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Onsite Wastewater Treatment System Design for an Effective Groundwater Conservation in a High Water Table Area.

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Abstract:
Background of Study*: Because of the improper disposal of industrial waste in a number of situations, the groundwater environment is faced with an ever-increasing number of soluble chemicals* **[6].** *In many areas where there is great pressure for development, onsite systems have often been installed on land that is not suitable for conventional soil absorption systems. With the increase in the generation of wastewater from residential apartments with no adequate management system, the need for a soil evaluation and assessment for a possible wastewater treatment system design is high to treat the wastewater discharging to the groundwater system. In this regard, this study aims to characterize soil profile and subsurface hydraulic properties for appropriate onsite wastewater treatment system design, using the Federal University of Technology Akure's(FUTA), Nigeria stream basin as a case study.*
Material and Methods*: An onsite assessment was conducted at the study site, and the site soil profile, site slope, site size and the depth of the groundwater table was determined. Having conducted the site assessment and reconnaissance, soil test such as the atterberg limit test, soil moisture content test, and the soil particles size distribution test was conducted using the soil samples taken from the observation pit(Eleventh hole). The results gotten from the soil test were used to proffer an effective onsite wastewater treatment system design suitable for the study site.*
Results*: The soil percolation rate conducted at the study site is 0.128cm/min (19.53min/in). This value justifies that the soil is sandy-loam soil with an infiltration rate of 0.6gpd. The sandy loam soil has moderate water retaining capacity and percolation rate and this enables it to give a proper and reliable wastewater treatment. The laboratory test conducted on the observation pit soil sample revealed that the soil moisture content of the study area is 62.72%. The percentage values of the moisture content of the soil also show that the area of study is a high groundwater table site. It has a liquid limit of 29.5%, plastic limit of 19.87% , and a plasticity index of 9.13% and 30.31% of the soil sample passes through the number 200 sieve, hence the soil is classified as A-2-4 soil (sandy loam)using the ASSHTO soil classification system.*
Conclusion: *The result gotten from the site reconnaissance to the evaluation of the soil affirms the mound system as the appropriate onsite wastewater treatment system for the study site. Hence, a mound system consisting of a mound of 38 m x 3.9m, dosing chamber of 1.5m x 0.75m x 1.5m, and a septic tank of 3m x 1.5m x 3m was designed for and proposed to be constructed on the case study site for effective wastewater treatment since the site is located in a high water table area.*
Key Words: *Wastewater, Groundwater, Soil Test, Mound System, Wastewater Treatment System, Percolation.*

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I. Introduction

In recent years, the amount of wastewater produced from several activities has increased as a result of the rapid improvement of living standards **[7].** Although some communities treat their wastewater in a suitable way, others lack convenient treatment systems, thus discharging untreated wastewater into the natural environment. Pollutants (e.g. heavy metals) enter aquatic systems via numerous pathways, including effluent discharge, urban and agricultural run-off. The vast subsurface reservoir of freshwater, which a few decades ago was relatively unblemished by man's activities is gradually becoming degraded **[3].** Contaminants present in sewage commonly include a wide range of metallic and organic compounds **[4].** Soil and streams have been used for multifarious purposes including waste disposal. Our careless dumping of waste has affected these precious resources. This has resulted in the continuous introduction of natural and anthropogenic substances into the soil which acts as a medium of purification. Some of the toxic chemicals and microbes may not be removed sufficiently during percolation through the soil which in turn contaminates the nearby groundwater soil. The current study aimed to characterize the Federal University of Technology Akure (FUTA) stream basins' soil profile and subsurface hydraulic properties to determine the appropriate onsite wastewater treatment system design.

II. Material And Methods

Description of Study Site:

The study area is a stream basin area located at various regions of the Federal University of Technology Akure community. The case study site (LOT A1) is made up of many geographical features like buildings, roads, trees e.t.c surrounding it in respect to the four cardinal orientations. Taken the site orientation in the anti-clockwise direction, the site is located at an approximate linear distance of 29.6m to the stream, 155.38m to 3-in-1 Lecture theatre, and 142.96m to CERAD building towards the north orientation of the site. The walking path to the school of science from the GNS building is at an approximate distance of 29.53m to the study site towards the west direction. Trees and bushes are also present in the western direction of the building. Towards the south orientation, the study site is located at an approximate linear distance of 62.08m to the graduate research laboratory, 104.56m to the GNS lecture building. Toward the eastern orientation, the study site is located at an approximate linear distance of 143.88m to the main road leading from the Engineering building to the School of Environmental Technology building.

Soil Investigation/ Field Work:

During the investigation of the soil, the soil profile of the site, site slope, site size, the groundwater table depth, and the rate at which the water percolation into the soil was determined. Eleven holes at uniform geo-referenced points (see Table 1.0) were dug to a depth of 1m each and the soil percolation rate was conducted using these holes. After the percolation rate test, the eleventh hole is used as the observation test pit. Soil samples were taken at the last soil profile levels to the groundwater and laboratory test like Soil Particle Size Distribution, Soil Moisture Content, and Atterberg Limit Test was conducted on the soil sample. The test pits were dug to the groundwater level and the depth of the water table was measured to be 1.7m.

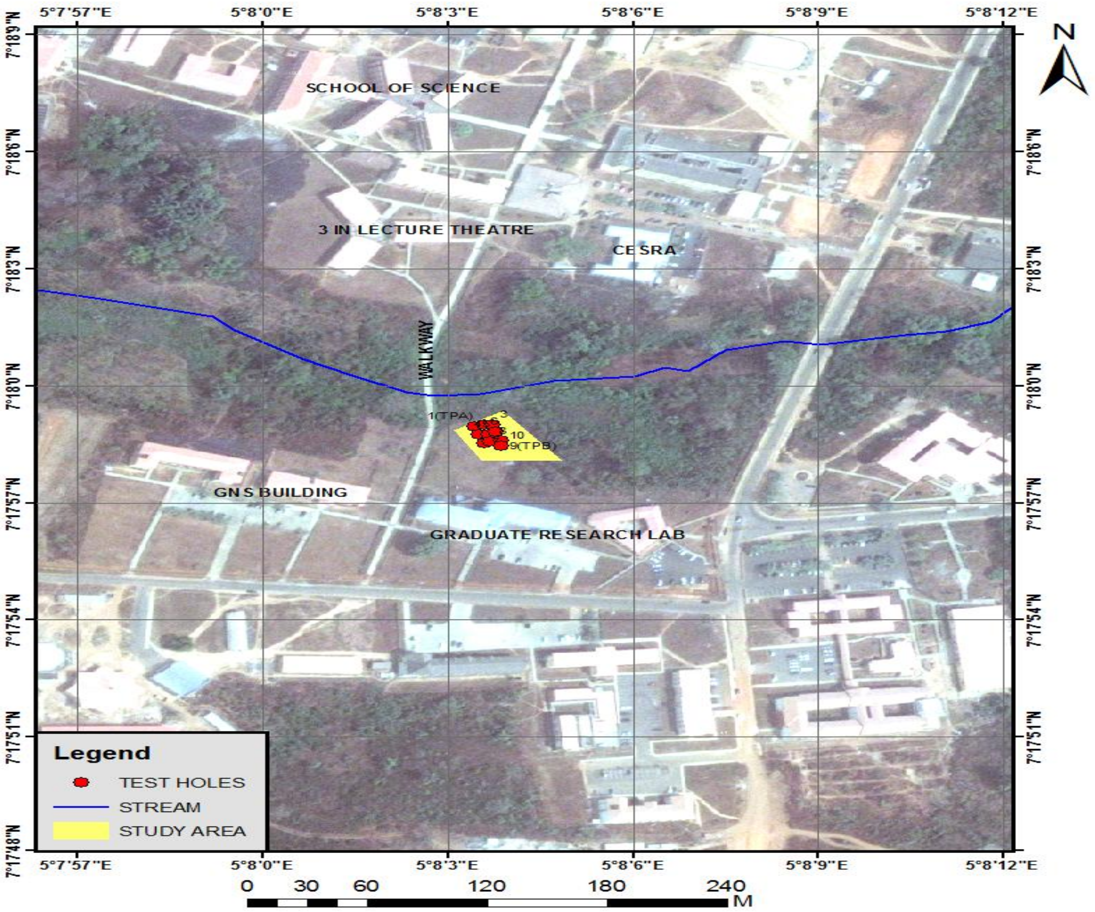

Fig1.0: Map of FUTA Community in Ondo State showing the Case study area and the feature around it.

Table1.0 Geo-Referencing location of the test holes

TEST HOLE NUMBER	LATTITUDE	LONGITUDE
1	7.29971°N	5.13429°E
2	7.29972°N	5.13433°E
3	7.29972°N	5.13437°E
4	7.29965°N	5.13431°E
5	7.29965°N	5.13435°E
6	7.29967°N	5.13438°E
7	7.29959°N	5.13433°E
8	7.29960°N	5.13436°E
9	7.29961°N	5.13441°E
10	7.29957°N	5.13441°E
11	7.29955°N	5.13441°E

Soil Percolation Rate Test

Equipment Used In Carrying Out Percolation Rate Test: Hand bucket Auger, Knife, Stop Watch, and Pipe.

An area of (25mx10m) was marked out on the site (one plot of land) and divided into grids that can contain 10 holes with each hole 5m apart. After the marking out of the grids, using a hand bucket auger, holes of 1m deep with 100mm diameter will be dug. The bottom base of the pipe was closed and an opening was made at the bottom side of the pipe through which water passes out. A knife was then be used to scarify the bore holes to remove debris and a 5cm sized gravel will be placed to prevent the bottom from scouring. After this, the test holes were filled with water (see Plate 3.4) and it was allowed to drain overnight to saturate the soil. The pipes of diameter 100mm and a length of 1000mm were placed into each hole. The water level drop was determined by placing a ruler into the pipe or by marking out the required water level drop on the pipe with a marker. The pipes were refilled with water to a depth of 1000mm and the depth of the water level drop was determined after 30minute. The procedure will be repeated for all the holes and the percolation rate in min/mm by will be determined using the formula below;

Percolation Rate in (mm/min) = Depth of water percolation/ Time taken to percolate

After calculating the time taken for the water to drain per 1mm, the average time taken for percolation in min/mm will be calculated by dividing the sum of the percolation rate/1mm by the total no of tests carried out per site.

Laboratory Tests Carried Out

After the various fieldworks have been carried out, the soil sample from the observatory pits was taken into the laboratory to carry out natural the soil moisture content test, the particle size distribution test using sieve analysis, and the atterberg limit test.

Particle Sized Distribution Test:

A particle sized distribution test was conducted on the soil sample gotten from the case study site to determine the different grain sizes contained within the soil at different soil profile level of the observation pits. The soil sample from the site location was placed in a container at a specified weight before it was oven dried for 24 hours. The weight of each sieve as well as the bottom pan to be used in the analysis was measured. After the second stage, the weight of the dry soil sample was measured using the weighing balance and it was properly recorded. All the sieves were kept clean and were assembled in the ascending order of sieve numbers. After this, the soil samples were carefully poured into the top sieve with the cap on it. The sieve stack was placed in the mechanical shaker and shaking was done for 10 minutes. The stack was removed from the shaker and the weight of each sieve with its retained soil was recorded. In addition, the weight of the bottom pan with its retained fine soil was also recorded for further analysis. The procedure for the test is performed in accordance to **[1].**

Natural Moisture Content Test:

For many soils, the water content may be an extremely important index used for establishing the relationship between the way a soil behaves and its properties.

The consistency of fine-grained soil largely depends on its water content. The water content is also used in expressing the phase relationships of air, water, and solids in a given volume of soil. The procedure for the test is performed in accordance to **[1].**

Atterberg Limit Test

Atterberg limit test can be defined as the measure of the critical water content of a finely grained soil such as its shrinkage limit, plastic limit, and liquid limit **[9].** This test was conducted to determine the expansion and contraction ability of the soil at the study site. This test enables us to know the amount of water a particular soil can take to prevent the soil excessive change in volume and shear strength collapse. The procedure for the test is performed in accordance to **[1].**

III. Results

Percolation Rate Test (Site Test)

The result for the percolation rate test for ten different test holes are shown in the Table 2.0:

Table 2.0: Percolation Rate Result.

HOLE	TIME INTERVAL (mins)	HEIGHT (cm)	PERCOLATION RATE (PR)	AVERAGE PERC. RATE (cm/min)
1	0	85.0	-	0.137
	30	80.98	0.134	
	60	77.35	0.121	
	90	62.67	0.156	
2	0	90.0	-	0.161
	30	85.47	0.151	
	60	80.58	0.163	
	90	75.51	0.169	
3	0	80.0	-	0.151
	30	75.47	0.151	
	60	70.82	0.155	
	90	66.41	0.147	
4	0	98.0	-	0.110
	30	94.61	0.113	
	60	90.68	0.131	
	90	88.10	0.086	
5	0	78.0	-	0.163
	30	73.47	0.151	
	60	68.55	0.164	
	90	63.33	0.174	
6	0	94.0	-	0.121
	30	90.07	0.131	
	60	85.48	0.153	
	90	83.11	0.079	
7	0	88.0	-	0.171
	30	83.11	0.163	
	60	71.89	0.174	
	90	66.61	0.176	
8	0	95.0	-	0.123
	30	90.77	0.141	
	60	86.81	0.132	
	90	83.93	0.096	
9	0	76.0	-	0.029
	30	74.89	0.037	
	60	73.84	0.035	
	90	73.39	0.015	
10	0	97.0	-	0.114
	30	91.27	0.191	
	60	85.78	0.183	
	90	84.82	0.032	
	SUM OF AVERAGE PERCOLATION RATE			1.28

Percolation Rate for the whole site $= \frac{\text{SUM OF AVERAGE PERCOLATION RATE}}{\text{NUMBER OF TEST HOLES}} = \frac{1.28}{10} = 0.128\text{cm/min}$
Pipe Diameter: 100mm

Soil Natural Moisture Content Test (Laboratory Test)

Table 3.0: Soil Moisture Content Result for Test Pit (Hole 11) Soil Layer (1.3-1.7m)

MOISTURE CONTENT TEST ON THE SAMPLE			
WEIGHT OF CAN 1a,1b,1c (KG) = W1	11.3	12.5	14.3
WEIGHT OF CAN 1a,1b,1c + WET SAMPLE (KG) = W2	72.99	68.51	78.23
WEIGHT OF CAN 1a,1b,1c + DRY SAMPLE (KG) = W3	48.6	46.4	52
WEIGHT OF PORE WATER=(W2-W3)	24.39	22.11	26.23
WEIGHT OF DRY SOIL= (W3-W1)	37.3	33.9	37.7
% MOISTURE CONTENT IN SAMPLE = ((W2- W3)/(W3-W1))*100	65.39%	65.22%	69.58%
AVERAGE % MOISTURE CONTENT		66.72%	

Particle Size Distribution Test (Laboratory Test)
Sieve analysis test was carried out on the soil samples gotten from observation test pit, the results of the test are shown in Table 4.0 while the Graph of % Passing against Sieve sizes are shown in Figure 1.0:

Table 4.0: Sieve Analysis Result for Test Pit (Hole 11) Soil Layer (1.3-1.7m)

SIEVE ANALYSIS						
Sieve No	Sieve Size(m)	Weight Of Sieve(G)	Weight Of Sieve + Sample(G)	Weight Retained(G)	%Weight Retained	% Passing
4	4.75	391.1	429.92	38.82	7.31	92.69
10	2.36	479.5	485.45	5.95	1.12	91.57
12	1.70	369.0	387.74	18.74	3.53	88.04
16	1.18	365.0	398.5	33.50	6.31	81.73
30	0.60	348.5	441.53	93.03	17.52	64.21
35	0.50	365.1	462.43	97.33	18.33	45.88
40	0.425	335.0	346.42	11.42	2.15	43.73
70	0.212	354.1	408.85	54.75	10.31	33.42
100	0.150	342.0	349.01	7.01	1.32	32.10
200	0.075	314.7	324.20	9.5	1.79	30.31
<200	Pan	287.3	448.25	160.95	30.31	0
TOTAL				531		

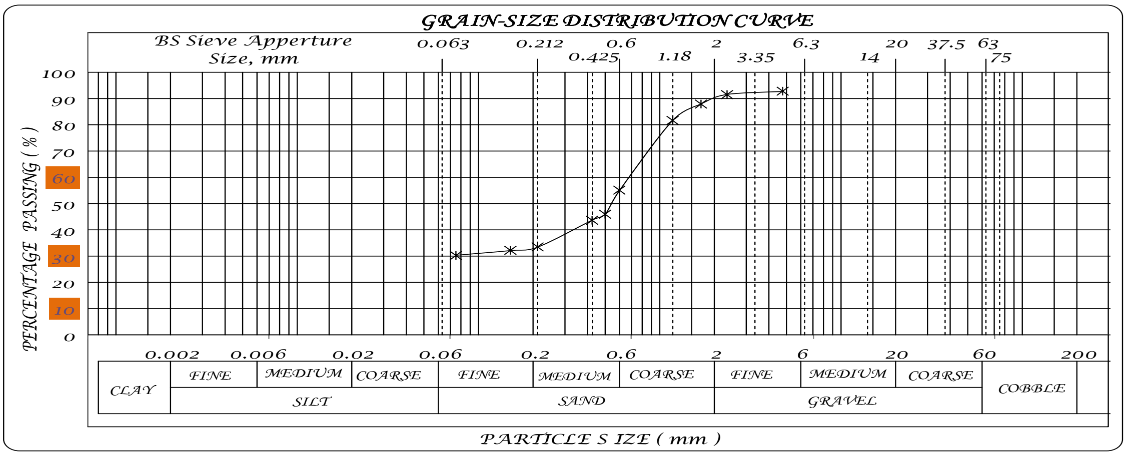

Figure 1.0: Graph of % Passing against Sieve sizes for Test Pit (Hole 11) Soil Layer (1.3-1.7m)

Atterberg Limit Test

Table 5.0: Plastic Limit Result for Test Pit (Hole 11) Soil Layer (1.3-1.7m)

SAMPLE NO	**1**	**2**	**3**
WEIGHT OF CAN (KG) = W1	12.53	10.8	9.78
WEIGHT OF CAN + WET SAMPLE (KG) = W2	16.71	15.44	14.75
WEIGHT OF CAN + DRY SAMPLE (KG) = W3	16.03	14.70	13.88
WEIGHT OF PORE WATER=(W2-W3)	0.68	0.74	0.87
WEIGHT OF DRY SOIL= (W3-W1)	3.5	3.9	4.1
% MOISTURE CONTENT IN SAMPLE = ((W2- W3)/(W3-W1))*100	19.43	18.97	21.21
AVERAGE % MOISTURE CONTENT(PL)	**19.87%**		

The Liquid Limit is gotten at blow 25, therefore Liquid Limit (LL) =29.5%.
Plastic Limit = 19.87 % (see table 4.23)
Plasticity Index = Liquid Limit – Plastic Limit = (29.5-19.87) % =9.13%

IV. Discussion of the Results

Soil Percolation Rate

The average percolation rate conducted at depth of 1m for the ten observation test holes is 0.128cm/mins (19.53min/in). This value justifies that the soil is sandy-loam soil with an infiltration rate of 0.6 gpd/ft^2. The slope of the soil falls within the interval 0-6% since the percolation rate is slower than 60min/in. The percolation rate in which water passes through the soil is said to be moderate due to the nature of the soil present on the study site. The particle size distribution test conducted on the soil samples of the site indicates that the soil in the study area is majorly made of sandy loam soil. The sandy loam soil has moderate water retaining capacity and water percolation rate and this enables it to give a proper and reliable wastewater treatment.

Natural Soil Moisture Content

The results gotten from the natural moisture content test carried out which is in accordance with the physical appearance of the soil show that the moisture content of the soil sample increases with depth. For the test pit, the moisture content is 66.72% for (1.3-1.7m) layer. This result indicates that the soil at the lower horizon is taken from the groundwater layer. The percentage values of the moisture content of the soil also show that the area of study is a high groundwater table site.

Sieve Analysis

The soil sample in the observatory pit A and pit B are classified based on the AASHTO classification of soil using the soil particle sizes. The last soil layer (1.3-1.7m) of the **test pit** is classified as A-2-4 soil. It has a liquid limit of 29.5%, plastic limit of 19.87% , and a plasticity index of 9.13%. 30.31% passes through the number 200 sieve. The soil sample in this layer is sandy loam. This can be explained using Table 6.0:

Table 6.0: Classification of the Soil Samples based on AASHTO Classification

TEST PIT	SOIL LAYER	NO200 SIEVE	NO 40 SIEVE%	PL (%)	LL(%)	PI(%)	GI	CLASSIFICATION
	1.3-1.7m	10.31	43.73	19.87	29.5	9.13	0	**A-2-4(0)**

V. Analysis For The Design Of a Proposed Mound System (Mound, Absorption Field, Septic Tank And Dosing Chamber) For The Graduate Research Laboratory Phase 2 (FUTA).

After various assessment and tests have been conducted on the study sites, the results gotten are used in proposing a design for the Graduate Research Laboratory Phase 2 building. The Graduate Research Laboratory Phase 2 is a building located in the Federal University of Technology Akure for postgraduate research purposes. The building is made up of two floors, the ground floor, and the first floor. There are needs for the recommendation of a designed mound system in place of the already existing soak away pit for the building. The various apartments and sections in the building are shown in Table 7.0:

Table 7.0: Sections in the Graduate Research Laboratory (FUTA)

SECTION	UPPER FLOOR	GROUND FLOOR
Office	2	3
Toilet/ Bathroom	6	6
Laboratories	5	5

The Mound Design

Site Natural Soil Texture- Clay Loam

Percolation Rate at 1m depth- 0.128cm/min (19.53min/in)

Depth to High water Table- 1.7m

Slope- 6%

Note: This mound system design is in accordance to the standard of the United State Environmental Protection Agency.

STEP 1: Selection of the Site

The site for the construction of the mound system was selected in accordance to the United State Environmental Protection Agency standard site criteria for mound system (see Table 4.30). The site at the back of the Graduate Research Laboratory Obanla, (FUTA) is the best location for the mound system design. In view of this, it should be selected for this design.

STEP 2: Selection of Suitable Fill

Two important factors were considered when selecting the Fill for this design. These factors are (1) Transportation cost (2) Quality of the fill material. Medium sand is used for the fill material since it is of nearer availability within Akure metropolis and thus reducing transportation cost.

The design daily loading rate is 1.2 gpd/ft^2.

STEP 3: Estimate Design Flow

The graduate research laboratory is made up of 5 offices, 12 toilets and 11 laboratories. The offices and 3 of the laboratories does not make use of water. An estimated design flow for a population of 100 students was assumed for this design. GPF- Gallon per flush, GPD- Gallon per day (for 8 working hours).

Table 8.0: Toilet, Urine and Laboratory water use in school **[2].**

Source	GPF/unit	Flush/day/unit
Toilet water use	3.0	2.60
Urine water use	1.6	2.60
Laboratory water use	3.0	2.60

The estimated water used use assumed for 100 students per day is estimated in the table below:

Table 9.0: Standard estimated water use in school **[5].**

Source	GPF/unit	Flush/day/unit	GPD/unit	GPD/100 units
Toilet water use	3.0	2.60	7.8	780
Urine water use	1.6	2.60	4.16	416
Laboratory water use	3.0	2.60	7.8	780
TOTAL				1976 GPD (7489)LPD

STEP 4: Size of the Absorption Bed

Absorption Bed Area $= \frac{\text{Estimated water use}}{\text{Daily Loading Rate}} = \frac{1976 \text{ gpd}}{1.2} = 1647ft^2 (148.23m^2)$

STEP 5: Absorption Bed Dimension

Assuming a width of B = 3.9m

Bed width A $= \frac{\text{Absorption Bed Area}}{\text{Width B}} = \frac{148.23}{3.9} = 38$m

Bed dimension A = 38m

Bed dimension B = 3.9m

STEP 6: Calculate Mound Dimension

The Mound Height:

Fill depth (D) = 2 *ft* (0.6m)(Since the site is sloppy)

Fill depth (E) = D + [Slope x (B)] = 0.6 + [0.06 x 3.9] = 0.834m

Bed Depth (F) = 10 inches (0.25m)> (9 inches minimum)

Cap at Edge of Bed (G)- 2 *ft*(0.6m) > 1 *ft* (minimum)

Cap at Centre of Bed (H) – 1.5 *ft* (0.45m)

The Mound Perimeter:

Download Slope (I): The downward slope of the mound, which is the natural soil has is a clay-loam with an infiltration rate of 0.25 gpd/ft^2

Downward Slope used: 3:1

Up Slope Setback (J) = (Mound height at upslope edge of bed) x [3:1 (slope)]

= [(D) + (F) + (G)] x 3

= [0.6 + 0.25 + 0.6] x 3

= 1.45 x 3 = 4.35m(use 4m).

Side Slope Set back (K) = (Mound height at bed Centre) x [3:1 (slope)]

$= [\frac{D+E}{2} + F + H] \times 3$

$= [\frac{0.6+0.834}{2} + 0.25 + 0.45] \times 3$

= 1.42x3 = 4.26m

Base Area Required = A x (I + B)

Note: Mound Base Area is made of Clay Loam soil with a daily loading rate (infiltration rate)of 0.25 gpd/ft^2

Base Area $= \frac{\text{Estimated water use}}{\text{Daily Loading Rate}} = \frac{1976}{0.25} = 7904ft^2 (711.36m^2)$

A x [I + B] = 711.36m^2

$I + B = \frac{711.36}{A}$

$I + B = \frac{711.36}{38} = 18.72$m

I = 18.72 – B= 18.72–3.9 = 14.82m

Check to see if the downward slope setback (I) is large enough so as not to exceed 3:1 slope

(Mound height at down slope edge of bed) x [3:1 (slope)]

[E + F + G] x 3

[0.744 + 0.25 + 0.6] x 3

1.594 x 3 = 4.78m

Since the distance needed to maintain a 3:1 slope is less than the distance needed to provide sufficient basal area (I) = 23m

Mound Length (L) = (A) + 2(K) = 38+ 2 (4.26) = 38 + 8.52 = 46.52m (use 47m)

Mound Width (W) = J + B + I = 4+3.9+14.82 = 22.72m

Septic Tank Design
The septic tank is designed in such a way that its size can accommodate a wastewater flow through the tank for at least 24 hours with sludge and scum present. This will allow the settling of solid heavier than water and allow scum, grease to float to the surface before its discharge.

Each student water demand is 180litres/day (24 hours) (World Health Organization Estimates).
Wastewater flow for 8 working hours/day = 60litres

Wastewater flow/day for an assumption of 100 students = 60l x 100 = 6000l/day. ($6m^3$/day)
Size of the septic tank= 3m x 1.5m x 3m (as twice as the wastewater flow).

Dosing Chamber Design
This chamber helps to provide a better distribution of wastewater effluent over the infiltration surface and provides intervals between doses, when there is no application of wastewater.
Soil Texture: Sandy Loam.
Dosing Frequency = 1 dose daily for medium sand fill
Size of the Dosing chamber = Half the volume of septic tank = 1.5m x 0.75m x 1.5m

Dosing Volume $=\frac{\text{Daily wastewater flow}}{\text{Dosing frequency}} = \frac{6000}{1}$ = 6000 l doses^{-1} ($1.5m^3$)

Let the distance between float (ON) and float (OFF) = d
1.5 x 0.75 x d = 1.5
d = 1.5/(1.5 x 0.75) = 1.33m

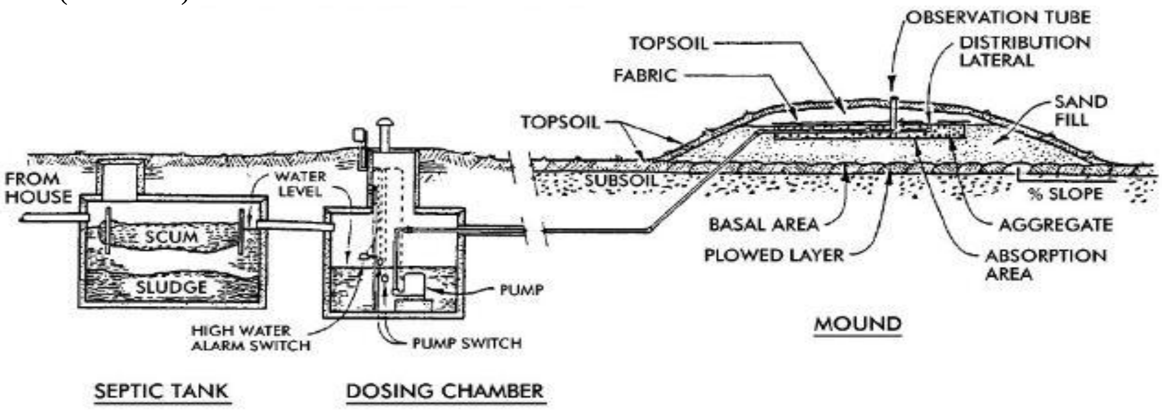

Figure 2.0 Cross section of an Absorption field **[8].**

VI. Conclusion

After a comprehensive study and evaluation has been undertaken towards the achievement of a characterized stream basin soil profile and subsurface hydraulic properties for appropriate onsite wastewater treatment system design, conclusion is drawn by the objective of the project as follows

From the properties of the behavior of the dominant soil of the study area which is the sandy loam soil, it can be concluded that the soil profile of the study site will provide an efficient moderate water percolation rate into the groundwater.

The percolation rate of the soil which is 0.128cm/min enables one to ascertain that the soil is good for effective wastewater treatment. It is then concluded that the result gotten from the soil subsurface evaluation denotes that the study site soil is good for the design of an on-site wastewater treatment system.

Finally, from the results gotten from the site reconnaissance to the evaluation of the soil, we can conclude that a mound system is an appropriate onsite wastewater treatment system in a high water table region. Hence a mound system consisting of a mound of 38m x 3.9m, dosing chamber of 1.5m x 0.75m x 1.5m, and septic tank of 3m x 1.5m x 3m was designed for and proposed to be constructed on the case study site for effective wastewater treatment.

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