

Spatial Distribution of Soil Physical and Chemical Characteristics at Umaisha, Nassarawa State of Nigeria

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Abstract

Soil samples were taken from Umaisha village (derived savanna) in Nassarawa State to produce spatial maps of soil physico-chemical properties. Surface (0 – 20 cm) composite soil samples were taken at random. The soil samples were analysed using standard methods. Data generated were subjected to descriptive statistics. Ordinary Kriging was used for extrapolation to produce the spatial distribution maps. Results indicated that the soil was characterized by a loamy sand texture with a high sand content (76.50 %) predominant over the silt (14.00 %) and clay (9.50 %) fractions. The soil showed a slightly acid reaction (mean=6.27 in H₂O) and was non-saline (mean EC=0.04 Cmol/kg) and non-sodic (mean Na=0.09 Cmol/kg). Mean total nitrogen (0.67 %), calcium (3.67 Cmol/kg) and magnesium (1.04 Cmol/kg) were high while mean available phosphorus (9.84 mg/kg) and potassium (0.43 Cmol/kg) were moderate. Organic carbon (0.78 %), sodium (0.09 Cmol/kg), cation exchange capacity (5.67 Cmol/kg), exchangeable acidity (0.50 Cmol/kg) and electrical conductivity (0.04 Cmol/kg) were low in the soil. Strong variability existed in the distribution of total nitrogen (CV=134.79 %) and exchangeable acidity (CV=102.63 %). In conclusion, the soil showed moderate variability in silt (CV=69.31 %), clay (CV=55.87 %), organic carbon (CV=47.87 %), available phosphorus (CV=55.23 %), calcium (CV=72.28 %), magnesium (CV=66.46 %), potassium (CV=65.96 %), sodium (CV=50.93 %), cation exchange capacity (CV=57.91 %) and electrical conductivity (CV=68.51 %) with only the sand (CV=17.78 %) fraction showing a low variability.

Keywords: Spatial Distribution, Physical, Chemical, soil Characteristics, Derived Savanna, Nigeria.

1. Introduction

Monitoring concentrations of soil fertility indicators become highly imperative for sustainable soil management and profitable crop production (Antwi *et al.*, 2016). Food insecurity is one of the major problems affecting humanity in Sub-Saharan African (SSA) countries where the human population is about 646 million (Antwi *et al.*, 2016). This necessitates continuous cropping and subsequent loss of soil fertility leading to low crop yields (Martey *et al.*, 2014; Wairegi, 2011; Nkonya, 2004).

The tedious and costly conventional methods needed to obtain soil nutrient information will also be reduced when nutrient levels are mapped because those conventional methods are no more affordable (Behrens and Scholten, 2006). Accordingly, mapping of the nutrient levels will provide spatial soil nutrients information that can be used as a decision support tool. Hence, developing spatial distribution maps of soil nutrients is important.

Mapping of soil fertility indicators especially nitrogen (N), phosphorus (P) and potassium (K) would also facilitate proper monitoring and review of recommended farming technologies at locations from time to time. To increase the productivity of soils in the region these soils for enhanced crop yields and increase the income of smallholder farmers, spatial distribution of the major soil nutrients needs to be mapped and based on the results of the distribution, appropriate fertilizer needs could be recommended. The mapped results of the soil nutrient

assessment could then be used for effective monitoring of changes that might occur between cropping systems' and seasons' overtime (Behrens and Scholten, 2006).

In addition, due to the growing knowledge in precision agriculture (Buick, 1997; Ping *et al.*, 2009) researchers and decision-makers in soil science would be in a better position to implement location-based technologies, if approximate levels of soil nutrients in specific locations in the region are mapped. This approach will improve soil fertility management in the study area. The objectives of this study are therefore (i) to determine the soil fertility indicators in the study area (ii) To produce a spatial distribution map of these indicators in the area.

2.0 Materials and Methodologies

2.1 Background Information on the Study Area

The study area is located at Umaisha in Toto Local Government Area of Nasarawa State of Nigeria which falls within derived savanna region or the dry woodland savanna as part of the major floral formation of the Nasarawa State (FDF, 2019) lying between latitude $7^{\circ}46'10''$ to $8^{\circ}42'5''$ N and longitude $6^{\circ}48'45''$ to $7^{\circ}39'35''$ E (Figure 1). The region constitutes an east-west band between the Lowland Rain Forest and Guinea Savanna ecological zones, and is characterized by dense populations. The impact of man has been so intense in this area that areas left to regrow tend to grow savanna type grasses (FDF, 2019).

It has a climate typical of the tropical zone because of its location and is quite pleasant. It has a maximum and minimum temperature of 81.7° F and 16.7° F respectively. Rainfall varies from 131.73cm in some places to 145cm in others. The months of December, January and February are cold due to harmattan wind blowing across the State from the North-East. It is characterized by two distinct seasons: dry and rainy. The dry season spans from November to February, while the rainy season is from March to October.

(<http://www.nasarawastate.gov.ng/about.php>).

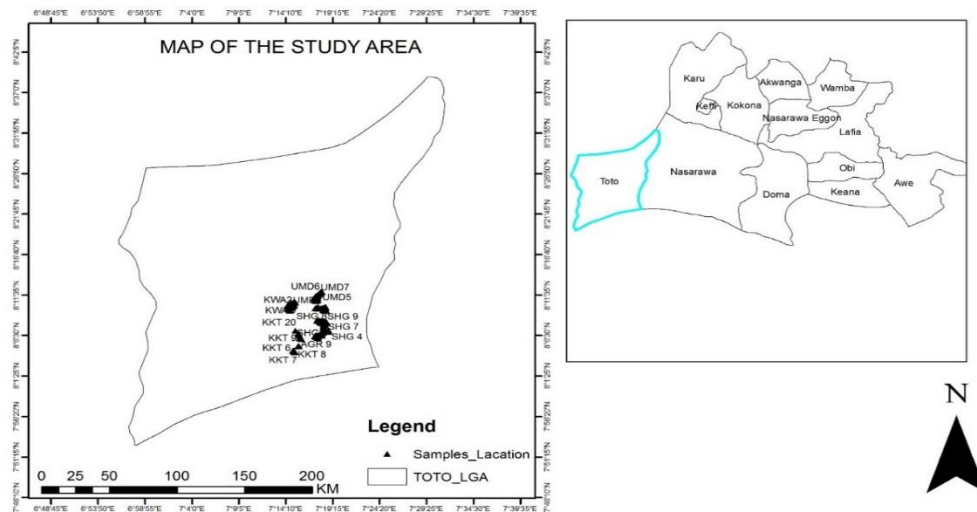


Figure 1: Location of the Study Area



2.2 Soil Sampling and Preparation

Random soil sampling technique was used to collect the soil samples across the entire area. A total of 170 composite surface (0 – 20 cm) soil samples were collected (Figure 1). Each composite sample was a mixture of four (4) soil cores.

The soil samples were air-dried, sieved to pass through a 2mm mesh and analyzed for soil fertility indicators including particle size distribution, textural class, soil reaction (pH: H₂O), electrical conductivity (EC), organic carbon (OC), total nitrogen (TN), available phosphorus (AVP), exchangeable acidity (EA), exchangeable bases (Ca, Mg, K and Na) and cation exchange capacity (CEC) using standard laboratory analytical methods.

2.3 Soil Analytical Methods

The soil pH was determined in soil water ratio of 1:2.5 by using glass electrode pH meter (Mclean, 1965). Ten (10 g) of air-dried soil sample was weighed and used. The pH meter was calibrated with buffer 4 and 7. The result was reported as "soil pH measured in water" pH (H₂O) while total nitrogen (N) and available P (phosphorus) were determined using the methods described by Bremner (1965) and Bray and Krutz (1945), respectively. Organic carbon (OC) was determined by wet oxidation method as described as described by Nelson and Sommers (1982). Exchangeable bases (Ca, Mg, K and Na) were extracted using the method described by Anderson and Ingram (1993). Potassium and sodium were determined using flame photometer while calcium and magnesium were determined using atomic absorption spectrophotometer. The electrical conductivity (EC) was determined using saturated paste extract of 1:2.5 soil water ratio using electrical conductivity meter at 25°C (Bower and Wilcox, 1965). The cation exchange capacity (CEC) was determined with 1 M ammonium acetate saturation method (Chapman, 1965).

2.4 Data Analysis

The collected data from the surface points were subjected to descriptive statistics (minimum, maximum, average, coefficient of variability and standard error) in order to summarize the distribution and the status of the result. To understand the spatial distribution of the studied soil properties, the geo-referenced data were interpolated using an Inverse Distance Weighing (IDW) in ArcMap version 10.2.2 and ArcGIS Geo-statistical Analyst Extension were used. The semivariogram models (Circular, Spherical, Tetraspherical, Pentaspherical, Exponential, Gaussian, Rational Quadratic, Hole effect, K-Bessel, J-Bessel, Stable) were tested for each soil parameter data set. Ordinary Kriging was used for extrapolation to produce the spatial distribution maps.

3.0 Results and Discussion

3.1 Physical Properties of the Soil

3.1.1 Soil Particle Size Distribution

The result of particle size distribution (percentage of sand, silt and clay) is presented in Table 1. The predominant textural class observed Loamy Sand with high sand content of more than 70 % across the area. There was low variability in the sand content as expressed by the low CV of 17.78 %). The sand fraction predominates over the silt and clay fractions across the area as indicated by the mean value (Table 1). Imam (2014) also reported predominance of sand fraction over the silt and clay in similar soils ranging from 81 to 85%. This may be probably attributed to the fact that the soil was developed on unconsolidated sediments. The clay content was low

(9.50 %) on the average. The sandy nature of the soil calls for proper soil management to reduce the effect of nutrient leaching during the cropping season.

Table 1: Physical Properties of the Soil

Soil Parameter	Mean	Min	Max	CV	Std Err
% Sand	76.50	27.12	93.12	17.78	1.04
% Silt	14.00	1.84	49.84	69.31	0.74
% Clay	9.50	1.04	39.04	55.87	0.41

The spatial distribution of percent sand, silt and clay in the study area is presented in Figures 2, 3 and 4, respectively.

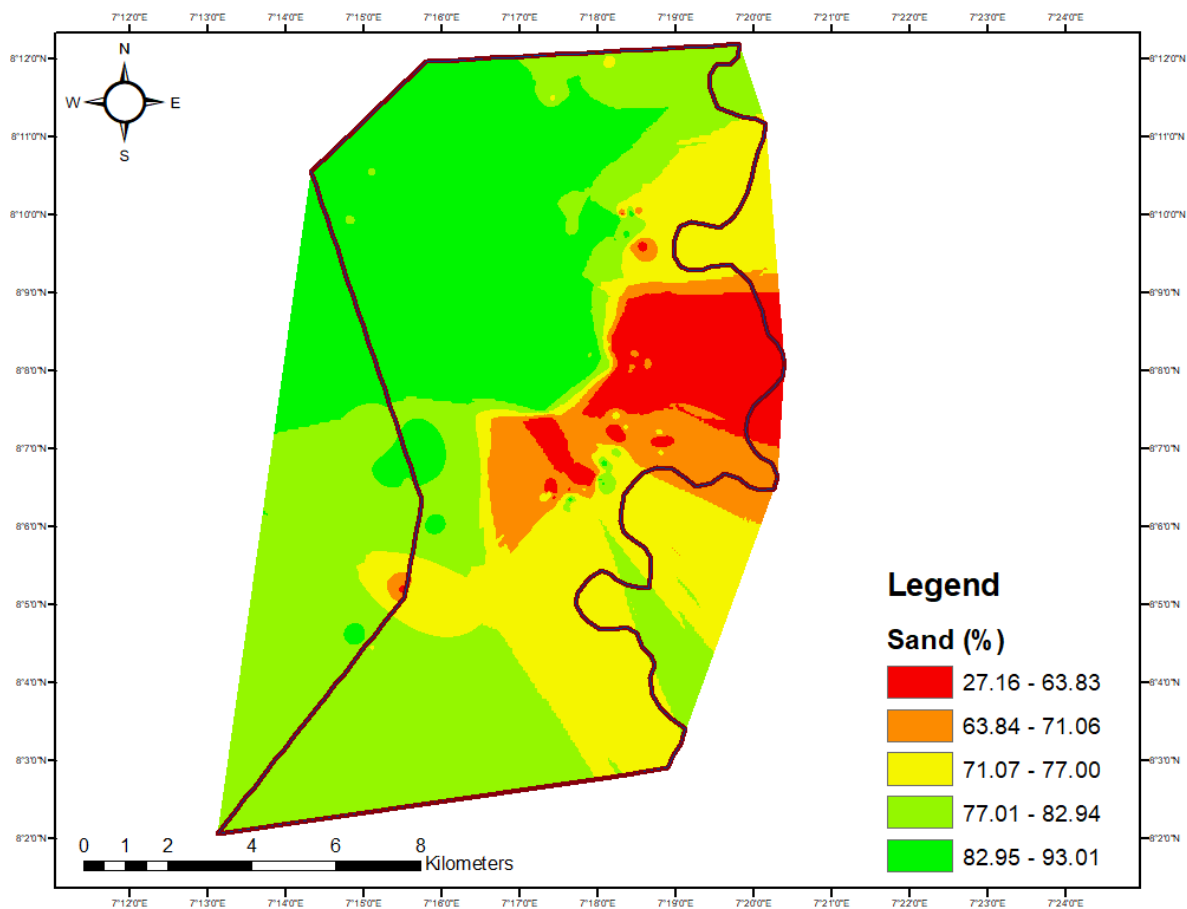


Figure 2: Spatial Distribution of Sand across the Study Area.

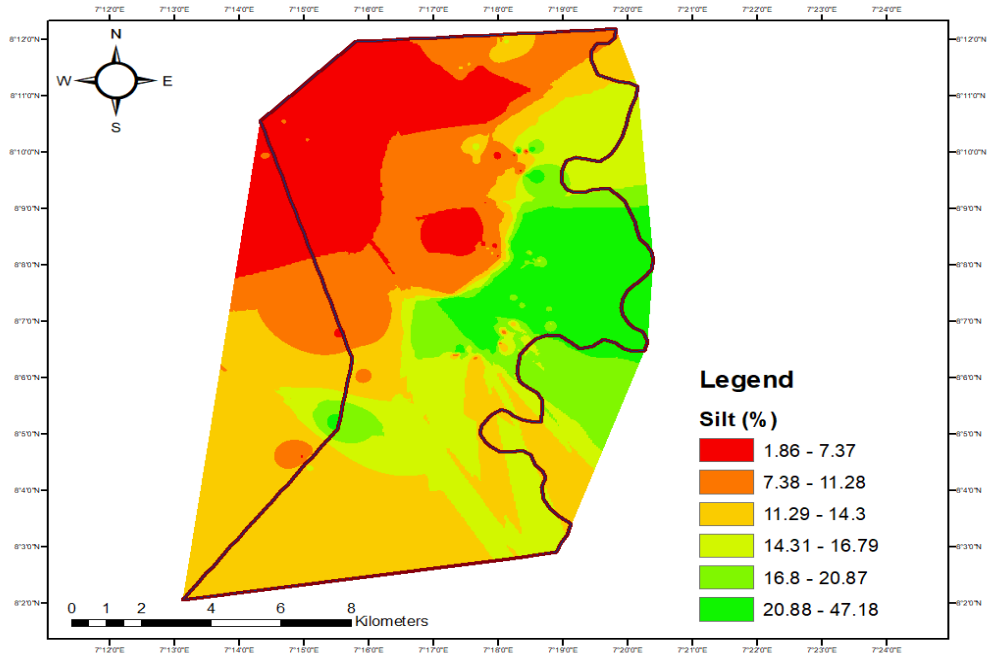


Figure 3: Spatial Distribution of Silt across the Study area

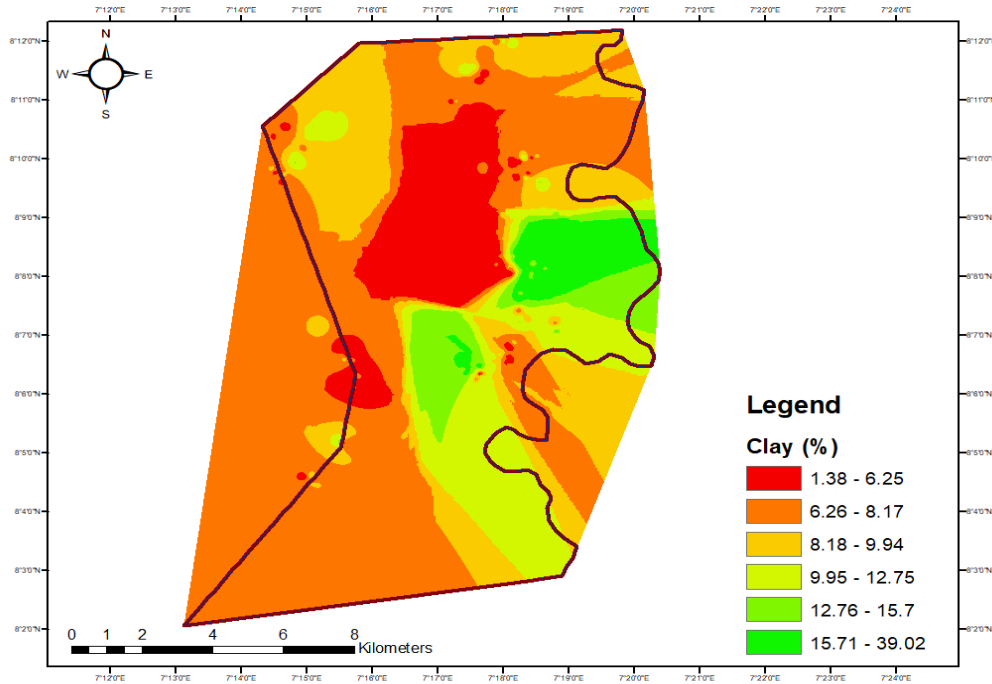


Figure 4: Spatial Distribution of Clay across the Study Area

3.2 Soil Chemical Properties

The descriptive statistics of the soil chemical properties is presented in Table 2. The spatial distribution of soil pH, total nitrogen, organic carbon, available phosphorus, exchangeable potassium, exchangeable calcium, exchangeable magnesium, exchangeable sodium, cation exchange capacity, exchangeable acidity and electrical conductivity is presented in Figures 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15 respectively.

Table 2 Descriptive Statistics Soil Chemical Properties

Soil Parameter	Mean	Min	Max	CV	Std Err
%O.C	0.78	0.06	1.78	47.87	0.03
%O.M	1.35	0.10	3.06	47.87	0.05
AVP (mg/kg)	9.84	5.36	22.17	26.88	0.20
Ca (Cmol/kg)	3.67	0.85	19.53	72.28	0.20
Mg (Cmol/kg)	1.04	0.18	4.90	66.46	0.05
pH(H ₂ O)	6.27	5.08	7.36	7.23	0.03
pH(KCl)	5.12	3.76	6.26	9.27	0.04
EC (dS/m)	0.04	0.00	0.24	68.51	0.00
N (%)	0.67	0.07	6.93	134.79	0.07
K (Cmol/kg)	0.43	0.07	1.58	65.96	0.02
Na (Cmol/kg)	0.09	0.03	0.30	50.93	0.00
E.A (Cmol/kg)	0.50	0.17	6.67	102.63	0.04
CEC (Cmol/kg)	5.67	1.08	22.39	57.91	0.25

3.2.1 Soil pH

It was observed that the mean pH value across the area was 6.27 which was categorized as slightly acidic. There was low variability in pH across the area with a low coefficient of variability of 7.23 %.

The pH classes ranged from strongly acidic through moderately acidic to slightly acidic (NSPFS, 2005). Figure 5 shows that most part of the area falls within the slightly acidic class which is optimum for most of the cereals, legumes and vegetable crops grown in the Savanna of Nigeria. This is because at this pH level most of the mineral nutrients for the growth and development of the plant are available (Odunze *et al.*, 2006).

3.2.2 Total Nitrogen

The average total nitrogen across the study area was found to be 0.67 %, with a minimum value of 0.07 % and a maximum of 6.93 %. The average total nitrogen across the sampling points was categorized as high (NSPFS, 2005) with a high CV of 134.79 % indicating high variability. This is in agreement with the findings of Antwi *et al.*, (2016) that generally the distribution pattern for N and K nutrients were found to be clusters of low or high contents at specific locations. The spatial distribution of nitrogen across the area also reveals that the nitrogen was high across the sites (Figure 6). The high nitrogen content of the soil is an indication of high fertility, therefore

there is a need for improving the soil structure through fertilizer and manure management practices to maintain the fertility status.

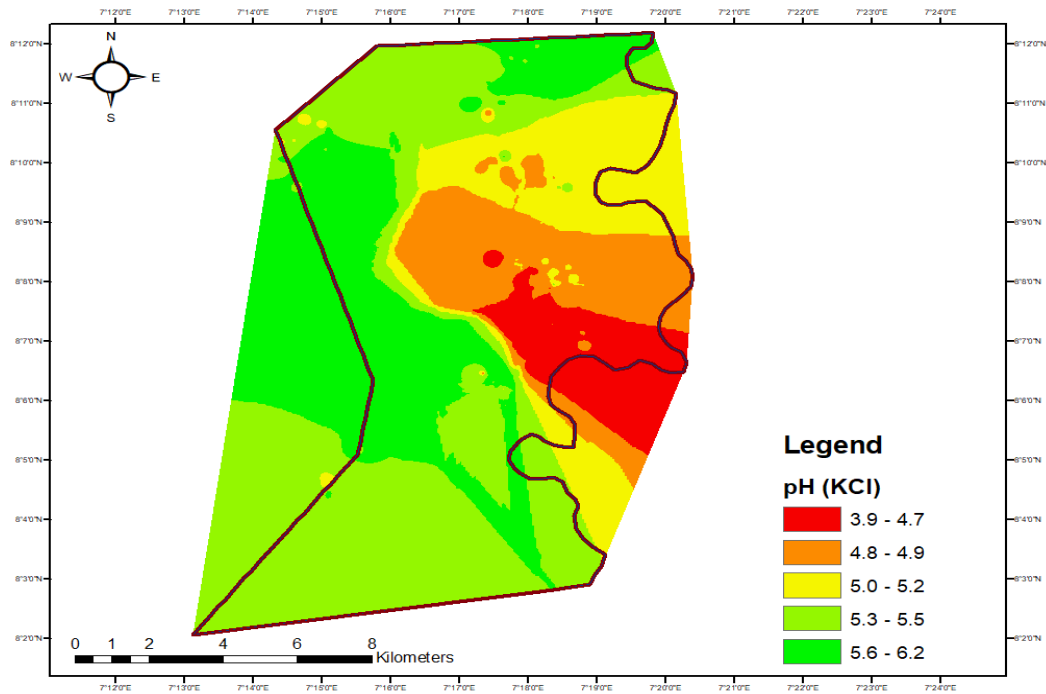


Figure 5: Spatial Distribution of Soil pH across the Study Area

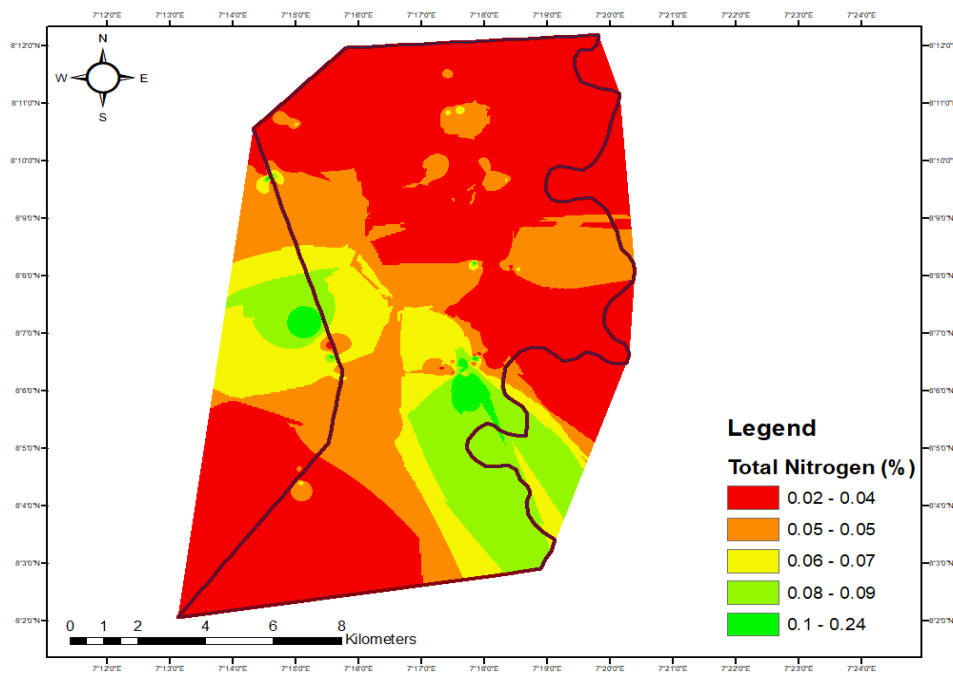


Figure 6: Spatial Distribution of Total Nitrogen across the Study Area

3.2.3 Soil Organic Carbon

The mean value of organic carbon in the study area was 0.78 % which was categorized as very low. The organic carbon level across the area ranged from 0.06 % to 1.78 %, showing moderate variations (CV = 47.87 %). The spatial distribution of soil organic carbon across the area shows that organic carbon was low as indicated in Figure 7. Although some part of the area has higher organic carbon than others, the difference is insignificant considering the importance of organic carbon both in terms of improving soil structure and as a pool for plant nutrients.

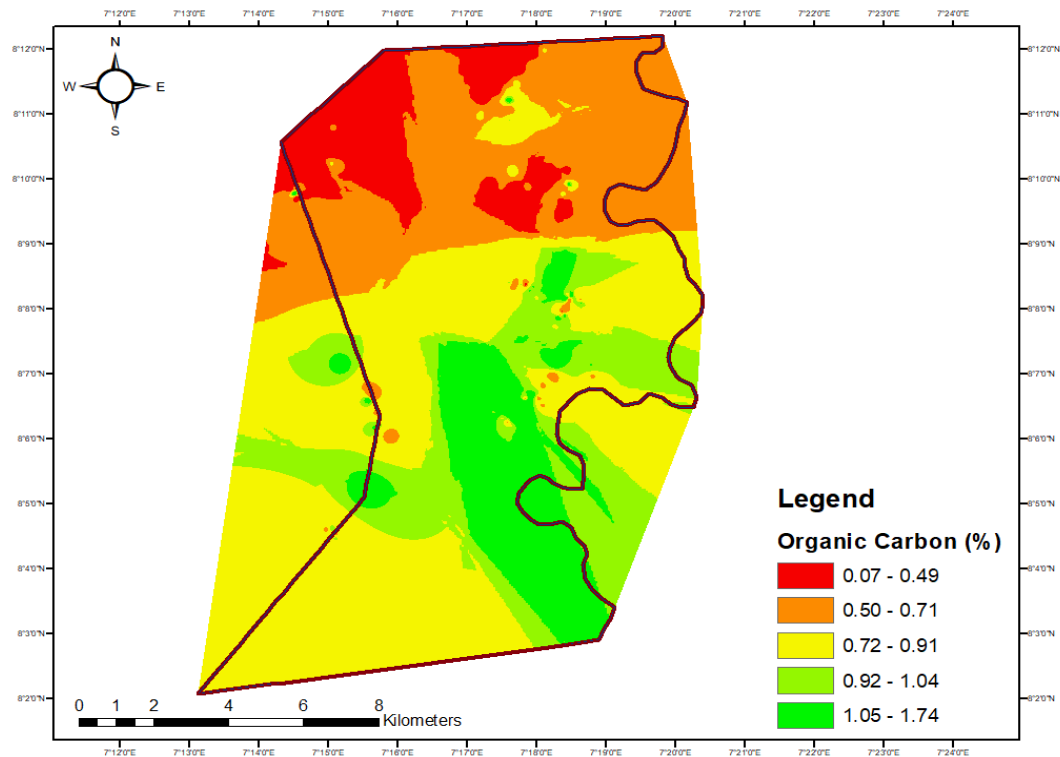


Figure 7: Spatial Distribution of Soil Organic Carbon across the Study Area.

3.2.4 Available Phosphorus

The available phosphorus ranged from 5.36 to 22.70 mg/kg with a mean value of 9.84 mg/kg which falls under the moderate category (NSPFS, 2005). The spatial distribution of phosphorus (Figure 8) showed a moderate variability with a CV of 55.23 %. Polygons of moderate phosphorus levels may be targeted for legumes production due to the high demand of phosphorus by the leguminous crops. Phosphorus availability in the farm may be improved by manure and phosphorus fertilization.

3.4.5 Soil Exchangeable Bases and Cation Exchange Capacity

The mean exchangeable potassium was 0.43 Cmol (+)/kg which was rated as high according to Esu (1991). Considering the spatial distribution of potassium in the area (Figure 9), it could be observed that a large portion of the area has medium to high potassium content, while some few areas are low in potassium. These showed that the farm requires different potassium management strategy, such that places with high potassium level should be allocated for high potassium demanding crops like tree crops. The high potassium content in some part of the area is expected due to the presence of an appreciable

amount of K-bearing Feldspar minerals previously reported in the basement complexes of Northern Nigeria (Esu, 1991).

The mean exchangeable calcium, magnesium and sodium across the study area were 3.67, 1.04 and 0.09, respectively. Calcium and magnesium were rated as high while sodium was rated as low (Esu, 1991). Figures 10, 11 and 12 show the spatial distribution of calcium and magnesium and sodium across the area, respectively. Although most part of the farm have high calcium and magnesium levels, there are areas of moderate to low level of these soil parameters which should be taken into consideration during the crop suitability analysis. Sodium was generally low making the soil to be non-saline. The exchangeable Ca, Mg, K and Na varied moderately across the study area with CV values of 72.28, 66.46, 65.96 and 50.93 % respectively (Table 2).

The average cation exchange capacity of the area was 5.67 Cmol (+)/kg with a range of 1.08 to 22.39 Cmol (+)/ kg, rated as low (NSPFS, 2005; Esu, 1991). The low cation exchange capacity implies low nutrient holding capacity of the soil. Considering the spatial distribution of cation exchange capacity across the area (Figure 13). The cation exchange capacity varied moderately in the area with a CV of 57.91 %.

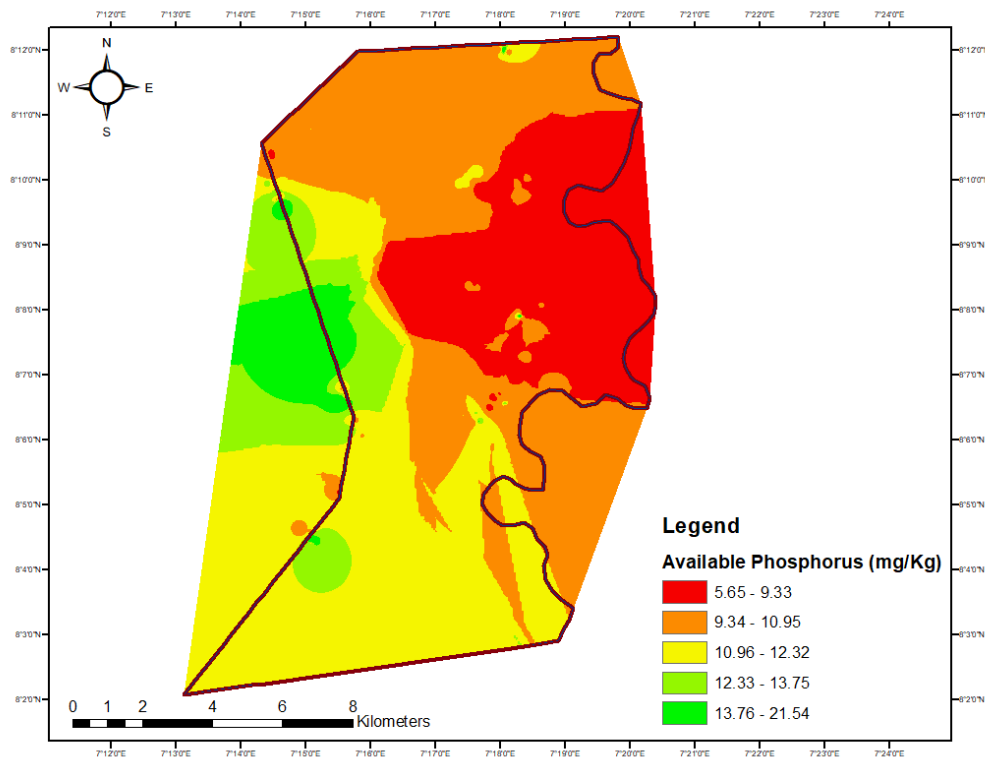


Figure 8: Spatial Distribution of Phosphorus in the Study Area

3.4.6 Electrical Conductivity

The spatial distribution of electrical conductivity is presented in Figure 15. It was found to be very low and varied moderately (CV = 68.51 %) across the study area. Thus, the soils were non-saline.

Notably, all the soil nutrients studied showed variability in their spatial distribution in the study area with only the sand content showing low variability. This may be as a result of differences in nutrient management strategies (Tsirulev, 2010), pattern of land use or quantity of fertilizer used (Liu *et al.*, 2006).

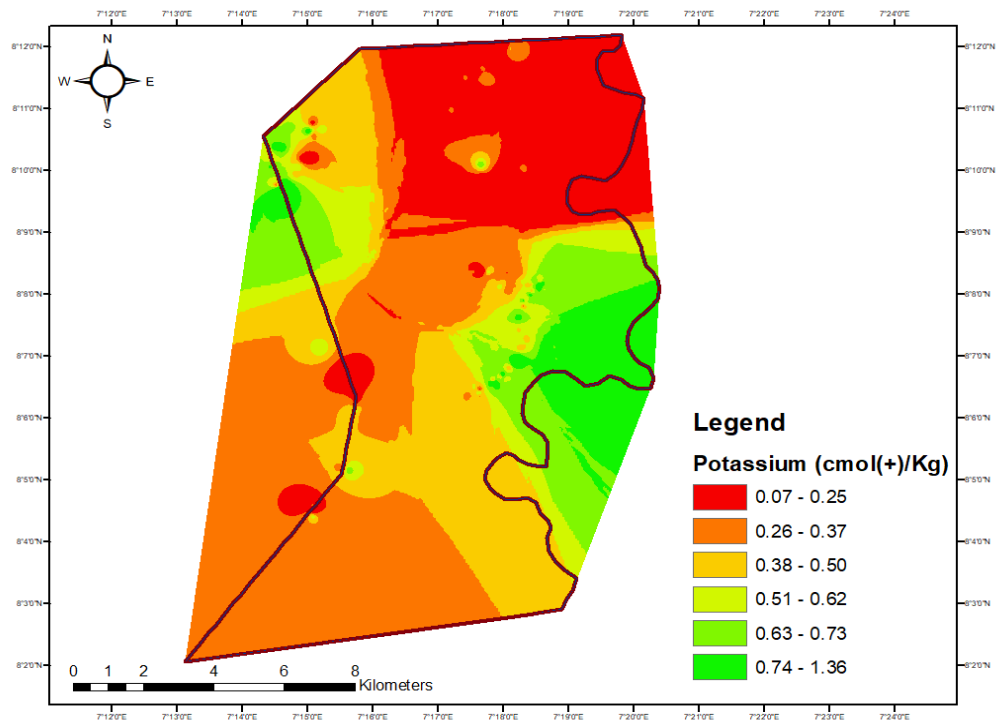


Figure 9: Spatial Distribution of Potassium across the Study area

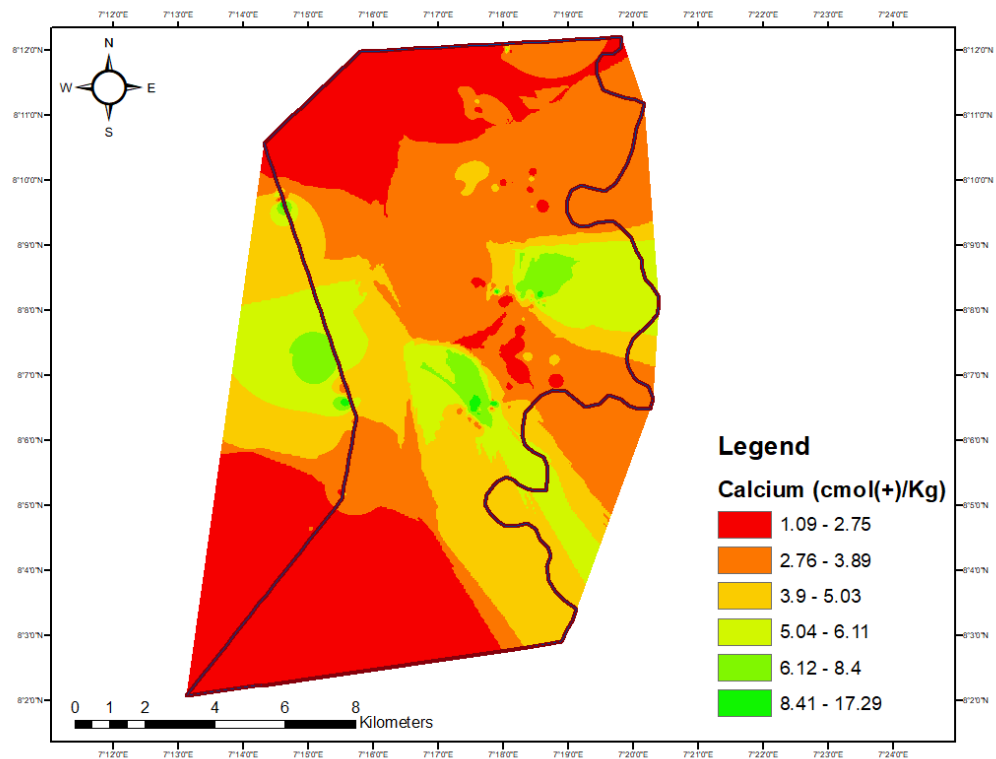


Figure 10: Spatial Distribution of Calcium across the Study area

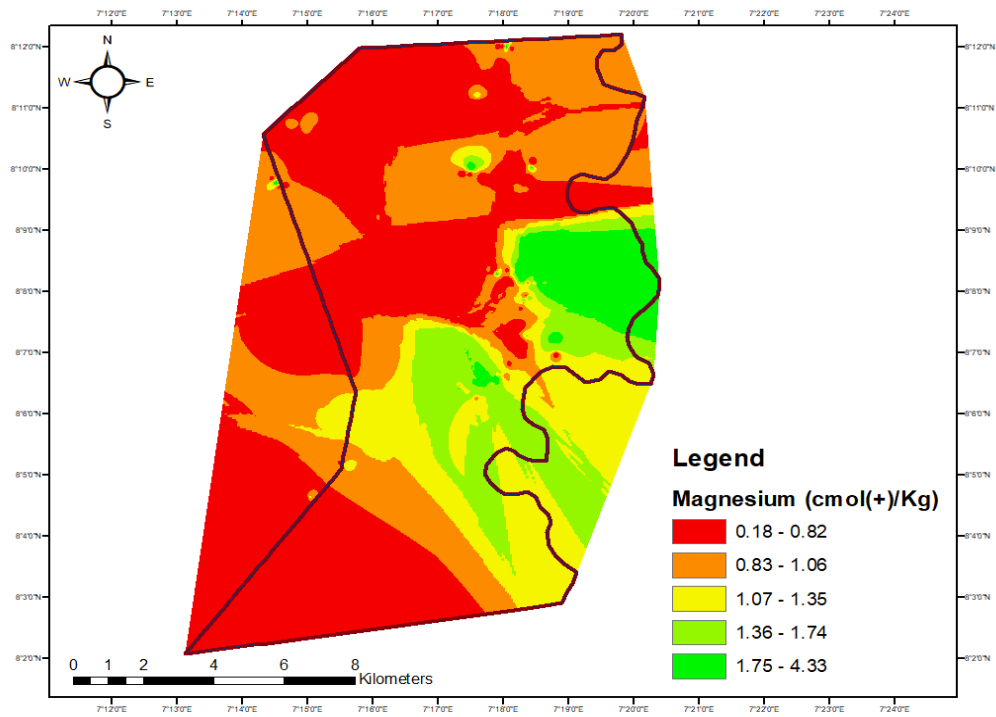


Figure 11: Spatial Distribution of Magnesium across the Study area

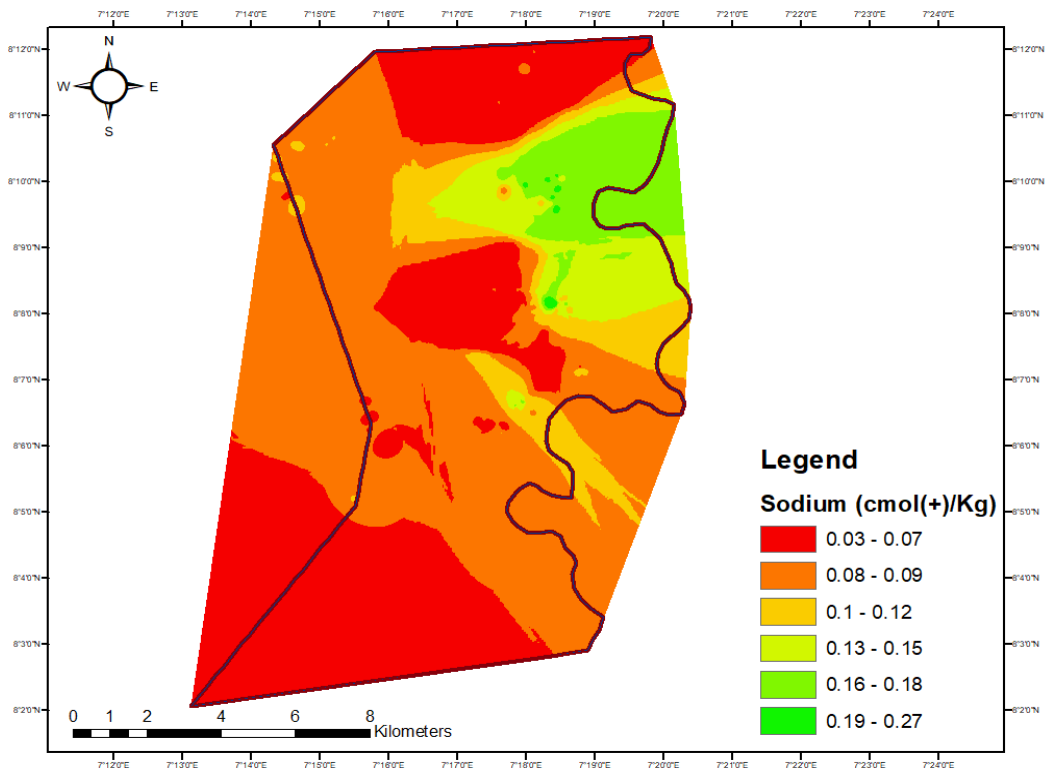


Figure 12: Spatial Distribution of Sodium across the Study area

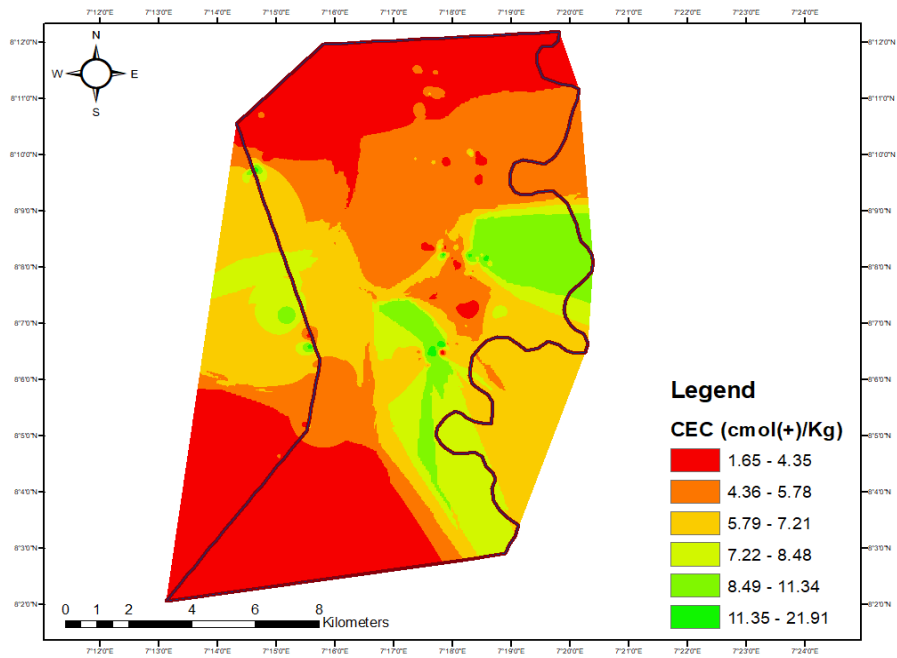


Figure 13: Spatial Distribution of Cation Exchange Capacity across the Study area

3.4.7 Exchangeable Acidity

The spatial distribution of exchangeable acidity is presented in Figure 14. The exchangeable acidity was observed to be low. However, it varied highly across the study area (CV = 102.63 %).

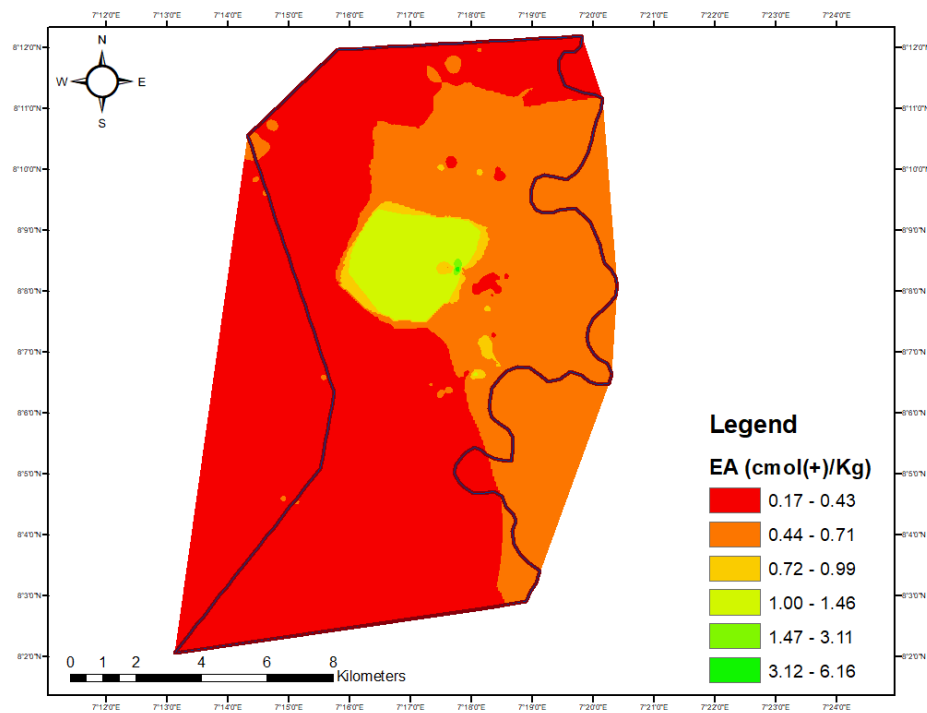


Figure 14: Spatial Distribution of Exchangeable Acidity across the Study area.

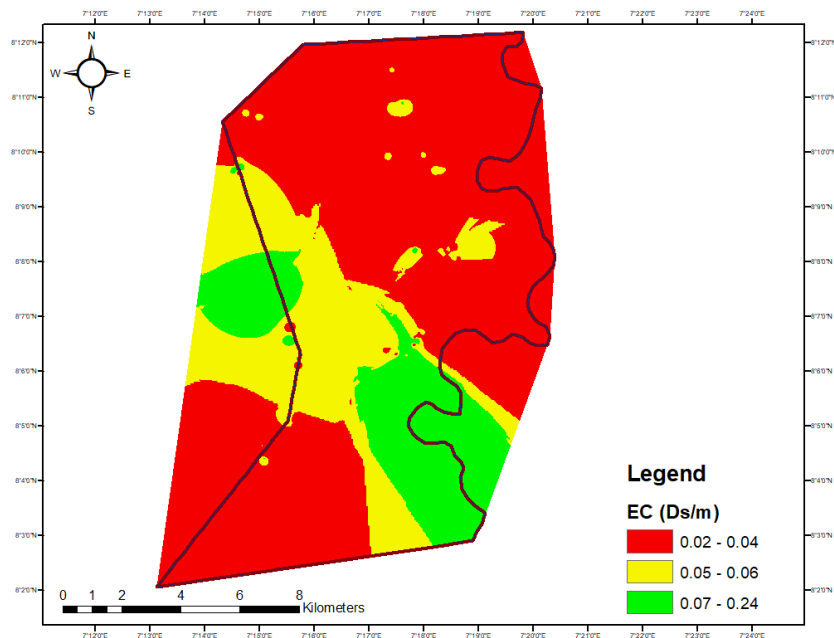


Figure 15 Spatial Distribution of Electrical Conductivity across the Study area

4.0 CONCLUSION

The objectives of the research were clearly achieved. The soil was characterized by a loamy sand texture with a high sand content predominant over the silt and clay fractions. The soil showed a slightly acid reaction and was non-saline and non-sodic. Concentrations of total nitrogen, exchangeable calcium and magnesium were high in the area while concentrations of available phosphorus and exchangeable potassium were moderate in the soil. However, organic carbon, exchangeable sodium, cation exchange capacity, exchangeable acidity and electrical conductivity were low in the soil.

Strong variability existed in the distribution of total nitrogen and exchangeable acidity. The soil showed moderate variability in silt, clay, organic carbon, available phosphorus, exchangeable calcium, magnesium, potassium, sodium, cation exchange capacity and electrical conductivity with only the sand fraction showing a low variability.

5.0 RECOMMENDATION

It is recommended that incorporation of organic materials such as crop residues and farmyard manure should be adopted in order to improve the low organic matter and cation exchange capacity of the soil. Different potassium management strategies, such as the allocation of high potassium-demanding crops e.g. tree crops to areas with high potassium content should be adopted for increased and sustainable crop production in the study area.

6.0 ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of Mal. Ibrahim Mohammed who assisted in the collection and laboratory analyses of the soil samples.



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