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Research article



ICT-based solution for efficient fecal sludge management: An experience from Bangladesh

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ABSTRACT

In Bangladesh, people primarily depend on on-site sanitation facilities (OSSF) with an immense challenge in achieving safe sanitation due to unplanned infrastructure development, improper management of fecal sludge, and inadequate monitoring. The commitment of attaining Sustainable Development Goals (SDG) 6.2 (ensuring safe sanitation for all) by 2030 requires immediate attention in the management of fecal sludge for low-middle income countries. This paper presented the findings, challenges, and possible ways forward from a study conducted to provide data for Information and Communication Technology (ICT)-based fecal sludge management (FSM) at a municipality in the northwest of Bangladesh. A total of 18,808 households and 407 institutions in Saidpur municipality, a non-sewered town in Nilphamari district, were studied to understand the type of containment structures and on-ground desludging practices. The study showed around 10% of containments were connected to the drains illegally, 95% of the people in Saidpur practiced unsafe disposal, and 7% still practiced open defecation. To identify these malpractices, the study also implemented an ICT-based sustainable solution through a web

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application that enabled the local administrator to have a global look at the sanitation scenario of the municipality. The dashboard was developed to create a total sanitation monitoring system, identify defaulters, allow target-based safe managed sanitation service strategies, and ensure sustainability in FSM. The study highlighted the accessibility of vacuum truck services projecting through a spatial map and identified methods to empty the septic tanks where Vacutag services are unavailable by engaging local pit emptiers. The innovative approach of fecal sludge management will help not only to improve the existing sanitation practices but also raise community awareness to ensure sustainable sanitation system. Altogether, the web system will work as a medium to manage the faecal sludge for the existing co-compost plant where the faeces is converted into organic soil conditioner, creating prospects for a green business mechanism.

1. Introduction

The world is progressing towards achieving universal access to clean water and ensuring safe sanitation for all, according to the framework of the 2030 Agenda for Sustainable Development Goals (SDG) #6 [1]. At the same time, the Joint Monitoring Program (JMP) reflects that people will lack access to sanitation services in 2030 unless adequate steps are taken at the community level immediately [2]. Approximately 2.8 billion people of low-middle income countries get access to on-site sanitation technologies like pits and septic tanks where half of the sanitation systems are poorly designed and do not optimally treat human excreta [3–6]. Eventually, sludge ends up untreated in agricultural lands, drainage ditches, and open waterways. Thus, it causes environmental pollution and health hazards, risking human health and the natural environment [5,7–11]. The process of fecal sludge management from containment to disposal/end-use in low-middle income countries has a critical link that makes it difficult to treat the sludge for sustainable resource recovery [12].

Bangladesh is one of the low-middle income countries that falls under these challenges with countries across Asia and Africa. The municipal agencies in Bangladesh coordinate the desludging that in general lacks management structures, institutional arrangements, infrastructure, skills and financial systems to deliver proper services for sludge collection to disposal [3,13–15]. Due to this

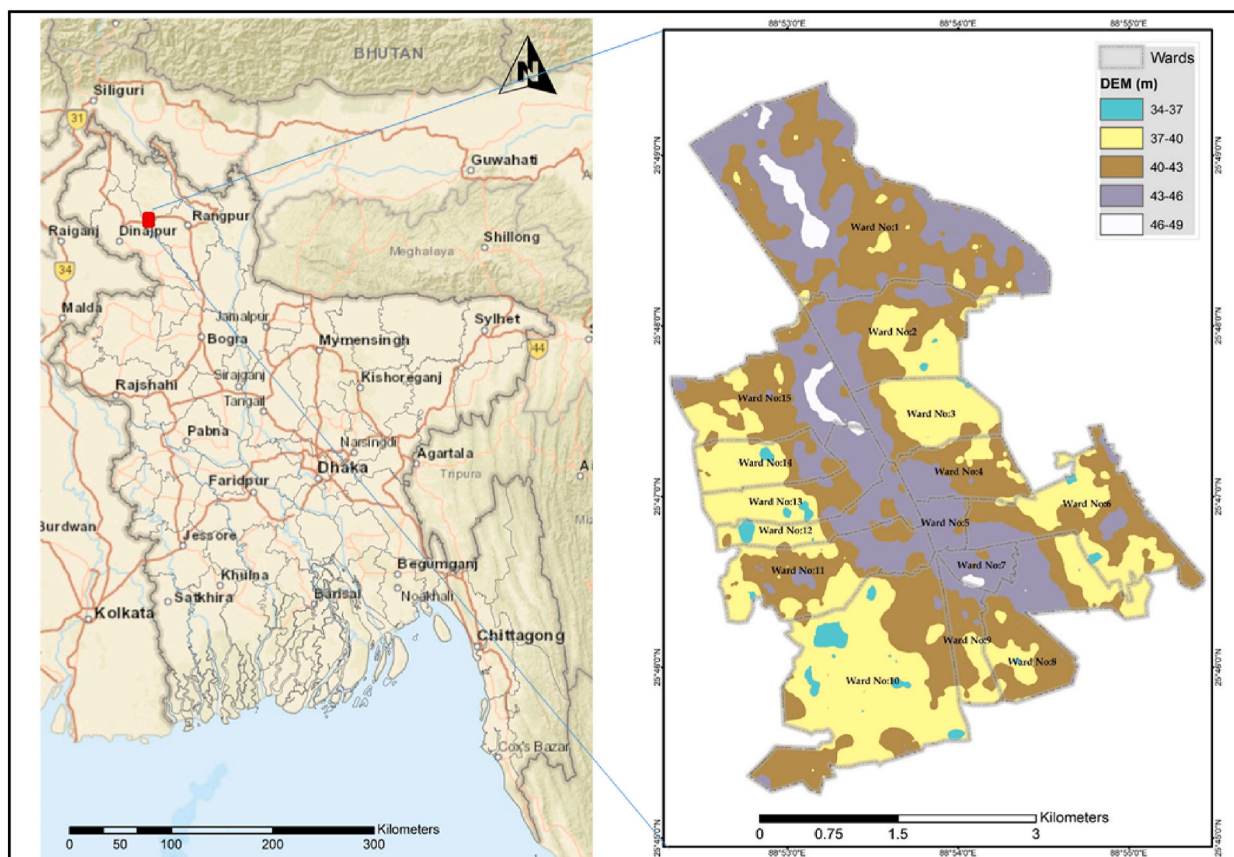


Fig. 1. Study area representing Saidpur Municipality (on right) in the Dinajpur district of Bangladesh (on left). The Saidpur Municipality map (on right) shows the 15 wards and reflects the demographics which was considered as our main study area.

mismangement, most people built their toilet containments independently without having proper knowledge about its design and desludging methods [11].

The aim of this paper is to develop an effective and sustainable ICT-based sanitation practice in a municipal area in Bangladesh. The paper focused on bringing the practical setbacks of safe sanitation in low-middle income countries under one umbrella by conducting a comprehensive study of the FSM in Saidpur municipality to identify the total sanitation practices. The study used a web application to identify key issues and the web-based solution documented storage, management and monitoring of the sanitation practices of the municipality. It aims to help the FSM service provider to locate houses that automatically need emptying services to avoid overflows. In addition, the local authority could track back and take necessary measures at the houses practicing unsafe containment and disposal. Moreover, this web application also contributes to the prospects of a green business mechanism where the faecal sludge is properly collected and transformed into organic soil conditioners for agricultural purposes. The ICT-based solution aims to increase access to equitable and sustainable safely-managed sanitation services to support and achieve SDG #6 through access to water and sanitation [16].

2. Materials and methods

2.1. Study area

The study was conducted in Saidpur municipality situated on the northern side of Nilphamari district in Bangladesh, which is part of the Rangpur division (Fig. 1). It covers a total of 34.82 sq. km area with a population density of 1,908 people per sq. km. It has a total population of 127,104 people, (59,204 men and 55,129 women) and the literacy rate is 63.9% for the population aged seven and above [17]. The city's total household population is 26,311 [18].

The history of Saidpur city dates back to the year 1870 when the British colonial regime was established in the area. The area is mainly inhabited by poor urban communities being Pakistani refugees (Bihari). Housing in this settlement is characterized by small semi-permanent structures, camps, and few apartments constructed in the both side of rail tracks of Saidpur having predominantly shallow pit latrines and septic tanks.

The study targeted all the households with single or shared household pit latrines and septic tanks to identify sanitation practices of communities and bottlenecks in fecal sludge management of the whole municipality consisting of 15 wards.

2.2. Assessing the sanitation situation for data collection

A questionnaire was prepared based on the objectives of the survey, which was divided into four parts that included households and different types of institutions (healthcare centres, educational institutions, marketplaces etc.). All the 18,808 households in the municipality and 407 institutions were surveyed after taking their informed consent. Most of the households were actively willing to participate, and their consent was taken verbally before the survey. Several attempts were made to cover the households where the residents were absent. The data collection was made easy due to the cooperation of City Corporation, who announced the onset of the project in the area beforehand.

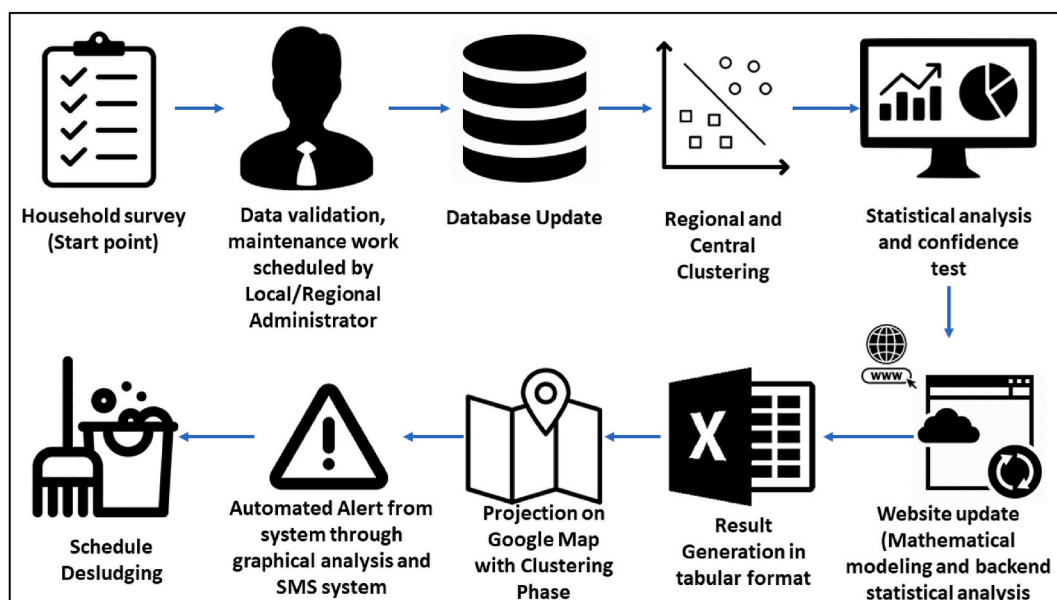


Fig. 2. Overall process flow of developing the web application.

A digital survey by the application called KoboCollect included close-ended questionnaires, semi-structured interviews, and spatial data, which covered the whole households and institutions of Saidpur in order to get first-hand data on their sanitation practices. Focus Group Discussion (FGD) and Key Informant Interviews (KII) were used as data collection tools, which enabled the interviewer to delve further into the subject of concern and develop a greater understanding of the situation at hand and cross-check with the field data to understand the major gaps.

A total of 20 FGDs were conducted with the selected heterogeneous group of respondents. The pattern of questions was open-ended and concentrated mostly on their strong views and perspectives regarding the management of solid waste and fecal sludge in their area, and the bottlenecks in the management system. A total of 18 KIIs were conducted with different stakeholders related to solid waste and fecal sludge management in Saidpur municipality. It helped to understand the key responsibilities of their role in management, their capacity and constraints, and future aspects they carry regarding safe sanitation practices.

2.3. Design of web application

A web application was designed to address the FSM issues in Saidpur with objectives of creating a total sanitation monitoring system for FSM, identifying defaulters, allowing target-based and safely-managed sanitation service strategies, and ensuring sustainability in FSM. A detailed model of the application is presented in Fig. 2.

The development started with a digital survey embedding the results into the dashboard and processed on a website. The results were displayed in the dashboard through graphical representations including an excel sheet. The system used the following equation:

$n = \text{estimated number of days}$

$V = \text{volume}$

$C = \text{sludge/feces generation rate}$

$P = \text{number of persons}$

$n = V/1.33CP$

An automatic alert generated in the dashboard through the calculation, which referred to a particular tank as full to the respective owner of the house mentioning the cleaning date and asking for a feedback reply. The Short Message Service (SMS) body held a dedicated Uniform Resource Locator (URL) to send their feedback about septic tank and pit status (full or not). If not, the end-users could set an estimated date in the system based on their observations. The system also tracked the number of times an end-user had been notified.

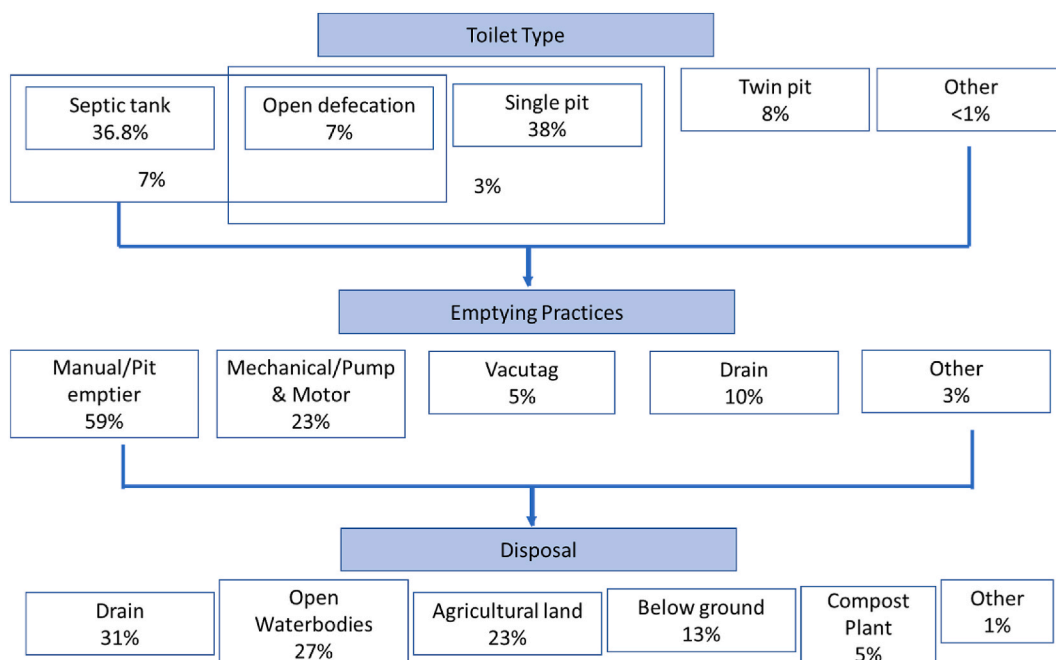


Fig. 3. The sanitation process of fecal sludge from toilet infrastructures, emptying practices to disposal.

3. Result

3.1. Sanitation situation in Saidpur municipality

The primary toilet containments in Saidpur municipality are septic tanks, used by 37% of the households. The pit toilets were divided into singular pits and twin pits, used by 46% of households. Less than 1% of the household turned their dug wells into a toilet containment (Fig. 3).

However, 10% of the households illegally connected their tanks with the drains and open waterbodies. Despite having sanitation infrastructure and services, there was around 7% of households that still practice open defecation. The existing containments were emptied in five different ways involving pit emptiers, motors, and vacuum trucks. Around 59% of the households, used pit emptiers with a bucket to empty their containments, other 23% used pit emptiers with a mechanical pump, and 5% of containments were emptied by vacuum truck known as Vacutag. The rest of the 10% of households admitted to connect their containments to drains, while 3% either cleaned their containments or waited for the monsoon season to open their tanks and clean by floodwater overflow.

After emptying the tanks, around 13% of the emptiers buried the sludge in the grounds, 23% disposed of in the agricultural land, 27% dumped in the water bodies, and the other 31% were either connected directly or dumped by the emptiers to the drains. Households also practiced washing away their sludge during the monsoon flood. Only 5% of the households' fecal sludge ended up at the compost plant after emptying the toilets. Hereby, the study considered only 5% to be a safe disposal procedure for the fecal sludge

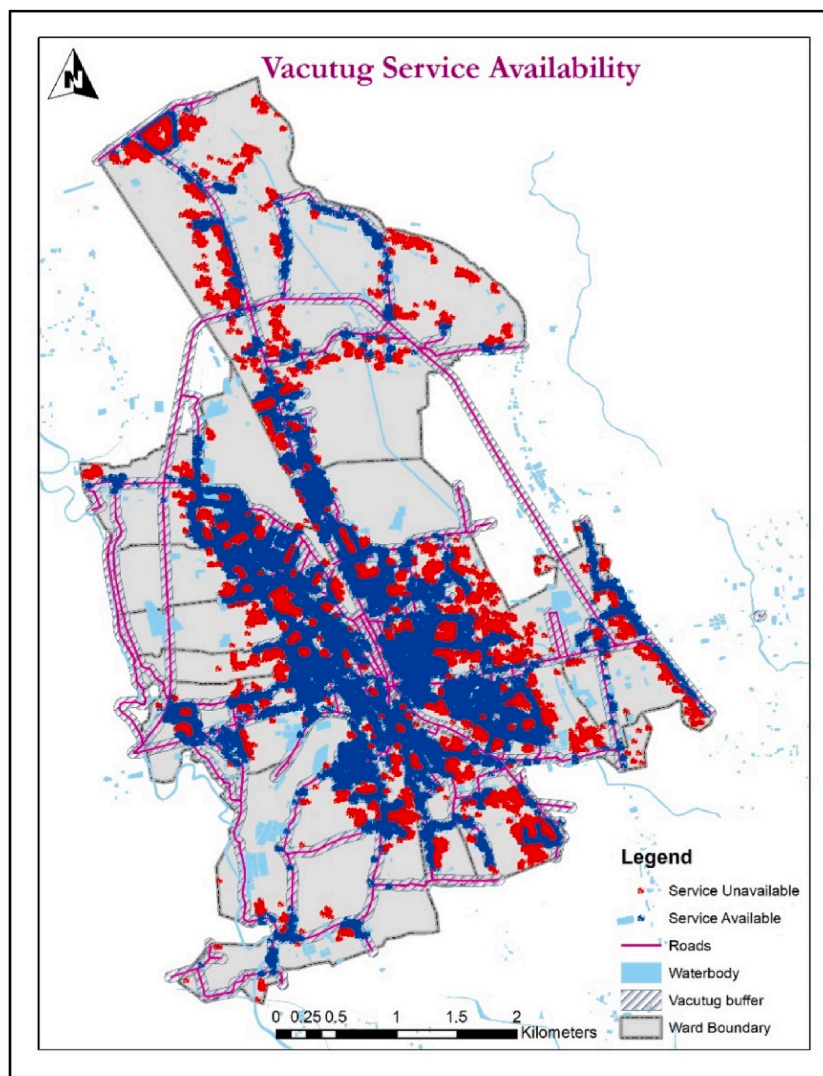


Fig. 4. Spatial map generated to mark the underserved areas where Vacutag services cannot be provided. The blue dots represent the areas where the service is available and the red dots are where it is unavailable. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

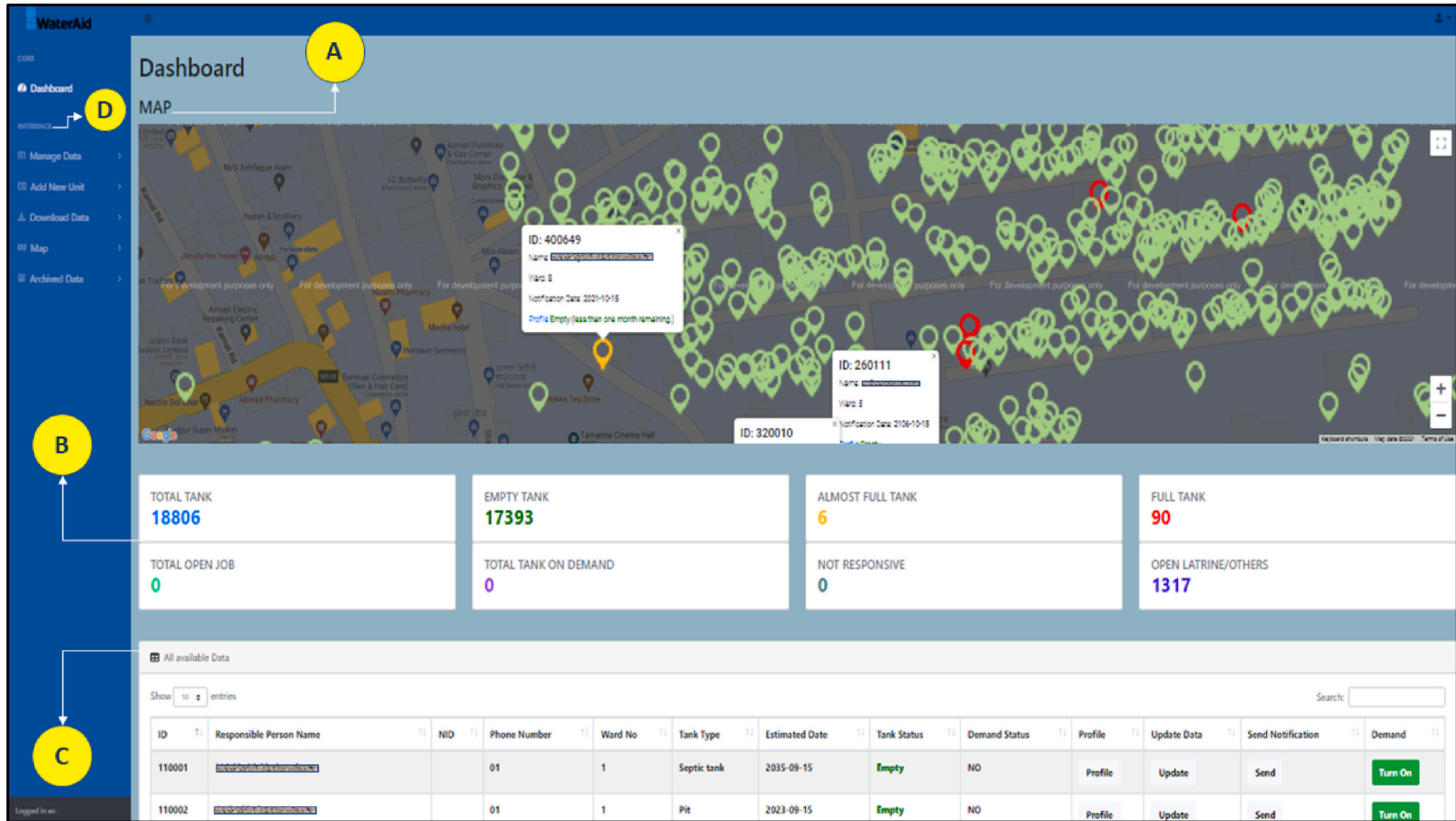


Fig. 5. The dashboard of the web application showing A: A map based on the tank status result (green, yellow and red) and visualize the tank locations, B: Overall status of the tanks, C: Details about toilet owners, D: Data Storage and Upload option. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

because the other 95% of the household's fecal sludge ultimately ended up in the drains, open waterbodies, and agricultural land. This eventually becomes hazardous for the environment and a threat to the human health.

3.2. Geographic information system (GIS)-aided strategy for desludging services: mechanical vs manual

The study identified a major dependency of people cleaning their tanks on pit emptiers either using buckets or mechanical pumps. The city corporation of Saidpur municipality introduced the vacuum truck services known as Vacutag to reduce the manual emptying by pit emptiers for its dangerous exposure to their health. However, the Vacutags were not widely popular due to their cost, accessibility, and long application procedure resulting in only 5% availability of this service since its introduction in 2012.

There are more than 200 pit emptiers in Saidpur municipality whose livelihood depends on this job for generations. The sudden change from manual to mechanical service like Vacutag directly jeopardized the livelihood of the pit emptiers overall. Hence, to ensure secure livelihood and enhancing the service of Vacutag, the study generated an accessibility route map of the Vacutag service allowing the local administrator to mark the unreachable and accessible areas for Vacutag service (Fig. 4).

3.3. Web application to ensure total sanitation and zero waste concept

The on-site sanitation facilities are independently structured without connection to the mainstream sewage system, making it a challenge to manage and monitor fecal sludge situations through a centralized authority. It is very critical to identify problems as the sanitation infrastructure varies widely from socio-economic structure. The management dealing with fecal sludge lacks manpower, technical support and inadequate application system of the emptying service. Here, our study has developed a web-based application capable of acting as an ICT tool to display the existing sanitation situation of an area through a dashboard to efficiently manage, alert, and guide the emerging fecal sludge issues (Fig. 5).

For the implementation of the web application, the study has analyzed a part of the sanitation value chain for Saidpur municipality and has identified major issues such as unsafe faeces disposal, illegal containment connection to drains, and unable to identify emptying demand. The web application advances the technology of information storage and communication to resist major setbacks through spatial information, mathematical model, and data of the households under one platform.

The system ran an automated mathematical model in the back-end to estimate the date to clean a certain septic tank based on the number of persons a residence has, household size and containment volume. As the system automatically detected the respective septic tank of any household reaching the estimated date for cleaning, an automatic alert generated in the system's dashboard referring to that particular tank as full. Then, the system administrator could send an SMS to the respective owner of the house mentioning the cleaning date and asking for reply feedback if the tank was ready/filled for cleaning. It was also customized to flag those individuals who do not participate in the cleaning procedure accordingly.

The web system (website) landed on a login/sign-up page for the local administrator. After login, the user was directed to the dashboard page, which carried all the summarized and vital information of the system. The dashboard held an interactive map that was updated in real-time. From the map, users could easily visualize the positions of the septic tanks, and markers placed in the map indicate the status of the tank. Clicking upon each marker a summary would pop up describing vital information on the tank. The markers were color-coded accordingly to guide the administrator of field-level workers. The red, yellow and green colors represented full tank, almost full tank and empty tank respectively.

The web-based platform was a transforming agent for municipalities to move from on-demand emptying services to scheduled desludging services for fecal sludge. The study also made the system sustainable considering the fact that toilet number or household number can increase in the future by adding a unit where the local administrator can either manually input toilet details or upload a data sheet of the additional information.

WaterAid has already established a co-compost plant where faeces are converted into organic soil conditioners by adding organic solid waste and saw dust. The web application plays a vital role to gather and allocate adequate raw materials for the compost as it aims to collect faecal sludge from every household and institution in a standardized way. The system will not only help the local administration to allocate faecal sludge services in terms of monitoring, information storage and collection but also, work as a medium to encourage the city to shape themselves towards a city with 100% safely managed sanitation services.

4. Discussion

Sustainable Development Goal 6 aims to meet universal sanitation by 2030. However, this coverage only met the toilet amenities of a community rather than focusing on the management aspects of their sanitation facilities. Thus, it emerges an alarming concern whether countries are not on track in working towards sanitation for all as depicted by SDG 6. In order to be familiar with the sanitation situation of an area, a comprehensive survey is essential along with a sustainable management solution. Such solution needs to include infrastructure, robust monitoring and management to attain safe sanitation as reflected in this study. Recently, the SDG 9 has recognized the need to create knowledge societies where everyone has access to education and interpersonal interactions, which emphasizes the importance of having access to ICTs [19]. In order to align with the current emphasis, the study implemented an ICT-based fecal sludge management system to digitize the surveillance procedure. This reduced unsafe disposal of faecal sludge and help the municipality to acquire enough raw materials to turn it into organic compost for the prospect of green business through a web application. This is a powerful tool to streamline all the fecal sludge issues and status of the existing sanitation infrastructures and emptying services. It also assists disposal practices of an area under one platform, which will eventually help the local administrator to

assemble their management strategies according to the issues.

The illegal connection of tanks to open waterbodies/drains, 95% unsafe disposal of faeces and 7% open defecation practice have been a serious threat to the environment and human health in Saidpur municipality. These major issues are not only emerging in Saidpur but also in other low-middle income countries where there are no designated disposal points [11]. The dashboard enhanced the knowledge of local authorities regarding these issues and enabled them to take adequate action, such as penalizing them or raising awareness with a target to turn the municipality into a zero-waste town. Accordingly, this study has identified that even when Bangladesh has made a remarkable reduction of open defecation from 34% from 1990 to 0% in 2017, there are still people in small towns who practice open defecation including the 7% in Saidpur municipality. This identification of the number of households defecating openly allow the municipality to allocate resources for them in a proper way to stop open defecation completely. It will directly contribute to achieving SDG 6.2 to give access to adequate and equitable sanitation and hygiene for all and end open defecation by 2030.

Fig. 4 map will help the municipality to allocate and distribute services among the Vacutag and sanitation workers to empty the containments. The municipality should allocate pit emptiers with proper health and safety to improve public health and quality of life. The ICT tool will make it easier to locate houses that need the service before its emptying date, the local people no longer have to wait for a time-consuming application process to clean the septic tank. This efficient service method will work as a benefit to the locals as they will be more encouraged to take the service from the municipality and reduce the practice of connecting to drains. Also, it can act as a vital tool for the total collection of faecal sludge from every household in the use of prospective compost production in the co-compost plant. The website was built in such a way that it will not only be concentrated for Saidpur municipality but can be replicated to the different municipalities as well. If it is incorporated in every municipality, the whole system of emptying service of the fecal sludge will be swifter and less time-consuming in the future both for the local community and the municipality.

The systematic management of the faecal sludge through the dashboard contribute to the prospects of a green business mechanism where the proper collection of faecal sludge will create raw materials to make organic compost for fertilization. The sludge sent to the compost plant built in Saidpur by WaterAid, Bangladesh reflects prospect of green business for organic composts. This is beneficial for farmers as it is a high-quality soil fertilizer in Bangladesh. As a result, the web application will help expand the water and sanitation support to low-middle income countries which is target 6.A of SDG 6. Alongside, Indicator 6.B.1 of SDG 6 is the proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management. This will be achieved by the evident engagement of local support in terms of operating, monitoring and implementation of the web application in the municipality level.

Nevertheless, it is important to consider normalizing the usage of the web application for monitoring and establishing a digital management system for fecal sludge. As it is a new approach for the community, there will be constraints in adapting to the system as they will be mostly drawn towards traditional and unfunctional way. Hence, to motivate people there should be scope for environmental management measures in influencing the human behaviour towards safe sanitation system. Since, community are most likely to follow the conventional way, there can be a regulatory instrument imposed involving laws, policies and penalties which will bound people more to use it, at first. Gradually, the system can move towards more soft measures like economic instruments or suasive instruments to influence people to continue using the web application as a tool to manage their fecal sludge.

Bangladesh shares a similar sanitation scenario as other low-middle income countries, based on on-site sanitation systems [16]. Thus, the study is limited to the low-middle income countries where on-site sanitation systems exist. These on-site containments need emptying once full done manually or mechanically. However, these emptying services are not stored in data or can detect the illegal practices of people connecting their tanks to drains and open water bodies. Hence, the web application is a benefit to the municipalities of Bangladesh as well as other regional countries that need safe sanitation and hygiene. If sanitation is not incorporated, then the risk of transmission of diarrhoeal diseases such as cholera and dysentery, as well as typhoid, intestinal worm infections and polio increases by many folds.

5. Conclusion

Based on the sanitation process of every low-middle income country, it is difficult to determine whether we are achieving total sanitation only by considering the availability of toilet facilities in an area. It is also important to appraise the in-depth issues related to the sludge generation and disposal of these toilet facilities along with its availability in order to adequately determine 100% sanitation of an area. There is no existing method till now that can give us a whole sanitation scenario of a particular region. In this context, to work towards the total sanitation goal, the web application will help to unveil the comprehensive picture of fecal sludge issues, which usually stays unknown to the local administrator while making management decisions in aspects of fecal sludge collection, emptying, and disposal. The study also identified underserved areas where the Vacutag services are unavailable. The dashboard of the web application will work as a proactive tool both for awareness purposes and problem identification tools in the management system of fecal sludge in an area. The web application is not limited to Saidpur municipality but has features that are versatile for all the regional countries sharing similar on-site sanitation facilities. It is quite difficult for the local concerned authority to identify the defaulters from 18,808 houses in Saidpur municipality; the dashboard created an opportunity for them here to have a global look at all the households together under one platform. The dashboard automatically highlighted the number of houses that are not responding to the emptying alert and thus, the local administrator could take action accordingly identifying the defaulters. The web application will not only contribute to eradicating the fecal sludge issues in the Saidpur municipality but also help raising community awareness, which will ultimately help to ensure safe sanitation. Simultaneously contribute to the newly established co-compost plant in the Saidpur municipality. It will help manage the faecal sludge to produce raw materials for the compost plant where the sludge converts into organic

compost, promoting circular economy. However, concerns over infection risk are present hence, it is highly noted that WaterAid Bangladesh has incorporated establishment to reduce the risk of infection during composting in their compost plant before marketing to the locals. In this way, the web application will be a potential tool to encourage green business in the community and promote the notion of zero waste generation with an aim of a total sanitation approach.

Author contribution statement

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Md. Jakariya, Turasa Nahla, Silvia Ahmed, Ahmed Ali: Performed the experiments.

Md. Jakariya, Turasa Nahla, Silvia Ahmed, Marufa Ferdousi, Md. Tahmidul Islam, Md. Sajadul Alam, Ahmed Ali, Saman Saad, Ragib Ahmed: Analyzed and interpreted the data. Md. Jakariya, Turasa Nahla, Silvia Ahmed, Taoseef Ishtiak, Md. Sajadul Alam, Md. Sharif Uddin Ruman, Kazi Al Amin, Sumon Kumar Saha, Imamur Rahman, Hossain I. Adib: Contributed reagents, materials, analysis tools or data: Md. Jakariya, Turasa Nahla, Md. Shakhawat Hossain, Marufa Ferdousi, Lamia Mahzabin, Ragib Ahmed, Mohammed Fahim Murshed, Md. Aminul Islam, Saman Saad, Tom Van der Voorn, Damià Barceló, Christian Sonne: Wrote the paper.

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Data availability statement

Data included in article/supp. material/referenced in article.

Additional information

Supplementary content related to this article has been published online at [URL].

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.heliyon.2023.e15200>.

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