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# Assessment of the Efficiency of Onsite Wastewater Management Systems Peri Urban Areas, Case Study: *Utawala, Nairobi County*

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**Abstract**

*This paper studies the efficiency of onsite wastewater management systems in a developing peri urban area, Utawala, on the outskirts of Nairobi city, Kenya, currently used due to lack of a centralised waste management system. It relates the system efficiency with environmental considerations, sizing, construction, and maintenance of the systems which are some of the factors considered during selection. A total of 25 systems were studied ranging from pit latrines, biodigesters and septic tanks. The total efficiency for the systems studied was 44% with 56% considered to be failing. When considering the systems serving 25 – 100 persons only, the efficiency rate was 22.22% with 77.78% considered to be failing. The area studied had clay black cotton soils and a hard phonolite layer beneath as its geological make up. This study demonstrated that the study area with poor soil absorption capacity was not suitable for handling absorption-based systems for large developments. While maintenance is critical to improve the functioning of these systems, especially in areas with absorption difficulties, it is often expensive and can be neglected leading to failure. Sizing of absorption-based systems in less absorbent areas should include a soak pit detail based on the actual geophysical properties to improve the working of these systems. Thinking about waste as a resource is helpful and can promote the use of recycling systems but they could be expensive install and therefore decentralised systems to serve a larger group of developments should be considered where the centralised sewer treatment option is not available.*

**Keywords:** Absorption-based systems, biodigesters, onsite wastewater management systems, septic tanks, Soak pits

## INTRODUCTION

Sub-Saharan Africa (SSA) is widely recognized as the world's fastest urbanizing region. Presently, urban areas house 472 million people, and this number is expected to double within the next 25 years. By 2050, the global share of African urban residents is projected to increase from 11.3 percent (as of 2010) to 20.2 percent, Saghir et al, (2018). This is characterised by pressure on the service provision systems. As proposed by Filion et al., (2017), there is an urgent need to study the inefficiency of the local infrastructure in keeping with the high urbanisation rate especially in the developing countries where urban area wastewater management suffers. Peri urban areas pose a unique challenge to wastewater management attributed to its non-uniform characteristics of the population and mixed use of land. This makes it difficult to choose appropriate technologies to serve the areas. Septic tanks, which have been the go-to for most new developments are inefficient for most high-density developments.

This study dove into the suitability and efficiency of the existing onsite wastewater management systems (OWMS) in the peri urban areas of Mihango, Embakasi East Constituency in Nairobi County Kenya. It also evaluates the potential causes of failure and provide a framework for appropriate selection of common onsite wastewater management methods for peri urban areas.

## THEORY

Human activities generate waste. Wastewater management refers to any practises and set of

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principles that relate to the collection, treatment, and the disposal of waste in the various forms of existence which include but is not limited to refuse, wastewater from households and human excrement. Onsite wastewater management systems are systems that are used to treat wastes from homes and businesses wherever they occur as described by Omenka (2010). Ergas et al. (2021) proposes that although sewerage coverage will continue to improve in the future, the costs of construction remain prohibitive in rural and suburban communities. OWMS (Onsite wastewater management systems), therefore provide a real opportunity for urban dwellers and city planners to manage their waste by storage for exhaustion, partial treatment, and full treatment. As illustrated by Mochu et al (2016), in the Mlolongo and Ruiru study areas, 74% of the population in these satellite/peri urban areas relied on OWMS. According to Ergas et al. (2021) the benefits of these systems include their affordability, simplicity in operation, potential for groundwater recharge and recovery of water, energy, and nutrients in proximity to their point of origin.

Critical in the understanding of wastewater management is how the process impacts people and the environment. Wastewater management approach should not be confined to the thinking that wastewater should be discarded, but instead should embrace the cyclic nature of the natural environment and view it as a resource, Buechler et al. (2005).

According to Peal et al. (2020) Increasing amounts of human waste produced in developing cities is managed poorly and an estimate of about 14% of the contents of pit latrines and tanks are not efficiently emptied which may lead to overflowing, leakages, or discharge into the surrounding environment. However, this failure of onsite waste management system can be a result of aggregation of causes that shows up as failed onsite systems. Omenka et al. (2010) noted that failure of these systems could stem from improper choice of systems and a lack of maintenance. Failure of OWMS can be visible or invisible. Invisible failure predisposes the community to health hazards. Visible failure is presents as effluent and bad odour emanating from the OWMS.

A range of factors have been cited in the OWMS provision that could cause failure. At the building plans approval levels, Architects, engineers, and urban planners approve the construction of typical OWMS (i.e. septic tanks) for most proposed developments. During construction, the level of expertise in building these units cannot be appropriately assessed which could lead to structural failure. The construction regulating organisations are not equipped with enough band width to follow up with the quality of construction on individual construction projects. After construction, the role of maintenance falls on the owner of the building and negligence on their part could also cause failure of OWMS. However, Schneider (2020) argues that even though wastewater management systems suffer an ill repute due to their documented high failure rates, most of the failure can be accredited to insufficient monitoring and maintenance system. Willets et al. (2007), proposes that onsite wastewater management systems are sustainable for single dwelling units but on a larger scale, their efficiency and sustainability is reliant on the maintenance and management of these systems. Strande et al. (2014) set out the conditions that can be deemed for the successful implementation of technologies and system options which included geographical conditions, climate considerations, and population density, as well as the importance of operation and maintenance in their book on Faecal Matter Management (2014). Omenka et al. (2010), collaborates this citing local circumstances such as the area topography, the development density, the type of soils, community attitudes and site characteristics.

According to Bradley et al. (2002), it is common to find that the simplest, most affordable, and least maintenance systems are the ones that are chosen by landlords. With increasing technological advancement, they suggested a criterion for the selection of wastewater management systems based on a reasonable set of social, economic, and environmental criteria holding that previously, systems such as septic tanks had been approved without much consideration of their maintenance requirements. OWMS include septic tanks, pit latrines, cesspits, biodigesters and wastewater recycling units. Their application in Kenya and Nairobi is highly dependent on the availability of funds (cost), and the handling capacity of the units. In Kenya, these systems are applied indiscriminately and can be a function of common practice, cost and the required capacity.

The role of efficient onsite wastewater management systems in urban planning cannot be side-lined. Mouratidis, (2021) outlines residential wellbeing as one of the pathways to the linking the built environment to the subjective sense of wellbeing. He proposes that urban planning a strategy to improve the subjective sense of wellbeing that residents develop from the environment.

A study conducted by Cookey et al. (2016), in Nigeria found that the public policy documents on OWMS were inadequate to cater for standard construction, installation, operations and maintenance and ultimately enforcement. Mochu et al, (2016), proposes a sustainable model that includes generation, containment, and treatment and re use/minimum disposal that this project sought to build upon to allow developers and builders to select the appropriate technologies to help them attain this formidable goal. It is quite clear from literature and previous studies that there is a need to create actionable planning processes that enable decision makers to comparatively analyse available sanitation options allowing them to choose the most appropriate systems which could vary between distinct locations and densities (Carrard et al. (2010).

Types of onsite wastewater management systems include mechanical treatment methods (e.g trickling filters and sequential bath reactors), Aquatic treatment methods (eg. facultative lagoons and constructed wetlands) and terrestrial/ land treatment methods (eg. Septic tanks)

Factors considered when choosing a wastewater management system include the capacity required, the type of waste to be handled, the ground water level, the soil type in the area, impervious surfaces present and the monitoring and maintenance required during operation.

Systems theory proposed by Ludwig, Niklas and Keneth and further expounded by Midgley (2003), can be used to explain the relationship between various components in the wastewater management system that can be attributed to the failure or success these systems. The efficiency of onsite wastewater management systems is an interaction of various components such as the structure of the system itself, environmental conditions and the human aspect of maintenance and management. If these systems are inefficient, the impact is felt on the larger ecological system of an area.

The tragedy of the common's extension by Hardin (1998) has been this research to illustrate the impact of inefficient waste management technologies on the environment and illuminate on the reasoning behind the use of the common resource (land) by the masses for wastewater management. The tragedy is not taking out of the environment but rather adding into the environment. This is a demonstration of unlimited freedom on the use of land resource. The uncontrolled use of land eventually leads to pollution

## RESEARCH METHODS

This research was a case study by design. Both qualitative and quantitative approaches were used, as descriptions, numbers and statistics were employed to highlight and analyse the data collected. Specifically, the research design is correlational as the study aimed to find if there existed the hypothesized relationship between the variables presented in the conceptual framework. Due to the extensive amount of data that was required for this study, the research methods employed included observation of the physical environment, guided interviews to find out the details on the onsite waste management systems available and their management, questionnaires where applicable and study of archival data and empirical documents to confirm the geotechnical conditions in the area of study and to come up with the framework for selection of the onsite waste water technologies.

The research was conducted in Embakasi, Nairobi County, Kenya. The exact location of the study has been omitted to ensure the privacy of the respondents. The study aimed to investigate the efficiency of OWMS within the case study area. The source of data were the waste management units within the housing developments in the case study area.

The population describes the total number of OWMS that the study seeks to find out the characteristics. For this study, the population is the entire number of OWMS serving residential units in the area demarcated for the case study, as described in the geographical scope of the study. The sampling frame (30 units) was accurately determined once ground truthing had taken place and the residential units pre-qualified.

In this study, all units in the case study area had an equal and known chance of being selected for the study if they were pre-qualified for data collection. Bad odour, rate of evacuation, visibility of effluent within the environment of the waste systems had been identified as indicators of inefficiency in OWMS as outlined in **Figure 1**. Data was acquired through direct observation and guided questionnaires with housing development managers. Additional data on the structural, environmental and maintenance aspects was also gathered using the guided questionnaires.

The analysis that was performed included frequency tables to show the most common OWMS, the general efficiency across systems and across diverse types of residential developments. These results were then presented in cartographic presentations such as tables and pie charts. The collected data was taken through various diagnostic analyses to get data that further allowed the study to make various inferences from the calculated factors. Correlations were used to determine to which extent the variables affect each other. The study used Pearson's correlation coefficient to test the relationship between the variables.

## RESULTS AND DISCUSSION

### a. Geographic Characteristics of the Area

From the data collected, the area physical characteristics were mostly uniform with a layer of black cotton soil, between four feet (1.2 m) to a maximum of eight feet (2.4m) deep. This therefore skews this study towards the study of efficiency of OWMS in these geographical conditions. Below the surface, according to Saggerson (1991) the area to the east of Nairobi where the study area is located has an extensive phonolite layer which is characteristically impermeable (**Figure 2**).

### b. Descriptive statistics

The following is the distribution of the types of OWMS systems visited during the study period.

### c. Overall Efficiency of the Onsite Wastewater Management Systems

The failure rate among the OWMS visited was 56% with 44% found to be in good working condition **(Table 1)**.

### d. Efficiency of Onsite Waste Management Systems with respect to System Type

The failure rate varied among the available OWMS as repsesnted in **Table 2.**

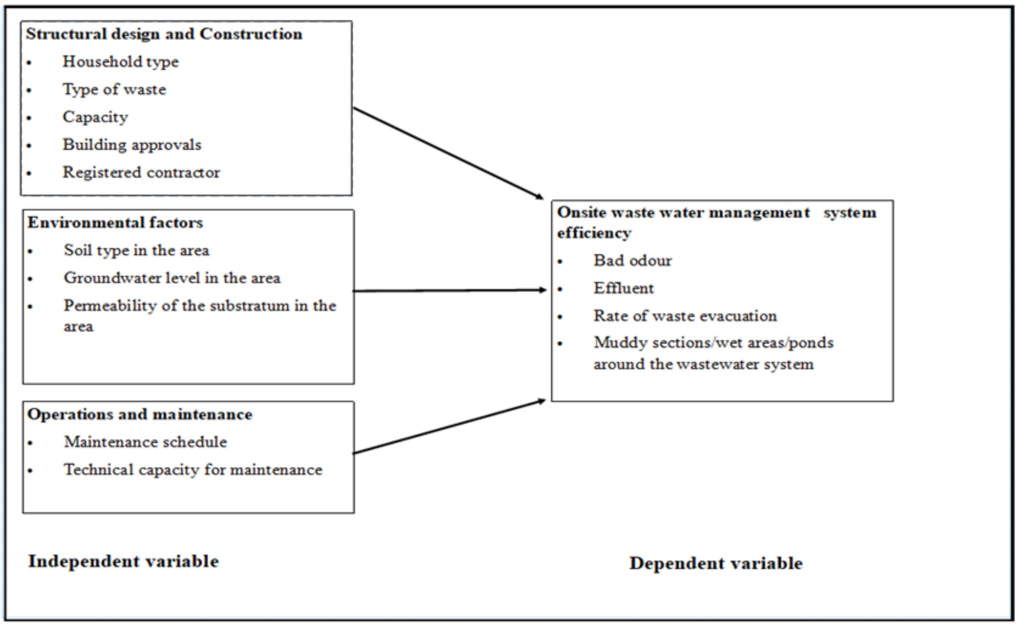


**FIGURE 1**
Conceptual framework
**Source:** Field survey, 2024

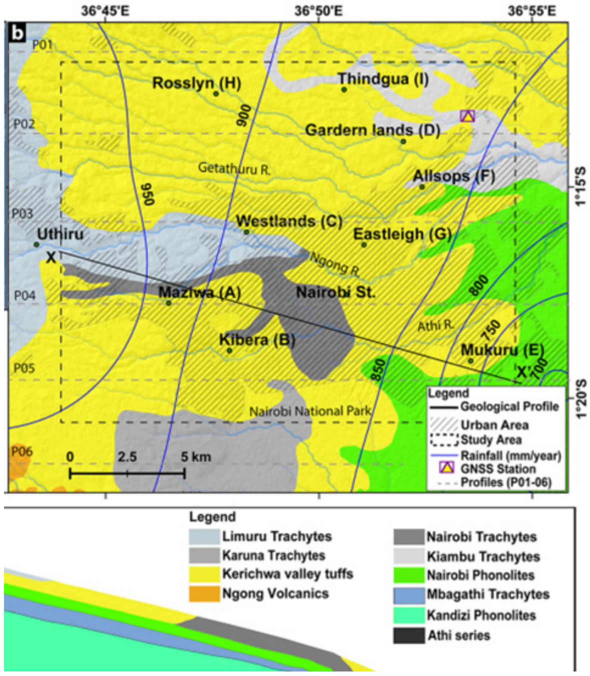


**FIGURE 2**
The geology of Nairobi
**Source:** Adapted from Coetsiers et al., (2008)

**TABLE 1**
OWMS systems visited during the study

ONWS systen

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Pit latrine | 2 | 8.0 | 8.0 | 8.0 |
| | Septic tank | 19 | 76.0 | 76.0 | 84.0 |
| | Septic tank + Biodigester | 4 | 16.0 | 16.0 | 100.0 |
| | Total | 25 | 100.0 | 100.0 | |

**Source:** Field survey, 2024

**TABLE 2**
Failure rate among different waste management systems

| OWMS System Type | Total Number | Failed systems | Failure rate |
|---|---|---|---|
| Septic tank | 19 | 11 | 57.89% |
| Septic tank and biodigester | 4 | 3 | 75.00% |
| Pit latrines | 2 | 0 | 0.00% |

**Source:** Field survey, 2024

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**e. Efficiency of onsite Waste Management Type with Respect to Size of Structure**

The study considered the impact of capacity on the efficiency of the structure with the results as shown in **Table 3**.

**f. Most Common Types of Failure**

The OWMS were investigated for various failure types which included bad odour, dark effluent being released into the environment, soggy ground within the vicinity of the development and short desludging intervals **(Table 4).**

**g. Causes of Failure in OWMS**

A number of factors had been highlighted in the conceptual framework **(Figure 1)** and their occurrence from the data is as shown in **Table 5.**

**Limitations of the study** - The area of study

**TABLE 3**

Efficiency of OWMS vs Capacity

| Residential type | OWMS Type | Number of respondents | Failed systems | Failure rate |
|---|---|---|---|---|
| Single dweller unit (less than 10 persons) | Septic tanks and Pit latrines | 5 | 0 | 0.00% |
| Commercial residential unit (10-25 persons) | Septic tanks | 2 | 1 | 50.00% |
| Commercial residential unit (25 - 50 persons) | Septic tanks | 9 | 7 | 77.78% |
| Commercial residential unit (50 -100 persons) | Septic tank and Septic tanks combined with biodigesters | 9 | 7 | 77.78% |

**Source:** Field survey, 2024

**TABLE 4**

Most common types of failure in OWMS

| Failed OMWS | Failure mode | Number | Occurrence |
|---|---|---|---|
| 15 | Bad odour | 4 | 26.67% |
| 15 | Effluent being released into the environment (dark effluent) | 10 | 66.67% |
| 15 | Soggy ground in the vicinity of the development | 6 | 40.00% |
| 15 | Short de sludging intervals | 10 | 66.67% |

**Source:** Field survey, 2024

**TABLE 5**

Most common sources of failure in OWMS in the case study area

| Total failed OWMS | Cause of failure | Occurrence in failed units | Percentage in failed units |
|---|---|---|---|
| 15 | Mismatch between waste production and system selected/Inappropriate system choice | 0 | 0.00% |
| 15 | Soils and geographical characteristics | 13 | 86.67% |
| 15 | Inappropriate sizing of the system | 3 | 20.00% |
| 15 | Poor construction | 3 | 20.00% |
| 15 | Poor maintenance | 13 | 86.67% |
| 15 | Nearby ground water use e.g. Boreholes, Wells, groundwater | 15 | 100.00% |

**Source:** Field survey, 2024

had one similar soil type (black cotton soil on impermeable rock) and therefore does not offer comparison between distinct types of soil.

**Framework Proposal**

Based on the data collected from the study and literature on the types of onsite waste management systems that are mostly used, the following simple

**TABLE 6a**

Commonly used OWMS selection framework

| Type of system | Capacity required | Type of waste handled | Cycle time required to waste removal | By product safety/Type of effluent (Removal efficiency) | Cost | Soil types and geotechnical condition | Maintenance required | Effect on ground water use in vicinity ie 30m or less | Difficulty/Technicality in construction | Common sources of failure |
|---|---|---|---|---|---|---|---|---|---|---|
| Pit latrines | 0-5 persons<br>5 - 10 persons<br>10 – 100 persons – Not Advisable | Both black water and grey water | Years. Until they fill up after which they are emptied or covered | Effluent and sludge. (Not safe for the environment and requires treatment if exhausted) | Affordable/Low cost | Suitable for most types of soil. Not recommended for flooding areas and areas prone to heavy rains or high ground water. In areas with unstable soils, such as black cotton pit will require to be lined for support. | Minimal maintenance required. Requires emptying if use is high, or grey water is fed into the pit. | High impact on ground water use and wells. Should be 30-50m away minimum. | Most pit latrines are easy to construct. Those in areas with unstable soils should consult experienced technicians and/or engineers | Collapsing due to unstable substructure. Location close to boreholes and walls. Shallow pits that can be affected by high water levels during flooding. |
| Biogas digesters<br>(Not to be confused with biodigesters – see below) | 0-5 persons | (0 - 5 persons) Can handle both black water and grey water. Grey water shoud be minimal. If unsure, separate. | 40 - 100 days depending on waste type and biogas digester type. | Sludge (Not pathogen free) and should be subjected to further treatment eg. Planted drying beds | Medium range | Suitable for all soil types | Medium. The system is not passive. Waste requires further treatment | Low impact as the system is sealed. | Requires technical expertise in construction and installation. | Not maintaining regular feedstock. |
| | 5 - 10 persons<br>10 - 25 persons<br>25 - 100 persons | (5 - 100 persons) Handles black water only. Requires separation of black water and grey water. to maintain a good condition for working of the bacteria | | | | | | | | |

**Source:** Field survey, 2024

framework was developed to improve the system selections among relevant professionals such as engineers and architects and to allow urban planners to question proposed OWMS in new developments (**Tables 6a, b & c**).

**TABLE 6b**
Commonly used OWMS selection framework

| Type of system | Capacity required | Type of waste handled | Cycle time required to waste removal | By product safety/Type of effluent (Removal efficiency) | Cost | Soil types and geotechnical condition | Maintenance required | Effect on ground water use in vicinity ie 30m or less | Difficulty/Technicality in construction | Common sources of failure |
|---|---|---|---|---|---|---|---|---|---|---|
| Septic tanks with soak pits | 0-5 persons<br>5 - 10 persons<br>25 - 100 persons | Both black water and grey water | This depends on the sizing of the system. Efficient system are desludged every 1-2 years. | Effluent is highly pathogenic | High capital investment | (0-5 persons) Suitable for all soil types<br>(10 -100 persons) Only advised for areas with high infiltration capacity. Rate of daily loading should be lower than the infiltration capacity. Black cotton has very low infiltration capacity. | Medium to high maintenance depending on efficiency of the system. If infiltration capacity is low, desludging services must be readily available. | High impact as the waste is expected to infiltrate into the ground. Ground water should be more than 2 m below the bottom of the soak pit. | Requires specialised labour to construct | Low infiltration capacity in some soils. Overloading of the system with too much output per day. Blockages. Location of the soak pit close to water sources. |
| Biodigester and soak pit | 0-5 persons<br>5 - 10 persons<br>10 - 25 persons<br>25 - 100 persons | Works better when handling black water only. Requires separation of black water and grey water to maintain conditions for the working of the bacteria | For an efficient system, no desludging is required. | Effluent is Partially or fully broken down | Medium range investment | Only advised for areas with high infiltration capacity. Rate of daily loading should be lower than the infiltration capacity. | Medium maintenance to ensure good working conditions. Care must be taken not to use strong chemicals and disinfectants. Can easily fill up if infiltration does not occur as planned. | Low impact as the waste is mostly broken down if the system is working correctly. Ground water should be more than 2 m below the bottom of the soak pit. | Requires specialised labour to construct though off the shelf options are now available | Low bacteria performance, no separation of grey water and black water, inadequate soaking away capacity, overloading the system |

**Source:** Field survey, 2024

**TABLE 6c**
Commonly used OWMS selection framework

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Cess pits /collection tank/holding tank** | 0-5 persons<br>5 - 10 persons<br>10 - 25 persons<br>25 - 100 persons | Both black water and grey water | Waste is exhausted once the system fills up | Effluent is highly pathogenic and unsafe for the environment | High capital investment especially for large projects | Suitable for all soil types as waste is contained within the structure | High maintenance. Desludging is required at regular intervals depending on storage capacity. | If well-constructed, minimal impact | Requires specialised labour to construct though off the shelf options are now available | Leakages due to cracks, lack of maintenance and adherence to desludging periods |

**Legend**
- Advisable
- Use with caution
- Not recommended

**Source:** Field survey, 2024

## CONCLUSION AND RECOMMENDATIONS

Most construction professionals are aware of the size requirements based on the number of people the system is expected to serve. Construction professionals also have experience in this sector regarding the type of construction of structure required. Therefore, there was no significant correlation between the soundness of the structure itself with the low levels of efficiency that were recorded in the study especially for systems serving twenty-five or more persons. However, there was a culture of replication of OWMS from one development to the next which does not allow people to appropriately respond to the variable ground conditions that they encounter especially in the case of infiltration-based systems.

When sizing the systems especially in the case of biodigesters and septic tanks, the drawings submitted for approval should also show the size of soak pit allocated to the system and indicate the existing ground conditions in order for the county engineers to be able to assess the viability of the proposed systems. Ultimately, the absorption reliant waste management systems are not practical for areas with clay soils over a rocky substratum especially with the increasing number of high-density developments which increase the wastewater output and reduce the already limited ground for absorption of this waste.

Regarding the proximity of water sources to waste management systems, most respondents were not aware of the level of risk posed and therefore further study on the risk and public education on the same should be conducted to ensure developers and own property developers (landlords), understand the risk. Lack of maintenance was mostly seen where the systems were not working as anticipated which therefore led to the increased need for exhaustion of waste. Developers, not having factored this cost of operations abandon maintenance unless necessary which leads to effluent being released to the environment.

When choosing waste management systems, the expected running costs should be clearly outlined to give developers and landlords a true estimate of the cost of the project. It is also key to equip the caretakers/house managers with the specific skills required to handle the systems. For rapidly developing semi urban areas with poor soil absorption and rocky substratum such as the study area, decentralised wastewater management systems (community systems), or centralised sewer systems offer the best solution to the constantly changing landscape.

## CITED REFERENCES

**Bradley, B. R., Daigger, G. T., Rubin, R., & Tchobanoglous, G. (2002).** Evaluation of onsite wastewater treatment technologies using sustainable development criteria. *Clean Technologies and Environmental Policy*, 4(2), 87-99.

**Buechler, S., Mekala, G. D., & Keraita, B. (2005).** Wastewater use for urban and peri-urban agriculture. *Cities farming for the future, urban agriculture for green and productive cities*, 1, 244-260.

**Carrard, N., Willetts, J., Mitchell, C., Paddon, M., & Retamal, M. (2010).** Selecting sanitation solutions for peri-urban areas: A case study of can Tho, Vietnam. *Water Practice and Technology,* 5(4), 2010109.

**Coetsiers, M., Kilonzo, F., and Walraevens, K. (2008).** Hydrochemistry and source of high fluoride in groundwater of the Nairobi area, *Kenya, Hydrological Sciences Journal*, 53(6), 1230-1240

**Cookey, P. E., Koottatep, T., van der Steen, P., & Lens, P. N. (2016).** Public health risk assessment tool: strategy to improve public policy framework for onsite wastewater treatment systems (OWTS). *Journal of Water, Sanitation and Hygiene for Development, 6(1), 74-88.*

**Ergas, S. J., Amador, J., Boyer, T., & Friedler, E. (2021).** Onsite and decentralized wastewater management systems. *Journal of Sustainable Water in the Built Environment*, 7(3), 02021001(1-3)

**Filion, P., & Keil, R. (2017).** Contested infrastructures: Tension, inequity, and innovation in the global suburb. *Urban Policy and Research*, 35(1), 7-19.

**Hardin, G. (1998).** Extensions of" the tragedy of the commons". *Science*, 280(5364), 682-683.

**Midgley, G. (Ed.). (2003).** *Systems thinking.* London: Sage.

**Mochu, W., Munala, G., & Njuguna, M. (2016).** *Domestic wastewater management in satellite towns around Nairobi city: A comparative study of Mlolongo and Ruiru in Kenya. Scholarly Research Journal for Interdisciplinary Studies*, 4, 2659-2677

**Mouratidis, K. (2021).** Urban planning and quality of life: A review of pathways linking the built environment to subjective well-being. *Cities,* 115, 103229.

**Omenka, E. (2010).** *Improvement of decentralised wastewater treatment in Asaba, Nigeria.* Master Thesis, Department of Chemical Engineering, Lund University, Sweden.

**Peal, A., Evans, B., Ahilan, S., Ban, R., Blackett, I., Hawkins, P., & Veses, O. (2020).** Estimating safely managed sanitation in urban areas; lessons learned from a global implementation of excreta-flow diagrams. *Frontiers in Environmental Science*, 8, 1.

**Saggerson, E. P. (1991).** *Geology of the Nairobi area* (No. 98). Nairobi: Mines & Geological Department.

**Saghir, J., & Santoro, J. (2018).** Urbanization in Sub-Saharan Africa. *In Meeting Challenges by Bridging Stakeholders. Washington, DC, USA: Center for Strategic & International Studies.* Retrieved June 15, 2023 from https://www.csis.org/analysis/urbanization-sub-saharan-africa.

**Schneider, M. Y., Furrer, V., Sprenger, E., Carbajal, J. P., Villez, K., & Maurer, M. (2020).** Benchmarking soft sensors for remote monitoring of on-site wastewater treatment plants. *Environmental Science & Technology*, 54(17), 10840-10849.

**Strande, L., & Brdjanovic, D. (Eds.). (2014).** *Faecal sludge management: Systems approach for implementation and operation.* London, UK: International Water Association (IWA) publishing.

**Willetts, J., Fane, S. & Mitchell, C. (2007).** Making decentralized systems viable: A guide to managing decentralised assets and risks. *Water Science and Technology*, 56(5), 165-173.