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Experimental Evaluation of the Permeability Coefficient of Soils Around the Premises of the Federal Polytechnic, Bauchi, North-Eastern Nigeria

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Abstract: *Soils from the vicinity of the Federal Polytechnic, Bauchi, Nigeria, were obtained and subjected to different laboratory analyses to obtain the soil class and the permeability coefficients. The constant head permeameter was employed in the analysis of the various soil samples in order to estimate the permeability coefficients. Results obtained showed that sandy soils in the area have an average permeability coefficient of 0.372cm/sec, sandy loam soils have 0.0078cm/sec and loamy sand soils 0.095cm/sec. Since crops' consumptive use rate and available moisture content heavily depend on soils permeability, it is recommended that the design of irrigation systems in this part of the country should take a careful consideration of the permeability and particle size analysis of soils for an effective performance of the irrigation systems.*

Key Words: *Permeability, Coefficient of Permeability, Laminar flow, Turbulent flow, Permeameter*

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I. Introduction

The permeability of a soil defines its ability to transmit a fluid or the ability with which water and, or, other fluids are able to travel through the soil. This downward travel occurs in any given soil under a unit hydraulic gradient when there exists a difference in the potential gradient through a constant pull of gravity. As moisture travels down the soil profile, the textural grades determine how fast or slow it will travel. As this moisture percolates a permeable material, the individual moisture particles move along paths which deviate erratically, but slightly from smooth curves known as flow lines. If adjacent flow lines are straight and parallel, the flow is said to be linear. A material is said to be permeable if it contains continuous voids. Since such voids are contained in all soils including the stiffest clays, and in particularly in all non-metallic construction materials, including granite and neat cement, they are all permeable (Pumia et al, 2008). In addition, the flow of water through all of them obeys approximately the same laws (Lambe and Whitman, 1969; Ewa, 2019).

Knowledge of soil permeability offers many of advantages in both the agricultural field and in the engineering profession. In agriculture, for example, the permeability of a given soil is a determining factor to the type of crop that would be expected to thrive well in that soil. This is because permeability affects the soil field capacity, the wilting point and hence the readily available water for the crop. The water retention capacity of the soil, the consumptive use rate of the crop, the alkalinity and salinity of the soil are either directly or indirectly affected by the soil permeability (Matthew, 1989).

In engineering, the permeability of soils has a decisive effect on the cost and the difficulty of many constructional operations such as the excavation of open cuts in water-bearing sand, or on the rate at which a soft clay stratum consolidates under the influence of the weight of superimposed fill. As a property of soil, which permits water to flow through its pores, it is of paramount importance and significance in many other engineering problems such as drainage (Schroeder, 1975, Onigbanjo, 1979).

In many applications, the use of flow net analysis, together with permeability data, enables the rate of seepage through or beneath dams and other structures to be estimated; to determine the amount of water that must be pumped so as to be able to excavate in the dry. Vis-a-vis hydraulic structures, permeability values are required to determine the extent to which drainage facilities must be contracted, since many earth slides and retaining structure failure are due to poor drainage. If an excavation below the groundwater level is to be dewatered, a highly permeable soil will require a carefully planned and executed pumping system with comparative large capacity (Njong, 2018; Ewa, 2019).

II. Concept of Permeability

The study of soil water in motion is one of the most important aspects of engineering in soils. Any change in the state of static equilibrium converts the soil cavity from water storage reservoir to passageways through which the water can flow. Although this change may be induced by mechanical, thermal, gravitational and other gradients, the most common causes of flow are:

- Water addition to the soil in the form of rainfall, ice, snow, sleet, dew.
- Water loss from the soil in the form of evaporation, transpiration, evapotranspiration. (Sowers and Sowers,1981.)

Generally, the flow of fluids through soils fall into two (2) categories.

- Turbulent Flow: In which fluid particles move in very irregular paths, causing losses of energy approximately proportional to the square of the flow velocity. The development of turbulent flow in soils requires a high velocity and large flow profile. This flow is however not common in soils.
- Laminar Flow: The fluid particles of which move in smooth, orderly streams, causing energy losses directly proportional to the flow velocity. The development of this flow requires high viscosity, low velocity and small flow profiles. This flow is basically a characteristic of all soils finer than gravel. (Sowers and Sowers ,1981.)

Water drains from soil under a constant pull of gravity. Case studies show the rate of drainage to be more rapid immediately after irrigation or precipitation and decreases constantly, the drainage continuing at a relatively slow rate even after the gravitational water has been removed (Matthew, 1989). Saturation is said to occur when free water stands on the soil surface, runoff may occur if the surface is not leveled and the excess of the saturation water not drained off.

No other engineering property of construction materials is so variable as permeability. Coarse gravel, open joints and crevices allow water to flow rapidly and in large quantity; but stiff clays are so impervious that the rate of flow through them, and the drainage of water out of them are infinitesimal. The coefficient of permeability of natural earth deposits and man-made embankment may vary from more than 35 cm/sec for clean gravels to as low as 0.000000000001cm/sec for fine clays.(Cedergren, 1989).

A rock may be virtually impervious yet contains cracks and joints that make a formation highly permeable to the flow of water. The permeability of most rock abutments and dam's foundations is determined almost entirely by the joints and cracks' pattern, and many clays are extremely resistant to the flow of water, yet shrinkage cracks or interbeds of silt or sand may increase their permeability thousands of times.

A permeable material has been defined as one that is capable of being penetrated or permeated by another substance, usually a gas or liquid. Thus, dry cement is permeable to air, and an air permeability test is a useful means of obtaining an indirect measure of its fineness of grind, since the speed of flow of air through it can be related to the size of the pore spaces between the particles.

2.1 Measurement of Permeability

Bowles, (1978) explained that any method adopted for testing and measurement of this parameter used Darcy's law, simply given as

$$V = Ki \qquad \text{- Eqn. 1}$$

The corresponding flow rate is given as

$$q = KiA \qquad \text{- Eqn. 2}$$

where q = quantity of fluid flow is a unit time
k = Coefficient of permeability
i = Hydraulic gradient = h/L
h = Differential head across the sample
I = Sample length across which his measured
A = Cross sectional area of soil mass under consideration

As long as the flow is not turbulent, the velocity v and the flow through saturated soils is proportional to the soil permeability k, and the slope of the piezometric headline h/L (Darcy, 1856). The discharge velocity is defined as the quantity of water that percolates in a unit time across a unit of a section oriented at right angles to the flow lines. Typical values of permeability for soils range from 1×10^{-2} m/s for a coarse sand to 1×10^{-10} m/s for clay. A very rough estimate of permeability for a relatively uniform sand can be obtained from Hazen's law. $K = D_{10}^2/100$, where D_{10} is the 10% size of effective size in mm and k is in m/s. The 10% size of effective size is the particles sizes at which the grading curve crosses the 10% line.

Constant head permeameter: A permeameter is basically a soil permeability test instrument which normally consists of a cell, an overhead tank and piezometric tubes to measure the head difference. The constant head permeamter is used for granular soils whose particle size diameter ranges from 0.2mm to 2.0mm.
Falling head permeameter: The falling head permeameter is a soil instrument used in the determination of the permeability of cohesive soils with tiny pore space and particle size ranging from 0.005mm to 0.2mm in diameter.

III. Area of Study

The area of study, The Federal Polytechnic near Yelwa, Bauchi, is located approximately on Latitudes 10º 15'' and 10º 16''N of the Equator and 9º 46'' and 9º 47''E of the Meridian (Fig.1). It is one of the Tertiary Institutions in Bauchi State, North-Eastern Nigeria.

Geologically, Bauchi lies within the Pre-Cambrian Basement Complex area of Nigeria which consists essentially of rocks that are granitic in composition and in different stages of metamorphism as Gneisses, Migmatites, Quarzites, Schists, etc, and the basement rocks are severely weathered (Obiefuna and Nur, 2003;Shemang and Jiba, 2005; SEDI, 2015).

The area has relatively high relief, over 600m above sea level, and is located in the Northern axis of the Savanna belt which may be distinctly subdivided into shrubbed grassland (Sudan Savanna) and wooded shrub land (Northern Guinea Savanna) (Ekanem, et al, 2013; Hassan and Ogbonnaya, 2016)

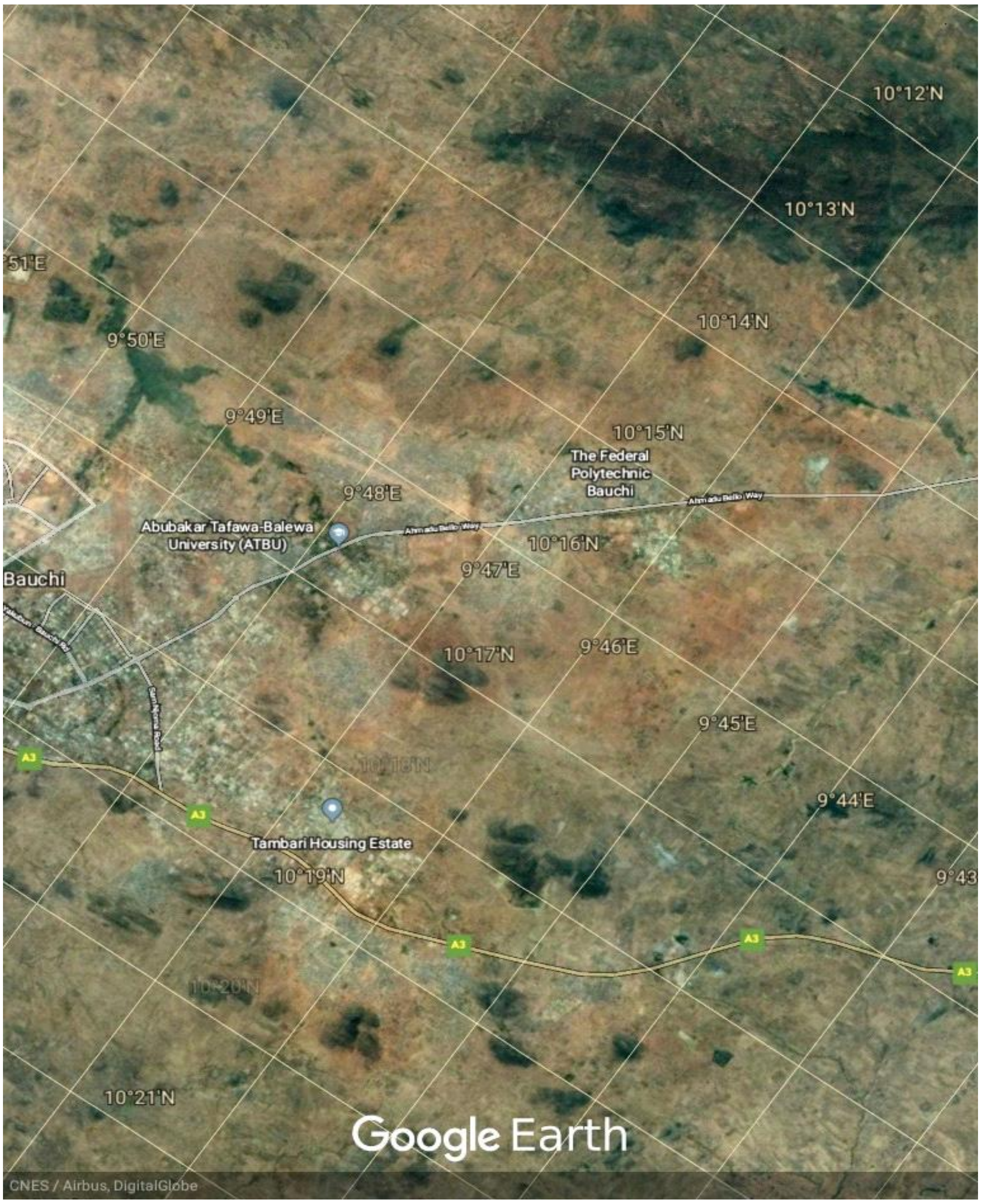

Fig.1: Map of the Study Area

3.1:Sample Collection

Soil samples were collected from eight test locations within the premises of the Federal Polytechnic, Bauchi using the spiral soil auger. Samples were placed in labeled containers to avoid mix-up. The samples were collected at a depth of at least 200mm below the surface.

3.2:Preparation and Testing

The plastic tubings from each manometer tube were connected to the pressure – take – off – points in the permeameter cell. The cell top was lifted clear of the permeameter body. The tap fitted in the cell base was closed and the cell was filled with de-aired water. A pinch clip or some similar device was attached to each rubber tubes connected between the cell and manometer tubes so that the water in the manometer is trapped. An aluminum disc filter was placed at about 30mm height of the cell from the cell bottom, the test specimen was poured into a separate container which was full of de-aired water. The specimen was thoroughly stirred so that all the air was expelled, and the specimen was then transferred into the cell until it was about 30mm below the top of the cell. The specimen was again stirred to ensure that no air is trapped inside. An aluminum disc filter was placed on top of the sample to filter the water. The top of the cell was closed and made water tight. A length of rubber tubing was connected to the tap fitted to the cell base and its free end was placed or inserted into a glass measuring cylinder. It was ensured that there was no kink in the tubing before the base tap was opened. The water supply to the reservoir was turned on, the pinch clips were removed from the rubber tubes connected to the manometer panel. Water was allowed to flow through the specimen until a steady level of water was obtained on the manometer. When this condition was achieved, the stopwatch was started and the time taken for a known volume of water to pass through the specimen in the cell was determined. The difference in the head of water in each manometer tube was measured during this time. The measurements of time, volume and heads were repeated three times.

3.3:Calculations

The following information were recorded

- The difference in head between the water in the two manometer tubes, h in cm;
- Length of specimen between the pressure - point – take – off on the wall of the cell, L in cm;
- Diameter of specimen d, in cm;
- Cross sectional area of specimen, a in cm^2;
- Duration of test, t in seconds;
- Volume of water collected in measuring cylinder relative to above time, q in cm^3

The coefficient of permeability, k, was calculated from the following formula.

$$K = \frac{q \times l}{h \times a} \quad \text{(cm/sec)} \qquad - \qquad \text{Eqn. 3}$$

The cross sectional area of the permeameter was calculated from the formula

$$a = \frac{\pi D^2}{4} \qquad - \qquad \text{Eqn. 4}$$

Where D = diameter of the permeameter

This gave a constant cross sectional area of 44.20cm$^{2.}$

A constant length of 10.0cm between pressure points – take off was used throughout the calculations.

IV. Results and Discussion

4.1: Results of Tests

The results obtained for eight study locations within the premises of the Federal Polytechnic, Bauchi were obtained. Particle size analysis revealed that soils from Mechanical Engineering Building, C Quarters and the Irrigation Plot are sandy; soils from B Quarters, the Female Hostel C and Agricultural Engineering Demonstration Plot are sandy loam while soils from A Quarters and the School Gate Rice Plots are Loamy sand. The permeability of soil is usually dependent on its particle size. Results obtained for soils from all the 8 plots are shown respectively in tables 1 – 8.

Table1: Permeability Coefficient of Soil Around Staff School, B Quarters

Time (Min)	Head Difference (cm)	volume (m^3)	K (cm/sec)
10	41.50	168	0.0153
20	41.50	180	0.0164
30	41.10	257	0.0236
Average k = 0.0184 cm/sec			

Table 2: Permeability Coefficient Of Soil Obtained From The Irrigation Demonstration Plot

Time (Min)	Head Difference (cm)	volume (m^3)	K (cm/sec)
10	9.6	775	0.304
20	14.6	883	0.228
30	16.2	960	0.221
Average k = 0.251 cm/sec			

Table 3: Permeability Coefficient Of Soil At The School Gate Rice Plot

Time (Min)	Head Difference (cm)	volume (m^3)	K (cm/sec)
10	5.7	178	0.118
20	6.4	160	0.094
30	8.0	140	0.066
Average k = 0.093 cm/sec			

Table 4: Permeability Coefficient Of Soil At The Female Hostel C

Time (Min)	Head Difference (cm)	volume (m^3)	K (cm/sec)
10	34.5	1	0.00011
20	41.8	20	0.0018
30	43.2	34	0.003
Average k = 0.00164 cm/sec			

Table 5: Permeability Coefficient Of Soil At The Agric. Engineering Demonstration Plot

Time (Min)	Head Difference (cm)	volume (m^3)	K (cm/sec)
10	12.5	20	0.00060
20	15.5	9.0	0.0022
30	16.5	8.6	0.0020
Average k = 0.0034 cm/sec			

Table 6: Permeability Coefficient Of Soil At The C Quarters

Time (Min)	Head Difference (cm)	volume (m^3)	K (cm/sec)
10	4.7	1000	0.802
20	8.1	935	0.435
30	8.5	700	0.311
Average k = 0.516 cm/sec			

Table 7: Permeability Coefficient Of Soil Behind The Mechanical Engineering Building

Time (Min)	Head Difference (cm)	volume (m^3)	K (cm/sec)
10	13.2	1.215	0.347
20	11.5	1.080	0.354
30	10.0	910	0.343
Average k = 0.348 cm/sec			

Table 8: Permeability Coefficient Of Soil At The A Quarters

Time (Min)	Head Difference (cm)	volume (m^3)	K (cm/sec)
10	1.0	38	0.143
20	1.1	20	0.069
30	1.2	17	0.053
Average k = 0.088 cm/sec			

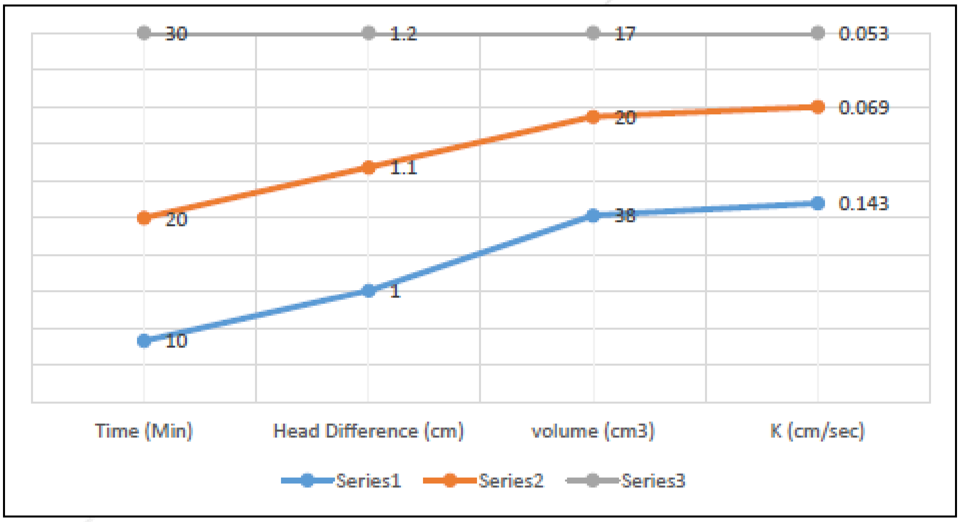

Fig. 2: Permeability Plot for Location 1

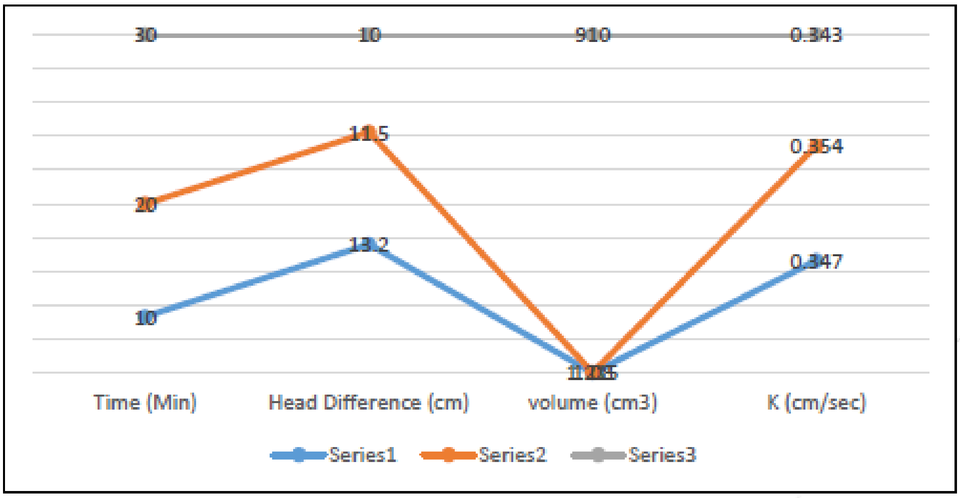

Fig. 3: Permeability Plot for Location 2

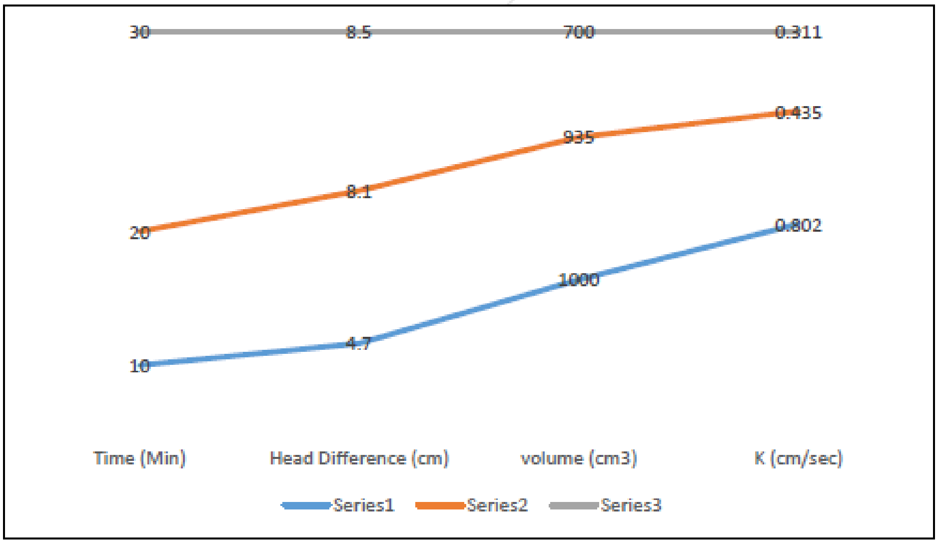

Fig. 4: Permeability Plot for Location 3

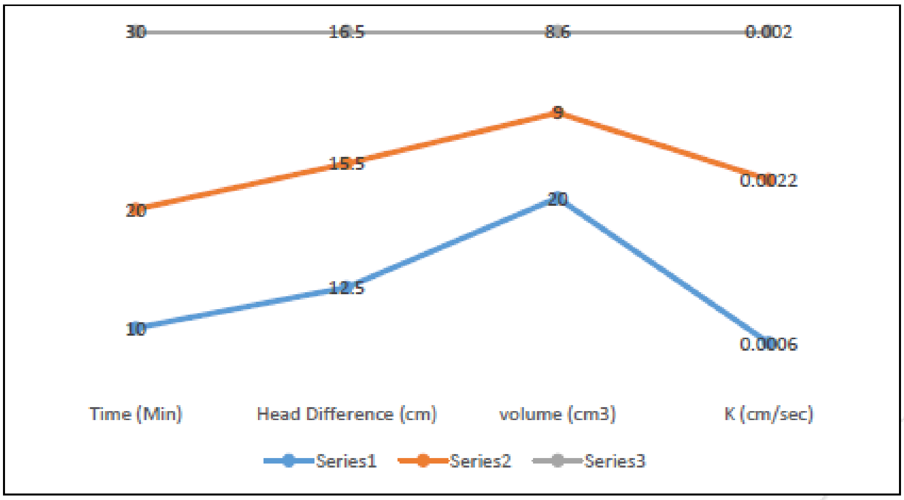

Fig. 5: Permeability Plot for Location 4

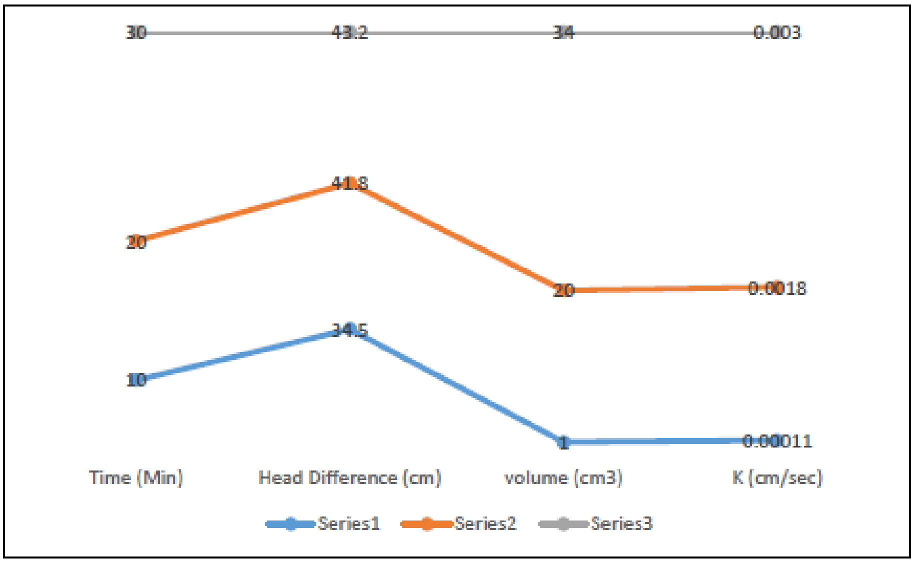

Fig. 6: Permeability Plot for Location 5

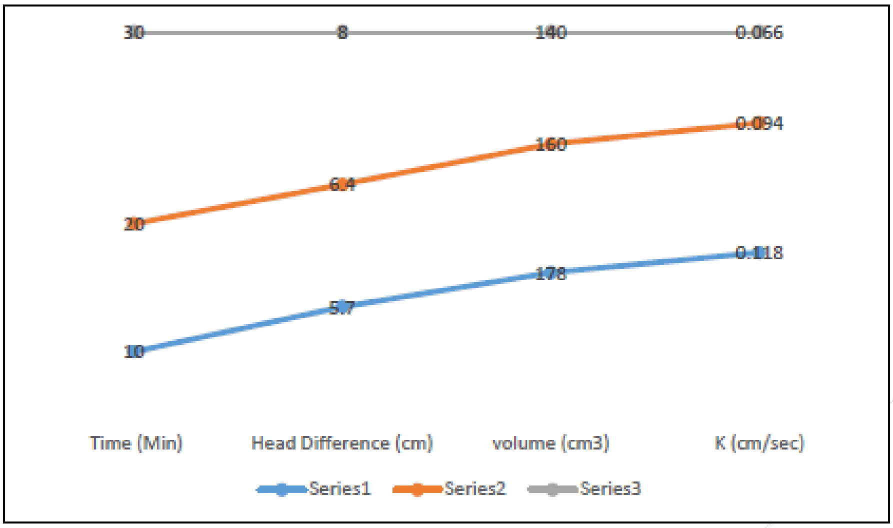

Fig. 7: Permeability Plot for Location 6

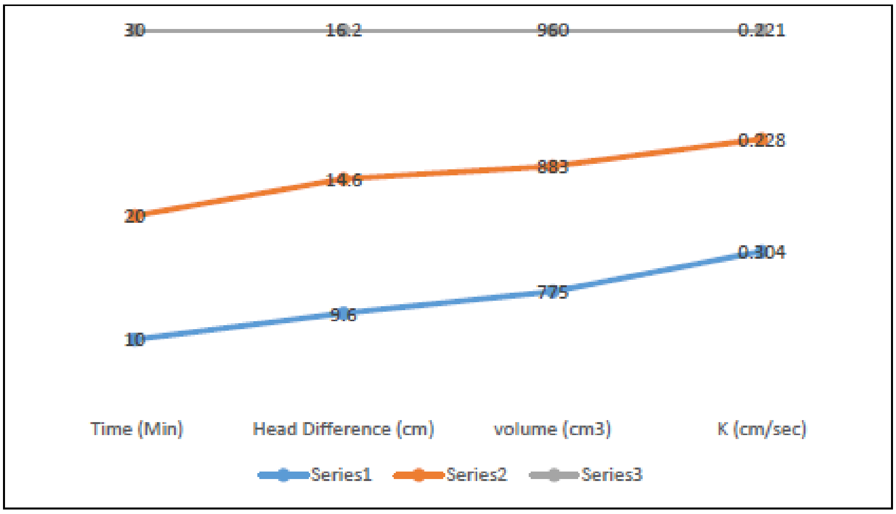

Fig. 8: Permeability Plot for Location 7

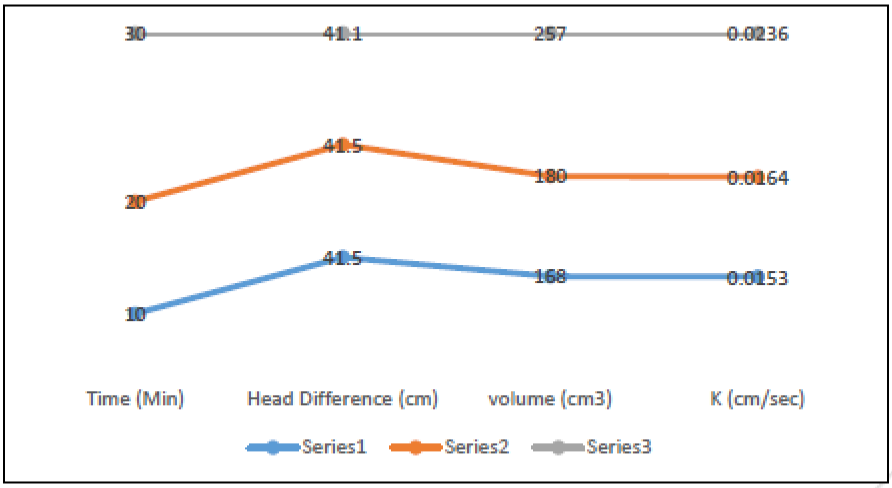

Fig. 9: Permeability Plot for Location 8

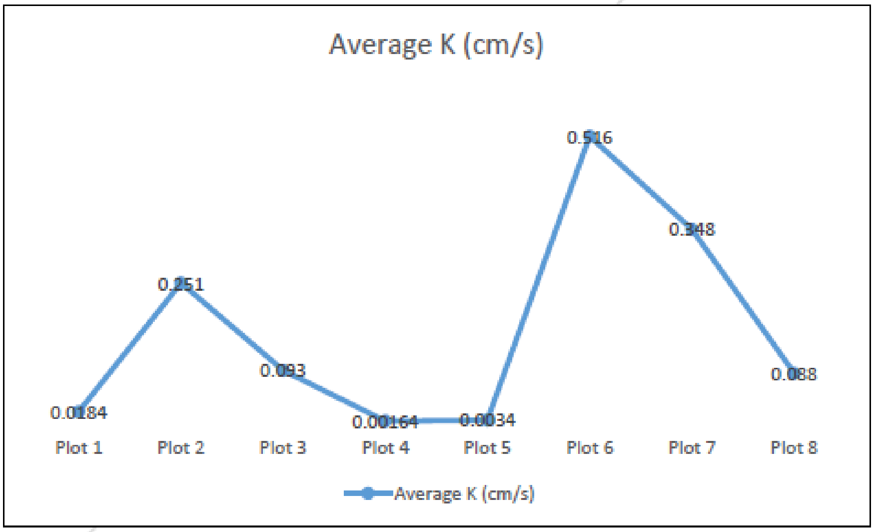

Fig.10: Average Permeability Coefficient Plots for all Locations

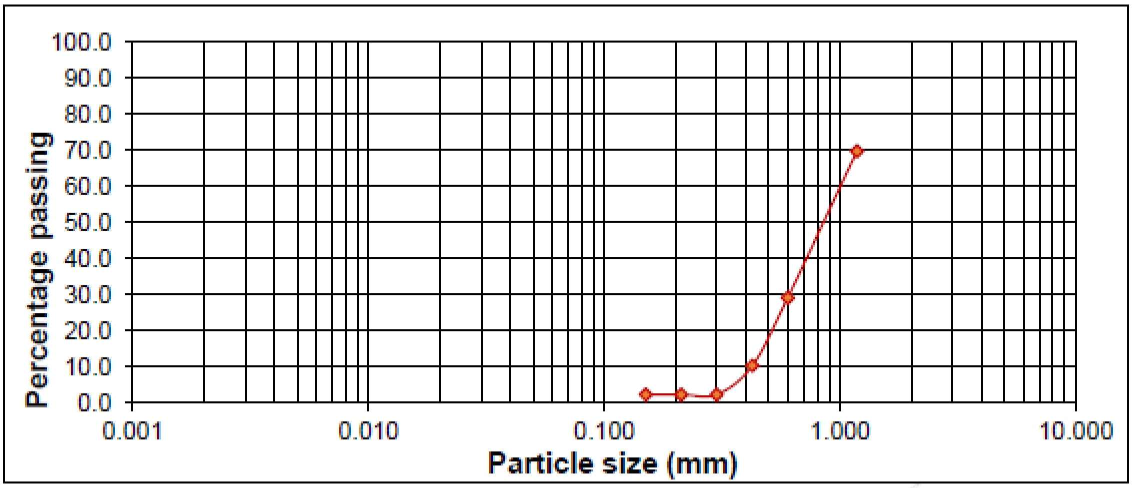

Fig. 11: Percent Passing for Location 1

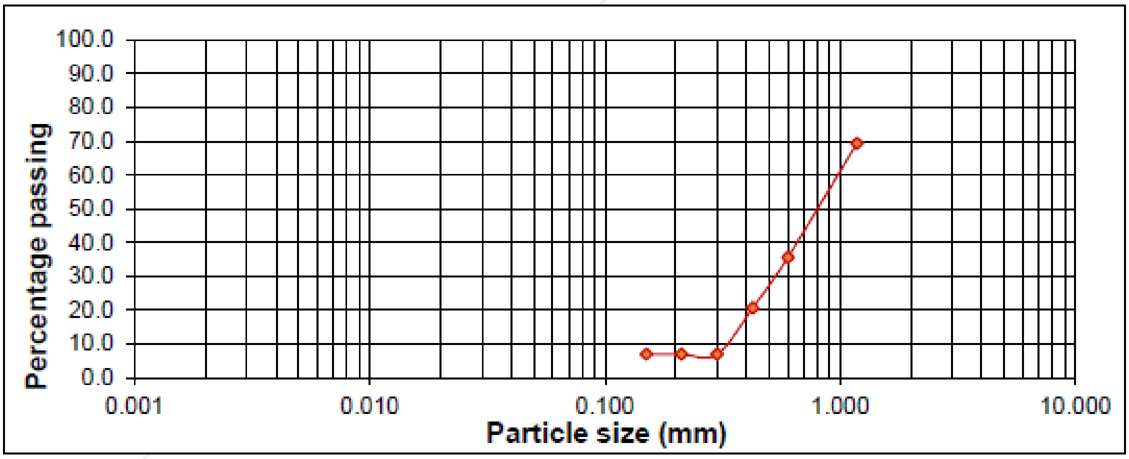

Fig. 12: Percent Passing for Location 2

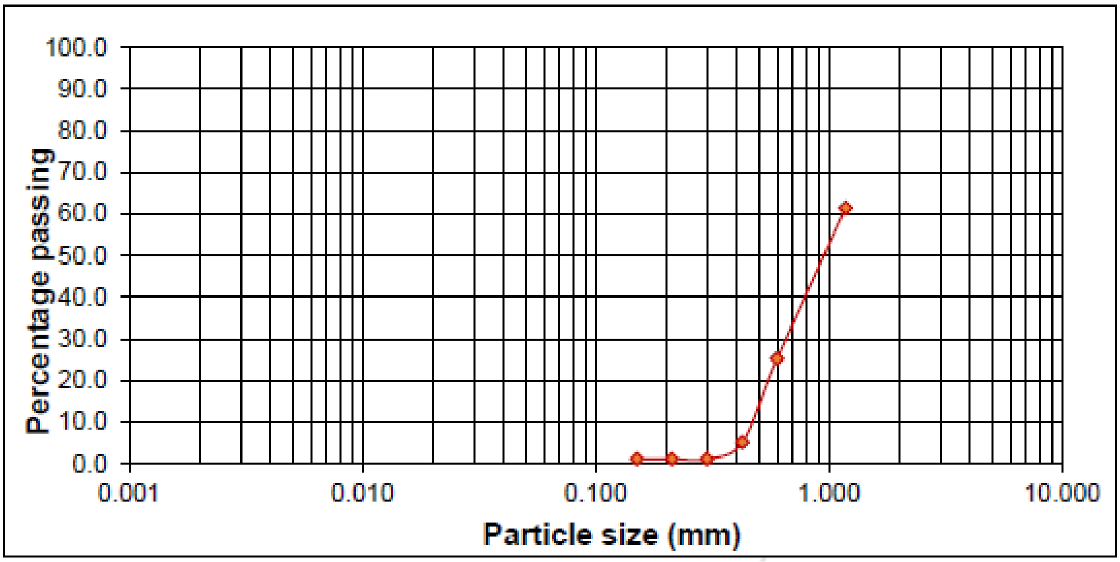

Fig. 13: Percent Passing for Location 3

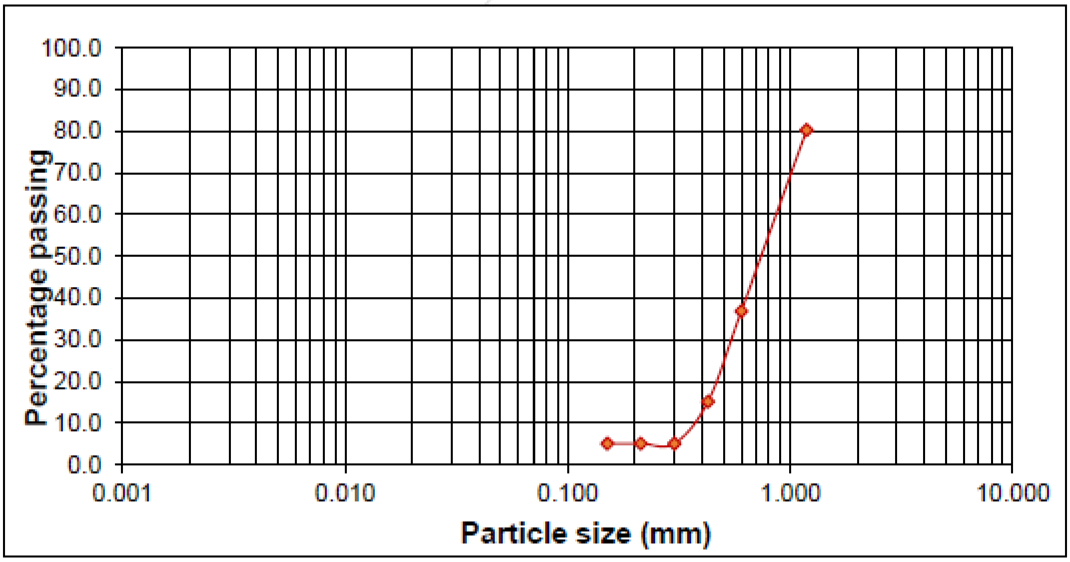

Fig. 14: Percent Passing for Location 4

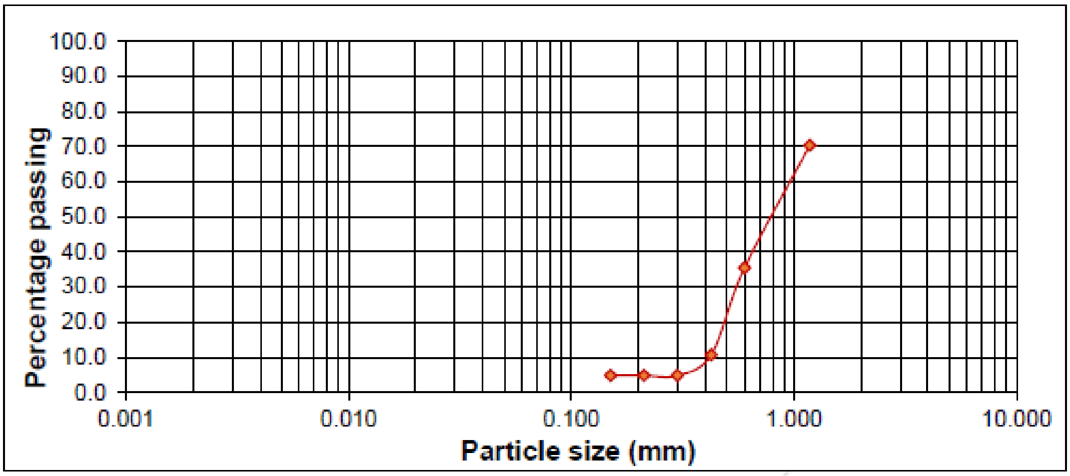

Fig. 15: Percent Passing for Location 5

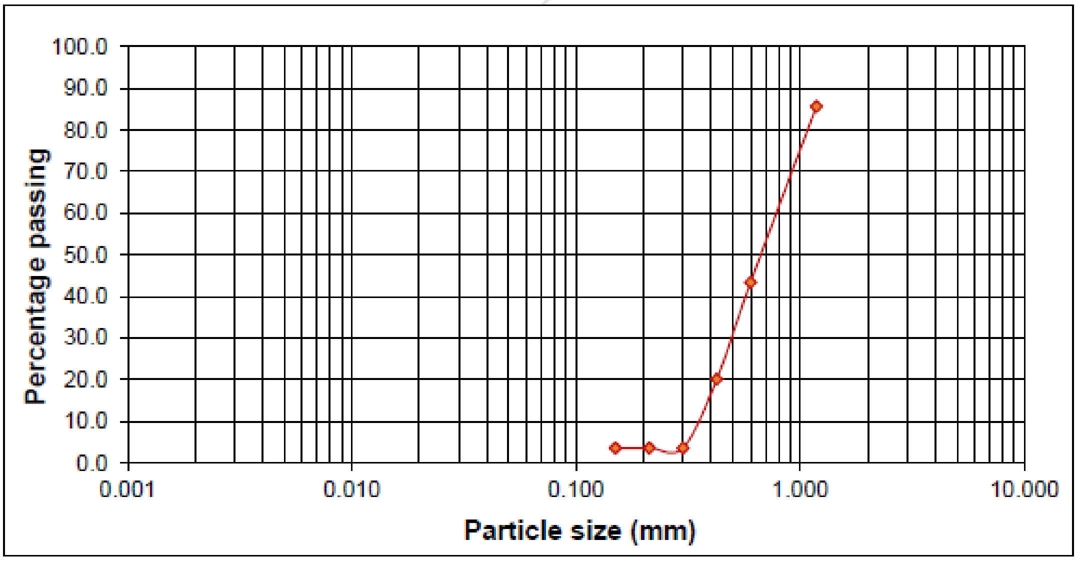

Fig. 16: Percent Passing for Location 6

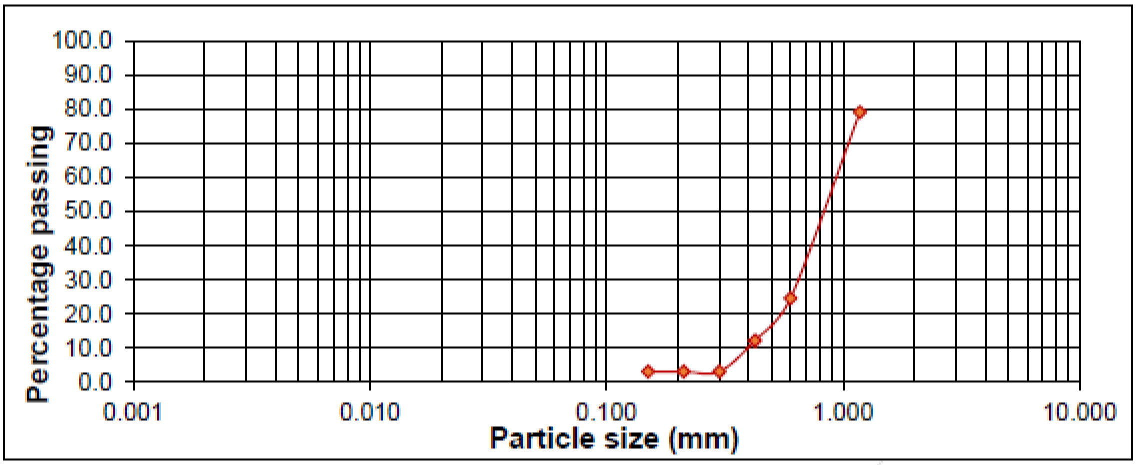

Fig. 17: Percent Passing for Location 7

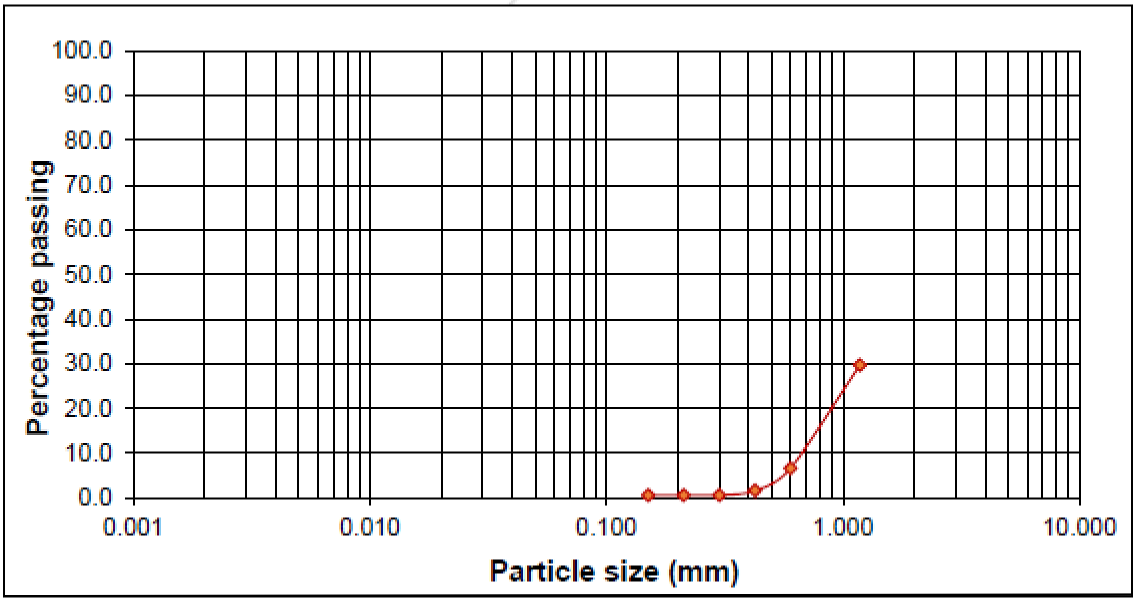

Fig. 18: Percent Passing for Location 8

4.2: Discussion of Results

The permeability coefficient, K, of soils within the vicinity of the Federal Polytechnic, Bauchi, was observed to vary significantly with the textural class of the soil in the area under study. For the eight test locations within the school premises, three different textural grades were observed. These grades were, sand, sandy loam and loamy sand. The different plots are shown in Figures 2-9 corresponding to the different locations 1-8, the average coefficients for all locations are shown in Figure 10 while the percent passing for all soils from the study location are shown in Figures 11-18.

Soils around the Mechanical Engineering Building, the C Quarters and the Irrigation Plot were observed to be predominantly sandy and their respective coefficients of permeability were 0.348 cm/sec, 0.516 cm/sec and 0.251 cm/sec which averaged to 0.372 cm/sec. Soils around B Quarters, the Female Hostels C and the Agricultural Engineering Demonstration Plot were observed to be predominately sandy loam and their respective coefficients of permeability, K, were 0.0184, 0.00164 and 0.0034 which gave an average of 0.00078 cm/sec.

Soils around A Quarters and the School Gate Rice Plot were observed to be predominantly loamy sand with coefficients of 0.088 cm/sec and 0.093 cm/sec respectively which gave an average of 0.0905 cm/sec.

By comparison, permeability coefficient, K of sandy soils in the zone of the study area was 0.372 cm/sec while that determined by Peck, (1980) of same sandy soil gave K as 0.231 cm/sec, a difference of 0.141 cm/sec.

Also permeability coefficient, K for sandy loam soils under zone of experiment was 0.0078 cm/sec while that determined by Peck, (1980) of same sandy loam soil gave K as 0.0025, a difference of 0.0053 cm/sec.

For loamy sand soils in the zone of study, the coefficient of permeability, K was 0.0905 while that determined by Peck, (1980) of same loamy sand gave K as 0.096, a difference of 0.0055 cm/sec.

V. Conclusion and Recommendation

For the soil types observed in the zone of study which were sandy, sandy loam and loamy sand, their coefficients of permeability were found to vary quite significantly. Their respective average coefficient of permeability was 0.372 cm/sec, 0.0078 cm/sec and 0.0905 cm/sec. This variation was expected as soils texture and structures vary significantly from region to region, heavily dependent on the parent rocks and the vegetative cover

The standard test results from Peck, (1980) for the same soils gave an average K of 0.231 cm/sec, 0.0025 cm/sec and 0.096 cm/sec respectively. The percentage variation for the respective soils for standard and observed results were 38%, 68% and 5.8%.

Since crops' consumptive use rate and available moisture content heavily depend on soils' permeability, it is recommended that irrigation designers' study and analyze this all-important soil component to aid designs. Additionally, the soils in the area, though friable, should also be analyzed with the use of the variable head permeameter to compare the results.

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