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ORIGINAL RESEARCH ARTICLE

CHARACTERIZATION OF SOILS IN EAST AND WEST ZONES OF KANO RIVER IRRIGATION PROJECT, NIGERIA

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ABSTRACT

The relationship between clay composition and on organic matter content, Saturated Hydraulic Conductivity, bulk density and location of soils in a different part of the Kano River Irrigation Project (KRIP) was studied by taking soil samples from forty (40) sectors. Sampling was done from the depth of 0-45 cm with soil auger, digger, a wooden plank and core samplers. Particles size analysis has shown that the percentage of clay varies from the range of 22.12% to 5.4% as observed in Raje and Butalawa respectively. The texture in most of the sectors was dominated by sandy loam. The organic matter (OM) content is typical of agricultural topsoil as all the sectors have organic matter within the range of 1–6%. Spearman correlation coefficient of 0.452 indicates that the relationship between % clay and Bulk density was more of a non-linear relationship than linear. The Pearson correlation coefficient of 0.876 between % clay content of the soil in all the sectors and saturated hydraulic conductivity represents a strong negative relationship between the variables, as % clay content increases, the strength of Sat. hydraulic conductivity tends to decrease. The % clay has no relationship with location of sectors based on the correlation analysis. The Pearson and Spearman coefficients between % Clay content and % OM were 0.407 and 0.473 respectively and this represent a positive relationship between the variables. It was recommended that organic matter content, saturated hydraulic conductivity and bulk density can be used as one of the determinant variables in the development of a model aimed at predicting the % clay of soils in KRIP. Application of organic manure and fertilizer to improve soil productivity and buffering capacity was also recommended due to low organic matter content.

1.0 Introduction

The most efficient method of ensuring sufficient food supply to support life is sustaining soil and environmental qualities. Management of tropical soils is important in addressing challenges of food security, soil degradation, environmental quality and the issue of the global carbon cycle (Chimdi et al., 2012). The knowledge of particle-size distribution or texture is a determining for many agricultural factors such as choice of crops, irrigation methods, management of soil and fertilizer application. It is very important in the management of agricultural soils for optimum crop production. Plants' growth is influenced by the size of the soil particle because they control the availability of nutrient and root growth. Three types of grains control soil texture, these are sand, silt and clay (Chakraborty and Biswaranjan, 2015). Soil usually contain some amount of clay which influences its management and productivity (Newman, 1984). The amount of clay in soil is very important as the structure of soil depends very much on clay (Dixon, 1991).

The term clay refers to the soil separate consisting of particles less than 0.002mm in equivalent diameter. It influences many of the chemical and physical properties that make the soil a useful medium for plants' growth (Dixon, 1991). The Cations Exchange Capacity (CEC) of clays is among their most important properties in retaining plant nutrient because the selectivity of cations influences soils as a medium for plant growth and disposal of wastes e.g., radioactive and toxic metal ions (Dixon, 1991). Under any environmental condition, plant growth and production are controlled by soil structure resulting from reactions involving clay. Soil with low clay content such as sand and silt exhibit a narrow range over which physical properties can change and such soils may have low fertility and therefore, unfavorable for plant growth (Page, 1952). Soils with little clay have a simple structure compared to the one that has a higher amount with a more complex structure. Clay contributes to the formation of soil structure by undergoing seasonal shrinking and swelling (Dixon, 1991). Compared to other soils separates, clay often have a large predominantly negatively charged large surface area that retains nutrients against leaching and buffers the soil against extreme change in pH. When clay degrades, it is a source of plant nutrients (Newman et al., 1984). Soil organic matter tends to increase as the clay content increases. Under similar climate conditions, the organic matter content in heavy textured soils like clayey is two to four times that of light- textured soil like sandy soil (Bot and Benites, 2005). Presence of clay in soil particularly with small amounts of organic matter has a great effect on soil properties. Sodium Adsorption Ratio and Exchangeable Sodium Percentage relationship (SAR-ESP) vary with soil type due to differences in clay minerals content and consequently soil texture (Ezlit et al., 2010).

This paper is aimed at identifying variables that can be a determinant in the development of the proposed regression model for predicting the percentage of clay from saturated hydraulic conductivity, Bulk density, organic matter content and location. Coordinates of each irrigation sector were used for the location. The research will also study the relationship of clay as it exists in soil not as a soil separate with the aforementioned properties in the Kano River Irrigation Project (KRIP). The knowledge of this relationship is important due to the influence of these properties on soil condition that favours the growth of crops. The findings will be applied in the management of soil both under rain-fed and irrigated conditions.

2. Material and Methods

2.1 Study Area

The study was conducted in Kano River Irrigation Project located between latitudes 11°32`N and 11°51`N and longitudes 8°20`E and 8°40`E within the Sudan savannah zone of Northern Nigeria (Figure1). Rainfall is usually between July and September with maximum amounts of 214.0 mm. Average annual rainfall ranges from 635 to 889 mm, about 60% of which falls in July and August and varies considerably from year to year (Maina et al, 2012). The geology of the area consists of older granites and younger Meta sediments of Precambrian to lower Paleozoic age. The soils are mostly moderately deep to deep and well-drained with sandy loam texture at the surface and sandy clay loam textured subsoil (Jibrin et al., 2008).

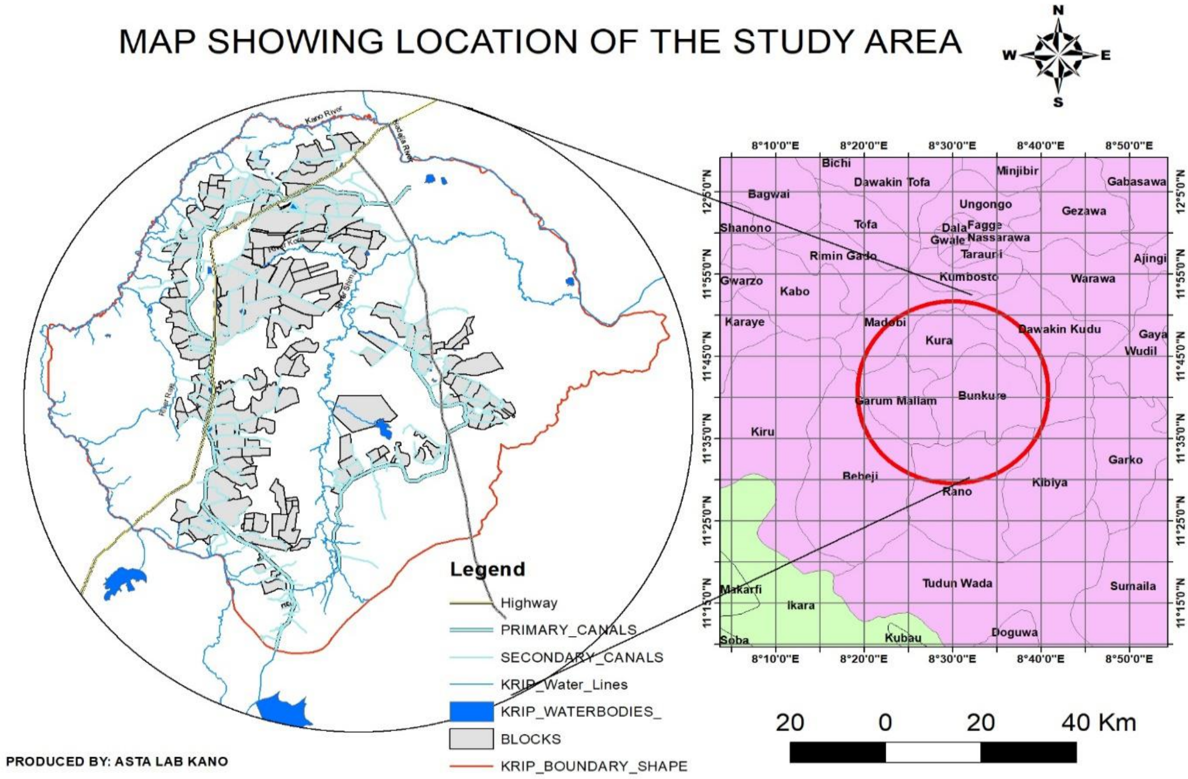

Figure 1: Map showing the location of the study area.
Source: Advance Space Technology Laboratory, BUK, 2019

The KRIP with a total area of 62,000 ha was planned to be implemented in two phases; the Kano River Irrigation Project Phases I and II. The main source of water for irrigation is the Tiga Dam which was constructed across River Kano between 1970 and 1974 and has a capacity of 1.968 billion m^3, a length of 6km and a height of 48 m (Mohammed et al., 2015).

2.2 Collection of Soil Samples

Soil samples were collected from forty (40) sectors in the study area for the measurement of soil properties. The collection was done with soil auger, digger, a wooden plank and core samplers. The auger was driven to a depth of 0-45 cm (active rooting depth for the crop grown in the study area). The collected samples were placed in a properly labeled polythene bags. The choice of the sampling points in a sector was done making sure that representative samples were collected. The coordinates of all the sampling points were taken using Garmin 78 GPS. The samples were taken to the laboratory for analysis.

Laboratory Analysis

Grain size analysis was performed in the laboratory by the Bouyoucos hydrometer method (Gee and Dr, 2002). The percentage of sand, silt and clay particles in the samples were determined using Eqns. 1 through 4 (Zakari et al, 2014):

$$\%(Si + C) = \frac{CHR_1}{Ws} \times 100 \quad (1)$$

$$\%C = \frac{CHR_2}{Ws} \times 100 \quad (2)$$

$$\%Si = \%(Si + C) - \%C \quad (3)$$

$$\%S = 100 - \%(Si + C) \quad (4)$$

where: Si = silt, C = clay, S = sand, CHR_1 = First Corrected Hydrometer Reading and CHR_2 = Second Corrected Hydrometer Reading, W_s= weight of sample.
Bulk density was determined by the use of the core sampler method (Grossman and Reinsch, 2002). The saturated hydraulic conductivity (K_{sat}) was measured using the constant-head permeameter method (Klute and Dirksen, 1986).

2.4 Statistical Analysis

Kriging which involved spatial interpolation was used to estimate values at unknown points of the sectors based on the values at sampling points. This is based on the fact that the result of the measured areas of the sectors in the KRIP close to points where samples were not taken have the most influence. Krige map of the parameters are presented in figures (2.0, 3.0 and 4.0). Pearson Correlation and Spearman coefficients were also used to determine the correlation between the variables viz-a-viz percentage clay content, saturated hydraulic conductivity, bulk density percentage organic matter content and location.

3. Results and Discussion

The result of the percentage of clay, saturated hydraulic conductivity (K_{sat}), and Organic matter content as well as soil texture was presented in Table 1. The data was used to study the influence of clay composition on these related properties of soil. The texture in most of the sectors of the KRIP is dominated by sandy loam. Jibrin et al. (2008) reported moderately deep and well-drained soil with sandy loam texture at the surface and sandy clay loam textured in the subsoil as recorded in Cirin and other sectors. The percentage of clay varies from the range of 22.12% to 5.4% as observed in Raje and Butalawa respectively. Soil having more clays and organic matter percentage composition could exhibit higher buffering capacity which is associated with greater Cation Exchange Capacity (Goswami et al., 2012).

Figure 2 shows the distribution of organic matter in KRIP. The mean value ranges from 0.956-1.83%. Goswani et al. 2012 reported that organic matter composition in tropical soil is often less than 1% compared to a range of 5 - 10% in the temperate regions. The lowest organic matter content of 0.1% was observed at Danbaki sector located in Bunkure local Government (Table 1). Variations were observed in the organic matter contents of the soils studied and this was largely attributed to the management and the environmental condition they are subjected to. These might be the reason for the difference in organic matter composition among the sectors. Most of the productive agricultural soils have organic matter content ranging between 3-6% (Bot and Benites, 2005). The organic matter content of agricultural topsoil is usually in the range of 1–6% (SARE, 2012).The percentage composition of organic matter in some of the sectors is outside this range as seen in Figure 2.

Table 1: Some Physical Parameters in the KRIP

S/n.	Sector	Latitude	Longitude	%clay	Sat. H. C. mm/s	B.Density g/cm3	% O.M	Texture
1	Makwaro	11.79361	8.42555	13.76	37.09	1.48	0.93	sandy loam
2	Samawa	11.72648	8.41517	14.12	40.1	1.49	0.75	sandy loam
3	Maura	11.71181	8.41544	5.76	86.15	1.44	0.89	Loamy sand
4	Yadakwari	11.75556	8.43	16.12	19.85	1.42	2.3	Loam
5	Karfi	11.82691	8.49362	13.04	48.18	1.48	0.62	sandy loam
6	Yakasai	11.80896	8.48967	6.12	91.26	1.44	0.72	Loamy sand
7	Fako	11.80427	8.4489	7.76	72.48	1.45	1.13	Loamy sand
8	Majabo	11.80896	8.48967	6.12	96.48	1.44	1.17	Loamy sand
9	Kadawa	11.65653	8.42211	13.76	38.08	1.48	1.17	sandy loam
10	Agalawa	11.66929	8.41747	14.12	0.56	1.4	2.71	Silt loam
11	Raje	11.67514	8.41458	22.12	12.94	1.43	0.86	Loam
12	Bangaza	11.62383	8.4228	9.76	39.37	1.44	1.06	Loam
13	Yantomo	11.62702	8.4181	11.76	50.82	1.48	1.06	sandy loam
14	Waire	11.62011	8.42201	12.12	33.66	1.45	1.48	Loam
15	Gayere	11.6088	8.4401	10.12	42.15	1.45	2.13	sandy loam
16	Dorayi	11.60343	8.45695	15.76	30.06	1.49	1.13	sandy loam
17	Butalawa	11.80043	8.43136	5.4	85.05	1.43	0.96	sandy loam
18	Gore North	11.7838	8.41911	9.76	54.28	1.46	1.34	sandy loam

19	Gore South	11.77794	8.41166	17.76	24.83	1.49	2.37	sandy loam
20	Rakauna	11.77254	8.41522	17.76	23.19	1.48	1.37	sandy loam
21	Azore	11.75889	8.40485	9.76	51.12	1.46	0.65	sandy loam
22	Makwaro T.	11.76028	8.41473	12.12	44.32	1.47	1.44	sandy loam
23	Agolas	11.76083	8.76083	21.76	14.88	1.47	2.3	Loam
24	Kosawa	11.77075	8.45932	13.76	44.27	1.5	0.82	sandy loam
25	Dalili	11.78264	8.42941	19.76	18.01	1.47	1.85	sandy loam
26	Kuruma	11.65692	8.54608	13.4	31.58	1.45	2.75	Loam
27	Turba	11.67368	8.5572	5.76	73.85	1.44	0.75	Sandy loam
28	Danbaki	11.6786	8.57298	12.12	33.66	1.45	0.1	Loam
29	Lautaye	11.68669	8.57095	13.76	40.1	1.49	1.85	sandy loam
30	Bunkure East	11.70087	8.54927	9.4	56.48	1.45	0.86	sandy loam
31	Bunkure west	11.70425	8.53818	5.76	73.85	1.44	0.62	Sandy loam
32	DANBALA UNGUWAR	11.72052	8.52496	9.76	69.45	1.47	0.79	Loamy sand
33	RIMI	11.7253	8.52774	11.76	40.61	1.46	1.1	sandy loam
34	Korawa	11.70209	8.53122	13.76	32.3	1.46	2.26	sandy loam
35	BARNAWA	11.59692	8.46341	11.4	43.52	1.46	1.68	sandy loam
36	SHIYE	11.62968	8.48921	9.76	49.57	1.46	1.48	sandy loam
37	KODE	11.6458	8.50751	13.76	26.97	1.44	2.33	Loam
38	CIRIN	11.64561	8.52347	23.64	13.36	1.53	1.34	Sandy clay loam
39	GAFAN	11.67092	8.41915	17.2	22.41	1.46	1.82	Loam
40	KORE	11.71632	8.42597	13.76	28.69	1.45	1.48	Loam

In western canal, nine sectors which include Karfi, Yakasai, Butalawa, Raje, Azore, Makwaro, Maura, Samawa and Kosawa were found to have a value of less than 1 %. Sectors with the composition of organic matter below 1% in Eastern canal are Turba, Danbala, Bunkure east and Bunkure west (Table 1.).

These imply the soils in such sectors are likely to have the low buffering capacity, low fertility and low microbial activities as well as low moisture retention(Overstreet and DeJong-Huges, 1992). The difference might be due to variation in texture, mineral composition and topography which influences organic matter accumulation through drainage. Organic matter could easily be lost from fine-textured soils whereas soil reach in clay minerals such as montmorillonite that favours accumulation of organic matter become aggregated (Goswami et al., 2012). These might be the reason for the variation in texture of the soils in the KRIP as reflected in Table 1. This study stresses the need for the application of manure and fertilizers to improve the productivity of soil in the KRIP.

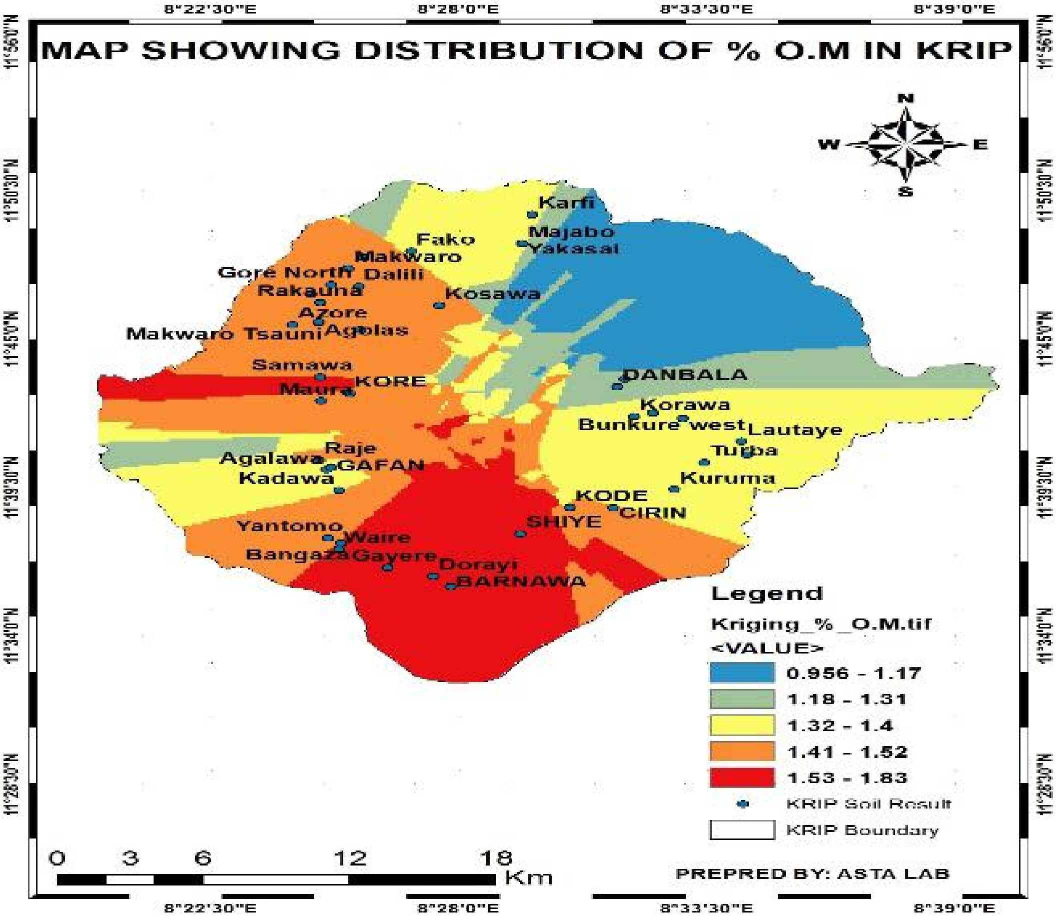

Figure 2.: Map Showing Distribution of Organic Matter

In clayey soils, the ideal soil bulk density that favors plant growth ranges from 1.47 and 1.10 g/cm^3 (Arshad et al., 1996). This is because it is an indicator of soil compaction. It also indicates the suitability for root growth and soil permeability and is very important for the soil-plant-atmosphere system (Katherine and Andrew, 2019). It is generally desirable to have soil with a Bulk Density <1.5 g/cm^3 for optimum movement of air and water through the soil (Hunt and Gilkes, 1992). Bulk density above thresholds indicate impaired function or soil's ability for structural support, water and solute movement, and soil aeration. However, the prevalent texture in the KRIP is sandy loam and in almost all the sectors, the value observed is below this range as seen in Figure 3. Therefore, soils in all the sectors are well aerated and will facilitate the movement of water through them.

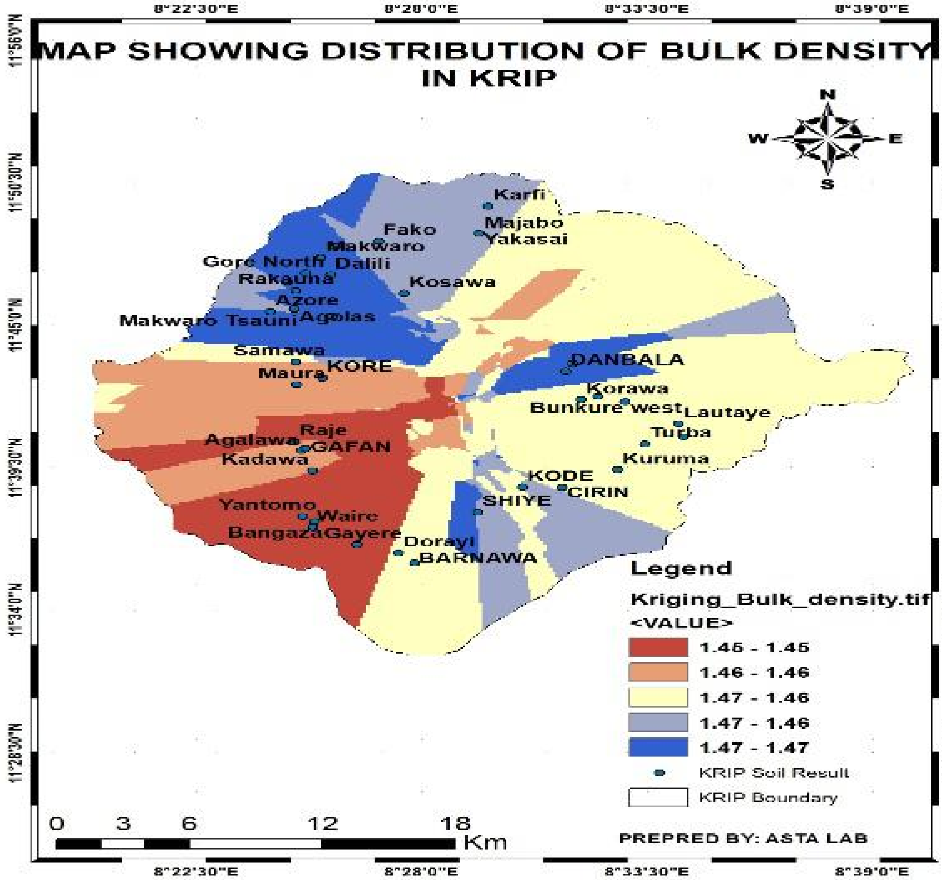

Figure 3.: Map showing Distribution of Bulk Density

The bulk density of the clay is usually low in contrast to the coarse grain soils like sand which has larger values, but fewer, pore spaces. In clay soils with good soil structure, there is a greater amount of pore space because the particles are very small, and many small pore spaces in between. The difference in soils bulk densities usually alters their saturated hydraulic conductivity. Saturated hydraulic conductivity is a measure of soil's ability to transmit water under saturation conditions. It is an essential parameter as it affects several processes such as infiltration rate, runoff, groundwater recharge, and nutrient transport in soil. The magnitude of saturated hydraulic conductivity is a function of texture among other factors, and is very essential in cultural and management practices, such as irrigation scheduling, drainage, flood protection, and control of erosion (García-Gutiérrez,et al, 2018). Variation of texture and bulk density in the KRIP might be the reason for the high range of K_{sat} in the sectors as seen in Figure 4.

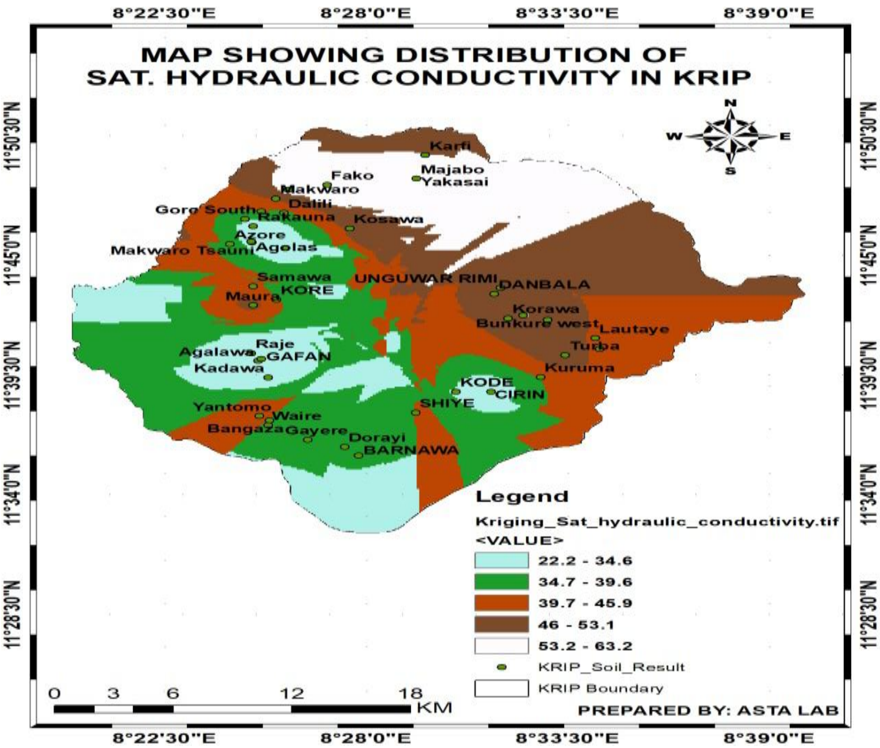

Figure 4. Distribution of Hydraulic Conductivity in KRIP

4. Correlation Analysis

The Pearson correlation coefficient between location (Latitude and longitudes) and % clay content as presented in Table 2 is -0.107 and represents a week negative relationship between the variables. The p-value of 0.511 for latitude as seen in Table 3 and Figure 5 indicates insignificant correlation as the value is higher than the significant level of 0.05.

Table 2: Correlation Coefficients of the variables with location

	% Clay		Saturated hydraulic conductivity (mm)		Bulk (g/cm3)	density	% Matter	Organic
	(r)	Rho	(r)	rho	(r)	rho	(r)	Rho
Latitude	-0.107	-0.1	0.322	0.283	0.025	0.055	-0.202	-0.255
Longitude	0.072	-02	0.018	0.152	0.08	-0.052	0.077	-0.048
% Clay			-0.876	-	0.442	0.452	0.407	0.473

r = Pearson correlation coefficient rho =Spearman correlation coefficient

A similar relationship was observed between latitude and saturated hydraulic conductivity, latitude and bulk density, latitude and percentage of organic matter content. The same trend of week and insignificant relationship between longitude and saturated. hydraulic conductivity, bulk density, %Organic Matter were also observed as presented in Figure 6.

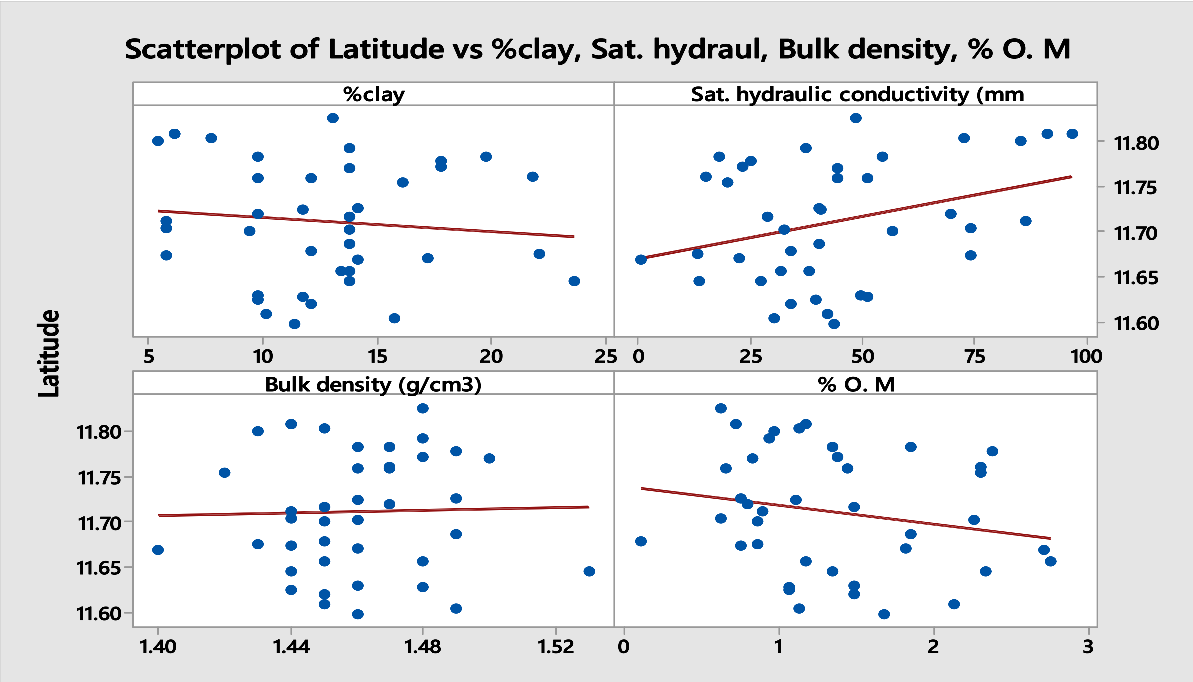

Figure 5: Scatter plot of Latitude vs % Clay, Saturated Hydraulic Conductivity, Bulk Density and % Organic Matter

This implies that the clay composition in all the sectors has no relationship with the location of the sector in the KRIP. Correlation analysis has also shown that the bulk density, organic matter content and saturated Hydraulic conductivity of soils in all the sectors have no relationship with the location of the sectors in the scheme.

Table 3: Strength (P-value) of the correlation coefficient

	% Clay		Saturated hydraulic conductivity (mm)		Bulk density (g/cm^3)		% Organic Matter	
	(r)	Rho	(r)	rho	(r)	rho	(r)	Rho
Latitude	0.511	0.539	0.043	0.076	0.879	0.735	0.212	0.113
Longitude	0.658	0.217	0.91	0.348	0.624	0.749	0.636	0.769
% Clay	-	-	0.000	-	0.004	0.003	0.009	0.002

r = Pearson correlation coefficient, rho =Spearman correlation coefficient

However, the results show that there is a linear relationship between % clay content and saturated hydraulic conductivity, latitude and bulk density, latitude and % Organic Matter. The Pearson correlation coefficient between % clay content of the soil in all the sectors and saturated hydraulic conductivity as seen in Table 2 is -0.876 and represents a strong negative relationship between the variables. This is evidenced in Figure 3. The p-value of 0.000 as shown in Table 3 is less than the significant level of 0.05 and that indicates significant correlation, i.e. as % clay content increases, the strength of saturated hydraulic conductivity tends to decrease.

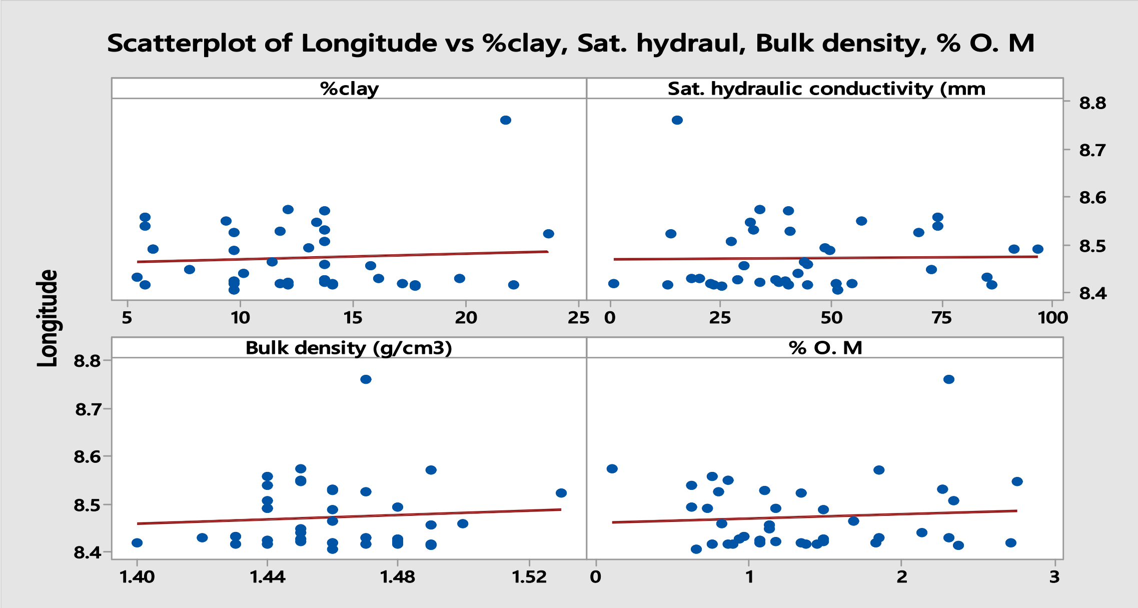

Figure 6: Scatter plot of Longitude vs Clay, Saturated Hydraulic Coductivity, Bulk Density and % Organic Matter

The Pearson correlation coefficient between % clay content of the soil in all the sectors and bulk density is 0.452 and represents a medium positive linear relationship between the variables. However, the Spearman correlation coefficient of 0.452 which is slightly higher than the value of the Pearson coefficient indicates that the relationship is more of a non-linear relationship than linear. The p-values for both Pearson and Spearman coefficients (0.04 and 0.03 respectively) are less than the significant level of 0.05.

This indicates that the correlation is significant. As percentage clay content increases, the bulk density tends to increase. The Pearson and Spearman coefficients between percentage Clay content and percentage O.M content are 0.407 and 0.473 respectively. This represents a positive relationship between the variables as seen in Figure 7. Based on the magnitude of the coefficient, it may be deduced that the relationship is more of non-linear. The p-values (0.009 and 0.002) of these coefficients, are also less than the significant level of 0.05. Hence, the correlation is significant. The reason for the increase might be due to the presence of sand particles more than the silt in the soils as higher percentage of sand was observed compared to other soil separates.

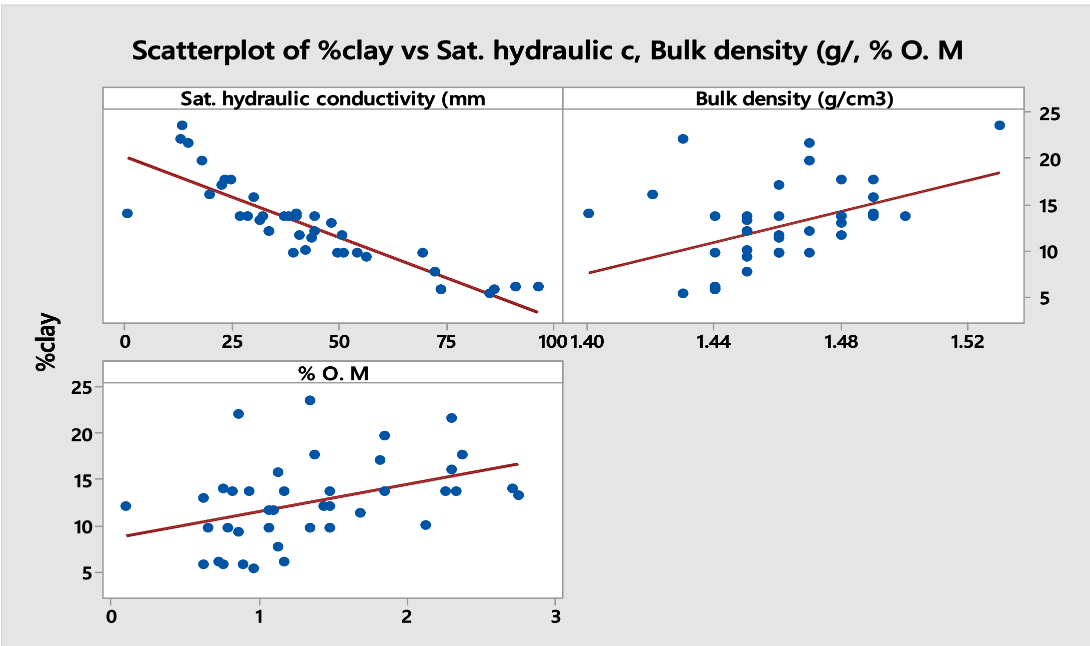

Fig. 7: Scatter plot of Clay vs Sat. Hydraulic, Bulk Density and % O.M

Based on the above analysis, it is only % clay content of the soil that has a relationship with the other variables and hence organic matter content, Saturated Hydraulic Conductivity and bulk density can be used as one of the determinant variables in a model aimed at predicting the percentage clay in soils.

5. Conclusions

The influence of clay composition on organic matter content, Saturated Hydraulic Conductivity and bulk density of soils in a different part of the KRIP was studied. The percentage clay varied from the range of 22.12 to 5.4% as observed in Raje and Butalawa respectively. The texture in most of the sectors is dominated by sandy loam. The organic matter content is typical of agricultural topsoil as all the sectors have an organic matter within the range of 1–6%. However, there is a need for the application of organic manure and fertilizer to improve soil productivity and buffering capacity as the organic matter of all the sectors is below the range of 3-6% for Productive soils. The variation of texture and bulk density in the KRIP might be the reason for the high range of K_{sat} in the sectors.

The Pearson correlation coefficient between percentage clay and bulk density is 0.452 and represents a medium positive linear relationship between the variables. However, the Spearman correlation coefficient of 0.452 indicates that the relationship is more of a non-linear relationship than linear. The Pearson correlation coefficient (0.876) between percentage clay content of the soil in all the sectors and saturated hydraulic conductivity represents a strong negative relationship between the variables that is to say as the percentage clay content increases, the strength of saturated hydraulic conductivity tends to decrease. The percentage clay has no relationship which location of sectors based correlation analysis. The Pearson and Spearman coefficients between percentage Clay content and percentage organic matter are 0.407 and 0.473 respectively and this represents a positive relationship between the variables. Therefore, organic matter, Saturated Hydraulic Conductivity and bulk density can be used as one of the determinant variables in a model aimed at predicting the percentage clay of soils in KRIP.

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