Effect of Bulk Density on Saturated Hydraulic Conductivity

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ABSTRACT

Soil samples were taken from five local governments (Yola, Tongo, Lamurde, Fofure and Hong) in Adamawa State. One meter deep soil was dug and composite samples were taken from 0 to 0.5m and 0.5 to 1m from each hole. A total of ten bulk samples were taken from the field to the laboratory. The disturbed soil was mixed thoroughly before taking to the laboratory for tests. The soil samples were subjected to 2,3,4,5,6 and 7 blows using a standard proctor hammer in a cylindrical mold to achieve bulk densities of 1.51,1.63,1.79,1.86,1.97 and 2.01g/cm^3 respectively at 7.25% moisture content. The saturated hydraulic conductivity (K_s) was determined by falling head permeameter method. Measurement of K_s was done in three replicates and the mean values of K_s were recorded. Simple linear regression was done using computer to establish a functional relationships between saturated hydraulic conductivity and bulk density of the soils studied. The equations obtained in this study could be used to estimate the saturated hydraulic conductivity of the soils in the study area.

Keywords: Bulk density (γ_b), Saturated Hydraulic Conductivity (K_s), and Soil Samples
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INTRODUCTION

Saturated Hydraulic Conductivity usually designated as K_s, is the ease with which a fluid (in this case water) passes through a porous medium (in this case soil or aquifer). Technically it is the rate of flow of a fluid at prevailing kinematic viscosity per unit cross sectional area of the medium normal to the direction of flow per unit hydraulic gradient (Baver, 1972; Todd, 1980). It is the same as coefficient of permeability, and its dimensions are length per time (TL^{-1}). Hydraulic conductivity is a function of the properties of the fluid flowing as well as the properties of the medium through which it flows (Lambe and Robert, 1979).

As the knowledge of K_s is of great practical importance in many engineering undertakings especially in geotechnics, ground water resources and drainage projects, specifically in solving seepage problems through and under dams, as well as in artificial ground water recharge, it is desirable to have a simple, accurate, reliable, reproducible and relatively cheap method of estimating it (Adeniji, 1991). At the moment, conventional laboratory methods using either core or disturbed samples have too many unquantifiable assumptions to make them reliable and reproducible. The laboratory method according to Baver (1972) is severely limited by the assumption that field structure is maintained or attained in reconstitution. This is hardly true as shrinkage and swelling during handling and microbial activities often lead to appreciable changes from field conditions. Also, one or more several samples from an aquifer may not give the overall hydraulic conductivity of an aquifer. Variation of several orders of magnitude in the value of the hydraulic conductivity frequently occurs for different depths and locations in an aquifer. Field methods on the other hand are too tedious, laborious and expensive to fulfill the desired requirement of "simplicity". Therefore, one must seek ways of quantifying as many of the assumptions underlying the laboratory methods as possible in order to make them reliable and reproducible and at the same time avoid the rigor, high cost and tedium of the field methods.

The purpose of this study is to measure saturated hydraulic conductivity of soil samples in Adamawa State at various bulk densities and to establish functional relationship between bulk density and the measured saturated hydraulic conductivity of the soil samples.

MATERIALS AND METHODS

Five sample points were located in five local governments (Yola, Lamurde, Tongo, Fofure and Hong) in Adamawa State. Samples were taken from 0 to 0.5m and 0.5 to 1m from each hole using, digger, shovel, can, meter rule, measuring tape, airtight polythene bags and wheel barrow. A total of ten bulk samples were taken from the field to the laboratory. The disturbed soil was mixed thoroughly before taking to the laboratory. The samples were dried by spreading them on the table in the laboratory for two weeks after which, they were crushed and sieved using 2mm mesh sieves. Bulk densities of 1.1, 1.2, 1.3, 1.4, 1.5 and 1.6g/cm^3 were fixed and mass of soil samples of 1122.6, 1224.6, 1326.67, 1428.7, 1530.8 and 1632.8g were calculated respectively using the volume of a cylindrical mold of 10cm diameter by13cm height. Each of the soil samples were then compacted in the cylindrical mold using a standard proctor compaction hammer by subjecting them to 2, 3, 4, 5, 6 and 7 blows at the moisture content of 7.25% following the proctor compaction procedure as described by Lambe (1951). The volume of the samples in the mold were then determined which was used to calculate the actual bulk densities of the soil samples as 1.51, 1.63, 1.79, 1.86, 1.97 and 2.01g/cm^3.

The saturated hydraulic conductivity of the soil samples was determined using the falling head permeameter method as described by Klute (1965). Each of the compacted soil samples of bulk densities 1.51, 1.63, 1.79, 1.86, 1.97 and 2.01g/cm^3 was saturated by ponding before transferring it to the permeameter cell. The K_s of each samples was measured in three replicates and the average values of K_s were recorded. The particle size distribution was obtained by hydrometer method following the procedure described by Day (1965). The soil textural class was determined using Marshall textural triangle adopted by Richards (1969).

RESULTS AND DISCUSSION

The number of samples taken per local government in Adamawa State was shown in Table 1. While particle size distribution of the soil samples at two depths was presented in Table 2. Table 3 shows the effect of bulk density on saturated hydraulic conductivity of the soil samples at two depths. Table 4 contains the average saturated hydraulic conductivity of the soil samples from the various local governments. While the results of the summary of the simple regression of saturated hydraulic conductivity (K_s) on bulk density (Υ_b) for the soil samples was presented in Table 5 and the regression equations for estimation of saturated hydraulic Conductivity for the soils in the five local governments were shown in Table 6. Figures 1 and 2 shows the graph of saturated hydraulic conductivity versus bulk density of the soil samples from the five local governments in the state; at 0 to 0.5m and 0.5 to 1m depths respectively.

Table 1: The Number of Sample Taken Per Local Government in Adamawa State

Local Government	**Yola**		**Lamurde**		**Tongo**		**Fofure**		**Hong**	
Hole reference	H_1		H_2		H_3		H_4		H_5	
Sample No.	I	II	III	IV	V	VI	VII	VIII	IX	X

Table 2: Particle Size Distribution at Two Depths of the Soil Samples

	Particle Size Distribution %							
Depth	**0 to 0.5m**				**0.5 to 1m**			
Local Govt.	**Sand**	**Silt**	**Clay**	**Texture**	**Sand**	**Silt**	**Clay**	**Texture**
Yola	58.9	33.15	7.95	Sandy loam	51.4	30.6	17.95	Sandy loam
Lamurde	38.9	35.65	25.45	Loam	38.9	33.15	27.95	Clay loam
Tongo	41.4	50.65	7.95	Silt loam	48.9	43.15	7.95	Loam
Fofure	86.4	13.15	0.45	Sand	83.9	15.65	0.45	Loamy sand
Hong	58.9	35.65	5.45	Sandy loam	61.4	20.65	17.95	Sandy loam

Table 3: Effect of Bulk Density on Saturated Hydraulic Conductivity at Two Depths of the Soil Samples

	Depth / 0 – 0.5m					**0.5 – 1m**				
	Saturated Hydraulic Conductivity, K_sx 10^{-4}mms^{-1}									
Bulk Density (Υ_b) gcm^{-3}	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**
1.51	1.934	1.812	1.841	2.167	2.053	1.912	1.791	1.914	2.012	1.985
1.63	1.812	1.713	1.732	2.013	1.987	1.791	1.698	1.834	1.873	1.937
1.79	1.736	1.634	1.593	1.896	1.827	1.732	1.612	1.635	1.812	1.785
1.86	1.583	1.563	1.427	1.730	1.694	1.512	1.521	1.547	1.696	1.621
1.97	1.464	1.424	1.392	1.597	1.574	1.413	1.397	1.438	1.532	1.514
2.01	1.291	1.367	1.213	1.435	1.396	1.231	1.298	1.293	1.393	1.297

Where; I – X are the sample references

Table 4: Average Saturated Hydraulic Conductivity of the Soil Samples from the Various Local Governments

	Saturated Hydraulic Conductivity, K_sx 10^{-4}mms^{-1}				
Bulk Density (Υ_b) gcm^{-3}	**Yola**	**Lamurde**	**Tongo**	**Fofure**	**Hong**
1.51	1.873	2.004	1.982	1.8525	1.9985
1.63	1.7625	2.4372	1.889	1.766	1.923
1.79	1.683	1.9276	1.5735	1.6235	1.7985
1.86	1.573	1.5785	1.6025	1.534	1.6585
1.97	1.444	1.4945	1.4935	1.4175	1.532
2.01	1.329	1.324	1.3135	1.2955	1.345

Table 5: Summary of the Simple Linear Regression of Saturated Hydraulic Conductivity on Dry Bulk Density for the Various Soil Samples

Local Government	Function	a	b	r
Yola	$Ks = a + b\,\Upsilon b$	3.44	-1.02	.98
Lamurde	$Ks = a + b\,\Upsilon b$	4.95	-1.73	.84
Tongo	$Ks = a + b\,\Upsilon b$	3.93	-1.27	.97
Fufore	$Ks = a + b\,\Upsilon b$	3.51	-1.07	.98
Hong	$Ks = a + b\,\Upsilon b$	3.94	-1.24	.97

"a" and" b" = Are regression coefficient
K_s = Saturated hydraulic conductivity (x10^{-4}mms^{-1})
Υb = The dry bulk density (gcm^{-3})
r = The correlation coefficient

Table 6: Regression Equations for Estimation of Saturated Hydraulic Conductivity for the Soils in the five Local Governments

Local Government	Regression Equation	r
Yola	$Ks = 3.44 - 1.02\,\Upsilon b$	.98*
Lamurde	$Ks = 4.95 - 1.73\,\Upsilon b$	.84*
Tongo	$Ks = 3.93 - 1.27\,\Upsilon b$	.97*
Fufore	$Ks = 3.51 - 1.07\,\Upsilon b$	.98*
Hong	$Ks = 3.94 - 1.24\,\Upsilon b$	.97*

Ks = Saturated hydraulic conductivity(x10^{-4}mms^{-1})
Υb = Dry bulk density (gcm^{-3})
*** = All values are significant at 0.05 levels.**
r = As previously defined

From the result of the grain size distribution shown in Table 2, it can be observed that the soil textural classification are sand ,sandy loam, silt loam, loam and clay loam. Figs. 1 and 2 are illustrations of the change in saturated hydraulic conductivity in response to variation in bulk density for the soil samples in the five local governments at two level of depth (0-0.5 and 0.5-1m). It can be seen that K_s kept decreasing with increasing bulk density irrespective of the depth, at which the soil sample were taken. This type of relationship between K_s and bulk density was expected. Similar results were reported by Cameron (1979), Miyazaki (1996) and Dusa (2011). The trend of results so obtained could be due to the reduction of the macro pores with corresponding increase in bulk density by compaction which automatically kept on changing the structural pattern of the soil. This process, as explained by Voorhes (1977), enhances water retention instead of transmission.

Computer was used to determine the best for the data in Table 4, the result of the best fit analysis showed that the data fitted reasonably well according to straight line equation $Ks = a + b\Upsilon b$

Where;

Ks = Saturated Hydraulic Conductivity ($x10^{-4} mms^{-1}$)

Υb = Bulk density (gcm^{-3})

b = Slope of the line

a = constant

The saturated hydraulic conductivity and dry bulk density values of all soils used in this study were used to generate expressions for predicting saturated hydraulic conductivity values for a given bulk density in each local government the summary of the analysis was presented in Table 5. The exercises produce a linear regression equation (Table 6). The equation could be useful in quick estimation of saturated hydraulic conductivity of soils in each local government when the bulk density is known. Hence field experiment involving determination of saturated hydraulic conductivity could be avoided especially in areas where such equipment is not easy to be found.

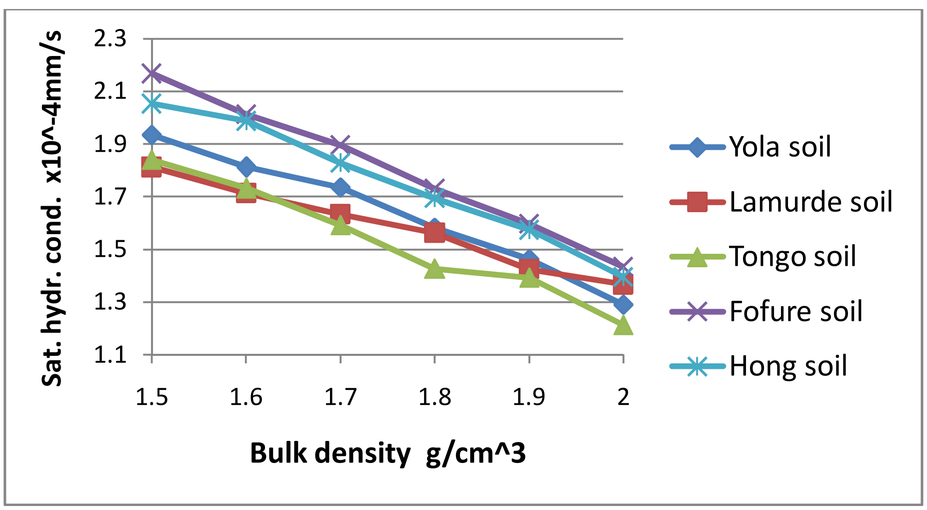

Fig. 1: Saturated Hydraulic Conductivity Verse Bulk Density of the Soil Samples from the Five Local Governments in Adamawa State at 0 to 0.5m Depth.

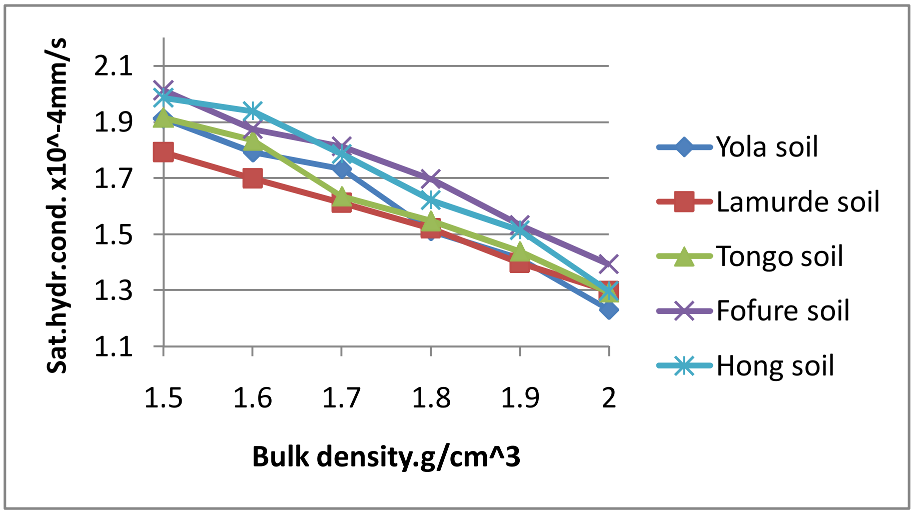

Fig. 2: Saturated Hydraulic Conductivity Verse Bulk Density of the Soil Samples from the Five Local Governments in Adamawa State at 0.5 to 1m Depth.

CONCLUSION

Result from this study showed that K_s was influenced significantly by bulk density, Υb. It was observed from the result of the experiment that K_s decreased with increased bulk density in respect to the depth at which the soil samples were taken. Essentially, the equations derived in this study will enable the geotechnical, irrigation and drainage engineers, farmers and agronomist to predict the K_s of the soil fairly accurately at least in the study area.

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