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Selecting Appropriate Onsite Systems for Effective Domestic Sewage Disposal in Yenagoa, Nigeria

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Abstract: The study was aimed at selecting appropriate onsite system for effective domestic sewage disposal in Yenagoa, Nigeria. The various types of onsite systems considered were the soakaway pit, subsoil disposal bed and the Sand-Filter Systems. Field investigations and site tests carried out during the study revealed that Yenagoa had silty clay soil that had very low acceptance rate of 5.21 L/m^2/day and a low percolation rate of 218 min/100 mm and the soil was of semi-impervious nature and had high ground water table of 3.0 m and <300 mm in the dry and wet seasons, respectively. The implication of findings was that the study area with very low acceptance and percolation rates was not suitable for soakaway pit system which was only suitable for soils with reasonably permeable and relative absorptive surface and the field disposal bed which only suitable for soil of semi-impervious nature with low ground water table both in dry and wet seasons. The sand-filter system was selected for onsite disposal of domestic sewage because it was found to provided the required treatment capacity and its operation do not depend on whether the soil has low acceptance and percolation rates or high ground water table. In comparing the cost between the two systems, sand-filter system cost about twice that of the soakaway pit system. However, the sand-filter system was still selected for the study area because it will protect public health and reduce environmental pollution that characterised the use of soakaway pit system.

Key words: Soakaway, sand-filter, field tile, percolation, acceptance, porosity, flow-rate, sewage, onsite, appropriate, Yenagoa, treatment, Nigeria

INTRODUCTION

Domestic sewage is the liquid waste which originates from sanitary conveniences of dwellings (McGhee, 1991) and it is made up of the human wastes (faeces and urine) and the sullage which is composed of wastewater resulting from personal washing (bath and shower), laundry, food preparation and cleaning of kitchen utensils (Mara, 1978; Henry and Heinke, 1996; USEPA, 1995). However, because of the contaminating effects of domestic sewage, especially when it becomes 'stale' or 'septic', various methods have been employed in its disposal.

Before the advent of sewage systems and their wide application, treatment and disposal of wastewater at its source was necessary. The original onsite system was the dug pit which is predominately used in Nigeria rural areas, in camps and other temporary residences. It consists simply of a deep pit between 1.5-2.0 m in which human excrement is deposited. When the pit is filled up, it is covered and a new pit is dug for use (Henry and Heinke, 1996). From the dug pit came the pit privy which consists of a pit about 1.0 m wide and long and 1.2-1.5 m deep. It may be boarded on all sides and covered with a reinforced concrete slab. A concrete riser supports the seat and a ventilator pipe conveys odours through the roof and the floor is elevated to prevent run-off from entering the pit. It can serve an average family for about 10 years. Because cleaning is not practicable, a new pit must be dug when the old one is full (McGhee, 1991).

A further development of the pit system is the conservancy inform of cesspool. It is used when a building is not sewered and also site treatment is not possible either because of the size and configuration of the site which do not permit the construction of a treatment plant or the disposal of the effluent. The

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cesspool is constructed using a watertight but ventilated underground container which receives the flow from drains while the received pool is pumped out at intervals (Burberry, 1997).

From the era of pit systems, the septic tank and field disposal systems was in vogue. It is a decent and more environmentally acceptable than the other methods. In the United States, about 25% of most housing units dispose off their wastewater using onsite systems and this percentage has remained relatively constant for the past 30 years despite extensive sewer constructions in most urban areas (USEPA, 1980).

Domestic sewage is comprised of urine and faeces which consists of various constituents concentrated in varying degree. The various components found in domestic sewage are organic matter, nitrogen, Phosphorus (P_2O_5), oxides of potassium (K_2O), Carbon and Calcium (CaO) (Mara, 1978). The organic fraction of both faeces and urine is composed principally of protein, carbohydrates and fats. This compounds particularly the organic matters and nitrogen form an excellent diet for bacteria. The microscopic organisms have voracious appetite for food and this is exploited by sanitary engineers in the biological treatment of sewage. The majority of these bacteria are harmless and beneficial but an important minority is able to cause human disease (Mara, 1978). Sullage contributes a wide variety of chemicals such as detergents, soap, fats and grease of various kinds and anything that goes down the kitchen sink (sour milk, vegetable peelings, tea leaves, soil from vegetable and sand used in cleaning cooking utensils).

Domestic sewage when fresh is a grey turbid liquid which has an earthy but in-offensive odour. It contains suspended solids such as partially disintegrated faeces, tissue papers including very small solids in colloidal (non-settable) suspension as well as pollutants in solution. It is objectionable in appearance and extremely hazardous in content mainly because it contains several disease-causing (pathogens) organisms. In the tropics, sewage can soon loose its content of dissolved oxygen and becomes 'stale' or 'septic'. Septic sewage has an offensive odour usually of hydrogen sulphide (Mara, 1978). Because of the odour, domestic sewage should be treated before its ultimate disposal in other to reduce the spread of communicable diseases caused by the pathogenic organisms in the sewage and to prevent the pollution of surface and ground water.

Many environmental engineers have criticised the use of central wastewater systems because they consider the collection of wastewater and providing the treatment at a large central location as not making any sense especially in the developing countries. The reason is that developing countries do not have the finance and technology to execute any elaborate project such as central wastewater systems. Also, it is convenient to provide individual onsite domestic sewage systems because it is cost effective and do not require any advance technology since the local mason with relative experience can construct the onsite systems. The idea is not to have any treatment plants at all but dispose-off the wastewater onsite with each house or building having its own treatment system (Peirce *et al*., 1998).

Apart from the environmental engineer's position on the use of onsite systems, various reasons have adduced for the predominant use of onsite systems in the developing countries as well as small communities in the developed countries. The reasons according to Metcalf and Eddy (2002) are because of the following problems that are likely to be encountered: the stringent discharge requirements for treated wastewater are the same for both large and small communities. It means that the small communities must also provide the same degree of treatment like the large communities if the environment is to be protected. Also, the high per-capita cost does not benefit the small communities from the economy of scale that is possible in the construction of wastewater management facilities for large communities. It cost a smaller community of 1,000 persons two to four times as much per capita when compared to a community 10,000 persons.

Further, the smaller communities have limited financing and therefore have difficulties in financing wastewater management facilities because of lower household income and residential tax base. In addition, the smaller communities have limited operational and maintenance capabilities because of limited economic resources and expertise. Therefore, overcoming these problems makes the implementation of treatment facilities a major undertaking thus makes the provisions of onsite domestic sewage disposal systems become imperative.

The onsite domestic sewage systems may not be sophisticated and elaborate but the most important design objective is the effective treatment performance of the sewage from individual residences so that it does not impart on any of the beneficial use of local ground water. The treatment performance of domestic of domestic sewage disposal systems have been found to be effective especially where field disposal trenches or sand-filter beds are used for the disposal. For a depth of 900 mm below the bottom of the disposal field trench, most of the constituents (BOD_5), Suspended Solids (SS), nitrogen, phosphorous, bacteria and viruses have their concentration at or below the lower limits of detectability (Metcalf and Eddy, 2002). However, nitrates and phosphorous are exceptions. Priority pollutants and metals found in septic tank effluent are also of concern but information available on the fate of the constituents in the disposal field is limited.

In the case of sand-filters, the effluent quality is excellent and concentration values of the BOD_5 and SS are below 10 mg L^{-1} and in most cases below 5 mg L^{-1}. Under normal circumstances, complete nitrification is achieved as the effluent passes through the sand-filter. Specifically designed sand-filters can be used to reduce the concentration of nitrates to levels below 10 mg L^{-1} (Metcalf and Eddy, 2002). In emphasizing the relevance of onsite domestic sewage disposal systems, Fair *et al.* (1981) reported that onsite systems remain of interest where raw-water quality and economics of construction and operation favour their use and that their value under such conditions should not be ignored even though they may appear to lack the technological sophistication of their successors; filters can produce a clear effluent that is readily and reliably amenable to disinfection and that they can offer effective barrier to water borne pathogens.

There are basically three types of onsite domestic sewage disposal systems namely: septic tank and soakaway pit; septic tank and subsoil disposal bed (field tiles) and septic tank and sand-filter disposal systems. In all the three systems, the septic tank is used. The septic tank is concrete, fibreglass, sandcrete block or coated steel tank usually located below the ground level but accessible from ground level (Henry and Heinke, 1996). It can be constructed by any contractor or made from commercial units of steel, precast concrete or fibreglass (Jerus, 1997). Septic tank must be watertight and structurally sound if it is to function properly. It is therefore necessary to test for watertightness and structural integrity by completely filling it with water before and after installation. The septic tank is used to treat sewage from isolated group of country houses where a public sewer does not exist (Fair *et al.*, 1981; Pumnia and Jain, 2005; Obande, 1985). The purpose is to serve as a combined setting and skimming tank as well as an unheated and unmixed anaerobic digester. It serves the two purposes of deposition of the settling solids in sewage, the sedimentation and the partial or complete digestion of sludge prior to its disposal (Pumnia and Jain, 2005). When in operation, the raw materials (domestic sewage) from the house or houses enter the septic tank and by means of a submerged intake, it reaches the liquid in the tank below the overflow level. The mixture quickly forms three distinct layers or strata. The solid matter or sludge settles to the bottom; effluent sewage forms the liquid content in the middle and the upper stratum is composed of scum that keeps air out of contact with the effluent sewage. This permits septic action (or septicization) with the aid of anaerobic bacteria present in the sewage (Jerus, 1997).

The anaerobic bacteria breaks down the proteins, carbohydrates, cellulose and fatty matters present in the sewage into simpler constituents. The nitrogen is converted to ammonia while the colloid matter is flocculated, then liquefied and finally digested. The effluent from the septic tank is discharged into either soakaway pit or disposal field. Most of the gases so formed escape through the vents provided for the purpose. The design of septic tank is governed by domestic sewage flow rate. It shall be large enough to ensure that the contents are not noticeably disturbed by overflows entering it. It must also be large enough to contain the accumulation of the sludge which will take place between emptying without restricting the necessary capacity (Burberry, 1997).

The soakaway pit is another method effluent disposal for onsite systems. It is designed in form of a chamber constructed with bricks, stones or sandcrete blocks with dry joints. Holes or seepage joints are provided through the wall thickness. It has either a spread footing or oversite concrete base to minimize settlement. Broken stones or blocks are used to fill the space between the outer walls and the inner surface of the excavation to exclude the entranced of soil into the pit. It also has an openable cover as inlet for the removal of debris. The soakaway pit receives the effluent from the septic tank. The effluent or liquid that comes into it is allowed to pass through the side seepage holes into the surrounding layer of broken stones or blocks and absorbed into the subsoil. The reaction in the soakaway is anaerobic and therefore odorous and is subject to plug the absorptive surfaces of the soakaway pit. The number and sizes of the soakaway pits required in any project is determined by the amount of effluent to be treated and the relative absorption of the soil (Jerus, 1997). It is usually dug in a convenient position in a reasonably permeable or pervious soil which can absorb the effluent (Pumnia and Jain, 2005; Burberry, 1997) and where the water table does not approach too close to the surface that is not <1.5 m (Burberry, 1997). In rocky or clay soils or where permeable soil is not available, cesspool is not advisable for effluent disposal (Henry and Heinke, 1996).

The attributes of soakaway system according to Jerus (1997) are that it can be used in minimum land area and on sites of any slope on all reasonably absorptive soils and where initial low cost and seldom cleaning at frequent intervals is required. The limitations of the soakaway system are that it cannot be used in semi-impervious soils; requires a location with ground water level at 2.4 m below grade level or 600 mm below the bottom of the soakaway must not be located within 30 m of portable water supply or within 5 m of the building it serves and it is limited in capacity and thus require several units to handle the effluent of large septic tank.

The subsoil disposal bed (field tile) system consists of pipes laid in about 900-1000 mm deep trench; end on end but with short gaps between pipes. The trenches are filled with a porous medium (usually gravel and sand) to promote the absorption of the effluent into the ground (Peirce *et al.*, 1998). The capacity of the subsoil bed is governed by the number of lineal metres of 100 mm drainage line laid with open joints. The capacity is also related to both the quantity of the sewage upon which the entire system is designed and the relative absorption of the soil (Jerus, 1997). Perforated pipes can be substituted for the open joint tiles. The drain lines or tiles are laid at slopes that usually follow the contour. When the disposal beds are operational, the effluent from the septic tank is applied to the disposal filed usually by dosing siphon. The treatment provided by the disposal field occurs as the effluent flows over and through the porous medium used in the disposal field trenches; infiltrates into the soil and percolates through the soil.

The treatment on the porous medium is a combination of physical, biological and chemical mechanisms. The porous medium acts as submerged anaerobic filter under continuous inundation and as an aerobic trickling filter under periodic application. In this regard Metcalf and Eddy (2002) reported that the principal functions of the porous medium are to maintain the structure of the disposal trenches, provide partial treatment of the effluent, distribute the effluent to the infiltrative soil surface and provide temporary storage capacity during peak flows if the trenches are not filled with liquid.

The attributes of the disposal field bed system are that it may be used in any soil except that rated impervious, if it is used in soil rated rapid, medium or slow absorption, distribution drain only are required and if it is used in soils rated semi-impervious both distribution and collection drain are needed and the filtered effluent sewage from the collection drain must either be disposed to a more absorptive soil or carried to a non-portable water course the bed may be located on ground that is level or slightly slopping or occasionally or relatively steep slopes by proper arrangement of drainage lines and it requires little or no cleaning if the septic tank is kept in good operating conditions. The limitations in this type of disposal system is that ground water levels should not exceed 600 mm below grade level; initial cost of subsoil disposal is usually greater than the cost of soakaway though less than that of sand-filters and the amount of land required is greater than that required for either soakaway or sand-filter.

The sand-filter system comes in two types namely: the closed and open type. The closed type carries both the distribution and under drains (collection drains) underground in the filter bed with upper layer of the drain covered with earth. It has two patterns of laying either rectangular or round manner. The open type is usually far less desirable because it exposes the effluent sewage and requires a filter bed free from any covering over the sand. The capacity of the sand-filter bed is expressed as its surface area in square metres and is related to the sewage load of the building it serves (Jerus, 1997). The sand-filters are shallow bed of 600 -700 mm deep provided with a surface distribution system and under-drain (collection drain).

The sand-filter works when the septic tank effluent is applied periodically to the surface of the sand bed. The treated liquid is collected in the under-drain system located at the bottom of the filter. The effluent from the filter is discharged to surface water or drainage system. The treatment of effluent is brought about by physical, chemical and biological transformation. Suspended solids are removed principally by mechanical straining due to chance contact and sedimentation. Further removal of the suspended solids is achieved by auto-filtration caused by the growth of bacteria in the sand grains. The removal of BOD_5 and conversion of ammonia to nitrate (nitrification) occurs under aerobic conditions by the microorganisms present in the sand bed. The conversion of nitrate to nitrogenous gas (denitrification), routinely occurs resulting in significant (about 45%) loss of nitrogen and normally brought about by anaerobic bacteria that co-exist on sorption (chemical and physical treatment). To maintain a high performance level, intermittent application and vetting of the under drains helps to maintain aerobic conditions within the filter.

Sand-filter is used when local site conditions preclude the use of disposal bed or soakaway systems and when the soil is rated impervious on the test of relative absorption. From the foregoing, the attributes of sand-filter system are that it can be adapted to impervious soils. In addition it can be used where the soil cover is shallow; percolation rates are considered too rapid; in high ground water areas and it requires land that is considerably less than that required for subsoil disposal bed (Metcalf and Eddy, 2002; Jerus, 1997). The limitations of the sand-filter system are basically the need to provide collection drains and in locations with limited soil cover and the possibility of the partially treated effluent reaching the surface or ground water where the percolation rates are too rapid.

Objective of the study: In Nigeria and specifically Yenagoa, the septic tank and soakaway system is the common means of disposing domestic sewage where private or public sewer does not exist (Obande, 1985).

With urbanization and improved conditions of living, there has been proliferation and un-regulated use of septic tank and soakaway pit system and this comes with various environmental pollution problems. These pollution problems arise because of inappropriate disposal of domestic sewage through the soakaway system. Domestic sewage not properly disposed contaminates the soil, underground water used for drinking and the aquatic life of streams especially where waste finds its way into such aquifer.

With the growing public concern on environmental pollution especially with many cases of burst septic tanks and soakaway pits; the exposure of these wastes and the pollution of the land and air has become a problem to public health and good environment. These perceived problems bring to focus the areas of materials for construction, selection and design of onsite domestic sewage disposal systems that will be appropriate for various types of soil. This is because the treatment performance of a particular system may not be suitable for another type of soil with different hydro-geological characteristics. From the foregoing, an assessment must therefore be made on the effectiveness or otherwise of the various onsite sewage disposal systems and select a system appropriate for effective onsite domestic sewage disposal in for Yenagoa, a Niger Delta town in Nigeria. The specific objectives of the study are to:

- Ascertain the size of the existing septic tank and soakaway systems
- Determine the flow rate of individual residential units
- Determine the treatment capacity of the existing septic tank and soakaway systems in terms of detention time and de-sludging period
- Determine the treatment performance of the existing soakaway systems in terms of percolation (relative absorption) rate of effluent into the subsoil and acceptance rate of effluent into the subsoil
- Select and design an appropriate onsite domestic sewage disposal system where the existing system is ineffective
- Determine a comparative cost between the existing system in use and the selected system

MATERIALS AND METHODS

Study area: The study area is Yenagoa, the capital of Bayelsa State, Nigeria. It is lies between latitudes 5° and 4°45' North and South and longitudes 6°30' and 6°15' East and West, respectively (Angaye and Okpara, 1981). It is a low lying, broad and gentle sloping plain of the Niger Delta and surrounded by meandering creeks and back swamps. The soil is alluvial which was formed by water deposits and has greater percentage of silt and a clay foundation. Drainage is poor and pools of standing water persist from March to December. It is always inundated by flood and suffers a shortage of adequate dry-land (Udo, 1981). The residential quarters of Opolo Housing Estate with prototype four-bedroom duplexes and an average family (occupants) size of seven which comprised father, mother and five children (Makinwa, 2000) was used.

Theory/calculation/results: Data collected through field studies was used to compute the capacity of existing septic tank; flow rate of individual residential units; treatment capacity of the existing septic tank; treatment performance of the existing soil; selection and design of an appropriate onsite domestic sewage disposal system and to determine a comparative cost between the various onsite domestic sewage disposal systems.

Assessment of capacity of existing septic tank: The treatment capacity of the existing septic tank was determined after computing the volume of the tank, flow rate, detention time and desludging period.

Volume of the existing septic tank. The average size of septic tank from field study was Length (L), 2.4 m; Width (W), 1.2 m and Depth (D), 1.8 m:

$$\begin{aligned} \text{Volume } (V_S) &= L\times W\times D \\ &= (2.46\times 1.2\times 1.8)\ m^3 \\ &= 5.2\ m^3 \text{ or } 5{,}200\ L \end{aligned} \tag{1}$$

Flow rate for individual residential unit (7 persons): The amount of litres of domestic sewage per person per day or the amount of litres of sewage to be treated per 24 h (Metcalf and Eddy, 2002):

$$\begin{aligned} \text{Flow rate (Fr)} &= 151 \text{ L/residence/day} + (151 \text{ L/resident/day} \times \\ &\quad 7 \text{ persons/residence} \\ &= 151+(151\times 7) \\ &= 1{,}210 \text{ L day}^{-1} \end{aligned} \tag{2}$$

Detention time: It is determined to provide a tank with the required treatment capacity (Metcalf and Eddy, 2002):

$$\text{Detention time } (D_t) = \frac{V_s \times E_a}{P_f \times F_r} \quad (3)$$

Where:
V_s = Volume of septic tank (5,200 L)
E_a = Actual effluent (100-30 = 70%)
P_f = Peak factor (4 for family of 7 persons)
F_r = Flow rate (1,210 L)

$$D_t = \frac{5{,}200 \times 0.70}{4 \times 1{,}210}$$
$$= 0.75 \text{ day or } 18 \text{ h}$$

Desludging period: It is determined to provide a tank with the required treatment capacity (Metcalf and Eddy, 2002):

$$\text{Desludging period } (D_p) = \frac{V_S \times E_a}{R_{sa}} \quad (4)$$

where, R_{sa} is rate of sludge accumulation (40 L years^{-1}), (Mara, 1978):

$$D_p = \frac{5{,}200 \times 0.70}{40}$$
$$= 3.79 \text{ years or approx. 4 years}$$

Assessment treatment performance of the soil
Moisture content of soil: An indication of the amount of water present in soil (Liu and Evett, 2008).

Dry season:

$$\text{Moisture content of soil } (W) = \frac{(W_w - W_s) \times 100}{W_s} \quad (5)$$

Where:
W_w = Weight of moist soil (1,000 g)
W_s = Weight of oven-dried soil (658 g)

$$W = \frac{(1{,}000-658) \times 100}{658} = 52\%$$

Wet season:

$$W = \frac{(1{,}000-523) \times 100}{523} = 91\%$$

$$\text{Average } W (\%) = \frac{(52+91)}{2} = 72\%$$

Porosity of soil: The proportion of total volume of a soil not occupied by solid (Jackson and Dahir, 1997):

$$V_s = \frac{W_s}{G_s Y_w} \quad (6)$$

Where:
V_s = Volume of dry soil (cm ^{3})
W_s = Weight of dry soil (1,360 g)
G_s = Specific gravity of soil (2.66 assumed)
Y_w = Unit weight of water (1 g/cm^3)

$$V_s = \frac{1{,}360}{2.66 \times 1} = 511 \text{ cm}^3$$

$$V_v = V_t - V_s \quad (7)$$

Where:
V_v = Volume of voids (cm^3)
V_t = Volume of wet weight soil (1,000 cm^3)
V_s = Volume of dry weight of soil (511 cm^3)

$$V_v = 1{,}000-511 = 489 \text{ cm}^3$$

$$\text{Porosity } (n) = \frac{V_v}{V_t} = \frac{489}{1{,}000} = 0.49 \quad (8)$$

Soil classification (Grain analysis): To identify the type and determine its suitability for use in specific application (Liu and Evett, 2008; Bowles, 1984):

- Soil sample retained by sieve No. 10 = Nil
- Soil sample retained by sieve No. 200 = 15.6 g (15.6% of soil sample retained by sieve No. 200 had particle sizes above 0.07 mm but below 5 mm indicating sandy soil)
- Soil sample passing through sieve No. 200 = 84.4 g (84.4% of soil sample passing through sieve No. 200 had particle sizes below 0.047 indicating silty clay soil)

Percolation (relative absorption) rate: An indication of rate at which water moves through soil in relation to effluent disposal or soil absorption systems (Metcalf and Eddy, 2002). The average value of percolation rate of the soil as shown in Table 1 was 218 min/100 mm.

Table 1: Percolation rates at different locations of the study area

Locations	min/100 mm	Relative absorption
A	189	Semi-impervious
B	228	Semi-impervious
C	278	Semi-impervious
D	181	Semi-impervious
E	213	Semi-impervious
Average	218	Semi-impervious

Researchers field work

Acceptance rate of soil: An indication of the ability of soil to accept or assimilate water in order to estimate how much water can be transported away from the sewage disposal system (Metcalf and Eddy, 2002). The computations below are used to arrive at the acceptance rate of the soil under study. Data collected from field work are as follows:

- Area of trench bottom (A_t) = 1.2×0.9 m (1.08 m^2)
- Depth of trench (d_t) = 0.60 m
- Total extent in area of water plume (W_p) = 16.5 m^2
- Height of water maintained at trench bottom (h_t) = 0.30 m
- Depth below bottom of trench (d_b) = 0.45 m
- Total water applied during test (V_t) = 4.0 m^3
- Height of capillary zone (h_c) = 0.30 m
- Assumed degree of saturation in capillary (Ds) = 30%
- Total elapse time (E_t) = 6 days (144 h)
- Porosity (n) = 0.49

Water remaining in the trench within saturated zone and capillary fringe (Metcalf and Eddy, 2002):

$$\begin{aligned}\text{Water remaining in trench } (W_t) &= A_t \times h_c \\ &= 1.08\times0.30 \\ &= 0.324 \text{ m}^3 \text{ or } 324 \text{ L}\end{aligned} \tag{10}$$

$$\begin{aligned}\text{Water remaining in saturated zone } (W_{sz}) &= \left[\frac{1}{2}(W_p + A_t)\times d_t - W_t\right]\times n \\ &= [0.5\ (16.5+1.08)\times(0.6)-0.324]\times0.49 \\ &= 2.43 \text{ m}^3 \text{ or } 2{,}430 \text{ L}\end{aligned} \tag{11}$$

$$\begin{aligned}\text{Water remaining in capillary zone } (W_{cz}) &= W_p\times h_c\times D_s\times n \\ &= 16.5\times0.30\times0.30\times0.49 \\ &= 0.73 \text{ m}^3 \text{ or } 730 \text{ L}\end{aligned} \tag{12}$$

$$\begin{aligned}\text{Total water remaining } (W_{tr}) &= W_t+W_{sz}+W_{cz} \\ &= 0.324+2.43+0.73 \\ &= 3.484 \text{ m}^3 \text{ or } 3484 \text{ L}\end{aligned} \tag{13}$$

$$\begin{aligned}\text{Water absorbing into underlying soil } (W_u) &= W_t-W_{tr} \\ &= 4.0-3.484 \\ &= 0.516 \text{ m}^3 \text{ or } 516 \text{ L}\end{aligned} \tag{14}$$

$$\begin{aligned}\text{Acceptance Rate (AR)} &= \frac{W_u}{W_p\times E_t} \\ &= \frac{516}{16.5\times6} \\ &= 5.21 \text{ L/m}^2\text{/day}\end{aligned} \tag{15}$$

RESULTS AND DISCUSSION

Presented in Table 2 were a summary of field studies and computation of capacity of existing septic tank and the effluent treatment performance of the soil of the study area.

Selection and design of septic tank: Although, the existing septic tank provided the required detention and desludging time, the new septic tank was designed for a desludging period of 5 years to reduce frequent desludging. The design parameters and recommended specification for septic tank presented in Table 3 were used in the design of the septic tank for an average family of seven persons. The computations for the design septic tank shall take the following steps:

Table 2: Summary of results of data analysis

Assessed parameters	Results	Remarks
Capacity of existing septic tank	5.2 m^3 or	Within the recommended value of 3,700-5,700 L and 5,200 L was used to compute the detention time and desludging period
Flow rate for a residential family	1210 L day^{-1}	Flow rate value was used to compute the 7 persons detention time and desludging period
Detention time of tank	0.75 day (18 h)	Appropriate and above the minimum limit of 0.5 day (12 h)
Desludging period	4 years	Within the acceptable limits of 3-5 years
Moisture content of soil		
Minimum	53	Average value greater than the recommended value of 50%
Maximum	91	An indication of high moisture and low water absorption
Average	72	Suitable for sand-filter system only
Porosity of soil (n)	0.49	High porosity. Indicated low permeability Suitable for sand-filter system only
Soil classification (Grain analysis)		
Retained by sieve No. 200	Above 0.074 mm	Grain sizes smaller than of 0.074-2 mm indicating presence
Passing sieve No. 200	(15.6%) silty clay to dirty sand. Below 0.074 mm (84.4%)-Silty clay	of silty clay to dirty sand. Soil suitable for sand-filter and field disposal systems
Ground water table	Between below grade level in the dry season and 2.0-3.0 m. 0.15-0.30 m grade level in the wet season and flooding up to 0.50 m above grade level	The acceptable values are 2.40 m below grade level or 0.60 m below bottom of soakaway pit. Suitable for sand-filter and field disposal systems
Percolation rate of soil (Average value)	218 min/100 mm	Value greater than the maximum percolation value of 118 min/100 indicating semi impervious soil and suitable for only sand-filter system
Acceptance rate of soil	5.21 L/m^2/day	Value less than the required minimum of 81/L/m^2/day indicating low ability to accept or assimilate water and suitable for sand-filter system
Available land area	Medium	Appropriate for sand-filter and soakaway pit and not field disposal system

Table 3: Design parameters for septic tank for seven persons

Design parameters	Recommended specifications
Family size or number of residents (N)	7 persons
Flow rate (Fr)	1210 L
Detention time (D_t)	Not <0.5 day
Peak factor for individual residence (P_f)	4
Actual waste flow (E_a) (Volume of effluent flow rate-Volume of flow rate lost to sludge and scum)	100-30%
Desludging period (D_p)	4-5 years
Sludge accumulation rate (S_a)	0.04 m^3/h day year or 40 L/h day year
Liquid volume of effluent in septic tank for 7 persons	3,700-7,700 L
Septic tank length/width ratio	Not more than 3:1
Depth of septic tank	1.8 m
Ratio of first compartment to second compartment	3:1
Clear space above liquid in septic tank	0.25 m
Depth of liquid surface below inlet	75 mm
Number of inspection chambers	Depends on the location of the toilets in the building (L = 0.3 m, W = 0.3 m and D = 0.45 m)
Inspection ports	2 No. (L = 0.45 m, W = 0.45 m)
Cover thickness	75 mm
Compartments	2 No. (1st, 67% and 2nd, 33%)

Metcalf and Eddy (2002), Jerus (1997) and Mara (1978)

$$\begin{aligned}\text{Volume of septictank } (V_s) &= P_f \times S_a \times D_p \times N \\ &= 4 \times 0.04 \times 5 \times 7 \\ &= 5.6 \text{ m}^3 \text{ or } 5{,}600 \text{ L}\end{aligned} \quad (16)$$

Comment: The septic tank of 5,600 L is appropriate because it fell within the recommended value of between 3,700 and 5,700 L for a family of seven persons:

$$\begin{aligned}\text{Detention time } (D_t) &= \frac{V_s \times E_a}{P_f \times F_r} \\ &= \frac{5{,}600 \times 0.7}{4 \times 1210} \\ &= 0.81 \text{ day, approx. 1 day or 24 h}\end{aligned}$$

Comment: The value of detention time is appropriate since it is more than the specified minimum of 0.5 day or 12 h.

Table 4: Design criteria for sand-filter onsite domestic sewage disposal systems

Parameters	Recommended specifications
Capacity of septic tank (V_s)	5,600 L or 5.6 m^3
Filter medium	Material: Washed clean sand; Effective size: 0.025-0.5 mm; Depth: 1.0-1.5 m
Under-drain bedding	Type: Washed gravel or stones; Size: 10-19 mm
Pressure distribution pipes	Type: Slotted or perforated PVC pipes; Size: Main and under-drain, 75-150 mm; Lateral: 25-50 mm; Under-drain slope: 0-10% or 1 mm in 200 mm; Under-drain venting: Up-stream; Lateral Orifice size (D_{LO}): 3-6 mm; Orifice size (under-drain): 12 mm; Orifice spacing: 0.45-1.20 m; Orifice discharge head (O_{dh}): 1.20 m
Lateral spacing	0.45-1.20 m
Hydraulic loading (H_L)	24 L/m^2/day
Difference in discharge between the first and last orifice	Not more than 2%
Distance of disposal field from building	
Property	1.5-3.0 m
Foundation	3.0-6.0 m

Metcalf and Eddy (2002)

Demension of septic tank

Assumptions: Depth, 1.5 m; Width, 1.2 m and the given Volume of 5.6 m^3:

$$\text{Length of Septic tank (L)} = \frac{\text{Volume}}{\text{Width}\times\text{Depth}}$$
$$= \frac{5.6}{1.2\times1.5} = 3.0 \text{ m}$$

Comment: The septic length of 3.0 m is appropriate because it has a length to width ratio of 2.5:1 which is within design limits of 3:1:

Length of each compartment of septic tank:

$$\text{First compartment (67\%)} = 3.0\times0.67 = 2.0 \text{ m}$$

$$\text{Second compartment (33\%)} = 2.6\times0.33 = 1.0 \text{ m}$$

Selection and design of appropriate onsite domestic sewage disposal system: The field study results indicated a silty clay soil of high porosity, low permeability, slow percolation rate and high water table. The appropriate onsite domestic sewage disposal system selected based on data analyzed was the sand-filter system. This choice was consistent with (Metcalf and Eddy, 2002; Jerus, 1997; Liu and Evett, 2008) where they reported that soils exhibiting low percolation rate of more than 118 min/100 mm was considered semi-impervious soil and therefore not suitable for seepage pits and disposal beds. In the same vein, Cooke (2008) stated that sand-filters should only be used where other systems were not feasible such as soils having percolation rate of 25 mm in 30 min and above.

The design of the sand-filter system for a family of seven occupants was based on the design criteria in Table 4 and some data from Table 3. The computations for the design of sand-filter shall take the following steps:

Determination of size of sand-filter (8):

$$\text{Area of sand-filter } (A_S) = \frac{F_r}{H_L} = \frac{1210}{24} = 50 \text{ m}^2 \quad (17)$$

Depending on the land space available, size of the sand-filter will be approximately 49.5 m (9.0×5.5 m) which is within the 50 m^2 computed for area of sand-filter.

Layout of sand-filter and effluent distribution system: The layout and effluent distribution was derived from the data in Table 4 where the spacing between lateral distributions pipes, 1.20 m; spacing of orifices, 0.60 m; size of main distribution pipe, 100 mm and size of lateral pipe, 50 mm. The layout of the sand-filter consists of sixteen laterals of 2.10 m long on each side of the main pipe and four orifices equally space 600 mm centres on each lateral. Determination of flow discharge in each lateral (Metcalf and Eddy, 2002):

$$\text{Flow discharge per lateral } (F_L) = \frac{\text{Flow rate}}{\text{Number of laterals}} = \frac{1210}{16} = 76 \text{ L/day/lateral} \quad (18)$$

Flow rate in each lateral (Metcalf and Eddy, 2002):

$$\text{Flow rate in last orifices (qn)} = 8.9\ C\ (D^2)\ (2ghn)^{0.5} \quad (19)$$

Where:
qn = Discharge from orifices in L/sec
8.90 = Conversion factor where discharge is expressed in m^3/sec when the diameter of the orifice is in mm and velocity in m/sec
C = Orifice distance co-efficient for holes drilled in the field (usually 0.61)
D = Diameter of orifice (3 mm)
hn = Orifice discharge head (1.50 m)
n = Number of orifices per lateral (4)
g = Acceleration due to gravity (9.81)

Therefore:

$$qn = (8.9\times 0.61\times 0.0032)\ (2\times 9.81\times 1.5)^{0.5}$$
$$= 2.65\times 10^{-5}\ m^3/sec$$
$$= 0.265\ L\ sec^{-1}$$

$$\text{Total flow in each lateral based on four orifices per lateral} = n\times qn$$
$$= 4\times 0.265\ L\ sec^{-1}$$
$$= 1.06\ L\ sec^{-1}$$

Determination of head loss in lateral distribution pipes:

$$\text{Head loss through pipe from orifice } (h_{fp}) = 189.18\ (L_1\text{-n})\ (Q/C)^{1.85} D^{-4.87} \tag{20}$$

Where:
h_{fp} = Actual head loss through pipe from orifice L to n (m)
L_1-n = Space between end of lateral pipe and inner surface of excavation (0.30 m)
Q = Pipe discharge (total flow rate) (1.06 L sec^{-1})
C = Hazen-William discharge coefficient (150 for plastic pipes)
189.18 = Conversion factor
D = Diameter of orifice (3 mm)

Therefore:

$$h_{fp} = 189.18(2.4-0.3)\left(\frac{1.06}{150}\right)^{1.85}\times 0.003^{-0.87}$$
$$= 397.28\times 6.36\times 2.3^{-5}$$
$$= 0.058\ m$$

$$\text{Head loss in actual distribution pipe } (h_L) = \frac{1}{3} h_{fdp}$$
$$= \frac{1}{3}\times 0.058$$
$$= 0.019\ m$$

Determination of difference in the discharge between the first and last orifice in each lateral:

$$\text{Head loss on first orifice } (h_1) = h_n + h_L \tag{21}$$

Where:
h_n = Orifice discharge head (1.50 m)
h_L = Head loss in distribution pipe (0.019)

Therefore:

$$h_1 = 1.50+0.019 = 1.519\ m$$

$$\text{Determination of decimal value (m)} = \left(\frac{h_n}{h_1}\right)^{0.5} = \left(\frac{1.50}{1.519}\right)^{0.5} = 0.9937 \text{ (m is a decimal value <1)} \quad (22)$$

$$\text{Difference in discharge between the first and last orifice in each lateral} = (1\text{-}0.9937)\times 100 = 0.63\%$$

Since, the value of 0.63% is below the specified value of 2%, the distribution system therefore does not require re-sizing.

Components used with the sand-filter system: The components used in conjunction with the sand-filter system for effective disposal of domestic sewage were the holding and chlorine contact tanks.

Holding tank or collection tank: It was used in collecting treated effluent from the sand-filter before it is pumped into the chlorine contact tank with the bottom of the tank lower than the sand-filter base to allow the treated effluent flow into it. The tank can be with concrete base and sandcrete block walls and a plastered internal surface.

The computation for the design of the tank and the capacity of the pump took the following sequence: determining the discharge pump capacity (Q_{dp}) (USEPA, 1995, 1980):

$$Q_{dp} = Q_a \times P_f \quad (23)$$

Where:
Q_a = Average septic tank flow rate (1210 L/day)
P_f = Peak factor (4)

$$Q_{dp} = 1210\times 4 = 4{,}840 \text{ L day}^{-1}$$

This value is the discharge capacity of the pump required for the size of the sand-filter system. Determining the Total Dynamic Head (TDH):

$$TDH = H_s + H_f + H_v \quad (24)$$

Where:
H_s = Static head (0.30 m)
H_f = Friction head (0.60 m)
Ht = Tank head (approx. 0.50 Hg)

$$TDH = 0.30+0.60+0.50 = 1.40 \text{ m}$$

This value is the maximum depth of the treated effluent in the collection below the pump centre line which should not be exceeded. Determining the operative volume of the holding tank (USEPA, 1995, 1980):

$$\text{Operating Volume } (V_o) = \frac{V_{ct}}{3} \quad (25)$$

where, V_{ct} is 1,500 L (minimum holding tank volume):

$$V_o = \frac{1{,}500}{3} = 500 \text{ L or } 0.5 \text{ m}^3$$

This value is the expected effluent in the holding tank below the bottom of the sand-filter. Determining the depth of the effluent level in the holding tank (assumption: Length of holding tank = 1.0 m and width 1.0 m) (Metcalf and Eddy, 2002; USEPA, 1980):

$$\text{Depth of effluent level } (D_{eL}) = \frac{V_o}{L\times W} = \frac{0.5}{1\times 1} = 0.5 \text{ m or } 500 \text{ mm} \quad (26)$$

The pump most frequently used was the non-clog type that was capable of passing 75 mm sphere and to reduce vortexing in the tank, the pump suction line is usually 50 mm larger than the discharge line.

Chlorine contact tank: The chlorine contact tank or chamber was designed such that 80-90% of the effluent from the sand-filter was retained for specific contact or detention time in order to avoid dead zones that will reduce the hydraulic detention times. When designing the tank, the Length to Width ratio (L/W) must be at least 10 to 1 to minimize short-circuiting (Mara, 1978; Metcalf and Eddy, 2002). The minimum detention time of average effluent flow as 1-2 h (Mara, 1978) and minimum tank size was 50 gal or 190 L. The design of the chlorine contact tank took the following sequence: Determining the capacity of chlorine contact tank (C_{ct}) (USEPA, 1995, 1980):

Table 5: Summary of comparative cost estimates for sand-filter, soakaway pit and field disposal systems

	Amount (₦)		
Description	Sand-filter system	Soakaway pit system	Field disposal system
Excavation and earthwork	171,700.00	163,450.00	145,000.00
Concrete and blockwork	381,500.00	255,500.00	205,000.00
Auxiliary works (Pipe works, holding tank, chlorine tank, pumps, filter media and miscellaneous works) for sand-filter system	357,300.00		
Auxiliary works (Pipe works and miscellaneous works) for field disposal pit system			270,000.00
Auxiliary works (Pipe works and miscellaneous works) for soakaway pit system		35,500.00	
Inspection chambers or distribution boxes	25,000.00	25,000.00	25,000.00
Total estimate	935,500.00	479,450.00	645,000.00

$$C_{ct} = \frac{D_t \times D_r}{A_t} \tag{27}$$

Where:

D_t = Detention time (2 h or 0.083 day)

D_r = Pump discharge rate from holding tank (Eq. 23) (4,840 L)

A_t = Actual effluent flow into contact tank (70%)

$$C_{ct} = \frac{0.083 \times 4{,}840}{0.70}$$
$$= 570 \text{ L or } 0.57 \text{ m}^3$$

Determining the length/width ratio of tank $(L) = \dfrac{C_{ct}}{W \times D}$

Where:

C_{ct} = Volume of tank (0.57 m^3)

W = Width of tank (0.60 m, assumed)

D = Depth of tank (0.45 m, assumed)

Therefore:

$$L = \frac{0.57}{0.60 \times 0.45} = 2.1 \text{ m}$$

The value of 2.1 m for the length was within the L/W ratio of 1-10. The chlorine is expected to be constructed with reinforced concrete with cascading baffles for proper mixture and left open to sunlight for further breakdown.

Comparative cost between sand-filter and soakaway systems: The sand-filter was selected as an appropriate onsite domestic sewage disposal system over the soakaway pit and field disposal systems, respectively. It was necessary to compare the cost between the sand-filter, soakaway pit and field disposal systems in their construction and to ascertain whether the sand-filter system apart from providing a better disposal of domestic sewage than the other two was cost effective with same surface area and volume that was required for effective treatment of domestic sewage.

The comparative cost estimate for the three systems with effluent flow rate of 1210 L/day presented in Table 5 indicated that the cost of sand-filter system was ₦935,500.00; soakaway pit system, ₦479,450.00 and field disposal system, 645,000.00. The cost estimates further revealed that the sand-filter system cost twice that of the soakaway pit system and one and half times the cost of the field disposal system.

From the findings, the capacity of the existing septic system, the detention time, desludging period and effluent flow rate was appropriate for a family size of 7 persons. The existing septic tank therefore provided the required treatment capacity for onsite domestic sewage disposal system. The moisture content of the soil was high indicating low water absorption. The porosity of the soil was high indicating low permeability which was not suitable for a soakaway pit system. The soil was classified as silty clay indicating characteristics of low permeability and percolation rates. The ground water table especially during the wet season was very high and this could create water absorption problems for any soakaway pit system. Also, the percolation rate of the soil was lower than required values. It means that the existing soakaway pit system will not provide the required treatment capacity of domestic sewage. In addition, the acceptance rate of the soil was lower than the required value. This was an indication that the soil of the study area was more appropriate for sand-filter systems while the soakaway pit and field disposal system may not provide the required treatment capacity (Mara, 1978; Metcalf and Eddy, 2002; Jerus, 1997).

CONCLUSION

The sand-filter system was found to be suitable for onsite domestic sewage disposal system in Yenagoa and in the Niger Delta riverine areas because it had some technological advantage over the soakaway pit and field disposal system in the effective treatment of domestic sewage. It can be installed in soils termed impervious and does not depend on whether the level of ground water table was high or low. Conversely, the soakaway pit and field disposal system can only provide some level of treatment in the dry season and little or no treatment in the wet season when there is high ground water table.

The cost of constructing the soakaway pit and field disposal systems that will provide the same treatment capacity in terms of equivalent absorption area and volume was less than the cost of installing a sand-filter system. However, because of the limitations of the soakaway system in the disposal of domestic effluent in silty clay soils which exhibits impervious to semi-impervious character as well as the fact that Yenagoa has high ground water table both in wet and dry seasons; the sand-filter system was considered as the most appropriate due to the fact that it provides a better treatment capacity. It was therefore selected for the study location. In terms of public health and friendly environment, the sand-filter systems was preferred to the other two systems irrespective of the cost difference since, the sand-filter system provided a better domestic sewage treatment capacity and reduce the pollution of the environment which cannot be assured by the soakaway pit and field disposal systems.

REFERENCES

Angaye, S.M.S. and C.E. Okpara, 1981. School Atlas for Rivers State of Nigeria. Macmillan Education Ltd., London.

Bowles, J.E., 1984. Physical and Geotechnical Properties of Soils. McGraw-Hill Book Company, New York.

Burberry, P., 1997. Environment and Services. B.T Batsford, London.

Cooke Jr. L.J., 2008. Sewage and Drainage-Septic Drainage Fields. In: Ramsey/Sleeper Architectural Graphics Standards, Ramsey, G. and H.R. Sleeper (Eds.). John Wiley and Sons, New York, pp: 826.

Fair, G.M., Geyer, J.C. and D.A. Okun, 1981. Water Purification and Wastewater Treatment and Disposal: Water and Wastewater Engineering. Vol. 2, John Wiley and Sons, New York.

Henry, G. and G.W. Heinke, 1996. Environmental Science and Engineering. Prentice Hall Inc., New Jersey.

Jackson, N. and R.K. Dahir, 1997. Civil Engineering Materials. Macmillan Press Ltd., London.

Jerus, G.R., 1997. Plumbing-Sewage Disposal. In: Time-Saver Standards for Architectural Design Data. Callender, J.H. (Ed). McGraw-Hill, Book Company, New York, pp: 256-270.

Liu, C. and B. Evett, 2008. Soil Properties-Testing, Measurement and Evaluation. Prentice Hall Inc., New Jersey.

Makinwa, M., 2000. Finding the missing Nigerians in the year 2001. Punch, January 29, 2000, pp: 4.

Mara, D., 1978. Sewage Treatment in Hot Climates. John Wiley and Sons, Chichester, England.

McGhee, T.J., 1991. Water Supply and Sewerage. McGraw-Hill Inc., New York.

Metcalf and Eddy, 2002. Wastewater Engineering, Treatment, Disposal and Reuse. Tata McGraw-Hill Publishing Company, New-Delhi.

Obande, M.O., 1985. Blocklaying and Concreting. Longman Nigeria Ltd., Ikeja-Lagos.

Peirce, J.J., P.A. Vesilind and R. Weiner, 1998. Environmental Pollution and Control. 4th Edn., Butterworth Heinemann, London, ISBN: 13-9780080531113, Pages: 392.

Pumnia, B.C. and A.K. Jain, 2005. Building Construction. Firewall Media, New-Delhi.

USEPA, 1980. Design manual: Onsite wastewater treatment and disposal systems. Technology transfer Report. EPA/625/1-80-102, US Environmental Protection Agency. http://nepis.epa.gov/Adobe/PDF/300043XO.pdf.

USEPA, 1995. Manual: Alternative wastewater collection systems. Technology transfer Report. EPA/1625/191/024, US Environmental Protection Agency.

Udo, R.K., 1981. Geographical Regions of Nigeria. Heinemann Educational Books Ltd., London.