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Bridging the rural–urban divide in sanitation with a cluster-based approach to faecal sludge management: a case study from Dhenkanal district in Odisha, India

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ABSTRACT

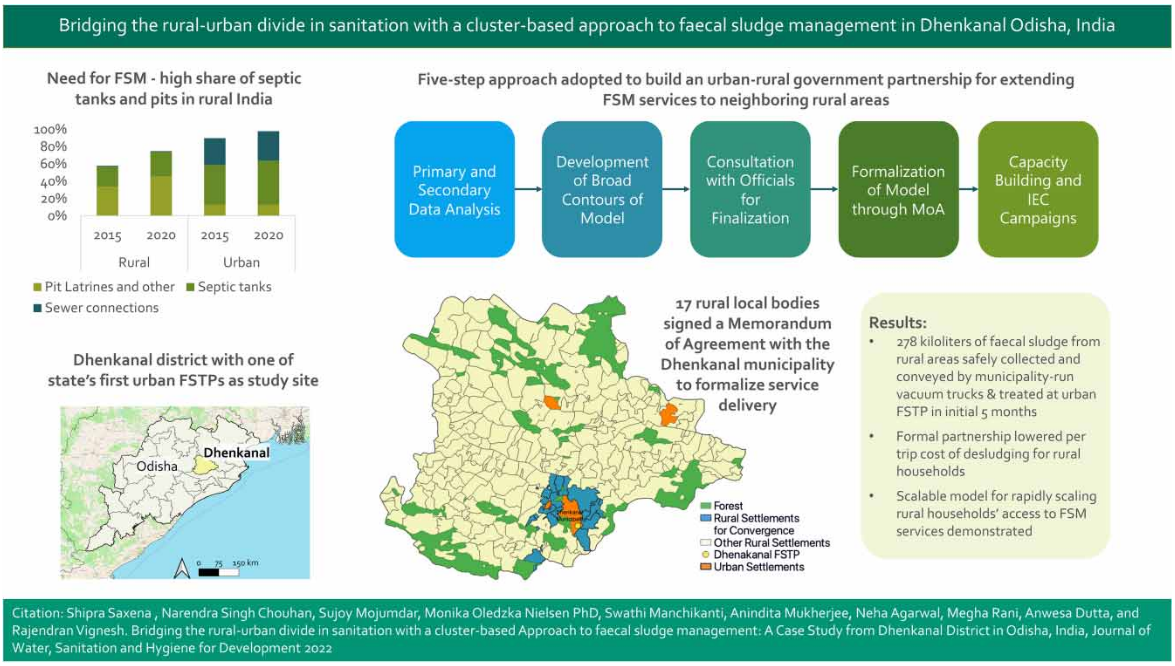
Halfway into the sustainable development goal (SDG) period, the rural and urban divide in sanitation persists. As of 2020, less than half of the global rural population has access to safely managed sanitation. In India, the Swachh Bharat (Clean India) Mission – Rural helped over 100 million rural households to construct individual toilets and access at least basic sanitation during 2014–2019. Expectedly, the increase in toilet usage has led to an urgent need for faecal sludge management (FSM). The present paper describes a novel model, rooted in an urban–rural partnership, to increase access to FSM services among rural households. In 2020–2021, we piloted the model in the Dhenkanal district in Odisha, which had a functional urban faecal sludge treatment plant (FSTP) and publicly run desludging trucks. The model adopted a five-step approach that included a data-led situational assessment, model development, stakeholder consultation, legal formalization of urban–rural partnership, and capacity building. Upon its implementation, the partnership transformed the rural sanitation service chain and resulted in the safe collection, conveyance, and treatment of 278 kL of faecal sludge from rural households within the first 5 months of implementation. As rural governments in India and other developing countries strive to achieve safely managed sanitation by 2030, the urban–rural partnership model discussed in the paper can present a viable pathway for rapidly scaling-up FSM services.

Key words: cluster-based planning approach, faecal sludge management (FSM), rural governance, rural–urban convergence, safely managed sanitation, sustainable development goals (SDGs)

HIGHLIGHTS

- The increased access to toilet in Dhenkanal district has produced a high dependence on single pits and septic tanks and consequently, heightened a need for FSM.
- A novel model based on urban-rural partnerships is presented for scaling up FSM services among rural households.
- Under the partnership, the urban local government has formally expanded the service catchment area beyond its boundary to include 17 neighbouring rural settlements This novel arrangement has been able to treat 278 KL of sludge or 93 truckloads from rural areas leveraging urban FSTP infrastructure.

GRAPHICAL ABSTRACT



1. INTRODUCTION

As we approach 2030, rapid progress is required to meet the sustainable development goal (SDG) of universal 'safely managed sanitation', which includes better sanitation facilities (designed to hygienically separate excreta from human contact), facilities that are not shared with other households, and where excreta are safely disposed of *in situ* or removed and treated off-site (WHO-UNICEF JMP 2018). Over the past 6 years, in large part due to the drive initiated by the Swachh Bharat Mission, India has made significant strides in furthering access to individual household toilets for over 100 million households, mainly in rural communities where coverage gaps were larger (Ministry of Jal Shakti 2022). In 2019, 4,360 statutory towns and 262,769 gram panchayats, or rural local bodies, had declared themselves open defaecation free (ODF), indicating that all households within their census territory had toilets (Ministry of Housing and Urban Affairs (MoHUA) 2022).

The emerging evidence on the impact of unprecedented gains in access to individual household toilets among rural households hints at its positive correlation with water pollution abatement and improvement in the overall quality of life. For instance, according to a study by UNICEF India and the Department of Drinking Water and Sanitation, the Ministry of Jal Shakti (the erstwhile Ministry of Drinking Water and Sanitation) in 2019, villages that could not attain ODF status were 10% more likely to have bacterial contamination of their soil and over 12 times more likely to have contamination in their water sources (Ministry of Jal Shakti, UNICEF India, and SRI Delhi 2019). An economic assessment by Hutton *et al.* (2020) found that households with toilets in India, living in ODF settlements, saved approximately USD 727, primarily owing to costs saved from averting health and costs. Furthermore, Jadhav *et al.* (2016) have shown that access to household toilets is positively correlated with a reduction in the instances of violence against women and an increased sense of dignity and safety. While access to improved toilet facilities is associated with these multidimensional benefits, it is still only the first step towards ensuring universal access to safely managed sanitation. Moreover, the continuous usage of these newly constructed toilets itself is contingent on the household's ability to keep the toilets functional through the timely evacuation and management of the faecal sludge collected from the households via on-site sanitation (OSS) systems like septic tanks and pits.

A proper faecal sludge management (FSM) system provides for the safe desludging, conveyance, and treatment of faecal waste before it is reused or discharged in the open environment (Harada *et al.* 2016). However, until recent times, centralized sewerage systems comprising vast networks of underground pipes to convey wastewater to large-scale sewage treatment plants (STPs) had been considered the gold standard in wastewater and sludge management (Prasad & Ray 2019). However, these systems are resource-intensive to build, operate, and maintain. They require an uninterrupted supply of electricity, a vast amount of water for conveyance and treatment, and skilled operators and managers for the operation and maintenance (O&M) of the network and the plants (Dodane *et al.* 2012). Moreover, given the typical complexity and fragmentation endemic to local governance and funding mechanisms in India, sewage development projects come with unpredictably long gestation periods. Resultantly, as per the latest data from the National Sample Survey Organisation (NSSO) of India 2018, sewage systems serve only 17% of the total households and 39% of the total urban households. Therefore, the on-site containment of wastewater combined with FSM emerges as an indispensable solution to ensure ODF sustainability and safely managed sanitation, especially in rural areas. Owing to the diversity of India's settlements, underpinned by varying trends in urbanization, hydrogeological structures, and unregulated procurement of the various sludge containment options, there is a need to create a diverse portfolio of strategies and models for implementing an all-inclusive FSM strategy.

Currently, the National Policy on Faecal Sludge and Septage Management (FSSM) issued by the Ministry of Housing and Urban Affairs (MoHUA 2017) (2017) in India, evinces an institutional commitment to achieve the goal. However, its scope is limited to cities and towns. Similarly, other national programmatic investments, such as the Atal Mission for Urban Rejuvenation and Transformation (AMRUT), have underwritten FSM infrastructure in the 500 most populous cities of India (Ministry of Urban Development 2015). On the other hand, rural sanitation programmes since the 1980s have confined themselves to the construction of twin leaching pit toilets for providing the complete faecal sludge treatment at the household level itself (Dasgupta & Agarwal 2021). This is because unlike septic tanks and single pits, twin pits allow for near-continuous use without the need for mechanized or semi-mechanized desludging and off-site treatment of evacuated faecal sludge. After one pit fills up, it is sealed, and the wastewater is diverted to the second pit using a simple valve mechanism. In the time that it takes the second pit to fill up (usually 2–3 years), the contents of the first pit are expected to have dewatered and decomposed to a humus-like material that is safe for manual removal and ready for reuse as a soil conditioner (Tilley *et al.* 2014).

However, despite their continued promotion under government programmes, twin pits continue to have limited adoption in rural areas in favour of septic tanks and single pits. Resultantly, under the Swachch Bharat Mission – Gramin (SBM-G) Phase II, it is recommended to retrofit single pits to twin pits for obviating the need for FSM (Bhol *et al.* 2020). While twin leaching pits are an efficient system for achieving safely managed sanitation, due to their inherent operating principle, they are unlikely to meet the objective of complete household-level treatment in low-density and low groundwater table settings. Moreover, though limited, existing research on the techno-economic feasibility of retrofitting single pits to twin pits shows that households exhibit low willingness to pay for the implementation of such a strategy (Agarwal *et al.* 2020).

Therefore, a retrofitting-focused strategy in rural areas and the confinement of FSM to only urban areas will impede India's trajectory towards universal safely managed sanitation, especially among its rural population, which accounts for a majority of India's total population, at 898 million residents as of 2020 estimates (World Bank 2020). If India is to speed up its progress towards SDG 6, it is important to include a focus towards including rural communities as part of the target population for FSM too.

This paper presents a novel service delivery model for achieving universal, safely managed sanitation based on urban–rural convergence and transcending the false dichotomy typical of programmatic investments. The model was piloted in the Dhenkanal district of Odisha and provides a rapidly scalable pathway to increase access to safely managed sanitation among rural households in other Indian districts as well. While the model was implemented in an existing, well-functioning urban FSM system, planners and practitioners designing FSM systems in the future could incorporate the principle of urban–rural convergence from the onset and plan investments for a larger service area of urban–rural continuum.

The development and operationalization of the model have benefitted from strong political will, the lack of which could present a challenge in settings with limited institutional buy-in. The model also presupposes a specific pattern of socio-spatial transformations common in India, which leads to a preference for urban-like infrastructure among rural households and proximity between urban and rural settlements (Dasgupta *et al.* 2017). Therefore, the model may hold applicability in global contexts where rural and urban settlements are governed independently but share a common need for FSM and spatial continuity.

2. LITERATURE REVIEW AND STUDY CONTEXT

2.1. Global FSM

Managing faecal waste systems and practices differs from region to region based on underlying problems. Knowledge on the operational factors of faecal sludge is complemented by different procedural aspects like the quantification of sludge, the characterization of faecal sludge, features of collection, transport, and appropriate treatment. The evolution of sanitation practices shifted enormously with the advancement of treatment technologies. Some of the important studies carried out globally would provide the current scenario of the challenges faced, improvement in managing the challenges faced, changes in policies from countries, etc.

OSS technologies simplify the management of faecal waste to a large extent, and these systems are largely prevalent in the urban regions of sub-Saharan Africa ranging from 65 to 100% (Strauss *et al.* 2000). It is important to note that these on-site technologies are found in low- and middle-income countries and could result in the accumulation of faecal sludge. The existence of sewer systems and faecal sludge systems were also tried in unison in some countries, especially in Japan providing some useful insights into studying the FSM (Gaulke 2006). Apart from this study, there exists a variety of different technologies and a wide range of septic tanks used in Bangkok, Dakar, and Buenos Aires, whereas various types of pit latrines are predominant in Kampala, Nairobi, Kenya, and some other cities (Strande *et al.* 2014). A Water Sanitation Programme (WSP) (2014) study analysed the systems used in FSM in 12 cities representing different regions, sizes, and levels of service delivery. In these studies, dependence on OSS technologies, minimum percentage on-site management, unsystematic, unhygienic manual emptying, and unplanned regulations in treatment facilities of the waste are some of the common issues identified. A persistent challenge across these study contexts in particular and in the sanitation sector in general has been finding an adequate funding for sanitation development. Investment and cost are significant factors in implementing FSM technologies (Dodane *et al.* 2012).

Changing perceptions of how sanitation should be implemented, through networked or non-networked approaches, with innovation towards more flexible approaches, greater technical know-how, new strategies, combined with sound financial mechanisms will allow innovations to prosper. Governance and institutional structures for sanitation projects are also problematic. Up until recently, public organizations provided the most basic consumer utilities, such as water, sanitation, and transportation. Many non-state actors, especially in developing countries like India, Bangladesh, Nepal, and some African countries, have invested heavily for the betterment of the sanitation sector in recent years. Scholars and analysts have yet to acknowledge the combination of state and non-state providers prevalent in the sector and define their role through regulation. Where decentralized approaches are being implemented, non-state actors are already involved (Kelkar & Seetharam 2019). Therefore, it is significant that developing countries are already using hybrid unregulated systems for service delivery. However, the provision of water and sanitation services has largely been an activity of the public and heavily affected by the politics of user charges and the fate of regimes, where the general sentiment has been protective. Due to the emergence of NGOs, private companies, and social enterprises in this sector, service provision has been highly fragmented and unregulated, leading to challenges in replication and scalability. Sector-wise, these structures have helped to resolve issues in some areas but fail to address the larger sanitation problem.

2.2. Current status of FSM in India

In 2017, around the time of MoHUA's release of its FSSM policy, many states began conducting FSM pilots in cities and smaller towns. As of July 2020, more than 19 Indian states have issued state-level FSM policies (FSSM Policy 2017), and 13 have constructed 109 faecal sludge treatment plants (FSTPs) with another 193 underway (National FSM PMU GoI 2020). Although cities adopted varying business models, the policy mandated the formation of a City Sanitation Task Force (MoHUA 2017) to coordinate the planning and implementation of the FSM-inclusive city sanitation plan to ensure streamlined support and inclusion of overlooked communities.

As per the Joint Monitoring Programme (JMP) ladder, in India (Table 1), 67% of rural households have access to at least basic sanitation facilities, 8% with limited or shared, and 2% have access to unimproved sanitation facilities, whereas 22% households are practising open defaecation, which has improved from 40% in 2015 to 22% by 2022 (WHO & UNICEF 2021).

2.3. FSM in rural India

As of the 2011 Census, only 17% of India's total population was served by the centralized sewerage system with the majority of the coverage being restricted to urban areas. The rest of the population currently depends on OSS

Table 1 | Status of the management of faecal sludge and wastewater in India

		Sanitation status (%)						
		Proportion of the population using improved sanitation facilities (excluding shared)				Proportions of the population using improved sanitation facilities (including shared)		
Year	Location	Safely managed	Disposed *in situ*	Emptied and treated	Wastewater treated	Pit latrines and other	Septic tanks	Sewer connections
2015	Total	36	33	<1	3	27	30	11
	Rural	37	37	<1	<1	34	23	<1
	Urban	33	24	<1	9	13	46	31
2020	Total	46	42	<1	4	35	36	13
	Rural	51	50	<1	<1	46	28	1
	Urban	37	27	<1	11	13	51	34

systems, such as leach pits and septic tanks, for containing and partially treating faecal waste on-site. Generally, OSS systems (MoHUA 2017) are considered relatively easy to build and maintain in rural areas, given that there are several safe, low-cost, and low-effort options. These include septic systems, single pits, composting toilets, and twin leaching pits, among others. These OSS systems, however, come with their own challenges for maintenance, continued functionality, and performance. There needs to be periodic removal and conveyance of faecal waste to an off-site treatment facility like an FSTP, where it can be scientifically treated before disposal.

Twin leach pits were widely promoted during SBM-G Phase I as a sustainable self-contained system. However, in rock soil or high water-table areas, the risk of overflowing or contamination of groundwater was higher. In addition to the twin pits in unsuitable terrains, the toilets constructed with a single pit or septic tanks also present a need for FSM to ensure the safe management of effluent once filled. The single leaching pit remains one of the most widely used sanitation technologies – especially in rural India – that stores the faecal matter over time. Once the single pit is filled, it requires a second pit to empty the contents of a single pit with the safe management of sludge to protect the environment.

Prior to the large-scale construction of subsidized toilets, over 40% of rural households (38.5 million) had toilets connected to septic tanks as per Census 2011. The continued preference for septic tanks is highlighted in a 2017 study by WaterAid India (WaterAid India 2019), which revealed that rural households prefer septic tanks despite the government efforts to promote twin leach pits, especially as their socioeconomic status improved. The study also found that many septic tanks that were constructed did not comply with all the standards set by the Bureau of Indian Standards, making them more susceptible to system failure and contamination. According to the NARS 18–19, 34% of all rural toilets at the national level are connected to septic tanks without soak pits, while only 3% are connected to tanks with soak pits. Nearly 19% of the rural toilets are connected to single pits.

The differential prevalence of the three main types of OSS systems in rural India is also determined by the diverse characteristics of the rural settlements. Administrative boundaries of 'urban' and 'rural' notwithstanding, the Census of India 2011 identified census towns, as rurally governed, urban-like settlements having more than 5,000 residents and a population density of 400 people per square kilometre with 75% or more of the workforce employed in non-agricultural activities. As of 2011, there were 3,894 of them compared to 1,362 in 2001. Similarly, there are large and densely populated villages (LDVs) which like census towns are administered as rural and have a population of at least 1,000 and a density of 400 persons per square kilometre (Dasgupta *et al.* 2017). Through this study, Dasgupta *et al.* (2017) show that the dependence on septic tanks steadily increases on going from villages to largely and densely populated villages further to census towns and finally, urban statutory towns. Therefore, the demand for FSM shows a clear pattern in relation to the rural settlement's demographic characteristics and its proximity to urban areas – creating an opportunity for graded FSM interventions in rural areas.

2.4. FSM in the state of Odisha, India

The state of Odisha has been at the forefront of FSM and urban sanitation in India and issued the Odisha Urban Sanitation Policy and Odisha Urban Sanitation Strategy in 2017. The state also established two of the lighthouse urban pilots on FSM in smaller towns and nine FSM pilots in bigger AMRUT cities. Following their success, the state is currently scaling-up FSM to all its 114 urban local bodies and poised to emerge as a pioneer in rural sanitation with the release of the Odisha Rural Sanitation Policy, 2020. The policy provides a systematic framework to understand and address the gaps in rural sanitation and covers several aspects like access to toilets, behavioural change for elimination of open defaecation, FSM, greywater management, solid waste management, and menstrual hygiene management.

The administrative structure for sanitation and FSM is splintered across the urban–rural divide in the state, with two distinct arms that govern urban and rural developments in Odisha. At the state level, while the Panchayati Raj and Drinking Water Department (PR&DWD) governs rural administrations, the Housing and Urban Development Department (H&UD) performs a similar function for urban local bodies also called municipal authorities. Following the enactment of the Orissa Grama Panchayat Act, 1948, the state introduced a three-tier system of rural governance via Panchayat Raj Institutions (PRIs) at the district, block, and village levels. Additionally, in 1992, the 73rd amendment of the Constitution of India further strengthened the role of PRIs – repositioning gram panchayats as institutions of rural local governance. Therefore, at the local level, gram panchayats, with the support of their constituent committees (e.g. Village Water and Sanitation Committee (VWSC)), are responsible for water and sanitation service delivery. Urban local bodies, municipal corporations, and municipalities fulfil the function in urban settlements.

2.5. Study context

Indian states are divided into smaller governance units called districts that comprise multiple urban (municipalities) and rural local bodies (gram panchayats). The state of Odisha is divided into 30 districts including Dhenkanal (Figure 1). It is located in the central part of the state and is spread out over 4,452 km^2. As per the Census of India 2011, the district had a total population of 1.2 million with about 270,000 urban and rural households residing in 3 statutory towns and 199 gram panchayats. The rural areas in the district comprise more than 90% of its total population.

The majority of the blocks in the Dhenkanal district are considered to be at a safe level of groundwater development that is measured as a ratio of annual groundwater draft and net annual groundwater availability in percentage by the Central Ground Water Board (CGWB). The groundwater table varies between 2 and 10 metres below the ground level (mbgl) annually (Figure 2).

Located near the coastal belt of the state, about three-fourths of the district's land area falls in the 'very high damage risk zone' and the remaining in the 'high damage risk zone with respect to cyclones'. In addition to cyclones, the district also suffers from moderate risk to earthquakes. The Dhenkanal Municipality in the district is one of the first small towns in the country to have introduced a city-wide FSM system. The municipality commissioned a nature-based FSTP capable of treating 27 kL per day (KLD) of sludge in 2018. Given the district's

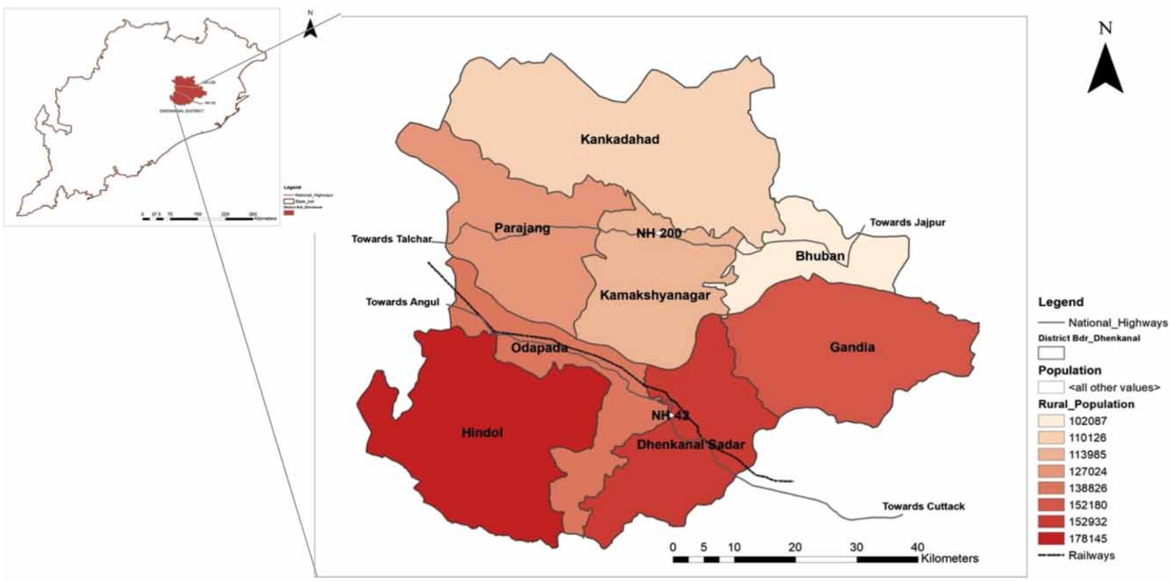


Figure 1 | Location of the district and population in different blocks of the district.

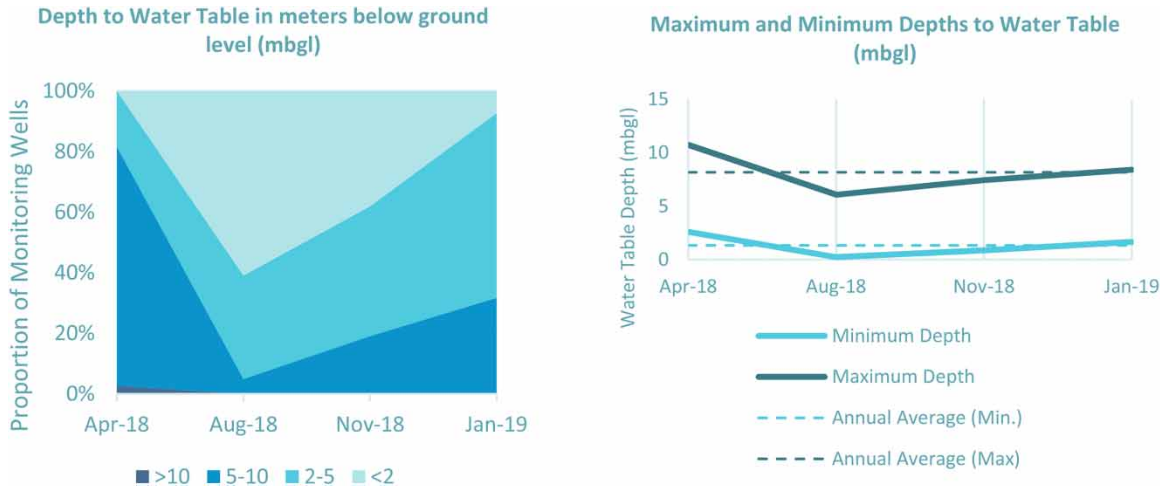


Figure 2 | Depth to the groundwater table in the Dhenkanal district.

attainment of ODF status across its rural and urban areas in 2019, the next step was to institute district-wide safely managed sanitation.

As of late, 17 gram panchayats and the Dhenkanal Municipality signed a one-on-one Memorandum of Agreements (MoAs) on 28 December 2020. The MoAs set the price of desludging at INR 1,250 (USD 17) and INR 750 (USD 10) per trip for vehicles of 3 and 1 KL sizes, respectively, which are lower than the *ad hoc* price that rural households were paying for the services before the operationalization of the model. Moreover, to bring down the cost of desludging services per household further, the request allocation allows for the pooling of multiple requests in one trip. During the first 5 months (Feb–Jun 2021) of its operations, 278 KL of sludge or 93 truckloads from rural areas have been treated in the FSTP, thereby preventing its indiscriminate disposal from polluting the open environment. While the average fees paid by rural households has decreased following the formalization of the plug-in model, total revenue amounting to INR 140,000 or USD 1882 has been collected during this period, thus supporting and ensuring service sustainability.

Currently, the state government is testing the approach in six additional districts to further explore the adaptability required for the model to be replicable state-wide. The national government has also paved the way for the institutionalization of the approach by espousing it in an official letter issued in September 2021.

3. METHODOLOGY AND APPROACH

In the last couple of years, the state of Odisha has witnessed a rise in the requirement for FSM services in its rural areas and a parallel scale-up of urban FSM systems across all its cities and towns. The phenomenon presented a unique opportunity to rapidly increase access to safely managed sanitation in rural Odisha by creating a partnership between urban and rural local governments for the co-utilization of FSM systems. Motivated by it, we sought to pilot and study a model of urban–rural FSM strategy that was effective, scalable, and built on an understanding of the mismatch between supply and demand relating to infrastructure, awareness, governance capacity, and regulation. Figure 3 presents the process through which this progressive FSM strategy was realized. In this process, study results, as informed through the preliminary and secondary data analysis (Step 1 of this process shown

Figure 3 | Process adopted for developing and institutionalizing the urban–rural convergence model in Dhenkanal, Odisha.

in Figure 3), were used to pilot the implementation of the urban–rural FSM strategy. The subsequent sections in this paper present these steps and associated outputs in more detail.

3.1. Model development

Given the Dhenkanal FSTP was the only available functional facility in the district, we considered the available spare capacity of the FSTP as a given boundary condition. Therefore, we undertook an assessment of FSTP's capacity utilization as the first step, which we discuss in Section 5. As a logical next step, we aimed to estimate the size of the rural population that the FSTP could comfortably serve over the next 3 years. A practical estimate of the current and future infrastructure demand would require knowing the average:

- share of the rural population that depends on single pits and septic tanks and would therefore require FSM services,
- the sizes of the single pits and septic tanks,
- the number of users,
- the hydraulic loading of single pits and septic tanks, and
- the average desludging frequencies of the systems.

Owing to the paucity of universal benchmarks for these parameters in the rural context, we had to determine their values using a primary household survey as discussed in Section 4. Moreover, given the novelty of toilets and the deficiencies in behavioural change towards regular and consistent toilet usage, we were interested in understanding how well the relatively hypothetical infrastructure demand would translate to the uptake of services among rural households. Therefore, the survey was also used to ascertain the rural households' willingness to pay for the two mainstream alternatives to safely managed sanitation, for example, by retrofitting existing single pits to twin pits and FSM. Interviews with government officials, conducted as part of the survey helped to define the need for capacity building and to assess the role that Information, Education, Communication (IEC) campaigns, could play in shifting household behaviour towards safer sanitation outcomes.

Following data collection and analysis, a list of gram panchayats was identified in the vicinity of the Dhenkanal municipality that the urban FSTP could serve by matching supply against demand. As a part of the evaluation, we determined if the municipality's existing fleet of desludging vehicles (DVs) would suffice to cater to both urban and rural households with requisite promptness on the receipt of service requests. The findings were utilized to build the urban–rural convergence model in consultation with urban and rural local body officials and the district administration. For its institutionalization, the rural and urban local governments were supported to formalize the terms of the engagement in an MoA. The operationalization of the model and service delivery was followed by the capacity building of gram panchayat officials and IEC campaigns for raising awareness in households about the need for and access to FSM services.

3.2. Data collection and analysis

Assessing the gap towards safely managed sanitation in a given setting requires building a holistic understanding of the existing infrastructure, behaviour, and capacity. Data on the prevalent OSS systems typology, their characteristics, and local hydrogeology are key factors for estimating the need for FSM in any given region. Government datasets like the Census of India, National Sample Survey, and National Annual Rural Sanitation Survey, while providing adequate information on the OSS systems in use (including at the settlement level), do not provide detailed information on the size of OSS systems, toilet usage, and hydraulic loading, among others, that are crucial for infrastructural planning. Therefore, a district-wide sample survey of households led to a deeper understanding of the sanitation facilities in use in rural areas of the Dhenkanal district.

The survey included a sample of 1,000 households in the district. This allowed us to report the results with a margin of error of less than 5% and a confidence level of 99% according to the Cochran formula and achieve representativeness of the findings at the district level. The next steps, as discussed below, focused on determining how to allocate these 1,000 households across the district:

- *Gram Panchayats*: Since gram panchayats form the primary local governance unit in rural areas, it became the first-stage sampling unit. In order to approximate a normal probability distribution at the gram panchayat level, a sample size of 30 households was adopted per panchayat (Kwak & Kim 2017). Therefore, considering the total sample size of 1,000 households and a gram panchayat sample of 30 households, the sample was distributed across 33 gram panchayats (or 1,000/30). Probability proportionate to size sampling was deployed to select the 33 gram panchayats out of 199 in the district.

- *Villages*: Since gram panchayats are typically comprised of one or more villages often with varying socioeconomic characteristics, the gram panchayat sample was allocated across three villages in each panchayat. Here, simple random sampling was used to select the three villages of the total. In the case where the gram panchayat had three or fewer villages, all the villages were selected for surveying. In both cases, the sample was distributed equally across the selected villages.
- *Households*: Within each village, the households were randomly selected to ensure the maximum geographical coverage by the field enumerators.

Overall, the household survey covered 97 villages in 33 gram panchayats. The questionnaire for the household survey sought information on the household's socioeconomic characteristics, access to the toilet and its usage, type, and characteristics of the OSS system, access to desludging services, willingness to pay for services, and other aspects related to sanitation such as water supply and drainage. It was administered in the computer-assisted personal interviewing mode using the Survey123 application provided by the Environmental Systems Research Institute (ESRI). A quantitative analysis was conducted using Microsoft Excel 16.0 and Stata Standard Edition 13.0.

In addition to the household survey, we interviewed key stakeholders including gram panchayat officials, members of the VWSCs, local masons, and desludging service providers. Understanding the governance side of the service delivery enabled us to further contextualize and triangulate the quantitative data collected through household surveys. These interviews were conducted in 8 out of the 33 GPs selected for the survey.

4. RESULTS AND DISCUSSION

This section presents the results from the primary survey and secondary data analyses and discusses how these data-informed programmatic actions took place within the urban–rural FSM model in the Dhenkanal district in Odisha. We conclude this section with a higher-level reflection on study insights and their broader application to global FSM programmes.

4.1. Survey results on FSM technology use, demand, and feasibility

The data sample (Table 2) from the primary survey consisted of 60% male respondents and 40% female respondents. Thirty percent of the sample was from the general category, 34% from other backward classes (OBCs), 24% from scheduled castes (SCs) and 12% from scheduled tribes (STs). Most of the respondents are either self-

Table 2 | Demographic profile of the sample

Socioeconomic variable		Percentage of responses
1. Gender	Female	60
	Male	40
2. Social category	General	29
	OBC	34
	SC	24
	ST	13
3. Income source	Self-employed in agriculture	35
	Self-employed in non-agriculture	17
	Casual labour in agriculture	4
	Casual labour in non-agricultural	31
	Salaried – public/government	3
	Salaried – private	9
	No source of income	2
4. Monthly per capita expenditure (MPCE)	≤INR 500	14
	INR 500–1,000	37
	INR 1,000–2,000	42
	>INR 2,000	7
5. House type	Kutcha	28
	Pucca	72

employed in agriculture (35%) or casual labourers in the non-agricultural sector (31%), and 80% of the sample has monthly per capita expenditure (MPCE) between INR 500 and 2,000 (USD 7–29). It was found that the SC and ST category households were concentrated in the lower consumption categories. Overall, nearly all households report residing in self-owned houses, with 28% of the sampled households residing in *kutcha* or hut-like dwellings, and 72% in *pucca* or brick and cement dwellings. Subsequently, we present salient findings from this survey including (i) an increased dependence on single pits and septic tanks, (ii) low techno-economic feasibility for retrofitting, and (iii) unsafe manual desludging services due to high on-ground demand for FSM.

4.1.1. Increased dependence on single pits and septic tanks

A substantiative increase in the accessibility to toilet facilities was seen in the data, a likely result from the progress under SBM-G, between 2014 and 2019 (Figure 4). The toilets that have been constructed under the scheme are predominantly connected to a single pit (84%). All the eight-gram panchayat *sarpanches* that were interviewed and confirmed that single leaching pits were the predominant system constructed under SBM-G in their villages. The prevalence of single pit increases as one moves from higher-to-lower consumption quintiles. From the stakeholder interviews, it was found that the primary reasons for preferring single pits include low cost for household, rapid construction targets for contractors, and social norms of purity–impurity with the Y-junction. Richer households preferred septic tanks, which show a statistically significant correlation ($p < 0.001$) with non-SBM or privately constructed toilets.

4.1.2. Low techno-economic feasibility for retrofitting

The data highlighted a low preference for retrofitting a single-pit toilet to a twin-pit one, as it involves both financial and technical challenges. Although 25% of the households believed that the addition of a second pit would make toilet use more convenient and maintenance easier and sustainable, a lower proportion reported that they would be willing to pay for such an intervention. Nearly 73% of the households who expressed the willingness to pay reported that they would be willing to pay up to INR 500 (USD 7) for retrofitting, a fraction of the anticipated retrofitting costs. *Swachhagrahis*, or community sanitation volunteers, interviewed for the study also reaffirmed that financial support or subsidy would motivate households for retrofitting (UNICEF-CPR 2020).

Research shows that less than 2% of the reported single pits have a junction chamber for connecting a second pit, thereby further complicating the retrofitting process. A district-wide retrofitting drive would also entail a comprehensive capacity-building programme with only one out of five masons interviewed reporting any prior experience in retrofitting. Therefore, the need arises to facilitate beneficiary-led retrofitting of all dysfunctional or ill-constructed toilets and OSS systems to ensure their continued functionality and usage through market linkages, creating awareness among communities, building capacities of masons, other key stakeholders, etc. Even if these challenges are overcome, the high groundwater table underlying the district restricts the strategy's hydrogeological suitability. Figure 5 shows a map of groundwater availability (and feasibility) within the Dhenkanal district. The map is created by using district and GP/village boundaries provided by the Census 2011 District handbook and overlaying the CGWB groundwater data on this base to assess the feasibility of retrofitting strategy in the district.

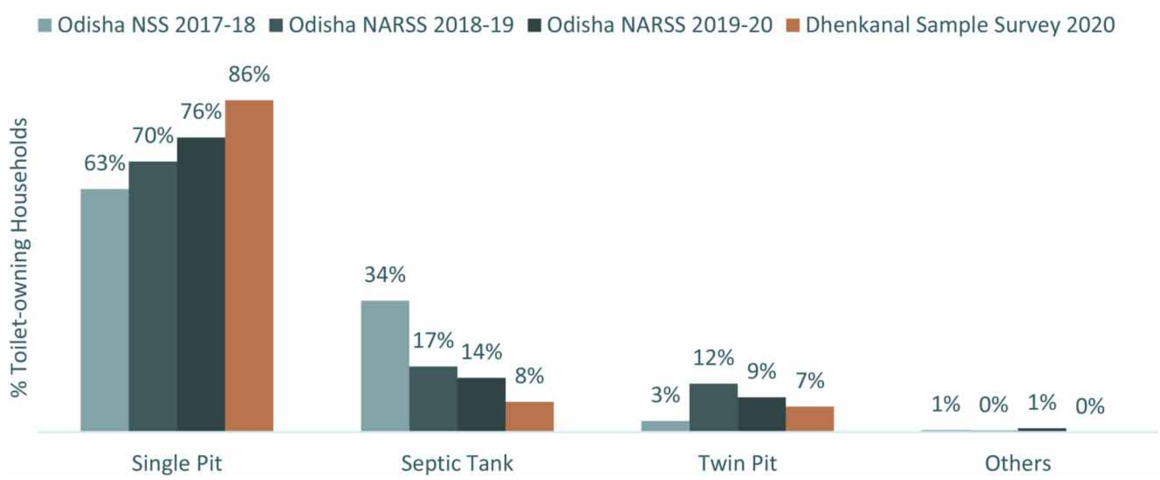


Figure 4 | Different types of OSS systems in use in Odisha.

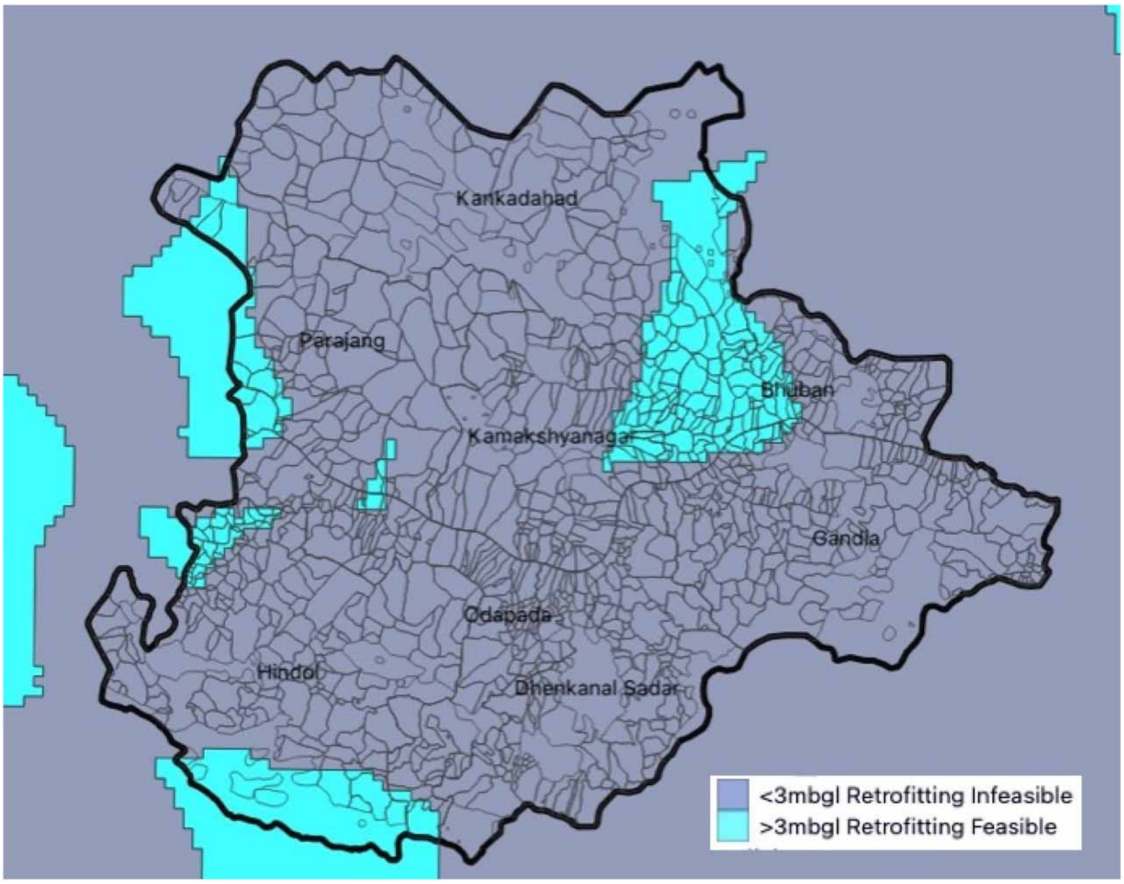


Figure 5 | Retrofitting feasibility in the Dhenkanal district guided by groundwater criteria based on groundwater data (mbgl) published by [CGWB 2019–Central Ground Water Board. Ground Water Year Book 2019-2020] 2020.

4.1.3. Unsafe manual desludging services due to high on-ground demand for FSM

In view of the above situation, with large numbers of septic tanks and single-pit toilets, both of which require emptying, the institution of FSM services would be critical towards preventing risks to public health and the environment but also for the safety and dignity of those providing manual desludging services (Figure 6). The data show that a high share of households engage in manual labour for desludging their OSS systems in the absence of widely available, affordable, safer mechanized desludging services. As the demand for desludging services increases concomitant to increased toilet usage, the inaccessibility of safe desludging services could further entrench the dependence on manual labour. Therefore, it is imperative to establish proper FSM services and safely managed sanitation in rural areas.

4.2. Results from secondary and primary data to evaluate household demand and implementation strategies

Subsequently, we provide a summary of the results obtained from the analysis of the primary household survey, operational data from the Dhenkanal FSTP, and other operational data to evaluate the available spare capacity of

Figure 6 | Prevalence of different types of desludging service providers in Dhenkanal.

FSTP, to estimate the demand for services from rural households, and to estimate the associated implications this demand has on the need for additional DVs. These results, combined with the other insights from the primary survey, informed the piloting, formalization, and future monitoring and evaluation of an urban–rural FSM programme, as well as a monitoring and evaluation strategy for future programme implementation.

4.2.1. Estimating the available spare capacity of FSTP

An analysis of the capacity utilization of the urban FSTP over a 2-year period, 2019–2021, was deployed to estimate the spare capacity and ascertain the maximum range of the rural demand for FSM that could be served. We observed that although the utilization fluctuated between months and across individual days, on average, the capacity utilization was consistent at 50% or about 13 KLD for both years (Figure 7). While data from more years of operation are necessary to understand and identify any cyclical patterns in demand for services, the trend for the first 2 years suggests overall constancy in the amount of sludge arriving at the FSTP for treatment each year.

4.2.2. Estimating demand from rural households

Once the available capacity was established, we estimated the hypothetical demand from rural households over a 3-year period based on average values of parameters including household size, septic tank and single-pit sizes, and hydraulic loading that we assessed using the survey data. Due to the significant difference in the average sizes of septic tanks and single pits reported by households, 16,990 and 600 L, respectively, and the difference in the benchmarked sludge accumulation rates (Bureau of Indian Standards 1985), the demand for the two types of systems were estimated separately. To arrive at the total demand, we weighted the estimated demand per septic tank and single pit by the respective number of households dependent on them. We used a relative share reported by the survey and the total number of households from governmental records to calculate the latter. The estimation considered two scenarios – first, where erstwhile and ongoing IEC campaigns focused on toilet usage would result in 100% usage of toilets in the next 3 years and second, where the campaigns meet limited success and toilet usage, and resultingly, the demand for FSM services would ramp up slowly.

We started with an initial radius of 10 km for the extended rural service area and listed all the gram panchayats falling within it (Figure 8). Since the constituent villages of a gram panchayat may fall outside or within the cut-off radii independently, an inclusive criterion was adopted while preparing the list of gram panchayats. Based on the aforementioned 2 scenarios and the list of 17 gram panchayats, the estimated rural demand was settled in a range of 9–12 KLD, which is within the available spare capacity of the FSTP calculated in the previous step.

4.2.3. Estimating requirement for additional vehicles

The Dhenkanal municipality owns two DVs of 3,000 KL and is the primary and sole provider of demand-based desludging services in the town. It has contracted out the day-to-day management and operations for desludging service delivery to a women self-help group (WSHG). Like many other small towns and cities in Odisha, it lacks private service providers. Noting the inaccessibility of DVs in settings with high density and narrow approach roads over 2 years of operation, the Urban Local Body (ULB) procured an additional smaller-sized vehicle of 1 KLD, which has been under operation since October 2020. Considering that the rural demand for FSM will ramp up slowly, it was concluded that for the next 2 years the existing fleet will suffice. In the medium term, an additional DV of 3 KLD – allowing the pooling of desludging requests – will be required to cover the full-service area.

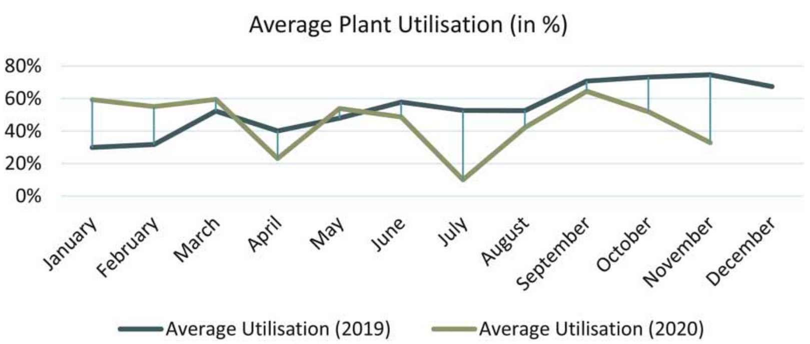


Figure 7 | Capacity utilization at FSTP.

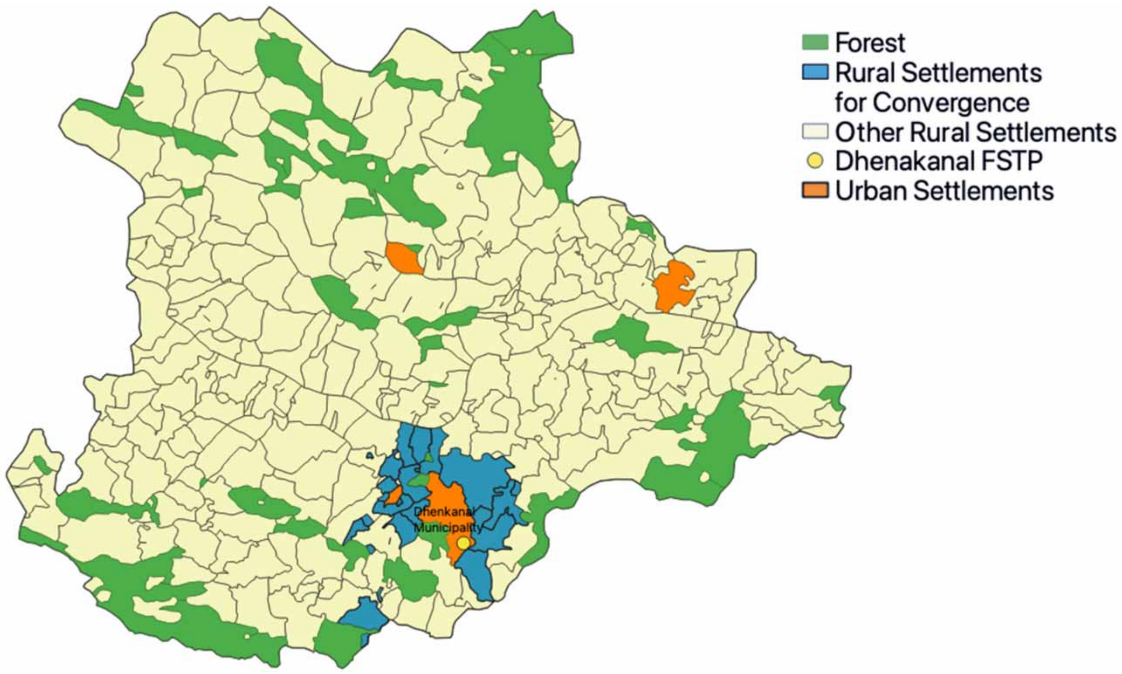


Figure 8 | Location of the Dhenkanal municipality and gram panchayats identified for urban–rural convergence.

4.2.4. Formalizing governance and regulation

The governance and coordination mechanisms between the rural and urban local bodies for the delivery of demand-based desludging services to rural households and the treatment of the collected faecal sludge at the urban FSTP have been articulated in an MoA. Given that the plug-in model is based on the rural–urban and rural–rural coordination of multiple local bodies, it was critical to set out a clear framework that specifies the terms of their cooperation. It helps define the roles and responsibilities of the district/block/local governments and provides a clear framework for the day-to-day engagement between the urban and rural local bodies, as applicable, on issues of invoice generation, payment transfers, monitoring, and recordkeeping, among others.

Specific to the municipality, the MoA requires it to amend its contract with the WSHG to ensure that the extended service area is included under the purview of the group. Other major responsibilities of the municipality include:

- Ensuring the safe treatment of faecal sludge collected from OSS systems,
- Extending the services of the call centre/toll-free helpline number/mobile application currently available to urban households for requesting services to rural households,
- Providing the necessary equipment and personal protective gear to the sanitation workers and ensuring their safety,
- Maintaining digital records of complaints and their redressal, and
- Developing desludging tariff in consultation with the gram panchayat and officially notifying it.

Under the MoA, the gram panchayat is similarly responsible for:

- Maintaining a database of OSS systems and
- Undertaking IEC campaigns to build awareness of households about the availability of services and the importance of timely desludging and FSM.

Most importantly, the MoA provides systematic review and monitoring of the model, under the guidance of the district administration, to facilitate continued and smooth service delivery.

4.2.5. Future progress, monitoring, and future adjustments

The 17 gram panchayats and the Dhenkanal Municipality signed one-on-one MoAs on 28 December 2020. The MoAs set the price of desludging at INR 1,250 (USD 17) and INR 750 (USD 10) per trip for vehicles of 3 and 1 KL sizes, respectively, which are lower than the *ad hoc* price that rural households were paying for the services before the operationalization of the model. Moreover, to bring down the cost of desludging services per household further, the request allocation allows for the pooling of multiple requests in one trip. During the first 5 months (Feb–Jun 2021) of its operations, 278 KL of sludge or 93 truckloads from rural areas have been treated in the FSTP, thereby preventing its indiscriminate disposal from polluting the open environment (Figure 9). While the average fees paid by rural households has decreased following the formalization of the plug-in model, total revenue amounting to INR 140,000 or USD 1882 has been collected during this period thus supporting and ensuring service sustainability.

The state government is testing the approach in six additional districts to further explore the adaptability required for the model to be replicable state-wide. The national government has also paved the way for the institutionalization of the approach by espousing it in an official letter issued in September 2021.

The formalized urban–rural convergence model for FSM and safely managed sanitation is the first of its kind in India. To ensure its operational success and efficiency, the team worked with the urban local body to modify its Management Information System (MIS) to track service delivery to rural areas. The MIS-tracked parameters include the date on which desludging was requested, the time taken to fulfil the request, the fees charged, the type of OSS system, the name of the gram panchayat, the roundtrip distance covered, etc.

As the model matures, the time may come for a dynamic repository of data and more on-ground consultations to answer more questions and ensure that community access to safely managed sanitation is sustained and equitable. Some of these could be:

- Is the service delivery to rural households timely? Does it differ from the average amount of time taken to fulfil requests from urban households? How does it impact the sustainability of the ODF status?
- Are the DVs running at optimal capacity? Does the municipality need more DVs to deliver timely services to a larger service area?
- Is the FSTP beginning to near the designed capacity? Is the demand from rural households exceeding its estimate? Could the municipality augment the FSTP? Could the reduction of service area and the development of greenfield FSM systems for the areas left out work as a more realistic solution?
- Is pooling of requests, especially for the low-volume single pits, in a single trip of the DV (to and from the FSTP) a viable and efficient mechanism to bring down costs for desludging services per household?
- Is the desludging tariff applicable to rural areas adequately covering the cost of service delivery? Does the gram panchayat need to subsidize services to balance affordability with the financial sustainability of services?

4.3. Higher-level insights for global FSM programmes

Our results indicate that the household preference for different sanitation systems has transcended the rural–urban divide (Dasgupta & Agarwal 2022). As such, the current success of the 'plug-in' model that bridges the urban–rural divide in Dhenkanal offers exciting potential to replicate the approach for hundreds of other municipalities with functioning FSTPs and surrounding rural communities sustaining deficits in treatment options. The model also demonstrates that there are multiple variables involved in determining the feasibility and sustainability of this intervention.

Figure 9 | Progress of the plug-in model.

First, it is imperative to understand the existing needs of the communities to be supported. This aligns with various best practices on sustainable community development (e.g. Narayan-Parker 1993, 1995; Chambers 1994). While precedence for the evaluation of community need is not surprising, the more nuanced characterization of salient community needs to be illuminated through this study that is useful and aligns with insights from other studies in the water and sanitation sector. For example, the pre-intervention survey assisted us in identifying not just the various types of OSS systems that existed – with the majority being single pits – but also the geographic spread and density of the households (Allen *et al.* 2006; OECD 2013), and income-sensitive willingness to pay for integrated treatment services (Whittington *et al.* 2009; Arouna & Dabbert 2012; Naiga & Penker 2014). Overall, the findings from the study survey provided qualitative feedback on the appetite for and awareness of FSM's importance.

Second, such approaches cannot function without agreed upon governance models (Caffyn & Dahlström 2005). This is especially true in India, where urban and rural services are segregated between ministries and departments serving each population separately. Given that this effort to connect urban services with rural populations is unprecedented, outlining strategies for stakeholder collaboration based on key roles and responsibilities served to generate consensus among policymakers and also ensure that there was shared accountability for the success of the model. Such forms of collective agreement and action are key activities in pursuit of sustainable water and sanitation development (Pugel *et al.* 2020, 2022a, 2022b). Previous studies in the area of inter-municipal cooperation have also highlighted the potential role played by urban–rural partnerships in efficiently delivering services and raising the capacity of local governments in Europe and the USA (Warner 2006; Hulst & van Montfort 2011; OECD 2013). In many developing countries, however, hybrid models of system delivery, consisting of a combination of state and non-state providers, remained prevalent in the sanitation sector albeit unregulated (Kelkar & Seetharam 2019). The current success of the 'plug-in' model that bridges the urban–rural divide in Dhenkanal offers exciting potential to replicate the approach for hundreds of other municipalities with functioning FSTPs and surrounding rural communities sustaining deficits in treatment options. In Dhenkanal specifically, the ULB signed MoAs between the rural local bodies to formalize the terms of the partnership and also ensured not just the horizontal alignment but also vertical integration, by restructuring the terms of labour for the service providers themselves, while also granting them the necessary autonomy for deliberating on tariffs and community engagement. Such urban–rural partnerships can help maintain distinct local governments, which may still be relevant due to persistent differences between these areas, while creating networks of governance that help coordinate the management (Warner 2006; OECD 2013) of urban–rural linkages. A final element that is continuing to play a key role in programme success is social and behaviour change communication (BCC). Developing the necessary information and communication materials has supported the uptake of the services offered to rural communities, which have previously not been familiar with the treatment option and thus risked having low demand for it. Sanitation literature point to BCC in general, through the thoughtful development of communication materials in particular, is an important tool in promoting sustainable service use and provision (Mwakitalima *et al.* 2018; Kalam *et al.* 2021). The proper communication on the impetus for and the proper use of FSM infrastructure is necessary, given that even though the tariff for collection is, on average, lower per household than previous offers, it is still a relatively large lump sum when compared to the average incomes earned by the rural households serviced. Therefore, information campaigns that advertised the importance of FSM, supported by government bodies, as well as making it easy to access the service, played a strong role in generating demand.

5. LIMITATIONS AND FUTURE WORK

Given that the study approach applied here has many uncontrolled components, there are limitations that would affect future replication and scale-up. Currently, while an MIS is being developed, it is not tracking all relevant indicators and thus would not be able to give the full set of data needed to analyse whether the model will continue to remain successful with various household densities over time and whether the tariff model is sustainable for the long term. What adjustments the partnership arrangement may need over the medium- to long term is still an open question that more experience could answer. Government cooperation and interest play a large role in the success of a social good – such as waste management – and the investment may vary depending on the day-to-day priorities of policymakers and leaders in various cities and rural habitations. Essentially, the levels of institutional strength and willingness would be a strong determinant of the approach's successful replicability in varying contexts. Finally, FSM is only one stream of waste management and while it is clear that tonnes of faecal waste treated safely are saving local resources from contamination, it cannot alone influence significant changes in public health. There will need to be more holistic investments in waste management across all streams – greywater, solids including plastics, animal waste, etc. – for there to be a sustained and positive impact on the health of communities and especially those of marginalized communities. Greywater management, in particular, will be critical as exploitation and water stress continues to burden households, and recycled water can have a large role to play in continuing FSM in stress-prone regions of the country (Cisneros 2011). Future research is needed that studies the implementation and formalization of such technologies for FSM service delivery and sustainability.

6. CONCLUSION

India has made unprecedented gains in improving access to sanitation among rural households in the last 5 years. In the run-up to 2030, leveraging these gains to institute safely managed sanitation will be critical to meet the WASH-related targets under the SDGs. The diverse characteristics of rural settlements and the differential preferences in toilet technologies necessitate a multi-pronged approach to ensuring that faecal waste is safely collected, contained, conveyed, and treated before it is discharged into the open environment. The focus on mainstreaming urban FSM in India presents a tremendous opportunity to bridge the urban–rural divide that has been typical of infrastructure and investment planning under the development programmes in the country.

The FSM model used here could serve as an exemplar of urban–rural convergence for sanitation as the first district in the country that has successfully leveraged urban infrastructure for the delivery of FSM services to the adjacent rural areas. It has demonstrated how to institutionalize the urban–rural convergence working within complex and multi-jurisdictional governance systems. It underscores the importance of a robust landscape assessment, capacity building, and regulation in achieving sustainable urban–rural cooperation towards regional environmental sanitation. Lastly, it maximizes the use of the investment made in sanitation and highlights the importance of evolving new governance models in transcending administrative silos to create more efficient pathways and rapidly scalable shifts to safely managed sanitation.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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