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Spatial Variability and Mapping of Selected Soil Physical Properties under Continuous Cultivation

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A B S T R A C T

Assessments of Soil physical properties and estimation of their associated variability are essential for making site-specific decisions on soil and crop management This study examined the spatial variability of soil hydro-physical properties and variance structure at Sector F1 of the Jibia Irrigation project Katsina State, Nigeria. Grid sampling technique was used to obtain one hundred and forty-four (144) soil samples from 206 ha of land using Google earth. The grids were drawn using Google earth software at intervals of 150 m x 150 m. Surface soil samples (0 - 20 cm) were collected at grid intersection points. The collected soil samples were air-dried and passed through a 2mm sieve, and analyzed using standard laboratory procedures for physical parameters. The ArcGIS software package 10.3 was used to model the variance structure of Sand, Silt, Clay, Bulk density, Particle density, Percent total porosity and Organic Matter (OM). Results obtained revealed that the coefficient of variation (CV) ranged from 5.724% in particle density to 109% in clay. The Semivariogram showed that the range of spatial dependence varied from 0.342m for (Dry mean weight diameter) to 9.3m (Organic matter) for all measured soil properties. High Spatial dependency ratios were observed for Bulk density, Sand, Silt and clay contents. Particle density exhibited moderate spatial dependency (Nugget to sill ratio 0.25 – 0.75%). Wet Mean weight diameter and organic matter content have a weak spatial dependency. The results indicated that sandy textured soils dominated the greater part of the study area with low to moderate organic matter content. The soils being sandy-dominated has a high infiltration rate and low ability to retain moisture and nutrients were observed as the major characteristics of the soil of the study area.

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Introduction

One of the key features of soils is their variability in properties at different spatial scales. Following the groundbreaking work of Folorunsho et al. (1998) and Ogunkunle (1993) in northern and southern Nigeria, respectively, and recently Okon and Babalola (2006), there has been an increase in interest in the topic in Nigeria. Other recent studies include those by Oku et al. (2010), Oyedele and Tijjani (2010), Abu and Malgwi (2011), Denton et al., (2017), Sani et al., (2022), Ibanga et al., (2022) and Turgay et al.,(2022) sought to understand soil spatial variability across different land uses using different methods.

Soils are spatially variable at various scales (Jankowski et al., 2011; Pedrera-Parrilla et al., 2016). The main sources of the variability are related to soil-forming factors, topography (Jankowski et al., 2011; Wang and Shao, 2013), and management practices (Ozpinar and Ozpinar, 2015; Gałka et al., 2016). Evaluating and understanding the spatial and temporal variability of the physical properties of soils are required to precisely determine the best soil management practices and amendments to improve crop quantity and quality while being environmentally sustainable (Awe et al., 2015; Gajda et al., 2016; Aranyos et al., 2016).

The variability of physical parameters within-field is an important source of uncertainty in crop production (Diacono et al., 2013). The use of geostatistics enhances the identification of soil spatial variability in un-studied sites (Nielsen and Wendroth, 2003) and improves the precision of models used to predict changes in soil behavior (Serrano et al., 2010; Behera and Shukla, 2015). Consequently, knowledge of spatial variability is crucial for comprehending the ecosystem and developing sustainable soil management options for particular land uses (Perez et al., 2007, Ziadat and Taimeh, 2013).

Since the Jibia Irrigation Project's inception in 1991, crops like wheat, maize, onion, tomatoes, cabbage, etc. are grown year-round there (Sani et al; 2019). These soils' aggregates in the area lack the strength, quick productivity loss, and nutrient and water retention needed for long-term crop development. These traits suggest that in order to ensure sustainable crop production, soil physical conditions must be controlled, even with the best soil fertility amendments (Salako, 2003). The knowledge of spatial variability of soil physical properties is therefore crucial for optimum and sustainable agriculture (Wilding, 1985). According to reports, variations in soil characteristics placed restrictions on the potential of the soil and its current level of output (Olatunji and Ewetola, 2015).

Using GIS technology to understand the spatial variability of physical factors is a real task that will be extremely helpful in agricultural landscape decision-making systems. Therefore, the goal of this study is to identify the soil's physical characteristics as well as its spatial variability and variance structure at the Jibia Irrigation Project.

Additionally, no research of this kind has ever been done in the subject area.

Jibia irrigation project involves 110 km of farmlands divided into six sectors (Hydrological boundaries F1-F6), 192 km of concrete irrigation canals that supply water to irrigation plots and sub-canals, 114 km of drainage channels, and 50 km of service roads. Jibia irrigation project is intended to develop 3450 ha of land for irrigation purposes (SRRBDA, 1991).

Materials and Methods

Study Area

The study was carried out in Sector F1 of Jibia Irrigation Project located in Jibia Local Government Area (Latitudes 13°04'18" N – 13°10’27’’N and longitudes 07°15’06”E – 07° 18’.15’’E. (Sani et al., 2019). 13.10058 N - 13.091182 N and longitudes 7.241055-7.248039 E. The landscape is nearly level to gently undulating with 0 - 2% slope and averaging 442 meters above sea level (FDLAR, 1990). The study area falls within the Sahel savannah zone of Nigeria which consists of few scattered trees and little vegetation. Rainfall ranges between 600-700mm annually; The Rainfall pattern is seasonal and occurs between June and September with the peak rainfall occurring in August. The dry season lasts between October and May. The mean annual temperature ranges from 30-38^{o}c. (KTARDA, 2010).

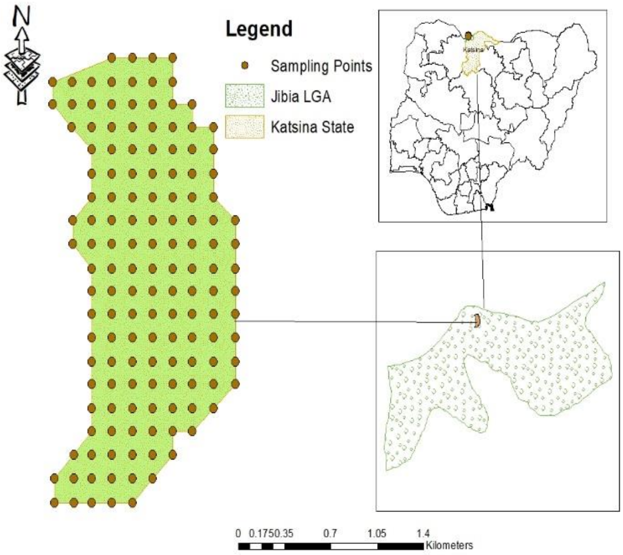

Figure 1. Map of Katsina state showing the study area

Soil Sampling, Preparation and Analytical Procedures

To determine the location and size of the sampling area as well as the sampling locations, a reconnaissance survey was carried out in the study area. The grid sampling technique was used. The study area was divided into longitudinal and latitudinal transects. Grids were drawn at 150 meters intervals and a total of One hundred and forty-four (144) soil samples were collected at grid intersection points which were identified with the help of a handheld GPS device (Figure 1). Both disturbed and undisturbed soil samples were taken at each sampling location. The collected disturbed samples were gently crushed, air-dried, and sieved through a 2 mm mesh size. The fine earth separates were then carefully labeled and kept for laboratory analysis.

Soil Laboratory Analysis

Particle size analysis was determined using Bouyoucos hydrometer method (Bouyoucos, 1951). Bulk density was determined using the tube core method as described by Blake and Hartge (1986). Particle density was determined using the pycnometer method as described by Kretz (1974). The amount of pore space of the soil was estimated mathematically as described by Rattan (2009). Soil organic carbon content was determined by the dichromate oxidation method (Nelson and Sommers 1982). Aggregate Stability was determined by dry and wet sieving procedures described by Kemper and Chepil (1965). The mean weight diameter (MWD) of aggregates was calculated by summing the product of the mean diameter of aggregates and the proportion of soil in each aggregate-size class (Kemper and Rosenau, 1986). The results were used to define the stability of the soil aggregates. Structural Stability Index; which is an index for assessing the risk of structural degradation in cultivated soils, was calculated using the equation described by Pieri (1992).

Data Analyses

Data obtained from the soil properties were subjected to descriptive statistics and correlation analysis using SPSS version 20.0 to obtain Mean, Median, Range, Maximum, Minimum, Variance, Skewness, Kurtosis, Coefficient of variation and relationships among the soil properties measured. Shapiro-Wilk test (Shapiro and Wilk, 1965) was conducted on the data of all the measured soil properties to check for normality. Skewed variables were transformed using natural logarithms to a nearly normal distribution before geostatistical analysis

Geospatial Analysis

Spatial variability analysis of the soil physical properties measured was carried out by using geostatistical analyst extension of ArcGIS 10.3 software. The spatial variation was observed with the aid of an experimental semivariogram using the data obtained from sampling points (Webster and Oliver, 2007). The spatial structure of the different soil properties was identified by calculating the semivariogram; and the best model that describes these spatial structures was identified. These results are shown in Table 3. The model with the best fit was applied to each parameter. Models such as rational quadratic, stable, K-Bessel, exponential, etc. were fitted to the different soil properties. Nugget (Co) is the error in the estimation process as a result of sampling errors, whereas sill $C_o + C$ denotes spatially independent variance, where the data locations were separated by a distance beyond which semi variance becomes static.

Variable spatial dependency was calculated by the Nugget to sill ratio, which is the ratio of nugget variance to the total variance (sill) multiplied by 100.

$$\text{Spatial dependency} = \frac{C_o}{C_o + C} \times 100$$

Where;
C_o = Nugget
C_o+C= Sill

The nugget effect (Co), the sill (Co + C) and the range of influence (measured in meters) for each of the parameters were noted. The spatial dependencies (Nugget/Sill ratio) were found to be related to the degree of autocorrelation between the sampling points and expressed in percentages. The spatial dependent variables were classified as strongly spatially dependent if the ratio was <0.25, moderately spatially dependent if the ratio is between 0.25 and 0.75% while it is classified as a weak spatial dependent if it >0.75% (Cambardella et al., 1994; Erşahin, 1999; Robertson, 1987; Trangmar, Yost and Uehara, 1985).

The Semivariogram can be expressed mathematically as:

$$\gamma(h) = \frac{1}{2N(h)} \left[\sum_{i=1}^{N(h)} [Z(x_i+h) - Z(x_i)]^2 \right]$$

Where;

(h) is the semi-variance for interval class h, N (h) is the number of pairs separated by a lag distance (separation distance between sample positions. $Z(x_i)$ is a measured variable at spatial location i. $Z(x_i + h)$ is a measured variable at the spatial location, $i + h$.

Results and Discussion

Descriptive Statistics

Table 1 displays the descriptive statistics for the research area's physical parameters. According to Ogunkunle's (1993) classification of CV for classification of soil variables, soil properties with a coefficient of variations between 0 and 15% are regarded the least variable, 15-35% are considered moderately variable, and CV beyond 35% are considered highly variable.

The soils of the study area had a higher percentage of sand content than clay and silt proportions. The sandy nature of the study area might be attributed to the nature of the parent materials of the soils in the study area, as the soils were developed predominantly on granitic sandstone and aeolian deposits. The results are in agreement with the findings of Malgwi et al. (2000) and Voncir et al. (2008) who both reported that the dominance of sand contents in Northern Nigerian soils is a result of sorting of materials by clay eluviation and surface wind erosion. The coefficient of variation (CV) for soil particle size distribution indicates medium variability for sand and high variability for silt and clay. The high variability in the distribution of silt and clay may be attributed to different land-use systems across the study area. The results are in agreement with the observations of Okon and Babalola, 2006; Oku et al., 2010; Phil-Eze, 2010; Obalum, et al., 2012) who found high variation for the silt and clay whereas medium variation for sand.

The coefficient of variation for soil bulk density was found to depict a low level of variability. This variation may be random and could thus be attributed to the nature of the higher sand content. MacCarthy et al. (2013) and Haruna and Nkongolo (2013) found similar results and reported low CV which is in agreement with the report of this study. Similar results showing low CV for bulk density have also been reported across various landscapes in the West-African savanna (Abu and Malgwi, 2011; Folorunso et al., 1988; Ghartey et al., 2012; Idowu et al., 2003; Okon and Babalola, 2006; Obalum *et. al*., 2012, Aliyu, 2022).

Particle density exhibited the lowest variability of all the measured soil properties with a CV value of 5.72% indicating homogeneity of parent material from which the soils were formed and corroborated with the findings of Kavianpoor et al. (2012) and Ramzan, (2016) whose findings confirmed 8.45% and 7.33% CV for soil particle density while studying some chemical and physical soil properties in Nesho Mountainous Rangelands and Kashmir respectively.

The percentage of porosity in the study area was observed to be between compact (5%) to porous (58%) averaging 33.9 % and having a moderate variability (CV 22.6%). This may be due to differences in the textural classes of the soils across the study area. These values are in agreement with the literature reported by Rabbi et al. (2004) and Haque et al. (2007) who reported 43.3 to 57.91% and 48.90 to 51.64% porosity, respectively. However, these values are much higher than that recorded by Sparling and Schipper (2004).

The organic carbon content of the soil of the study area was found to be between low to moderate. The low to moderate organic carbon content might be as a result of intensive continuous cultivation and the nature of the soil parent materials.

Table 1. Descriptive Statistics for Soil Physical Properties

Variable	Mean	Minimum	Maximum	SD	CV (%)	Skewness	Kurtosis
SAND (%)	82.79	34	98	13.011	15.72	-1.699	2.739
SILT (%)	11.21	0.56	41.28	8.309	74.1	1.492	2.096
CLAY (%)	5.998	0.72	50.72	6.536	109	3.346	15.68
BD (g/cm3	1.574	0.99	2.06	0.177	11.27	-0.164	0.303
PD (g/cm3	2.374	1.81	2.65	0.136	5.724	-1.017	2.228
POROSITY (%)	33.9	5	58	7.684	22.6	-0.305	0.862
SOM (%)	1.54	0.14	4.05	0.98	63.64	0.734	0.20
MWD_d	0.56	0.14	2.41	0.49	87.5	2.05	3.78
MWD_w	0.49	0.16	1.31	0.21	42.9	1.12	1.63

SD = Standard deviation; CV = Coefficient of variations; SOM = Soil Organic Matter, BD = Bulk density, PD = Particle density; MWD_d = Dry Mean weight diameter, MWD_w = Wet Mean weight diameter

Table 2. Pearson Correlation Matrix of Soil physical Properties

Variables	BD	PD	TP	OM	Sand	Silt	Clay	MWDw	MWdd	SI
BD	1									
PD	.20*	1								
TP	-.84**	.33**	1							
OM	-.37**	-.46**	0.12	1						
Sand	.37**	.52**	-0.08	-.66**	1					
Silt	-.31**	-.45**	0.05	.60**	-.90**	1				
Clay	-.34**	-.47**	0.09	.55**	-.84**	.53**	1			
MWDw	-0.06	-.187*	-0.03	.50**	-.49**	.41**	.44**	1		
MWd_d	-0.04	-.18*	-0.04	.45**	-.46**	.38**	.45**	.41**	1	
SI	-0.37**	-0.47**	0.09	0.56**	-0.83**	0.52**	0.99**	0.44**	0.45**	1

MWD_d = Dry Mean weight diameter, MWD_w = Wet Mean weight diameter, SI= Structural stability index

Low organic carbon content leads to low water holding capacity, low aggregation, and high infiltration rate. This observation agrees with the work of Salako (2003); Noma and Sani (2008) and Shehu et al. (2015). Another reason for the low level of organic carbon in the study area might be attributed to the seasonal character of the savannah climate (Jones and Wild, 1975) and bush burning (Hopkins, 1966; Shehu et al, 2015; Sani et al., 2019).

The higher the MWD of the soil sample the better the stability of the soil to break down caused by erosion agents and degradation. (Le Bissonnais, 1996; M.Annabi et al; 2017). The mean coefficients of variation of the dry and wet mean weight diameter were 87.5 and 42.9% indicating high variability in the study area. Similar results have been found by Ramzan, (2016) who observed high CV (> 35%) of MWD in both studied layers. The higher CV of the mean weight diameter in studied soils could be the consequence of agricultural practices such as soil tillage, fertilization, vertical eluviation of finer materials, and the changes in soil water balance (Ramzan, 2016).

Sand content had a significant positive correlation with bulk density and particle density; and a significant negative correlation with Organic matter content and porosity. Both silt and clay were observed to significantly correlate with bulk density and particle density negatively, whereas, correlation with organic matter was found to be highly positive. This implies that bulk density generally increases with an increase in sand content and organic matter decreases with a corresponding increase in sand content and the opposite can be said of silt and clay content. This observation agrees with the work of Gulser et al., 2016, Gulser and Candemir, 2014 and Abu and Malgwi, 2012). Bulk density also had a significant negative correlation with organic matter (r = -0.37**) which shows a decrease in Bulk Density as a result of increases in OM. This observation is consistent with the reports of other researchers (Abu and Malgwi, 2011, Igwe *et. al*; 1995, Oguike and Mbagwu, 2009). A similar correlation was also observed with soil porosity (r = -0.84**). Thus, the bulk density of the soil is inversely related to the soil porosity. The result is in agreement with the observation of Wagner et al. (1994) and Kumar et al. (2009). Particle density has a significant positive correlation with porosity and sand content; and significant negative correlations with organic matter, silt, clay contents and structural stability index. This shows particle density decreases with increasing organic matter content as observed by Schjonning et al. (2017). There was a highly significant (r = -0.8**) inverse relationship between Total Porosity and the soil bulk density of soils of the study area. This observation might be to increase in OM matter content of the soil. Organic matter weighs less, thus reducing the bulk density of the soil, and at the same time occupying more volume, increasing the porosity of the soil (Ekeh et al., 1997). This observation agrees with the works of Vogelmann et al., (2010), Kay and Angers (2002); Gantzer and Anderson (2002); Ringrose-Voase (1996) and Olorunfemi & Fasinmirin, (2011) who all reported bulk density to have a highly significant negative correlation with total porosity. Both MWD_{dry} and MWD_{we}t have a significant positive correlation with clay and organic matter content but negatively correlated with sand content. The stronger correlation of MWD with soil organic matter (r^2 = 0.5**) suggests that soil aggregation may provide a degree of physical protection and thus serve to prevent the decomposition of Soil organic carbon (SOC). The positive correlation between SOC and MWD was also reported by Zhang et al. (2016). The result showed that clay and organic matter content enhances aggregation of soil particle and reverse in the case of sand content (Hartge and Horn, 1984; Horn and Dexter, 1989; and Horn et al., 1995). This is also in agreement with the work of Zhang et al. (2016) that reducing soil disturbance or increasing the input of organic materials increases the abundance of soil macro aggregates and reduces that of micro aggregates, thereby improving the aggregate stability of the soil. Structural stability index (SI) had a significant negative correlation with bulk density, particle density and sand content; and a significant positive correlation with organic matter content, clay content, silt content and wet mean weight diameter.

Geostatistical analysis.

Spatial structure analysis

The spatial structure of the different soil properties was identified by calculating the semivariogram; and the best model that describes these spatial structures was identified. These results are shown in Table 3. The model with the best fit was applied to each parameter. Models such as rational quadratic, stable, K-Bessel, exponential, etc. were fitted to the different soil properties. The spatial dependent variables were classified as strongly spatially dependent if the ratio was <0.25, moderately spatially dependent if the ratio is between 0.25 and 0.75% while it is classified as a weak spatial dependent if it >0.75% (Cambardella et al., 1994; Erşahin, 1999; Robertson, 1987; Trangmar, Yost and Uehara, 1985).

Table 3. Semivariogram model parameters of soil physical properties

Soil Properties	Statistical model	Nugget (Co)	Sill (Co+C)	Range (m)	Nugget/sill C/(Co+C)	SDC	R^2	Interpolation techniques
BD (g/cm3)	Exponential	0.016	0.1534	4.64	10.4	Strong	0.82	Simple
PD(g/cm3)	Exponential	0.00195	0.00353	2.66	55.2	Moderate	0.84	Ordinary
POROSITY(%)	Exponential	30.39	56.44	3.02	53.8	Moderate	0.89	Simple
% OC	Exponential	0.4073	0.5113	9.3	79.7	Weak	0.36	Ordinary
%SAND	Stable	0.00	0.984	3.24	0.00	Strong	1	Simple
% SILT	Exponential	0.00	0.5652	2.93	0.00	Strong	1	Ordinary
% CLAY	K-Bessel	0.000102	0.7392	8.5	0.14	Strong	1	Universal
MWD dry	Exponential	0.00	0.478	0.342	0.00	Strong	1	Ordinary
MWD wet	J-Bessel	0.118	0.149	2.86	79.2	Weak	0.84	Universal
Stability index	Exponential	0.22	0.595	4.53	36.9	Moderate	1	Simple
% O.M	Exponential	0.407	0.511	9.3	79.6	Weak	0.36	Ordinary

SD=Standard deviation; CV= Coefficient of variations; BD= Bulk density; SOC=Soil Organic Carbon; MWD dry = Dry Mean weight diameter, MWD Wet = Wet mean weight diameter, PD = Particle Density, % OC = percentage organic carbon, SDC = Spatial dependency class

All of sand, silt and clay contents of the soils were found to be strongly spatially dependent with a nugget to sill ratio $(Co/C(0+C)) < 0.25$. A variable has strong spatial dependency if the proportion of nugget/sill is equal or less than 0.25%, moderate spatial dependency if the ratio is between 0.25 and 0.75%, and weak spatial dependency if the ratio is greater than 0.75% (Cambardella et al., 1994; Bo et al., 2003). The strong spatial dependency of soil properties is related to structural intrinsic factors such as texture, parent material and mineralogy. Weak spatial dependency is related to random extrinsic factors such as plowing, fertilization and other soil management practices (Zheng et al., 2009). In this study, parent materials from which the soils are made up might be responsible for the strong spatial dependence among the mineral particles.

Semivariograms (Figures 2, 3 and 4) obtained for the particle size fractions indicated a range of about 8.5 m for clay, 2.93 m for silt and 3.24 m for sand. The relatively higher range obtained (8.5 m) for clay might be a function of intrinsic variations in the soil texture and mineralogy (Abu and Malgwi, 2011). A study by Abu and Malgwi (2011) in Kadawa Irrigation Scheme of Kano State, Nigeria reported a much higher range of 53 m and 594.5 m for sand and clay content respectively. According to Lopez-Granados et al., 2002 and Ayoubi et al. (2007), a large range indicates that the measured soil parameter value is influenced by natural and anthropogenic factors over greater distances than parameters that have smaller ranges. Thus a larger range of clay indicates that observed values of the soil variable are influenced by other values of this variable over greater distances than sand and silt which have smaller ranges. The different ranges of the spatial dependence among the soil properties may be attributed to differences in response to the land use-cover, topography, and differences in management practices carried on the field, physical disturbances, human and livestock.

The Bulk density also has a strong spatial dependence with a nugget to sill ratio of <0.25 implying that the variations were as a result of intrinsic factors such as texture and the parent materials from which the soil was formed. The range for bulk density was short (4.64 m). Other researchers reported a higher range for bulk densities: 900 to 1200 m by Santra et al. (2008), 21 m by Rabbi (2014) and 23 m by Yogita et al. (2012). Out of the total variation, the nugget component was 0.016 for bulk density, which shows that the micro-scale variation of this property was relatively high as the nugget ($C0$) defines the micro-scale variability and measurement error for the respective soil property, whereas partial sill (C) indicates the amount of variation which can be defined by spatial correlation structure.

The particle density also has a strong moderate spatial dependence with a nugget to sill ratio 0.25 - 0.75% implying that the variations were as a result of the interplay between intrinsic factors such as texture and the parent materials from which the soil was formed and land use management. Semivariogram obtained for the particle size fractions indicated a short range of about 2.66 m.

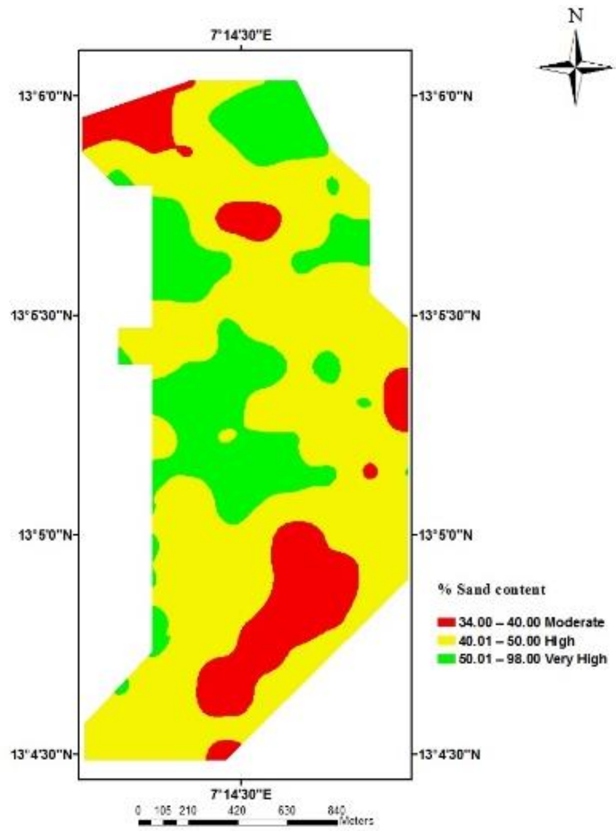

Figure 2. Semivariogram for sand content

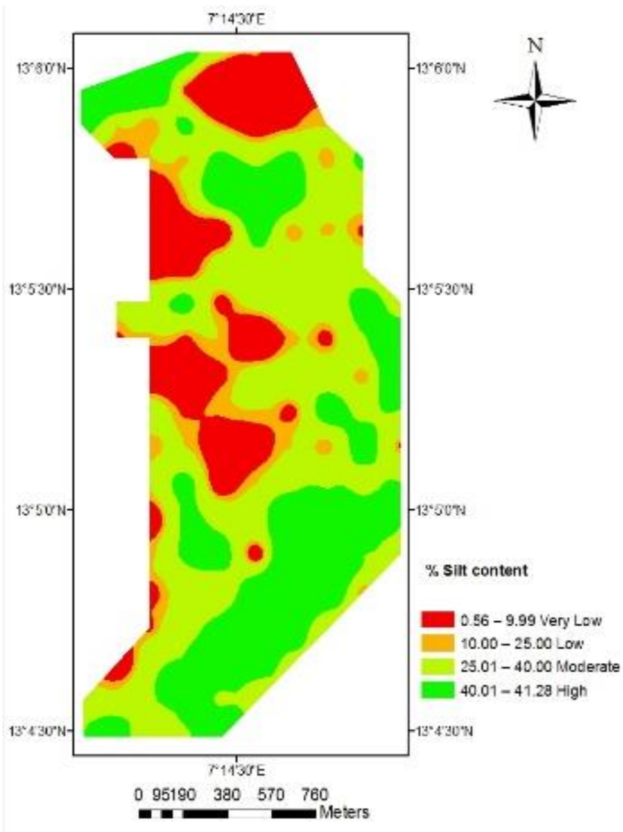

Figure 3: Semivariogram for Silt content

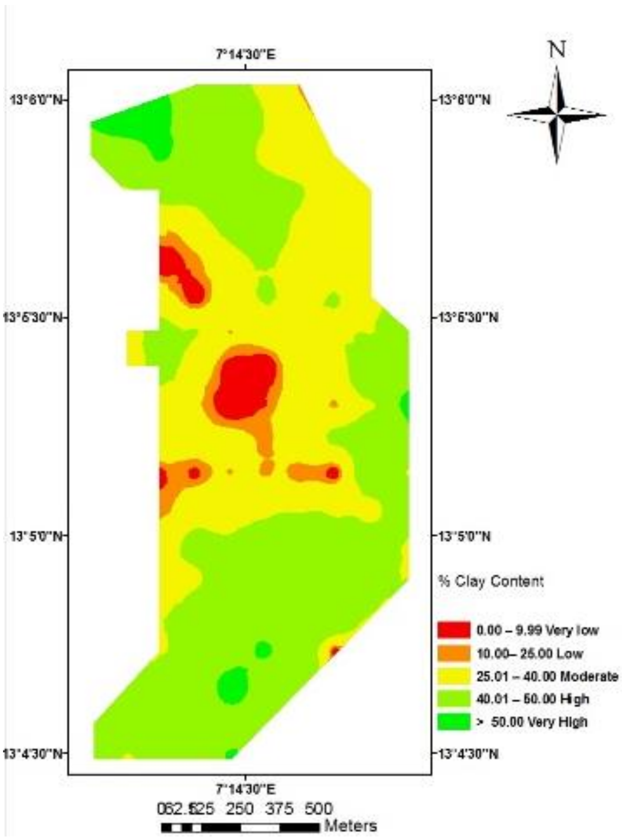

Figure 4. Semivariogram for Clay Content

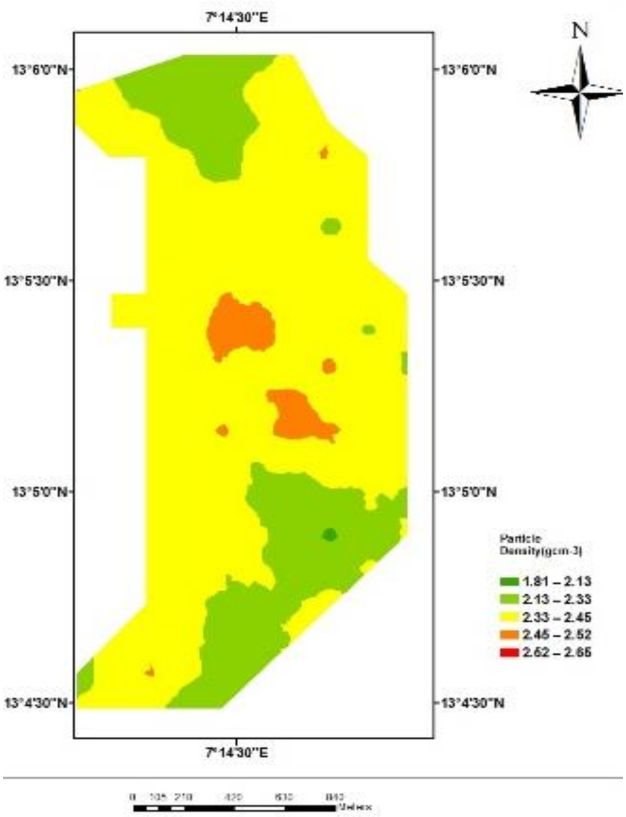

Figure 5. Semivariogram for Partile Density

Semivariogram analysis for organic carbon in the study area indicated weak spatial dependence with $(Co/C(0+C)) > 0.75$. A Short range of 9.3 m was observed and the result was similar with the findings of Reza et al. (2010) who observed a close range of (10.6 m) for OC.

The result shows that Dry mean weight diameter (MWD_{dry}) has a strong spatial dependence with a nugget to sill ratio of < 0.25%. The structural variation, therefore, was as a result of inherent factors such as soil texture, clay mineralogy, nature of exchangeable cations and quality of humus fractions (Tobergte & Curtis, 2013). Semivariogram obtained for MWD_{dry} indicated a range of about 0.342 m within which all the variables were spatially correlated.

Wet Mean Weight diameter of the soil aggregate (MWD_w) had a weak spatial dependence with a nugget to sill ratio > 0.75%. Semivariogram obtained for MWD_w indicated a range of about 2.86 m within which all the variables were spatially correlated. Weak spatial dependence is normally associated with interplay between exogenous and endogenous factors. Land use and management practices in association with soil properties such as texture might be responsible. Tillage methods and soil disturbance activities that break down plant organic matter prevents accumulation of soil organic matter and disrupts existing aggregates. Continuous Cropping and grazing over the years leave soil bare and expose it to the physical impact of raindrops or wind-blown soil particles; and above all removing sources of organic matter and surface roughness by burning, harvesting or removing crop residues Salako (2003); Arshad and Lowery (1996).

A low mean weight diameter observed for both dry aggregate (0.56 mm) and wet aggregate (0.49 mm) indicated that the soil of the study area is both prone to soil and water erosion. This observation agrees with the findings of Salako (2003).

Spatial mapping of Soil physical properties

The spatial distribution maps of soil particle size distribution generated from their Semivariograms are presented in Figures 2, 3 and 4. From the spatial distribution map, it was observed that the highest value patches of sand (65 to 98%) was distributed mainly on the central, north-east, western boundary and small patches at the southern part of the study area and lowest value patches (34 to 52 %) occurred around the boundary in the north-western, east and the southern part of the study area. The silt content in the soils of the study area was maximum (24 to 41.3%) in south-eastern and north-western parts. Small patches (0.56 to 24%) of silt were seen along with the east, north-east, south-east and central parts of the study area. The clay content was highest (20 to 51%) in the southeast direction in small patches while lower clay content (0.72 to 20%) was found in the central, northern parts of the study area and covers almost the entire field.

Figure 5 is the Semivariogram for Particle density of the soil in the study area. Lower particle density values (1.81 to 2.49 gcm^{-3}) were observed in north, east, central and south-western parts of the study area; and higher values of particle density (2.49 to 2.65gcm^{-3}) appeared in small patches in the central part of the study area.

Figure 6 shows the spatial distribution of soil bulk density in the study area. From the spatial map, high bulk density values (1.61- 2.06gcm^{-3}) were mostly observed toward the western, eastern and central parts of the study area with some patches at the southern areas of the study area. Medium bulk density values (1.31 – 1.6gcm^{-3}) were observed at the entire northern, central parts and stretching to the southern parts of the study area.

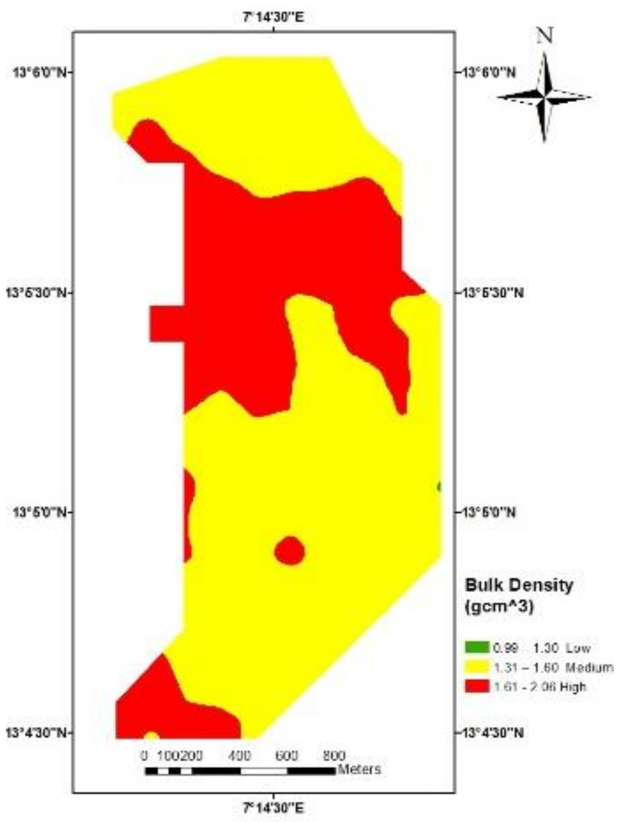

Figure 6. Semivariogram for Bulk density

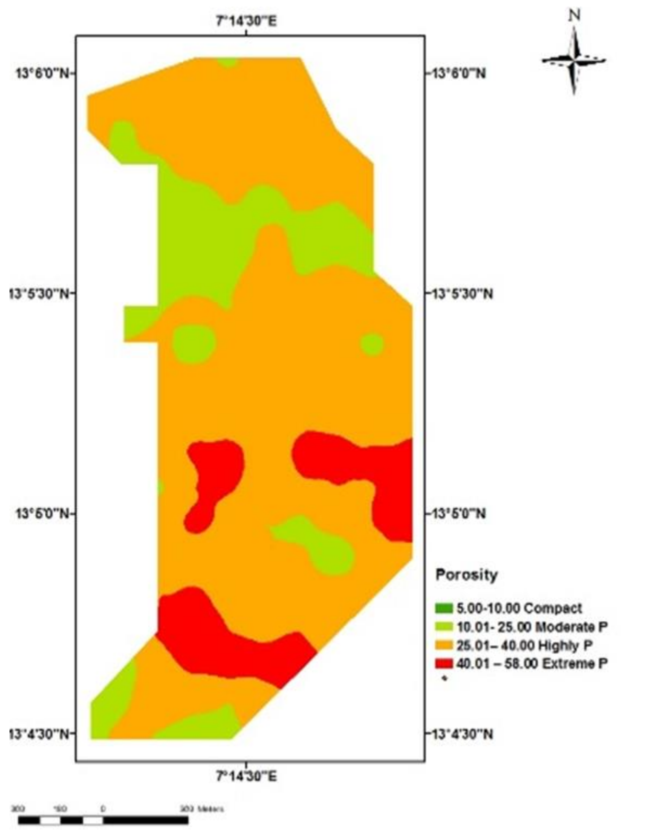

Figure 7. Semivariogram for porosity

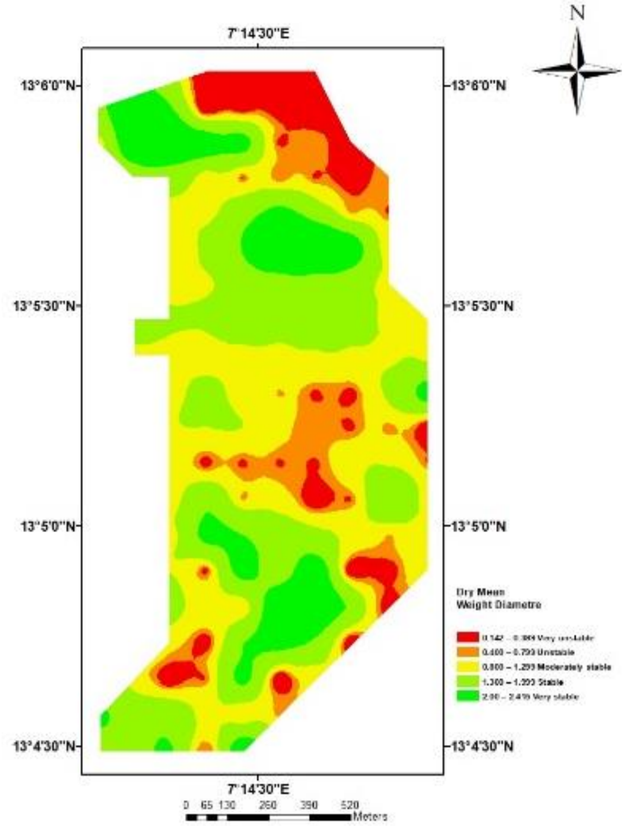

Figure 8. Semivariogram for Dry Mean Weight Diameter

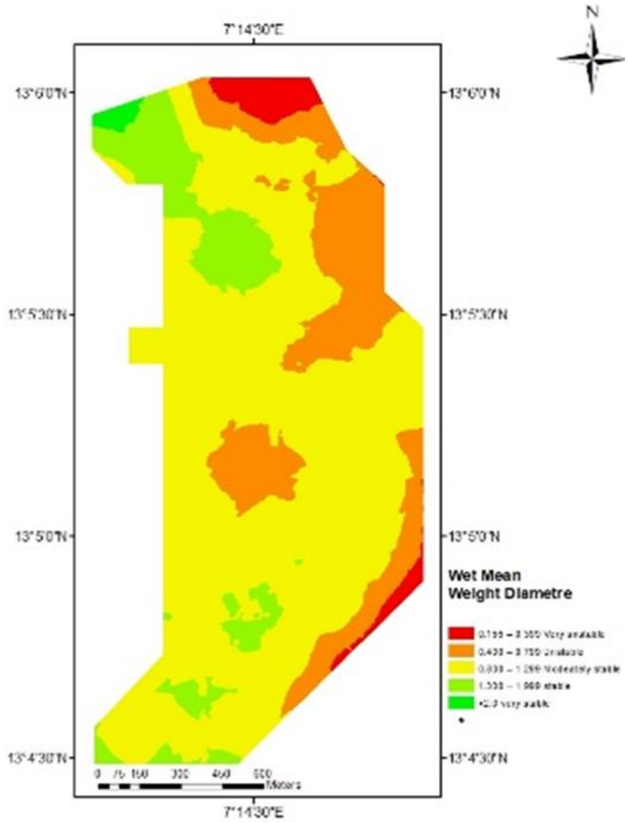

Figure 9. Semivariogram for Wet Mean Weight Diameter

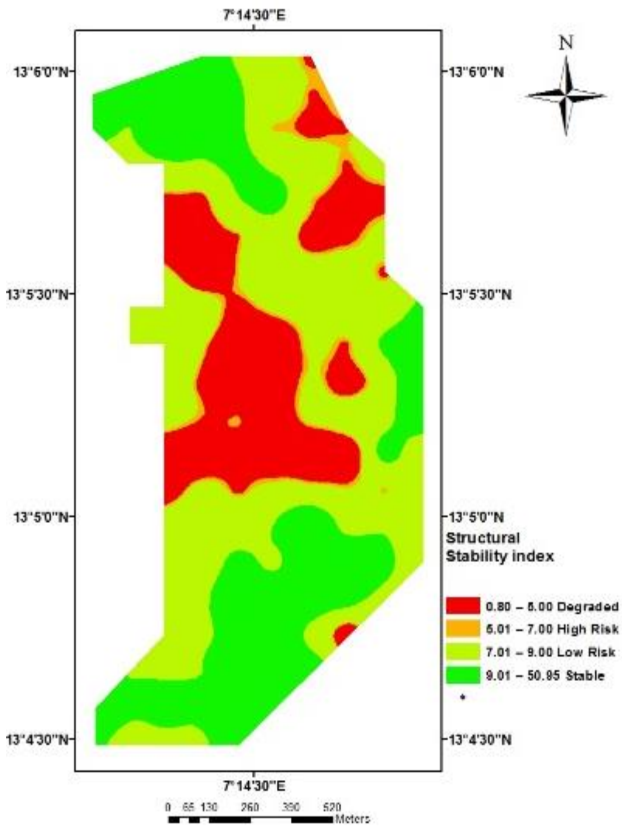

Figure 10. Semivariogram for Structural Stability Index

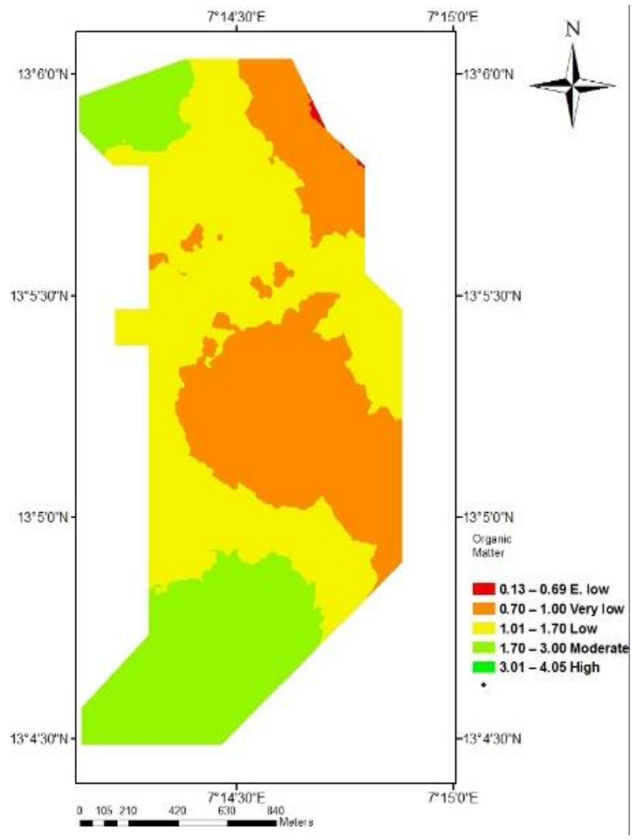

Figure 11. Semivariogram for Organic Matter Content

The distribution of soil porosity shows that there was higher soil porosity (58%) at the north-eastern and in small patches towards the southwestern boundaries of the study area. Lower values of soil porosity (5 to 40%) were observed along the northern-eastern, entire central and southern parts of the study area.

From the kriged map (Figure 8) of dry MWD of soil aggregates, it was clear that highly unstable aggregates were found in east, north-eastern, central, south-western and south-eastern parts of the study area. Unstable aggregates were found in the north-western, central and southern parts of the study area. Moderately stable aggregates were observed in the north-western, central and southern parts of the study area. Conversely, stable aggregates were observed in small portions along the north-western boundary and central and south-eastern parts of the study area. Highly stable aggregates were observed in small patches along the central and north-eastern parts of the study area.

Spatial map of wet mean weight diameter (Figure 9) showed that unstable aggregates dominated the study area occupying the entire north-western, central, eastern and southern parts; followed by highly unstable aggregates which were observed in the north-eastern border, eastern, central and south-eastern parts of the study area. Moderately stable aggregates were observed in small patches along the north-eastern boundary of the study area.

The spatial map of soil structural index (Figure 10) showed that structurally degraded soils were observed at the eastern boundary, central as well as the southern portion of the study area occupying more than half of the entire study area. High-risk areas were observed at the north-west, north-east and southern boundaries of the study area in small patches; and low-risk areas occupying the western and southern edge of the study area. Structurally stable soils were observed in small patches along the western and southern boundaries of the study area.

Spatial Map of soil organic matter (Figure 11) showed that the Organic matter content was very low in the central and eastern boundaries of the study area and lower organic matter content was observed at the northern, western and north-eastern edges of the study area. Moderate organic matter content was observed at the north-western and southern boundaries of the study area.

Conclusion

The results of this study indicated that sandy textured soils dominated the greater part of the study area, Bulk density was observed to be moderate and particle density was also observed to be within the normal range averaging 2.37gcm^{-3}. Total porosity and Organic matter were found to be low. Unstable soil aggregates were in dominance, resulting in a low structural stability index thereby making the soil of the study area susceptible to both water and wind erosion. Sand content was observed to have moderate variability, while silt and clay contents were highly variable. Bulk density and Particle density were observed to have low variability with Particle density having the lowest variability of all the measured soil parameters. Dry mean weight diameter of soil aggregates exhibited high variability. Mean weight diameter of wet soil aggregates was observed to have moderate variability. This implies that the soil in different parts of the study may require different management options. Semivariogram analyses revealed that sand, silt, clay, Bulk density and dry mean weight diameter were observed to exhibit strong spatial dependence. Particle density, porosity and structural stability index were found to have moderate spatial dependence. Weak spatial dependence was observed for organic matter content and mean weight diameter of wet stable aggregates. The exponential model was observed to be the best-fitted model for most of the measured soil parameters, the exception being sand, clay, wet mean weight diameter that were best fitted to the stable, K-bessels and Quadratic models respectively.

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