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Application of GIS in the Study of Spatial Variability of Selected Soil Properties in Southeastern Nigeria

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Abstract
Assessment of spatial variability of soil is a key component to sustainable food production. Soil sampling is being threaten by the insecurity ravaging the African nations. The combination of both the conventional analytical method and geostatistical method were used to analyse the variability of some soil properties in three state of the Southeastern Nigeria. A total of 18 profile pits were dug and sampled on soils underlain by six different parent materials. The sand content, clay content, porosity, pH, organic carbon (OC), available phosphorus (AP), base saturation (BS) and effective cation exchangeable capacity (ECEC) were analysed using standard analytical procedures. The study reveal that sand content predominate other soil properties with highest value of 87.7%. The clay content varied and falls within the range of 9.31 – 3.45%. The total porosity was more than 40% in all the soils studied. The pH ranged from 5.47 – 7.14, the OC ranged from 3.9 – 11.7g/kg, the AP ranged from 7.21 – 12.45mg/kg, the BS ranged from 37.75-89.13% and the ECEC ranged from 4.03 – 11.23cmol/kg. The result of the geostatistical analyses revealed that spatial dependence (SD) below 25% indicating strong SD was observed in porosity, organic carbon, phosphorus and ECEC. Moderate SD was observed in in sand content, clay content and pH while weak SD was observed in the percentage base saturation. The SD was apparent in 13873 -79156.76m ranges. The coefficient of determination (R^2) of clay content and ECEC were greater than 0.5 indicating a good fit. The Root Mean Standardized Error (RMSE) <1 was observed in pH and ECEC indicating good prediction of the measured value. This study suggest that OK interpolation method can be used to predict spatial distribution of some soil properties at large scale with few sampling points.
Keywords: spatial variability, soil properties, spatial dependency, ordinary kriging.

Introduction
The use of current technology to achieve food production is critical at this moment most Africa countries are faced with security challenges. The drastic increase in global population has brought about an increasing demand of agricultural production. Therefore, there is urgent need to outline strategies that will encourage sustainable production of food with consideration to soil nutrient management (Jones, Pual, and Wither, 2013). It is not only enough to understand the nature, properties, dynamics and functions of the soil as part of landscapes and ecosystems but also how soil information are managed for effective use. Following the rise in the use of technology, many innovations have been put in place to sustain human existence on earth. Geographic Information System, a very efficient computer-based tool is playing an important role in soil resource management. It is a most recent tool capable of storing, retrieving and analysing different types of soil data for proper management of soil resources (Igboekwe and Akankpo, 2011).

The accessibility and availability of geographic information systems (GIS), remotely sensed spectral data, global positioning systems (GPS), digital elevation models (DEM), Interpolation models and software have made significant contributions to the science and art of soil surveying (U.S.D.A, 2019).

Several studies (Hengl, Rossiter, and Husnjak, 2003; Nkwunonwo and Okeke, 2013) have demonstrated that such activities are effective methods of assuring the continuous availability of soil data.Conventional data displaying systems like the use of tables as seen in most research work in Southeastern Nigeria is becoming obsolete since the increase in the use of technology. Setia, Verma, and Sharma (2012) used a decision support that is based on GIS system to determine the potentials and constraints of different types of soils for crop production. The aim of this research is to monitor the spatial variability of some properties in large scale with few sampling points in order to encourage precision farming especially in areas facing security challenges in Africa.

Materials and Methods

Location

The study was carried out in three states in the Southeast geopolitical zone of Nigeria. Southeastern Nigeria is located within latitudes 4° 47' 35'' N and 7° 7' 44'' N and longitudes 7° 54' 26'' E and 8° 27' 10'' E. The three states studied include Anambra, Enugu and Ebonyi State (Fig 1). The geomorphology is predominantly covered by laterite soil. The average annual rainfall and temperature is 1600mm and 26^{0}C. Southeastern Nigeria is located in the rainforest natural vegetation belt. This vegetative zone is characterized by evergreen trees toward the south and rainfall-savanna forest toward the north. The rainfall-savanna forest is made up of trees and grasses scattered everywhere. Anthropogenic activities have significantly impacted this vegetation with variety of plant types like cassava (Manihotspp), plantain (Musa spp), oil palm (Eleais guineesis), maize (Zea mays), yam (Dioscorea species), ogbono tree (Irvingia gabonensis), ube (Dacryodes edulis), mango (Mangifera spp.) etc. About 50% of the total area is used as cultivated land.

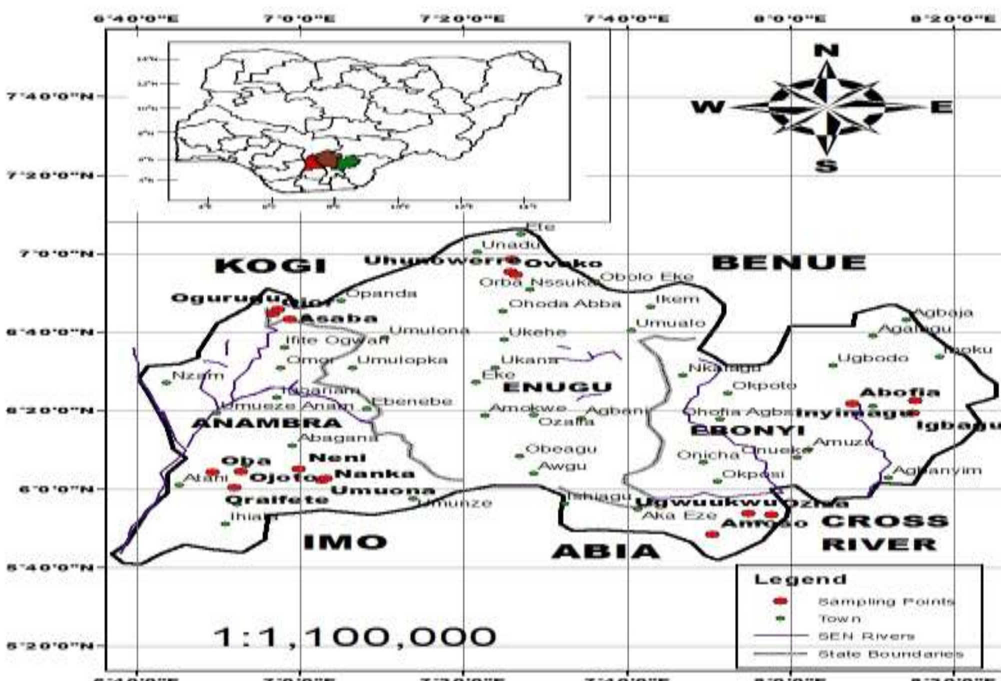


Figure 1: Location Map of the Study Area indicating its Position in the Map of Nigeria

Soil Sampling and Measurements

A reconnaissance field study was carried out for the purpose of identifying the parent materials and free survey approach (Onweremadu, Opoke and Ohaeri.,2014) was used in locating sampling points with the help of a geology map. A total of six parent materials were identified and three profile pits were dug on each of them making a total of 18 profile pits. The parent materials identified were Imo clay shale in Ojor, Asaba and Ogurugu (Enugu State), Ajali sandstone in Uhunowere, Ovoko and Enugu Ezike (Enugu State), Asu river group in Inyimagu, Igbeagu and Abofia (Ebonyi State), Afikpo Sandstone in Ugwukwu, Oziza and Amoso (Ebonyi State), Ogwashi-Asaba formation in Oba, Oraifite and Ojoto (Anambra State), and Bende-Ameki formation in Neni, Umuona and Nanka (Anambra State). Mapping units were delineated and soil profile were located at undisturbed and slightly disturbed site. Soil profiles were described according to FAO guidelines for soil description (FAO, 2006) and sampled according to the genetic horizons in December 2019 and January 2020. Soil samples were subjected to various physical and chemical analyses. Standard analytical techniques were used to determine the soil particles (Hydrometer method; Gee and Or, 2002), porosity (Vomocil, 1965), pH (1:1 soil/water ratio using digital pH meter), soil organic carbon (SOC) (Walkley and Black dichromate wet oxidation method; Nelson and Sommers,1982), phosphorus (P) (Bray II method; Olsen and Sommers 1982), The exchangeable bases (extracted with 1N NH4OAc solution) and exchangeable acidity (leached out from the soil with 1N KCl) were determined and the results were used to calculate the Effective Cation Exchange Capacity (ECEC) and the base saturation (BS). The mean result from each profile was used for the geostatistical analysis.

Geostatistical Methods

All sites were geo-referenced using handheld GPS receiver. The shape files were developed from the open street map and the coordinate of each location from the GPS was used to place the sampling sites in the actual geospatial position using Arc GIS 10.2 software. The soil properties determined were linked to the respective positions in the GIS database for the purpose of generating attribute maps. The geostatistical analyses were carried out with the help of the Geostatistical Wizard of Arc GIS 10.2 in the geostatistical analyst extension. The normality of the spatial distribution of the soil properties was monitored using descriptive statistics. Soil data that are not normally distributed was transformed using log transformation for easy interpolation. The spatial distribution structure of the soil properties analysed was monitored using semivariogram and this was based on the regionalized variable theory and intrinsic hypotheses (Nielsen and Wendroth 2003). The spatial dependence is strong if SD $< 25\%$, moderate for SD between 26% and 75% and weak with SD $> 75\%$ according to method detailed by Cambardella et al., (1994). The GIS software was also use to perform the ordinary kriging (OK) interpolation for the prediction of the values of the un sampled locations (Wang, 2018). The best-fit model with the lowest value of residual sum of squares was selected for each of soil property analysed. Cross-validation technique was adopted for evaluating and comparing the performance of Ordinary Kriging interpolation method. The cross validation techniques revealed the root mean square error (RMSE) and the coefficient of determination (R^2).

Result and Discussion

The results of the selected soil properties are presented in Table 1. The sand content of the soil predominates other soil particles. This is in line with the study of Onweremadu et al., (2011) and, Okebalama, Igwe and Okolo., (2017) on soils of Southeastern Nigeria. The highest value for sand content (87.7%)was observed in soils of Ogwashi-Asaba Formation (OAF) while the least sand content (47.05%) was observed in the soils of Imo Clay Shale (ICS). The clay content of the soils varied. The soils of Asu River Group (ARG) had the highest clay content (25.29-31.45%) while the soils of Ogwashi-Asaba Formation (OAF) had the least clay content (9.31- 15.48%). This variation may be as a result of the varying underlying parent materials. The total porosity (Table 1) of the soils studied were between the range of 40 -50.16g/kg which is very suitable for crop production. Landon (1991) noted that total porosity of soils less than 40% is likely to restrict root growth due to excessive strength. The pH values of the soils studied were generally acidic irrespective of their parent materials. The least pH value (5.47) was observed in one of the soil of Bende-Ameki Formation (BAF) while the highest pH value (7.14) was observed in one of the soil ARG (Table 1). However, according to Landon (1991) pH range of 5.50 to 7.50 provides the most satisfactory plant nutrient levels for most crops and most of the soils studied fall within this range.

Table 1: Physical and Chemical Properties of Soils

Sampling Location	Sand (%)	Clay (%)	Porosity (%)	pH	OC (g/kg)	Phos (mg/kg)	BS (%)	ECEC cmol/kg
			Imo Clay Shale					
Asaba	47.05	26.98	46.35	6.07	8.65	9.14	57.65	8.94
Ojor	76.72	15.00	45.25	6.46	6.04	7.50	83.99	7.48
Ogurugu	602.80	19.87	47.17	6.24	7.07	6.84	62.34	6.68
			Ajali Sadstone					
Enugu Ezike	73.12	22.92	44.77	6.63	8.16	7.64	77.90	4.87
Uhunoowerre	81.77	14.20	48.53	6.69	6.00	8.35	72.20	5.10
Ovoko	80.12	17.00	46.00	6.46	6.44	7.32	89.13	5.43
			Asu River Group					
Inyimagu	53.32	25.20	42.33	6.04	6.52	11.91	37.75	8.99
Igbagu	51.52	28.87	46.32	7.14	11.73	8.28	64.87	11.23
Abofia	48.52	31.45	40.70	6.15	10.90	12.43	61.23	9.12
			Afikpo Sandstone					
Ugwuukwu	76.52	15.70	43.89	6.06	5.50	9.40	57.43	6.75
Oziza	62.92	25.92	42.92	5.62	8.16	7.39	54.85	8.32
Amoso	77.52	13.57	45.56	6.48	2.64	6.96	61.39	6.01
			Ogwashi-Asaba formation					
Oba	87.72	10.12	48.66	5.59	5.76	8.08	71.40	5.57
Oraifete	82.00	15.48	44.85	5.92	5.72	7.83	64.78	4.59
Ojoto	87.13	9.31	48.06	5.59	3.90	7.14	71.36	4.65
			Bende- Ameki formation					
Neni	82.32	14.37	47.10	5.86	5.14	7.21	72.41	4.88
Umuona	66.96	26.88	49.71	5.83	8.10	7.27	60.15	4.03
Nanka	78.72	18.00	50.16	5.47	6.24	7.36	55.64	4.53

The soils of ARG had the highest organic carbon content value of 6.5-11.7g/kg while the soils of OAF had the least organic matter content value of 3.9-5.8g/kg. Soil with greater clay content typically have greater soil organic carbon stocks due to physical protection of organic minerals. The available phosphorus in most of the soils studied was generally below 10ppm/g and thus classified as low according to Landon (1991) nutrient requirement for most crops. The highest value of phosphorus was recorded in soils of ARG with range of 8.28 – 12.43mg/kg while the least value was observed in soils BAF with range of 7.21 – 7.36mg/kg. The low available phosphorus observed could be due to the fact that in the humid tropics like Southeastern Nigeria, there is rapid fixation of phosphorus compound found in the soil into unavailable form by forming complexes with iron, aluminium and manganese (Brandy and Weil, 2002, Onweremadu and Dunigbo, 2007).

Table 2: Semivariogram and Cross Validation Parameters.

Soil Prop.	Model	Nugget	Sill	Range (m)	Spatial Ratio (%)	Spatial Class	R^2	RMSE
% Sand	Gaussian	0.0156	0.0526	79156.76	29.66	moderate	0.5412	9.5452
% Clay	Spherical	0.0444	0.135	25055.66	32.89	moderate	0.256	6.0181
Porosity	Spherical	0.0003	0.0025	15557.59	12	strong	0.4242	2.0665
pH	Gaussian	0.0021	0.007	145385	30	moderate	0.3291	0.398
OC	Spherical	0.007	0.1298	18553.26	5.39	strong	0.0684	2.3749
Phosphorus	Spherical	0.3174	1.6654	14143	19.06	strong	0.0914	1.2716
ECEC	Gaussian	0.011	0.1162	13873	9.47	strong	0.7241	0.9543
BS%	Gaussian	0.023	0.0242	68217.26	95.04	weak	0.1325	11.78

Generally, the base saturation ranges from 37.75% to 89.13% across the study sites. The effective cation exchangeable capacity (ECEC) of the soils studied was generally low with range of 4.03 – 11.23 cmolkg^{-1}. Soils of South-eastern Nigeria had earlier been reported to have low ECEC and basic cations (Ahukaemere et al., 2016). The low effective cation exchange capacity of these soils revealed low capacity of these soils to retain nutrient elements in the soil exchange site (Chikezie et al., 2010).

Geostatistical Analysis

Table 2 shows the results of the semivariogram parameters (range, nugget, and sill) for each soil property studied with the best-fitted model (Fig. 2A and Fig. 2B). The degree of spatial variability of these soil properties are affected by both structural (climate, parent materials, topography and other natural factors) and stochastic factors (fertilization, cropping system and other anthropogenic activities). The lower spatial ratio (Spatial dependency) suggests that structural factors plays significant role in spatial variability while higher value suggest that that stochastic factor primarily caused spatial variability (Shit, Bhunia and Maiti, 2016).

The spatial dependence (SD) was graded as strong if SD < 25%, moderate for SD between 26% and 75% and weak with SD > 75% (Cambardella et al, 1994). The SD below 25% indicating strong spatial dependence was observed in porosity, organic carbon, phosphorus and ECEC. Moderate spatial dependency was observed in in sand content, clay content and pH while weak spatial dependence was observed in the percentage base saturation. The spatial dependence was apparent in 13873 -79156.76m ranges (Table 2).

The semivariance function model fits Gaussian curve for sand content, pH, ECEC and percentage base saturation. The Spherical curve was the best fit model for clay content, porosity, organic carbon and phosphorus. The curves gradually increase with increasing spatial distance before stabilizing (Fig. 2A and Fig. 2B). All the soil properties studied have coefficient of determination (R^2) values of 0.0684 – 0.7241. The R^2 measures the goodness of fit (Harisuseno et al 2020; Ikuemonisan, et al., 2020). The R^2 of clay content and ECEC were greater than 0.5 indicating a good fit (Table 2).

The Root Mean Standardized Error (RMSE) indicate how closely the model predicts the measured values. The lower the RMSE, the better the prediction. RMSE <1 was observed in pH and ECEC. The highest RMSE was observed in percentage base saturation (Table 2).

Figure 2A: Semivariogram Curves

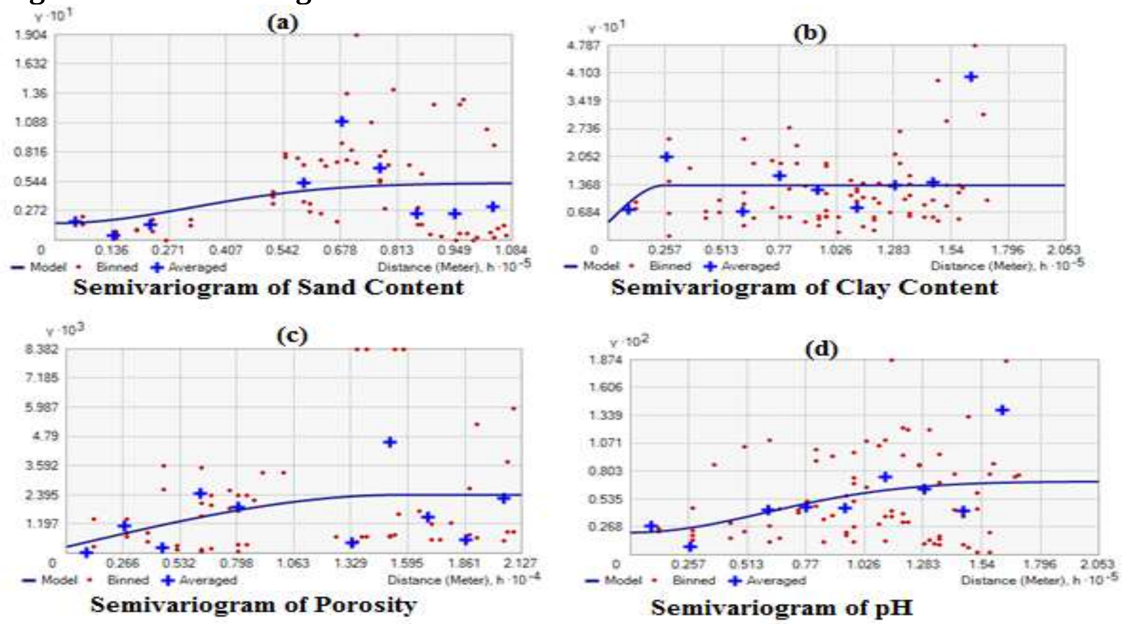
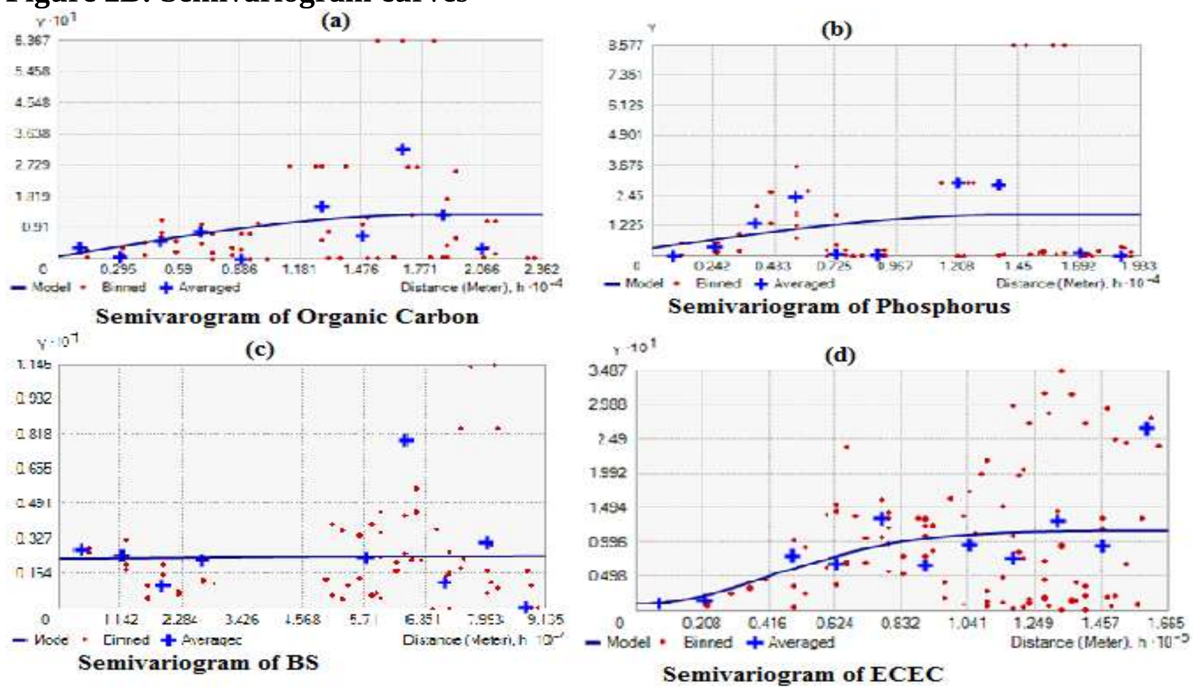


Figure 2B: Semivariogram curves



Spatial Distribution of Soil Properties

The spatial distribution of soil properties is displayed in Figure 3 to 10. The sand content (Fig 3) followed an observable pattern with the highest percentage of it found in the southwest part of the study area in Atani, Anambra State and it reduced towards the eastern part of the study area in Ebonyi State. Asu river group which covered more than 80% of the soils of Ebonyi State had less sand content when compared to other soils studied. The sand content of 69.68 -76.55% and 60.18 to 69.68% covered the entire soils of Enugu State. The highest clay content was found in the soils of Ebonyi State and the least clay content was found in soils of Anambra State. The clay content of 15.42-23% covered most soils of Enugu State.

The lowest porosity was observed in soils around Ezzagu and Abofia in Ebonyi state. The porosity of 44.91-47.11% covered most of the soils of Enugu State. The least porosity was also observed in Nanka in Anambra State and this could be attributed to the sandy nature of these soils. Porosity also had spatial ratio less than 25%, and this implies that structural factors such as parent materials, topography and other natural factors plays significant role in its variability. The pH of the soils studied followed an observable pattern (Figure 4) with the soils in southern part Anambra having the lowest pH and soils in the northern part of Enugu and Ebonyi State having the highest pH. The variability in the degree of leaching and the dominant clay mineralogy must have contributed in the variation of pH.

Organic carbon content of 6.38-7.57 gkg^{-1} and 5.54- 6.38 gkg^{-1} covered most of the soils of Enugu State while organic carbon content of 5.54- 6.38 gkg^{-1} and 4.35-5.54 gkg^{-1} covered most soils of Anambra State. Greater percentage of organic carbon was observed in soils of Ezzagu and Igbeagu of Ebonyi State and organic carbon of 7.57-9.28gkg^{-1} covered almost the rest of Ebonyi State. Available phosphorus (Figure 5) was also observed to be higher in Agbaja, Agalagu, Ugbodo, Abofia and Ezzagu all in Ebonyi State. The least value of 6.84-8.25$mgkg^{-1}$ covered the entire Anambra State.

The value of 8.25. 9.79 $mgkg^{-1}$ and 6.84-8.25$mgkg^{-1}$ covered most of soils of Enugu State. All these observations revealed that pH affected the availability of phosphorus because there is rapid fixation of phosphorus compound in acidic soil into unavailable form by forming complexes with iron, aluminium and manganese (Brandy and Weil, 2002).

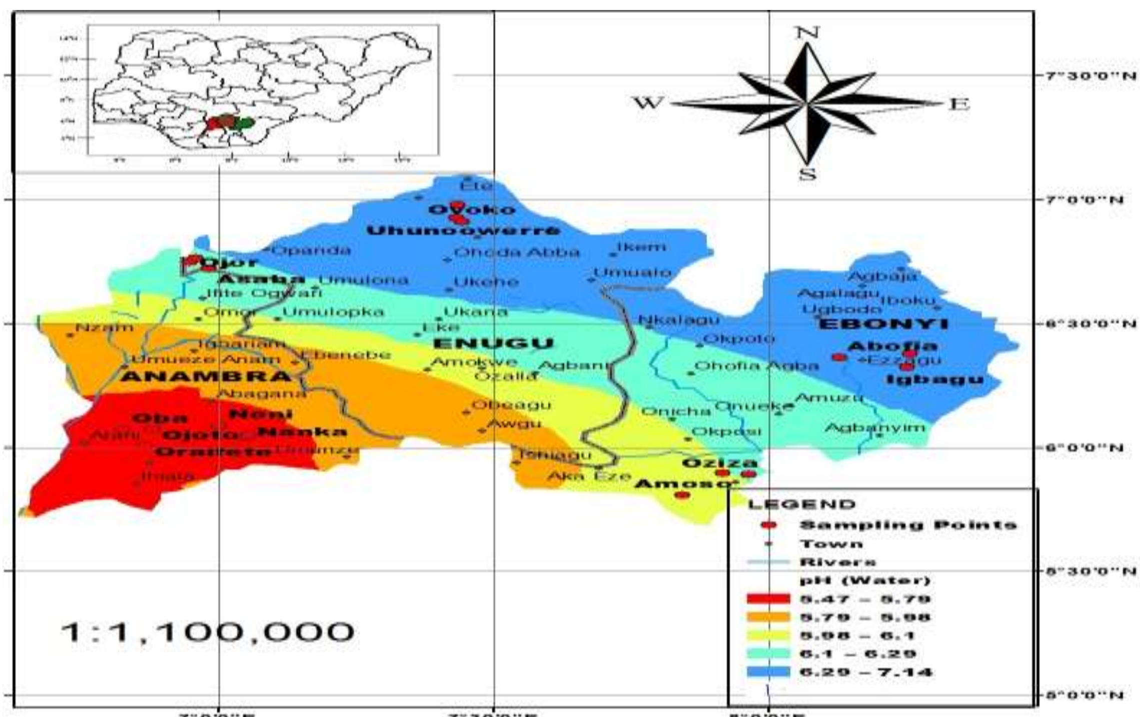


Figure 3: Kriged Map for Percentage Sand Distribution

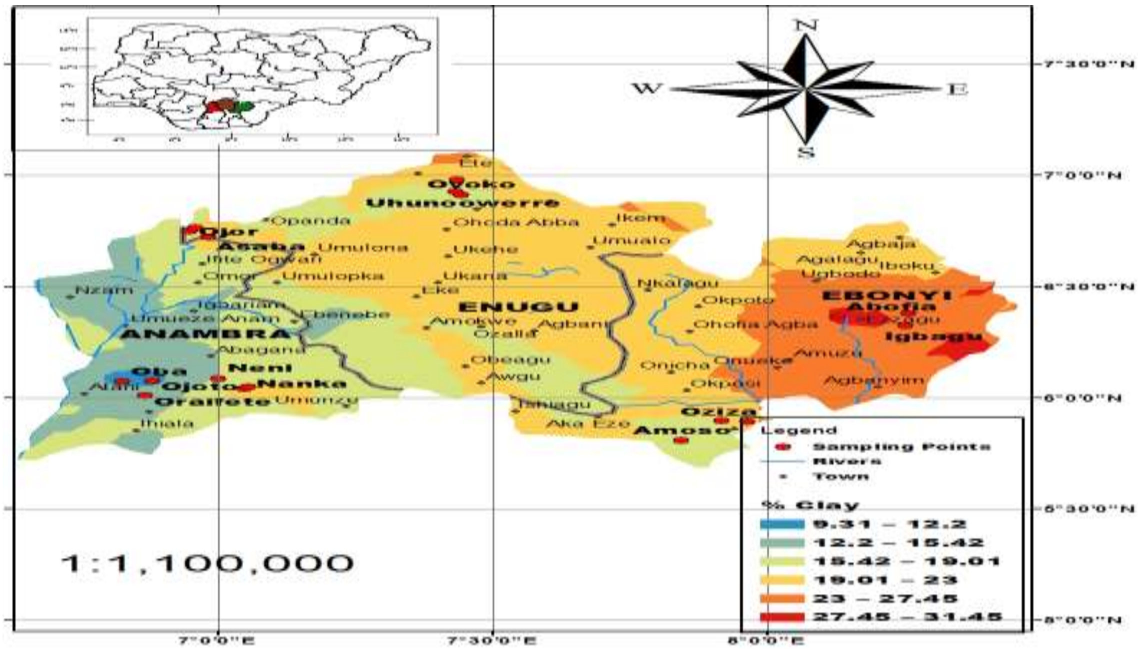


Figure 4: Kriged Map for Percentage Clay Distribution

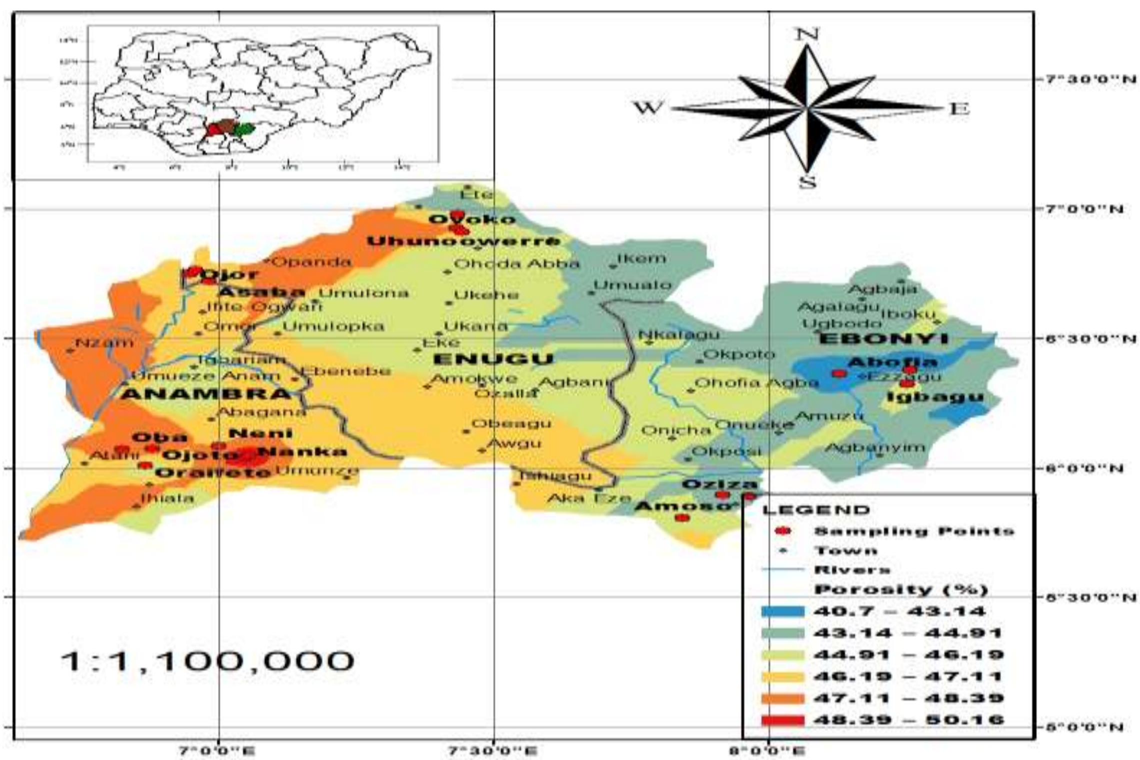


Figure 5: Kriged Map for Porosity

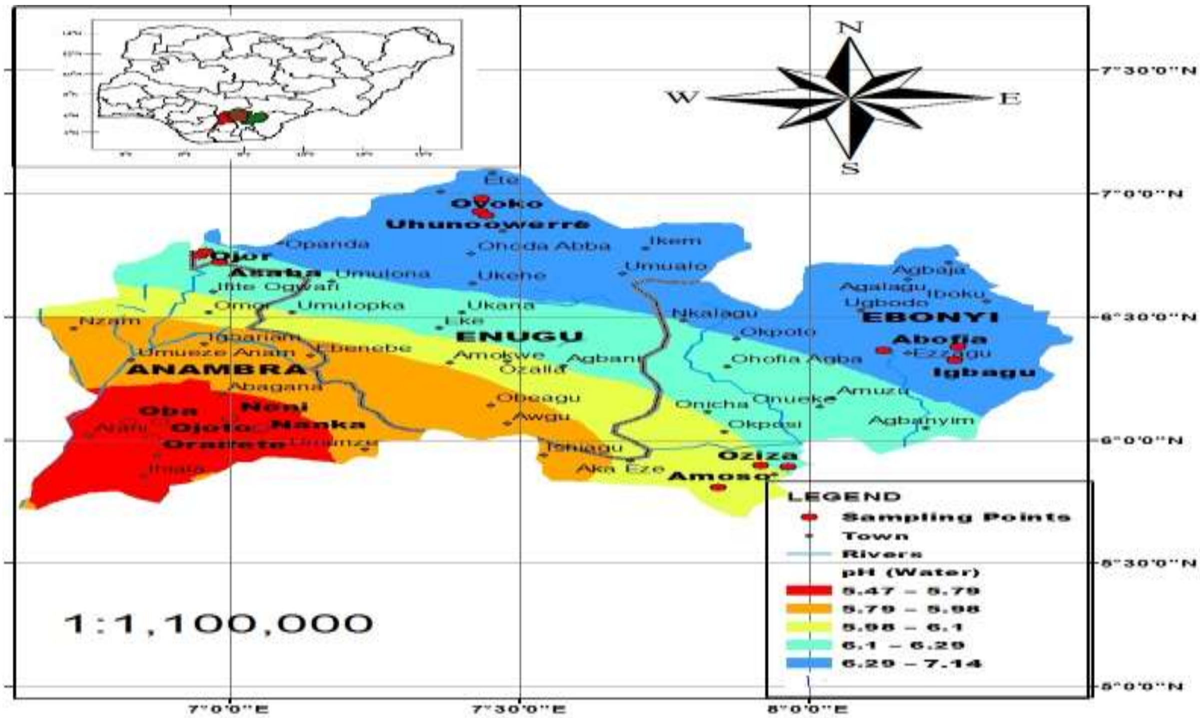


Figure 6: Kriged Map for pH

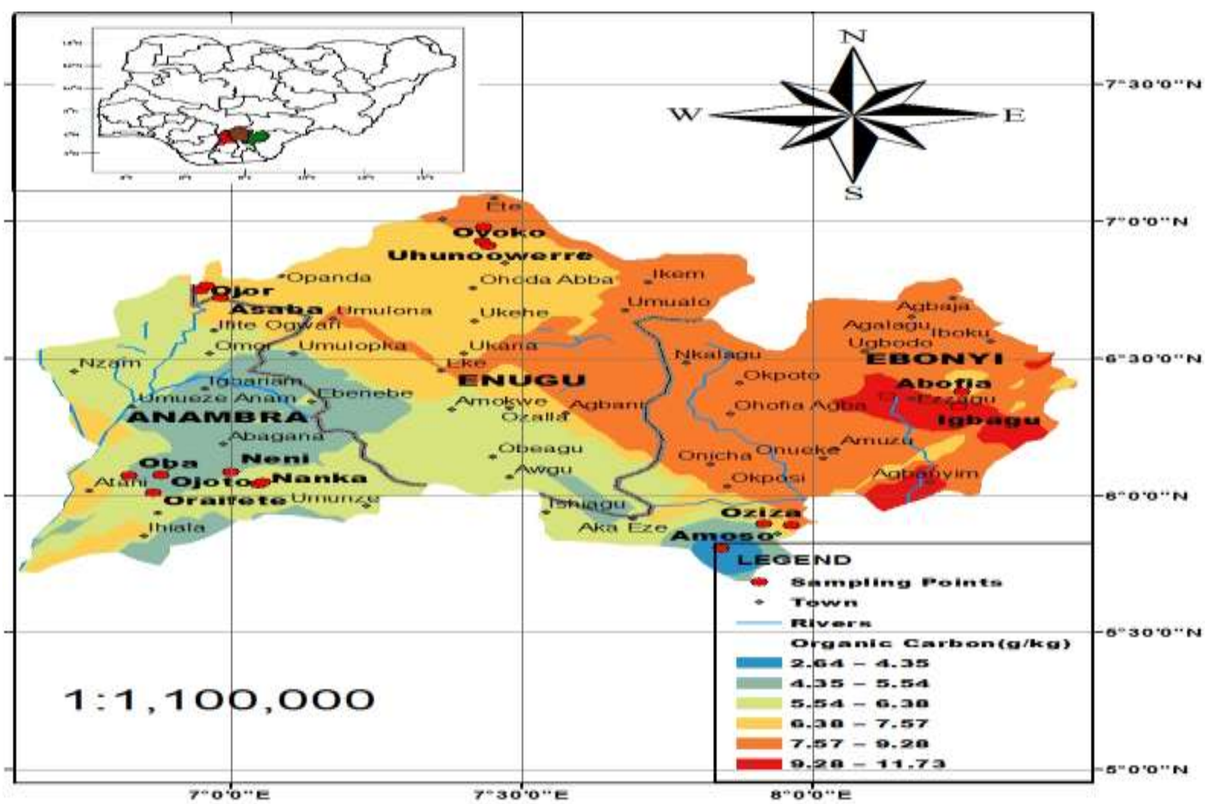


Figure 7: Kriged Map for Organic Carbon

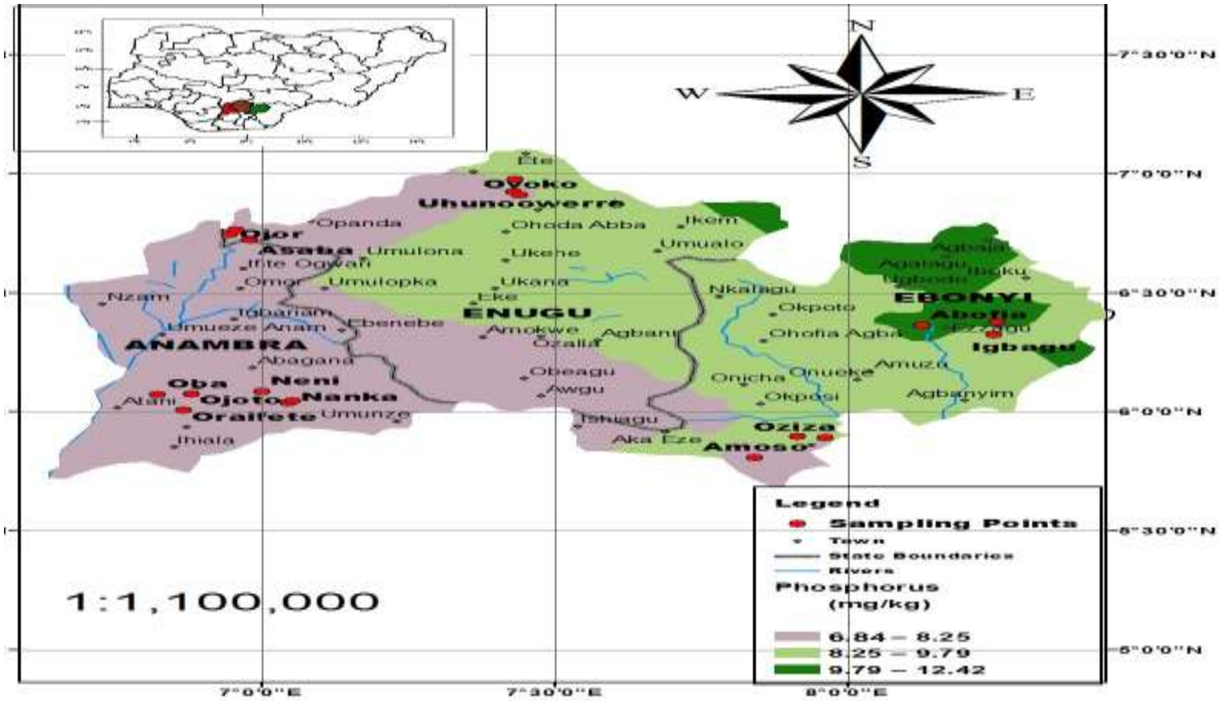


Figure 8: Kriged Map for Phosphorus

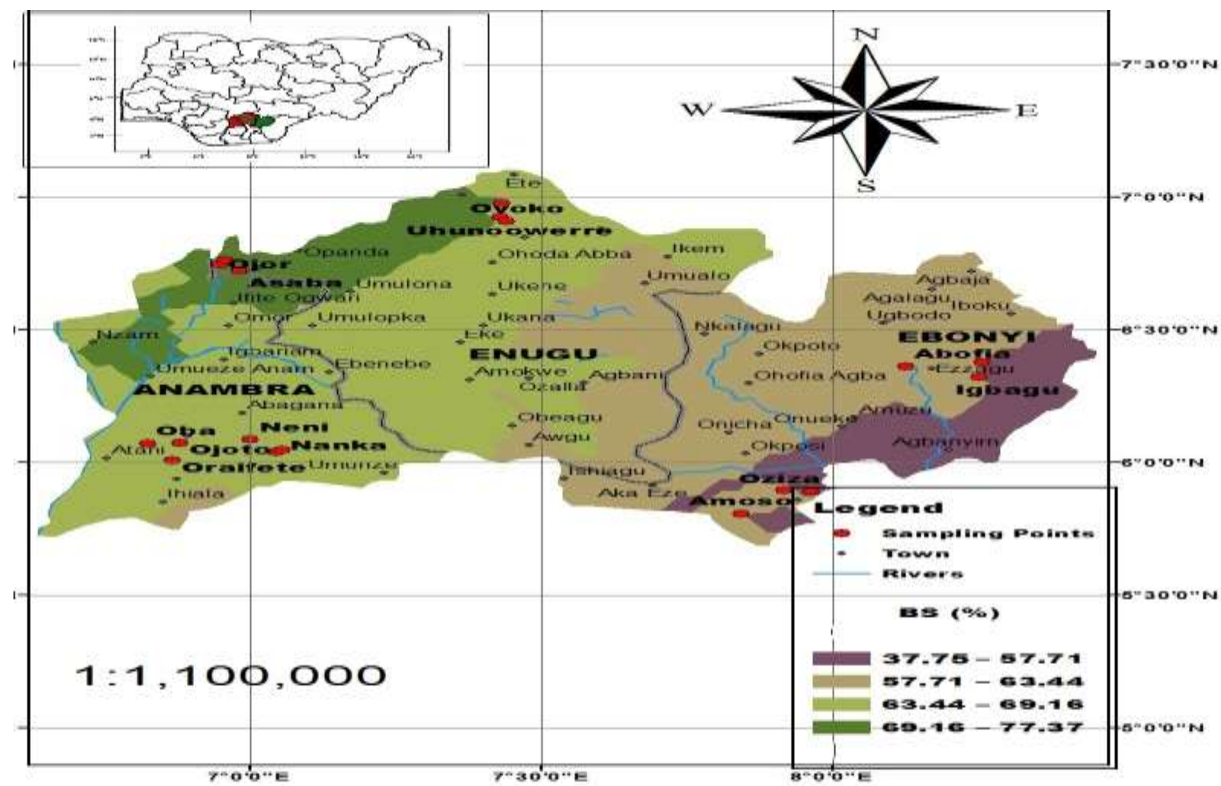


Figure 9: Kriged Map for Base Saturation

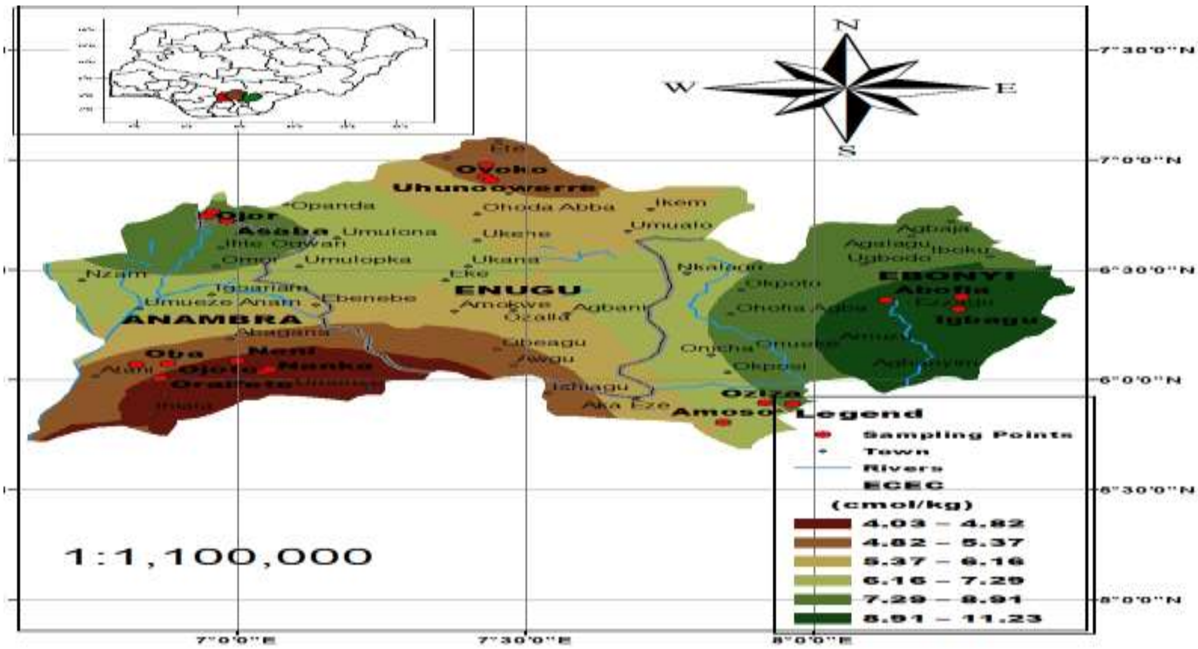


Figure 10: Kriged Map for ECEC

There was also high rate of variation in the base saturation (Figure 10) and is probability caused be structural factors such as parent materials, topography and other natural factors. Higher value of 69.16-77.37% observed in northern part of Anambra and Enugu State. The least value for base saturation was observed in eastern part of Ebonyi State. The value of 63.44-69.16 covered most soils of Enugu State.

The ECEC (Figure 11) followed an observable pattern increasing towards east with the highest value (8.91-11.23 cmolkg^{-1}) observed in Ebonyi State. The least value (4.03-4.82 cmolkg^{-1}) was observed in the northern part of Anambra State.

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Conclusion
There is need to understand the spatial distribution of soil properties in a large scale for precision farming and environmental monitoring irrespective of the security challenges facing soil sampling in Southeastern Nigeria. This study showed that few sampling points can be used to predict the value of much large area with some level of accuracy. Geostatistical models were fitted for eight soil properties namely sand content, clay content, porosity, pH, organic carbon, phosphorus base saturation (BS) and effective cation exchangeable capacity (ECEC). Cross validation of semivariogram models through ordinary kriging (OK) method reveals that sand content and ECEC made a good fit and pH and ECEC had the Root mean standardized error (RMSE) less than 1 making good predictions for the unmeasured locations. However, future studies should be made with a standard sampling distance and compare with these results.

References
Brady, N.C & Weil, R.R. (2002). The Nature and Properties of Soils.13th Edition. Pearson Prentice Hall, New Delhi, India.

Cambardella, C.A.; Moorman, T.B.; Novak, J.M.; Parkin, T.B.; Karlem, D.L.; Turco, R.F. & Konopka, A.E. (1994). Field scale variability of soil properties in central Iowa soil. *Soil Science. Society of American. Journal.*, 58, Pp 1501–1511.

Chikezie I. A., Eswaran H., Asawalam D.O. & Ano A. O. (2010). Characterization of Two Benchmark Soils of Contrasting Parent Materials in Abia State, Southeastern Nigeria. *Global Journal of Pure and Applied Sciences* Vol 16, No. 1, Pp 23-29

FAO, (2006) Food and Agriculture Organization of the United Nations Vialedelle Terme di Caracalla, 00153 Rome, Italy.

Gee, G.W. & Or D., (2002). Particle size distribution: In: Dane, J.H. and G.C. Topps. (ed.). Methods of soil analysis, Part 4, Physical methods.Soil Science Society of America Book Series, No. 5. SSSA, Madison, WI.,Pp: 225-293

Harisuseno, D., Evi, N. Cahya, E. N. (2020). Determination of soil infiltration rate equation based on soil properties using multiple linear regression. *Journal of Water and Land Development.* No. 47 (X–XII): Pp 77–88

Hengl, T., Rossiter, D. & Husnjak, S. (2003), Mapping Soil Properties from an Existing National Soil Data Set Using Freely Available Ancillary Data. Bangkok.

Igboekwe, M. U. & Akankpo, A. O. (2011). Application of Geographic Information System (GIS) in Mapping Groundwater Quality in Uyo , Nigeria. *International Journal of Geosciences*, 2011(2), 394–397. https://doi.org/10.4236/ijg.2011.24042

Ikuemonisan, F. E., Ozebo, V. C., and Olatinsu (2020). Geostatistical Evaluation of variability of Land Subsidence Rates in Lagos, Nigeria. Geodesy and Geodynamics. Vol 11, Issue 5, Pp 316 -327.

Jones D.L, Pual C. P & Wither P.J.A. (2013) Nutrient Stripping: The global disparity between food security and soil nutrient stocks. *Journal of Applied Ecology.*; *10(11):*1365-2664.

Landon, J.R. (1991) Booker Tropical Soil Manual. A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and sub Tropics. Longman Scientific & Technical Publ., Harlon.

Nelson, D. N & Sommers, L.E (1982).Total carbon, organic carbon and matter. In: methods of soil analysis part 2 (Miller, A.D and Keeney, D.K.M). American Society of Agronomy. Pp 539-579.

Nielsen D.R, & Wendroth O. (2003) Spatial and temporal statistics—sampling field soils and their vegetation. Catena Verlag GMBH, Reiskirchen

Nkwunonwo, U. C. & Okeke, F. I. (2013). Gis-Based Production of Digital Soil Map For Nigeria. *Ethiopian Journal of Environmental Studies and Management Vol. 6 No.5* 2013, 6(5), 498–506.

Okebalama C.B., Igwe C.A., & Okolo C. C. Soil Organic Carbon Levels in Soils of Contrasting Land Uses in Southeastern Nigeria. *Tropical and Subtropical Agroecosystems*, 20 (2017): 493 – 504

Olsen, S. R. and Sommers, L.E. (1982). Phosphorus In: Methods of soil analysis, part 2 (eds. Page, A. L., Miller, R. H., Keeney, D. R.) American Society of Agronomy Madison Wisconsin. Pp 15 – 72.

Onweremadu E. U., Opoke P. & Ohaeri J. E. (2014). Moisture Retention Characteristics of Soils of Different Lithosequences in Southeastern Nigeria in Relation to Particle Size Distribution. *Nigerian Agricultural Journal*, Vol. 43, pp. 45 – 50.

Onweremadu, E. U. & Dunigbo, C. I. (2007), Assessment of Cd concentration of crude oil polluted arable soils. *International Journal Environmental Science Technology*, *4(3):* pp 409-412.

Onweremadu, E. U., Okon, M. A., Ihem E. E., Okuwa, J., Udoh B. T. & Imadejemu, P. (2011). Soil exchangeable calcium mapping in central Southeastern Nigeria using Geographic Information Systems. *Nigeria Journal of Agriculture, Food and Environment. 7(2)*:24-20.

Setia R, Verma V & Sharma P (2012) Soil informatics for evaluating and mapping soil productivity index in an intensively cultivated area of Punjab, India. *Journal of Geographic Information System.; 4*: 71–76.

Shit, P. K., Bhunia, G. S. and Maiti, R. (2016). Spatial Analysis of Soil Properties Using GIS Based Geostatistics Models. *Model. Earth Syst. Environ*. Vol 2: 107

U.S.D.A. (2019). United States Department of Agriculture. Retrieved August 2019, from United States Department of Agriculture, Natural Resources Conservation Services: www.nrcs.usda.gov

Vomocil, J.A. (1965). Porosity.In: Black, C.A. (ed.). Methods of soil analysis, part 1. America Society of Agronomy., 9: 299 – 314.

Wang, S.; Zhuang, Q.; Jia, S.; Jin, X.& Wang, Q. (2018) Spatial variations of soil organic carbon stocks in a coastal hilly area of China. *Geoderma*, 314, Pp 8–19.