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The technologies used in sanitation delivery in Mukuru kwa Reuben, Kenya.

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ABSTRACT

The Sustainable Development Goals agenda 6.2 aims to improve access to safely managed sanitation by 2030. However, the sewer system serves only 17 % of the Sub-Saharan African population in informal settlements. Possible interventions and options to address sanitation issues in informal settlements have been advanced through research. However, upscaling and improving sanitation in informal settlements has been a challenge. The study investigated the technologies used in sanitation delivery in Mukuru Kwa Reuben. The study employed a descriptive survey design. The unit of analysis was the household level. The target population comprised the household heads involved in sanitation service provisions. Cluster and simple random sampling technique enrolled 100 household heads from 10 clustered administrative units. Data from the questionnaires and structured observations were analyzed using SPSS version 25, applying both descriptive and inferential statistics at the 5% significance level. The sanitation technologies for containment and storage of excreta/sludge included pit latrine, fresh life toilet, pour flush, cistern flush, and composting toilet. In emptying and transportation, eco bags, washing machines, transfer stations, buckets, urine containers, hand carts, trucks, and sewers were used. The excreta/sludge treatment/disposal options encompass treatment plants, septic tanks, open grounds, rivers, and landfills. There was a moderate positive correlation between accessibility and the construction/installation process of the toilet ($r = .546$, $p < .001$). There was statistically significant variation in the provision of sanitation technologies for emptying and transportation of sludge/excreta concerning accessibility ($p = 0.013$), availability ($p = 0.047$), and accountability ($p < 0.001$). The study concludes there was significant variation in the type of sanitation technology used and its construction/installation process which influenced the affordability, accessibility, and availability of sanitation technologies. The study recommends upscaling of compositing toilets, sewers, and treatment plants.

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Introduction

Globally, the Sustainable Development Goal (SDG) 6 advocates for a safely managed sanitation system (Mara & Evans, 2018a). However, In Sub-Saharan Africa, 56.2% of the urban population live in slums, but only 17 % of slum dwellers use safely managed sanitation facilities with 18% still defecating in the open (UNICEF & WHO, 2020). In Cap Haitien, Haiti, Container-Based Sanitation (CBS) reduced unmanaged feces by approximately 3.5-fold and was beneficial to 9,300 residents living in the area. However, only 70% of residents living within the range of 100-220 meters used the facility. Moreover, the high capital costs of $ 18,742, and collection and conveyance cost for household CBS at $ 22/ per household/month during the pilot phase (*Tilmans et al.*, 2015). There was limited access to long-term financing strategies (Evans et al., 2017; Williams, 2021a), and a lack of capital expenditure on conveyance equipment (Ferguson et al., 2021; Gitonga et al., 2021a). The installation of onsite sanitation is politically difficult and is occasioned by some landlords having illegitimate land ownership (*Russel et al.*, 2019b; Tilmans et al., 2015).

Container-based sanitation, ecological sanitation, and the Kenya Informal Settlement Improvement Programme (KISIP) aimed to address sanitation challenges in informal settlements. However, upscaling and improving ways of managing fecal sludge remain complex (*Simiyu et al.*, 2021a; Tsinda et al., 2021a). 11% of households access toilets and 16% of the residents share toilets with their neighbors in Mukuru (UNICEF & WHO, 2020a). Moreover, only 7.6% of the population is served by sewer systems, high emptying and transportation cost of CBS at $ 22/ household/month, 100,561 families were only served with 3863 pit latrines, and only 5% of sewage being effectively treated (*Evans et al.*, 2017; Mallory et al., 2021b; Mansour & Esseku, 2017; WHO, 2020b). The community groups and NGOs own pit latrines and communal toilets which are not connected to sewerage lines and are closed at night. As for the yard-shared toilets, they are owned by the structure owners and are usually shared by the residents of the structures with poor operation and maintenance (*Corburn et al.*, 2017).

Despite the interventions, programs, and goals, the challenges of providing accessible, affordable, available, and accountable sanitation solutions in informal settlements like Mukuru Kwa Reuben persist. This study investigated the technologies used in sanitation delivery in Mukuru Kwa

Methodology

The study was conducted in Mukuru Kwa Reuben in August 2022. This study site was chosen due to the sanitation challenges yet there have been innovative sanitation technologies piloted in the informal settlement (*Mallory et al.*, 2021). This study employed a descriptive survey design where questionnaires and a structured observation guide were used to collect data from the household. As per KNBS (2019), Mukuru Kwa Rueben had a total population of 65,691, with 36,402 men, and 29,288 women who inhabited 26,699 households. The unit of analysis was the household, with a focus on household heads as the primary respondents. The questionnaire was administered to the household heads. Questionnaires and structured observation were used to gather data on sanitation service and technology access, affordability, and sustainability. The computation of sample size followed the Yamane (1967) formula. The sample size was calculated using the formula:

$$n = \frac{N}{1 + N\ (e)2}$$

Where;

n = Sample size

N = Population size = 26,699

e = Margin of error = 0.1

$$n = \frac{26{,}699}{1 + 26{,}699\ (\ 0.1^{\ 2})}$$

$$n\ =\ 100.$$

The study utilized a cluster sampling approach. First, the ten administrative villages that received sanitation interventions were treated as cluster in Mukuru Kwa Reuben (Mara & Evans, 2018b). The study utilized cluster random sampling due to the nature of the households that existed in clusters (*Devaraj et al.*, 2021).The number of households were determined proportionately. From the clusters, a simple random sampling was employed to select the required number of households. There was a total of 100 households sampled from the ten villages proportionately as seen in Table 1 below..

Clusters (villages)	Households (N)	Sample Size (n)
Kosovo	2,136	8
Diamond	4,538	17
Mombasa Zone	2,670	10
Simba cool	3,204	12
Gateway	4,272	16
Rurie	1,602	6
Railway	1,602	6
Feed the Children	2,937	11
Riverside	1,602	6
Transformer	2,136	8
Total	**26,699**	**100**

Table1*: Sampling Frame*
Source: (KNBS, 2019).

The study used SPSS software version 25 for analysis. The analysis was carried out using analysis of variance (ANOVA), correlation analysis, and descriptive statistics at a 95% confidence interval.

Results and Discussion

In the study, there was a 100% response rate from the 100 questionnaires administered to the household heads. There were 57% male and 43% female respondents, which implies a gendered role in household decision-making. The largest age group was between 26 and 35 years (33%) suggesting a youthful population who were likely in their most economically active stage. The respondents aged between 56 and 65 years constituted 10% of the sample. In terms of level of education, 60% of the respondents had attained secondary education, wherease only 4% had no formal education, and this suggests relatively high literacy levels which influenced uptake and awareness of sanitation services.The religious composition was predominantly Christian (91%), with Muslims comprising 9% of the sample. This distribution reflects the broader religious demographics of the area. Employment status showed that a majority (59%) of respondents were unemployed, while 41% reported being employed. This employment distribution had implications on household income levels and the ability to afford sanitation services. The majority of the respondents were in the 26-35 age bracket, and which signify that sanitation services satisfy the needs of a relatively young population. The high percentage of respondents with secondary level of education suggests an educated population, which influences the adoption of improved sanitation practices. The majority of Christian respondents that religious practices and beliefs play a role in shaping sanitation preferences and behaviors. The high unemployment rate shows economic barriers affect the prioritization and affordability of sanitation services. *Kariuki et al*. (2024) found the age, education levels, and level of income of women influence the utilization of sanitation facilities in Mukuru Kwa Reuben. The findings underscore the significance of targeted incentives and subsidies, religious considerations, targeted interventions for young adults, gender-inclusive planning, and educational programs in improving sanitation services.

Type of Sanitation Technology	Frequency	Percentage (%)
No toilet	15	15.0
Fresh Life	18	18.0
Pour Flush	13	13.0
Pit Latrine	40	40.0
Cistern Flush	12	12.0
Compounding	2	2.0
Buckets	34	34.0
Hand Carts	30	30.0
Trucks	24	24.0
Sewers	12	12.0
Open Ground	39	39.0
Septic Tank	18	18.0
Landfills	10	10.0
Treatment Plant	17	17.0
Rivers	16	16.0

Table 2: *Sanitation Technologies*

Technologies for Sanitation Delivery

The majority 40% of respondents used a pit latrine when compared to just 2.0% who used a composting toilet. A notable 15% indicated not having any toilet facilities. The relatively high usage of fresh life 18% and pour flush (13%) indicates they are accepted and viable in the community. 12% used cistern flush toilets suggesting they were less common, due to higher water requirements. The low usage of composting toilets is a result of maintenance challenges, higher costs, and limited awareness. *Simiyu et al*. (2021a) link the prevalence of pit latrines to being cheap and easy to maintain. However, the majority of the residents share toilets in informal settlements Simiyu et al. (2021b) which goes against SDG 6.2 of safely managed sanitation (UNICEF & WHO, 2020). The respondents without toilets highlight an urgent call for interventions to provide basic sanitation facilities. Given that majority of respondents use pit

latrines, improving the maintenance, safety, and design of these facilities will have a great impact.

For emptying and transportation excreta/sludge, notably, 34.0% of respondents reported using buckets, while only 12.0% relied on sewer systems. In the treatment and disposal of excreta/sludge, the majority of the respondents 39% reported they dislodged in open grounds, 16 % in rivers, and 10 % disposed to landfills. The significant use of hand carts and buckets stresses the dependence on manual methods for excreta management, which pose health risks to workers and are inefficient. The significant proportion of excreta disposed of on rivers and open ground shows eminent environmental and health risks. The limited use of treatment plants and sewers depicts inadequate sanitation infrastructure in the community. *Russel et al.* (2019b) found fecal sludge desludging services were done by unskilled people with inadequate personal protective equipment. The findings suggest a need for improvement of waste management systems, encompassing increased access to mechanized transport, septic tanks, and effective treatment of excreta/sludge.

Ease of Access of Toilets	Frequency	Percentage
Very Accessible	21	21.0
Moderately Accessible	22	22.0
Slightly Accessible	39	39.0
Not Accessible	18	18.0
Availability of Sanitation facility		
Yes	21	21.0
No	79	79.0
Accountability of sanitation providers		
Very Accountable	24	24.0
Moderately Accountable	22	22.0
Slightly Accountable	20	20.0
Not Accountable	34	34.0
Affordability of Sanitation facilities		
Very affordable	17	44.0
Moderately affordable	16	16.0
Slightly affordable	23	17.0
Not affordable	44	23.0

Table3: *Sanitation facilities*

Table 3 depicts perception of respondents concerning the ease of access, availability, accountability, and affordability of sanitation facilities. From the findings, the participants rated the accessibility of toilet facilities where the majority 39.0%, indicated as slightly accessible, while 18.0% rated as not accessible. This suggests that while sanitation facilities are present, they were not easily reachable for many. On availability of sanitation, the majority 79% indicated not available, while 21.0% reported being available emphasizing a severe gap in service provision. Similarly, in Cap Haitien, Haiti, a study by *Tilmans et al.* (2015) established that 70% of residents living within the range of 100-220 meters used container-based Sanitation. The findings indicate a crucial need for infrastructure development to enhance access and availability of sanitation facilities, particularly in informal settlements.

The majority of the respondents 34.0% rated sanitation providers as not accountable, while 20.0% indicated slightly accountable. Moreover, 44% of respondents considered sanitation services to be "not affordable," and only 16% considered it as moderately affordable. These findings show a perceived lack of responsibility and transparency from sanitation providers. Moreover, almost half of the respondents struggle to pay for sanitation services. This implies that affordability is a significant barrier which is influenced by high service fees and economic constraints of the users. The findings agree with *Mallory et al.* (2021) who posited that there is fragmented governance and vested local interests in sanitation service provision. In explaining the disparity, *Russel et al.* (2019b); and Tilmans et al. (2015) reported illegitimate land ownership, while *Evans et al.* (2017); and Williams (2021) linked it with a lack of capital expenditure and limited access to long-term financing strategies.

The respondents rated the maintenance and operation of sanitation technologies. The majority 32.0% strongly disagreed with the statement while only 7% strongly agreed. The findings illustrate the limited maintenance and operation such as pit larine were full, odor, and missing doors and roofs. This conforms with findings by *Peal et al.* (2013) who found the majority of septic tanks were not water-tight, and only 9.1% were plastered in Panchayat, India.

Table 3 also presents the rated perceptions of respondents regarding the ease of toilet construction and installation process. A significant proportion 37.0% indicated the process to be not easy. It is apparent construction and installation process of sanitation facilities is not easy and which is attributed to illegitimate ownership of land as landlords lack

Sanitation facilities well-maintained	Frequency	Percentage
Strongly Agree	7	7.0
Agree	20	20.0
Neutral	13	13.0
Disagree	28	28.0
Strongly Disagree	32	32.0
Total	**100**	**100.0**
Ease of installation		
Very easy	20	20.0
Easy	37	37.0
Not easy	37	37.0
Not very Easy	6	6.0
Total	**100**	**100.0**
Cost of emptying and transportation		
Very affordable	23	23.0
Moderately affordable	16	16.0
Slightly affordable	17	17.0
Not affordable	44	44.0
Total	**100**	**100.0**

Table 4: *Construction/installation Process, Maintenance and Operation, and Cost of emptying and transportation*

		Sum of Squares	df	Mean Square	F	Sig.
Accessibility Toilet	**Between Groups**	49.020	5	9.804	11.557	.000
	Within Groups	79.740	94	.848		
	Total	128.760	99			
Accountability Toilet	**Between Groups**	65.463	5	13.093	16.864	.000
	Within Groups	72.977	94	.776		
	Total	138.440	99			
Availability Toilet	**Between Groups**	5.094	5	1.019	8.330	.000
	Within Groups	11.496	94	.122		
	Total	16.590	99			
Affordability Toilet	**Between Groups**	67.711	5	13.542	15.585	.000
	Within Groups	81.679	94	.869		
	Total	149.390	99			

Table 5: *ANOVA on Toilet Technology and its Accessibility, Affordability, Availability and Accountability*

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Accessibility Sanitation Technologies and Services	Between Groups	13.695	3	4.565	3.809	.013
	Within Groups	115.065	96	1.199		
	Total	128.760	99			
Accountability sanitation technologies and services	Between Groups	30.550	3	10.183	9.061	.000
	Within Groups	107.890	96	1.124		
	Total	138.440	99			
Availability of Sanitation Technologies and Services	Between Groups	1.315	3	.438	2.754	.047
	Within Groups	15.275	96	.159		
	Total	16.590	99			
Affordability of sanitation technologies and services	Between Groups	7.106	3	2.369	1.598	.195
	Within Groups	142.284	96	1.482		
	Total	149.390	99			

Table 6: *Emptying and Transportation of Sludge/Excreta*

title deeds. The installation of onsite sanitation is politically difficult and is occasioned with some landlords having illegitimate land ownership (*Russel et al*., 2019b; *Tilmans et al*., 2015).

Table 4 shows the respondents' perceptions on the cost of emptying and transporting excreta. The majority 44% rated not affordable, and only 16.0% indicated moderately affordable. The majority of respondents rated sanitation services as not affordable in Mukuru. This implies that affordability is a significant barrier in emptying and transporting of excreta which is influenced by high service fees and economic constraints of the users. This is in agreement with *Tilmans et al*. (2015b) who found that the high capital costs of $ 18,742, and collection and conveyance cost for household CBS at $ 22/ household/month for the Container-Based Sanitation during the pilot phase.

There was a significant variation in the accessibility, accountability, availability, and affordability of toilet technologies ($F(5, 94) = 11.55$, $p < .001$), ($F(5, 94) = 16.86$, $p < .001$), ($F(5, 94) = 8.330$, $p < .001$), and ($F(5, 94) = 15.585$, $p < .001$) respectively. A significant variation was reported by people using fresh life ($p < .001$), pour flush ($p < .001$), cistern flush ($p = 0.004$), and those without toilets ($p = 0.007$). However, there was no significant difference among the users of composting toilets ($p = 1.000$). The significant differences illustrate variation in distance to the toilets, functionality, operations, space, land ownership and tenure, costs, and decision-making processes. The findings are in agreement with findings by *Genter et al*. (2021) and *Mansour et al*. (2017) who found a glaring disparity in spaces, routes, insecure land tenures, 'cartels', political sabotage, and limited governance structures in informal settlements.

The accessibility, accountability, availability, and affordability of sludge/excreta conveyance and emptying technologies showed significant variation ($F(3, 96) = 3.81$, $p = .013$), ($F(3, 96) = 9.06$, $p < .001$), and ($F(3, 96) = 2.75$, $p = 0.047$), respectively. The Post Hoc Test revealed the notable variations in mean scores noted for trucks ($p < .001$) buckets ($p = 0.085$), handcarts ($p < .001$), and sewers ($p < .001$) attributed to variation in service cost, operation, and maintenance, access routes, and the distance from homes. A transfer station with less than 50 users and with a short driving distance from homes offers the best usage (*Ferguson et al*., 2021). Addressing the disparities through expanding and improving sanitation infrastructure, is vital for improving sanitation services.

Table 7 depicts the significant variation in the accessibility, accountability, availability, and affordability and the type of technologies used in excreta/ sludge treatment and disposal ($F(4, 95) = 8.98$, $p < .001$), ($F(4, 95) = 8.43$, $p < .001$), ($F(4, 95) = 4.69$, $p = 0.002$) and ($F(4, 95) = 4.90$, $p < .001$) respectively. The post hoc shows significant variation in the

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Accessibility Sanitation Technologies and Services	Between Groups	35.326	4	8.832	8.980	.000
	Within Groups	93.434	95	.984		
	Total	128.760	99			
Accountability sanitation technologies and services	Between Groups	36.263	4	9.066	8.429	.000
	Within Groups	102.177	95	1.076		
	Total	138.440	99			
Availability of Sanitation Technologies and Services	Between Groups	2.737	4	.684	4.692	.002
	Within Groups	13.853	95	.146		
	Total	16.590	99			
Affordability of sanitation technologies and services	Between Groups	25.558	4	6.390	4.902	.001
	Within Groups	123.832	95	1.303		
	Total	149.390	99			

Table 7: *Excreta/sludge Treatment or Disposal*

		Accessibility	Type of toilet	Siting of toilet	Construction/installation process of the toilet.	Emptying and transportation of excreta/sludge
Pearson Correlation	Accessibility	1.000	.426	-.230	.546	.065
	Type of toilet	.426	1.000	-.302	.329	.044
	Siting of toilet	-.230	-.302	1.000	-.336	.026
	Construction/ installation process of the toilet.	.546	.329	-.336	1.000	.091
	Emptying and transportation of excreta/sludge	.065	.044	.026	.091	1.000
Sig. (1-tailed)	Accessibility	.	.000	.011	.000	.261
	Type of toilet	.000	.	.001	.000	.334
	Citing of toilet	.011	.001	.	.000	.397
	Construction/installation process of the toilet.	.000	.000	.000	.	.183
	Emptying and transportation of excreta/sludge	.261	.334	.397	.183	.
N	Accessibility	100	100	100	100	100

Table 8: *Correlation Analysis*

accessibility of septic tanks ($p < .001$), landfills ($p = 0.070$), and open grounds, ($p < .001$). The significant variation in accessibility and availability implies that septic tanks, landfills, and open grounds, are more readily accessible and available to users. The findings denote the variation in the user costs, distance from homes, quantity, functionality, and user familiarity with these technologies. This is in agreement with *Devaraj et al.*, (2021), and *Okoth et al.*, (2017), who linked the disparities of sanitation services with policy failures, affordability, effectiveness, and practicality of solutions.

There was a moderate positive correlation between accessibility and the construction/installation process of the toilet ($r = .546$, $p < .001$). The findings posit that construction and installation processes tend to make toilets accessible. This signifies that improving the installation and construction processes, it can enhance significantly accessibility of toilets. However, accessibility and siting of toilet, and type of toilet and siting of toilet depict a weak negative correlation respectively ($r = -.230$, $p = .011$) and ($r = -.302$, $p < .001$). The weak negative correlation between accessibility and the siting of the toilet depicts that poorly sited toilets tend to be less accessible. This association shows the significance of strategic siting in the accessibility of toilet structures. Inappropriate siting can result in toilets being located in less accessible or inconvenient areas, which can prevent usage and affect the effectiveness of sanitation facilities. Therefore, by enhancing the installation and construction processes of toilet facilities, can greatly improve accessibility. Moreover, proper siting of toilet facilities is important for their accessibility and usability.

Conclusion

The type of sanitation technology and installation/construction process significantly influence the availability, accessibility, accountability, and affordability.

Recommendation

The sanitation stakeholders such as public health officers, sanitation specialists, national environmental and Management Authority (NEMA) officials and engineers should consider introducing an innovative and context-appropriate type of sanitation technologies for the containment, emptying, transportation, and treatment/disposal of excreta/sludge suitable for informal settlements.

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