



A RATIONAL APPROACH TO SEPTIC TANK DESIGN

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Abstract

A new approach to the design of septic tanks was developed based on a number of critical parameters, namely: residual detention time, minimum residual detention time, residual depth and minimum residual depth. This method involved first specifying a desired desludging interval. This interval was then substituted in a septage accumulation model to obtain the volume of sludge accumulated in this time interval. Using a minimum detention time of 24 hours and a desired minimum residual depth, the plan area of the tank was then determined and hence, the depth of sludge volume. The total depth of the tank was obtained as the sum of the sludge depth, residual depth and depth of reserve space. The length and width of the tank were also obtained from the plan area by using a length to width ratio (L/W) ranging between 2 to 4 or any other range depending on land configuration. Design charts and a Microsoft Excel based design programme were produced to aid the design of septic tanks. A predetermined desludging interval ensures septic tanks are efficient and durable.

Keywords: septic tank, desludging, sewage, design, sludge

1. Introduction

The septic tank system is the most widely used onsite system for wastewater treatment especially in developing countries where the cost of central wastewater treatment facilities is prohibitive. In the United States only, over 50 million people use the septic system [1]. According to [2], over 46% of the Nigerian population use the septic tank system. Given enough detention time, the septic tank can achieve as much as 81% total suspended solids removal, 68% BOD removal, 65% phosphate removal and 66% fecal coliform removal [3,4]. In Nigeria, septic tanks are rarely designed, rather, most contractors resort to arbitrary sizing or adopt the specifications of the Public Works Department [5] shown in Table 1 or other local government specifications. The specifications on this table are based on 1 day detention time and a wastewater flow of 0.114m³/capita/day. This

specification is not realistic as a septic tank sized for 1 day detention time will need desludging frequently.

The code recommended that a septic tank serving 10 people should have a dimension of 2.032m (length), 0.457m (width) and 1.22m (depth) giving a total volume of 1.13m³. Even if the usual constant sludge accumulation rate of 0.04m³/capita/year [6,7] is assumed, in three years the tank will be overflowing with sludge (1.2m³). This implies that the tank will need desludging about every two years. Compare this with the recommendations in Table 2 [8]. For instance, they recommended a tank of 2000 US gallons (7.57m³) for a four bedroom house (see Table 2). Obviously this is a very long shot from the meager 1.13m³ recommended by PWD for a septic tank serving 10 people.

The septic tank is a very vital aspect of waste

Table 1: Schedule of Septic Tank Sizing and Dimensions (PWD, 1943).

Tank Size	Dimensions				No. of Users
	Length(m)	Width(m)	Depth(m)	Capacity(m ³)	
I	2.032	0.457	1.220	1.134	10
II	2.286	0.534	1.220	1.448	13
III	2.286	0.610	1.220	1.700	15
IV	2.540	0.686	1.220	2.125	18
V	3.048	0.762	1.220	2.832	25

Table 2: Septic Tank Volumes [8].

No of Bedrooms	Tank Capacity (<i>US gallons</i>)	Tank Capacity (m ³)
One or two bedrooms	1,000	3.785
Three bedrooms	1,500	5.678
Four bedrooms	2,000	7.570

management and public health that merits more than casual sizing. Every septic tank is unique and must be designed to maintain minimum conditions. In this regard, [9] noted that the key to effective sewage treatment is proper design, installation, periodic maintenance and responsible operation. The most critical parameter in septic tank design and operation is the detention time. At any point in time, the detention time must be sufficient to allow solid particles to settle, otherwise, its performance will be impaired.

2. Development of Design Approach

The design approach developed in this study is based on critical parameters viz: residual depth which depends on the residual detention time, sludge depth which determines desludging interval and reserve space which helps accommodate intermittent overloading and malfunctioning.

2.1. Residual depth

As sludge accumulates in the septic tank, the depth of the tank decreases. In the design of septic tank, it is necessary to specify a minimum residual depth and a minimum residual detention time in order to maintain the efficiency of the tank above a threshold limit. These conditions should be the prevailing conditions at desludging. Considering a septic tank of plan area A , receiving wastewater at the rate of Q m³/s per capita which is required to maintain a minimum

residual detention time, θ_{re} days and a minimum residual depth per capita h_{re} (m), the following relationship holds.

$$h_{re} = \frac{Q\theta_{re}}{A} \quad (1)$$

For the sake of economy, it is necessary to choose plan dimensions that will yield the minimum plan perimeter for a given plan area. This will ensure that the minimum amount of materials is used for construction. Tank perimeter, P is given as:

$$P = 2w + 2l \quad (2)$$

$$P = \frac{2A}{l} + 2l \quad (3)$$

For minimum perimeter, we differentiate with respect to l and equate to zero.

$$\frac{dP}{dl} = 2 - \frac{2A}{l^2} = 0 \quad (4)$$

Hence $l = w$ for the most economic plan area. This implies that the most economic plan should be a square. However, researchers have been advocating for tanks with narrow plan for higher efficiency, hence three classes of plan specifications will be included in the evolving design approach. The cases are: $l = w$ for economy; and $l = 2w$ and $l = 3w$ for laminar conditions [10]. Adopting a minimum detention time of 24 hours (1 day) at desludging:

$$\text{Case 1 } (l = w) : h_{re} = \frac{Q}{l^2} \quad (5)$$

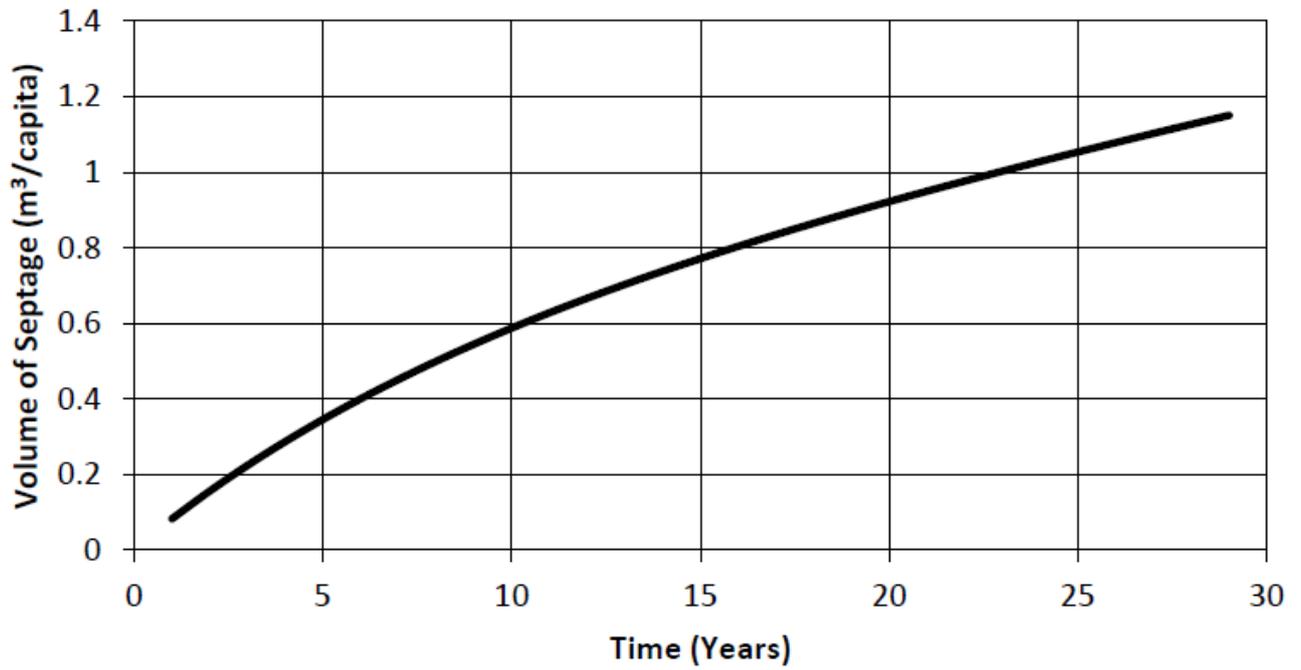


Figure 1: Chart for determining volume of sludge for a chosen desludging interval.

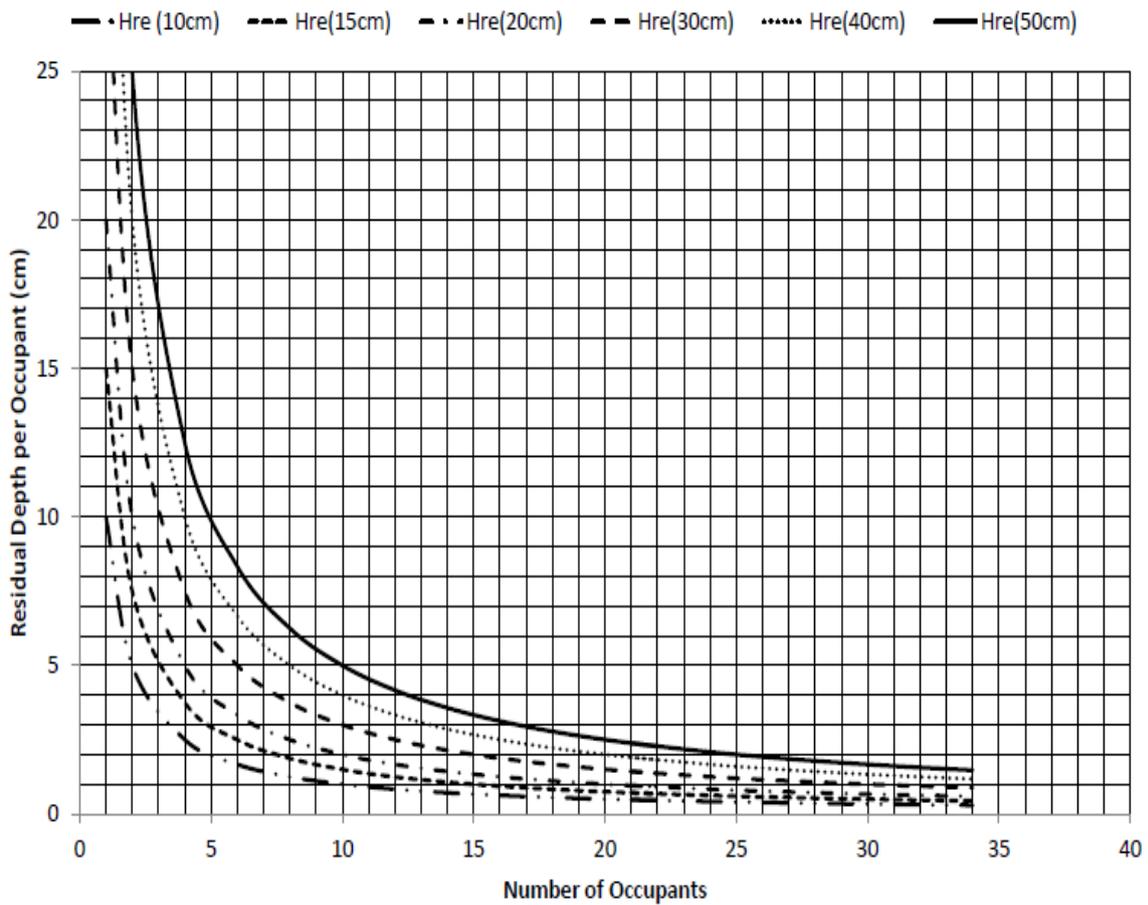


Figure 2: Residual Depth per Occupant (h_{re}) versus Number of Occupants.

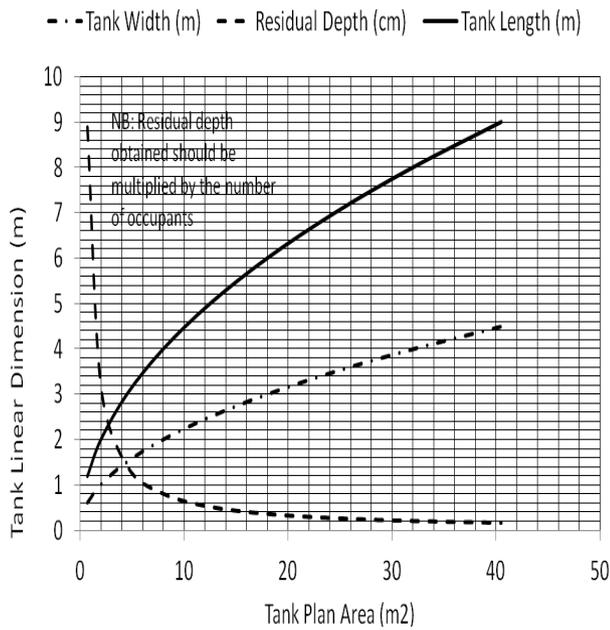


Figure 3: Tank dimensions and residual depth for simple house connection, pour flush ($Q = 0.064\text{m}^3/\text{capita}/\text{day}$) and $L = 2w$.

$$\text{Case 2 } (l = 2w) : h_{re} = \frac{2Q}{l^2} \quad (6)$$

$$\text{Case 3 } (l = 3w) : h_{re} = \frac{3Q}{l^2} \quad (7)$$

It is necessary to state at this point that under normal circumstances, a septic tank should not have a square plan even though it is the most economical plan as this could lead to shortcircuiting. However, where the shape and size of land poses a restriction, some sort of compromise could be reached.

2.2. Reserve space

The reserve space refers to the empty space above the liquid level of the septic tank or above the effluent pipe. The reserve space is an additional space that takes care of such malfunctions as blockage of the effluent pipe, clogging of the drain field or temporary overloading. When blockage of effluent pipe or clogging of drain field occurs, the additional space in the tank accommodates influent until the defect is corrected. If the defect is not corrected then sewage will back up into the house. The reserve space should be such that it will take the tank about one full day to fill up the extra space so that there will be adequate time to effect repairs. Considering that, one day detention time is also allowed for the

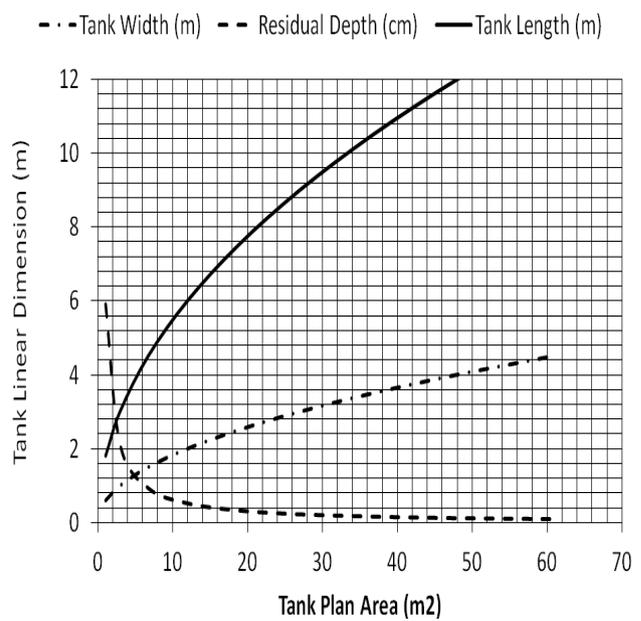


Figure 4: Tank dimensions and residual depth for simple house connection, pour flush ($Q = 0.064\text{m}^3/\text{capita}/\text{day}$) and $L = 3w$.

residual depth, hence, volume of the reserve space is equal to the residual volume.

$$h_{re} = h_{rev} \quad (8)$$

Where h_{re} = residual volume and h_{rev} = reserve space or volume

2.3. Sludge depth

For any reasonable design of the septic tank to be undertaken, sludge accumulation rate must be considered. This will help in determining the volume of the tank as well as desludging interval. In this design approach, the sludge accumulation model developed by [11] will be adopted.

$$V_{septage} = 0.043 + 0.021t - 0.56(e^{-0.11t} - 1) \quad (9)$$

$V_{septage}$ = volume of sludge and scum (m^3), A = plan area of septic tank (m^2) and t = number of years of operation.

2.4. Design procedure

The new design approach has been presented in three different packages to suit the designers fancy and level of education. The three aspects are

- Use of Equations 1, 8 and 9 (for the learned designer),

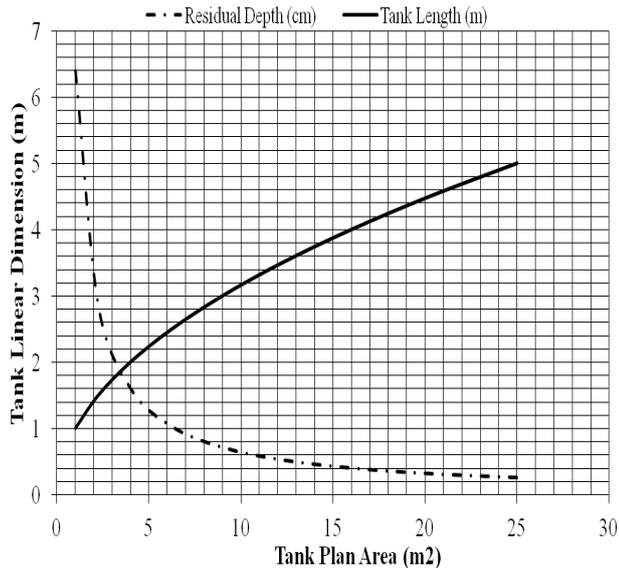


Figure 5: Tank dimensions and residual depth for simple house connection, pour flush ($Q = 0.064\text{m}^3/\text{capita}/\text{day}$) and $L = w$.

- Use of charts which will be presented shortly (for anyone),
- Use of simple Microsoft Excel based programme (for the computer literate designer).

2.4.1. Use of Equations 1, 8 and 9

A good septic tank design must fix a minimum residual detention time at which it becomes necessary to desludge the tank. Many standards usually specify 24 hours. Also, based on Equation 1, a minimum residual depth per occupant (h_{re}) corresponding to the chosen *residual detention time* should also be specified. The overall residual depth (H_{re}) is the product of the residual depth per occupant and the number of occupants. For good design and for practical purposes, the value of the overall residual depth should not be less than 10cm and not more than 75cm. This is because too low residual depth will cause the wash out of sludge and also interfere with inlet and outlet fittings while too high residual depth will result in a tank with very low length to depth ratio which will be inefficient. Narrow tanks have been found to provide quiescent hydraulic conditions which favour settling and thus solids removal. Then using Equation 1, the plan area of the tank is determined. A desired desludging interval is chosen and then Equation 9 is used to

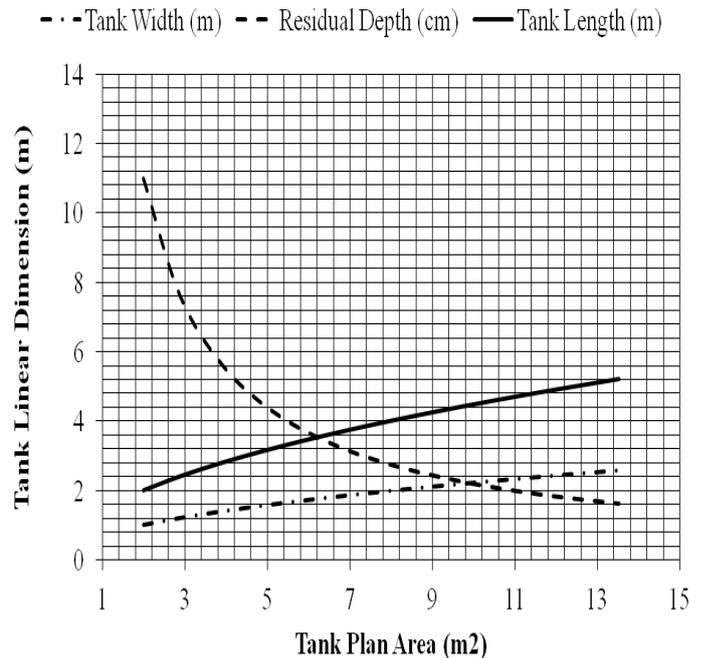


Figure 6: Tank dimensions and residual depth for full house connection, urban with garden ($Q = 0.22$) and $L = 2w$.

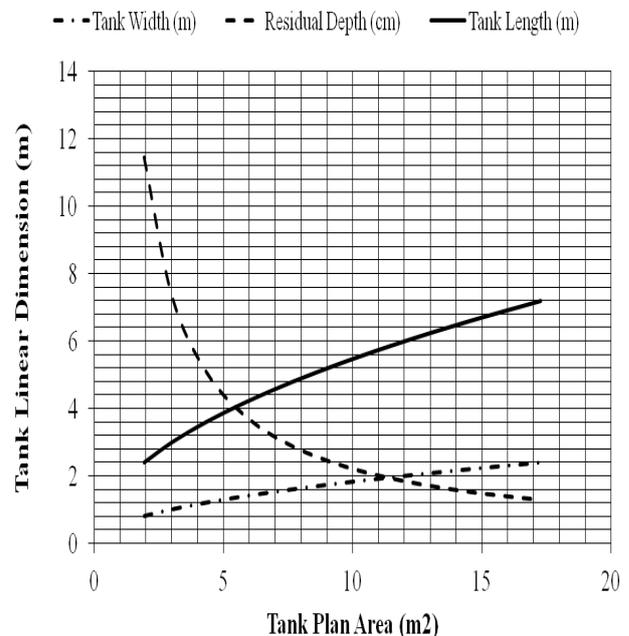


Figure 7: Tank dimensions and residual depth for full house connection, urban with garden ($Q = 0.22$) and $L = 3w$.

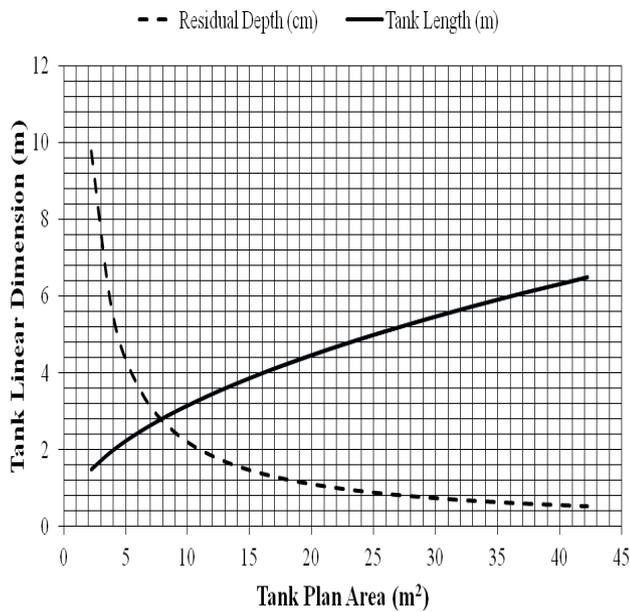


Figure 8: Tank dimensions and residual depth for full house connection, urban with garden ($Q = 0.22$) and $L = w$.

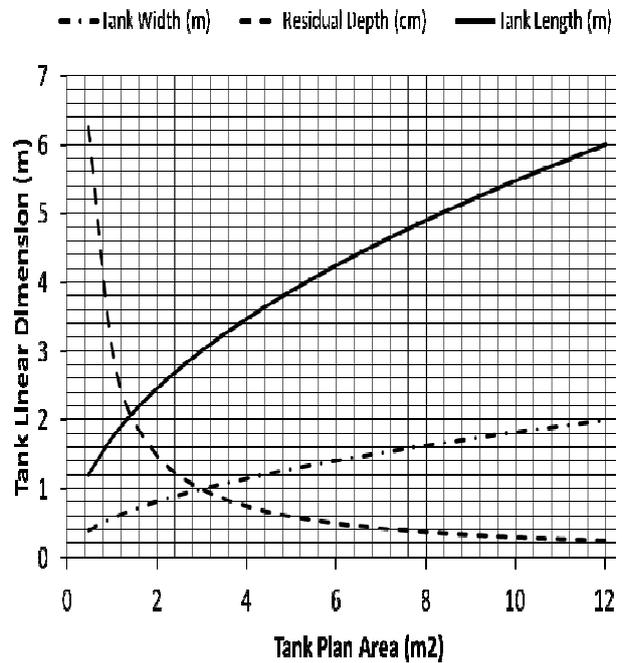


Figure 10: Tank dimensions and residual depth for Nigerian average, urban areas without pipe borne water ($Q = 0.03$) and $L = 3w$.

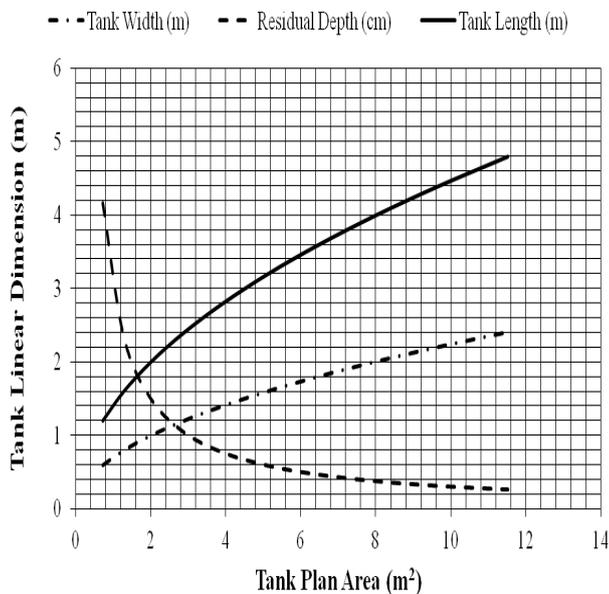


Figure 9: Tank dimensions and residual depth for Nigerian average, urban areas without pipe borne water ($Q = 0.03$) and $L = 2w$.

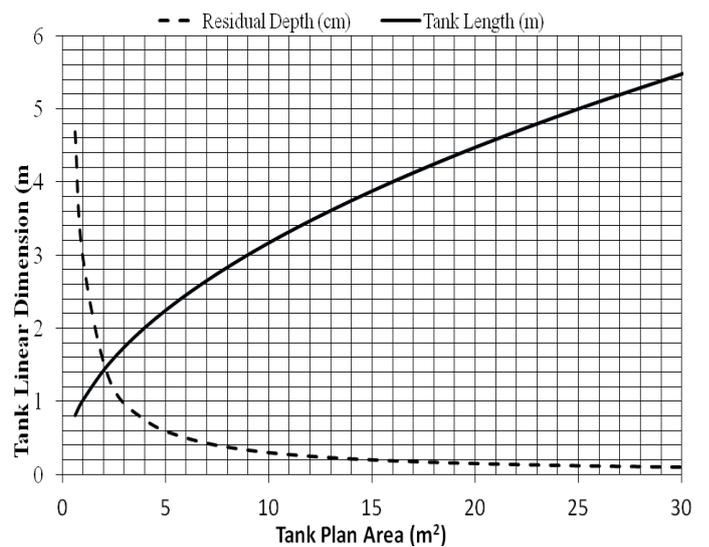


Figure 11: Tank dimensions and residual depth for Nigerian average, urban areas without pipe borne water ($Q = 0.03$) and $L = w$.

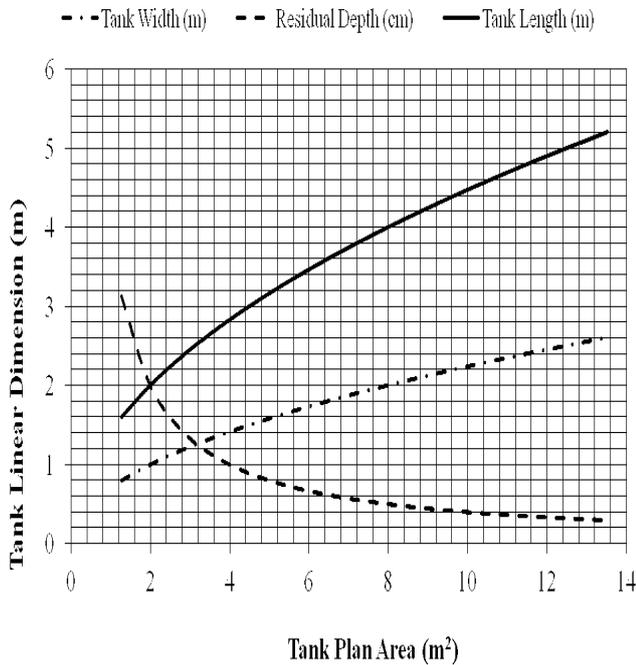


Figure 12: Tank dimensions and residual depth for basic water requirement ($Q = 0.04$) and $L = 2w$.

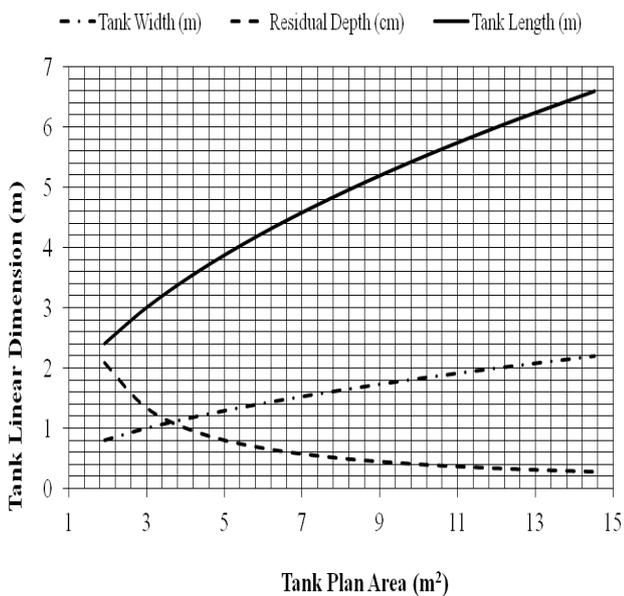


Figure 13: Tank dimensions and residual depth for basic water requirement ($Q = 0.04$) and $L = 3w$.

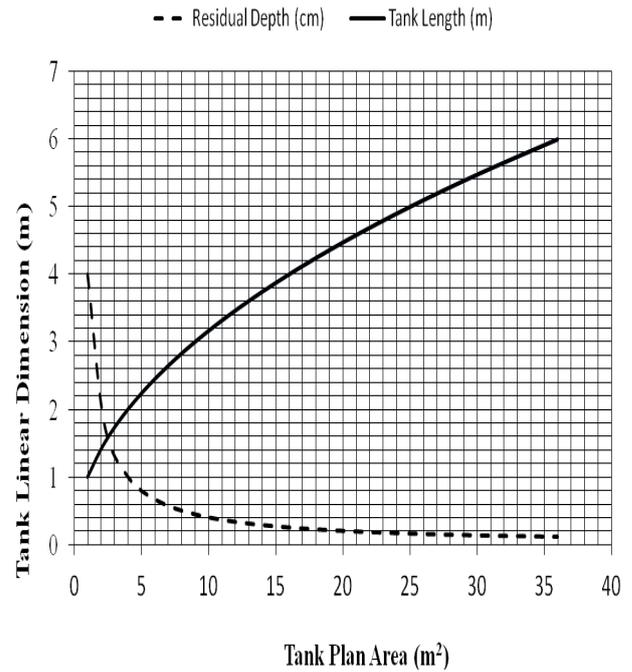


Figure 14: Tank dimensions and residual depth for basic water requirement ($Q = 0.04$) and $L = w$.

determine the volume of sludge that will accumulate in that period of time. The depth of sludge in the tank at this time is then obtained by dividing the volume of accumulated sludge with the plan area obtained as described above. The total depth of tank is obtained as the sum of sludge depth, the residual depth and the depth of the reserve space. The reserve space should correspond to a volume of 24 hours detention time. Finally a ratio of length to width is chosen and hence, the length and the width can be determined. The length should always be longer than the width to provide for quiescent conditions.

2.4.2. Use of charts

The steps described above have been translated into a series of charts using the relevant equations and covering as many scenarios as possible (see Figures 1 to 14). The overall residual depth is chosen and the residual depth per occupant (horizontal axis) corresponding to the number of occupants to use the septic tank is read off on the vertical axis of Figure 2. The residual depth per occupant obtained is located on the vertical axis of Figures 3 to 14 depending on the length to width ratio chosen. Figures 3 to 13 have been produced to cover cases where length to width ratio is equal to 1, 2 and 3 as well as different wa-

ter availability conditions. Figures 3 to 5 are for simple house connections where toilet is flushed by pouring with buckets. Figures 6 to 8 are for full house connection with adequate water supply conditions. In this case, the shower, the sink taps, the water closet and kitchen connections are in full service. Figures 9 to 11 are for an average Nigerian house located in an urban area where water is purchased from commercial water suppliers. Figures 12 to 14 are for the basic water requirement. Here, water is not in abundance but is sufficient to meet basic needs. The residual depth per occupant is then traced horizontally to meet the residual depth per occupant curve. From this point, the line is produced vertically to cut the length and width curves as well as the horizontal axis which represents the area of the tank. The length and width are noted. The volume of sludge corresponding to the desired (chosen) desludging interval is obtained from Figure 1. The depth of sludge is obtained by dividing the volume of sludge by the plane area read off from Figures 3 to 14. The total depth of tank becomes the sum of sludge depth, overall residual depth and depth of reserve volume. The depth of the reserve space should be equal to the residual depth since it is based on 24 hours detention time. If the overall depth of the tank is much higher than the length, a lower overall residual depth should be chosen and the design repeated.

2.4.3. Use of simple MS Excel based programme

A simple Microsoft Excel programme has been written to aid quick and easy sizing of the septic tank. All the relevant mathematical relationships have been coded into cells in Ms Excel worksheet; and all the user needs to do is to enter the desired desludging interval, wastewater flow per capita per day and number of occupants. Immediately this is done Excel will automatically produce a series of tank sizes corresponding to the chosen desludging interval and number of occupants based on different residual depths. The designer does not need to write a fresh programme, neither can he modify the codes in this programme because the cells containing formulae have been protected to prevent modification. However, the cells for receiving input have been clearly distinguished and are not protected. All the designer needs to do is to use engineering judgement to

select the appropriate dimensions. However, in order to aid the designer who might get confused as to which dimension to choose, a conditional formatting has been performed on the depth row such that Excel highlights all the tank dimensions whose depths are less than the length but greater than the width. It should be noted that all the tanks whose dimensions are generated by this programme for a specified desludging interval, flow rate and number of occupants will have the same volume and require desludging at the same time. However, it has been established that narrower tanks enhance solids removal.

3. Sample Design Problem

In order to demonstrate the use of the design approach developed in this research, a design example shall be presented using the three packages. Consider a building that will accommodate 15 people in a typical Nigerian middle class city, say Enugu. It is required to construct a septic tank that will require desludging once every five years.

3.1. Solution using Equations 1, 8 and 9

$Q = 0.03 \text{ m}^3/\text{capita}/\text{per day}$ (based on UNDP average Nigerian water use), $t = 5$ years.

First determine the volume of septage accumulated in five years using equation 9, where $t = 5$. Substituting $t = 5$ in the equation, we obtain $V = 0.384\text{m}^3$ per capita. Hence the total volume of sludge accumulated is $0.384 \times 15 = 5.76\text{m}^3$. Next, we use Equation 1 to obtain the plan area of the tank. Equation 1 is for one occupant, so for N occupants, the overall residual depth (H_{re}) = $Nh_{re} = \frac{NQ\theta_{re}}{A}$. Using a minimum residual detention time of 24 hours (1 day) and an overall residual depth of 15cm, and substituting in the above equation, we obtain the plan area as: $A = 3.0\text{m}^2$.

Hence the depth of sludge is obtained as

$$y = \frac{V}{A} = 1.92\text{m}$$

Total depth of tank = depth of sludge + residual depth (h_{re}) + depth of reserve space (h_{rev}). But previously, it has been shown that $h_{re} = h_{rev}$. Hence total depth (D) of tank = $y + 2h_{re} = 1.92 + 2 \times 0.15 = 2.22$. Finally, a suitable length to width

ratio is chosen. For this design, let $L/w = 2$. Hence $w = \sqrt{A/2} = \sqrt{3/2} = 1.22\text{m}$ and $L = 2.5\text{m}$.

The tank dimension is $2.5\text{m}(\text{length}) \times 1.2\text{m}(\text{width}) \times 2.2\text{m}(\text{depth})$ for a desludging interval of 5 years, a minimum residual detention time of 24 hours and a minimum residual depth of 0.15m . For a large population, the design dimensions may become excessive. When this is the case, two septic tanks or more should be designed or the desludging interval may be reduced.

3.2. Solution using charts

First, an overall residual depth per occupant is chosen. In the preceding solution, the overall residual depth was taken as 15cm (0.15m). The population (15) is located on the horizontal axis of Figure 2. From here, a vertical line is drawn to meet the curve for 0.15m overall depth (see Figure 15). The residual depth per occupant (h_{re}) is 1cm .

Next choose a suitable length to width ratio, and as before let $L/w = 2$. Hence we locate 1cm on Figure 9 (chart for Nigerian average water use and $L = 2w$) and draw a horizontal line to meet the residual depth per occupant curve. From this point, the line is extended vertically upwards and downwards to meet the length and depth curves as well as the area (horizontal) axis (see Figure 16).

From Table 3, $L = 2.4\text{m}$, $w = 1.2\text{m}$ and $A = 3\text{m}^2$. The depth of sludge is obtained by dividing the volume of sludge obtained from Figure 4.31 with the area obtained. The total volume of sludge $= 0.265 \times 15 = 5.76\text{m}^3$, hence the depth of sludge (y) $= 5.76/3 = 1.92\text{m}$. Finally, the total depth of tank (D) $= y + 2 \times 0.15 = 1.92 + 0.3 = 2.22\text{m}$. The tank dimension is 2.4m (length) $\times 1.2\text{m}$ (width) $\times 2.2\text{m}$ (depth) for a desludging interval of 5 years, a minimum residual detention time of 24 hours and a minimum residual depth of 0.15m . The slight differences between these dimensions and those previously used stemmed from the interpolation and reading errors inherent in the use of graphs. However, for all intents and uses, the two tanks are practically the same.

3.3. Solution using Excel code

This is the simplest and most straightforward of the three approaches. The only values required to be entered are wastewater flow Q

($\text{m}^3/\text{capita}/\text{day}$), suitable desludging interval in years (Excel converts it to days before using it to compute), the number of occupants and the desired length to width ratio. As can be seen from Table 3, tank dimensions corresponding to overall residual depths from 0.1m to 0.75m will automatically be generated so that the designer can make a pick. For a residual depth of 0.15m (used in two previous approaches), the corresponding tank dimensions are 2.45m (length), 1.22m (width) and 2.07m (depth) to two decimal places. Any other suitable dimensions can also be chosen from the array of results.

Hence the tank dimension is 2.5m (length) $\times 1.3\text{m}$ (width) $\times 2.1\text{m}$ (depth) for a desludging interval of 5 years, a minimum residual detention time of 24 hours and a minimum residual depth of 0.15m .

4. Advantages of the Design Approach

This method developed in this study has the following advantages.

- Desludging will not be frequent and hence the cost of maintenance will be reduced.
- Occupants will have an idea when to expect the tank to require desludging.
- At desludging, the septic tank will still be performing within acceptable limits by maintaining a minimum residual detention time of 24 hours.
- Under sizing, which is very critical, will be averted.
- The soakpit or drain field (whichever is applicable) will be protected since the carry-over of sludge into these units will be reduced.
- The life span of the whole septic tank system will be prolonged.

5. Conclusion and Recommendation

The method developed in this study is based on specifying a desired desludging interval, a minimum residual detention time and a residual depth. This approach ensures that the septic

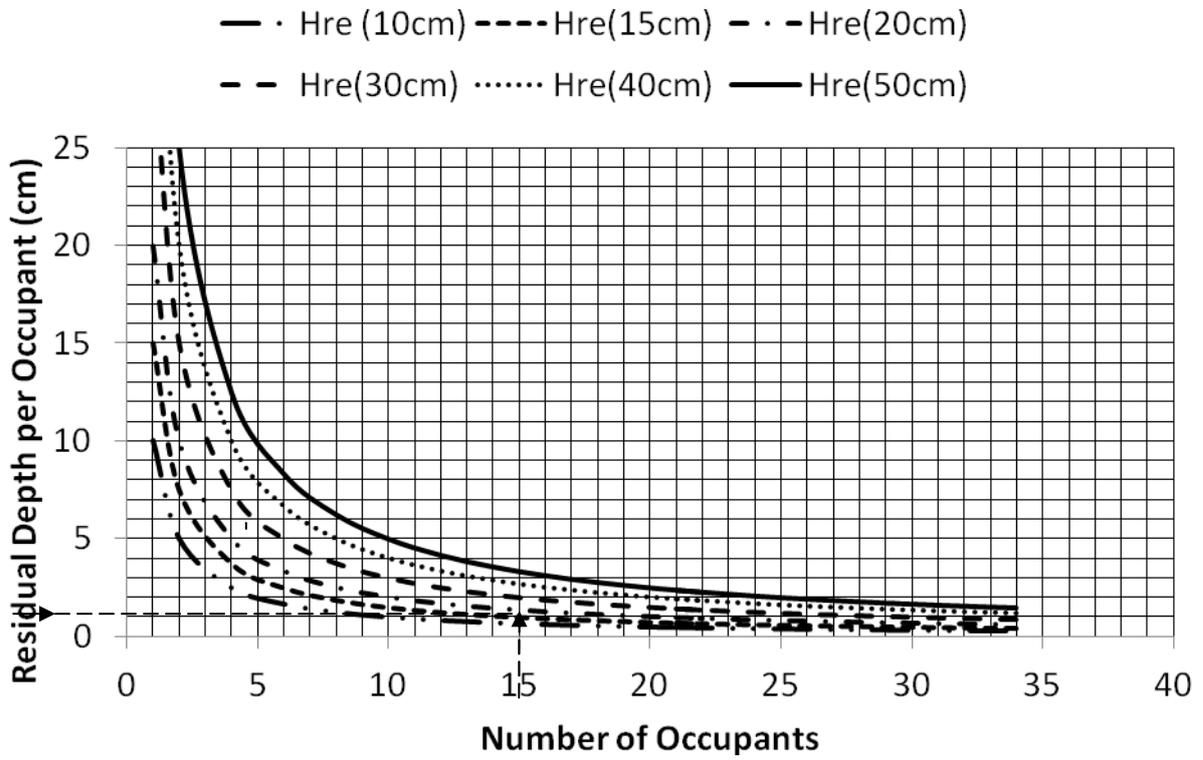


Figure 15: Determination of residual depth per occupant using charts.

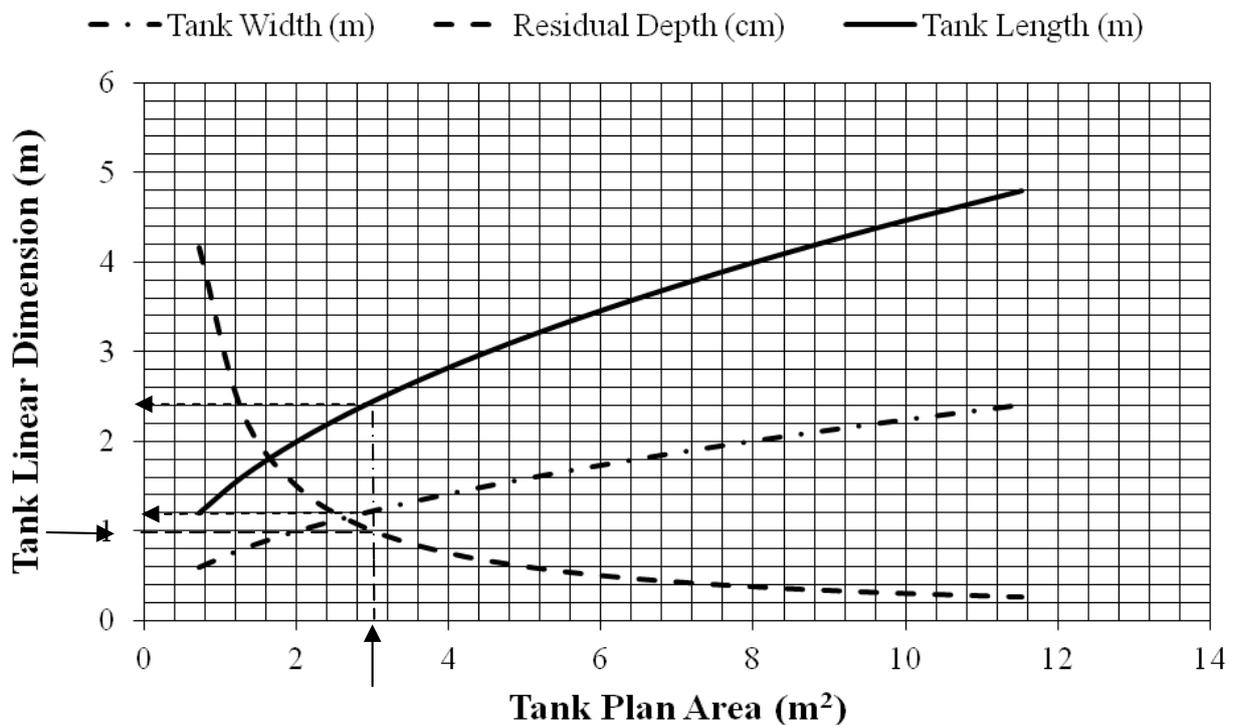


Figure 16: Determination of tank dimensions using charts.

Table 3: Tank design using Excel codes.

H _{re}	h _{re}	Plan Area(m ²)	Sludge Depth(m)	Depth(m)	Width(m)	Length(m)	Volume(m ³)
0.1	0.006667	4.5	1.283027	1.383027	1.5	3	6.223622
0.15	0.01	3	1.924541	2.074541	1.224745	2.44949	6.223622
0.2	0.013333	2.25	2.566054	2.766054	1.06066	2.12132	6.223622
0.25	0.016667	1.8	3.207568	3.457568	0.948683	1.897367	6.223622
0.3	0.02	1.5	3.849081	4.149081	0.866025	1.732051	6.223622
0.35	0.023333	1.285714	4.490595	4.840595	0.801784	1.603567	6.223622
0.4	0.026667	1.125	5.132108	5.532108	0.75	1.5	6.223622
0.45	0.03	1	5.773622	6.223622	0.707107	1.414214	6.223622
0.5	0.033333	0.9	6.415135	6.915135	0.67082	1.341641	6.223622
0.55	0.036667	0.818182	7.056649	7.606649	0.639602	1.279204	6.223622
0.6	0.04	0.75	7.698162	8.298162	0.612372	1.224745	6.223622
0.65	0.043333	0.692308	8.339676	8.989676	0.588348	1.176697	6.223622
0.7	0.046667	0.642857	8.981189	9.681189	0.566947	1.133893	6.223622
0.75	0.05	0.6	9.622703	10.3727	0.547723	1.095445	6.223622

tank is desludged when it no longer has enough detention time for efficient performance. Every septic tank is unique and therefore should be designed taking cognisance of the number of users, desired desludging interval and expected wastewater flow which is a function of water availability. Users should always know when to expect to desludge their tanks. This should be an intrinsic aspect of the design. Septic tanks should have enough initial volume for long term storage of sludge to avoid frequent desludging. Tanks with small initial volumes soon get silted up with sludge thus requiring frequent desludging. People should not wait for their septic tanks to be overflowing with sludge before desludging as this reduces the life span of the whole system and also reduces the efficiency of the drain field or soak pit.

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