SAND FILTER SYSTEM: A MEANS FOR SOLVING DOMESTIC SEWAGE DISPOSAL PROBLEMS IN RIVERINE AREAS

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ABSTRACT

The relative effectiveness of the "Soak-away pit" system and the "Sand-filter" system in the disposal of domestic waste in the riverine area of the Niger Delta has been investigated as presented in this paper. This investigation was prompted by observed proliferation of the soak-away pit system with attendant environmental pollution problems in many Niger Delta communities witnessing rapid urbanisation. In many instances inappropriately disposed sewage has contaminated both the soil and the underground water harnessed for drinking, and also destroyed the aquatic life of streams especially where the waste found its way into such water bodies. Field and laboratory test results indicate that the soil underlying the area is silty Clay with a low acceptance rate (5.21litres/m^2/day), low percolation rate (218 min/100mm), high ground water table and, in most cases, prone to flooding above grade level in the rainy season. These parameters indicate that the soil is semi-impervious and hence the soak-away pit system would be of very low efficiency in the domestic waste disposal in this area. The "Sand-filter" system, on the other hand, is portrayed by the results as having a high potential of providing the required treatment capacity for the type of soil underlying the area and is therefore efficacious for domestic sewage disposal in this deltaic environment. The "Sand-filter" system is therefore recommended in preference to the "Soak-away" since the soil properties revealed by the test programme cannot allow a satisfactory post-construction performance of the soak-away pit system of domestic sewage disposal.

1.0 INTRODUCTION

The Soak-away pit system of disposing domestic sewage is a common practice in Nigeria. In this method, the domestic sewage from an individual residence is piped into an underground septic tank and allowed to settle to form sludge at the bottom. The effluent (liquid waste) is discharged into an adjoining soak-away pit from where it is absorbed into the subsoil through the side openings (Obande, 1983; Jerus, 1983; Metcalf and Eddy, 1995; and Henry and Heinke, 1996).

With urbanization and improved condition of living, there has been proliferation of the soak-away pit system with attendant environmental pollution problems. The environmental pollution arises from inappropriate disposal of the domestic sewage through the soak-away pit system. The inappropriately disposed sewage contaminates both the soil and the underground water harnessed for drinking, and also destroys the aquatic life of streams especially where the waste finds its way into such water bodies.

As public awareness on environmental pollution grows, the effect of wastes released from burst septic tanks and soak-away pits in polluting land, streams and air becomes a serious concern to public health and environmental managers. The effort to solve the problems brings to focus the issue of selection and design of domestic sewage disposal systems that will be appropriate for various types of soil. This is because the performance of a particular system may be satisfactory in a given soil medium but not suitable for another type of soil with different geotechnical and hydro-geological characteristics. Therefore, for any disposal system to be effective in terms of cost, efficiency and durability, its selection and design should meet some design criteria, specified in terms of such parameters as flow-rate, soil type (as indicated by moisture content and gradation), groundwater table, soil porosity, acceptance rate of soil and percolation rate of the effluent in the soil.

These parameters have been exhaustively discussed by previous researchers. According to Lui and Evett (1990), moisture content has been established to be an indicator of the average amount of water present in the soil. In the same vein, Jackson and Dahir (1996) conclude that soil porosity indicates the proportion of the total volume of the soil that is not occupied by solid constituents. Soil gradation is defined by Bowles (1982) and Lui and Evett (1990) as a soil identification and classification index which is also used in the evaluation of soil stability and for other specific applications. The groundwater table delineates the depth below ground surface of the upper limit of the zone of saturation where the water is free to move or flow under gravity (Bowles, 1984). The flow rate is generally well-known, and represents the quantity (in litres) of domestic sewage generated per person per day. It is used extensively in the determination of the size of domestic sewage systems. Metcalf and Eddy (1995) define acceptance rate of soil as an indicator of the ability of the soil to absorb or assimilate water. They further explain that this parameter is generally used to estimate the amount of water that can be transported away from the sewage disposal system. Based on their findings in the same research work, they state that percolation rate (relative absorption) of soil is the rate at which water moves through soil in operational effluent disposal systems.

1.1 Definition of the Problem

There is a general assumption that the soak-away pit system of domestic sewage disposal is always very appropriate. Sometimes it is even ranked above other methods like the disposal field bed (field tiles) and the sand filter systems. As a result, the soak-away pit is generally used for domestic sewage disposal irrespective of the soil type. This practice is widespread despite the shortcomings of the system as stated by Jerus (1983). According to him, the system cannot be used in soils rated as semi – impervious, and in soil deposits where the water table is not at least 2.4m below grade level or 600mm below the bottom of the soak-away pit. He is also of the view that the system should not be located within 30m of portable water supply or within 5m of the building it serves.

This assumption on the appropriateness of the soak-away pit system is as a result of limited engineering and scientific information available with regard to other types of domestic sewage disposal systems such as field bed and sand filter. Presently however, extensive background data are available showing that disposal systems that are not suitable for a particular soil type may nevertheless be effective for the disposal of domestic sewage in other soil types.

In Nigeria, the effective disposal of domestic sewage has become an important issue both in terms of public health and good environment. Consequently, an assessment of the relative effectiveness or otherwise of the soak-away pit system in the riverine communities, with their peculiar geographical terrain, is deemed necessary.

2.0 FIELD SURVEY AND DATA COLLECTION

2.1 Description of study area

The study site is the Bayelsa State Housing and Property Development Authority's Housing Estate, Azikoro Road, Ekeki, Yenagoa, shown in Fig 1. The estate consists of 152 plots of land, each measuring 38m x 30m ($1140m^2$). Each plot has a four-bedroom detached bungalow building with a floor area of $228m^2$ and occupies about 22% of the plot. These details are contained in Fig 2. According to Amasuomo, (1983) and Mekinwa (2000), the population of the estate is 1064 persons, made up of members of 152 residential families, with an average family size of seven, comprising the father, the mother and five children per family unit.

2.2 Data Collection

In order to accomplish the task stated above in the problem definition, data were collected on moisture content, porosity, gradation, ground water table, acceptance rate and percolation rate of the soils of the study area. These soil properties were targeted because of their perceived characteristic influence on the selection and design of domestic sewage disposal systems.

Moisture content was determined from a representative soil sample of about 1000g collected during the dry and wet seasons, while the gradation was obtained using a representative soil sample obtained from a trial pit. The determination of the soil porosity was achieved using a representative sample of soil with a volume of about $1000cm^3$. The ground water table, on the other hand, was determined by drilling a well of 600mm diameter into the water-bearing formation and measuring directly by means of a measuring tape.

The acceptance and percolation (relative absorption) rates of the soil were obtained from field tests conducted in the study area, which yielded data employed in their calculation. The flow rate, as stated earlier, was evaluated in terms of the quantity (in litres) of domestic sewage per person per day.

Table 1: Summary of results of data analysis

Assessed parameters	Results and/or observations	Recommended Value	Remarks
Flow rate for a family unit (7 persons)	1210 litres/day	As calculated	Used for computing size of sewage system
Moisture content (average value)	72%	< 50%	Result indicates high moisture content and low water absorption. Soil not suitable for soak-away pit system.
Porosity	0.49	<0.49	High porosity and low permeability soil. Not suitable for soak-away pit system.
Gradation analysis of	Above 0.074mm: 15.6%	0.074mm to 2mm	Result indicates silty

soil	Below 0.074mm: 84.4% Classification: silty Clay.	(Coarse to fine Sand, silty Sand to dirty Sand)	Clay soil. Therefore not suitable for soak-away pit system.
Groundwater table below grade level: (i) Dry season (ii) Wet season (iii) Flooding	Observations: 2.0m - 3.0m. 0.15 - 0.3m. Up to 0.5m above grade.	2.4m below grade level or 600mm below bottom of soak-away pit	High water table. Not suitable for soak-away pit system.
Percolation rate (Average value)	218 min/100mm	$\leq$ 118min/100mm	Result Indicates semi-impervious soil such as silty Clay. Not suitable for soak-away pit system.
Acceptance rate	5.21 lit/m^2/day	$\geq$ 8 lit/m^2/day	Not suitable for soak-away pit.

3.0 RESULTS AND DISCUSSION OF FINDINGS

The results of the analysis of data collected in this study are presented in table 1 above. From the results, the moisture content of 72%, obtained as average value for the dry and wet seasons, is an indication that the soil is of high water content and low water absorption. These features are not suitable for the soak-away pit system (Metcalf and Eddy, 1995; and Jerus, 1983).

The result of the gradation analysis – the preponderance of soil grains of less than 0.074mm diameter – indicates that the soil is silty Clay. This soil type is associated with a characteristic low permeability and therefore not suitable for soak-away pit system. This is despite the relatively appreciable porosity value of 0.49 because a fine-grained soil generally has little or no permeability. This low permeability is primarily owing to the small and narrow size of the pore throats, with their associated flow-inhibiting surface tension forces, typical of fine-grained soils. A suitable soil type should have a grain size range between 0.074mm and 2mm, which is considered normal for coarse to fine Sand; and silty Sand to dirty Sand (Henry and Heinke, 1996; and Metcalf and Eddy, 1995).

The ground water table (GWT) during the rainy season is between 0.15mm and 0.30mm below grade level and in some cases flooding of between 0.10m and 0.5m above grade level. During the dry season however, the GWT drops to between 2.0m and 3.0mm below grade level. This relatively high GWT creates absorption problems for any soak-away disposal system.
The average percolation rate of the soil was 218min/100mm which is greater than the acceptable value of 118min/100mm. This also makes the soak-away pit system unsuitable.
The acceptance rate of 5.21 lit/m^2/day was less than the recommended value of 8 lit/m^2/day and above. It also indicates the non-suitability of the soil for soak-away pit system.

4.0 SELECTION / DESIGN OF APPROPRIATE DISPOSAL SYSTEM

4.1 Selection of disposal system

The findings and results of data analysis summarised in table 1 of the previous section have indicated that all the parameters required for a suitable soak-away pit system were not obtainable at the study site. This narrows the selection of appropriate system to either the field disposal or the sand filter system. However, the field disposal system is also not suitable because the available land space is limited, while the soil is semi-impervious with high ground water table. As a result, the sand filter system is chosen as the most suitable in line with the views of Metcalf and Eddy (1995), and Cooke (1994).

4.2 Design of the Sand Filter disposal system

Details of the criteria and specifications for the design of the sand filter system have been summarized as presented in Table 2 below. These are in the form of specific parameters considered appropriate for achieving optimum performance of the system in domestic sewage disposal.

Table 2: Design Criteria and Specifications for Sand Filter System

Parameters	Recommended specification
Peak factor (P_f)	4
Flow rate (F_r) for 7 persons	1210 lit/day
Main and under drain pipe size	100mm diameter
Lateral pipe size	50 mm diameter
Orifice size (lateral pipes)	3mm
Orifice size (under drain pipes)	12mm
Orifice spacing	600mm
Orifice discharge head (h_n)	1.5m
Lateral pipe spacing	1.2m
Hydraulic loading (H_L)	24 lit/m^2/day
Difference in discharge between the first and last orifice	$\leq 2\%$

4.3 Detail Design/Calculations

The design of sand filter involves the determination of the following:

1. **Area of Sand Filter (A_s)**

$$A_s = \frac{F_r}{H_L} = \frac{1210 lit/d}{24 lit/m^2/d} \qquad - \qquad (1)$$

$$\approx 50m^2$$

Therefore recommended size of sand filter according to space available in the case study site is 54m^2 (10,000mm x 5,400mm).

2. Layout of Effluent Distribution System.

From the computed value of the area of the sand filter (10.0 x 5.4) m^2, and the parameters in table 2, the layout recommended shall consist of 16 laterals of 2.1m long on each side of the main pipe and four orifices equally spaced at 600mm centres on each lateral (Fig 2).

3. Flow Discharge per Lateral (F_L)

$$F_L = \frac{Flowrate(F_r)}{NumberofLaterals(L_n)} \qquad (2)$$

$$= \frac{1210L/d}{16Laterals} = 76 \text{ lit/day/lateral}$$

4. Flow rate in the Last Orifice (q_n)

$$= 8.9CD^2\sqrt{2gh_n} \qquad (3)$$

Where q_n = Discharge from orifices in litres per second.

8.90 = Conversion factor, where discharge is expressed in m^3/sec, diameter of orifice in mm, and velocity in m/s.

C = Orifice discharge coefficient for holes drilled in the field (0.61).

D = Diameter of orifice (3mm).

g = Acceleration due to gravity (9.81 m/s).

h_n = Orifice discharge head (1.5m).

n = Number of orifices per lateral (4No).

Therefore q_n = $8.90\ (0.61)(0.003)^2\sqrt{2 \times 9.81 \times 1.5}$

= $2.65 \times 10^{-4} m^3/s$ or 0.265lit/sec

5. Total flow in each lateral for 4 orifices per lateral

This is given by: n x 0.265 lit/sec

= 4x0.265 lit/sec.

= 1.06 lit/sec.

6. Head loss through pipes from orifice (h_{fp})

$$h_{fp} = 189.18\ (L_{1,n})\ (Q/C)^{1.85}\ D^{-4.87} \qquad (4)$$

Where h_{fp} = Actual head loss through pipes from L_1 to L_n (m)

$L_{1,n}$ = Effective length of lateral pipe (distance between first orifice,

L_1 and last orifice, L_n).

Q = Pipe discharge or total flow rate (1.06 lit/sec).

C = Hazen – William discharge coefficient (150 for plastic pipes).

189.18 = Conversion factor.

D = Diameter of orifice (3mm).

Therefore $h_{fp} = 189.18(2.4 - 0.3)(1.061/150)^{1.85}(0.003)^{-4.87}$

$= 0.058\text{m}$

7. Head loss in actual distribution pipe (h_{fdp})

$$h_{fdp} = 1/3\ h_{fp} \qquad - \qquad (5)$$

$= 1/3 \times 0.058\text{m}$

$= 0.019\text{m}$

8. Head loss in the first orifice (h_1)

$$= h_n + h_{fdp} \qquad - \qquad (6)$$

Where h_n = orifice discharge head (1.5m)

$h_1 = (1.5 + 0.019)\text{m}$

$= 1.519\text{m}$

9. Decimal value less than 1 (m)

$$m = \sqrt{\frac{h_n}{h_1}} \qquad - \qquad (7)$$

$$= \sqrt{(\frac{1.50}{1.519})} = 0.9937$$

Note: The calculated decimal value (m) of 0.9937 is above the critical value, 0.9800, below which the effectiveness of the sand filter system shall be affected. The m – value is also used to calculate the difference in discharge of treated effluent between the first and the last orifices in each lateral pipe.

10. Percentage Difference in discharge between the first and last orifices in each lateral (D_{dfl})

$$D_{dfl}\ (\%) = (1 - m) \times 100 \qquad - \qquad (8)$$
$$= (1 - 0.9937) \times 100$$
$$= 0.63\ \%$$

Comment: The value of 0.63% calculated above shows that the difference in time lag in the discharge of treated effluent between the first and last orifices in each lateral pipe is well below the specified maximum value of 2% (Metcalf and Eddy, 1995). The distribution system therefore does not require re-sizing and can effectively discharge the effluent for treatment in the sand filter system with a flow rate of 1210 lit/day and a peak factor of 4 for a residential unit for 7 persons.
The working drawings of sand filter are shown in Figs 3, 4 and 5.

5.0 SUMMARY AND CONCLUSION

The sand filter system has been determined to be suitable for soil described as "impervious with high ground water table" while the soak-away pit system was found to be suitable only for soils that indicated "rapid, medium or slow relative absorption and low ground water table". Because the soils in the riverine areas are predominantly of silty Clay type, which exhibits semi-imperviousness, the sand filter was selected as appropriate domestic sewage disposal system for the region.

The sand filter system has some significant advantages over the soak-away pit system in the effective treatment of domestic sewage onsite. These include the fact that it does not depend on low ground water table and the imperviousness of the soil. The soak-away pit system, on its part, can only provide some level of effluent treatment in dry season and little or no treatment in the wet season. In conclusion therefore, it can be stated that the sand filter system is the most appropriate for the study location.

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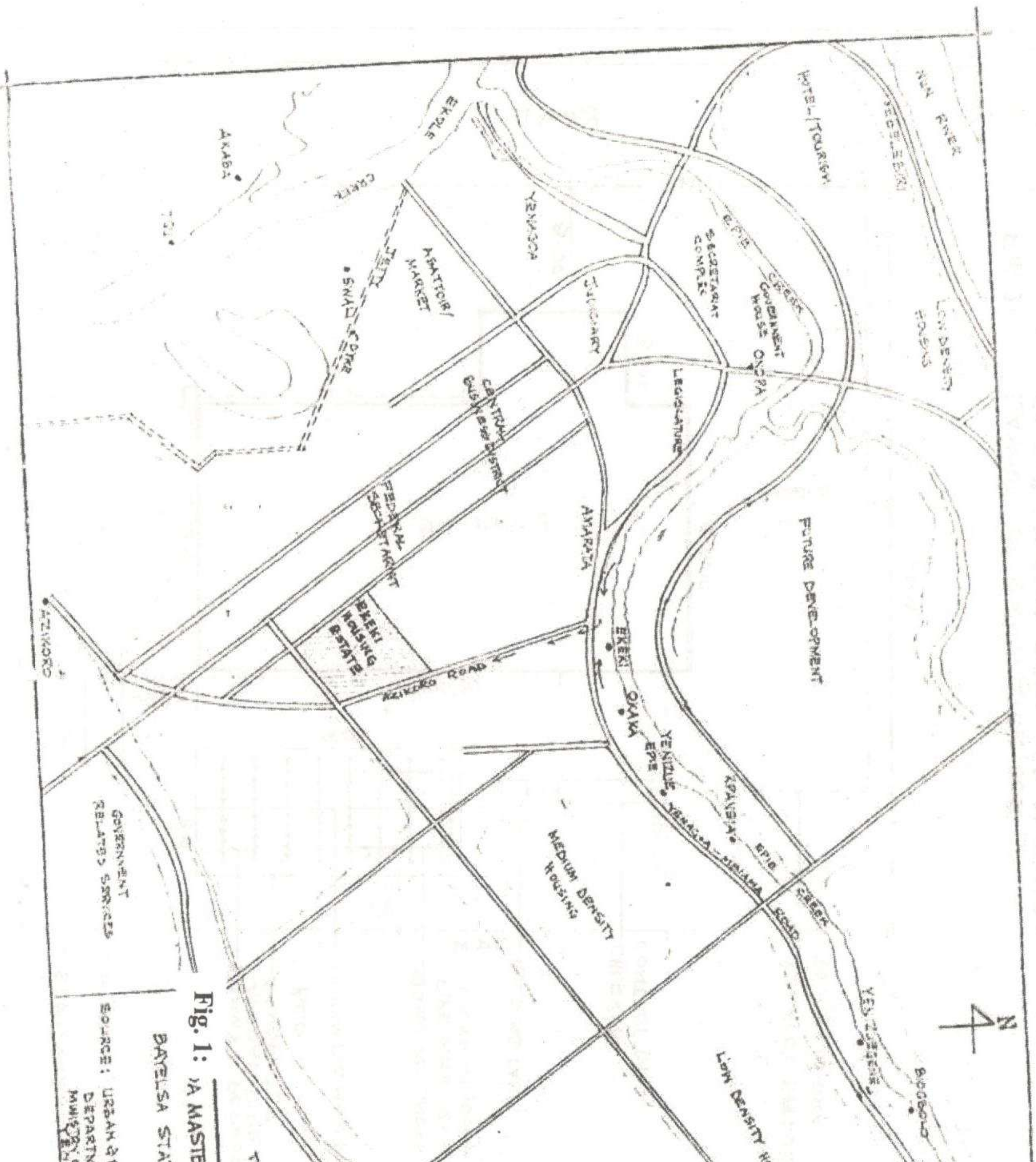

Fig. 1: A MASTER PLAN
BAYELSA STATE

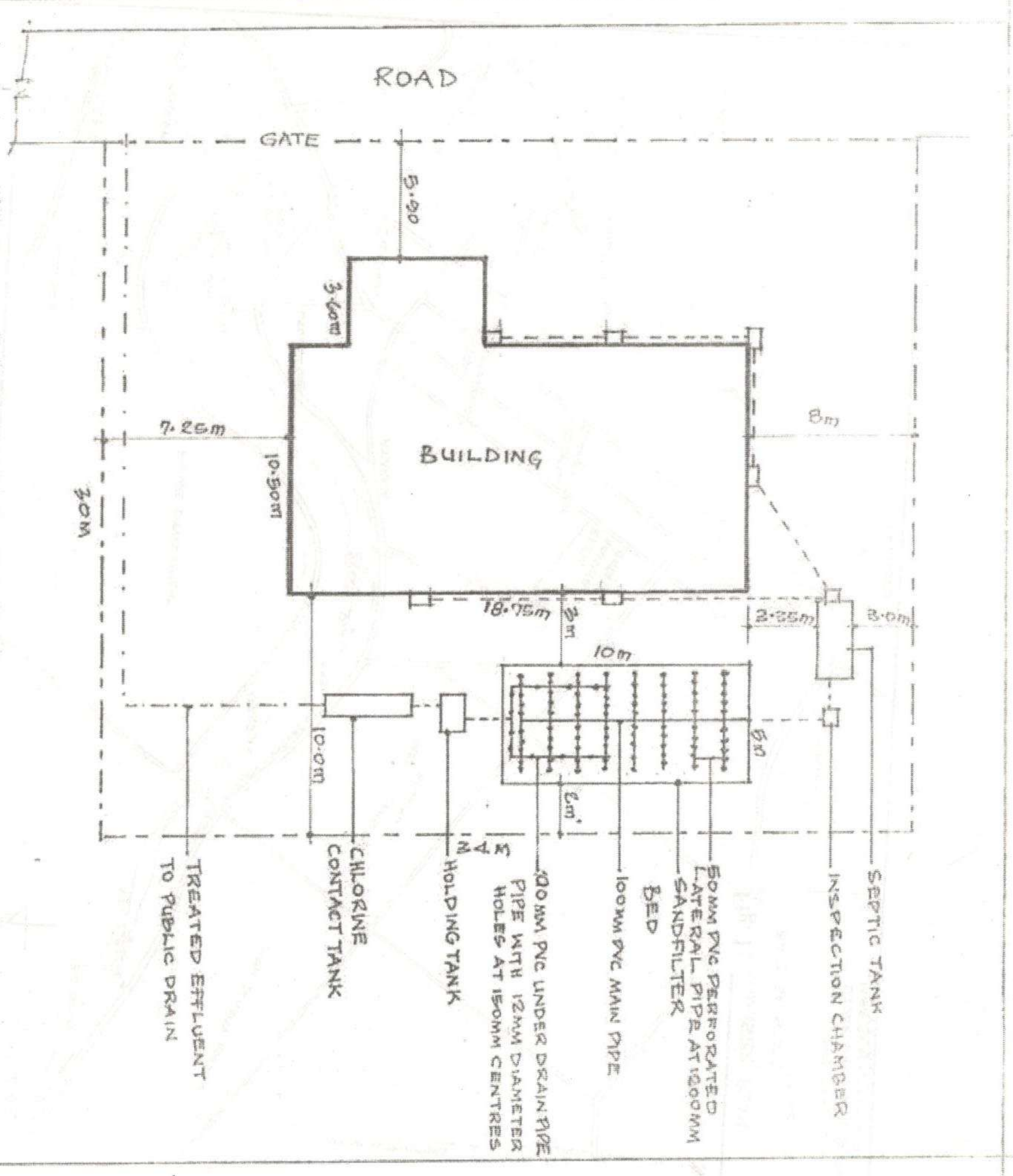

FIG. 2: LAYOUT OF SANDFILTER FOR FOUR-BEDROOMS DETACHED BUNGALOW

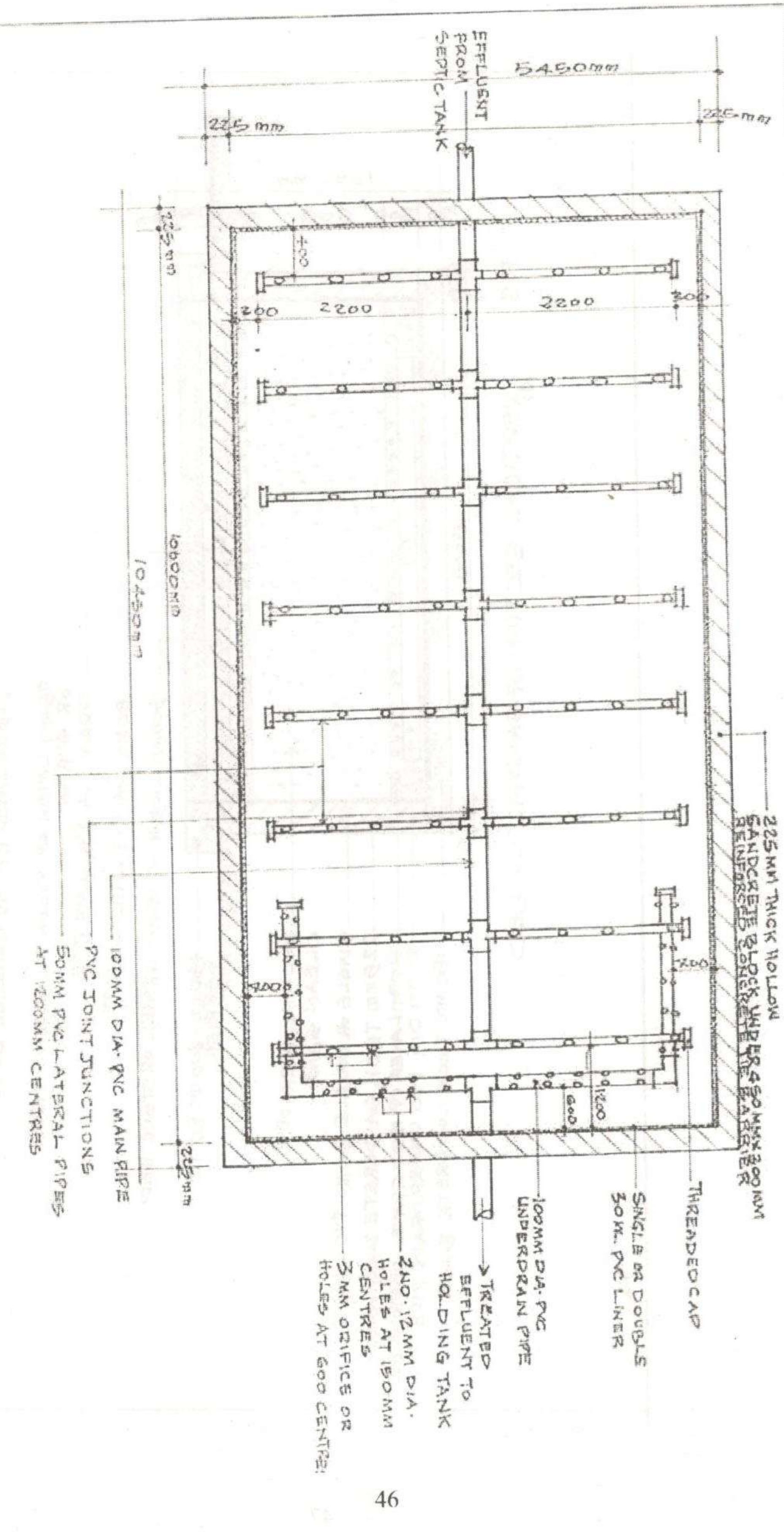

FIG 3: PLAN DETAILS OF SANDFILTER

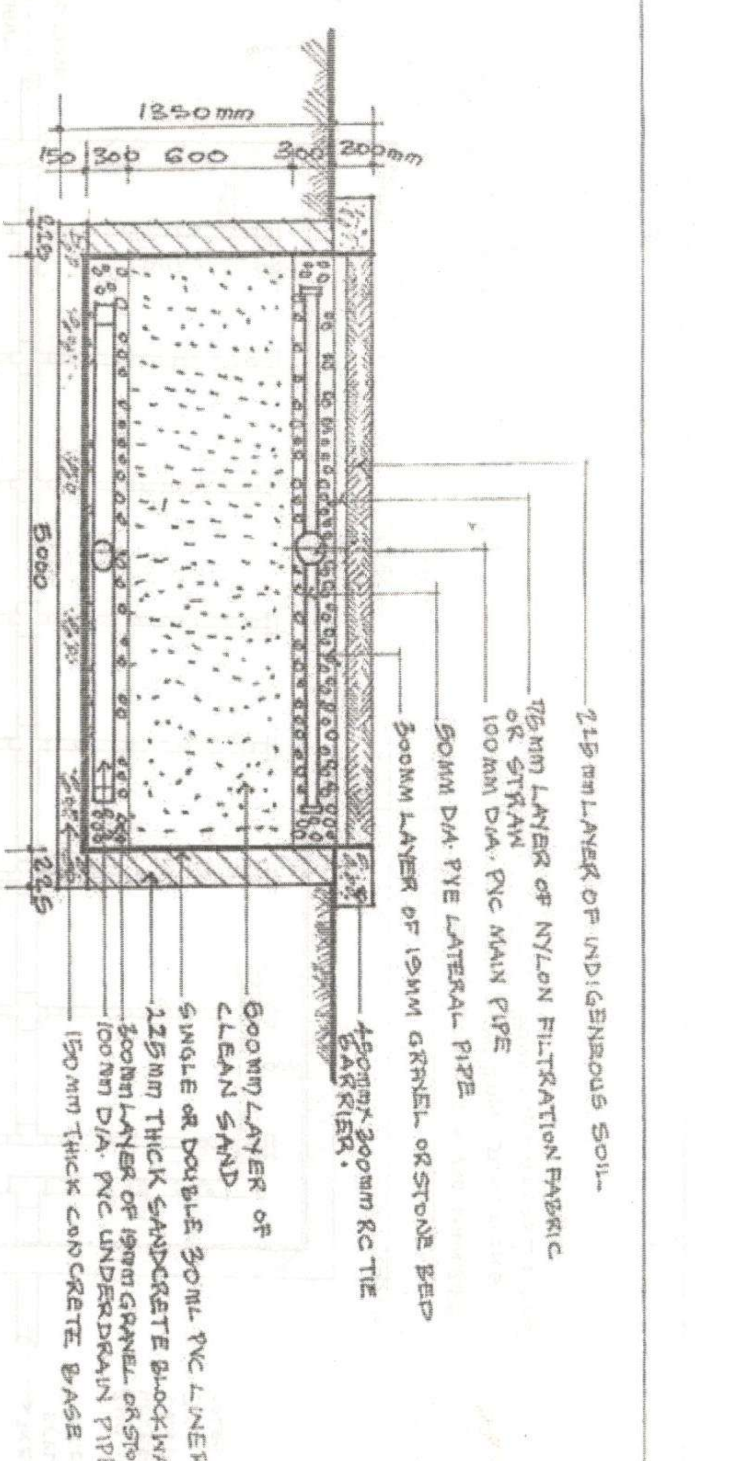

FIG 4: VERTICAL SECTION OF SANDFILTER BED

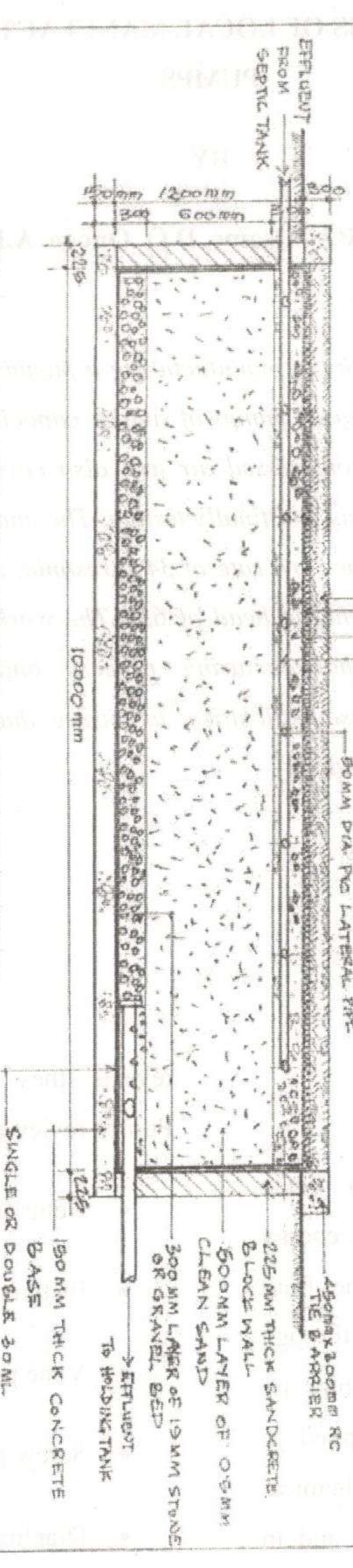

FIG 5: LONGITUDINAL SECTION OF SANDFILTER BED