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APPLICATION OF SEMI-VARIOGRAM ANALYSIS IN MEASURING SPATIAL VARIABILITY AND DISTRIBUTION OF SELECTED SOIL PROPERTIES IN NORTHEAST AKWA IBOM STATE, NIGERIA

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Abstract

Application of semi-variogram analysis in measuring spatial variability and distribution of selected soil properties in Northeast Akwa Ibom State, was carried out.The aim was to assess spatial variability and distribution of selected soil properties in the study area for effective site-specific soil management and precision agriculture using semi-variogram analysis. A digital elevation model (DEM) was acquired from United States Geological Surveys (USGS) at 30m resolution. Slope gradient map that is capable of capturing the short-scale spatial variability of soil properties in the study area was generated from the DEM to guide field sampling. Modified conditioned Latin hypercube sampling technique was used in selecting observation points. Soil samples were collected from each observation point at 0-30 cm and 30-60 cm depths using soil auger. A total of 152 soil samples were collected for laboratory analysis. Analysed data of depth interval of 0-30cm and 30-60 cm were integrated to form depth interval of 0-60 cm. The data were subjected to normality test to ascertain the normal distribution of the data. Selected soil properties were subjected to semi-variogram analysis. The study revealed that slope gradient was able to capture short scale spatial variation in some soil properties under study. Soil texture of the flat/nearly flat was sand in both surface and subsurface soils and sand in the surface soil and loamy sand in the subsurface soil gently sloping and sloping. Soil pH was slightly acidic in flat/nearly flat and gently sloping and strongly acidic in the sloping area in both surface and subsurface soil. Organic carbon was very high in the flat/nearly flat and gently sloping and high in sloping topography in both surface and subsurface soil. Total N was low in the sloping area and moderately low in gently sloping and nearly flat /flat. Base saturation was very high in the sloping topography and high in the gently sloping and nearly flat /flat. The result of semi-variogram analysis showed that all the selected soil properties exhibited spatial dependence within some distances. The range was 136.2 m for sand, 76.4m for silt, 1.6 m for clay, 1.7m for soil pH, 9.4m for organic carbon, 7.1m for total N, 9.2m for available P and 7.8 m for exchangeable K in the study area. Beyond these ranges, there was no longer relationship between sample points and sample values did not relate to one another. The strength of the spatial dependence of sand, silt, soil pH, organic carbon, total N and available P was moderate; exchangeable K was strong while clay was weak. The semi-variance (sill) was 57.4 for sand, 23.8 for silt, 7.15 for clay, 0.21 for soil pH, 1.18 for organic carbon, 0.002 for total N, 85.1 for available P, and 0.03 for exchangeable K. The nugget variance or nugget effect was 25.9 for sand, 10.2 for silt, 5.9 for clay, 0.06 for soil pH, 0.60 for organic carbon, 0.001 for total N, 33.4 for available P and 0.003 for exchangeable K. The best fitted models were Exponential for sand and silt; Gaussian for available P and Spherical for clay, pH, organic carbon, total N and exchangeable K.

Keywords: *Soil variability, spatial dependence, autocorrelation, semi-variogra*

INTRODUCTION

Spatial variability is one of the main features of soil properties. Soil properties exhibit marked heterogeneity even within a short distance. According to Webster and Oliver (2001), soil properties are continuous variables, whose values at any location are expected to vary according to distance and direction of separation from the neighboring locations (intrinsic stationarity assumption). Whatever is causing an observation in one location also causes similar observation in a nearby location (deterministic factor) but changes in observation may occur with increase in distance of separation (McBratney *et al*., 2003). A regionalized variable at a point A [$Z(x_1)$] is related (spatial dependence) to that same variable at point B [$Z(x_1) + h$] within a short distance of separation (h) (Hengel *et al.*, 2007). However, with further increase in distance of separation, at certain point, there may be no autocorrelation (spatial independence) in variable values between points (pairs of points). At this distance there is no longer relationship between sample points and sample values are not related to one another. At closer distance, the variable is more predictable and has less variability. As distance increases, the variable under investigation becomes less predictable and less related (more variable). (Hengel *et al.*, 2007). According to Tobler's First Law of Geography, "Everything is related to everything else, but near things are more related than distant things" (Millar, 2004). A terrain elevation may be similar within 5m apart, but less similar 100 m apart. Tobler's First Law of Geography is the foundation of spatial analysis (Webster and Oliver, 2001).

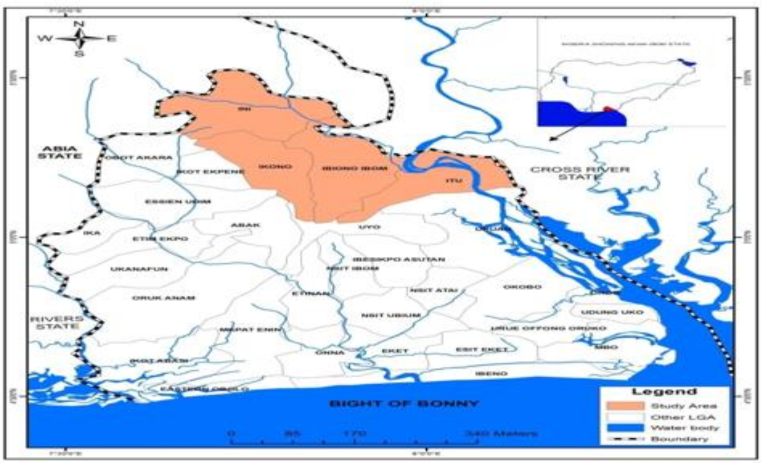
Tobler's First Law of Geography can be measured using semi-variogram and spatial autocorrelation / covariance.. Semi-variogram (semi-variance versus distance) measures the variability of values (dissimilarity) of regionalized variable between two points (Goovaerts, 1999). It measures the average dissimilarity of values of variable between pairs of points separated by a distance or class of distances. It graphs a variable by distance. Autocorrelation (Correlogram or correlation versus distance and covariance or covariance versus distance) on the other hand, measures the similarity of values of variables between two points separated by distance (h). Autocorrelation (Correlogram and covariance) decreases with increasing distance of separation and have small autocorrelation value while semi-variance (variability or dissimilarity) increases with increasing distance of separation and have high semi-variance value (Hengel *et al.*, 2007). Kriging which is interpolation technique is used in generating prediction surfaces and surfaces that describe how well the model predicts (prediction variance) relies on the semi-variogram (McBratney *et al*., 2003).

Spatial variability of soil properties is a major reason behind allocation of land to wrong uses and poor land-use planning in Nigeria (Fabami, 1990). This is because as distance increases, values of variables that are continuous are less related to one another, less predictable and required different management options. An intimate knowledge of extent of spatial dependence or spatial structure of soil properties in an area is a pre-requisite for precision agriculture. Farm inputs such as fertilizers, pesticides etc will be applied at the right place, right quantity and at the right time with the knowledge of extent of spatial dependence or spatial structure of soil properties in an area (Vanwalleghem *et al.*, 2010). Uniform application over a large area that led to over-application in some places and under- application in some places would be reduced or removed. Therefore, the objective of the study was to assess the spatial structure of selected soil properties for effective site-specific soil management and precision agriculture in Northeast Akwa Ibom State, Nigeria using semi-variogram..

MATERIALS AND METHODS

Study Area

The study was conducted in Northeast Akwa Ibom State (Fig. 1). The state is located in south-South Nigeria. It lies between latitudes $4^0$30'and $5^0$30'N and longitudes 7^0 30'and $8^0$20'E. The study area is underlain mainly by coastal plain sands; sandstone/shale and alluvial deposits parent materials. The annual rainfall ranges from more than 2500 mm to about 3000 mm, with 1 – 3 dry months in the year. Mean annual temperature varies between 26 and 28^0C, while relative humidity varies between 75 – 80 %. The landscape of some parts of the study area consists of hills and ridges with steep sided. The low-lying areas are underlain by alluvial deposits (Petters *et al.*, 1989).



Map of Akwa Ibom State showing the study area

Fig.1:

Preliminary Work

Slope gradient that is capable of capturing the short-scale spatial variability of soil properties in the study area was selected to guide field sampling. Slope gradient map of the study area was generated from digital elevation model (DEM) (Fig.2) at 30m resolution acquired from United States Geological Surveys (USGS). It was classified into three classes of straight or nearly flat/flat, gently sloping and sloping to guide field sampling.

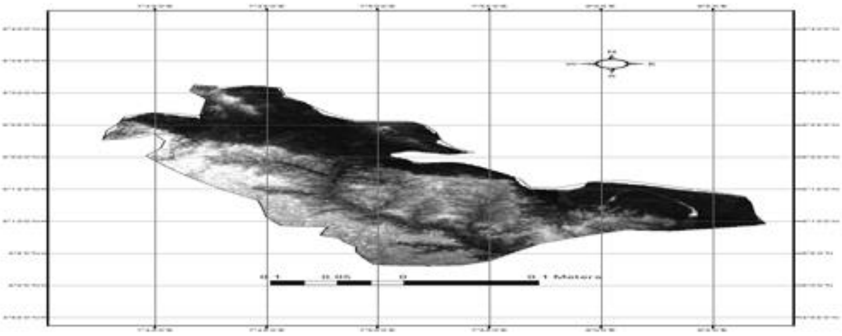


Fig. 2 Digital elevation model of the study area (30 m spatial resolution)

Field Sampling

With the aid of Global Positioning System (GPS), the classes obtained from Slope gradient map were cross-checked (ground-truthing) in the field. Modified Conditioned Latin Hypercube Sampling Method was used in selecting observation points. Each observation point was purposively selected to fall within the classes of slope gradient map to give a good coverage of both feature space (classes of slope gradient map) and geographical space (study area). The method ensures that sampling was done in a fully stratified manner. A total of 152 soil samples were collected at a depth of 0-30cm and 30-60 cm using soil auger. The samples were taken to the laboratory for analysis

Laboratory analysis

The following analyses were carried out using appropriate standard procedures:

Particle size analysis was carried out using the Bouyoucos hydrometer method as described by Udo *et al;* (2009). Soil pH was determined in water using a 1:2.5 soil to water suspension and the soil pH was read using a glass electrode. Electrical Conductivity was determined using the conductivity bridge (Udo *et al;* (2009). Organic carbon was determined by the dichromate wet-oxidation method as described by Nelson and Sommers (1996). Available phosphorus was determined using the Bray P.1 extractant. The phosphorus in extract was measured by the blue method as described by Udo *et al;* (2009). Total nitrogen was determined by Kjeldahl digestion and distillation method as described by Udo *et al*; (2009). Exchangeable bases (Ca, Mg, Na, K) were extracted using normal ammonium acetate (Thomas, 1996). The exchangeable K and Na were determined by flame photometer while Ca and Mg were determined using atomic absorption spectrometer. Exchange Acidity was determined using one normal potassium chloride (1NKCl) and by titration method as described by Udo *et al*; (2009). Effective cation exchange capacity (ECEC) was determined by summing up exchangeable cations and exchangeable acidity. Base Saturation was calculated by dividing the total exchangeable bases by the effective cation exchange capacity and multiplied by 100.

$$\% \text{ BS} = \frac{Total\ Exchangeable\ Base \times 100}{ECEC}$$ *(Udo et al., 2009).*

Statistical analysis

Data obtained were subjected to analysis of variance (ANOVA) and means were separated using least significant difference (LSD) at 5% level of significance (Matheron, 1963).

Depth integration and Transformation of the target variables: The depth interval of 0-30cm and 30-60 cm was integrated to form depth interval of 0-60 cm. The data were subjected to normality test to ascertain the normal distribution of the data. The target soil properties with skewed distributions were log transformed which is a requirement for semi-variance analysis (Venables and Ripley, 2002).

Semi-variogram analysis: Semi-variogram analysis was used to measure spatial variability (spatial dependence / structure or autocorrelation) of the selected soil properties in the study area. The differences between the observation points which constitute the pairs points were calculated, squared, summed and divided by two and by the total number of sample pairs (N) with intermediate distance (h) as described by the equation:

$$\boldsymbol{\gamma(h) = \frac{1}{2N(h)} \sum_{i=1.2}^{N(h)} (y_i - y_i + h)^2}$$ (Cambardella et *al*., 2004)

Where $\gamma(h)$ is the semi-variance for a distance h, N(h) is the number of observation pairs separated by a distance h and $y_i - y_i + h$ represents the measured value of the selected soil properties at two observation points. The plotted semi-variance versus distance was then fitted with best-fitted model. Variogram models such as exponential, Gaussian and spherical were fitted based on the least mean square error and on goodness of fit (visible interpretation). The sill which is the semi-variance value at which the variogram levels was measured. The range which is the distance at which the semi-variogram reaches the sill value was also measured. Autocorrelation or spatial dependence is zero beyond the range. The nugget variance or nugget effect which is the non-zero semi-variances as distance (h) tends to zero was equally measured. Ideally, the experimental variance should pass through the origin when the distance of separation is zero. However, many regionalized variables have non-zero semi-variances as distance (h) tends to zero. This is .often caused by measurement-errors or variability not detected at the scale of sampling. (Cambardella et *al*., 2004). The nugget to sill ratio (N/S) was used to quantify the strength of the spatial dependence. The values were rated as follow: < 0.25 = strong spatial dependence; 0.25–0.75= moderate, and >0.75= weak spatial dependence (Cambardella *et al*., 2004)..

RESULTS AND DISCUSSION

1.0: Physico-chemical properties of soils of the study area

The mean physicochemical properties of soils of the study area as influenced by slope gradient are shown in Table 1.

Soil Texture

The mean sand fraction of the flat /nearly flat slope was 85.21 % in the surface soils (0-30 cm) and 80.30 % in the subsurface soils (30-60 cm). The silt fraction was 7.13 % in the surface soil and 5.64 % in the subsurface soil while the mean clay fraction was 7.67 % and 14.06 % in the surface and subsurface soils respectively. In the gently sloping, the mean sand fraction was 88.58 % in the surface soil and 83.14 % in the subsurface soil; the mean silt fraction was 4.93 % in the surface soil and 5.36 % in the subsurface soil while the mean clay fraction was 6.49 % in the surface soil and 11.50 % in the subsurface soils. In sloping topography, the mean sand fraction was 82.35 % in the surface soil and 80.18 % in the subsurface soil; the mean silt fraction was 9.36 % in the surface soil and 9.62 % in the subsurface soil, while mean clay fraction was 8.37 % in the surface soil and 10.22 % in the subsurface soil. The mean sand fraction of the gently sloping was significantly higher ($p < 0.05$) than that of the sloping topography but not different from that of flat / nearly flat slope. The mean silt fraction of the sloping topography was significantly higher than that of flat/nearly/ flat and gently sloping. There was no significant difference ($p < 0.05$) in clay fraction between the flat/nearly flat, gently sloping and sloping. In term of soil depth, sand fraction was significantly higher ($p < 0.05$) in the surface soil (0-30 cm) than subsurface soil (30-60 cm) while clay fraction was higher in the surface soil than subsurface soil. There was no significant difference ($p < 0.05$) in silt fraction between the surface and subsurface soil. The low sand fraction of sloping topography compared to the nearly flat/flat and gently sloping could be attributed to rate of surface runoff and erosion. The surface runoff and erosion removed the sand fraction from the surface soil sloping topography and deposited it in the gently sloping and nearly flat surfaces (Ufot *et al.,* 2001). The high clay fraction in the subsurface soil compared to surface soil could be attributed to clay translocation or clay illuviation from the A- horizon to B- horizon (Ufot *et al.*, 2001). Generally, the soil texture of the flat/nearly flat was sand in both surface and subsurface soil. In gently sloping and sloping topography, the soil texture was sand in the surface soil and loamy sand in the subsurface soil. This shows variation in soil texture in the study area.

Soil pH

The mean soil pH of the flat/nearly flat surface was 6.1 in both surface and subsurface soils; gently sloping was 6.0 in the surface soil and 6.1 in the subsurface soil while the sloping topography was 5.5 in the surface and 5.6 in the subsurface soils. The mean soil pH of the flat/nearly flat was significantly higher ($p < 0.05$) than that of sloping topography but not different from that of gently sloping. There was no significant difference ($p < 0.05$) in soil pH between the surface (0-30 cm) and subsurface soil (30-60 cm) in the study area. The high pH values of flat/ nearly flat and gently sloping compared to sloping topography could be attributed to strong downslope colloidal movement. The flat/ nearly flat received runoff water from the sloping landscape with soluble cations; thereby increasing the pH of the soil (Kravchenko, 2002). Generally, soil pH was slightly acidic in flat/nearly flat and gently sloping and strongly acidic in the sloping topography in both surface and subsurface soil.

Electrical conductivity

The mean electrical conductivity (EC) of flat/nearly flat was 0.13 dS/m in the surface soil and 0.08 dS/m in the subsurface soil. In gently sloping, the mean electrical conductivity was 0.14 dS/m in the surface soil and 0.19 dS/m in the subsurface soil. In sloping topography, the mean electrical conductivity was 0.12 dS/m in the surface soil and 0.10 dS/m in the subsurface soil. There was no significant difference ($p < 0.05$) in electrical conductivity between flat/nearly flat, gently sloping and sloping topography. Also, there was no significant difference ($p < 0.05$) in electrical conductivity between the surface (0-30 cm) and subsurface soil (30-60 cm) in the study area.

Organic Carbon

The mean organic carbon of flat/nearly flat was 3.0 % in the surface soil and 2.9 % in the subsurface soils. In gently sloping, the mean organic carbon was 3.0 % in the surface soil and 2.7 % in the subsurface soil. In sloping topography, the mean organic carbon was 1.8 % in the surface soil and 1.9 % in the subsurface soil. The mean organic carbon of the flat/nearly flat was significantly higher ($p < 0.05$) than that of sloping topography but not different from that of gently sloping. There was no significant difference ($p < 0.05$) in organic carbon content between the surface (0-30 cm) and subsurface soils (30-60 cm) in the study area. The very high organic carbon content of flat/nearly flat (planar) and gently sloping compared to sloping topography (high) could be attributed to downslope colloidal movement. Soil loss is less in flat/nearly flat and gently sloping. This encouraged high biomass accumulation due to favourable physical, chemical and biological properties of the soil (Shary, 1991). This shows variation in the content of soil organic carbon in the study area.

Total N

The mean total N of the flat /nearly flat was 0.13 % in the surface soil and 0.12 % in the subsurface soils. In gently sloping, the mean total N was 0.13 % in the surface soil and 0.17 % in the subsurface soil. In sloping topography, the mean total N was 0.10 % in the surface soil and 0.08 % in the subsurface soil. The mean total N of sloping topography was significantly lower ($p < 0.05$) than that of the flat/nearly flat and gently sloping. Total N was low in the sloping topography and moderately low in gently sloping and nearly flat /flat. There was no significant difference ($p < 0.05$) in total N content between the surface (0-30 cm) and subsurface soils (30-60 cm) in the study area. Just like the organic matter, the flat/ nearly flat received runoff water from the higher landscape with suspended organic matter. The organic matter had undergone mineralization to release N into the soil (Kravchenko, 2002). Generally, there was observable variation in total N in the study area

Available P

The mean available P of flat/nearly flat topography was 45.0 mg/kg in the surface soil and 47.7 mg/kg in the subsurface soil. In the gently sloping, the mean available P was 32.5 mg/kg in the surface soil and 31.0 mg/kg in the subsurface soil. In sloping topography, the mean available P was 38.4 mg/kg in the surface soil and 38.0 mg/kg in the subsurface soil. The mean available P of flat/nearly flat topography was significantly higher ($p < 0.05$) than that of sloping and gently sloping topography. The high available P of the flat/nearly flat topography compared to gently sloping and sloping topography could be attributed to the less soil loss by runoff and erosion, favourable soil moisture and temperature resulting in high biomass, mineralization of organic materials to release available P (Kravchenko, 2002). There was no significant difference ($p < 0.05$) in available P content between the surface (0-30 cm) and subsurface soils (30-60 cm) in the study area. Generally, available P was high in the study. There was observable variation in available P in the study area.

Table 1: Mean physicochemical properties of soils of the study area as influenced by slope gradient

Soil properties	Sand (%)			Silt (%)			Clay (%)			pH			EC (dS/m)			Organic C (%)		
	Depth (cm)			Depth (cm)			Depth (cm)			Depth (cm)			Depth (cm)			Depth (cm)		
Strata	0-30	30-60	Mean	0-30	30-60	Mean	0-30	30-60	Mean	0-30	30-60	Mean	0-30	30-60	Mean	0-30	30-60	Mean
Nearly flat	85.21	80.30	82.75	7.13	5.64	6.38	7.67	14.06	10.87	6.1	6.1	6.1	0.13	0.08	0.11	3.0	2.9	2.9
G. sloping	88.58	83.14	85.86	4.93	5.36	5.15	6.49	11.50	8.99	6.0	6.1	6.0	0.14	0.19	0.17	3.0	2.7	2.8
Sloping	82.35	80.18	81.26	9.36	9.62	9.49	8.37	10.22	9.29	5.5	5.6	5.6	0.12	0.10	0.11	1.8	1.9	1.8
Mean	85.38	81.20		7.14	6.87		7.51	11.93		5.9	5.9		0.13	0.12	2.6	2.5		
$LSD_{(0.05)}$	Slope gradient = 3.9			2.1			3.0			0.3			0.08			0.6		
	Depth (cm) = 3.2			1.7			2.4			0.2			0.06			0.5		
	Gradient x depth = 5.5			2.9			4.2			0.4			0.11			0.9		

	Total N (%)			Available P (mg/kg)			Exch. Ca (cmol/kg)			Exch. Mg (cmol/kg)			Exch. Na (cmol/kg)			Exch. K (cmol/kg)		
Strata	0-30	30-60	Mean	0-30	30-60	Mean	0-30	30-60	Mean	0-30	30-60	Mean	0-30	30-60	Mean	0-30	30-60	Mean
Nearly flat	0.13	0.12	0.13	45.0	47.7	46.3	3.4	2.6	3.0	1.2	1.2	1.2	0.11	0.11	0.11	0.16	0.12	0.14
G. sloping	0.13	0.17	0.15	32.5	31.0	31.8	3.2	3.4	3.3	1.0	1.6	1.3	0.37	0.32	0.34	0.18	0.09	0.14
Sloping	0.10	0.08	0.09	37.5	38.4	38.0	2.2	2.2	2.2	2.1	1.8	2.0	0.58	0.90	0.74	0.15	0.12	0.13
Mean	0.12	0.12		38.4	39.0		3.0	2.7		1.4	1.5		0.35	0.44		0.16	0.11	
$LSD_{(0.05)}$	Slope gradient = 0.05			4.2			1.0			0.6			0.26			0.08		
	Depth (cm) = 0.04			3.4			0.8			0.5			0.21			0.06		
	Gradient x depth = 0.08			5.9			1.4			0.8			0.37			0.11		

Table 1: Mean physicochemical properties of soils of the study area as influenced by slope gradient (contd.)

Soil properties	Exch. Acidity (cmol/kg)			ECEC (cmol/kg)			Base saturation (%)		
	Depth (cm)			Depth (cm)			Depth (cm)		
Strata	0-30	30-60	Mean	0-30	30-60	Mean	0-30	30-60	Mean
Nearly flat	3.5	3.9	3.7	8.4	7.9	8.2	57.1	50.5	53.8
G. sloping	3.2	4.3	3.8	8.0	9.7	8.8	59.5	54.4	56.9
Sloping	2.9	2.9	2.9	8.0	7.8	7.9	64.0	64.2	64.1
Mean	3.2	3.7		8.1	8.5		60.2	56.4	
LSD(0.05)	Slope gradient = 0.9			1.4			7.9		
	Depth (cm) = 0.7			1.2			6.5		
	Gradient x depth = 1.3			2.0			11.2		

Exch. Acidity = exchangeable acidity, ECEC = effective cation exchange capacity, Base sat. = base saturation

Exchangeable Bases

Exchangeable Ca

The mean exchangeable Ca of the flat/nearly flat surface was 3.4 cmol/kg in the surface soil and 2.6 cmol/kg in the subsurface soil. In the gently sloping, the mean exchangeable Ca was 3.2 cmol/kg in the surface soil and 3.4 cmo/kg in the subsurface soil. In sloping topography, the mean exchangeable Ca was 2.2 cmol/kg in both surface soil and subsurface soil. Mean exchangeable Ca of gently sloping was significantly higher ($p < 0.05$) than that of sloping topography but not different from that of flat/nearly flat. The high exchangeable Ca in the gently sloping and nearly flat the sloping could be attributed to the less soil loss by runoff and erosion. The high biomass accumulation due to favourable physical, chemical and biological properties of the soil in gently sloping could lead to high exchangeable Ca after mineralisation of organic matter (Shary, 1991). However, exchangeable Ca was low in the study area. There was no significant difference ($p < 0.05$) in exchangeable Ca content between the surface (0-30 cm) and subsurface soils (30-60 cm) in the study area.

Exchangeable Mg

The mean exchangeable Mg of the flat/nearly flat was 1.2 cmol/kg in both surface and subsurface soils. In the gently sloping, the mean exchangeable Mg was 1.0 cmol/kg in the surface soil and 1.6 cmol/kg in the subsurface soil. In sloping topography, the mean exchangeable Mg was 2.1 cmol/kg in the surface soil and 1.8 cmol/kg in the subsurface soil. Mean exchangeable Mg of sloping topography was significantly higher ($p < 0.05$) than that of gently sloping and flat/nearly flat topography. This could be attributed to surface runoff and erosion which removed the topsoil particles, thus exposing the subsoil horizons with Mg bearing minerals which had undergone weathering to release Mg into the soil (Ufot *et al.*, 2001). There was no significant difference ($p < 0.05$) in exchangeable Mg between the surface and subsurface soils. Generally, exchangeable Mg was moderate in the study area.

Exchangeable Na

The mean exchangeable Na of flat/nearly flat was 0.11 cmol/kg in both surface soil and subsurface soils. In the gently sloping, the mean exchangeable Na was 0.37 cmol/kg in the surface soil and 0.32 cmol/kg in the subsurface soil. In sloping topography, the mean exchangeable Na was 0.58 cmol/kg in the surface soil and 0.90 cmol/kg in the subsurface soil. The mean exchangeable Na of sloping topography was significantly higher ($p < 0.05$) than that of flat/nearly flat and gently sloping topography. Just like exchangeable Mg, this could be attributed to surface runoff and erosion which removes the topsoil particles, thus exposing the subsoil horizons with Na bearing minerals which had undergone weathering to release of Na into the soil (Ufot *et al.,* 2001). There was no significant difference ($p < 0.05$) in exchangeable Na between the surface (0-30 cm) and subsurface soils (30-60 cm) in the study area. Generally, exchangeable Na was low in the flat/nearly flat; moderate in gently sloping and high in sloping topography in the study area.

Exchangeable K

The mean exchangeable K of the flat/nearly flat was 0.16 cmol/kg in the surface soil and 0.12 cmol/kg in the subsurface soil. In gently sloping, the mean exchangeable K was 0.18 cmol/kg in the surface soil and 0.09 cmol/kg in the subsurface soil. In sloping topography, the mean exchangeable K was 0.15 cmol/kg in the surface soil and 0.12 cmol/kg in the subsurface soil. There was no significant difference ($p < 0.05$) in exchangeable K between the flat /nearly flat, gently sloping and sloping topography as well as between the surface (0-30 cm) and subsurface soils (30-60 cm) in the study area. Generally, exchangeable K was low in the study area.

Effective cation exchange capacity (ECEC)

The mean effective cation exchange capacity (ECEC) of the flat/nearly flat was 8.4 cmol/kg in the surface soil and 7.9 cmol/kg in the subsurface soil. In the gently sloping, the mean ECEC was 8.0 cmol/kg in the surface soil and 9.7 cmol/kg in the subsurface soil. In sloping topography, the mean ECEC was 8.0 cmol/kg in the surface soil and 7.8 cmol/kg in the subsurface soil. There was no significant difference ($p < 0.05$) in ECEC between the flat/nearly flat, gently sloping and undulating as well as between the surface and subsurface soils. Generally, ECEC was low in the study area.

Exchangeable acidity (EA)

The mean exchangeable acidity (EA) of the flat/nearly flat was 3.5 cmol/kg in the surface soil and 3.9 cmol/kg in the subsurface soil. In the gently sloping, the mean EA was 3.2 cmol/kg in the surface soil and 4.3 cmol/kg in the subsurface soil. In sloping topography, the mean EA was 2.9 cmol/kg in both the surface soil and subsurface soil. There was no significant difference ($p < 0.05$) in EA between the flat/nearly flat, gently sloping and sloping as well as between the surface and subsurface soils.

Base saturation

The mean base saturation of the flat/nearly flat was 57.1 % in the surface soil and 50.5 % in the subsurface soil. In the gently sloping, the mean base saturation was 59.5 % in the surface soil and 54.4 % in the subsurface soil. In sloping topography, the mean base saturation was 64.0 % in the surface soil and 64.2 % in the subsurface soil. The mean base saturation of sloping topography was significantly higher ($p < 0.05$) than that of flat/nearly flat but not different from that of the gently sloping topography. The high base saturation of sloping topography compared to flat/nearly flat could be attributed to surface runoff and erosion which removes the topsoil particles, thus exposing the subsoil horizons with basic cations bearing minerals which had undergone weathering to release the bases into the soil. These increased the exchange sites occupied by basic cations (Ufot *et al.,* 2001). There was no significant difference ($p < 0.05$) in base saturation between the surface and subsurface soils. Generally, base saturation was moderate in flat/nearly flat and gently sloping and high in sloping topography in the study area.

2. Summary statistics and normality test of the selected soil properties for semi-variance analysis

The measured values of the selected soil properties were subjected to normality test to assess the skewedness and Kurtosis of the data as one of the requirements for semi-variance analysis (Emadi *et al.,* 2008). The summary statistics are presented in Table 2. The results showed that among the selected soil properties, the mean values of silt fraction, clay fraction, soil pH, available P and exchangeable K were greater than the median, indicating that the data distributions were right-skewed (positive skewness) with the majority of the data values greater than the mean. This shows that these variables were not normally distributed and required transformation. The mean value of sand fraction was less than median value, indicating that the data distribution was left-skewed (negative skewness) with the majority of the data values less than the mean, required transformation. The mean values of soil organic carbon and total N were similar to the median values, indicating symmetry and were normally distributed. After logarithmic transformation, skewness value of silt reduced from 0.57 to -0.91, clay reduced from 0.78 to -0.18, pH reduced from 0.81 to 0.47, available P reduced from 0.32 to 0.06 while exchangeable K reduced from 4.43 to -1.59. This shows that the skewness of logarithmic transformed data values were closer to 0 (symmetry) than the non- transformed data values. The skewness value of sand fraction on the other hand increased from -0.45 to -0.68 (left-skewed) after log transformation. Organic carbon and total N were near 0 (symmetric)' Logarithmic transformation resulted in smaller skewness and kurtosis, causing the distribution to approach Gaussian (normal distribution), which is a requirement, for semi-variance analysis (Emadi *et al*., 2008)

Table 2: Summary statistics and normality test of the selected soil properties

Soil property	Minimum	Maximum	Mean	Median	Skewness	Kurtosis	Distribution type
Before transformation							
Sand (%)	63.86	94.64	84.43	84.54	-0.454	3.5	Leptokurtic
Silt (%)	1.28	14.08	7.81	7.18	0.573	3.6	Leptokurtic
Clay (%)	2.64	21.48	7.74	7.21	0.780	3.0	Mesokurtic
pH	4.6	7.5	5.7	5.6	0.812	4.3	Leptokurtic
Org. C (%)	0.76	4.97	2.6	2.6	0.091	2.2	Platykurtic
Total N (%)	0.03	0.3	0.12	0.12	0.262	2.4	Platykurtic
Av. P (mg/kg)	27.3	72.83	43.3	43.0	0.324	1.9	Leptokurtic
Exch. K (cmol/kg)	0.002	0.61	0.14	0.09	4.428	27.9	Leptokurtic
After Log-transformation							
Log sand					-0.679	3.9	
Log silt					-0.909	3.7	
Log clay					-0.177	2.5	
Log pH					0.467	3.7	
Log Av.P					0.063	1.8	
Log exch. K					-1.586	8.0	

Leptokurtic shows sharp peak on the graph, platykurtic shows flat-top, mesokurtic shows bell curve. Normal distributions are mesokurtic distributions with coefficient of kurtosis equal to 3 or approximately close to 3. If the coefficient of skewness equal to 0 or approximately close to 0, the graph is symmetric and the distribution is normally distributed

3. Semi-variogram analysis of the selected soil properties

Eight variables were selected for the study of their spatial variability. They were sand, silt, clay, pH, organic carbon, total N, Av. P and exch. K. The semi-variance analysis was performed on the measured values. The semi-variogram models and parameters are presented in Table 2 and the graphs are presented in Figures 3-10. All the selected properties exhibited significant spatial dependence. Based on visible interpretation and sum of square error (SSEr), exponential model was the best fitted model for sand and silt when compared to other models while Gaussian model was the best fitted model for available P when compared to other models. Spherical model was the best fitted model for pH, organic carbon, total N, exchangeable K and clay fraction when compared to other models. The models provide mathematical function to the relationship between values and distances. In spherical model, the semi-variance value increases, reaches maximum and platens with increasing distance. In exponential model, just like spherical model, semi-variance value reaches the sill (maximum) gradually with increasing distance. Gaussian model uses a normal probability distribution curve where semi-variance value progressively rises up the y-axis with increasing distance (Kumar, 2009; Heuvelink and Webster, 2001).

The ratio of nugget /sill for sand was 45.1 %, indicating moderate spatial dependence; silt was 43.1 %, indicating moderate spatial dependence; soil pH was 28.5 %, indicating moderate spatial dependence; available P was 39.2 %;

indicating moderate spatial dependence; organic carbon was 50.6 % , indicating moderate spatial dependence; total N was 50.0 %, indicating moderate spatial dependence; exchangeable K was 11.1 % , indicating strong spatial dependence, clay was 83.1 %, indicating weak spatial dependence (Cambardella *et al.*, 1994).. Zheng *et al*. (2009) attributed strong spatial dependence of soil properties to intrinsic factors such as texture, parent material and mineralogy, and weak spatial dependency to random extrinsic factors such as plowing, fertilization and other soil management practices. The moderate to weak spatial dependence of the selected soil properties could partly be due to the weak correlation between soil properties and auxiliary variables and partly to land-use and soil management practices in the study area. The strong spatial dependence of exchangeable K could be attributed to parent material which accounts for very low exchangeable K content in the study area.

The sill which is the maximum possible variance at points far apart and represent the degree of variance when points are completely uncorrelated was 57.4 for sand, 23.8 for silt, 7.15 for clay, 0.21 for soil pH, 1.18 for organic carbon, 0.002 for total N, 85.1 for available P, and 0.03 for exchangeable K. Among the selected soil properties, available P had the highest sill, followed by sand while total N had the least.

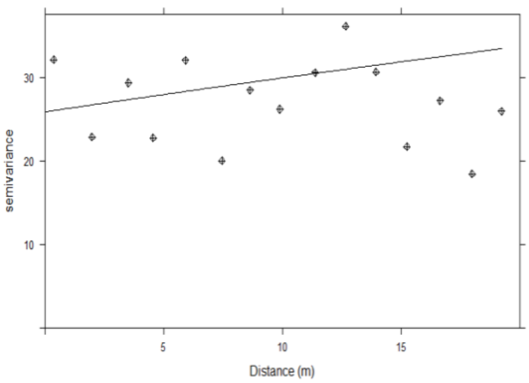
The nugget, which represents random variation caused mainly by the undetectable experimental error and field variation within the minimum sampling space (Cerri *et al*., 2004; Askin and Kizikaya, 2006) was 25.9 for sand, 10.2 for silt, 5.9 for clay, 0.06 for soil pH, 0.60 for organic carbon, 0.001 for total N, 33.4 for available P and 0.003 for exchangeable K. The implication is that the variation in soil pH, organic carbon, total N and exchangeable K were reasonably well explained or captured by the sampling distance or sampling scale used in the study as the nugget value was closer to zero (Cerri *et al*., 2004). But the sampling scale or distance for sand, silt, clay and available P could not adequately capture or explain the variation in these properties as their nugget values were far from zero.

The range, which is an indication of the distance beyond which measured selected soil properties were no longer spatially correlated (lack autocorrelation) (Tabi and Ogunkunle, 2007), was 136.2 m for sand, 76.4m for silt and 1.69m for soil pH. Available P was 9.2m, organic carbon was 9.4m, total N was 7.1m exchangeable K was 7.8 m and clay was 1.6 m in the study area. This shows that the values of sand fraction were related or more alike within 136.2m apart; that of silt were related or alike within 76.4m apart, that of soil pH were alike within 1.69m apart etc. This result shows that soil properties under consideration were not similar in distance of autocorrelation. This variation could be attributed to factors of soil formation and development and soil management practices. Hengl *et al*. (2007) observed that functional relationship between environmental variables (soil properties) and auxiliary variables or covariates can differ for different study areas, different seasons and different scales.

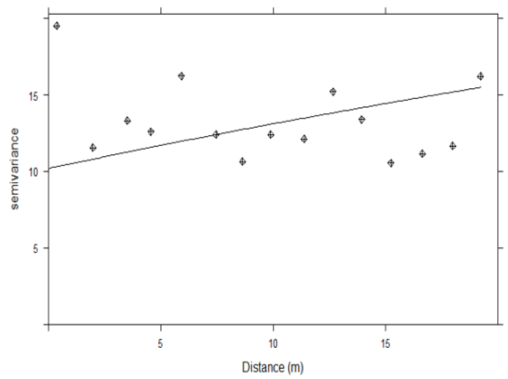
Table 3: Semi-variogram models and parameters of the selected soil properties

Soil property	Nugget (Co)	Sill (Co +C)	Co/Co+C (%)	Range (m)	Model	SSErr	Strength of Spatial dependence
Sand	25.87	57.37	45.1	136.2	Exponential	8736.8	Moderate
Silt	10.20	23.79	43.3	76.4	Exponential	10216.9	Moderate
Clay	5.94	7.145	83.1	1.58	Spherical	218.421	Weak
pH	0.059	0.207	28.5	1.69	Spherical	0.1550	Moderate
Organic C	0.598	1.181	50.6	9.42	Spherical	0.7742	Moderate
Total N	0.001	0.002	50.0	7.09	Spherical	5.85e-06	Moderate
Available P	33.35	85.05	39.2	9.23	Gaussian	4839.3	Moderate
Exch. K	0.003	0.027	11.1	7.83	Spherical	0.0017	Strong

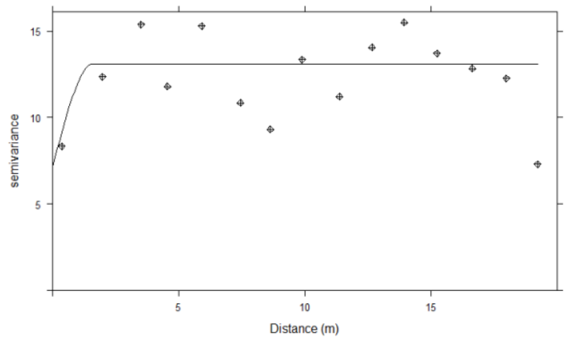
Classes of spatial dependence: ≤ 25% = strongly spatially dependent, 26-75%=moderately spatially dependent; > 75% = weakly spatially dependent (Cambardella *et al.,* 2004).



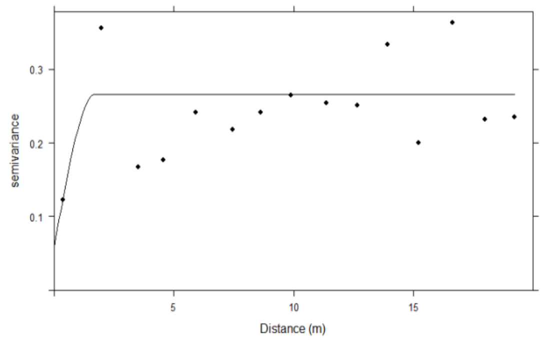
3.Semi-variogram of sand



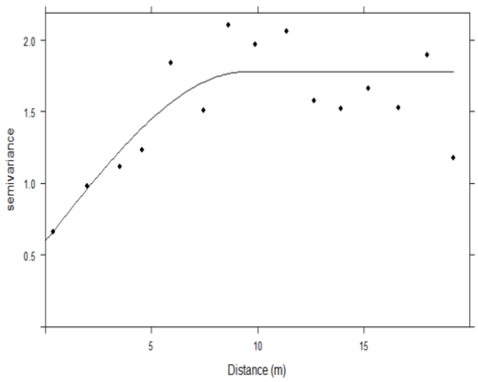
4. Semi-variogram of silt



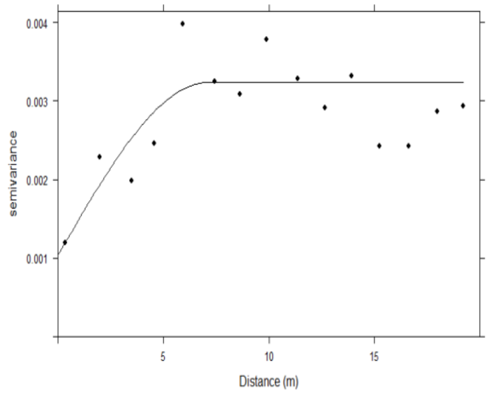
5.Semi-variogram of clay



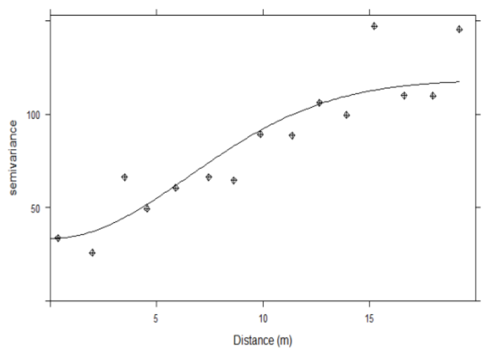
6. Semi-variogram of soil pH



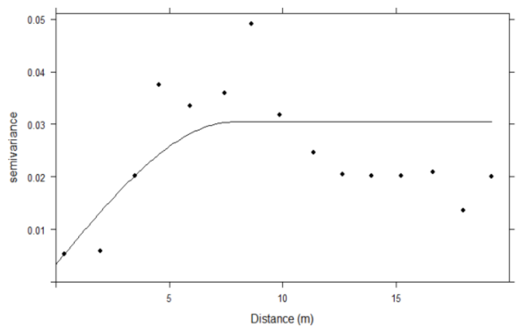
7.Semi-variogram of soil organic carbon



8 Semi-variogram of total N



9. Semi-variogram of available P



10. Semi-variogram of exchangeable K

Figs. 3-10

CONCLUSION

The study revealed that slope gradient was able to capture short scale spatial variation in some soil properties under study. Soil texture of the flat/nearly flat was sand in both surface and subsurface soils and sand in the surface soil and loamy sand in the subsurface soil in gently sloping and sloping. Soil pH was slightly acidic in flat/nearly flat and gently sloping and strongly acidic in the sloping area in both surface and subsurface soil. Organic carbon was very high in the flat/nearly flat and gently sloping and high in sloping topography in both surface and subsurface soils. Total N was low in the sloping area and moderately low in gently sloping and nearly flat /flat. Base saturation was very high in the sloping topography and high in the gently sloping and nearly flat /flat. The result of semi-variogram analysis showed that all the selected soil properties exhibited spatial dependence within some distances. The range was 136.2 m for sand, 76.4m for silt, 1.6 m for clay, 1.7m for soil pH, 9.4m for organic carbon, 7.1m for total N, 9.2m for available P and 7.8 m for exchangeable K in the study area. Beyond these ranges, there was no longer relationship between sample points and sample values did not relate to one another. The strength of the spatial dependence of sand, silt, soil pH, organic carbon, total N and available P was moderate; exchangeable K was strong while clay was weak. The semi- variance (sill) was 57.4 for sand, 23.8 for silt, 7.15 for clay, 0.21 for soil pH, 1.18 for organic carbon, 0.002 for total N, 85.1 for available P, and 0.03 for exchangeable K. The nugget variance or nugget effect was 25.9 for sand, 10.2 for silt, 5.9 for clay, 0.06 for soil pH, 0.60 for organic carbon, 0.001 for total N, 33.4 for available P and 0.003 for exchangeable K. The best fitted models which provide mathematical function to the relationship between values and distances were

Exponential for sand and silt; Gaussian for available P and Spherical for clay, pH, organic carbon, total N and exchangeable K.

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