., Zoellig, H., Mahamane, I., Mbequere, M. & Strande, L. 2013 Characterization of faecal sludge during dry and rainy seasons in Ouagadougou, Burkina Faso. In WEDC International Conference, 1–5 July 2013, Nakuru, Kenya.

Bhitush, L., Amrita, B., Mahreen, M. & Uday, B. 2017 ‘Septage Management, A Practitioner’s Guide’, editor A. A. Parrey, Centre for Science and Environment.

Burkitt, D. P., Walker, A. R. P. & Painter, N. S. 1972 Effect of dietary fibre on stools and transit-times, and its role in the causation of disease. The Lancet 300 (7792), 1408–1411. https://doi.org/10.1016/s0140-6736(72)92974-1.

Butler, C. S., Henderson, M., Rogers, B., Goodwill, J. E. & Castro, C. J. 2014 Deployment of the microbial fuel cell latrine in Ghana for decentralized sanitation. Journal of Water, Sanitation and Hygiene for Development 4 (4), 663–671. https://doi.org/10.2166/washdev.2014.020.

Coffey, D., Spears, D. & Vyas, S. 2017 Switching to sanitation: understanding latrine adoption in a representative panel of rural Indian households. Social Science Medicine 188, 41–50. https://doi.org/10.1016/j.socscimed.2017.07.001.

Cofie, O. O., Agbottah, S., Strauss, M., Esseku, H., Montanero, A., Awuah, E. & Kone, D. 2006 Solid-liquid separation of faecal sludge using drying beds in Ghana: implications for nutrient recycling in urban agriculture. Water Research 40 (1), 75–82. https://doi.org/10.1016/j.watres.2005.10.023.

CPHEEO (Central Public Health and Environmental Engineering Organisation) 2018 Standard Operating Procedure for Cleaning of Sewers and Septic Tanks. Ministry of Housing and Urban Affairs Government of India, New Delhi.

Crocker, J., Darren, S., Shields, K., Kolsky, P. J. & Bartram, J. 2017 The true costs of participatory sanitation: evidence from...
community-led total sanitation studies in Ghana and Ethiopia. *Science of the Total Environment* **601–602**, 1075–1083. https://doi.org/10.1016/j.scitotenv.2017.05.279.

CSE (Centre for Science and Environment) 2021 *Policy Paper on Septage Management in India*. Centre for Science and Environment, New Delhi. Available from: www.cseindia.org.

Doulay, K. & Martin, S. 2004 Low-cost options for treating faecal sludges in developing countries – challenge and performance. In: *Proceedings of the 9th International IWA Specialist Group Conference on Wetlands Systems for Water Pollution Control*, Avignon, France, 27 September–1 October 2004.

Faith, J., Nagy, S., Gombkoto, I., Bokanyi, L. & Barna, L. 2009 Assessment of a residual municipal solid waste landfill for prospective ‘landfill mining’. *Waste Management Research* **37** (12), 1229–1239. https://doi.org/10.1177/0734242X19881197.

Graham, J. P. & Polizzotto, M. L. 2013 Pit latrines and their impacts on groundwater quality: a systematic review. *Environmental Health Perspectives* **121** (5), 521–530. https://doi.org/10.1289/ehp.1206028.

Hammer, J. & Spear, D. 2016 Village sanitation and child health: effects and external validity in a randomized field experiment in rural India. *Journal of Health Economics* **48**, 135–148. https://doi.org/10.1016/j.jhealeco.2016.03.003.

Hueso, A. & Bell, B. 2015 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.

Knoop, O., Lewis, D., Greenman, J. & Ieropoulos, I. 2013 Energy production and sanitation improvement using microbial fuel cells. *Journal of Water, Sanitation and Hygiene for Development* **3** (3), 383–391. https://doi.org/10.2166/washdev.2013.117.

Kone, D., Coffie, O., Zurbugg, C., Gallizzi, K., Moser, D., Drescher, S. & Strauss, M. 2007 Helminth eggs inactivation efficiency by faecal sludge dewatering and co-composting in tropical climates. *Water Research* **41** (19), 4397–4402. https://doi.org/10.1016/j.watres.2007.06.024.

Kriithika, D., Thomas, A. R., Iyer, G. R., Kranert, M. & Philip, L. 2017 Spatio-temporal variation of septage characteristics of a semi-arid metropolitan city in a developing country. *Environmental Science and Pollution Research* **24** (8), 7060–7076. https://doi.org/10.1007/s11356-016-8336-z.

Lalander, C. H., Hill, G. B. & Vinneras, B. 2013 Hygienic quality of faeces treated in urine diverting vermicomposting toilets. *Waste Management* **33** (11), 2204–2210. https://doi.org/10.1016/j.wasman.2013.07.007.

Mehta, M., Mehta, D. & Yadav, U. 2013 Citywide inclusive sanitation through scheduled desludging services: emerging experience from India. *Frontiers in Environmental Science* **7**. https://doi.org/10.3389/fenvs.2019.00188.

Novotny, J., Hasman, J. & Lepic, M. 2018 Contextual factors and motivations affecting rural community sanitation in low- and middle-income countries: a systematic review. *International Journal of Hygiene and Environmental Health* **221** (2), 121–133. https://doi.org/10.1016/j.ijihel.2017.10.018.

NUSP (National urban sanitation policy) 2015 *Advisory Note on Septage Management in Urban India*. Ministry of Urban Development Government of India. Available from: https://smartnet.niua.org/sites/default/files/resources/advisory_note_on_septage_management_in_urban_india.pdf.

O’Reilly, K., Dhanju, R. & Goel, A. 2017 Exploring ‘the remote’ and ‘the rural’: open defecation and latrine use in Uttarakhand, India. *World Development* **95**, 193–205. https://doi.org/10.1016/j.worlddev.2016.12.022.

Pandey, K. & Sengupta, R. 2020 *State of India’s Environment 2020 – In Figures*.

Prasad, C. S. S. & Ray, I. 2019 When the pits fill up: (in)visible flows of waste in urban India. *Journal of Water, Sanitation and Hygiene for Development* **9** (2), 338–347. https://doi.org/10.2166/washdev.2019.153.

PUDR 2019 *Chronic ‘Accidents’: Deaths of Sewer/Septic Tank Workers, Delhi, 2017–2019*.

Routray, P., Schmidt, W. P., Boisson, S., Clasen, T. & Jenkins, M. W. 2015 Socio-cultural and behavioural factors constraining latrine adoption in rural coastal Odisha: an exploratory qualitative study. *BMC Public Health* **15**, 880. https://doi.org/10.1186/s12889-015-2206-3.

SFD 2018 *Manual Volume 1 and 2*. Available from: https://sfd.susana.org/news-events/news/96-sfd-manual-volume-1-and-2-version-2-0.

Srinivas, C., Maliki, R. & Safaris, A. 2017 *Towards a Model Sanitation City: Operationalizing FSM Regulations in Warangal*. Bill & Melinda Gates Foundation.

UNDP 2004 *Water Governance for Poverty Reduction: Key Issues and the UNDP Response to Millenium Development Goals*. United Nations Development Programme One United Nations Plaza, New York, NY.

Urban Management Centre 2015 *Standard Operating Procedure for Fecal Sludge Management for Municipalities in Gujarat*. Preformance Assessment System Project, Ahmedabad.

WHO (World Health Organization) 2018 *Guidelines on Sanitation and Health*. Available from: https://www.who.int/water_sanitation_health/publications/guidelines-on-sanitation-and-health/en/.

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