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Assessing the Performance of Liquid Waste Disposal Systems in West Africa: A Case Study in Ghana and Nigeria †

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Abstract: This research is an assessment of existing liquid waste disposal systems in West Africa and their performances over the years, using systems in Ghana and Nigeria as a case study. The main purpose of the study was to improve upon the sustainability of the systems, which according to earlier research activities, have been failing and resulting in health hazards. Ghana and Nigeria were selected because, from occurrences, especially in the West African sub-region, the two countries dictate the pace in contributions to the body of knowledge. Many portable liquid waste disposal systems were identified as part of the research process, as earlier researchers called for a paradigm shift from the practice of Europeanized systems that had not been successful in the entire sub-region. Many reasons have been attributed to the failures, and more worryingly, the systems continue to be operational despite their states of malfunctioning. Frequent power cuts and ineffective revenue generation contribute to numerous problems. West Africans have been enduring these occurrences for a long time with no solution in place. In a few instances, raw sewage is piped into a central biogas system for the future generation of electrical power; this system was found to be right on point because it was determined from the initial stages of development that by-products could be used to mitigate the high costs of maintenance. Another system that combines a biofil digester with its treated wastewater being channeled into a saturation pond was found to be a success because the outflow from the biofil was not meant to be channeled into main drains, as it did not wholly meet EPA approvals. The centralized sewage treatment systems have been functioning well in advanced countries; however, they are found to be ineffective in developing countries. The reasons included lack of availability for spare parts and coagulants, etc., which were normally imported. Additionally, when a larger community is targeted, revenue generation becomes a problem, thereby affecting return on investments (ROI) and operating and maintenance (O&M). None of the available central sewerage systems harvest by-products, making revenue generation a difficult task. The portable systems have been discussed in this research study, with examples and a record of performance over the years that could contribute to the body of knowledge in the field of sustainability for sewage treatment processes suitable for West Africa and for the whole of sub-Saharan Africa.

Keywords: raw sewage; treatment; return on investment; portable wastewater treatment; sustainability

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1. Literature Review

This research study was selected because of the stagnation in research towards the attainment of sustainability for liquid waste disposal systems in sub-Saharan Africa. Over the years, even well-designed systems do not last their designed project lifecycles; most are left to rot with no maintenance programs in place, even though they are still being utilized. Additionally, the under-sizing of most facilities was observed during the research study, as population growth was not factored into the design. Worst of all was the fact that during maintenance or expansion works, the facilities were subject to continuous usage, and as they did not factor in any emergency measures for these situations, untreated sewage was consequently directed into drains and water bodies. The resulting effects leave numerous questions to be addressed in terms of finding solutions to these perennial problems; most importantly, this includes an increase in sicknesses due to environmental health hazards, etc.

Earlier researchers have described the liquid waste disposal systems in the sub-region as being unsustainable [1–4]. A few have called upon sub-Saharan Africans to look for their own ways of attaining sustainability. This provoked the researcher to wade into possible areas that would mitigate the identified problem, calling for the introduction of well-analyzed and functioning portable systems in order to attain this feat. The researcher engaged engineers regarding completed projects for qualitative design activities in the two countries; these engineers were identified using secondary research data from literature reviews, as time did not permit for all of the areas to be visited. Many advised against this research exercise, describing it as being a difficult task; the sewage treatment systems in the sub-region had already been concluded as unsustainable.

The call by Samuel Beckett in 1983: "*Ever tried? Ever failed? Doesn't matter. Try again. Fail again. Fail better.*" encouraged the researcher to conduct this exercise in an effort to continue the ongoing research until a solution is attained. This is because no one will be able to solve these sub-Saharan African problems except for the sub-Saharan Africans themselves. Beckett's phrase, which is thought-provoking and was emphasized by Worst ward Ho in the 21st Century [5], could encourage the managers of LWDS in sub-Sahara Africa, as the operational situations within the various countries in the sub-region are similar. Management of the LWDS has not been successful, and most often, it has brought about the total malfunctioning of these systems; in most cases, the results affect environmental health, as untreated liquid waste runs into surface drains, which then flow into river bodies and into the Atlantic Ocean. The disturbing issue with this phenomenon is the fact that solutions need to be found for this anomaly, which has been worsening over the years along with an unavoidably increasing population. In this regard, laxity should not be entertained with the efforts to address this due to the harmful effects on citizens.

The problems in the sub-region have been cataloged, among which the lack of returns on investment has made it difficult for the systems to operate and for facilities to be maintained. The researcher waded into other systems that could be suitable for overcoming this; portable LWDS systems, for instance, would not warrant the importation of spares, etc., as compared with massive centralized systems. Other areas that could be explored to aid in this venture include: governmental inputs in tax waivers, the availability of loans to researchers and installers, and the inculcation of technology into early educational curriculums to increase awareness (such as for primary and junior high schools), etc. This fight cannot be successful without the slapping of penalties onto defaulters and an engagement into the allotment of slots for free; discounted advertisements were also found to be a necessity, all in an effort to achieve success. Thus, there is a need for all hands to be on deck in order to attain a paradigm shift from the activities of the developed world, where over 95% (or in some cases 100%) of citizens are literate. Hence, we should not downplay the effects that uncleanliness could have upon environmental hazards to life and property. In developed countries, for that matter, urban households consider sanitation as a service, and people are ready to pay for it as long as there are sound and reliable providers [6].

2. Existing LWDS and Diversities

The world is gradually moving away from the conventional septic tank and soak-away systems, especially in commercial buildings such as shopping malls, multi-story offices, etc. This is because it does not make economic sense to have large septic tanks, as numerous people are expected to frequent these locations at certain times of the year due to anniversaries and different occasions. One could imagine shopping malls, regional and district hospitals, market squares, and schools with conventional septic tanks and the effect of the effluent flowing through these septic tanks and overflowing into adjoining downstream. What happens during heavy downpours? There is an ongoing war on water usage, as water bodies become less available, as is being reported by water management establishments in Africa. What happens in the building industries, where water is the main item in construction? How about sand for construction? How about the numerous design proposals that are currently available regarding the need to protect the environment and the usage of by-products such as bio-gas for cooking, the generation of electricity, etc.? There is the knowledge that all of these are by-products that could be recycled to generate revenue which could curb the costs of O&M.

2.1. Management Compatibility

There was a need to consider the designs and the number of years needed for their implementation. Most of the existing central liquid waste disposal systems were properly implemented, with acceptable design standards; however, problems were with regard to post-implementation. A study on Nigeria and Ghana showed that apart from installations that are used for private properties, the installations managed by government agencies all failed with time, and since their usage could not be stalled, the untreated sewage ended up flowing into surface drains, which eventually flowed into the Atlantic Ocean.

This research did not depend on the designs, as there were many good designs that had been successfully implemented elsewhere. Rather, the solution to the problems rested on the management of the facilities. The following questions were posed: What were the reasons for the massive failures in the management of such facilities? Why should lack of funds be the main reason when the by-products could be harnessed and used to mitigate the needs of O&M? Why not locally produce the spare parts and the coagulants needed for the effective treatment and running of the facilities? The answers to these questions became limelight to the research in contributing to efforts to find a lasting solution to the canker associated with the LWDS in the sub-region.

The paper relied on the existing systems that have been documented in secondary research activities, examined them through various write-ups, and concluded on the authenticity of most of their findings. These were used to select the research design approaches. This required a qualitative approach, as it dealt mostly with activities regarding the management of once well-designed and functioning systems, most of which have seen deterioration over the years.

The management of LWDS in sub-Saharan Africa has been an albatross on the neck of every person at the managerial level in the sub-region. This is with regard to the fact that no leader would be pleased to see their citizens living in an unhealthy environment. Taking a tour throughout the main cities of selected countries in the sub-region, i.e., Nigeria and Ghana, and relating to the research on the reliability of LWDS in the sub-region, it became evident that the situations were similar to each other. This then made one ponder upon the possible reasons why it should be so poorly managed, especially in the sub-region. Many questions arose, some as follows:

- Why are executive leaders not emulating examples in areas where LWDS is well-managed?
- Why is this matter prioritized as highly as other sectors that are under governmental control, such as education, agriculture, economic management, mining, fuel, etc., to mention a few?

The responses to the two questions above gave a clear understanding of the mentality of governmental leaders in the sub-region over the past few years. The main LWDS in Accra that links the prime areas to the plant at Mudor has been defective for years, even though it was in operation, with the untreated liquid waste flowing into the Korle Lagoon. There is a second plant, the Lavender Hill Fecal Treatment Plant, which deals with discharges from septic trucks. This facility, which was commissioned in 2016, had been five years in operation; however, at the time of conducting this research, there were plans for an outright replacement to expand the system, as the then capacity of 2000 m^3/day did not meet the expected capacity of 6000 m^3/day.

2.2. Contribution of the Research Findings to Academia

What has baffled the minds of many, especially in academia, was the fact that in these days of great opportunity for researchers with the availability of eLearning and easier accessibility literature, there cannot be an excuse whatsoever for stalling in research that would increase our collective knowledge. What one needs to acquire knowledge is boldness, resilience, perseverance, humility, and always being prepared to listen. However, people in responsible positions shirk their responsibilities, and they fail to realize that their families would be affected, as they, by routine, leave their homes to attend various institutions, churches, and playgrounds. Once awareness is made for educating society about the consequent negative effects of living in an area with poor sanitation, this could serve as a caution of some sort, which would eventually create a positive feature for quelling the resulting hazards to human health.

The management of LWDS research must be continuous. Those in management must provide avenues for expansion, especially during the implementation stages, due to the increase in population.

2.3. Waste Definitions toward Sustainability

Pongracz et al. [7] attribute waste disposal systems to, in basic terms, the regulation of waste. However, they also attributed waste minimization as being the key to sustainable waste management, especially when the reduction in waste is tackled at the source of its generation. "Waste is a man-made thing that is, in the given time and place, in its actual structure and state, not useful to its owner, or an input that has no owner, or purpose" –Pongracz et al. [7]. Table 1 presents various definitions of the concept of waste: definitions 1–4 infer the time at which waste is to be moved from its place of generation. In this regard, the management of waste then can then be attributed as simply being a "reaction to waste". This is in collaboration with EPD, Ref. [8], which advocated that "avoiding the generation of waste in the first place and minimizing wastes are also crucial measures in any waste reduction strategy". It can then be related that the search for uses of waste, up to the very last qualification of "waste", depends on the strength and weight that the society of authorities would like to invest in related research on the topic. This assertion can be related to Lox's definition of "waste", as in Table 1, "as either an output with ('a negative market') 'no economic' value from an industrial system or any substance or object that has 'been used for its intended purpose' (or 'served its intended function') by the consumer and will not be reused".

Table 1. Various definitions of the concept of waste.

1	EU	Waste shall mean any substance or object in the categories set out in Annex I, which the holder discards or is required to discard
2	OECD	Wastes are materials other than radioactive materials that are intended for disposal, for reasons specified in Table 2
3	UNEP	Wastes are substances or objects that are disposed of, or that are intended to be disposed of, or that are required to be disposed of, by the provisions of national law
4	Lox	Waste is either an output with ('a negative market') 'no economic' value, from an industrial system, or any substance or object that has 'been used for its intended purpose' (or that has 'served its intended function') by the consumer, and that will not be reused

Table 1. *Cont.*

5	McKinney	Waste is the unnecessary costs that result from inefficient practices, systems, or controls
6	Baran	Waste is the difference between the level of output of useful goods and services that would be obtained if all productive factors were allocated to their best and highest uses under rational social order, and the level that is actually obtained
7	Hollander	Waste is something that needs to be expelled in order that the system continues to function
8	Elwood and Patashik	Waste, like beauty, is in the eye of the beholder
9	Gourlay	Waste is what we do not want, or what we fail to use
10	Pongrácz	Waste is an unwanted, but not avoided output, from whence its creation was not avoided, either because it was not possible, or because one failed to avoid it
11	Pongrácz	Waste is a man-made thing that has no purpose, or that is not able to perform with respect to its purpose
12	Pongrácz	Waste is a man-made thing that is, in the given time and place, in its actual structure and state, not useful to its owner, or an output that has no owner, and no purpose

Table 2. Classes of waste.

Class 1	Non-wanted things, created unintentionally, or without avoidance, and with no purpose
Class 2	Things with a finite purpose that are destined to become useless after fulfilling the purpose
Class 3	Things without acceptable performance, due to a flaw in structure or state
Class 4	Things with an acceptable performance, but which their users fail to use for their intended purpose

Source: Pongracz et al., Ref. [9].

Pongracz et al., Ref. [9] gave four classes of wastes that would lead towards the attainment of sustainability, as per Table 2 below.

Table 2 above gives a deeper meaning to this research, which can be narrowed down to the unsustainability issues of liquid waste disposal in sub-Saharan Africa. The practices in sub-Saharan Africa will not fall into any of the above definitions. A research study could be necessary, as its main purpose is to seek an alignment of the systems with the definitions as practiced in the developed world.

Figure 1 illustrates the Institutional Sustainable Waste Management (ISWM) framework indicating three important dimensions that need to be addressed when developing a system. They are:

1. The stakeholders: People or organizations that are involved and/or affected by the waste management system are identified and encouraged to participate in the planning and implementation phases of the projects.

2. The elements: The different elements of the whole waste system, from generation to disposal;

3. The aspects: All the necessary perspectives that need to be analyzed in order to have local waste issues developed in a sustainable way—Ademoski [10].

Figure 2 also shows the effect of the three main pillars of sustainability.

Social performance is largely dependent on the level of education and employment of the end user stakeholders. This shows the need to survey the environment and the population with the class of the indigenes before specifying the LWDS suitable.

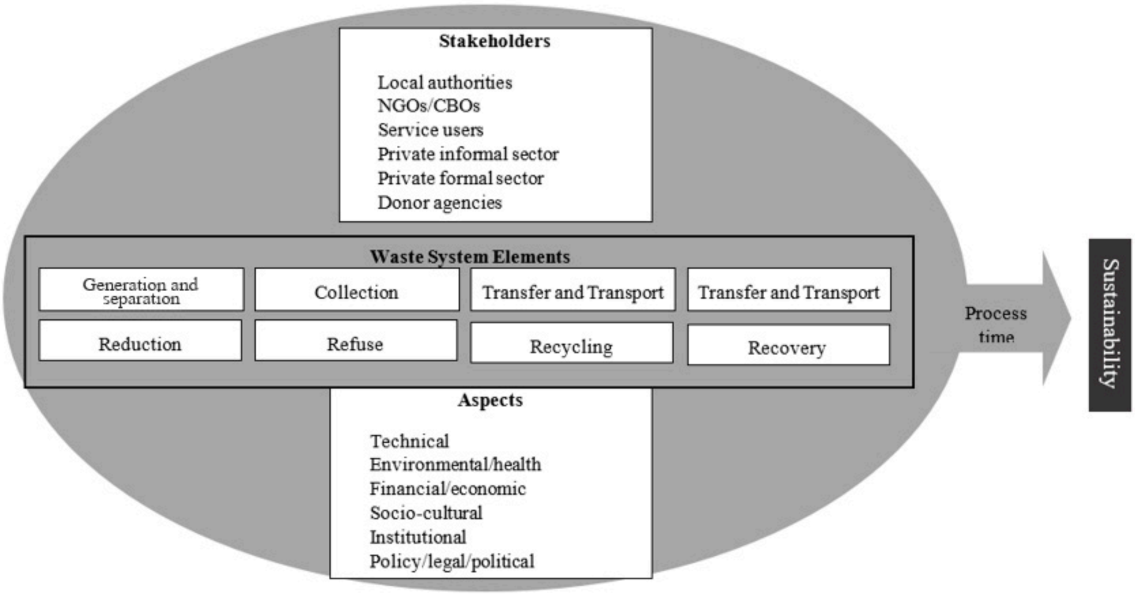

Figure 1. The Integrated Sustainable Waste Management framework. Source: Adamoski [10].

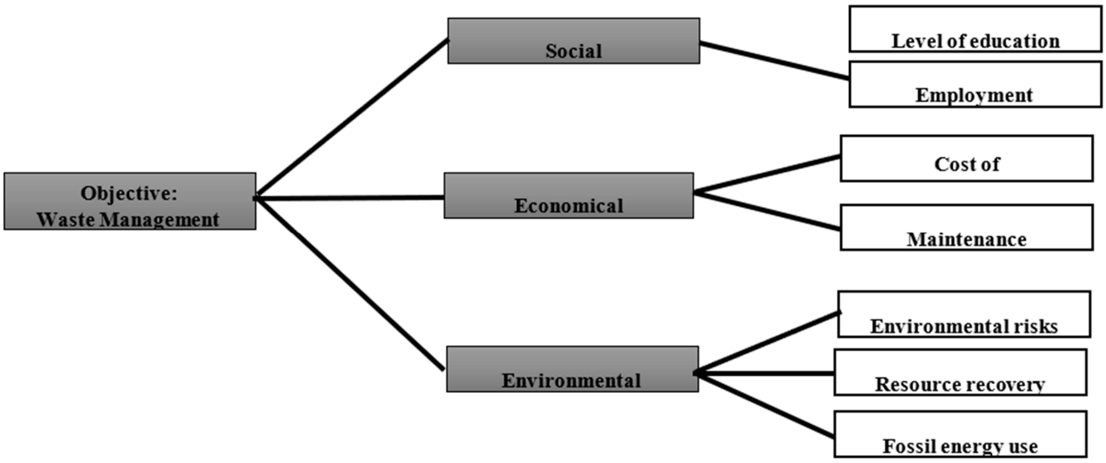

Figure 2. Structure used for modeling the waste management issue in West Africa. Source: Adamoski [10].

The environmental performance is dependent on environmental cost risks, resource recovery, and fossil fuel energy usage. This would involve the vegetation and availability of main drains as well as types of soil available. There would also be the need to trace the paths of the upstream and the downstream available water bodies in order to conclude the types of LWDS to apply.

Economic sustainability is also largely dependent on cost availability and operation and maintenance culture. This is very crucial simply because the history of the existing LWDS shows that maintainability is the main cause of the failures. There is, therefore, the need to put more emphasis on technical availability and spares.

Figure 3 shows a tentative theoretical framework depicting processes that are based, in theory, on the achievement of the general objective of the research study. It is based on the significance of the definitions in the evolving theories; as per Pongracz et al. [7], "every term used in a scientific theory or a given branch of science ought to be precisely defined". This assertion is a strong point, as it contributes to the process of determining the sustainability of waste disposal systems in developing countries, especially with regard to the minimization of waste generation, as well as the avoidance of environmental pollution. It is also defined, among others, as "the unnecessary costs that result from inefficient practices, systems or controls"—McKinney, [11]. Additionally, as per Hollander [12], "Waste is something that needs to be expelled in order that the system continues to function", and last but not least, "Waste is what we do not want or fail to use."—Gourlay, [13].

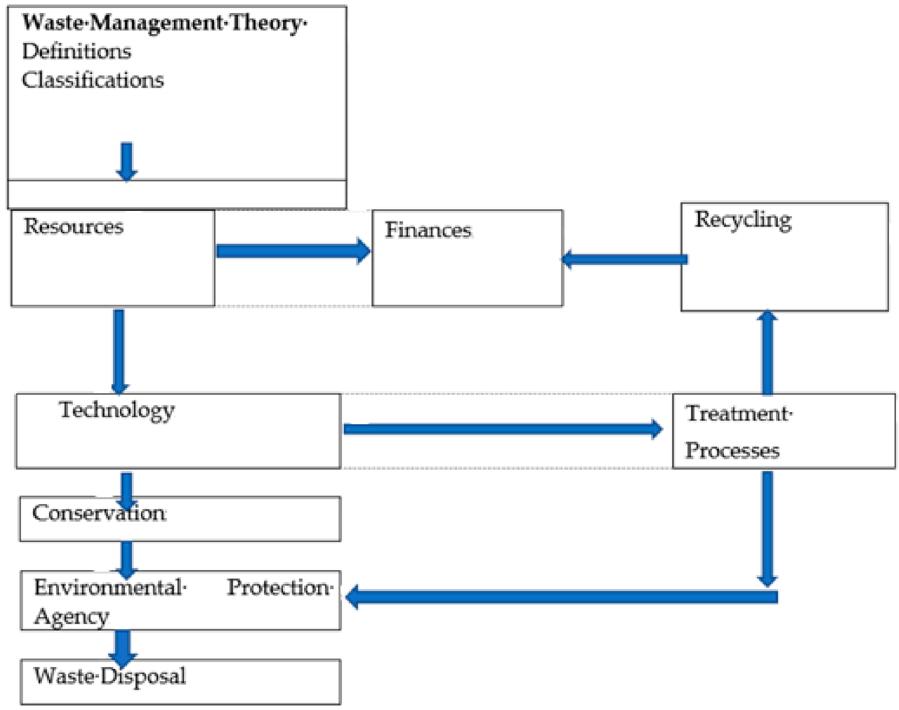

Figure 3. Theoretical framework for sustainability of wastewater disposal systems and environmental protection.

2.4. .Minimization of Waste Generation

An area that has been shunned when it comes to effective management in the sub-region is the need to minimize waste generation. For instance, if the total volume of waste generated per day is reduced, it would have a great effect on the treatment processes that generally appear to be undersized. This under sizing is associated with an increasing population, especially in major cities where the problem is enormous. This is due to urbanization; as assessed by many researchers, it is a problem that is related to the search for greener pastures.

The study on waste reduction could be treated as a policy because it would not only contribute to the alleviation of citizens from the pollution of water bodies in Africa, but it would also lessen the burden on developers. This is explained within the general objective of the study; " ... to help dwellers and property owners to dispose of liquid wastes in an acceptable manner thereby not only contributing to addressing the pollution of the environment but also reducing waste generation within their households and properties". This is corroborated with the following, as per EPD [8], "Waste reduction is often associated with recycling, but it is more complex than that. Avoiding the generation of waste in the first place and minimizing wastes are also crucial measures in any waste reduction strategy". The issue of reduction in waste generation within households is very relevant because, gradually, running costs are becoming unbearable. Water production is becoming expensive with time and affecting consumption. When the costs in operation and maintenance (O&M) rise beyond acceptable levels, the authorities have no choice but to pass the cost on to the consumers. Syed [14] related the concept of environmental management "to emissions of energy and mass from human system". This, he asserted, is not only affecting the natural environment but also "its vital processes including the very existence of life on this earth surface is endangered"—Syed [14]. The research would not only help to provoke certain topics to aid in addressing the unsustainability of the systems, but it also would help to alleviate the masses from health hazards resulting from the application of poor waste disposal methods. The WSA (year unknown) lamented the dangers involved, as "liquid domestic waste is discharged in a manner where it can impact on surface or shallow groundwater". Additionally, many researchers have concluded their findings on the management of sewerage systems in developing countries, especially in sub-Saharan Africa, as not being sustainable and prone to health hazards. Adesogan [1] concluded in his research that in towns and cities in Nigeria, sewage is directed into cesspits and septic tanks, which often become full; as a result, the ground becomes saturated. This situation, as explained in Nigeria, is similar to that in Ghana, as per Awuah et al. [15] regarding the sewerage system in Tema, the main harbor city in Ghana. The sewerage system often breaks down, and during such times, raw sewage is directed into the sea without the necessary treatment. Wang et al. [4] gave a similar account of wastewater disposal systems in Africa as being poor, as over 60% of the urban population live in slums due to the establishment of illegal settlements, making the construction of a correct and acceptable treatment facility difficult.

2.5. Liquid Waste Disposal in Relation to Urban Water

The WCED (1987) in Creese and Robinson [16] defined sustainable development as "development without compromising the ability of future generations to meet their own needs". This definition opened the door to many definitions and interpretations of sustainable development. Robinson et al. [10] interpreted it as being "persistence over an apparent indefinite future of certain necessary and desired characteristics of socio-political system and its natural environment". Creese and Robinson [16] criticized the definition of sustainability based on the socio-political system as "the idea that an urban water system should be sustainable is meaningless". They explained that "the goals of sustainable development must rather apply to the society which the water system serves". This is true to the extent that when the focus is related to socio-political interpretations, there would not be an in-depth analysis, as it normally takes a long time to realize the fruits of positivity in decision-making, which is needed for attaining sustainability. The usage of by-products would promote the sustainability of the system; planning for by-product usage needs to be emulated in sub-Saharan Africa, taking into account all the problems of lack of water. Figure 4 shows the flow of water usage from the source to the treatment processes and distribution as per Creese and Robinson [16]. They however as a means of caution left the re-usage and or final disposal of treated wastewater as an item to be outside managerial control. Normally to be outsourced by experts and managed. Africa is the world's second driest continent, apart from Australia, as noted by Wang et al. [4]. This must be a matter of concern, especially in urban areas, where revenue can be generated as compared to rural areas. Other factors that affect water systems when planning for urban water systems are global warming, which presents challenges that affect the environment, as well as population growth; the latter of which caters greatly to the problems in sub-Saharan Africa, as per Awuah et al. [15], Adesogan [2] Ho [2], and Wang et al. [4].

Wang et al. [4] concluded that insufficient infrastructure and poor O&M were key findings in their research into the challenges of water and wastewater treatment in Africa. Nikiema et al. [17] also added that poor institutional linkages affect management. For instance, the regular participation of the Ghana Institution of Engineering and its allied institutions in decision making can be of great help in knowledge improvement. This can also enhance public awareness and assist with addressing a low willingness to pay tariffs, etc. Adesogan [1] called for the incorporation of innovative systems in other parts of Nigeria since it has been a valuable technology that has been tried and tested over the years and which has overcome O&M, a major problem with regard to mechanical treatment technologies. They explained that mechanical treatment technologies are generally effective where land is available, but they need the energy to power the pumps, making the cost of O&M high. Ho [2] mentioned the difficulties in maintaining large septic tanks and cesspools in towns and cities during downpours. The untreated liquid waste then enters water bodies, thereby creating environmental hazards. CED KNUST [18] theorized that poor sanitation produces high costs for low-income households. This corroborates Wang et al. [4], who explain that in order to attain sustainability, the technology must be applicable, meaning that it must be affordable to the operators. All of these areas must be assessed in the selection of the most suitable system of application. The old process of adopting an internationally available system has seen ineffective management of the facility.

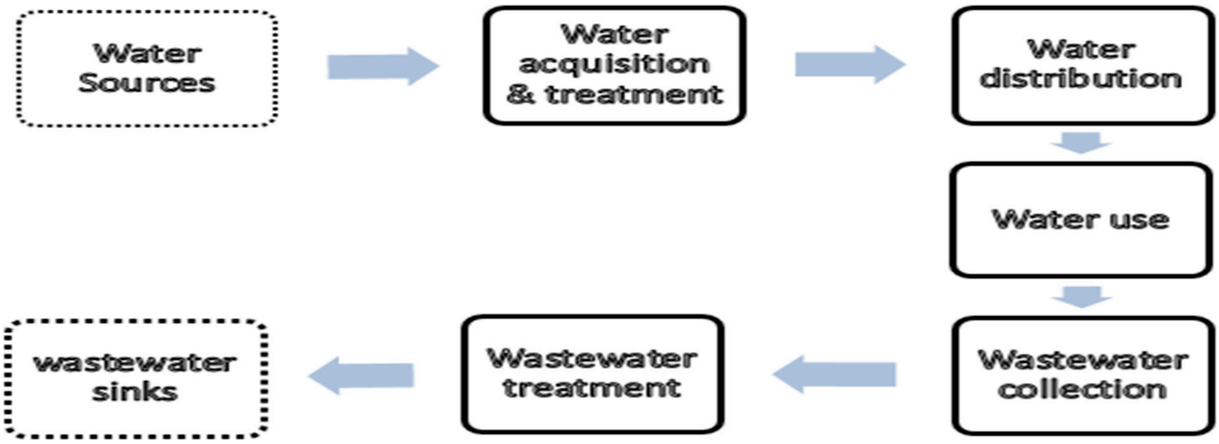

Figure 4. The Urban Water System (Solid Boxes and Arrows), With Water Sources and Wastewater Sinks (Dotted Boxes). Rounded Rectangular Compartments Are Outside Direct Managerial Control. Source: Creese and Robinson. [16] p. 211.

Nikiema et al. [17] described as per Tables 3 and 4, the processes of recycling of treated water for irrigation purposes. The paper cited the various countries with their recycling difficulties such as the sub-Saharan African countries, e.g. Ghana and Burkina Faso. In Accra, Ghana for instance the paper mentioned the recycling processes being carried out without legal control. In Accra according to the paper waste water from drains are reused for irrigation for vegetable cultivation without channeling it through any means of treatment whatsoever. Similarly, in Burkina Faso the government has succumbed to the use of untreated water for irrigation purposes but for selected vegetables." [17] Again Nikiema et al. [17] mentioned that the recycling of wastewater is however not practiced in Senegal, "even if a potential exists for that" purpose.

Countries like Senegal with lack of potential for effective O&M could at least benefit from the usage of wastewater treated for irrigation purposes or livestock watering but "for reasons including unsuitable location of the WWTP which causes the treated water not to be accessible to potential users" [17]. In conclusion Nikiema et al. [17] mentioned among others that the recycling must be looked into in order to make room for diversifications of existing systems as well as creating new developments for other purposes. They reiterated the need to revisit the areas to curb the "high energy prices and operation costs of the systems, which require trained and qualified staff as well, needed to be implemented in order to meet the current standards". (Nikiema et al. [17]) The paper however failed to clarify the 'How' even though listed the problems of O&M management causes of which include high energy costs, etc.

Table 3. Summary of the reported challenges (top 4 challenges of 3 West African countries.

	Burkina Faso	Ghana	Senegal
Technical	• No control over industrial disposals • Power cuts • Limited removal of nitrate or iron • Lack of compliance with regulations	• Pump failures • Power cuts • Overloading	• No control over industrial disposal • Power cuts • Limited removal of nitrate or iron • Lack of compliance with regulations
Social	• Solid wastedisposed in the collection network • Robbery • Vandalism	• Waste thrown in sludge • Complaints regarding odor and the breeding of mosquitoes	• Pump failure • Power cuts • Overloading
Economic	• High O&M costs	• Lack of funds for O&M or rehabilitation • High O&M costs	• Non-sustainable funding sources (charged fees are not sufficient) • Lack of funds for O&M (e.g., fuel for generators)
environmental		• Odor affecting locals in the vicinity	• Deterioration of living conditions of populations • Groundwater pollution • Ecosystem disturbance

Source: Nikiema et al. [17].

Table 4. Summary of the reported challenges (top 3 challenges for 3 West African countries in the reuse of treated wastewater.

	Burkina Faso	Ghana	Senegal	Algeria	Egypt	Morocco	Tunisia
Supply	• Unsus-tainable water quality • Odor in the water	• Shortages of water supply (seasonal and intermittent) • Odor and filth in the water • Poor water quality	• Inadequate infrastructure (e.g., for transport of treated sewage for re-users)	• Un-sustainable quality of treated water • High wateravailable	-	• Inadequate Infrastructure • Bad water quality (salinity, pathogens)	• Poor water quality due to high levels of pathogens and salinity
Social	• Lack of supervision of treated wastewater users	-	• Lack of potential users for treated water (given the location of the WWTP)	• Lack of Synergy between ministry of agriculture and ministry of water resources • Str-ingent regulation	• Lack of political will • Strict standards and regulations	• Limited public/farmers acceptance and awareness • Institution-al set-up not allowing proper Coordination • Lack of political will • Strict standards and regulations	-
Financial	-	-	-	• Low willingness to pay for treated water (prices must be subsidized)	• High O & M cost of networks P	• Low willingness to pay for treated water High O&M costs of networks • Negative impacts of nitrogen excess Deterioration of soil structure (due to salinity)	• No willingness to pay for the treated water
Long-term Impacts	• Reduction in soil fertility	-	-	-	• Deter-ioration of soil structure (due to salinity)	• Negative impacts of nitrogen excess • Deter-ioration of soil structure (due to salinity	
In many areas in Ghana and Burkina Faso, farmers use mostly untreated wastewater, which is diluted to different degrees.							

Source: Nikiema et al. [17].

3. Materials and Methods

3.1. Portable Liquid Waste Disposal Systems

Having observed and analyzed the effects of the centralized systems in the sub-region, the researcher conducted a survey on the portable liquid waste systems in Ghana, which generated enough observations to cover the systems over the sub-region. This is because Ghana and Nigeria share similar behavioral attitudes, according to the conducted survey. The problems enumerated in the survey were similar to each other, as per the literature review and primary data.

The following are the results that were based on observations from qualitative data conducted during the survey toward a target population of engineers and installers of the systems. The results were also based on an analysis from observations over a year and a half of operation of the installed systems, taking into consideration the problems experienced and improvements in the processes over the years.

3.2. MBR-Container-Biological Wastewater Treatment Plants

The MBR-Container is an Austrian-developed wastewater treatment system, and it is a fully biological wastewater treatment plant produced in 10-, 20-, or 40-foot ISO Norm containers, from 50 PE up to 10,000 PE. The system is suitable for smaller communities and shopping malls, office complexes, etc. There are a series of such installed systems in Nigeria, Ethiopia, and Ghana. A typical example is the Compact Wastewater Treatment Plant on the EKO Tower II in Nigeria, which was commissioned in 2015 and has been satisfactory. It incorporates ultrafiltration, and as such, it does not need retreatment. The other two that are installed in Nigeria to cite as examples are the Exxon Mobil building and the Sheraton Lagos Hotel. The Exxon Mobil building installation has a capacity of 70 m^3, and it has been effective since 2012. The Sheraton Lagos Hotel has a larger capacity of 400 m^3/day, was installed in 2013, and is functioning. These systems have been effective; however, they can only be installed when the property owners factor the cost of installation into the initial design. Spare parts have not been a problem once the installer is involved in the maintenance; when the installers are engaged, this reduces the running costs due to the continuous availability of spare parts in their custody. The wastewater treatment system installed in the Transitions Funeral Home and the Bank Hospital, all in Accra, Ghana, are similar to this system, and they have been effective over their years in operation. This system is a Danish-developed system. They were installed by their Ghanaian representatives, the Bioland Company in Ghana, who are always available to ensure that the systems are effective—Okla, Ref. [19]. Due to containerization, they always appear neat, and they hide the usual disorderliness that is present in the operation of most treatment plants. All of the equipment and systems are housed in the containers, and they are suitable for installation, even within the city, where the acquisition of land is expensive.

3.3. The Biofil Technology

The biofil digester technology process has been described as a "simple compact on-site treatment system that uniquely combines the benefits of the flush toilet system and those of the composting toilets by eliminating the disadvantages and drawbacks of both systems". Amoah et al. [20] gave the composition of collected outlet effluent samples, with WHO and EPA requirements explaining that the pollutant removal efficiencies were high; 84% for biochemical oxygen demand and 82.4% for total suspended solids. However, the *Escherichia coli* and total coliform levels were significantly reduced by 63% and 95.6%, respectively. These were satisfactory, as they were not necessarily required for discharge into the environment, but they were to be channeled into landscaping activities. The biofil technology was first introduced in Ghana by K. A. Anno Engineering (KAAE) in 2008. In 2014, the company received an SDF grant to train for the construction of innovative biofil digester toilets. This came about as a result of the rampant discharge of refuse, as well as the unacceptable discharge of untreated liquid wastes into the environment, leaving the city of Accra metropolis in a deplorable state. The training, however, did not impact the lives of the youth due to the attitudinal behavior of the present generation; they need to be gingered into action through a national youth orientation of some sort. (see Table 5 for sample test results by Davsar Biotechnoloy and Construction Limited in Ghana).

Table 5. Analysis results of the outflow of biofil digester by Dav-Tech Company.

Simple ID:	***Company Name:*** **DAVSAR BIOTECHNOLOGY&CONST., LTD.**		
Lab Code	Site Name		
Analysis state date: 01/08/16	Analysis stop date: 12/08/16		
Parameter	**RAW TOILET**	**TREATED TOILET**	**EPA Guideline Values**
pH, pH units	7.50	7.10	6.00–9.00
Conductivity, µS cm^{-1}	8450	2730	1500
Turbidity, NTU	235	2.00	75.0
Apparent Color, Hz	380	5.00	200
Total Suspended Solids (mg/L)	170	3.00	50.0
Total Dissolved Solids (mg/L)	5070	1638	1000
Ammoniacal Nitrogen (NH_4–N) (mg/L)	15.0	0.262	1.00
Nitrogen (NO_3) (mg/L)	26.8	24.0	50.0
Total Phosphorous (mg/L)	1.89	0.041	2.00
Chloride (mg/L)	1171	467	250
BOD (mg/L)	90.0	0.483	50.0
COD (mg/L)	595	1.42	250
Total Coliform (cfu/100 mL)	465×10^4	36×10^4	400
E. coli (cfu/100 mL)	186×10^4	0	10

Source: Water Research Institute, Environmental Chemistry Division. CSIR Premises, Airport Res. Area.

3.4. Biogas Digester Technology

Most of the visited sites containing biogas technology were not completed for gas harvesting, even though the intention for this was clear right from its inception. An investigation conducted by the researcher revealed that funds had not been procured for this purpose. The Central University had a policy for connecting all of the sewage into a central biogas station for the future generation of electricity. This was good, as it supported the green revolution towards sustainability. The raw material is in abundance, as human waste generation is unavoidable, and this could then be explored from all angles for its reuse. In simplistic terms, the average calorific value of biogas is around 23 MJ per cubic meter of biogas, which is approximately 0.5 L of diesel fuel, or approximately 6 kWh, as per Arthur [21] and Omani [9]. In this regard, it would be difficult to justify why hotels should not patronize it in order to reduce the increasing burden of students on user facilities. At the time of this research, the central biogas system at the Central University had still not been completed due to their priority setting. The Lavender Hill Fecal Treatment Plant, which was reported as having plans for expansion, also has a biogas plant that was not being used.

3.5. Duraplast Septic Tanks (DST)

The Duraplast septic tanks are produced by Duraplast Ghana Limited, a plastic-producing company in Ghana. It consists of a coal-loaded reinforced plastic chamber from where effluent is pre-processed before being loaded into a connecting dosing chamber. The Ghana Standards Authority has accepted that the treated effluent from the DST is acceptable for its transfer into the public drainage system. Acceptance of the treated effluent was based on tests that were conducted in 2015, as evidenced by a certificate in the Appendix A.

Below is an example of the test results for a sample submitted in 2013 in Ghana, giving way to its application nationwide.

The recommendations on the composition of the outlet effluent analyzed were simply put; the treated effluent was bacteriologically safe for its dislodgement into the environment, as the level of total coliforms was within the recommended limit. The absence of fecal matter was an indication of safe treatment. The inlet effluent sample taken was described as being unsafe, even for irrigation purposes, as crops are likely to be eaten uncooked. (See Table 6 for sample test results of the DST system in Ghana)

Table 6. Sample test results of treated waste from Duraplast septic tank outlet.

Sample Identification Effluent	Total Coliform (TC) cfu/100 mL Method: APHA 9222A	*E. coli* (cfu/100 mL) Method: APHA 9260F
Inlet	1488	930
Outlet	0	0
EPA Ghana—Maximum permissible levels	400	10
Recommended limits for irrigation	<1000	<10

Source: Duraplast Ghana Limited (2015).

3.6. Septic Tank and Soak Away System

This is the most common system applied in housing projects in the sub-region. Anderson [22] described the main functions of the septic tank as a system that "allows the separation of solids from wastewater as heavier solids settle and fats, greases and lighter solids float". In this regard, the solid content, which is the sludge as he described it, is reduced to between 60% and 80%. When the septic tank is divided into two or three chambers, the treatment is pre-treated because of the transference of the effluent from chamber to chamber; in this case, the first chamber becomes the heavily concentrated chamber as the effluent is transferred through the top, leaving the solids below. The second important function of the septic tank is a capacity of a minimum of two days' retention time, which can be dislodged in case of emergencies while the problem is being addressed. Hall and Greeno [12] described the septic tank as being self-cleansing and only requiring annual dislodgement. It is watertight, and the sewage is liquefied via anaerobic bacterial activity. The capacity of the septic tank is determined as $C = (180 \times P) + 2000$ (Hall and Greeno, 2004) (where C is the capacity in liters and P is the number of persons served). Effluent from the septic tank is passed through the pretreatment, and then it is channeled into other forms of treatments; in the case of the soak away, the ground conditions must allow for this process. Other acceptable forms of treatment could be used for different ground soil properties as long as they meet acceptable environmental standards. Some other treatments are described in this section.

3.7. Septic Tank and Agricultural Drainage

Agricultural drainage consists of corrugated pipes with perforations that are used as an underground network of pipes that collect groundwater and surface water, thereby balancing the level to prevent it from causing damage to property. The application of an agricultural drainage system can be reduced in a smaller way to replace the soak-away system, and this can be very effective in areas with household liquid waste disposal applications. In this case, the septic tank remains a holding tank for future dislodgement, making the combination with the agricultural drainage system effective. This system is rare and is used under all soil conditions, such as clay and swamp, etc., with the simple reason being that the effluent would be designed to spread within a wider area as much as possible. This system is, however, not necessary in lateritic soils, as it would be overly expensive. The usage of corrugated plastic pipes makes it expensive; however, polyvinyl chloride (PVC) pipes could be perforated to serve the same purpose for where it is within the household of its application. For it to be effective, the underground pipes should be surrounded with pebble stones to keep the perforations active before backfilling is applied. A more effective degree of agricultural drainage is attained with the application of geo-textile material around the entire piping, and pebble stone surrounds before selecting the excavated material that is used to complete the work. Where landscaping is available, this system works perfectly for maintaining green areas; a system that is recommended by water companies as they discourage the use of treated water for landscaping activities.

3.8. Septic Tank and DST

This system combines the traditional septic tank with the DST. The advantage of this is the fact that the DST system has been found to produce treated effluent that is suitable for connection into public drains, as permitted by the Ghana Standards Authority (See the Appendix A), after various tests have been conducted over a number of years, with certified results. However, regular monitoring is needed for the simple reason that the chemical that is introduced into the dosing chamber must always be available in order to ensure continuous satisfactory operation, as required. This means that the DST that most installers apply as a single item in the sewage treatment then becomes an effluent treatment, with the sludge being captured in the septic tank for easier dislodgement as and when it is necessary. This would obviously be rated as an improvement to the application of the DST system as a single entity that is observed in most installation areas.

4. Results and Discussion

4.1. Presentation of the Survey Results

The Tables as per Appendix A in Table A1 present the results of the survey on the various portable liquid waste disposal systems conducted, as described above.

The results were based on a direct assessment by the researcher, along with the installers. Confirmation was based on the client's representative, as well as the project managers. Most of these members were present and received reports during and after the construction processes. Inspections were also performed by the researcher for all of the projects, as mentioned, and recorded as tabulated. With regard to the approvals, the researcher based his analysis on the types of liquid waste disposal applied, as it was difficult to acquire certifications for each project. Once the system had received approval on a project elsewhere, it was deemed to have been accepted. The installers with certifications were rated highly, and when a visit was conducted at the sites, the researcher then engaged the facilities management, who reported the conditions to the researcher. The researcher then based his ratings on the results received. The biogas digesters were considered a failure in commercial projects such as the Pentecost Convention Center, a massive multi-disciplinary project with many hostels and auditoriums built for major and broader conferences that could be termed unlimited events, based on the capacity of the Church of Pentecost, which is located in the Central Region in Ghana. It was a failure because its main purpose was to harvest the biogas for cooking and other purposes; however, the gas could not be harvested for its intended purpose. At the time of preparing this report, the sewage treatment system was being revised with a secondary system, the aeration system, and the reason for outright failure was recorded. The Central University, on the other hand, had a policy in place from the inception of the university campus at Miotso in the Dangbe West in the Greater Accra Region, which included the major harvesting of biogas from each building and its centralization into the main biogas plant. The gas would then be used in the future for the generation of electricity, which had been forecast as being an expensive and necessary utility for such an institution. This process is ongoing; as new projects are being connected to the existing sewer manholes. It was also realized during the study that apart from the generation of electricity, there were other by-products, such as large volumes of water, which could also be subjected to various segments of treatments, depending on what the water would be used for. There were many hostels with many students, and as such, the idea was thought through with a cost–benefit ratio for student utility payments in mind.

4.2. Key Findings

Among the key findings as per Nikiema et al., Ref. [17] is "the amount per inhabitant of wastewater entering a treatment plant ranges from less than 0.2 liters/d/person in Ghana to 63.2 litres/d/person in Tunisia". Among the findings are the treatment plants which "face challenges such as organic loads, uncontrolled waste input, and power cuts, increasing wastewater flow rates, poor O&M, high energy costs and lack of re-investments"—Nikiema et al. [17].

From the findings of earlier research, which corroborates the facts on the ground, the following solutions were arrived at:

Selection of portable LWDS that would overcome the points as raised by Nikiema et al. [17] and others. The few centralized LWDS are limited to main lines, which makes it difficult and cumbersome for most houses and developers to access. Simple responses such as "No Connection Available", etc. are given to most applicants. This, as per Nikiema et al., Ref. [17], reduces the usefulness of the limited central system. In this regard, the returns on investments are affected. Another observation is the inability to collect tariffs, as most users explained that one-off payment is what they made. This was found not to not good enough as most developments on the main Accra Sewage Treatment Plant are patronized by international business ventures who can contribute immensely towards the maintenance of the LWDS.

The existing plants were facing challenges such as organic loads and uncontrolled waste input: This can be prevented when policies are factored in. For instance, a policy to disallow every house to connect directly into the main sewer without an in-house minimum treatment facility such as a holding tank. This can prevent oil from waxing in the pipeline. It can also avoid polythene materials which have become a common object flying about. A visit to the Accra Sewerage Improvement Project (ASIP), which was commissioned in 2016, showed how organic matters are causing serious treatment problems and must be addressed as discussed.

Incessant power cuts: This is a common phenomenon in West Africa. The need to adopt portable systems such as the DST, Biofil digesters, and Biogas systems to address this canker.

Increasing wastewater flow rates: It was also realized that the initial design of most existing plants did not factor-in urbanization. This caused a great disservice as, at the time of the installations some decades ago, the vicinity could account for ten times its population at the time of the research activity.

Poor O&M: This had to do with the poor collection of revenues, as explained. Furthermore, the types of LWDS deal with imported spare parts and coagulants. The sub-region is faced with local currency depreciation, and as such, anything to be imported has an effect on the system. This is the reason for the call for the portable sewage treatment systems as enumerated which do not need unavailable spare parts.

High energy costs: This could be addressed with the introduction of recycled treated waste. Such as sand for construction, charcoal production, fertilizers, etc., but they are non-existent.

Lack of re-investments: Investors shy away from investing in such projects where policies are difficult to be implemented.

4.3. Proposed Solutions

The above observations on the existing situation in Ghana led to the discovery of portable LWDS, which are being implemented in the sub-region. Primary data were sought as per the Appendix A with the types of facilities. The portable systems include biogas digesters, biofil digesters, septic tanks and soak-away, septic tanks and biological filters, septic tanks with reed beds through an agricultural drainage system, Duraplast septic treatment system, etc. Their successes and failures were recorded through qualitative analysis by carrying out interviews with the professionals in the field, engineers as well as installers of the various systems. The reason for carrying out the research on the above systems is purposely to overcome the problems, as enumerated above, as these systems depend on gravitational flows, etc. The problem associated with these had to do with fewer experts in the field, and as the unemployment rate increases, most of the installers carry out the installations with very little knowledge in order to make some dividends to survive. The successfully implemented ones were those that were carried out by professionals in the fields.

Simple problems such as blockages in sewer lines, and cracked manholes that allow rodents to damage sewers, do not need complex technologies to be solved; however, their effects have caused the centralized systems to become cankers. The problem lies not with the technology itself but with the management of the systems. From the activities observed and analyzed within the research, although the centralized systems seem to be the most acceptable facilities, as demonstrated in developed countries, they are, in fact, not sustainable in the sub-Sahara, as the factors pertaining to sustainability are not balanced. In this regard, the focus must shift from centralized systems to portable systems in order to avoid an accumulation of debt in operation and maintenance. There are many systems that are already in existence, that are well-documented, and that have been satisfactory; however, applying these systems within the sub-region is problematic. In order for the system to be sustainable, all of the factors of sustainability need to be balanced. The main pillars of sustainability are environmental, economic, and social factors, all of which must be sufficiently factored in order to meet the sustainability of the facility in question. This would keep the system operating satisfactorily over and above the designed period. Unfortunately, many installations do not meet their designed durations before collapsing. This is a source of worry due to the difficulty in raising funds, which mostly consist of loans that are paid for by the public purse. The research in this regard came to the conclusion that decentralization is a key direction towards sustainability, as most of the responsibilities would then lie with the developer, which would lessen problems with returns on investment, which greatly affects operation and maintenance. The portable systems, as identified, would then become a strong point for the consideration of improvements, as most of them are not documented and are currently handled by untrained personnel.

5. Data Collection and Analysis

Data collected were analyzed with a breakdown of three pillars of sustainability, namely, economic growth, environmental performance, and social development. Table 7 shows the Regression results using the Basic descriptive, Multiple regression, Durbin–Watson statistics. The study used Eviews 10 statistical software (IHS Global Inc., Irvine, CA, USA) to estimate the statistics results. The results were limited to four fields that were found to be competing in terms of performance. They were; the Biogas digesters, Biofil digesters, Duraplast Sewage Treatment (DST), and the Central Sewage Treatment Systems (CentralSe).

Discussions and Recommendations

The conclusions of the study were broken into three implications, namely, Practical implications, Theoretical implications, and Policy implications.

Practical Implications

Under practical implications, findings uncovered a few portable systems which need more technical support by tertiary institutions, etc. A call for governmental agencies can support economically. There should also be the need to weigh the end results with the community of the facility the type would serve before implementation of the system adopted. This conclusive remark was based on the fact that where regulatory bodies focus attention, the systems deliver positively with balance in sustainability as compared to others.

Theoretical Implications

Under theoretical implications, the classification of waste determines its effectiveness and impacts positively on the system; especially when the waste is described as a thing in its given state not useful to the owner, etc. What is also worthy of note is the fact that the application of waste disposal systems differs from each area, and, as such, there is the need to support each system with classifications.

Policy Implications

Under the policy implications, existing policies on waste management have been generalized affecting implemented. Literature on portable liquid waste systems is to be made available with research activity.

Table 7. Summary of key findings (Regression result).

PRESENTATION OF ANALYSIS			
REGRESSION RESULTS			
Explanatory Variable	**Economic Development**	**Environmental Protection**	**Social Performance**
Constant	(7.3885)	8.981	7.6952
	0.2028 **	(0.3166) **	(0.5113) **
Biogas digester	0.0760	−0.0597	0.0326
	(0.0081) **	(0.0126) **	(0.0204)
Biofil digester	0.3940	0.4905	0.3845
	(0201) **	(0.0313) **	(0.0506) **
DST System	−0.0003	0.0600	−0.0271
	(0.0074)	(0.0116) **	(0.0187)
Central Sewerage	−0.3049	−(5055)	−0.2634
	(0.0193)	(0.0302) **	(0.0487) **
R-squared	0.9958	0.9954	0.9685
Adjusted R-squared	0.9874	0.9862	0.9054
F-statistic	118.63	108.07	15.35
Prob (F-statistic)	0.0083	0.0091	0.0621
Dublin-Watson stat	2.1239	1.1.4748	2.2097
Observation	7	7	7

NB: ** shows significant statistical values at 5 percentage points.

6. Conclusions

From the summary of key findings as per Table 7, Biofil scored positive results in all the three pillars of sustainability used to determine the performance of the various liquid waste systems used. This was followed by Biogas digesters, with the DST recording the third in terms of performance. The Central Sewage treatment, as per the results, has many challenges in the sub-region and was used for effective analysis. The three top do not need the importation of spare parts as they are locally manufactured in the sub-region. They can also perform with no electrical power, especially when all the considerations, as enumerated in the implications, are factored into the selection.

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standards as per the results tabulated. They were the ones whose contributions were rated highest with regard to the phrase, "Ever tried? Ever failed? Try again. Fail again. Fail better."

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Acronyms

EPA	Environmental Protection Agency
ROI	Return on Investments
O&M	Operation and Maintenance
LWDS	Liquid Waste Disposal Systems
EPD	Environmental Protection Department
EU	European Union
OECD	Organization for Economic Co-operation and Development
UNEP	United Nations Environment Programme
NGO	Non-Governmental Organization
CBO	Community-based Organizations
ASCE	American Society of Civil Engineers
BS	British Standards
WSA	Waste Stream Assessment
WCED	World Commission on Environment and Development
CED KNUST	Civil Engineering Department/Kwame Nkrumah University of Science & Technology
MBR	Membrane Bioreactor
ISO	International Organization for Standardization
PC	Personal Computer
WHO	World Health Organization
CSIR	Council of Scientific & Industrial Research
PVC	Polyvinyl chloride
PPI	Plastic Pipe Institute
LDS	Latter Day Saints
DST	Duraplast Septic Tank
EU-BAM	European Union-Banana Acceleration Measures
GHC	Ghana Cedis
KAAE	K. A. Anno Engineering
SDF	Skills Development Fund

Appendix A

Table A1. Data on the performance of types of liquid waste disposal systems in selected areas in Ghana (survey by researcher; 2019–2020).

			GENERAL PREDICTOR VARIABLES				ECONOMIC DEVELOPMENT			ENV. PROTN	SOCIAL PERFORMANCE	
ITEM	LOCATION	TYPES OF LWDS	NO OF UNITS	STATE OF INSTN	AVG NO OF YEARS IN OPN	POPLN SERVED AT TIME OF SURVEY	MAINT'TY PER'NCE	BY-PRODUCTS COST RECOVERY	TARIFF GEN'N	EPA RATING	TARIFF GEN'ION	CUSTOMER SATISF'N
1	PENTECOST CONVENTION CENTER	BIOFIL DIGESTER	8	100	10	200	100	0	100	60	100	100
2	PENTECOST CONVENTION CENTER	BIOGAS TECH	20	80	10	1000	80	50	100	50	100	100
3	DZORWULU ACCRA	DST	6	100	8	200	100	50	100	100	100	100
4	DANSOMAN EST	PORTABLE SEPTIC TANK AND SOAKAWAY	100	100	40	1000	100	0	100	50	100	100
5	DANSOMAN EST	CONNECTION TO CENTRAL SEWER	100	100	40	2000	0	0	0	50	0	0
5	DANSOMAN EST	CENTRAL SEWAGE TREATMENT PLANT	1	100	40	2000	0	0	0	10	0	0
6	SSNIT FLATS DANSOMAN	LARGE SEPTIC TANK AND SOAKAWAY	3	100	40	1000	100	0	100	100	100	100
7	INDEPENDENCE AVE ACCRA	CENTRAL SEWER CONNECTION	45	100	20	10,000	100	0	20	100	20	100
8	ACCRA CENTRAL	CENTRAL SEWAGE TREATMENT PLANT	1	100	20	2,000,000	50	0	50	25	50	25
9	LAVENDER HILL	FECAL TREATMENT PLANT	1	100	5	160	50	50	100	40	100	50
10	OSU TOWNSHIP	BIOFIL DIGESTER	10	100	6	200	20	0	100	0	100	100
11	TRADE FAIR, LA	TRICKLING SYSTEM	1	100	40	1000	20	0	100	50	100	25
12	LABADI BEACH HOTEL	PACKAGE UNIT	1	100	10	500	100	0	100	100	100	100
13	KOFI ANNAN PEACE KEEPING CENTER	PACKAGE UNIT	1	100	10	500	100	50	100	100	100	100
14	CENTRAL UNIVERSITY COLLEGE	BIOGAS TECH	1	80	15	2000	100	50	100	100	100	100
15	PENTECOST UNIVERSITY COLLEGE	BIOGAS TECH	1	100	15	200	100	0	100	100	100	50
16	EU-BAM HOUSING, KASUNYA NANKANA	COMBINATION OF BIOFIL DI-GESTER/STABILIZATION POND	200	100	3	500	100	50	100	100	100	100
17	SSNIT FLATS, KUMASI	LARGE SEPTIC TANKS AND BIOLOGICAL FILTER	1	100	25	1000	100	0	100	100	100	100
18	SSNIT FLATS, BOLGATANGA	PORTABLE SEPTIC TANKS	100	100	25	500	100	0	100	100	100	100

Table A1. *Cont.*

ITEM	LOCATION	TYPES OF LWDS	GENERAL PREDICTOR VARIABLES				ECONOMIC DEVELOPMENT			ENV. PROTN	SOCIAL PERFORMANCE	
			NO OF UNITS	STATE OF INSTN	AVG NO OF YEARS IN OPN	POPLN SERVED AT TIME OF SURVEY	MAINT'TY PER'NCE	BY-PRODUCTS COST RECOVERY	TARIFF GEN'N	EPA RATING	TARIFF GEN'ION	CUSTOMER SATISF'N
19	AHINSAN, KUMASI	STABILZATION POND	100	100	25	5000	100	0	50	25	50	50
20	SSNIT STUDENTS HOSTEL LEGON	BIOGAS TECH	4	100	10	7000	100	80	100	50	100	100
21	SSNIT STUDENTS HOSTEL UEW	LARGE SEPTIC TANKS AND BIOLOGICAL FILTER	4	100	20	7000	100	0	100	100	100	100
22	LDS MEETING HOUSES IN GHANA	BIOFIL DIGESTERS	15	100	10	1000	100	50	100	100	100	100
23	LDS MEETING HOUSES IN GHANA	SEPTIC TANK AND SOAKAWAY	10	100	20	500	100	50	100	100	100	100
24	POLO HEIGHTS APARTMENT BUILDINGS	LARGE SEPTIC TANKS AND BIOLOGICAL FILTER	3	100	15	300	100	100	100	100	100	100
25	BEST WESTERN PREMIERE AIRPORT WEST	LARGE SEPTIC TANKS AND BIOLOGICAL FILTER	2	100	10	400	100	0	100	100	100	100
26	AIRPORT CITY	PACKAGE UNIT	1	100	25	10,000	0	0	100	100	100	100
27	POLICE TRAINING DEPOT ACCRA	SEPTIC TANK AND SOAKAWAY	3	100	30	1000	20	0	100	25	100	50
28	POLICE TRAINING DEPOT ACCRA	SEPTIC TANK AND DST COMBINATION	2	100	2	400	100	0	100	100	100	100
29	BANK OF GHANA HOSPITAL	AERATION PACKAGE UNIT	2	100	4	250	100	100	100	100	100	100
30	PEDUASE LODGE	SEPTIC TANK AND SOAKAWAY	3	100	14	100	100	50	100	100	100	100
31	ACCRA MALL	ACTIVATED SLUDGE SYSTEM	1	100	15	20,000	100	0	100	100	100	50
32	NUNGUA MALL	ACTIVATED SLUDGE	1	100	10	2000	100	0	100	50	100	100
33	ACCRA SPORTS STADIUM (PART A)	LARGE SEPTIC TANKS AND BIOLOGICAL FILTER	3	100	20	20,000	100	0	100	80	100	100
34	ACCRA SPORTS STADIUM (PART B)	CONNECTION TO CENTRAL SEWER	1	100	20	10,000	100	0	50	80	50	'100
35	TEMA CENTRAL	CONNECTION TO CENTRAL SEWER	200	100	20	2000	100	0	25	100	25	50
36	TEMA CENTRAL	TEMA SEWAGE SYSTEM	1	100	20	200,000	50	0	50	50	50	50

Table A2. Sewerage technologies captured in the urban area of Nigeria.

STATE	LOCATIONS OF SEWER LINES	KIND OF TREATMENT	LEVEL OF TREATMENT	STATUS
F.C.T, Abuja	Wupa Central Plant	Mechanical	Complete	Functioning
Markurdi	Markurdi Central	Mechanical	Complete	Not Functioning
Kaduna	Nigerian Brewery, Kaduna	Mechanical	Complete	Functioning
Kano	Kano Central	Mechanical	Complete	Not Functioning
Enugu	Abakpanike Estate	Biological	Partial	Functioning
Edo	Nigerian Brewery, Benin	Mechanical	Complete	Functioning
Delta	NNPC, Warri Shell Petroleum Main Office and Staff Quarters Warri	Mechanical Mechanical	Complete Complete	Functioning
Rivers	Ifruga Estate, Rivers Etope Estate, Rivers Chevron Office, Rivers Shell Petroleum Office, Rivers	Mechanical Biological Mechanical Mechanical	Partial Partial Complete Complete	Not Functioning Functioning Functioning Functioning
Lagos	Abesan Oke Afa Alausa Olusosum Nigerian Brewery, Lagos University of Lagos	Biological Biological Mechanical Biological Mechanical Biological	Partial Partial Partial Partial Complete Partial	Functioning Functioning Functioning Functioning Functioning Functioning
Ekiti	ABUAD	Mechanical and Biological	Partial	Functioning
Oyo	UCH University of Ibadan I.I.T.A Ibadan Nigerian Brewery, Ibadan	Mechanical Biological Mechanical Mechanical	Partial Partial Complete Complete	Not Functioning Functioning Functioning Functioning
Osun	OAU, Ile-Ife Nigerian Brewery, Ilesha	Biological Mechanical	Partial Complete	Functioning Functioning
Ogun	Agbara Industrial Estate	Mechanical	Complete	Functioning

Source: Adesogan (2013).

Table A3. Selected Portable Sewerage Systems in Ghana with their Performances Weighted according to Approval by Authorities.

Some selected portable sewerage systems in Ghana, and their performances according to approval by authoritiesSurvey by researcher, 2019				
A	Biogas	Pentecost Convention Center, Gomoa Fetteh Central University, Miotso, Greater Accra	Failed: Technology misapplied. System malfunctioning. System was replaced Successful because raw sewage from the various buildings was directed into a central system for the generation of electricity.	Approved The system is approved; however, it is not completed

Table A3. *Cont.*

Some selected portable sewerage systems in Ghana, and their performances according to approval by authoritiesSurvey by researcher, 2019				
B	Biofil Digester	Latter Days Saints Meeting Houses in several parts in Ghana The Housing Units & Social Center, For Banana Accompanying Measures (BAM) at Kasuna Nakana, Osudoku Pentecost Convention Center, Gomoa Fetteh	Successful: Smaller discharges due to frequency of usage Successful: All biofil-treated water channeled into stabilization pond Failed: There was no drain from upper stream to receive treated effluent, so resulting stagnated system was replaced	Approved
C	Septic Tank and Soak Away	Ayi Mensah Apartments (in progress)	Partial completion; successful; ground conditions conducive	
D	Septic Tank and Biological Filter	Ghana Free Zones Authority, Head Office Building at Cantonments, Accra Polo Heights Apartment Buildings, Airport, Accra Holi Flats at East Airport Best Western Premiere Hotel, East Airport Millennium Heights, East Airport	Successful. Installations correctly done and available environmental conditions favor the selected system	Approved
E	Sewage Treatment Plant Aeration type with bypass into central sewer	IFC—World Bank Office, Accra	Successful. Installations correctly done and available environmental conditions favor the selected system	Approved
F	Septic Tank with Biological Filter with effluent transferred into typical reed bed through Argic drainage system	District Hospital Projects	Successful	GSA Approved
G	Septic Tank and Biological Filter system	Best Western Premiere Hotel	Successful. Installations correctly done and available environmental conditions favor the selected system	Approved
H	Holding Tank and Aeration Treatment System	The Bank Hospital Transitions Home Haatso, Accra	Successful. Installations correctly done and available environmental conditions favor the selected system	Approved
J	Septic Tank and Duraplast Sewerage System	Police Depot, Tesano, Accra Niiyo Apartment Block, Dzorwulu, Accra	Successful. Installations correctly done and available environmental conditions favor the selected system	Approved

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