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Shared household septic tank: A case study of Fiapre in the Brong Ahafo Region of Ghana

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This study investigated the feasibility of utilizing composite septic tank to reduce cost, save space and prevent faecal related diseases. Survey research methodology was adopted based on people's experience with septic tank, water use, soil properties, land space, user numbers and user satisfaction. The study also provides procedure in the design of a two-compartment septic tank with soil absorption field for three composite houses of thirty residents. Calculation utilizing Brazilian code was employed in the sizing of a two-compartment septic tank, which considers the tank in four zones; the scum zone, the sedimentation zone, the sludge digestion zone and the sludge storage zone. It was found that majority of the residents in the study area connected with septic tanks are not only willing to share composite septic tanks but are also financially capable of constructing and maintaining it. Shared septic tank coupled with suitable conditions is cost effective for households.

Key words: Shared septic tank, households, sanitation, septic tank design, cost effective.

INTRODUCTION

Sanitation systems are systems designed to collect, store, process or treat and dispose human waste and other forms of waste back to nature in a safe way avoiding excreta-related diseases and pollution to the environment (Ahmad, 2015). Providing sanitation to people requires a system approach rather than only focusing on the toilet or wastewater treatment plant itself. The experience of the user, excreta and wastewater collection methods, transportation or conveyance of waste treatment and reuse or disposal all need to be thoroughly considered (Duncan, 2004). The main objective of sanitation systems is to protect and promote human health by providing a clean environment and breaking the cycle of disease (WHO, 2015). Effective sanitation systems provide barriers between excreta and humans in such a way as to break the disease transmission cycle, for example in the case of faecal-borne diseases.

Water resources are under increasing pressure. Continuing population growth, urbanization, rapid industrialization as well as expanding and intensifying food production all put pressure on water resources (UN,

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2015). Most houses are built with access to running water as a priority. Access to running water raises the need of sewerage disposal systems to dispose waste water safely to the environment, minimizing the risk of excreta-related diseases and pollution to the environment.

In most developing countries across the world, most people rely on the septic tank systems for sewerage treatment and disposal because of the relatively low cost as compared to conventional network sewerage system. The septic tank is a water tight chamber constructed beneath the earth surface, designed to receive and treat household sewerage (black water and grey water/ just black water) so that the effluents discharged from the tank to the environment have little or no chance of causing excreta-related diseases or pollution to the environment as well as factory nuisance (Carr, 2001).

According to WHO standards, septic tanks should not be used in areas with high water tables or areas with groundwater as the main source of drinking water and in soils with low permeability. Septic tanks must be emptied periodically at least every three years and the solids disposed of hygienically (Vaughan , 2013). This is usually done with a vacuum tanker. Septic tanks allow safe disposal of waste water particularly in rural areas where it might otherwise go directly into rivers. Therefore, in a typical situation like Fiapre community, where onplot latrines dominate and their contents are basically blackwater, septic tank is the commonest form of wastewater treatment system to be used in dealing with the treatment of the faecal waste (GSS, 2000). Septic tanks have advantages of little maintenance, isolation and partial treatment of excreta, little odor or few problems and the possibility of subsequent sewerage system (Reed, 2011).

Septic tanks or their disposal systems must be installed to ensure minimum clearance distances from:

1. The highest ground water level,
2. Water supplies such as bores, creeks, and dams,
3. Buildings and boundaries,
4. Subsoil and open drainage channels.

They should not be located where vehicles will drive over them. The weight of a vehicle may damage system components and compact the surrounding soil which reduces its ability to absorb effluent (WAPHD, 2014). Drainage characteristics of soils are of importance in both sizing and sitting of drainage receptacles. In poor draining soils, such as clay, bigger drainage receptacles are needed to increase the area of soil into which the effluent can be absorbed (WAPHD, 2014). In contrast, some coarse sands can be so free draining they provide little ability to filter out pollutants. In these cases, it may be desirable to surround the sides and base of drains with loam or other fine-grained soil (WAPHD, 2014). In areas with either shallow groundwater where only a thin layer of free draining topsoil overlies less absorbent soils, the drainage receptacles may need to be installed fully or partially above the natural surface. This is to allow effluent to be dispersed into and be absorbed by surrounding soils (WAPHD, 2014) as shown in Figures 1 and 2.

The main aim of this research was to design a septic tank for 3 composite houses of 30 residents. In order to achieve this aim the following objectives shall be considered;

1. Propose an alternative model option to existing domestic septic tanks.
2. Design a two compartments septic tank based on calculations with a soil absorption field for the proposed design.

METHODOLOGY

This research adopted a mixed methodology coming from qualitative means through structured questionnaire and quantitative study through calculations of design parameters. The calculations of the design parameters were based on the information received from the respondents through the structured questionnaire.

The study area

Fiapre is a suburb of Sunyani, the regional capital of the Brong Ahafo Region of Ghana. It is about 10 km from Sunyani. It shares boundary with Sunyani to the north, Nsoatre to the south, Odumase to the west and Baakoniaba to the east within the Sunyani west District (SMA, 2010). Fiapre is an urban community constituting 10.19% of Sunyani West district's population (SMA, 2010).

The use of septic tank has not been encouraging in Fiapre. This is due to relatively high cost of construction for many households. The selection of the study area was made after taking into consideration the following factors:

1. Availability of water,
2. Relatively poor sanitation situation,
3. Relatively low-level use of septic tanks,
4. Location and topology of the area,
5. Proximity advantage for the study.

The target population for this study consists of residents of Fiapre who use latrines that are connected to septic tanks. Sample size for this study was 100 households.

Data collection

Information gathered for the study was mainly primary and secondary. The primary data were information gathered from the field through the administration of a structured questionnaire. This was complemented with secondary data through a comprehensive review of journal articles and trusted publications from other sources.

For this study, questionnaires were used to get and understand people's ideas and opinions on the design and use of septic tanks. The daily toilet facility usage as well as the source of water used by residents in the study area was surveyed to ascertain the rate of filling and emptying of the septic tanks. As a main tool in qualitative research, interviews were conducted to ascertain users' willingness and acceptability of the shared septic tank concept. The qualitative interview is a very good way of accessing people's perceptions,

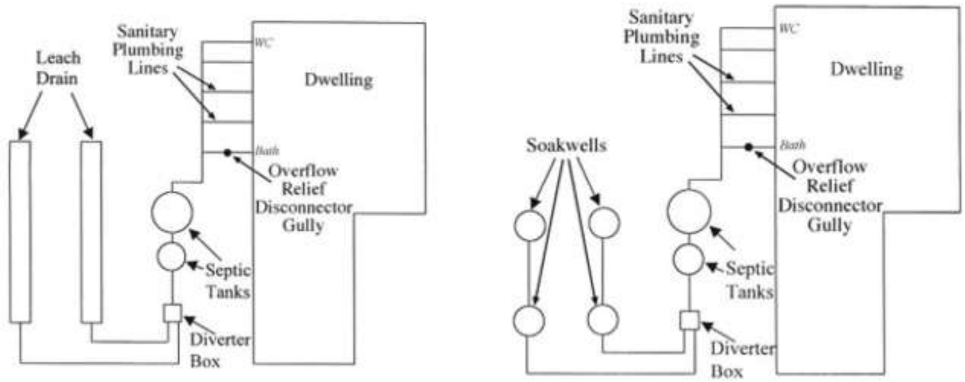

Figure 1. A septic tank and leach drain system (L) and soakaway system (WAPHD, 2014).

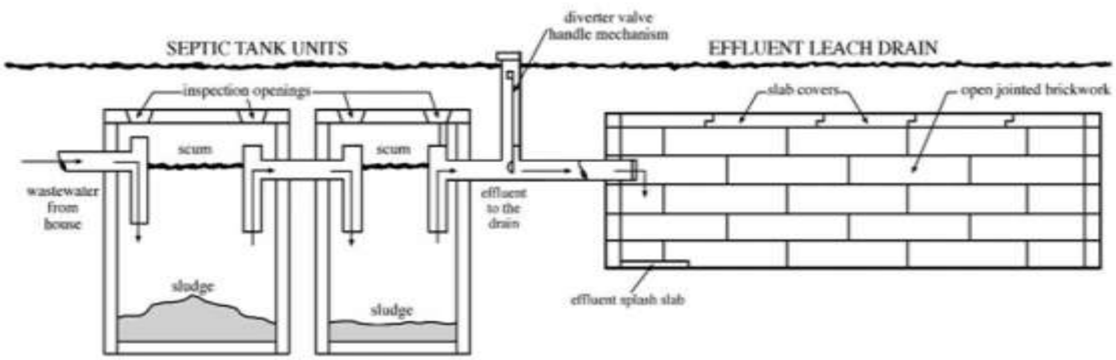

Figure 2. The side view section of a septic tank with one leach drain (WAPHD, 2014).

meanings, and definitions of situations and constructions of reality (Punch, 2006). Sampling method was used to study just a section of the population at a particular place at a point in time (Miles et al., 1994). Since Fiapre is quite populated, not everyone with a septic tank was included in this exercise, though the questionnaire was administered to a sizable number of the population. Data collected from the sampled number were treated as data for the whole of Fiapre community with septic tanks. Random sampling was employed for this activity, giving each one an equal probability of being selected for the data collection.

Shared septic tank design and assumptions

The total number of people to use this shared tank is estimated as thirty (30) persons comprising three households. Calculations were used to determine the volume of the tank required to receive and treat wastewater coming from these three households. The calculations were based on the user population, wastewater flow per capita per day, sewage generation and sludge accumulation rate. Also, the capacity indications for septic tanks for residential households and typical dislodging periods for septic tanks according to size of households as seen in Tables 1 and 2 respectively were also taken into consideration. Assumptions were made on the wastewater flow rate. Here it was assumed that 85% of the water consumed by an individual comes out as waste whiles the rest of the water is absorbed by the body.

Data analysis

Data collected from the administering of questionnaires was analyzed using statistical package for social science (SPSS), data analyses software. The carefully recorded information was inputted in SPSS to generate pictorial results of the analyses, including tables, and charts to visualize the data.

RESULTS AND DISCUSSION

Water usage points

Septic tanks are designed based on the volume of wastewater produced. Knowing the water usage points connected to the system will help to estimate the amount of wastewater that could enter the tank. From Figure 3 the results obtained from the survey shows that 93% of the houses surveyed had only their toilet facilities connected to the septic tank. The remaining 7 houses had both their bathroom and their toilets connected to the septic tank. The challenge here is that households with both bathroom and toilet connected to the septic tank will contribute more towards the filling rate of the septic tank. Therefore, in a situation of shared septic tank facility, an

Table 1. The minimum septic tank capacities for residential houses. (LRD, 2016).

Tank Size (gals)	Household size (Number of people)									
	1	2	3	4	5	6	7	8	9	10
500	5.8	2.6	1.5	1.0	0.7	0.4	0.3	0.2	0.1	-
750	9.2	4.2	2.6	1.8	1.3	1.0	0.7	0.6	0.4	0.3
1000	12.4	5.9	3.7	2.6	2.0	1.5	1.2	1.0	0.8	0.7
1250		7.5	4.8	3.4	2.6	2.0	1.7	1.4	1.2	1.0
1500		9.1	5.9	4.2	3.3	2.6	2.1	1.8	1.5	1.3
1750			6.9	5.0	3.9	3.1	2.6	2.2	1.9	1.6
2000			8.0	5.9	4.5	3.7	3.1	2.6	2.2	2.0
2250				6.7	5.2	4.2	3.5	3.0	2.6	2.3
2500					5.9	4.8	4.0	4.0	3.0	2.6

Table 2. Dislodging periods of septic tanks in years according to size and household (LRD, 2016).

Bedrooms (Number)	House size (square feet)	Tank capacity [without water-saving devices] (galons)	Tank capacity [with water saving devices] (gallons)
1 or 2	Less than 1500	750	750
3	Less than 2500	1000	750
4	Less than 3500	1250	1000
5	Less than 4500	1250	1250
6	Less than 5500	1315	1250

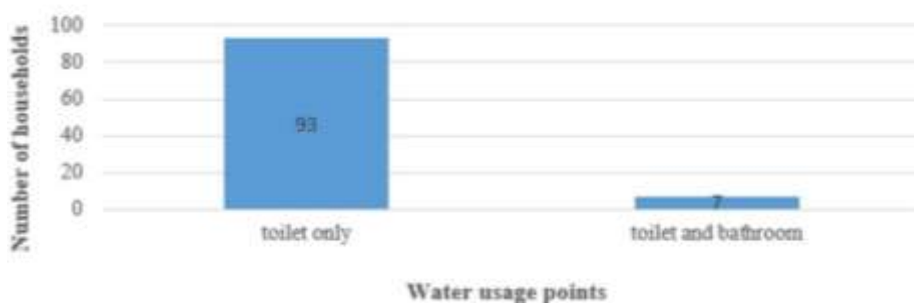

Figure 3. Water points connected to the septic tank in the household.

arrangement or agreement should be reached where proportional payment based on rate of usage will be made. Households were therefore asked if they would agree with such arrangement. Overwhelming majority of the households (about 96%), said they would agree to the proportional payment based on rate of usage in terms of what (toilet and or bath) is connected to the shared septic tank.

Toilet facility usage

The results showed that individuals in 60 out of the 100 houses surveyed, use their toilet facility twice in a day whiles the remaining 40 houses use their toilet facility once in a day as shown in Figure 4. The significance of this is to determine how often the system is used. This will help to know the rate of usage and filling rate of the septic tank. Households interviewed reported that they would not mind sharing septic tank facilities irrespective of how many times a household uses the toilet facility since it is impossible to record how often one uses a toilet facility in a day.

Water source

The results from (Figure 5) the survey showed that 78 out

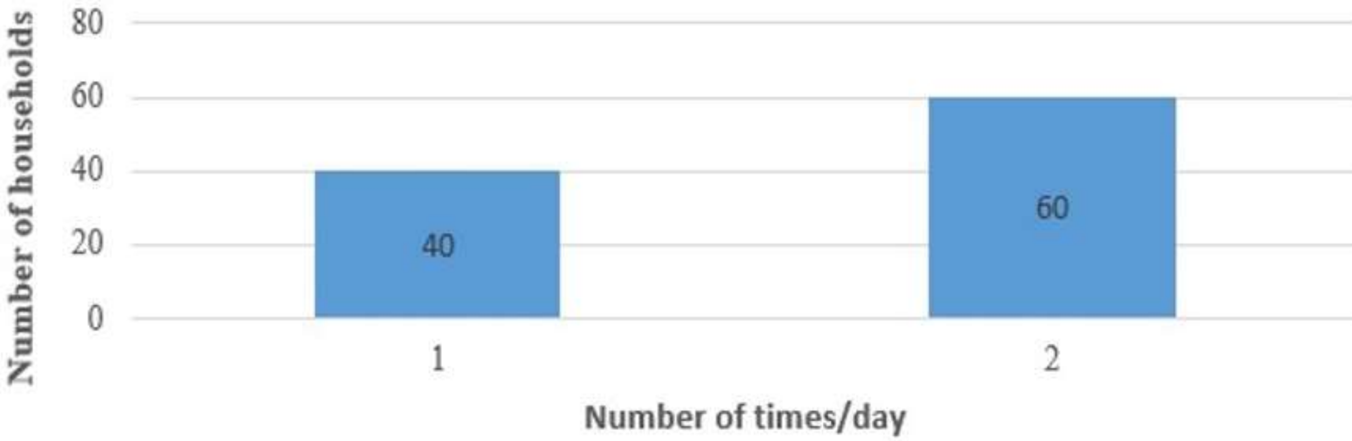

Figure 4. Toilet facility usage for each individual per day in the houses surveyed.

of the 100 houses surveyed are connected to a stand pipe system. 15 houses out of the remaining 22 use wells with pumps, while the remaining 7 use wells without pumps. Septic tanks are wet onsite sanitation systems which need water to function properly. This survey helps us to know the availability of water in the area which, in turn, helps to determine whether or not the area is suitable for septic tank installation. From this survey, it was found out that water is available to flush toilets and so water availability will not constrain the use of shared septic tank facility.

Major forms of occupation of residents

Figure 6 shows that residents in 45 out of the 100 houses surveyed are self-employed, 19 houses had residents who work in private sectors and 32 houses with residents work for the government sector. This implies that all the households interviewed are working, therefore there is the means for supporting the shared facility financially.

Willingness and acceptance of shared septic tanks

From the survey conducted, 84% of respondents were very happy with the shared septic tank facility if the average cost per household was cheaper than a household owning and maintaining own septic tank. However, 16% were either sceptical or unhappy about such facility. Some of the concerns raised included lack of cooperation from other households, non-compliance to payment rules and arrangement and difficulty in revenue collection towards emptying and maintenance especially when it becomes necessary to connect a distribution box to a drain field to evenly distribute the effluents coming from the tank to the soil (Awuah, 2012).

Septic tank design calculations and cost implications

Overall design capacity

The overall design volume under the Brazilian septic tank code is the sum of the volume of the four zones described by the approach (Ahmad, 2015). The four zones under the Brazilian septic tank code include:

1. The scum layer
2. The sedimentation zone
3. The sludge digestion zone
4. The sludge storage zone

$$V_T = V_{sc} + V_h + V_d + V_{sl} \quad (1)$$

Where, V_T is the total volume of the tank; V_{sc} is the volume of scum storage zone; V_h is the volume of the sedimentation zone; V_d is the volume of the digestion zone and V_{sl} is the volume of the sludge zone.

The sedimentation zone

In the septic tank the velocity of the black water is reduced greatly and allows the heavy particles (faecal matter) to settle when gravity works on it. The rate at which the faecal matter and other settleable solids settle in the tank is dependent on the number of users of the facility (Ahmad, 2015). The formula for finding the volume of the sedimentation zone is given as:

$$V_h = 10^{-3} \times P \times Q \times t_h \quad (2)$$

P is the user population, Q is the wastewater flow per

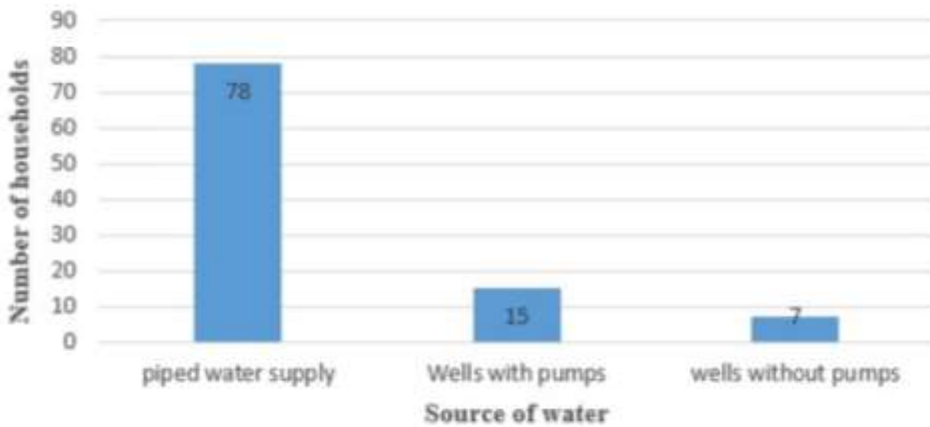

Figure 5. Sources of water for the houses surveyed.

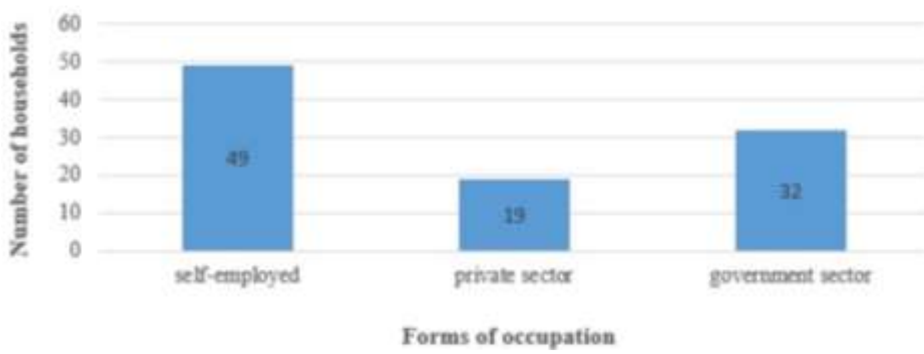

Figure 6. Major forms of occupation for residents in the houses surveyed.

person in litres/day and t_h is the minimum mean hydraulic retention time in days.

$$t_h = 1.5 - 0.3\log(PQ)$$

$$P = 30 \text{ people}$$

Average water consumption rate is 20 lpcd (CWSA, 2010)

$$Q = \frac{85}{100}(20 \text{ lpcd}) = 17 \text{ lpcd}$$
$$t_h = 1.5 - 0.3\log(30 \times 17) = 0.6877 \text{ days}$$
$$V_h = 10^{-3} \times 30 \times 17 \times 0.6877 = 0.35\text{m}^3$$

Sludge digestion zone

$$V_d = 0.5 \times 10^{-3} \times P \times t_d \quad (3)$$

t_d is the time for anaerobic digestion.

The time, t_d needed for the digestion of sludge in the tank is dependent on temperature (Ahmad, 2015).

$t_d = 30(1.035)^{35-T}$, T is the temperature in degrees Celsius

$$t_d = 30(1.035)^{35-20} = 50.261 \text{ days}$$
$$V_d = 0.5 \times 10^{-3} \times 30 \times 50.261 = 0.75\text{m}^3.$$

Digested sludge storage zone

The sludge storage volume, V_{sl}:

$$V_{Sl} = C \times P \times N \quad (4)$$

Where, C is the digested sludge accumulation rate, P is the number of users and N is the desludging period of the tank.

The volume of the sludge storage zone is dependent on two factors (Ahmad, 2015):

1. The digested sludge accumulation rate,
2. The desludging period of the tank,

For N<5, C =0.06 m^3/person/year, For N>5, C=0.04 m^3/person/year.

With N=3 years, C=0.06 m^3/person/year,

The volume for the digested sludge storage zone is given as:

$V_{sl} = 0.06 \times 30 \times 3 = 5.40\text{m}^3$.

Scum layer

It is the fatty, greasy or oily part that settles on top of the clear water space in the septic tank. The scum layer because of its greasy nature is less dense than water, the reason it floats on the clear water space area. The floating scum layer accumulates at approximately 30-40% of the rate at which the sludge accumulates (Ahmad, 2015).

The formula for the scum layer is therefore given as:

$$V_{sc} = 0.4 \times V_{sl} \quad (5)$$

$V_{sc} = 0.4 \times 5.4 = 2.16\ \text{m}^3$

Overall tank volume

$V_T = V_{sc} + V_h + V_d + V_{sl}$

V_{sc} = 2.16 m3, V_h = 0.35 m^3, Vd = 0.75 m^3, V_{sl} =5.40 m^3

$V_T = 2.16 + 0.35 + 0.75 + 5.40 = 8.66\text{m}^3 \sim 9.0\text{m}^3$

Dimensions of the septic tank

Assumptions made:

Tank depth of 2.3 m
Tank width of W meters
Total tank length of 3W
1st compartment length is $\frac{2}{3}$ of the overall tank length
2nd compartment length is $\frac{1}{3}$ of the overall tank length
V_T = 1st compartment volume + 2nd compartment volume
1st compartment volume = $2\text{W} \times \text{W} \times 2.3$ = 4.6W^2
2nd compartment volume = $\text{W} \times \text{W} \times 2.3$ = 2.3W^2
V_T = $4.6\text{W}^2 + 2.3\text{W}^2 = 6.9\text{W}^2$

Equating the two volumes,

$9.0\ \text{m}^3 = 6.9\text{W}^2$

$\text{W}^2 = \frac{9.0}{6.9} = 1.30$

$\text{W} = \sqrt{1.30} = 1.14\ \text{m} \sim 1.2\ \text{m}$

Tank depth $= 2.3$ m
Total Tank length $= 3 \times 1.2 = 3.6$ m
Tank width $= 1.2$ m
1st compartment length = $\frac{2}{3} \times 3.6\text{m}$ = 2.4 m
2nd compartment length = $\frac{1}{3} \times 3.6\text{m}$ = 1.2 m

Design of the soil absorption field

The parameters for the design include:

The number of users = 30 persons, the infiltration rate of porous silty loam soil = $20\text{l}/\text{m}^2\text{day}$
The daily wastewater flow (lpcd) = 17 lpcd

The trench sidewall infiltration area is given as:

$$\frac{\text{Effluent flow, l/day}}{\text{Infiltration rate, }\frac{\text{l}}{\text{m}^2}\text{day}}$$

Effluent flow $= 17$ lpcd $\times 30$ persons $= 510$ l/day
Infiltration rate $= \frac{20\text{l}}{\text{m}^2\text{day}}$, for porous silty loam soil (SMA, 2010).

The trench sidewall infiltration area = $\frac{510\text{l/day}}{20\text{l/m}^2\text{day}}$ = 25.5 m^2

The absorption trench should have a bed depth of 0.46 to 0.76 m deep (Schultheis, 2017).
Using an average trench depth of 0.6 m

The total trench length = $\frac{1}{2}\left(\frac{25.5}{0.6}\right) = 21.25$ m (Yukon, 2017)

Assuming 3 uniform trenches each trench length $= \frac{21.25}{3} = 7.1$ m.
Assuming the total width of the trenches is Y

Total trench sidewall infiltration area=$7.1\ \text{m} \times \text{Y}$
$25.5\text{m}^2 = 7.1\text{Y}$
$\text{Y} = \frac{25.5\text{m}^2}{7.1\text{m}} = 3.59\text{m}$
Width for a trench $= \frac{3.59\ \text{m}}{3} = 1.2$ m
Area for a trench $= 7.1 \times 1.2 = 8.5$ m

Design calculations

The calculations show the total tank volume and the overall tank length which was calculated based on the user population, given to be 30 and the per capita wastewater flow, 17 lpcd which is 85% of the water consumed. The average water consumption rate was found to be 20 lpcd (CWSA, 2010). A fraction of the water

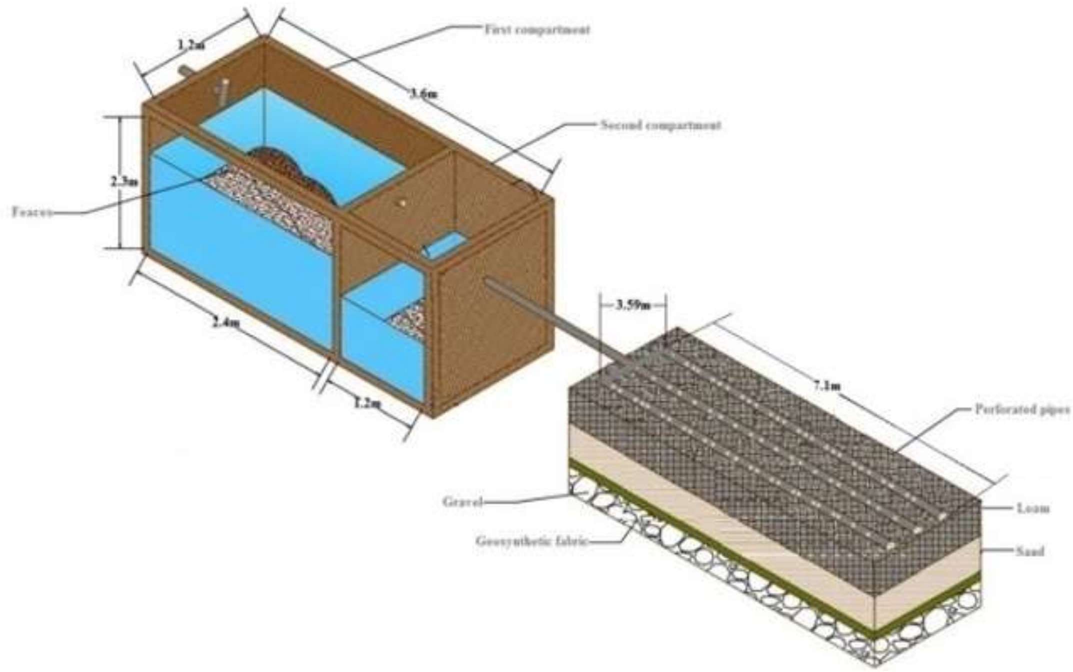

Figure 7. AutoCAD drawing showing the septic tank and drain field.

consumed comes out as wastewater while the rest is assimilated by the body. The return factor is usually 80 - 90% of the water consumed (Mara, 2004). The total volume and length of the tank was calculated to be approximately 9.0 m^3 and 3.6 m respectively.

The first compartment length which is $\frac{2}{3}$ of the total length was calculated to be 2.4 m and the second compartment length which is $\frac{1}{3}$ of the overall tank length was calculated to be 1.2 m. This is illustrated in Figure 7.

Cost implications

From the survey, the average volume size for the septic tank was $6m^3$. At the time of the survey, this could cost about 3,000 Ghana (GH) Cedis. The exchange rate of Ghana cedis to the United States (US) dollar at the time was 4 GH Cedis: 1 US dollar. By extrapolation, the shared septic tank of 9 m^3 could cost 1.5 times the existing average septic tank in the community. This could therefore cost 4,500 GH cedis. Sharing this cost among three household will amount to each household paying 1500 GH Cedis, which is half the cost of average single septic tank (3000 GH cedis) found in the community. Thus, households will save quite significant amount for constructing a shared facility. More studies and work need to be done regarding the filling rate and emptying frequency of the shared facility as this study did not cover that.

CONCLUSIONS AND RECOMMENDATIONS

Conditions suitable for shared septic tank facility in the study area included availability of water, suitable soil conditions for drain fields, positive user's employment status, and user's willingness for the shared facility. A shared septic tank volume calculated is approximately 9.0 m^3, based on the user population of 30 people, waste water flow rate of 17 lpcd (85% of water consumed, that is 20 lpcd) and a minimum desludging interval of 3 years. This volume is enough to handle the wastewater for 3 households in the Fiapre community. Also, the shared septic tank facility was comparatively less expensive to a household and therefore very appealing to be patronized.

The following recommendations are made to improve the project and for the sustainability of the shared septic tank facility;

1. The addition of soil absorption field or a drainage field to the septic tank system should be considered as it offers better treatment solution to the effluent from the tank.
2. Pipes used for the connections should be of good quality and buried in the ground and should not be exposed to avoid breakages of the pipes.
3. The septic tanks should be dislodged regularly.
4. Less fat or grease should be allowed into the system.
5. The alternating drain field system must be properly used.

6. Only human wastes should be allowed into the septic tank.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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