



Multi-Criterial Decision Support Framework for Faecal Sludge Management in Informal Settlement: Balancing Technical Feasibility, Financial Sustainability, and Community Participation in Mwanza, Tanzania

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Abstract

Proper faecal sludge management in urban informal settlement continues to be a significant sanitation challenges in Sub-Saharan Africa. This research presents extensive multi-criterial decision support framework that integrates technical, financial and social aspects of faecal sludge management in Igogo Ward Mwanza City in Tanzania. Convergent mixed methods design was employed which combined structured household surveys (n=379), key informant interviews (n=18), and focus group discussion (n=2; 10 participants total). Geographic Information Systems were used for spatial and multi-criterial analysis. The Results was 84.7% of households used pit latrines, 56.0% non-lines pit, 78.7% were inaccessible to emptying by trucks and 47.3% of latrine were located in floods prone areas. The willingness to pay sanitation services (82,109 TZS) was lower than the price of manual emptying (90,192 TZS), which illustrates the affordability gap. Household income was the factor that had statistically significant effect on willingness to pay ($R^2 = 0.784$, $P < 0.001$). Average per capital water consumption (67.3L/day) was significantly below WHO requirement of 100L/day which resulted in degradation of sanitation facilities. The research recommends intermediate emptying technology, flexible mobile payments system, targeted subsidies, improved institutional enforcement and integrated water-sanitation planning to enhance faecal sludge management in Tanzania and support progress toward SDG 6.2..

Keywords · Faecal sludge management, Informal settlements, Multi-criteria optimization, Onsite sanitation, Sub-Saharan Africa, Willingness-to-pay

1. Introduction

Faecal sludge management remains a major sanitation challenge in rapidly growing urban areas of Sub-Saharan Africa, where most resident depend on on-site sanitation facilities instead of sewerage system. Poor faecal sludge management practices in informal settlement contributes to serious public health and environment risk especially in flood-prone areas (Mremi et al., 2025; Niwagaba et al., 2025).

Globally, the population living in informal urban settlement is projected to reach two billion by 2030, with most resident in Sub-Saharan Africa relying on pit latrine as a primary sanitation option (Simiyu et al., 2021; Muoghalu et al., 2023). High population density, narrow access roads, unplanned settlement and

inadequate infrastructure creates major barriers to Sanitation Act (2019), demonstrating a gap between

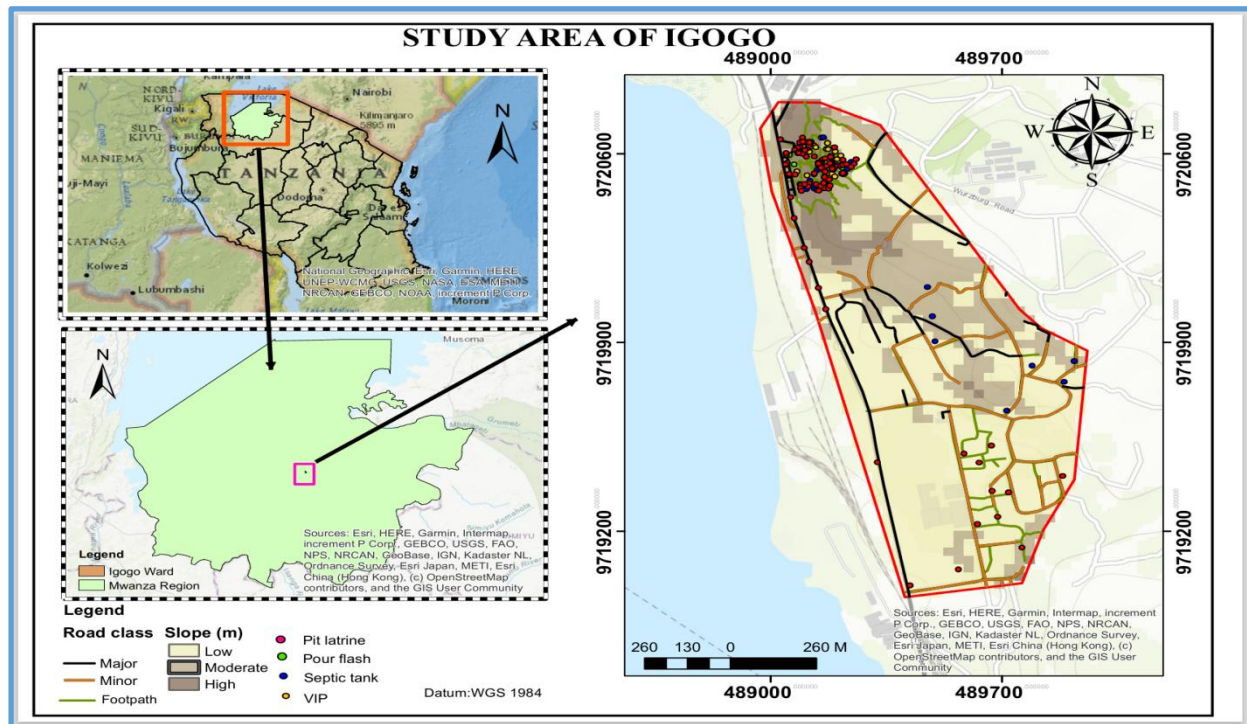


Figure 1: Location map of the study area

effective sludge emptying and transportation service. These condition, combined with weak institution capacity highlighting the need for context-specific optimization framework that integrate technical, financial, institution and social consideration.

Despite the global commitment under Sustainable Development Goal 6.2 to archive safely managed sanitation for all by 2030, access to affordable and efficient emptying services remains limited for low income households in informal settlement. Reviews on willingness to pay determinants reveal significant gaps in understanding household decision making and the financial sustainability of improved emptying services (Tomoi et al., 2024). In addition, studies on regulatory enforcement indicate inadequate and outdated institutional framework governing faecal sludge management services in many Sub-Saharan Africa cities (Luhiriri et al., 2022). These challenges persist Tanzania's policy frameworks, including the National Water Policy (2025) and the Water Supply and

policy formulation and local implementation.

Previous studies have mainly focused on ether technical or socio-economic aspect of faecal sludge management without integrating both dimensions. For example, faecal sludge accumulation rate of 214 liters per capita per year for pit latrine and 348 liters for septic tank were reported in Kampala's informal settlements as threat for people living in informal settlement (Niwabage et al., 2025). However, financial sustainability, institutional coordination and community participation have received limited attention in optimization studies. Evidence suggests that weak and fragmented institutional and legislative framework are among the major cause of ineffective faecal sludge management system (Muoghalu et al., 2023).

This study addresses these gaps by developing an integrated multi-criterial decision support framework that combine technical, financial, institution and social

dimension. The research also provides empirical evidence from high density informal settlement in Mwanza using mixed methods involving technical assessment, socio-economic analysis, geographic mapping and stakeholder engagement. The finding will support Tanzania's Development vision 2050 and contribute to achieving Sustainable Development Goals 6.2 through improved sanitation services, environmental protection and enhanced public health in urban informal settlements.

2. Materials and Methods

2.1 Case Study Description

Igogo Ward in Nyamagana District, Mwanza City, Tanzania, was the case study site chosen for this research, as it is representative of the sanitation challenges in Urban informal settlements, which are common in many parts of Sub-Saharan Africa (Fig. 1). This ward is located on about 235 hectares and its population was estimated to be 25,515 according to the 2022 National Census of Tanzania. The City of Mwanza, built on the southern shores of Lake Victoria, is the second largest urban center in Tanzania. It is facing specific challenges such as very narrow access paths, and a lack of sewerage systems. To support this, Geospatial characterization made use of high-resolution Sentinel-2 satellite images (10-meter resolution) combined with ground-truthing surveys that helped to define the boundaries of settlements and locate the zones that are prone to flooding (Alemayehu et al., 2024).

2.2 Research Design

This study adopted a convergent parallel mixed-methods design, combining quantitative technical assessment with qualitative stakeholder perspective to develop a comprehensive faecal sludge management optimization framework. Quantitative methods included sanitation infrastructure assessment, pit measurement and cost analysis of emptying services, while qualitative method involved semi-structured interview and focus group discussion to capture community, institution and socio-cultural factors. Data

collection was conducted in three phases: technical feasibility assessment, socio-economic household surveys and integration of finding into optimization model.

2.3 Sampling Design

Regarding sample size, Cochran's formula for finite populations was used along with a design effect as an adjustment for intra-cluster correlation in informal settlements Equation 1, (Cochran, W. G. 1977).

Where n is the desired sample size, Z is 1.96 (95% confidence level), p is 0.5 (maximum variability), q becomes $1-p$, e is 0.05 (margin of error), N stands for

$$n = \frac{Z^2 \times p \times q \times N}{e^2 \times (N - 1) + Z^2 \times p \times q} \times DEFF \quad (1)$$

25,515 households, and DEFF equals 2.0 (design effect).

The sample size determined by calculation was 379 households. Using a multistage stratified random sampling approach, we obtained a good representation of the different parts and socio-economic groups of Igogo Ward. This stratification was based on three sub-zones defined by topographic features and accessibility patterns: Zone A (high accessibility, 35%, $n = 140$). Zone B (moderate accessibility, 42%, $n = 168$) and Zone C (low accessibility, 23%, $n = 92$)- (Sisay et al., 2024; Ejekwu et al., 2025).

Systematic random sampling within each of the stratified zones, first making lists of households with the help of local leaders. We found random starting points using random number generation and then selected every k th house, where the sampling interval k was derived (equation 2)

$$k = \frac{N^h}{n^h} \quad (2)$$

where N^h represents the total number of households in stratum h and n^h stands for allocated sample size. Non-contact replacements procedures were

implemented after three unsuccessful visit attempts, with the replacement being done by the nearest adjacent household following a predetermined clockwise directional protocol. The primary respondents were adult household members (≥ 18 years) with sanitation decision-making authority.

The key informants for sampling were chosen through purposive criterion-based selection resulting in 18 individuals with specialized knowledge, including municipal sanitation officers ($n = 4$), private emptying operators ($n = 6$), community health workers ($n = 3$), ward-level political leaders ($n = 2$), and NGO representatives ($n = 3$). Two focus group discussions (each group having 5 participants; 10 participants total) involved different demographic segments including women, youth, and elderly residents (Muoghalu et al., 2023). It is acknowledged that two FGDs represent a limited qualitative base for a ward of 25,515 people, and full thematic saturation across all gender, youth, and elderly perspectives cannot be claimed. This is noted as a limitation of the study.

2.4 Data Collection Procedures

Data collection process was implemented by four trained enumerators who were recruited from local universities and had backgrounds in environmental health and social sciences. A three-day intensive training workshop addressed the topics of research ethics protocols, questionnaire administration techniques, informed consent procedures, and using mobile data collection platform Kobo Toolbox deployed on Android tablets with offline functionality (Blackett et al., 2024). Using structured questionnaires administered through face-to-face interviews in Swahili language and data was collected on household demographics, sanitation facility characteristics, emptying practices, service costs, and willingness-to-pay for improved services.

Willingness-to-pay elicitation used double-bounded dichotomous-choice contingent valuation methodology. Respondents firstly expressed acceptance of randomly assigned initial bid amounts

(20,000, 40,000, 60,000, 80,000, 100,000, or 120,000 TZS), then depending on first responses, they were presented with higher or lower follow-up bids. Besides giving an estimate which is more statistically efficient than single-bounded formats, this double-bounded approach also ameliorates starting point bias (Hanemann et al., 1991; Abu Hatab et al., 2025). Physical inspection of sanitation facilities was conducted using standard checklists that were derived from the WHO sanitation safety planning framework and adapted for Sub-Saharan African informal settlements (Alemayehu et al., 2024; Niwagaba et al., 2025).

The data collection instruments recorded pit latrine measurements (depth, diameter and volume), type of lining materials (unlined, partial lining, full lining with concrete rings or brick), structural integrity levels, and superstructure construction materials. Volume computations were made using a cylindrical volume formula for circular pits ($V = \pi r^2 h$) and volume of the rectangular prism formula for square pits ($V = l \times w \times h$), where V stands for volume in cubic meters, r is the radius, h is the depth, l is the length, and w is the width in meters.

For the assessment of faecal sludge volume in-situ, Volaser ultrasonic device was used in accordance with standardized protocols. Sludge accumulation rates were determined based on the well-known methodology (Equation 3):

$$AR = \frac{V \times 1000}{N \times T} \quad (3)$$

Where AR indicates the accumulation rate (L/capita/year), V =sludge volume (m^3), N = number of users, and T = facility age (years).

This approach follows the International Water Association standards and has also been tested successfully in similar urban areas (Niwagaba et al., 2025; Strande et al., 2018).

For the accessibility mapping, GPS coordinates with a ± 3 meters' horizontal accuracy were used to calculate the distance from the pit at a household level to the nearest vehicular access point.

Using these distances, three levels of accessibility were defined: high accessibility (< 10 meters), moderate accessibility (10-30 meters), and low accessibility (> 30 meters).

Assessment of road accessibility included measurement of road widths, documenting surface conditions and turning radii. The classification of areas into accessible (≥ 3 meters' width, stable surface) or inaccessible was done based on these factors.

Semi-structured interviews starting from the institutional setups and framework, regulatory enforcement mechanisms, service delivery difficulties, and policy governance structures. The interview guides, based on a semi-structured format, not only allowed a systematic comparison but also gave us the opportunity to delve into and discover new themes (Luhiriri et al., 2022).

Focus group discussions facilitated by participatory methods such as problem trees, preference rankings, and seasonal calendars were used to extract community thoughts and barriers to accessing hygienic emptying services. With the permission of the participants, all qualitative recordings were audio-recorded and the transcripts were made word for word and then translations done from Kiswahili to English by certified translators. Document analysis of policy frameworks including the Tanzania Water Supply and Sanitation Act (2019), National Water Policy (2025), and Mwanza City Council sanitation bylaws identified regulatory requirements and compliance monitoring procedures.

Verbal informed consent was obtained in Swahili, and at the same time participants received explanation sheets containing the study purpose, voluntary

participation, confidentiality safeguards, and the right to withdraw.

2.5 Statistical Analysis Methods

Quantitative data were analyzed with R Software version 4.3.2 and IBM SPSS Statistics version 28. Descriptive statistics described sample demographics, sanitation facility characteristics, and service utilization patterns by frequency distributions, measures of central tendency (mean, median), and dispersion (standard deviation, interquartile range).

Percentages and frequencies were used to summarize categorical variables whereas the continuous variables were reported as means with 95% confidence intervals for the normally distributed data and medians with interquartile ranges for the non-normal data (Alemayehu et al., 2024).

The Shapiro-Wilk test for samples below 2,000 observations and Kolmogorov-Smirnov test for the larger ones were used to check the normality which helped in selecting the right parametric or non-parametric tests.

Chi-square test of independence was used to check if there was any association between the categorical variables such as type of sanitation system, status of lining (lining or not), accessibility category, and socio-economic characteristics of households. The chi-square test statistic was computed (equation 4)

$$X^2 = \sum \left\{ \frac{(O - E)^2}{E} \right\} \quad (4)$$

where O is the observed frequencies while E is the expected frequencies.

Interval regression was our tool of choice for estimating willingness-to-pay, as it perfectly matched the data format of double-bounded dichotomous choice. The model formulates willingness-to-pay as a

$$WTP_i = \alpha + \beta_1 INCOME_i + \beta_2 EDUCATION_i + \beta_3 HHSIZE_i + \beta_4 DISTANCE_i + \beta_5 FLOOD_i + \varepsilon_i \quad (5)$$

function of a number of household characteristics. (See Equation 5)

In equation 5, WTP stands for willingness-to-pay, INCOME is monthly household income, EDUCATION is years of formal education, HHSIZE is household size, DISTANCE is distance to treatment facility, FLOOD refers to flood exposure, and ε is the error term. To determine these models, ordinary least squares with a stepwise variable selection that uses the Akaike Information Criterion (AIC) for parsimony were conducted. Several regression-based methods have been successfully applied in estimating factors of willingness to pay (Tomoi et al., 2024; Abu Hatab et al., 2025).

The reason to use binary logistic regression was to identify the different factors determining the households' decision in using improved mechanized emptying services versus manual methods. The logistic regression model calculated the likelihoods of service adoption as natural logarithm of odds (equation 6).

$$\text{logit}(p) = \ln \left\{ \frac{p}{1-p} \right\} = \beta_0 + \beta_1 X_1 + \dots + \beta_k X_k \quad (6)$$

Where p represents the probability of adopting new and improved services. To express the impact of one unit, change in the predictor variables in terms of multiplicative effects, the odds ratios were derived by exponentiation the model coefficients ($OR = e^{\beta}$). The model performance was assessed by means of the Hosmer-Lemeshow goodness-of-fit test, classification accuracy and the area under the receiver operating characteristic curve (AUC-ROC) (Tomoi et al., 2024).

2.6 Model Assumptions and Validation

Partial regression plots were used to check the linearity assumption by looking at the partial relationships between the predictors and the dependent variable, after the other predictors have been taken into account. The linearity assumption was also indirectly checked by assessing the component-plus-residual (or partial residual) plots for the presence of the non-linear

patterns (Nkwasa et al., 2024). Variables like income and current emptying costs, which showed high skews, were log-transformed using the natural log function for improving the linearity of the relationships and also for making the residuals distribution close to normal.

Multi-collinearity was checked by calculating the variance inflation factor (VIF) for each predictor. VIF is the reciprocal of tolerance (equation 7). The tolerance is the 1 R-squared value of a regression of that variable on all the others.

$$VIF_j = \frac{1}{(1 - R^2_j)} \quad (7)$$

where R^2_j is the coefficient of determination from regressing predictor X_j on all other predictors,

Values of VIF greater than 10 indicate that multi-collinearity is so severe that it requires the removal of variables, the combination of variables, or the use of principal components regression as a means of solving

the problem (Alemayehu et al., 2024; Kalnins and Hill, 2025). Tolerance levels, which are the reciprocal of the VIF, below 0.1 were one more indication of too much collinearity. Condition indices based on the eigenvalue decomposition of the correlation matrix were a further measure of structural multi-collinearity. Reaching a value of more than 30 means that the variance proportions should be examined. To check the assumption of normality of residual, quantile-quantile (Q-Q) plots of the standardized residuals against the theoretical normal distribution were used, a significant departure from the diagonal reference line was indicative of non-normality (Blackett et al., 2024). At a significance level of $p < 0.05$, the null hypothesis of normally distributed residuals is rejected. As an alternative test for large samples, the Kolmogorov-

Smirnov test was used. Histograms with a normal curve superimposed provide a very intuitive way to check the distributional shape, skewness, and kurtosis. When the normality assumption of residuals was violated, transformations (logarithmic, square root, Box-Cox) or non-parametric alternatives were used.

Homoscedasticity was examined by looking at residual plots that displayed standardized residuals against predicted values; funnel-shaped or other systematic patterns are signs of homoscedasticity violations (Niwaigaba et al., 2025). The Breusch-Pagan test, which involves regressing the squared residuals on the predictor variables, was used to formally test for homoscedasticity. The test statistic (equation 8)

$$BP = n \times R_e^2 \sim X_k^2 \quad (8)$$

where n is the sample size, R_e^2 is the coefficient of determination from an auxiliary regression, and k stands for the number of predictors.

Residual analysis was helpful to find influential data points and outliers which might be distorting the parameter estimates. Standardized residuals that were more than ± 3 standard deviations from the mean were considered to be potential outliers. Cook's distance was a measure of the influence of a single observation on the regression coefficients, and it was computed as equation 9.

$$D_i = \left\{ \frac{e_i^2}{k \times MSE} \right\} \times \left\{ \frac{h_{ii}}{(1 - h_{ii}^2)} \right\} \quad (9)$$

where e_i means the residual of observation i , MSE is the mean squared error, k refers to the number of parameters, and h_{ii} denotes leverage and Cases with values greater than $4/n$ were considered major outliers.

Durbin-Watson test statistic was used to check independence of residuals, and it was computed as per equation 10.

$$DW = \sum \frac{(e_i - e_{i-1})^2}{\sum e_i^2} \quad (10)$$

Values close to 2.0 represented no autocorrelation, on the other hand, strong departures hinted at violations which led to the use of generalized least squares or mixed effects models incorporating spatial correlation structures. For spatial data, Moran's I was used to detect spatial autocorrelation in residuals

$$I = \frac{\left(\frac{N}{W}\right) \times \{\sum_i \sum_j w_{ij}(x_i - \bar{x})\}}{\sum_i (x_i - \bar{x})^2} \quad (11)$$

(Alemayehu et al., 2024). Runs test was the non-parametric test that evaluated the randomness of residuals over the sequence of observations.

Internal validation was through cross-validation methods, with the whole dataset being randomly divided 70:30 into training and testing sets. Models trained on training data were checked for validity on the testing data. Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) were used to measure how good the predictions were. Sensitivity analysis was carried out to test the model's reliability by changing systematically the input parameters by $\pm 20\%$. Results changing less than 10% showed stable model performance. Monte Carlo simulation (10,000 iterations) was used to analyze the spread of uncertainty in decision-making framework by characterizing input uncertainties through probability

distributions.

2.7 Spatial and Multi-criteria Analysis

Geographic Information Systems analysis utilized ArcGIS P software to visualize spatial service coverage of sanitation system and lack of accessibility of Igogo Ward. Kernel density estimation was used to pinpoint areas with high concentration of underserved ones, hence, the need for intervention to be given top priority. Network analysis discovered the best routes for vacuum trucks that, on one hand, minimize the

distances travelled and, on the other hand, maximize the number of households serviced. Spatial autocorrelation analysis made use of Moran's I statistic to examine clustering patterns in the perception of service quality, computed as (equation 11)

Where N represents the number of spatial units, W is the total of spatial weights, w_{ij} shows the spatial weight between locations i and j , x_i is the value of the variable at location i , and $\bar{x}$ is the mean of variable. Significant positive Moran's I values pointed out spatial clustering which led to targeted service improvements (Chen, 2013; Li et al., 2023).

Analytical Hierarchy Process (AHP) broke down faecal sludge management optimization into a hierarchy of criteria such as technical feasibility, financial sustainability, institutional capacity, environmental protection, and community acceptance. Pairwise comparison matrices helped experts to express their judgments on relative criterion importance. Consistency ratios that are based on equation 12 were used to check the reliability of judgments

$$CR = \frac{CI}{RI} \quad (12)$$

Where CR = consistency ratio, CI = consistency index, and RI = random consistency index. A judgment consistency was considered acceptable for CR values below 0.10. [Weighted criterion scores were combined to determine the overall suitability of alternative management scenarios (Equation 13).

$$S_i = \sum_j w_j \times x_{ij} \quad (13)$$

Where S_i = suitability score for alternative i , w_j = weight for criterion j , and x_{ij} = normalized score for alternative i on criterion j .

2.8 Qualitative Data Analysis

Qualitative interview transcripts were coded thematically according to Braun and Clarke's

approach. The initial coding involved the use of both deductive codes based on the conceptual framework and inductive codes that were derived from the data. NVivo 14 facilitated organizing, coding, retrieving, and visualizing the network of thematic relationships. Two researchers independently coded 20% of the transcripts to measure the inter-coder reliability; Cohen's kappa was calculated as 0.78, showing a high level of agreement (Muoghalu et al., 2023). The process of triangulation combined quantitative survey findings and qualitative themes in order to identify the areas of convergence, complementarity, and discordance.

3. Results and Discussion

3.1 Results

3.1.1 Demographic and Socioeconomic Characteristics

The demographic profile of households surveyed mirrored the demographic features of the crowded informal settlements in secondary cities of East Africa. Generally, after analyses the raw data shows that Female respondents were 56.7%, whereas male respondents were 43.3% as shown in Figure 2A. The gender distribution shows women to be the primary managers of household sanitation, which is the common trend in the Sub-Saharan Africa (SSA) region. Women were confirmed as the ones responsible for toilet maintenance through FGDs, whose members also shared a thought that "We women manage everything about the toilet. We know when it needs emptying. Men only pay when we insist." Twenty-four percent of respondents had only primary education, 31% had secondary education, and only 3% of the total sample were at college/university level, with 12% missing data (Figure 2C). A breakdown of mean household size showed 6.2 persons (standard deviation 1.7, median 6.0), quite a bit over Tanzania's national urban average of 4.5 persons per household, which was reflective of overcrowding in informal settlement areas. Due to the close link between the size of households and facility usage as well as sludge

production rates, large households have a direct impact on these two aspects. In line with the study on the city of Kampala, a median value of faecal sludge accumulation has been estimated at 214 liters per capita per year for pit latrines and 348 liters per capita

Monthly income was split into five categories, as presented in Figure 1D. The most common category was that earning 150,000-300,000 TZS (45.3%, n=68), followed by those earning less than 150,000 TZS per month (44.0%, n=66). The remaining 7.3% were in the

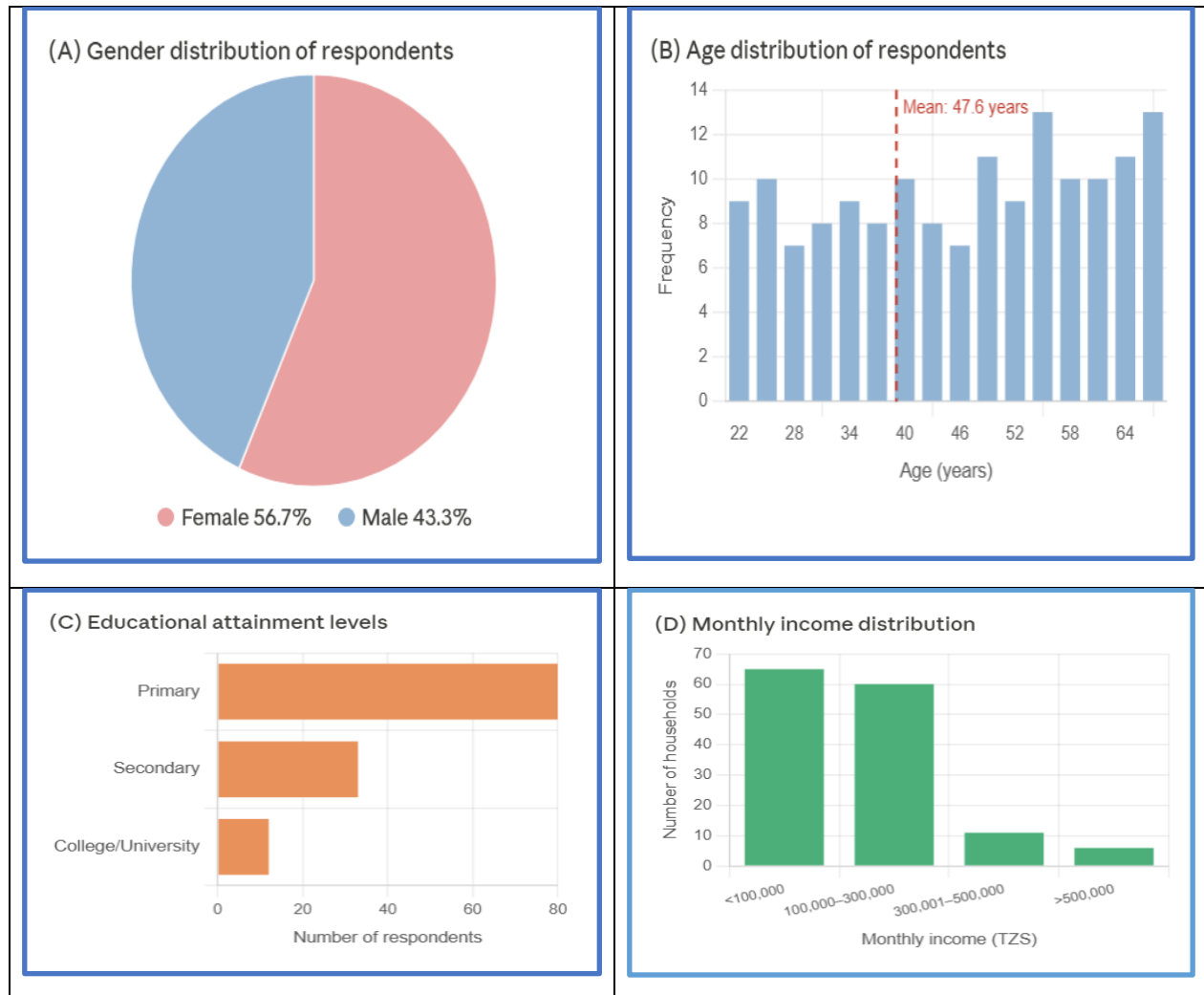


Figure 2. Demographic and socioeconomic characteristics

per year for septic tanks (Niwigaba et al., 2025). Based on these quantities, applying it to Igogo's average household size, each household will generate 1,327 liters of faecal sludge from pit latrines annually (using Equation 3). Consequently, based on the findings of this study, with the average pit size of 3.96 cubic meters, the pit would become full in about 3.0 years, which means that it is necessary to empty it at regular intervals.

300,001-500,000 TZS range (n=11) and 3.3% earned over 500,000 TZS (n=5). Taking into consideration that the exchange rate is around 2,300 TZS per USD, a substantial majority of 89.3 percent of households will have a monthly income of less than 130 USD, which is equivalent to approximately 4.33 USD per day, and, therefore, these families will be categorized as low-income groups. This creates a fundamental barrier to

the affordability of improved services. Municipal officials expressed: "Households simply cannot afford regular emptying. They either wait until the toilets overflow or resort to paying workers who then dump

odor control, fly prevention or groundwater protection. In Kampala, similar scenarios have been observed as pit latrines are the most common method of containment primarily because of the low cost of

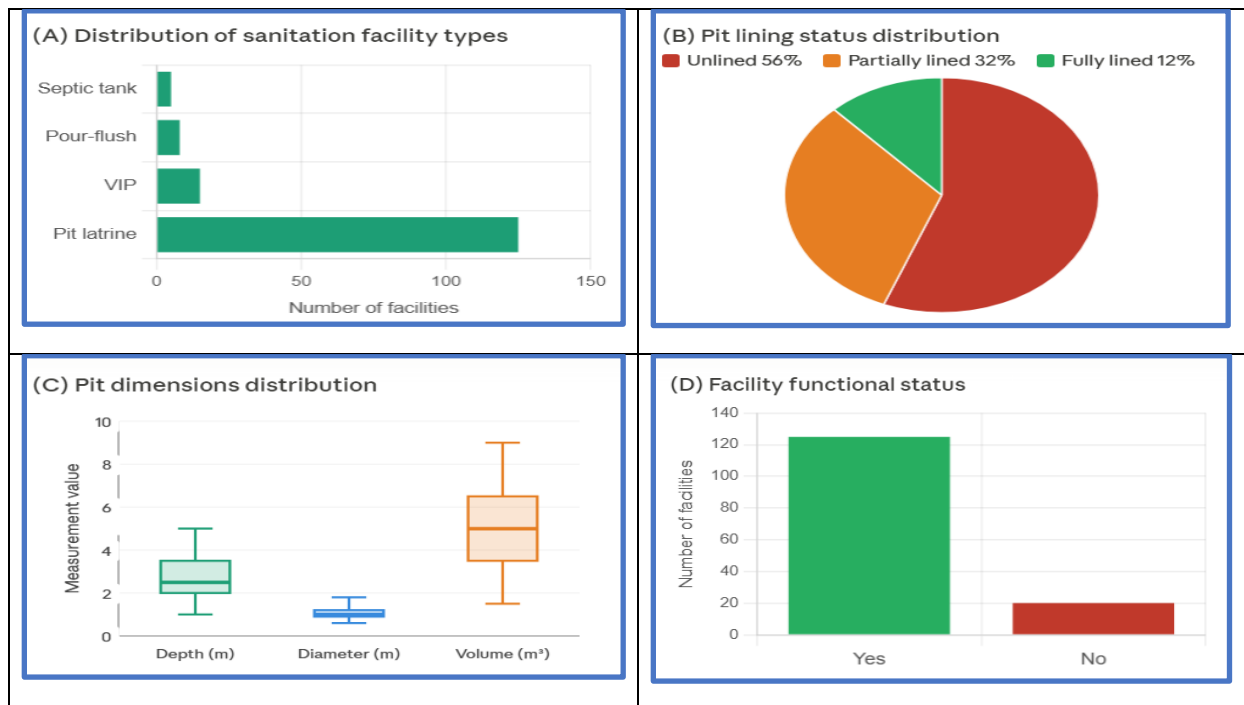


Figure 3. Sanitation infrastructure characteristics

the waste illegally." The average of users per day per toilet facilities is 11.9 (standard deviation 6.0), and such a high number of people per facility usage reflects that this is a shared usage which would significantly contribute to pit filling going much faster than the rate for a single household.

3.1.2 Sanitation Infrastructure Characteristics and Technical Assessment

Sanitation infrastructure evaluation revealed that there is almost a full dependence on basic pit latrine technology (Figure 3A). Traditional pit latrines made up 84.7 percent of the facilities (n=127) with ventilated improved pit latrines and pour-flush toilets comprising 7.3 percent (n=11) and 4.7 percent (n=7) respectively, whereas only 3.3 percent (n=5) were septic tanks. Such a distribution implies the neglect of adoption of improved technologies, with the majority still using unventilated pit latrines which do not have features for

construction and lesser technical skills requirement in contrast with septic systems (Niwagaba et al., 2025). The community health workers interviewed said: "Since they are cheap, people go for simple pit latrines. They dig a hole, put bricks if they can and build a shed. Nobody thinks about lining or a proper design." Assessment of functional status showed that 87.3 percent of the facilities were operational (n=131) whereas 12.7 percent were non-functional (n=19) due to reasons such as collapsed superstructures, damaged linings or complete filling. Focus group participants mentioned problems of functionality during certain seasons: "When it rains heavily, water gets into the pit

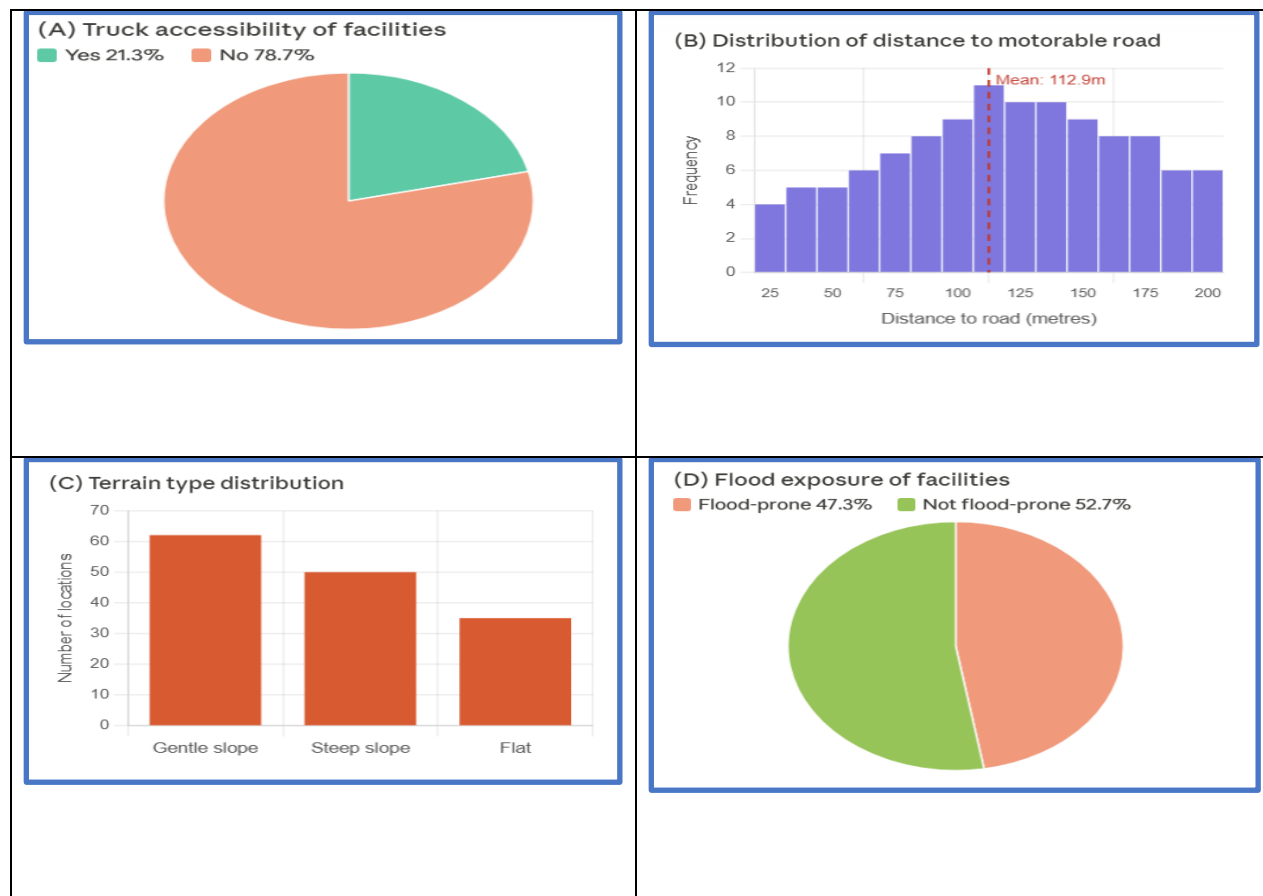


Figure 4. Accessibility constraints and geographic factors

and we are not able to use it. Some people go to the bushes for defecation till the water recedes".

Analysis of lining status exposed insufficient structural protection (Figure 3B). Pits without any lining made up 56.0 percent ($n=84$), with partially lined at 32.0 percent ($n=48$), and fully lined at only 12.0 percent ($n=18$). Such predominance entails very high dangers of both contaminations of groundwater and structural collapse, especially considering Mwanza's geological character which is rocky and also has groundwater tables that are not deep. Full lining done with concrete rings or brick masonry is a rather high-cost investment which most households cannot manage. According to one mason: "Full lining comes to 800,000-1,200,000 TZS. Most people only do line at the top 1-2 meters which is the part that is visible and leave the bottom unlined so as to save money." Chi-

square test performed for sanitation type and lining status did not register any statistical significance indicating that inadequate lining is a problem for all facility types irrespective of their technology level.

Measurement of physical aspects of the pit produced very important information for making estimates of filling rates and emptying needs (Figure 3C). Average pit depth was 2.49 meters (standard deviation 0.54 m, range 1.5 to 3.8m), average diameter 1.38 meters (standard deviation 0.35m, range 0.8-2.2m), and average volume 3.96 cubic meters (standard deviation 2.14m³, range 1.2-10.5m³). Volumes were worked out through use of the cylindrical formula for circular pits as given in the methods section. These depths which are comparatively shallow are the result of geological limitations of Mwanza's rockiness and groundwater tables being close to the surface which

hinder excavation without special machinery. A mean depth of 2.49m is very much below the recommended 3-5 m range for maximal capacity. Technical staff commented: "Digging to a great depth is not only difficult in a rocky place but it is also very expensive. When the rock is hard, the usual thing is that they stop at 2 meters unless they are using a machine, but that is very expensive." Given the current accumulation rates and typical household sizes, the average pit volume should be filled up after about 3.1 years, which puts a need for desludging every so often.

3.1.3 Accessibility Constraints and Geographic Factors

How accessible the facilities are being the main factor in deciding the type of emptying technology to use and also determines the overall possibility of faecal sludge service delivery (Figure 4A). Only 21.3 percent of the facilities were accessible by vacuum trucks (n=32), whereas 78.7 percent were inaccessible (n=118) due to narrow paths, steep parts, or location far from motorable roads. Accessibility of sanitation facilities was surveyed by means of structured interviews with household respondents, combined with direct observation and mapping the paths to the facilities. On average, the distance from the pit location to the nearest vehicular access point was 112.9 m (standard deviation 49.2 m, median 111.0 m, minimum 15 m, maximum 200 m), which reveals significant spatial constraints that might limit mechanized faecal sludge emptying services as depicted in Figure 4B. Such inaccessibility fundamentally determines the feasibility and economics of service delivery. A vacuum truck driver said, "We cannot access most of the houses in Igogo. The paths are too narrow for our 3-meter-wide trucks, and there is no place to turn. We only serve houses along main roads." A chi-square test for truck accessibility and emptying history revealed that there was no significant relationship ($\chi^2 = 0.000$, $df = 1$, $p = 1.000$), which means that households emptied their facilities regardless of whether they had access to a truck, although they used different methods. Based on shape of terrain, flat areas comprised 23.3

percent (n=35) of the total, gentle slopes 42.7 percent (n=64), and steep slopes 34.0 percent (n=51) (Figure 4C). A flood exposure survey showed that 47.3 percent of the facilities were in flood-prone areas (n=71) whereas 52.7 percent were in non-flood zones (n=79) (Figure 4D).

Flooding during the rainy season greatly disrupts faecal sludge management operations. A study in Dar es Salaam illustrated how rainfall fluctuation severely affects FSM service delivery in flood-prone informal settlements, with extreme wet periods causing increased flood risk that made damage to containment structures and prevented access to emptying services. At the same time, incorporating local rainfall variability into planning helps avoid structural damage and ensures sustainability (Mremi et al., 2025), and parts of Mwanza City, including Igogo Ward, are also facing vulnerabilities related to extreme rainfall and flooding resulting from poor drainage, rapid settlement expansion, and physical limitations of unplanned areas. Even though Mwanza's climate and hydrological conditions are different from those of coastal Dar es Salaam, local baseline data show that the unplanned settlements in Igogo are exposed to seasonal runoff and water stagnation which can disrupt both access to and sanitation service delivery, thus highlighting the importance of taking into account local climate and topographic factors when planning faecal sludge management. Chi-square did not establish a significant relationship between flooding status and pit investment in protective lining (chi squared = 0.070, $df = 2$) thus indicating that the pits in flood-prone locations are not more likely to get lined compared to those in other areas despite their higher risk of contamination. In short, it is a strong indication that FSM systems in these areas will, during flooding events, face overflow, structural failure, and environmental contamination, which is indeed a significant problem in risk-responsive planning. Therefore, interventions specifically aimed at increasing pit durability and service reliability in high-risk areas are necessary. This is a classic example of risk-responsive planning done

without taking the risks into account. A resident said, "When the floodwaters come, the pit is flooded, and the waste mixes with floodwater. The entire compound becomes contaminated. Children fall ill, but we cannot afford to improve the toilet."

3.1.4 Emptying Practices, Service Costs, and Provider Characteristics

The analysis of emptying history showed that about half (50.7%) of the households had their sanitation facilities emptied at least once ($n=76$), while the other half (49.3%) had never emptied their facilities

facilities mainly almost three quarters (75%) manually ($n=57$), rationally only one-tenth of households (13.2%) used semi-mechanical ($n=10$) and vacuum truck services were the least used at 11.8% ($n=9$) (Figure 5B). Manual emptying was found to be the predominant mode of stool disposal in Igogo Ward which was directly attributable to the fact that the access constraints described in Section 3.1.3.) existed. As 78.7% of the facilities were found to be located beyond the reach of vacuum trucks, the households had no other choice but to depend on informal manual



Figure 5. Emptying practices and cost analysis

($n=74$), see Figure 5A. Such a drastic split is a reflection of quite new establishment of facilities and stagnating economic status of the dwellers that prevent regular desludging leading to only after sale facility emptying. Of the 76 households that had emptied their

service providers. Interviews with the service providers confirmed the above-mentioned problems; one interviewee stated: 'Manual workers come at night with buckets and shovels.' The findings above are indicative of the fact that physical location and

infrastructure almost completely determine the type of FSM practice, which has the effect of limiting the use of mechanized technologies, and at the same time, dependence on the labor-intensive and informal services is reinforced. Informal service providers do charge lower prices, but they are illegal and dump sludge in drainage channels or bushes. It seems that no one cares or asks about where the waste goes. Moreover, it is cheaper than vacuum trucks and the only available option for those houses that are located deep in narrow paths.

Analysis of cost revealed huge price hikes between emptying methods (Figure 5C). Average cost for manual emptying was 90,192 TZS (standard

103 USD). Independent samples t-test showed that this difference was very highly statistically significant ($t = -27.877$, $df = 64$, $p < 0.001$) with vacuum truck services costing about 2.6 times as much as manual methods. On top of the higher prices, vacuum truck services are much safer and more hygienic as they dispose of waste at designated treatment facilities compared to the frequent illegal disposal occurring with manual emptying. Overall cost distribution (Figure 5D) shows a mean emptying cost of 116,450 TZS (median 90,000 TZS) when considering all methods.

3.1.5 Willingness to Pay for Improved Emptying Services and Payment Preferences

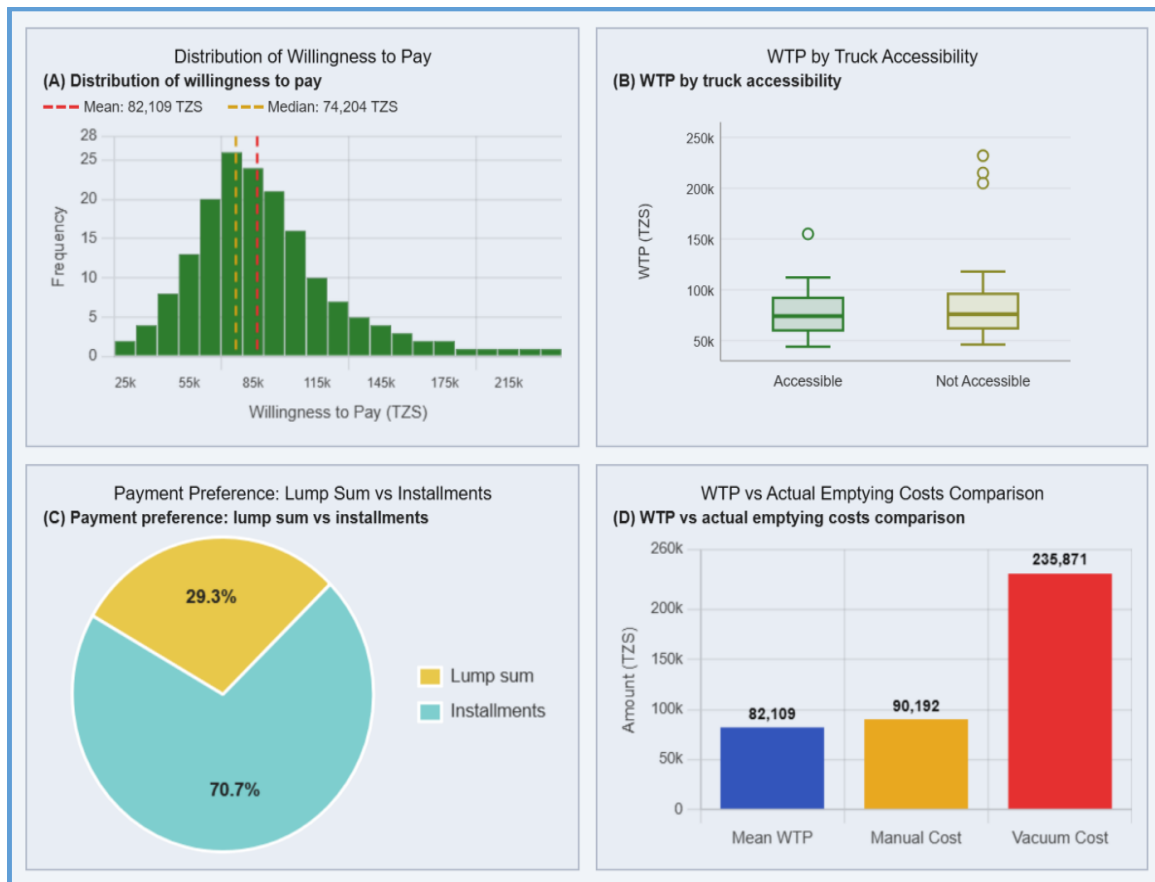


Figure 6. Willingness to pay analysis and payment preferences

deviation 6,348 TZS, roughly 39 USD), whereas vacuum truck emptying on the other hand averaged 235,871 TZS (standard deviation 37,630 TZS, roughly

The mean willingness-to-pay (WTP) was 82,109 TZS, which is lower than the average manual emptying cost (90,192 TZS) and far below vacuum truck costs

(235,871 TZS), indicating that user fees alone cannot sustain improved FSM services. WTP was incorporated into the framework establishment to represent household affordability and payment preferences. However, because the contingent valuation method may overestimate actual WTP, the affordability gap could be even greater, highlighting the need for subsidies or alternative financing mechanisms. average WTP (82, 109 TZS) is less than the average subsidies to bridge the gap should be interpreted with caution. This is acknowledged as a limitation of the contingent valuation approach used

When WTP was analyzed by whether a truck can access the location, quite unexpectedly, no statistically significant difference was found between accessible and inaccessible locations. This means that the households in inaccessible areas might declare willingness to pay at the same level as or even higher than those in accessible areas because their awareness of the difficulties they encounter in emptying their pits is greater. The lack of mechanized access probably leads to an increase in the perceived value of reliable emptying services and that is why persons are willing to pay more for the solutions that will transform these accessibility constraints even if it means that service delivery will still be difficult (see Figure 6B). More specifically, the households that reported the mean WTP value of 74, 456 TZS were located in truck-accessible areas while those from inaccessible areas indicated 84, 184 TZS ($t = -1.325$, $df = 148$, $p = 0.187$). What makes this finding even more interesting is that it counters the basic assumption that WTP will be hugely impacted negatively spatial constraints because it suggests that households that are not accessible may well understand more clearly their need for alternative service solutions.

The strong household preference for installment payments (70.7%, $n=106$) over lump sum payments (29.3%, $n=44$) shows that it is quite possible to develop alternative FSM service models that take into account the household cash flow when the costs are imposed. For example, one household stated, 'We cannot pay

200, 000 TZS at once. If we can pay 20, 000 per month for ten months, maybe we can manage' (Figure 6C). It is of the utmost importance here that they pointed out, 'Mobile money makes small payments easier.' The above-mentioned models, such as subscription-based desludging services, sanitation savings groups, or pay-as-you-empty schemes, can actually be the viable solutions that the use of mobile money or community-based collection methods to spread costs over time will be coupled with ensuring regular service delivery and financial sustainability. The comparison of average WTP and actual service cost prices clearly reveals the dimension of the affordability gap (Figure 6D). The average WTP (82, 109 TZS) only covers 91 percent of manual emptying costs (90, 192 TZS) and 35 percent of vacuum truck costs (235, 871 TZS). These figures demonstrate that even if the willingness to pay for improved services is high, household financial capacity is still insufficient to support cost-recovery pricing for mechanized emptying. The contingent valuation on improved irrigation in Egypt recently showed almost the same pattern of the willingness-to-pay of smallholder farmers, which fell substantially short of full cost recovery levels, subsidization with a targeted approach, and payment flexibility being the solutions to this issue (Abu Hatab et al., 2025). They confirmed the fact that a double-bounded dichotomous choice format provides more efficient WTP estimation than a single-bounded approach and hence the choice of the method in this study is supported.

3.1.6 Risk Awareness, Institutional Knowledge, and Community Participation

Risk awareness assessment categorized households' understanding of health hazards associated with inadequate faecal sludge management (Figure 7A). Medium risk awareness was most common (52.7%, $n=79$), followed by low awareness (26.0%, $n=39$) and high awareness (21.3%, $n=32$). The predominance of medium-to-low awareness (78.7%

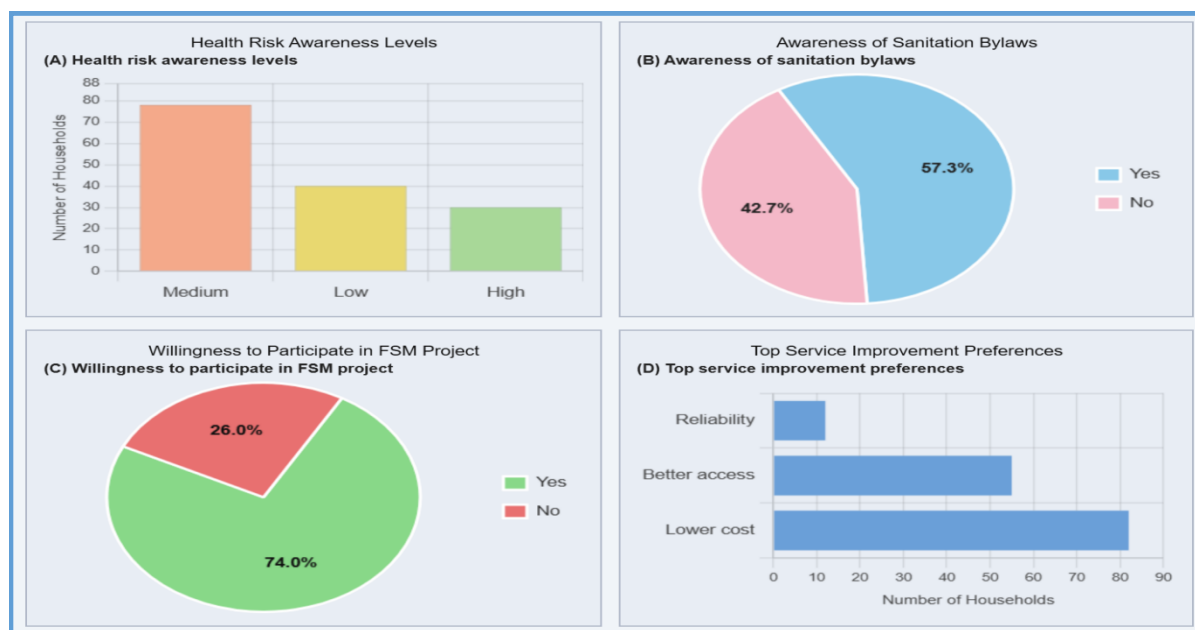


Figure 7. Risk awareness, institutional knowledge, and participation

combined) indicates substantial gaps in health education and community sensitization. Limited risk awareness can impact sanitation behavior through reduction of adherence to safe pit emptying practices, correct maintenance of containment, and hygienic disposal of faecal sludge. It may also limit technology adoption, as without understanding the health and environmental benefits of improved or mechanized FSM solutions, households would be hesitant to invest in them. Besides, low awareness could also mean less involvement in community-based initiatives or payment schemes for improved FSM services, both of which could lower service uptake and financial sustainability. These knowledge deficits should be tackled with targeted education and behavior change campaigns in order to improve both the effectiveness and adoption of improved sanitation interventions. Focus group participants exhibited varied understanding, with some acknowledging disease risk transmission while others were still confused: "We know the smell is bad and attracts flies, but once the pit is covered, the waste stays underground and does not harm anyone. Only when it overflows is there danger." This shows a lack of understanding of contamination of groundwater, soil pollution, and diseases carried by vectors that occur even with seemingly functional

covered pits, especially since 56.0% of pits are unlined as per this study.

A bylaw awareness examination found that 57.3% of the respondents knew of the municipal sanitation regulations ($n=86$) and 42.7% did not ($n=64$) (Figure 7B). Nonetheless, enforcement is very minimal despite the moderate levels of awareness. Local government officials explained that "We have regulations that require emptying the toilets in licensed facilities and proper treatment; however, we do not have enough staff, vehicles, and resources to monitor compliance. Manual emptier operate at night illegally, and we cannot catch them. Even when we find violations, the penalties are too small to deter." This enforcement gap between the frameworks laid down by regulations and the capacity of implementation is a fundamental institutional constraint. Assessment of community participation willingness revealed that 74.0% of households ($n=111$) were willing to participate in an improved FSM project, while 26.0% ($n=39$) declined. High rates of participation are essential for the successful implementation of improved FSM services, as participating households can contribute to cooperative desludging services, participate in shared financing schemes, and assist in community monitoring of service providers. They will have an

active role, which in turn will ensure accountability, facilitate co-sharing costs, and lead to the timely reporting of service gaps or operational issues. By

(Figure 8A). 62% of the total respondent households (n=93) reported that lack of water has been their main reason for stopping flushing, while 38% clearly

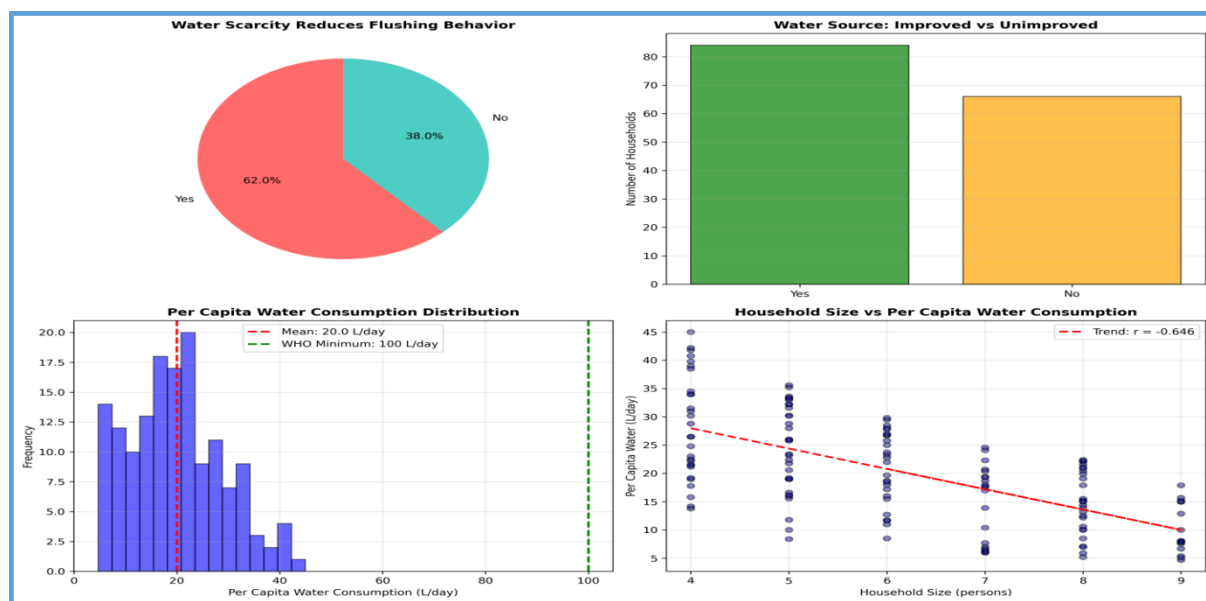


Figure 8. Water-sanitation nexus and facility performance

taking collective action, community participation can increase both the coverage and sustainability of FSM interventions, especially in densely populated or resource-constrained informal settlements like Igogo Ward (Figure 7C). This high willingness to participate indicates a readiness to accept interventions that would remove the affordability and accessibility barriers. Preferences for improved services were revealed by the respondents (Figure 7d) and they mainly pointed to demand for lower costs, flexible payment options, and better service quality. This is in line with the Igogo Ward results where 74.0 percent participation willingness and 70.7 percent preference for installment payments indicate the feasibility of cooperative financing schemes.

3.1.7 Water-Sanitation Nexus and Facility Performance

Analysis of the link between water and sanitation highlighted the essential mutual dependencies between getting water and the working of sanitation facilities

showed that water is always available to them (n=57). This water scarcity makes it very difficult for the operation of pour-flush toilets and septic tanks, which leads to the quick accumulation of solid waste and the reduced hydraulic flushing of finer particles. Further investigation of water sources showed that 56% (n=84) got their water from improved sources like piped water, boreholes, or protected wells, and the other 44% (n=66) used everything from surface water or unprotected springs (Figure 8B). Per capita water consumption was measured by first taking the average total household water use and then dividing that by the average household size. So, if the average household usage is 114.5 L/day and the average household size is 6.2 persons, then the average per capita water use would be $114.5/6.2 = 67.3$ L/day. This is the estimated daily domestic water usage per person at each household level, accounting for all household activities such as drinking, cooking, bathing and cleaning (Figure 8C). This is way below the WHO minimum recommendation of 100 liters per capita per day to

maintain adequate domestic hygiene, cooking, and sanitation needs.

The relationship between household size and per capita water consumption marked a significantly negative correlation ($r = -0.646$, $p < 0.001$) as also shown in (Figure 8D). It means that as household size increases, the amount of water available per person decreases disproportionately because of the fixed capability of water collection. A housewife shared: "We fetch water three times a day from the public tap carrying 40 liters each time with our 20-liter buckets. With eight people at home, there is never enough for proper washing, cooking, and flushing. We have to make a priority, and flushing is always last." This scarcity of water forms a vicious circle whereby limited flushing leads to the quicker filling of the pit through the retention of solid wastes, which in turn calls for more frequent emptying. However, households cannot afford to do so. The pattern line in Figure 8D illustrates clearly this inverse relationship, with larger households being more concentrated at lower per capita consumption levels." They conclude that it is very crucial to take into account local rainfall variability so as to properly plan in order to avert structural damages and guarantee the sustainability of services, especially in the zones susceptible to flooding. Igogo Ward is a good example since 47.3 percent of the facilities are in areas that are prone to floods and 62.0 percent of the households' water scarcity reducing flushing incidences. Hence, integrated water and sanitation planning making is crucial acknowledging that investments in one sector will inevitably influence the other ones.

3.1.8 Multiple Regression Model for Estimated Determinants of Willingness to Pay for FSM

A thorough statistical analysis was conducted to explore associations between main variables and to get the significant patterns and relationships. Chi-square tests for independence checked the associations between categorical variables using Equation 14 from the methodology:

$$X^2 = \sum \left\{ \frac{(O - E)^2}{E} \right\} \quad (14)$$

where O is the observed frequencies and E is the expected frequencies. Chi-square test for sanitation type and lining status showed no significant association ($\chi^2 = 7.657$, $df = 6$, $p = 0.264$), implying that unlined toilets are a problem in all types of toilet facilities regardless of technology. The chi-square test of truck accessibility and emptying history also revealed no significant association ($\chi^2 = 0.000$, $df = 1$, $p = 1.000$), indicating that households' decisions to Spatial constraints, rather than truck access, influenced emptying practices. No significant association was found between flood exposure and lining status ($\chi^2 = 0.070$, $df = 2$, $p = 0.966$). The AHP criterion weights and Consistency Ratio (CR) should also be reported in the Results to improve transparency and enable independent verification.

Correlation analysis for continuous variables showed mostly weak linear relationships (Figure 8), implying faecal sludge management outcomes are quite complex and not simply a result of bivariate associations. Correlation matrix in Figure 8 shows relationships between nine key variables. The highest correlation was a strong negative between household size and per capita water consumption ($r = -0.646$, $p < 0.001$), indicating that bigger families struggle more with water scarcity which then influences the functionality of sanitation. The correlation between pit depth and road distance was very small ($r = 0.002$), showing that how near the road is does not determine how deep the pit is dug. Likewise, WTP and household size hardly correlated ($r = 0.002$), which means that the ability to pay depends more on income levels than how many people live in the household. WTP and road distance had a small positive correlation ($r = 0.101$), whereas emptying cost and distance to the road showed a small negative correlation ($r = -0.090$).

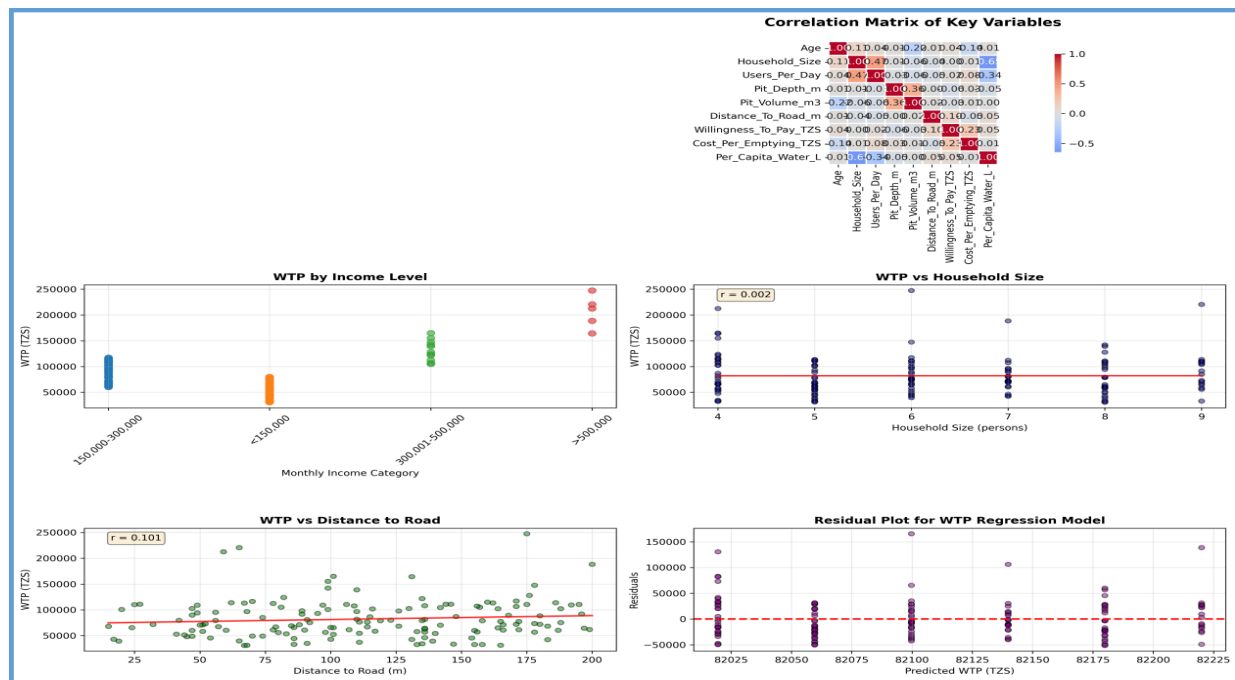


Figure 9. Statistical analysis and regression modeling

Multiple regression analysis was used to estimate the factors influencing willingness to pay from Equation 15 in the methods section:

Where WTP is willingness to pay, INCOME is monthly household income, EDUCATION is the number of years of formal education, HHSIZE is household size, DISTANCE is the distance to the treatment facility or road, FLOOD is a binary variable for flood exposure, and ε is the error term. The model was fit by ordinary least squares on 132 cases with complete data after listwise deletion of missing values. The model summary showed that $R^2 = 0.7843$, meaning that collectively the five predictor variables explain 78.43 percent of the variance in willingness to pay.

The intercept (α) was W TZS.

Interpretation within the model Income was the only. Significant predictor statistically ($\beta_1 = 0.2645$, $t = 21.841$, $p < 0.001$), with an increase in monthly income of 1, 000 TZS being associated to an increase in WTP of 264.5 TZS, other variables being constant.

Years of education did not have a significant effect ($\beta_2 = 90.72$, $t = 0.230$, $p = 0.819$), neither did the size

of the household ($\beta_3 = -460.45$, $t = -0.687$, $p = 0.494$), the distance to the road ($\beta_4 = 33.13$, $t = 1.160$, $p = 0.248$), or the exposure to flood ($\beta_5 = -2, 286.84$, $t = -0.740$, $p = 0.461$).

The regression scatter plots in Figure 8 depict the associations of WTP and main predictors. Figure 8C illustrates the change of WTP across income levels that increases distinctly. Figure 8D represents the change of WTP over household size, with the relationship almost non-existent ($r = 0.002$). Figure 8E exhibits WTP to the road distance, with a slight upward trend ($r = 0.101$). Figure 8F depicts the residual plot, residuals are rather evenly spaced on zero with no particular patterns, hinting that the assumptions of linearity and homoscedasticity by the model are fairly well met.

Finding a significant effect only for income and not for the other factors agrees with the expectations since the demographic analysis revealed the household' economic situation to be very constrained. Given that 89.3 percent of the households have monthly incomes of less than 130 USD, income represents the limiting factor for WTP irrespective of education, household size, or other factors.

4. Discussion

The study conducted in Igogo ward reveals that faecal sludge management challenges in informal settlement are strongly influenced by the combined effects of inadequate sanitation infrastructure, poor accessibility to emptying service, economic limitation, hydrogeological constraints and weak institutional capacity. It is important to note that the study analysed 150 completed surveys against a calculated requirement of 379, achieving an estimated margin of error of $\pm 8.0\%$ at 95% confidence rather than the targeted $\pm 5.0\%$. This reduced statistical precision should be considered when interpreting quantitative findings, including chi-square test results, regression coefficients, and WTP estimates. The finding that inaccessible households reported higher WTP (84,184 TZS) than accessible ones (74,456 TZS), though not statistically significant ($p = 0.187$), warrants interpretive attention: households physically constrained from conventional services may perceive greater unmet need and therefore express higher willingness to pay for alternative solutions. This is consistent with scarcity-value theory in sanitation economics. Similarly, the absence of a significant association between flood exposure and pit lining investment (chi-squared = 0.070, $p = 0.966$) is noteworthy: despite demonstrably higher contamination risk, flood-zone households are no more likely to invest in structural protection. This suggests that risk awareness alone is insufficient to drive investment behaviour under acute income constraints, reinforcing the need for targeted subsidy or co-financing mechanisms specifically directed at flood-exposed, low-income households. Quantitative finding showed that 89.3% of households less than 130 USD per month, while 78.7% of sanitation facilities are inaccessible to conventional vacuum trucks because of narrow road, steep terrain and unplanned settlement pattern. Additionally, 56.0% of pit latrines are unlined, increasing the risk of structures collapse, groundwater contamination and sludge leakage into surrounding soils.

Economic analysis demonstrated that the average household willingness to pay for FSM service was 82,109 TZS, which is lower than average manual emptying cost (90,192 TZS) and below mechanized emptying cost (235,871 TZS). Statistical testing confirmed a significant cost disparity between manual and mechanized services ($t = -27.877$, $p < 0.001$), highlighting severe affordability barriers for low-income households. As a result, 75% of households who had emptied their pits relied on unsafe manual methods, while 49.3% of pits have never been emptied, leading to frequent overflow incidents and environmental contamination. Regression analysis further identified income as the only significant determinant of WTP ($\beta = 0.2645$, $p < 0.001$), indicating the financial capacity is the primary factor influencing FSM service uptake.

Hydrological assessment showed that the average pit depth of 2.49 m is limited by Mwanza's rocky geology and shallow groundwater table. Average pit volume of 3.96 m³, household size of 6 person and sludge accumulation rate of 214 L/Capita/year, pit are estimated to reach capacity with approximate three years. Shallow pits reduce soil filtration capacity and increase hydraulic connectivity between pit contents and groundwater aquifers, thereby increasing risks of nutrient and pathogen contamination in nearby water bodies, including Lake Victoria

Water supply conditions were also found to significantly affect FSM performance. Average household water consumption was 67.3 L/capita/day, below the WHO-recommended minimum of 100 L/capita/day. About 62.0% of households reported reduced flushing due to water shortages, resulting in increased solids accumulation, higher sludge viscosity, and accelerated pit filling rates. Correlation analysis revealed a strong negative relationship between household size and per capita water consumption ($r = -0.646$, $p < 0.001$), confirming that larger households experience greater sanitation stress. Furthermore, 47.3% of sanitation facilities are located in flood-prone areas, exposing them to seasonal flooding, structural

damage, pit overflow, and fecal contamination of surrounding environments.

The study recommends integrated FSM framework strategies that combine technical, financial, institutional, and spatial planning interventions. Technically, there is a need to develop intermediate and semi-mechanized emptying technologies suitable for inaccessible settlements. Financially, the strong household preference for installment-based payments (70.7%) supports the introduction of mobile money financing systems, targeted subsidies, community savings schemes, and public-private partnerships. Institutionally, weak enforcement of sanitation bylaws despite moderate public awareness (57.3%) highlights the need for stronger municipal capacity, improved staffing, and better coordination among sanitation, water, drainage, health, and solid waste sectors.

5 Conclusions and Recommendations

5.1 Conclusions

This paper demonstrates that faecal sludge management in Igogo Ward is constrained by infrastructure deficits, the inaccessibility of 78.7% of sanitation facilities, affordability gaps where household WTP falls below service costs, and weak institutional enforcement. Among the determinants of WTP, only income was statistically significant ($\beta = 0.2645$, $R^2 = 0.784$, $p < 0.001$), indicating that economic capacity is the primary determining factor; however, the high R^2 should be interpreted cautiously given the small sample ($n=150$, below the targeted $n=379$) and the risk of overfitting. It is also noted that stated WTP from contingent valuation is likely to overstate actual household willingness-to-pay due to hypothetical bias, meaning the affordability gap is likely wider than the headline figures suggest. Achieving SDG 6.2 in secondary cities of Sub-Saharan Africa similar to Mwanza will require a combination of intermediate emptying technologies adapted to inaccessible settlements, mobile-money-linked installment payment systems, means-tested social subsidies, strengthened regulatory enforcement, and

integrated water and sanitation planning. The multi-criteria decision support framework developed in this study provides a structured basis for prioritizing these interventions under resource constraints

5.2 Recommendations

- Cost-effectiveness of intermediate emptying technologies, including motorized gulper pumps and vacuum-assisted tricycles, should be evaluated in spatially constrained informal settlements, generating transferable technical evidence for areas where access by conventional vacuum trucks is structurally impossible through pilot projects.
- Even though 70.7% of the households prefer periodic payment schedules, research is needed to figure out how mobile money-integrated installment payment models can be used for FSM services, to see if they can close the gap between willingness to pay and actual service costs in terms of affordability.
- It is necessary to study over time whether means-tested, income-based subsidy programmes achieve equitable and efficient uptake of FSM services compared to spatially or demographically targeted approaches, given that income is the only significant predictor of willingness to pay ($\beta=0.2645$, $p<0.001$).
- Also, research should address the effects of the 56.0% prevalence of unlined pits in shallow rocky terrain on groundwater contamination and, in particular, on pathogen transport to Lake Victoria, as this will help set minimum lining standards based on evidence for low-income informal settlement context.
- Community-based co-management models that are leveraging the element of 74.0% willingness to participate in FSM projects, as recorded, should go through rigorous controlled implementation studies in order to judge their impacts on service quality, environmental safety, and financial sustainability, in comparison with the traditional

municipal or private service delivery arrangements.

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Author Contribution

R.I drafted the manuscript; D.B AND A.M reviewed it; R.I together with R.N prepared it for grammar and spelling checks.

Conflict of Interest

We declare that there are no conflicts of interest in this study.

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