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Full Length Research Paper

Spatial heterogeneity of salinity parameters in vertisols of Kerau, Guyuk area of Adamawa state, Nigeria

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Abstract

This study assessed the heterogeneity of pH, Electrical Conductivity ($EC_{1:2}$) and Exchangeable Sodium Potential (ESP) of Vertisols of a 0.5hectares farmland in Kerau village located in Guyuk Area of Adamawa state, Nigeria. The objective was to examine the soil salinity status and variability at the study site. The grid sampling technique was used to collect 50 soil samples at each of 0-15cm and 15-30cm depths of the study site. Accordingly, descriptive statistics were used to examine the physical and chemical properties of the soil. Semivariogram analysis was used to assess the spatial variation of soil properties while ordinary kriging interpolation technique was used to map the spatial distribution of soil properties. The findings showed that vertisols of the study area are alkaline in nature evident by the high pH values recorded. They however exhibited very low EC and ESP values indicating the absence of salinity or sodicity problems in the soil of the study area. The study recommends periodic assessment of soil salinity parameter in the study area in order to avoid its effects on crops.

Keywords: salinity, sodicity, semivariograms, kriging, vertisols

INTRODUCTION

Soil salinity and sodicity according to Lovell *(2006)* are often related because both involve the metal element – sodium. While soil salinity is the result of high levels of soluble salts, soil sodicity is caused by high levels of exchangeable Na^+ adsorbed on the surfaces of clay particles (Wong, 2007). Soil salinity affects soil chemical properties through the presence of high soluble salt concentrations, which adversely affects soil biota and vegetation by altering the osmotic and metric potential of the soil solution (Wong, 2007). The predominant mechanism causing the accumulation of salt in soils is loss of water through evapo-transpiration, leaving ever-increasing concentrations of salts in the remaining water. Effects of soil salinity are manifested in loss of stand, reduced plant growth, reduced yields, and in severe cases, crop failure. Salinity may also cause specific-ion toxicity or upset the nutritional balance of plants. In addition, the salt composition of the soil water influences the composition of cations on the exchange complex of soil particles, which influences soil permeability and tilth. One of the methods of salinity measurement in soils is the measurement of the Electrical Conductivity (EC) of the soil. This, in conjunction with exchangeable sodium potential (ESP) -a measure for sodicity- of soils give invaluable information on salinity status and thus yield potentials of soils. The trend of later, according to Corwin and Lesch (2005) is the interpretation of the complex interrelationship between spatial EC/ESP measurements, spatial variation in crop yield, and spatial variation in soil properties measured by EC that influence the spatial variation in yield based on a theoretical understanding of EC.

Soil salinity has always been associated with arid and semi arid environments where, due to poverty and inadequate access to soil management inputs, there is indiscriminate use of agrochemicals, water logging and poor irrigation methods. This has most often been the cause of soil salinity and sodicity oblivious to farmers. Vertisols of the semi arid environment are exposed to dry spell and hot conditions that could predispose plants to salinity and sodicity effects. Chan et al (1988) and Dengiz et al (2012) observed high pH values in the 8.3-8.8 range for vertisols. Khresat and Taimeh (1998) study on vertisols of arid environments revealed low mean EC values of 0.22ds m^{-1} that increases with depth. Dengiz et al (2012) however observed moderate salinity and high sodicity in deltaic vertisols. Adhikari et al (2011) also found low to moderate variability in EC values between the top soil and the subsoil depths, with semivariograms exhibiting both short range and long range variability. Cemek et. al., (2007) analyzed the spatial distribution patterns of EC and ESP of 60 soil samples in an irrigated plain in Turkey. Their study showed that values of EC and ESP were generally high in the east and northeastern parts and manifesting moderate spatial dependence caused by extrinsic factors such as ground water level, drainage, irrigation system and microtopography. Similarly, Hartsock et. al., (2000) and Keshavarzi and Sarmadian (2012) found that EC values were substantially low during dry periods. Their study revealed that salinity and alkalinity parameters exhibited high coefficient of variations values with some spatial dependence within some localized parts of the fields. Variability was much greater in the southwest to northeast direction. They however, found that Ca and Mg were the main causes of EC variability in the study area. Their results are similar with those of Patil et al (2011) in arid parts of Arabia and Corwin et al (2003) in California. The seeming absence of research reports on salinity status of vertisols in the study area is a source of concern. The area is characterized with increased rain-fed intensive cropping on highly fragmented small holder farms that could trigger and/or exacerbate soil salinity problems. This study therefore assessed the level and distribution of soil pH, EC and ESP in vertisols of the study area.

The study area

The study site is a 0.5hectares piece of farmland located between latitude $9^0$38.595N - $9^0$38.613N and longitude $11^0$54.571E - $11^0$54.623E, with an elevation of approximately 200m above sea level in Kerau village of Guyuk Local Government Area in Adamawa State, Nigeria (Figure 1). The area has a wet-dry savannah climate with mean annual rainfall of about 980mm. The wet season spans between April and October with average temperatures as high as 35^0C in March and relative humidity that reaches 70% in August during the peak of the rainy season (Adebayo, 1999). The local environment is almost arid, having been modified by human activities of sorts such that very few scattered trees and grasses now prevail. The vegetation can thus be described as Sudan savannah grassland. The area is drained by a network of seasonal streams radiating from the Lunguda plateau into the Benue River (Tukur, 1999). The soil of the study area can best be described as Vertisols of the Ustert suborder (Ray, 1999). The soils have a deep A-C horizon with gilgai morphology because of their ability to crack and mulch between dry and wet seasons.

MATERIALS AND METHODS

Field Methods

Soil samples were collected at the depths of 0-15cm (topsoil depth where soil nutrients are available) and 15-30cm (subsoil depth where there is plant root penetration resistance) at an average point grid sampling distance of 10m over a 0.5ha (56x80m^2) farm plot. A total of 100 soil samples were obtained from the study area. This comprised 50 soil samples from the topsoil samples (0-15cm depth) and another 50 soil samples from the subsoil samples (15-30cm depth).

Data Analysis

Soil samples were air dried, crushed and passed through a 2mm mesh in preparation for laboratory analysis. Soil samples were analyzed for: Soil pH, Soil Electrical Conductivity (EC), and Exchangeable Sodium Percentage (ESP). The Soil pH was determined by 1:2 soil to water ratio (Jackson, 1958; Mclean, 1966) using a pH meter while Soil Electrical Conductivity (EC) was determined by the soil to water extract method using the EC meter (Delvalle, 1992; Whitney, 2007). The Exchangeable Sodium Percentage (ESP) is computed using the formula: ESP=(Na^+/CEC)/100. Where Na^+= measured exchangeable Na in cmol kg^{-1} and CEC = cation exchange capacity in cmol kg^{-1} (Santro et al 2008).

In order to examine physical and chemical properties of the study site, the SPSS 9.3 software was used to statistically analyze soil samples for mean, standard deviation (SD), sample variance (SV), minimum and maximum values, coefficient of variation (CV), skewness and kurtosis.

The Gamma Environmental Design Software version 9.3 was used for geostatistical analysis of the data. Each soil property data was subjected to a normality test prior to semivariogram analysis. Semivariogram models were used to bring out the spatial variation among measured points while Kriging interpolation was used to estimate values of soil properties at unsampled points and to map the pattern of distribution of soil properties in the study area. The semivariogram function $\gamma(h)$ represents a dependence of semivariance on distance *h* and is given

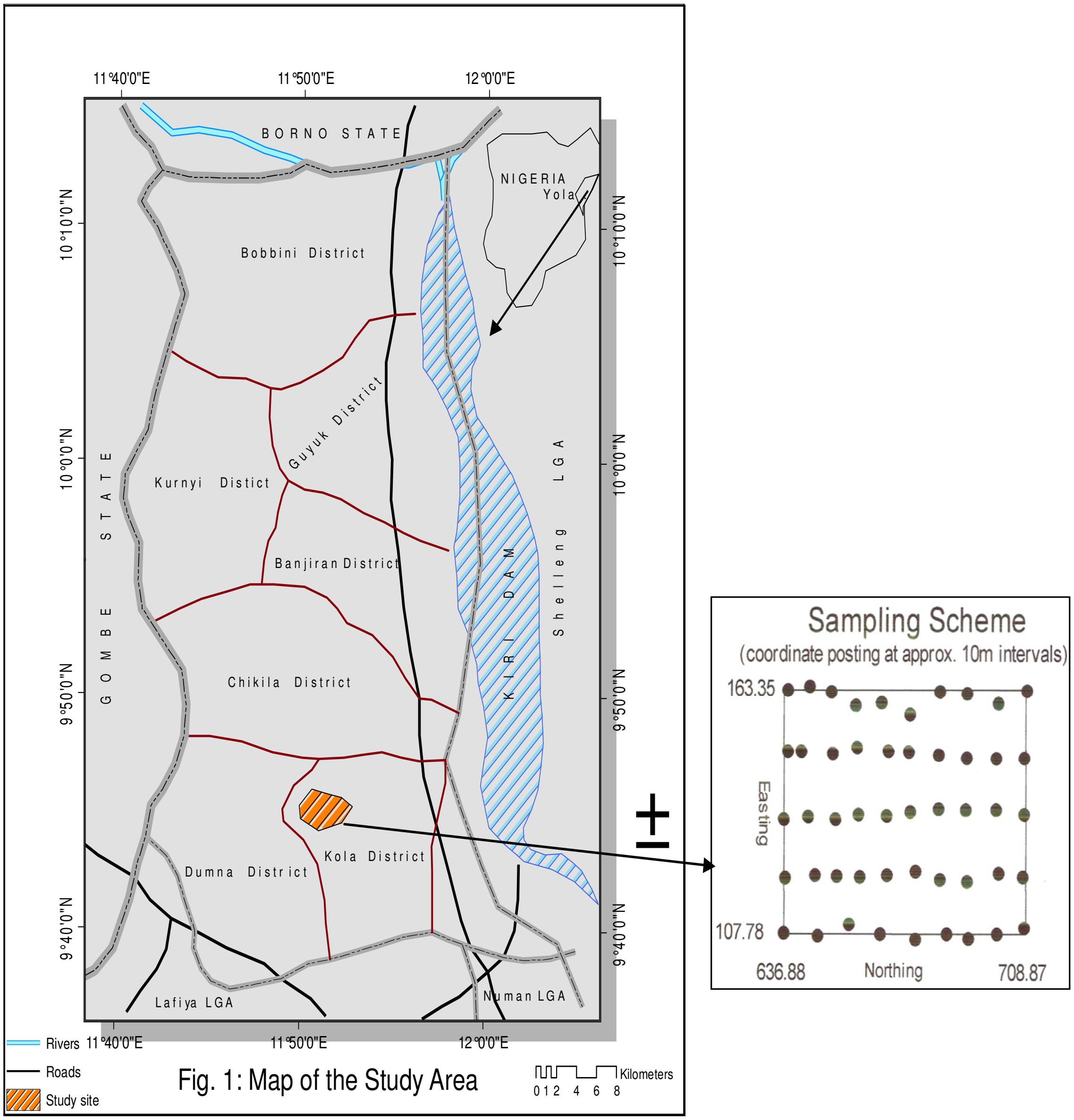


Fig. 1: Map of the Study Area

by the formula (Robertson 2008):

$$\gamma\{h\} = \frac{1}{2N\{h\}} \sum_{i=1}^{N(h)} \{z(x_i) - z(x_i + h)\}^2$$

where $\gamma(h)$= *semivariance; N= number of pairs; h=lag distance; x=data pair and i=location in space.*

RESULTS AND DISCUSSION

Descriptive statistics for chemical properties of the soil at both topsoil and subsoil depth are presented in Table 1. The table showed that Soil pH is generally high in Vertisols of the study site. Soil properties that exhibited very low values include Electrical conductivity (EC) and Exchangeable Sodium Potential (ESP). Low values of EC and ESP showed that Kerau Vertisol is not threatened by either salinity or sodicity problems for now; thus, plant toxicity or soil erosion problems (where found), should be attributed to other factors.

The mean values of soil pH and ESP are slightly higher in the subsoil than in the topsoil, suggesting an increase in these elements with increased depth while that of EC is higher in the topsoil than in the subsoil, suggesting decrease in these soil properties with depth. The standard deviations for soil pH and ESP are also

Table 1. Statistics of Soil Chemical Properties of Soil in the Study Area

Variable	Soil Depth	Mean	SD	SV	Min	Max	Skewness	Kurtosis	CV (%)	Variability
P^H	0-15cm	8.3	0.28	0.08	7.7	8.9	0.09	-0.74	3	Low
P^H	15-30cm	8.6	0.51	0.26	7.6	9.8	0.37	-0.29	6	Low
EC(dS/m)	0-15cm	0.058	0.016	0.0003	0.04	0.09	0.4	-0.83	28	Moderate
EC(dS/m)	15-30cm	0.056	0.014	0.0002	0.04	0.08	0.01	-1.28	25	Moderate
ESP (%)	0-15cm	2.47	0.84	0.7	0.52	4.47	-0.2	-0.11	34	Moderate
ESP (%)	15-30cm	3.1	1.09	1.18	0.35	4.89	-0.5	-0.61	35	Moderate

Source: (Field Survey, 2012);
EC = Electrical Conductivity; ESP = Exchangeable Sodium Potential; kurt = kurtosis; CV = Coefficient of variability
Variability rating: ≤15% = low; 16-35% = moderate; >35% = High variability]

slightly lower at the top depth than at the subsoil depth, meaning more variations as depth increases. Those for EC are lower at the topsoil depth than at the subsoil depth, indicating increase in EC with increase depths. Soil pH ranged from 7.7 to 8.9 at topsoil depth and 7.6 to 9.8 at subsoil depth, an indication of increase in p^H with increased, i.e. laterally from slight alkalinity to strong alkalinity Similarly, EC exhibited a range of between 0.04 and 0.09 and that of ESP is between 0.35 and 4.89 at subsoil depth. EC shows no variability with depth, EC exhibited low variability at both topsoil and subsoil depths.

Semivariogram Analysis of Soil Properties

The assessment of spatial structure of soil properties was carried out using semivariogram analysis. As a basic prerequisite for semivariogram analysis, a test of normality on each variable was carried out and where necessary appropriate transformations (scale to 1-10; log normal; square root) done to ensure a normal distribution. The generation of semivariogram parameters was then carried out for each theoretical model (spherical, exponential, Gaussian and linear). The selection of the best fitting model was based on: the smallest Residual Sums of Squares (RSS), which provides an exact measure of how well the model fits the variogram data (the lower the RSS, the better the model fit); the biggest (maximum) determination coefficient (r^2), which also provides an indication of how well the model fits into variogram data (should be between 0.5-0.99). Important model parameters are the nugget variance (C_0) – which is the y-intercept of the model that can never be greater than the sill; the sill (C_0+C) – which is the model asymptote that can never be less than the nugget; the Range (A) – which is the separation distance over which spatial dependence is apparent; and the Proportion ($C/(C_0+C)$ – which provides a measure of the proportion of the sample variance (C_0+C) that is explained by the spatially structured variance (C): it is 1 when the curve passes through the origin (no nugget variance) and 0 where there is no spatially dependent variation at the range specified (pure nugget effect). The results of the semivariogram analysis are presented in Table 2 and Figures 1-7 below.

The semivariogram analysis presented in Table 2 showed that the Spherical, the Gaussian and the Exponential models adequately described the spatial dependence of the pH, EC and ESP of vertisols at the study site. The low values of RSS and r^2 values above 0.5 substantiate the adequacy of these models.

The range of spatial dependence at the topsoil depth varied from 9.56m (EC) to 30.8m (pH); while at the subsoil depth it ranged from 10.7m for EC to 60.5m for ESP. The range for each soil properties suggest distances beyond which spatial dependence ceases.

Thus, future sampling plans must be within the range identified for each soil property in the study area. Observed values of nuggets (C_0) (in the range of 0.00 to 0.24) suggest the absence or insignificance of nugget effect (random variations) in the semivariogram of soil properties. Very low nugget to sill ratios suggest that EC and ESP at both depths exhibited strong spatial dependence except for topsoil pH that exhibited moderate spatial dependence in the topsoil.

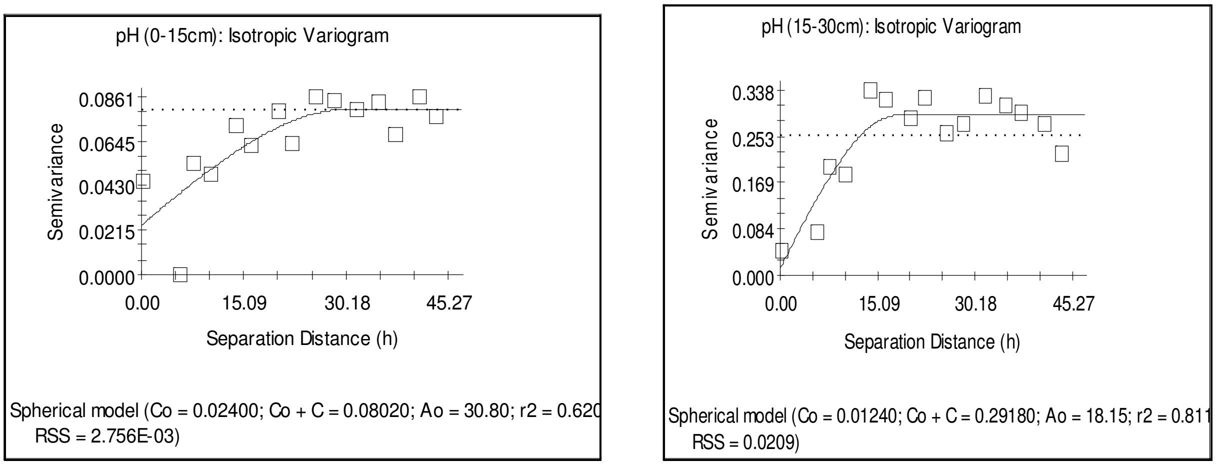
Soil Variograms of Salinity Parameters

Figure 2 reveals that the spherical model was the best fit for pH (with r^2 values at 0.62 and 0.81 and very small RSS) for the two depths. This suggests that there is a gradual decrease in spatial autocorrelation of pH at both depths within the observed range. The spatial dependence of soil pH with distance is thus limited to the 30.8m range laterally and 18m range vertically beyond which there is no spatial autocorrelation. This is an indication of high variability both laterally and with depth. Soil pH also exhibited a very negligible nugget effect both laterally and vertically; with smaller value vertically than laterally. This is an indication that the source of variability is structural. With a nugget to sill ratio between 30% laterally and 4.14% vertically, soil pH showed a strong

Table 2. Semivariogram Analysis of soil properties

Variable	Soil Depth (cm)	Model	Range A (m)	r^2	RSS	C_o	C_o+C	$\frac{C}{Co + C}$	$\frac{C_o}{Co+C}$(%) Nugget to Sill
pH	0-15	Spherical	30.8	0.62	0.003	0.024	0.08	0.70	30=M
P^H	15-30	Spherical	18.2	0.81	0.021	0.012	0.29	0.96	4=S
$EC_{(dS/m)}$	0-15	Gaussian	9.56	0.75	1.8E-04	0.0001	0.068	0.99	1=S
$EC_{(dS/m)}$	15-30	Gaussian	10.7	0.77	0.00	0.0	0.048	0.99	1=S
$ESP_{(\%)}$	0-15	Gaussian	29.1	0.71	0.38	0.19	0.9	0.79	21=S
$ESP_{(\%)}$	15-30	Exponential	60.5	0.83	0.33	0.05	1.33	0.97	4=S

Source: (Field Survey, 2012)
EC = Electrical Conductivity; ESP = Exchangeable Sodium Potential; C/C_0+C=1 = no nugget variance or 0 = pure nugget
Nugget/Sill ratio: S=Strong (<25%); M=Moderate (>25 & <75%); W=Weak (>75%).



a: Top soil P^H **b: Subsoil P^H**

Figure 2. Soil pH Variograms

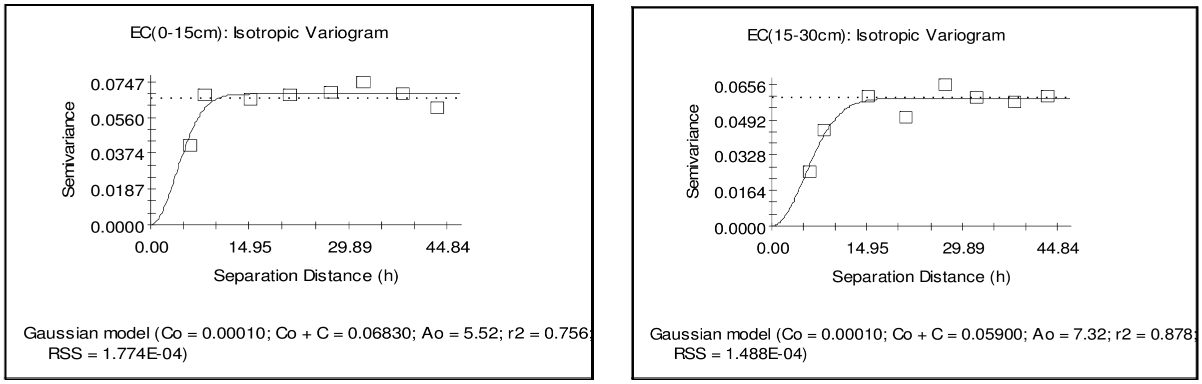
spatial correlation structure in both directions (Table 2). Soil pH did not however, show any significant directional variation (anisotropic behavior) in vertisols of the study area.

Figure 3 shows that the Gaussian model provided the best fit for Electrical Conductivity both laterally and vertically with an r^2 of 0.75 and 0.77 respectively. Soil EC also exhibited short range variations both laterally and vertically (range of 5m and 7m respectively) and nugget to sill ratios that portray a strong spatial variability structure. The absence of nugget effect indicates that this variability is systematic or structural.

According to the variogram in Figure 4, the Gaussian model provided the best fit for ESP at the topsoil depth (r^2 of 0.71). The semivariogram also indicates that there is a very strong degree of homogeneity over short distance of 16m range at the study site. A nugget to sill ratio of 21% suggests a strong spatial dependence in ESP laterally. Similarly, the exponential model provided the best fit for ESP at the subsoil depth (with an r^2 of 0.83). Spatial dependence was observed to occur within the 20m range in ESP at the subsoil depth, indicating short range variability. A nugget to sill ratio of 3.5 suggests a strong spatial dependence in ESP with depth. Thus, variability in ESP with depth seems more of structural than random.

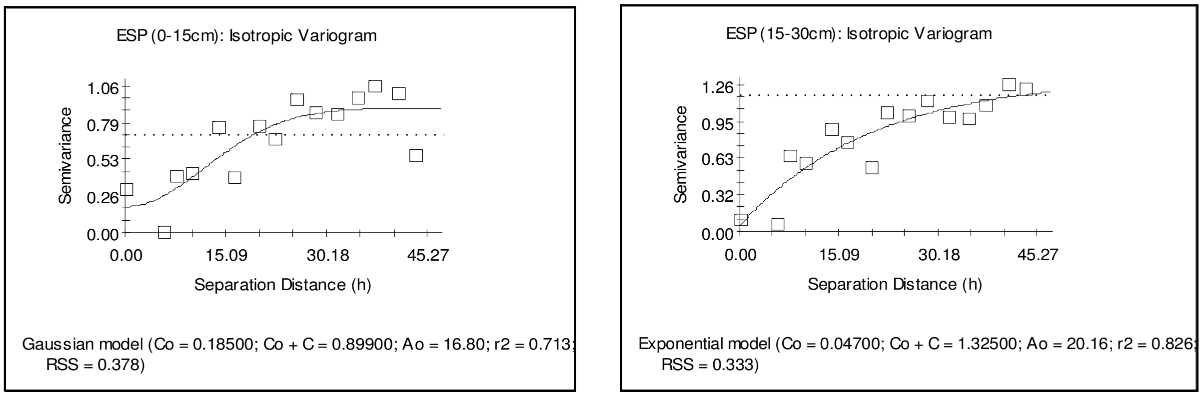
Soil Distribution Maps of Salinity Parameters

Figure 5 shows a patchy distribution of soil pH at the



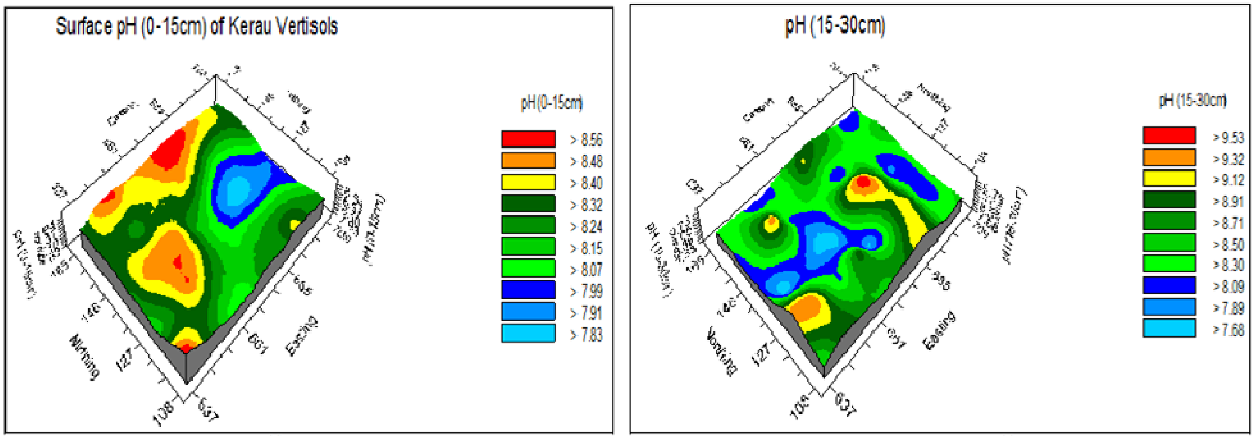
a: Top soil EC **b: Subsoil EC**

Figure 3. Soil EC Variograms



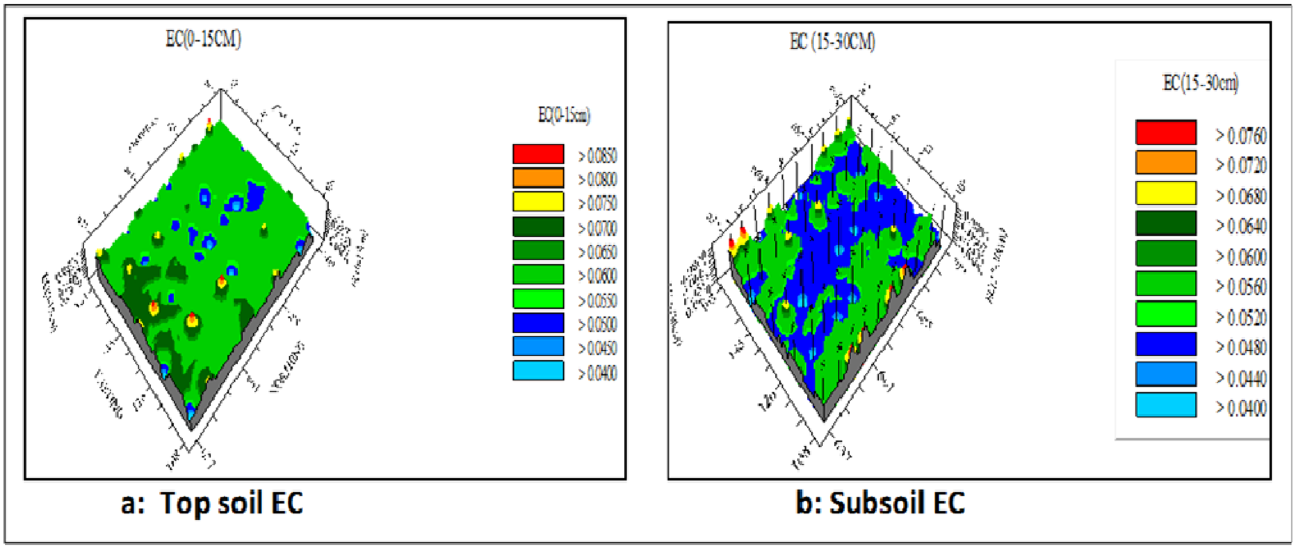
a: Top soil ESP **b: Subsoil ESP**

Figure 4. Soil ESP Variograms



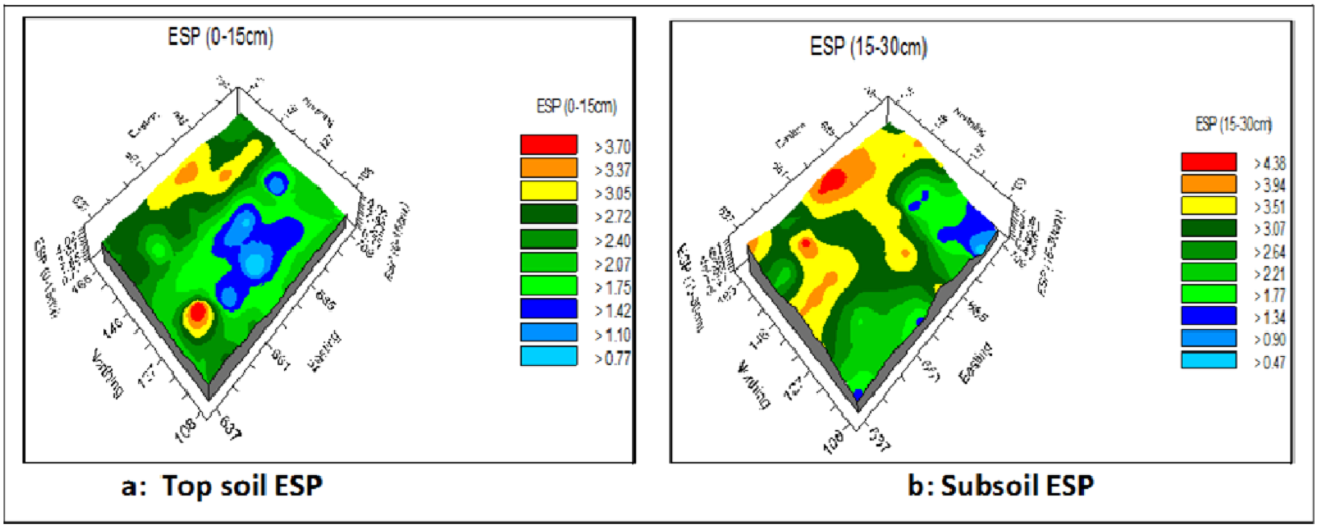
a: Surface P^H of Kerau Soil **b: Sub surface P^H of Kerau Soil**

Figure 5. Spatial Distribution of Soil pH



a: Top soil EC **b: Subsoil EC**

Figure 6. Spatial Distribution of EC



a: Top soil ESP **b: Subsoil ESP**

Figure 7. Spatial Distribution of Soil ESP

topsoil depth with higher values occurring on the western tip and the lower south of the study site. Lower values of pH occur also at the northern part of the site. Figure 5(b) also showed a patchy distribution of pH at the subsurface depth with a patch of high pH traversing the north-eastern and south-eastern parts of the site interlaced with patches of lower pH surfaces. This is an indication of that few localized areas of the sites have high pH due perhaps to fertilizer applications.

Figure 6(a) shows an almost uniform distribution of EC at the surface depth. Few patches of low EC content (<0.05) and higher ECs (>0.075) are observed to dot the entire study site. Generally, EC distribution at the study site is in the 0.06 range. Figure 6(b) revealed that the spatial distribution of subsurface EC vary quite differently from that of the surface EC in Figure 6(a). At the subsurface depth, very low EC content (<0.048) fragmented the study site from a northwest to southeast pattern. Patches of EC content of between 0.052 and 0.056 occupy the fringes of the study site.

Figure 7(a) suggests that the entire study site is characterized by ESP in the range of 1.0 to 3.0, with a small patch of high ESP (≥3.0) in the south and northwest corners, and a significant patch of very low ESP (≤1.4) in the east-central. Figure 7(b) on the other hand, revealed a gradual increase in ESP values from East to West of the entire study site.

CONCLUSION

The findings of this study shows that mean value of pH is 8.5, EC is 0.06 ds/m and ESP is between 2.8 and 3%. The spherical model adequately describes pH variability at the spatial scale measured; the Gaussian model describes EC variability at both depths, while the Gaussian model at the top soil depth and the exponential model at the subsoil depth describe ESP variation. Generally, all soil properties measured exhibited strong spatial dependence at the scale of measurement and; though EC and ESP values have been observed to be within tolerable range, there is the need for the continuous monitoring of these properties for optimal salinity management.

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