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SPATIAL DISTRIBUTION OF SOIL ORGANIC CARBON AND TOTAL NITROGEN IN A GRID SAMPLED LANDSCAPE

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Abstract:

Assessing of chemical properties and estimation of their associated variability are essential for making site-specific decisions on soil and crop management practices. This study was conducted with the aim of assessing thespatial variability of organic carbon and total nitrogen in the Kubani area, Zaria, Kaduna state(Lat 11° 06.625''N to 11°05.375''N and longitude 007°41.608"E to 007°39.680"E), with an elevation ranging from 631m to 689m above sea level, to observe changes in the variance structure caused by different sampling distances and to suggest future sampling distances with less spatial variability. 210 soil samples were collected at 0-15 cm depth at a distance of 3 m intervals using Geographical Positioning System (GPS). The geostatistical package was used to model the variance structure of Organic Carbon (OC), and Total Nitrogen (TN). Results obtained revealed that the standard deviation ranged from 0.44 (total nitrogen) to 2.36 (organic carbon). The semi-variograms showed that the range of spatial dependence varied from 14 m (Organic Carbon) to 45m (Total Nitrogen) for measured chemical soil properties were spatially correlated within that distance; therefore, kriging can be used to estimate organic carbon and total nitrogen from available data. The kriged contour maps showed positional similarities. These maps of organic carbon and total nitrogen, along with their spatial structures, can be used in making better future sampling measurements and management decisions.

Keywords **— Spatial Variability, Kriging, Total Carbon, Total Nitrogen**

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I INTRODUCTION

The evaluation of soil spatial variability is an important issue in agriculture and environmental research if accurate and precise estimation of treatment and management of crop yield is paramount to the farmer or researcher. Soil spatial variation includes components of long-range gradients of soil fertility status that relates to the general pedogenic processes as well as short range or micro-variation in much labile soil nutrients (Dobermann, 1994). Variation in some of the soil chemical properties (like Total Nitrogen and Organic Carbon etc) does not necessarily conform to a regular pattern which would be simple to take care of through blocking. This creates constraints in the use of some statistical tools for detecting or remedying treatment management problems as well as leading to erroneous conclusions about the efficacy of a given treatment. The inability of analysis of variance and covariance analysis to remove the effect of soil variability from treatment effect has necessitated the use of nearest neighbour analysis (Obidike et al, 2011). The nearest neighbour of mean analysis is use as a means not only to increase the precision of treatment mean difference but also to reduce the variance of treatment yield difference resulting from soil variability. Significant soil trends can also be taken care of by using geostatistical techniques like semi-variogram and kriging, which are more suited to regular and predictable environmental variations than to the random spatchiness that is common in many tropical environments. Variability is influenced by such factors as parent material and size of the sampling area (Webster and Oliver, 2007) A basic premise of these studies of spatial variability is that the spatial structure is preserved over time. However, not much attention has been paid to this issue beyond seasonal differences. SOC and STN have strong spatial heterogeneity, with internal changes in the vertical and horizontal directions and external exchanges with the atmosphere and biosphere. Many factors, such as topography, land-use type, field management and vegetation, can control SOC and STN spatial variability at various scales. Understanding and incorporating such heterogeneity and spatial distribution characteristics can improve the precision of carbon-nitrogen budgets and assist in implementation of effective measures toward vegetation recovery.

In this paper, we quantify the spatial variability and determine the spatial variance structure of chemical properties (OC and TN) of the study site, predict the spatial distribution of organic carbon and total nitrogen using kriging and suggest future sampling distances and validate the resulting maps using cross validation.

II MATERIAL AND METHOD

Soil Sampling

Geo-referenced soil samples were taken at 3 meters interval along 10 transects of 63m each. Soils were sampled at 0-15cm depth with the aid of a soil auger. A total of 210 soil samples were taken from the field for laboratory analysis.

Sample Preparation

The collected soil samples were air dry gently crushed with porcelain pestle and mortar and sieved with a 2mm sieve to remove coarse fragments. The less than 2mm portion were stored in another polyethylene bag and well labelled also for laboratory analysis. While the other uncrushed parts were passed through 5mm sieve and used for dry aggregate size distribution.

Laboratory Analysis of Physicochemical Properties

Laboratory determinations for both chemical and physical properties were carried out. These comprise of total organic carbon, total nitrogen, particle size distribution and dry aggregate size distribution.

Organic Carbon

Soil organic carbon was analysed by wet oxidation method of Walkey-Black (Nelson and Sommer, 1986). 1 gram of air dried, less than 2mm soil were placed in 250ml flask. 5ml of potassium dichromate ($K_2Cr_2O_7$) solution were pipette into the flask and swirled gently for soil dispersion. Then 10ml of H_2SO_4 were rapidly added, the flask was gently swirled immediately until soil and reagent mixed. After swirling the flask, it was allowed to stand on a sheet of asbestos for about 30minutes. 100mls of distilled water were added and allowed to cool before adding 3 drops of indicator. A blank was run without soil to standardize the dichromate. On titrating the ferrous ammonium sulphate against the dichromate + soil sample +H_2SO_4 a colour change of green was gotten before a red colour endpoint was noticed.

$$\% \text{ OC} = \frac{\text{B - T} \times \text{N.F} \times 0.003 \times \text{C.F} \times 100}{\text{Wt. of soil sample used}}$$

Where;

N.F = normality of ferrous sulphate

$$\text{N.F} = \frac{\text{5ml of potassium}}{\text{Blank}} = \frac{5}{10}$$

CF =

correction factor = 1.33

Wt. of soil sample used = 1g

Total Nitrogen

Total Nitrogen(TN) was determined by Kjeldahl method (Bremner, 1982). This is a wet oxidation method which involves digestion of the soil sample to convert N to ammonium and determination of the NH_4 in the digest by titration. 1 gram of air dried, less than 2mm soil sample were weighed into a digestion tube and a level spoon of Kjeldahl catalyst mixture ($CuSO_4$ + Selenium) then by 10mls of concentrated H_2SO_4. The sample + mixture was taken to the digester and heated on a digesting block for about 3 hours at a temperature of about 300°C until digestion was complete. After that, the digest was allowed to cool and was transferred to a plastic bottle and topped to 100ml using distilled water.
10mls of the aliquot was transferred into a distillation flask using a pipette. 10mls of NaOH solution was added and then attached to a distillation apparatus immediately where NH_4-N was trapped into 10mls of 2% boric acid. These distillates were titrated with H_2SO_4 to get to a pink or purple endpoint. Blank titration was also determined without soil sample.
% N content in the soil was calculated thus;

$$\% N = \frac{0.014 \times VD \times NA \times 100 \times (T-B)}{\text{Weight of soil} \times AD}$$

Where;
VD = Volume of digest
NA = Normality of acid
T = Titre
AD = Aliquot of digest
B = Blank

Particle Size Distribution

Particle size distribution was determined by hydrometer method as described by Gee and Bauder (1986). Clay, silt and sand were determined by dispersing the 50g of soil samples in 40g of hexametaphosphate (calgon) + distilled water that was marked up to 100ml of this solution. The dispersed sample were shaken on a reciprocating mechanical shaker for 15 minutes and later put into a 1000ml flask and added up to mark with water. After which the particle size distribution was determined with the aid of Boyoucous hydrometer at 40 seconds (silt) and 2 hours (clay) interval. The textural classes were determined with the aid of USDA textural triangle.

$$C = R_L - B + (0.36 \times T)$$

Where;
C = corrected hydrometer reading (g/L)
R_L = hydrometer reading
B = blank reading
T = temperature of suspension (°C)

$$\% \text{ clay} = \frac{\text{corrected 2 hours value}}{\text{Wt. of soil}} \times 100$$

$$\% \text{ silt} = \frac{\text{corrected 40 seconds value}}{\text{Wt. of soil}} \times 100$$

$$\% \text{ sand} = 100 - (\% \text{ silt} + \% \text{ clay})$$

Aggregate Size Distribution

The dry sieving method was used. 300g of the 5mm crushed soil samples were passed through a set of sieves with diameter ranging from 5mm – 0.05mm mounted on a CSC scientific sieve shaker. The sieves were arranged in descending order of diameter from top to bottom. The < 0.05mm soil aggregate were collected in the collecting pan placed below all other sieves. The nest of sieves was shaken for 120 seconds and the soil aggregates retained in each sieve were collected and weighed.
The aggregate size stability characterized by mean weight diameter (MWD) is defined according to Van Bavel (1950) as;

$$MWD = \sum_{i=1}^{n} x_i \omega_i$$

Where;
x_i = mean diameter of any particular size range of aggregate separated by sieve.
ω_i = weight of aggregate in the size range as fraction of the total dry weight of sample.

IIIRESULTS

Descriptive statistics analysis

Exploratory data analysis was performed on the data set and presented in Table1. The descriptive statistics for the study area revealed differences (low – high) in the amount of variability of the soil variable. Large differences were found between minimum and maximum values of the investigated soil properties indicating variation in soil properties. The coefficient of variation(CV) of a soil property, expressed as the ratio of standard deviation to the mean is the magnitude of variability was ranked according to Wilding,(1985); Shukla et al.,(2004c), into different classes: low (<15%), medium (15-30%) and high (>35%). The CV (Table 1) of the measured soil properties ranged from 8.6% to 179.8% with majority exceeding 20% which indicates spatial variability. Among these properties, one was low (silt, 0.25g fraction), one was medium (OC, 0.05g fraction) and the rest were high (TN, Sand, Clay, 5g, 2g and <0.05g fraction).
The low CV value recorded by silt fraction indicates spatial homogeneity in the study area, Timm et al., (2006); Duffera et al. (2007) and De Oliveira et al. (2011), recorded similar results.From the result, moderate CV value was seen in OC and CV value were noticed to be high in TN; the high CV obtained in TN is attributed to the size of the research area spatial variation of the soil texture and micro-topography as supported by Chien et al.(1997); Balasundram(2008).

Table:1 Physico- chemical properties of the study site

	O.C	TN	Particle size distribution (gkg⁻)			Aggregate size fraction (g)				
		gkg⁻	Clay	Silt	Sand	5	2	0.25	0.05	< 0.05
Mean	71.01	0.90	266.37	588.10	145.53	0.18	89.51	111.23	90.12	15.38
Min	25.94	-0.35	187.20	407.20	-45.60	0.00	25.70	76.80	32.50	4.70
Max	153.62	2.38	372.80	727.20	405.60	1.70	1120.60	137.20	148.10	30.80
STD	23.67	0.44	38.20	50.47	77.85	0.28	108.82	9.77	28.53	5.26
CV	33.30	47.90	14.3	8.6	53.50	179.80	34.90	8.70	28.90	37.80

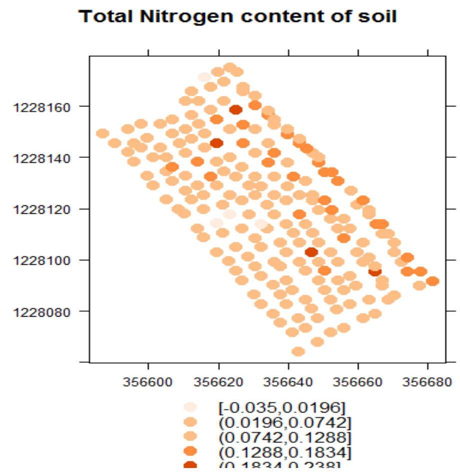
The low organic matter content of the soils in the northern guinea savanna has been attributed to factors such as continuous cultivation, frequent burning of farm residues commonly carried out by farmers in the area which tends to destroy muchof the organic materials that could have been added to the soil (Yakubu 2001). Furthermore, low organic matter content in soils of Kaduna area could be due to rapid decomposition and mineralization of organic materials contributed by sparse vegetation in the hot semi-arid climate as promoted by radiation. Similar low organiccarbon values have been reported by Ibrahim (2010a); and Mustapha, and Nnalee, (2007) for soils in the northern guinea savanna zone of Nigeria.The mean total nitrogen content was low (less than 1.5 gkg-1). This could be attributed to low organic matter contents of the soils and continuous cultivation of the soils which is rampant in the areas as well as annual bush burning. (Egbuchua, and Enujeke, 2013). Similar low total nitrogen values have been reported by (Ibrahim *et al*, 2010) for soils in the northern guinea savanna zone of Nigeria. The physical condition of the soil was assessed for particle size distributions and subsequently translated into textural class. The result is presented in Table 1. Going by these results, it shows that the coarse fraction (silt and clay) dominate the texture. This may be due to the granitic and gneissic origin of the parent material. The notably high silt content of samara soils appears to be responsible for the wildspread tendency for the soil surface to form crusts after rain. Morbeg and Esu (1991) in the studies of soils in the Savanna region of Northern Nigeria mentioned the influence of Harmattan dust in contributing silt to soil. The higher clay content often observed in the subsurface horizons of many soils may be attributed to illuviation and pedoturbation processes (Sharu et al., 2013).From the result shown on Table 1, almost azero fraction was seen at the 5mm sieve size which implies less of the gravelly fraction and so a poorly structured soil is eminent. Large portions from the total 300g fractionated in each of the augured points are seen around the 2-0.05mm sieved fraction implying a better silty nature and a little clayey nature, causing the soil to be easily washed either by wind or water. This co-relates given that from the particle size distribution results the bulk of the particle was seen to be silty.

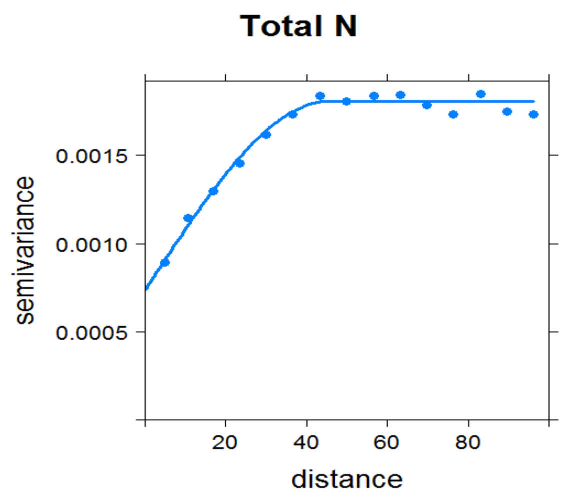
SEMIVARIOGRAM FOR TN: A set of soil samples collected at 3m intervals were analyzed for TN and tested for spatial autocorrelation.The resulting semivariogram fitted to the spherical model. The semivariogram parameters are presented below.

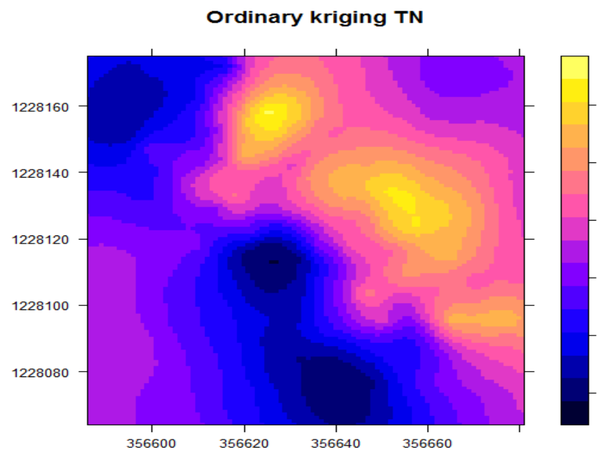
Table:2 Semivariogram parameter for total nitrogen

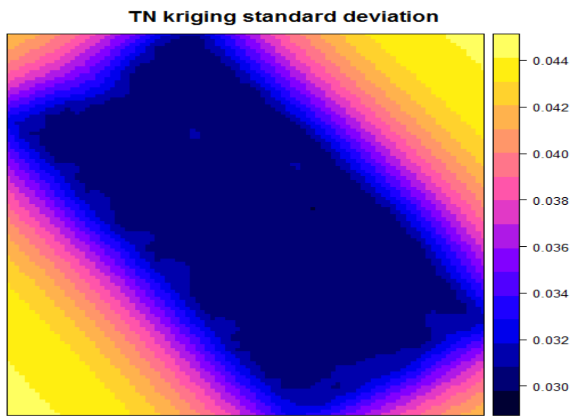
semivariogram parameter	Values
Sill	0.0018
Partial Sill (C)	0.0011
Nugget(C_o)	0.0007
Range	45m
Variogram model	Spherical

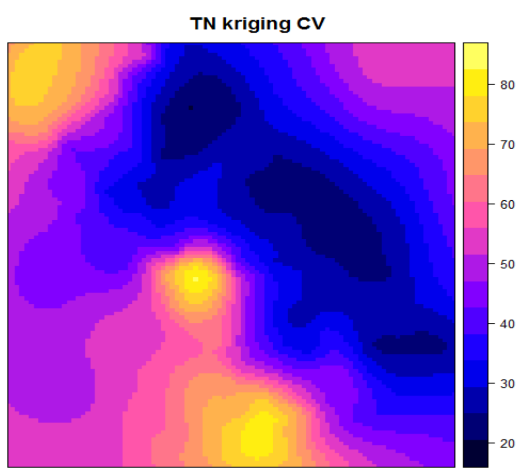
The relative structure of the semivariogram ($C/C+C_o$) (Table: 2) indicated that 61 % of the variation in TN content of the Kubanni area was spatially related over a distance of 45 m. Considering the range of 45 m, it means that samples separated by a distance of up to 45 m were same in their TN content.
This was mapped in an ordinary kriging (OK) approach. Resulting map showed a high TN content at the entire right portion of the study area. To evaluate the resulting map, the OK standard deviation map (a measure of the error associated with OK predictions) was plotted. The coefficient of
variation map showed the CV of the of the predictions were between 20 and 30.
The total nitrogen had a small nugget (0.0007), a relatively small sill (0.0018), nugget to sill ratio of <0.25 and a range (45m). This indicated weak **spatial variability** and independence of TN (Table 2).A range of 45 m indicated the distance beyond which semivariance for TN became constant and the soil samples can be assumed to be spatially independent. Within the range, the measurements of the variable are correlated with each other.
The result of the ordinary kriging (OK) map approach showed a high TN content at the entire right portion of the study area. To evaluate the resulting map, the OK standard deviation map (a measure of the error associated with OK predictions) was plotted. The coefficient of variation map showed the CV of the predictions was less than 30.











SEMIVARIOGRAM FOR OC: A set of soil samples collected at 3m intervals were analysed for OC and tested for spatial autocorrelation. The resulting semivariogram fitted to the spherical model. The semivariogram parameters are presented below.

Table:3 Semivariogram parameters for organic carbon

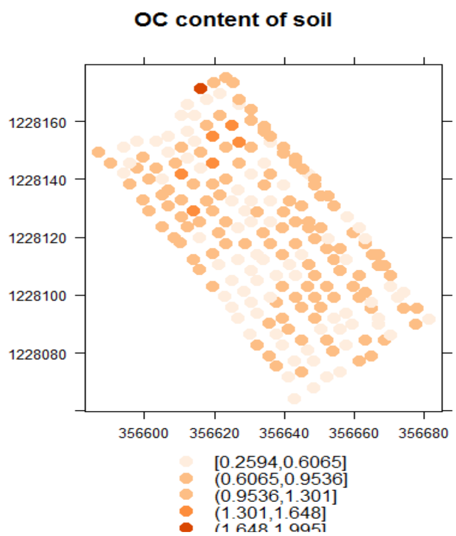
semivariogram parameter	Values
Sill	0.017
Partial Sill (C)	0.014
Nugget(C_o)	0.003
Range	14m
Variogram model	Spherical

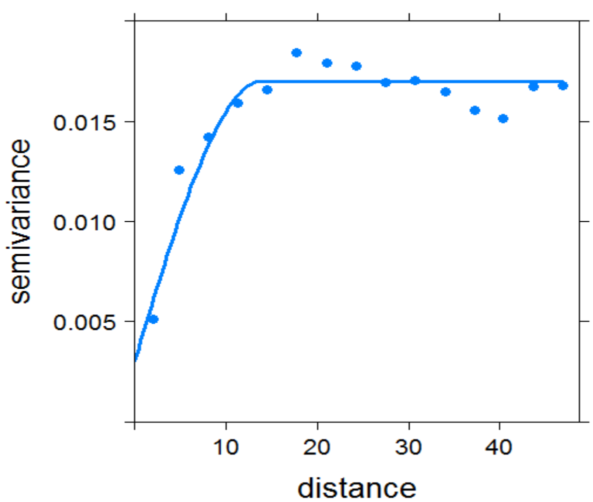
The relative structure of the semivariogram ($C/C+C_o$) (Table3) indicated that 17.65 % of the variation in OC content of the Kubanni area was spatially related over a distance of 14 m. Considering the range of 14 m, it means that samples separated by a distance of up to 14 m were same in their OC content.

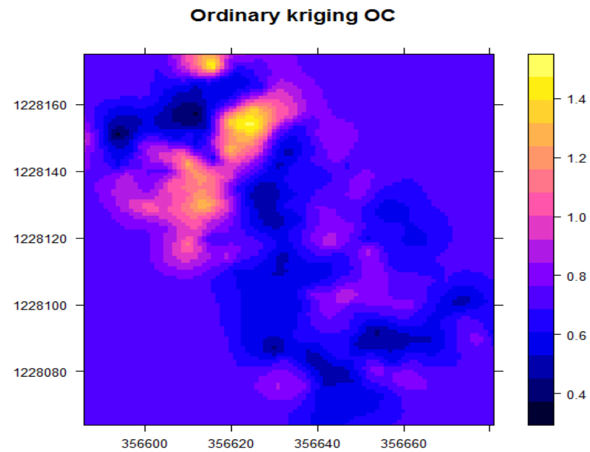
This was mapped in an ordinary kriging (OK) approach. Resulting map showed a patch of high OC content at the upper left of the study area. To evaluate the resulting map, the OK standard deviation map (a measure of the error associated with OKpredictions) was plotted. The coefficient of variation map showed the CV of the predictions was between 10 and 15.

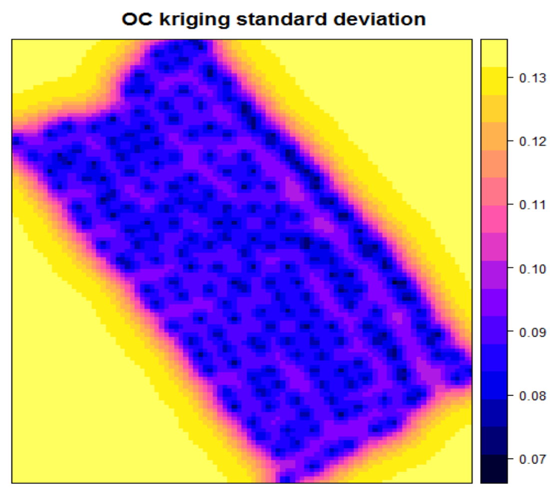
The organic carbon had a small nugget (0.003), a relatively small sill (0.017), nugget to sill ratio of <0.25 and a range (14m). This indicated strong spatial variability and dependence of OC (Table 3).A range of 14m indicated the distance beyond which semivariance for OC became constant and the soil samples can be assumed to be spatially independent. Within the range, the measurements of the variable are correlated with each other.

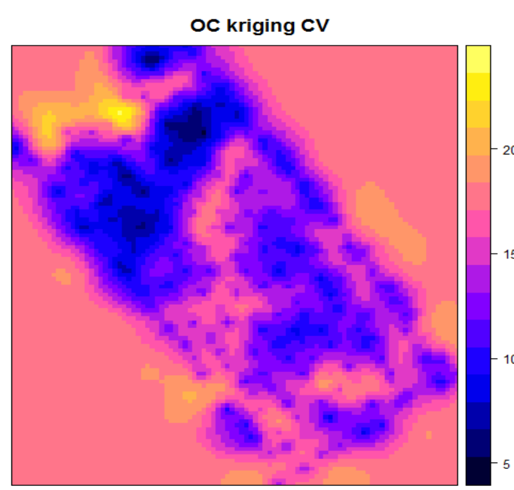
The result of the ordinary kriging (OK) map approach showed a patch of high OC content at the upper left of the study area. To evaluate the resulting map, the OK standard deviation map (a measure of the error associated with OK predictions) was plotted. The coefficient of variation map showed the CV of the predictions was between 10 and 15.











Cross Validation

The true prediction accuracy can be evaluated by comparing estimated values with actual observations at validation points in order to assess systematic error, calculated as mean prediction error (MPE) and accuracy of prediction, calculated as root mean square prediction error (RMSPE) which can be normalized by the total variation to give the $RMSPE_r$(Table 4).One way to evaluate the accuracy of prediction is to use the cross-validation technique implemented in the geostat package. N-fold cross validation partitions the data set in N parts. For all observation in N part, predictions are made based on the remaining N-1 parts; this is repeated for each of the N parts.

Table:4 Cross Validation

	MPE	RMSPE	$RMSPE_r$(%)
OC	0.0014	0.12	47
TN	0.000001	0.03	70

MPE = observed – predicted

Our result shows in the table above shows that the interpolation of OC and TN over the entire area was fairly accurate (Hengl*etal*, 2004).

IV **DISCUSSION AND CONCLUSION**

Conclusion

Spatial and classical statistical tools were employed to investigate the horizontal spatial variability in the study area and the degree of linear association within and between the soil chemical properties determined and to develop models for predicting the total nitrogen and organic carbon in a grid sampled landscape in the Kubani area of Zaria in Kaduna state. Descriptive statistics for the study area revealed differences in the amount of the variability of the soil property. The calculated coefficient of variation (CV) ranged from 33.3% (organic carbon) to 47.9 %(total nitrogen) for the chemical properties determined, indicating a low to medium spatial variation patterns. Although, the classical statistics showed the spatial variation pattern of soil property; they failed to point out the distribution of these spatial variations through space.The spatial behaviour of soil properties was evaluated through their semi-variograms and the kriging the investigated soil properties exhibited a definable spatial structure which was described by spherical model. The knowledge of the range of influence for various soil properties allows one to construct independent datasets to perform classical statistical analysis. Furthermore, it aids in determining the distance to resample if necessary, to avoid spatial dependency.
Classical statistical methods allow for the identification of variation in soil properties but do not provide information on how these variations are distributed in space. Geostatistical-based tools on the other hand, offer alternative methods to classical statistics for the estimation of soil properties and their associated variability.

REFERENCES

[1] Balasundram, S.K., Husni, M.H. A and Ahmed, O.H (2008). Application of geostatistical tools to quantify spatial variability of selected soil chemical properties from a cultivated tropical peat. Journal of Agronomy, (71): 82-87.
[2] Chien, Y. J., Lee, D.Y., Guo, H. Y., Houng, K.H. (1997). Geostatistical analysis of soil properties of mid-west Taiwan soils. Soil science, 162: 291-298.
[3] De Oliveira. M.P., Ferreira Tavres, M. H., Miguel Angel Uribe-Opazo, M. A and Timm, L. C. (2011). Selecting statistical models to study the relationship between soybean yield and soil physical properties. R. Bras. Ci. Solo, 35:97-104.
[4] Dobermann, A (1994). Factors causing field variation of direct seeded flooded rice. Geoderma 62:125-150.
[5] Duffera, M., White, J. G. and Weisz, R. (2007). Spatial variability ofsoutheastern U.S Coastal plain soil physical properties: implications for site-specific management. Geoderma, 137: 327-339.
[6] Egbuchua, C.N. and Enujeke, E.C. (2013). Characterization and classification of some hydromorphic vertisols in the Lake Chad basins of Nigeria in relation to their agricultural land use and limitations. International Journal of Advance Biological Research, Vol. 3(4): 485-489 ISSN 2250 – 3579.
[7] Ibrahim A.K. (2010a) Fertility and salinity/ Sodicity assessment of some fadama soil in Yamaltu, Gombe state Nigerian Journal of research in agriculture 7(1). 69-74.

[8] Ibrahim, A.K., Ibrahim, S.A and Mustapha, S (2010b). Physico chemicals properties of fadama soil in Yamaltu-Deba Gombe State. Journal of research in agriculture 7(3) 1-5.
[9] Moberg, J.P. and I.E. Esu (1991) Characteristics and Composition of Some Savanna Soils of Nigeria. Geoderma 48: 113-129.
[10] Mustapha, S.andNnalee, C.C (2007). Fertility and salinity/ Sodicity status of some fadama soil in Jos plateau State, Nigeria. Journal of sustainable development in agriculture and environment 3:96-103.
[11] Obidike, E.O., Ogunwole, J. O. and Odunze, A. C. (2011). Assessment of heterogeneity in soil properties of Nimbia Forest in southern Guinea savanna of Nigeria for site specific management.
[12] Sharu, M.B., Yakubu, Noma S.S. and Tsafe, A.I. (2013) Land Evaluation of an Agricultural Landscape in Dingyadi District, Sokoto State, Nigeria. Nigerian Journal of Basic and Applied Science, 21(2): 148-156.
[13] Shukla, M.K., Lal, R. and Ebinger, M. (2004c). Principal component analysis for predicting biomass and corn yield under different land uses. Soil science, 169: 215-224.
[14] Timm L.C., Pires, L.F., Reichardt, K., Oliveira, J.C.M., Roveratti, R., Arthur, R.C.J and Bacchi, O.O.S. (2006). Field spatial and temporal patterns of soil water content and bulk density changes. Science Agriculture Piracicaba, Brazil, 63: 55-64.
[15] Webster,R. and Oliver, M.A (2007). Geostatistics for environmental scientists. 2nd Edition, John Wiley and sons, UK. ISBN- 13: 9780470209394.
[16] Bremner, J.M. (1982). Inorganic nitrogen. In: Page, A.L., Miller, R.H. and Keeney, D.R (eds) methods of soil analysis, part 2, second edition, America Society of Agronomy, Madison
[17] Gee, G.W. and Bauder, J.W. (1986). Particle size analysis. In:Klute, A. (ed) Methods of soil analysis. 2nd ed. Madison, American society of Agronomy and soil science society of America, pp 383-423.
[18] Nelson, D.W and Sommer, L.E (1986).Total Carbon, organic carbon, and organic matter. In A.L. Page (ed.) Methods of soil analysis. Part 2. 2nd Ed. Agronomy Society of America and Soil Science Society of America, Madison, WI Agronomy Monogr., 9:539-579.

