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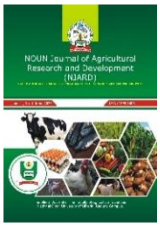

Original Article

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Spatial Variability and Geostatistical Mapping of Soil Physical Properties in Abia State Southeastern Nigeria

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ABSTRACT

This study assessed the spatial distribution of selected physical properties of soils formed over three lithological materials—false bedded sandstone, coastal plain sands, and shale—in six locations across Abia State, southeastern Nigeria. Eighteen geo-referenced soil profiles were sampled and analyzed. Results showed that total sand content ranged from 240 to 890 g/kg, with the highest mean value (850 g/kg) in soils derived from coastal plain sands. Clay content varied widely from 90 to 680 g/kg, peaking in shale-derived soils. Bulk density increased with depth, ranging from 1.18 to 1.61 Mg/m³, while total porosity decreased accordingly, from 55.5% to 39.2%. Saturated hydraulic conductivity (Ksat) values were highest at the surface (up to 22.61 cm/hr) and declined sharply with depth to as low as 0.8 cm/hr, reflecting reduced macro-porosity. Silt-clay ratio ranged from 0.17 to 0.89, with higher values in soils over younger parent materials, indicating varying weathering intensities. Ordinary kriging was applied to interpolate unsampled areas, and model validation showed good predictive performance for bulk density (R^2 = 0.20; RMSE = 0.04), total porosity (R^2 = 0.05; RMSE = 2.39), and Ksat (R^2 = 0.57; RMSE = 2.63). The results highlight the influence of parent material and topography on soil variability and underscore the value of geostatistics for precision land management. These insights support data-driven decisions in crop selection, land use planning, and sustainable soil management across Abia State.

Keywords: *Spatial variability, Soil physical properties, Lithological materials, Soil-landscape relationship*

1.0 Introduction

Soil physical properties are known to vary significantly across space, depth, and time as a result of interactions among lithological materials, topography, climate, land use, and pedogenetic processes (Onweremadu et al., 2024). In tropical regions, this complexity is further amplified by the interplay of multiple soil-forming factors such as parent material, relief, and climatic conditions, which collectively give rise to a diverse range of soil types (Ezeaku, 2013). Of particular interest is the role of parent rock in influencing the development of soil bio-physicochemical properties. These parent materials interact with soil water and biological activity to affect key attributes such as fertility, nutrient availability, metal toxicity, and microbial diversity (Gadd, 2010; Hinsinger et al., 2009; Kabata-Pendias, 2004; Konhauser, 2007; Tye et al., 2013).

Technological advancements in environmental science have improved the precision and efficiency of soil characterization. This has spurred extensive pedological research in southeastern Nigeria, leading to improved understanding of soil variability in relation to land use (Eshett, 1987; Igwe et al., 1999; Nuga et al., 2006; Onweremadu, 2007; Obasi et al., 2011; Chukwu, 2013; Ahukaemere et al., 2016; Osujieke, 2017). Nevertheless, the translation of soil information into informed land management decisions remains inadequate.

A systematic evaluation of soil properties—especially their extent, distribution, and variability—is crucial for effective land use planning and sustainable agricultural production (Pulakeshi et al., 2014). Such information aids in identifying soil potentials and limitations, thereby guiding appropriate land use options and enterprise selection (Karuma et al., 2015; Kebeney et al., 2015). In this context, pedometrics offers a scientific approach to quantitatively assess spatial and temporal variations in soil properties, enabling the development of predictive models and decision support tools for soil management (McBratney & Lark, 2018). This study accesses the spatial variability of selected physical properties of soils in Abia State, Nigeria.

2.0 Materials and Methods

2.1 Study Area

The study was conducted at six different locations which are underlain by three major lithological materials; falsebedded sandstone, coastal plain sands and shale in Abia State (Akwette, Alayi, Ibeku, Nkporo, Owerrinta and Uzuakoli), southeastern Nigeria. The study area lies within Latitudes 4°45’N and 7°15'N and Longitudes 6°50'E and 7° 30'E.

2.2 Geology and geomorphology

The soils of the study area are mostly derived from coastal plain sands (Benin Formation), shale (Bende - Ameki Formation), falsebedded sandstones (Ajali formation) The area has generally lowland geomorphology, less than 150 m above sea level. The Northeastern part of the area is characterized by rising hilly topography.

Climate: Abia State lies within the humid tropical climate. Tropical climate is characterized by rainy season (February/March – November) and dry season (November – February/March). Annual rainfall of the area is about 2,500 mm along the Atlantic coast, The temperature pattern has mean daily and annual temperature as 27°C and 30°C, respectively, while the average relative humidity ranges between 60-70% and 80-90% in January and July, respectively (NIMET, 2014).

2.3 Vegetation

The vegetation is a typical rainforest with a variety of plant species. The natural rainforest vegetation that previously characterized the study area is gradually receding to derived savannah due to human activities. The natural vegetation in the study area consists of some tree species that are remnants of a once dense evergreen forest occurring on slopes and sparse grass complex in various spots. Oil palm (*Elaeis guineensis*) is a dominant tree type in the area. Other plant species include pawpaw (*Carica papaya*), mango (*Mangifera indica*), native peas (*Dacryodes edulis)*,African breadfruit (*Treculia* spp.).raphia (*Raphia hookeri*), *Dactylademia barterri* and *Anthonata macrophylla*are.

2.4 Socioeconomic activity

Abia State is mainly agrarian especially in the rural areas. As agriculture is a major socio-economic activity of the area, about 70% of the total area is used as cultivated land. Slash-and-burn technique has been the major method of land clearing, whereas bush fallow is a soil fertility regeneration practice that has prevailed for over 10 decades. The land use consisted of a mixture of bush regrowth and arable crops. Most of the people in the district are engaged in mixed crop-livestock agriculture. Crop production is entirely rain-fed, except in some very specific and small areas where vegetables are grown using traditional small-scale irrigation. The most commonly produced crops in the study area are annual crops such as *Manihot spp*., *Zea mays* L., *dioscorea spp*., *Phaseolus spp*. Perennial crops including *Musa spp,* oil palm (*Elaeis guineensis*) and native peas (*Dacryodes edulis)* are also found in this area. Although very few of the farmers use inorganic fertilizers (Onweremadu, 2007). Other activities include fishing, trading, white collar jobs, manufacturing, welding, artisanry and sand mining.

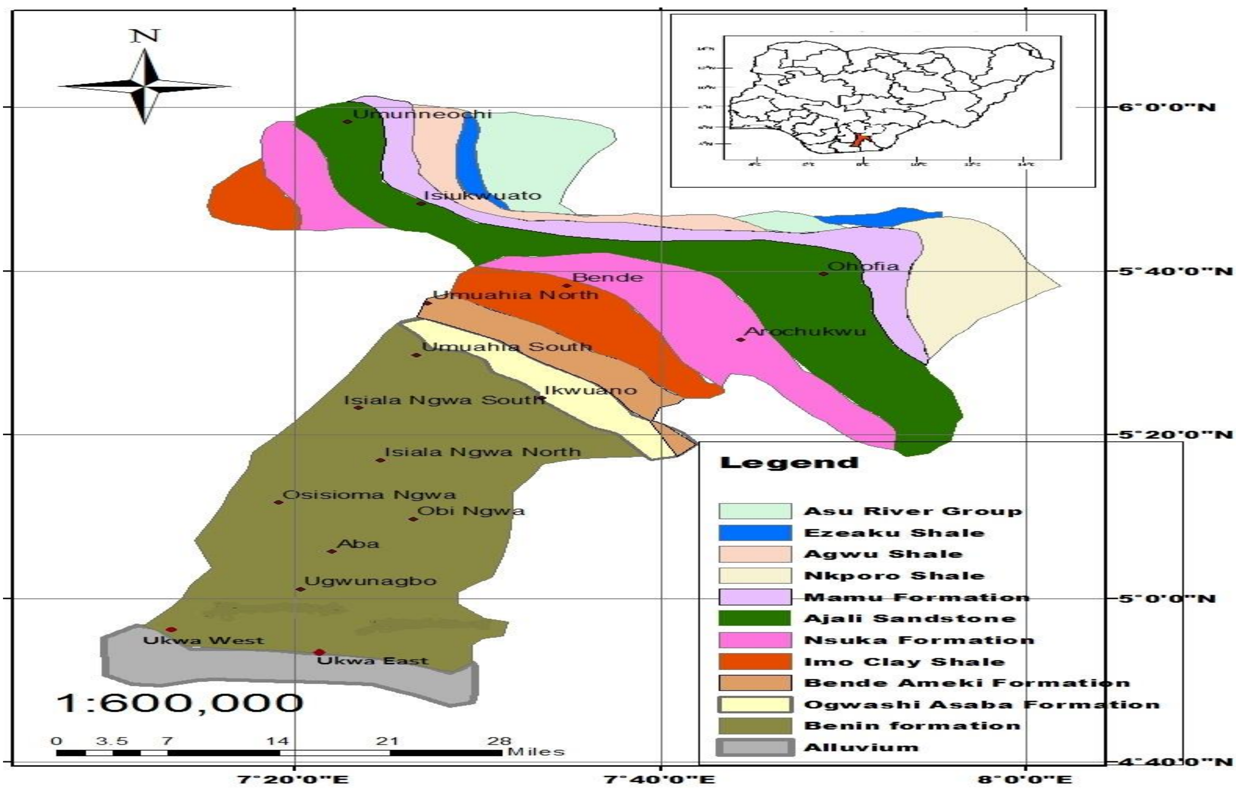

Figure 1: Geology Map of Abia State (Source: NEWMAP, 2017)

2.5 Field studies

Target soil survey technique guided by Geological map was used in field soil sampling. A soil profile was sunk in soils of each of the six communities with three different lithological materials in the study area. A total of eighteen soil profiles were used for the study which served as the representative pedons in the three parent materials. All soil profiles were geo-referenced using handheld Global Positioning System (GPS) Receiver (Garmin Ltd, Kansas USA).

Soil profiles were described and sampled according to genetic horizons for characterization and classification (FAO, 2006; Soil Survey Staff, 2014). Soil samples were collected from the bottom-most horizon to the topmost to avoid contamination of soils from the horizons. Soil color was determined using the Revised Munsell Soil Color Chart (Munsell Soil Color Chart, 1994). Soil structure was described in terms of the sequence: grade, size, and type (shape) of aggregates whereas horizon boundaries were described in terms of depth, distinctness, and topography. The soil consistence was identified at dry, moist and wet moisture conditions.

Samples were collected with core samplers for bulk density and moisture content analyses. The soil samples collected from the study area were bagged, labeled and transported to the laboratory for preparation and analysis of selected soil properties following standard laboratory procedures. In preparation for laboratory analysis, the soil samples were air dried, crushed, and made to pass through a 2- mm sieve size before conducting the following physico-chemical fertility indices analyses.

3.0 Laboratory analysis

3.1 Soil physical analysis

Bulk density was measured using core method as Grossman and Reinsch (2002) recommended Bulk density

$BD = Mg/Vt\ (g/cm^3)$…………………*Equation 1*

Where M_s = mass of oven dry soil (g)

V_t = Total soil volume (cm^3) which is equivalent to the volume of the cylinder

$V = \pi r^2 h$…………………………………*Equation 2*

Where V= volume of core (cm^2) assumed to be equal to soil volume.

Particle Size Distribution was determined by hydrometer method according to the procedure of Gee and Or (2002) using water and sodium hexametaphosphate (calgon) as dispersant.

Moisture content was determined by gravimetric method (Obi, 1990).

Total porosity was computed from the bulk density as described by Vomocil (1965). The calculation is as follows:

$Tp = 1 - \frac{BD}{PD} x \frac{100}{}$…………………………..*Equation 3*

Where, Tp=Total porosity, BD=Bulk density (g/cm^3), PD=particle density ($2.65g/cm^3$).

3.3 Data analysis
Data generated were subjected to mean, coefficient of variation and correlation analyses. The coefficient of variation (CV) was ranked according to the procedure of (Wilding *et al*., 1994) where CV < 15% = least variation, CV >15 < 35% = moderate variation, CV > 35 <100% = high variation. Degree of relationship among soil properties and fertility status of soils formed under these lithological materials was carried out using correlation analysis at P ≤ 0.05 and P ≤ 0.01 for significant association. Regression Analysis among the soil properties was carried out. All analyses were performed using Genstat Statistical Package Version 18.

Geostatistics
Descriptive Statistics was used to monitor the normality of the spatial distribution of this soil properties and log transformation was done on the ones that are not normally distributed to aid interpolation.
The Geostatistical Wizard of the Geostatistical analyst extension of Arc GIS 10.2 was used to perform all the geostatistical analysis of this research. The ordinary kriging (OK) interpolation method was used for prediction of the values of the unmeasured sites (un-samples locations) Semivariogram was used as the basic tool to examine the spatial distribution structure of the soil properties based on the regionalized variable theory and intrinsic hypotheses. The spatial dependence was graded according to method detailed by Cambardella *et al*., (1994); strong if SD < 25%, moderate for SD between 26% and 75% and weak with SD > 75%. Cross-validation technique will be adopted for evaluating the accuracy of the Ordinary Kriging interpolation method.

3.0 Result and Discussion
3.1 Morphological properties of soils studied in Abia
Results of the morphological properties of soils of Abia are presented in Table 1. Two master horizons, namely A and B in addition to two transitional horizons AB, BA and BC were identified in soils collected from Akwaette(profile 01), Alayi(profile 02), Ibeku (profile 03), Nkporo(profile 04), Owerrinta(profile 05) and Uzuakoli (profile 06). This is typical of tropical soils (Johnson *et al.,* 2005). Besides, it was only profile 03 and 06 that had argillic subordinate horizon g by gleying, indicating that there was a prominent translocation of clay down the profiles forming argillic horizons (Mulugeta and Sheleme, 2010). Generally, these soils were deep except soils of Ibeku with least depth of 0 –140. Accordingly, soil depth (cm) ranged from 0 –170, 0 –200, 0 –174, 0 –196 and 0 –190 in profile 01, 02, 03, 04 and 05. Earlier studies (Raji, 1995; Idoga *et al*., 2007) attributed extent of soil depth to parent material, erosion and slope of area.

It was showed that soil colour varied as very dark gray to brown at surface soils while at the sub-surface horizons it varied from yellowish brown, reddish brown to gray. These colours indicated the release of iron oxides and their occurrence in various hydrated forms due to difference in drainage of the soils (Walia and Rao, 1996). Similar findings were also reported by Arun Kumar *et al.* (2002). According to Brady & Weil,(2002), the brownish tinges in most of the horizons of the profile 02, 04 and 05 were due to the presence of organic matter which is the main colouring agent in top soil. Moreover, soils profile 03 and 04 were poorly drained as water saturated soils tend to have grey-colored B-horizons (Foth, 1990).

Mottles were identified in endopedons of all these soils exception being profile 05. These Mottles varied from red to yellowish colour. This mottleness according to Obi *et al*., (2009) could be due to lack of mechanical mixing by plant roots and soil. From the insitu finger test, soils sand, loamy sand and sandy loam textured in profile 01, 02 and 05 whereas it was dominated by sandy clay loam in profile 03, 04 and 06. Sand dominated textural classes encourage soil water holding capacity, particularly in the surface soils, and when combined with limited fertility properties, it is rare for such soils to be suitable for production of most crops (Ofem *et al.,* 2022). The soils had a weak, fine, subangular blocky structure at the epipedon while the subsurface horizons consisted of moderate, medium subangular blocky. The moist consistencies were friable in soils of profile 05, very friable and friable in epipedon and endopedons respectively (profile 01 and 02), very friable and firm (profile 03 and 05), firm and very firm (profile 04) and friable and very firm (profile 06). The very friable and friable consistence observed in the surface soils of most pedons could be attributed to the higher OM contents of the layers (Mulugeta and Sheleme, 2010).

Presence of roots at the epipedon of Akwaette (profile 01), Alayi (profile 02), Nkporo (profile 04) and Owerrinta(profile 05) was medium, few to many whereas common, few in Ibeku(profile 03) and Uzuakoli(profile 06). At the sub-surfaces it varied from few to rare. The combination of the soil structure and the gravel content also influenced the drainage of the soils which ranged from well drained in soils of profile 01, 02 and 05 and poorly drained in profile 03, 04 and 06. Ibia (2002) suggested that poor drainage condition of soils prevents strong weathering and subsequent formation of sesquioxides in the soils. Boundary distinctiveness indicated that soils were clear wavy at the epipedons of profile 01, 02 and 04, clear smooth in profile 03 whereas it was gradual wavy and abrupt in profile 05 and 06 respectively. However, it was clear smooth in all the endopepons except profile 06 gradual smooth. According to Esu (2010), a boundary form was a result of lateral movement of soils. Moreover the boundary forms of these soils could be as a result of lateral movement and properties of soils and weathering processes or clay lassivage in the soil horizons (Onweremadu *et al*., 2007).

Table 1: Physical properties of the soils studied in Abia

Ho	Depth (cm)	CS g/kg	FS	TS	Si	Cl	TC	SCR	BD (Mg/m^3)	TP (%)	Ksat (Cm/hr)	FC	PWP	AWC (Cm/m)
						AKWAETTE(profile 01)								
A	0-13	440	390	830	70	100	S	0.7	1.23	53.58	5.6	0.217	0.1	0.117
AB	13- 38	450	360	810	90	100	S	0.9	1.27	52.07	10.34	0.219	0.1	0.119
BA	38- 88	480	320	800	100	100	S	1	1.37	48.3	8.62	0.219	0.101	0.118
Bt$_1$	88- 135	480	260	740	130	130	SL	1	1.48	44.15	7.42	0.221	0.102	0.119
Bt2	135-170	490	160	650	160	190	SL	0.84	1.55	41.5	3.11	0.221	0.102	0.119
mean		**468**	**298**	**766**	**110**	**124**		**0.89**	**1.38**	**47.92**	**7.02**	**0.22**	**0.10**	**0.12**
CV		**4.63**	**30.61**	**9.53**	**32.14**	**31.54**		**14.12**	**9.83**	**10.68**	**39.70**	**0.16**	**0.99**	**0.16**
						ALAYI(profile 02)								
A	0-15	500	390	890	20	90	S	0.22	1.25	52.83	5.12	0.218	0.101	0.117
AB	15-39	520	320	840	20	140	LS	0.14	1.31	50.56	10.22	0.22	0.1	0.12
Bt1	39-112	550	310	860	10	130	LS	0.07	1.34	49.43	10.11	0.221	0.101	0.12
Bt2	112-150	600	220	820	10	170	SL	0.05	1.45	45.28	7.88	0.22	0.102	0.118
BC	150-200	620	230	840	40	110	LS	0.36	1.58	40.37	7.52	0.222	0.101	0.121
mean		**558**	**294**	**850**	**20**	**128**		**0.17**	**1.39**	**47.69**	**8.17**	**0.220**	**0.101**	**0.119**
CV		**9.17**	**23.88**	**3.11**	**61.24**	**23.70**		**75.22**	**9.42**	**10.33**	**25.80**	**0.17**	**0.10**	**1.38**
						IBEKU(profile 03)								
A	0-11	250	150	400	160	440	SC	0.36	1.21	54.33	9.21	0.223	0.1	0.123
AB	11-35	120	120	240	80	680	C	0.11	1.23	53.58	8.42	0.225	0.102	0.123
Bg1	35-70	250	350	600	60	340	SCL	0.17	1.27	52.07	2.61	0.225	0.102	0.123
Bg2	70-109	260	400	660	100	240	SCL	0.41	1.5	43.39	1.81	0.226	0.102	0.124
BC	109-140	300	150	450	80	470	SC	0.17	1.58	40.37	0.81	0.227	0.104	0.123
mean		**236**	**234**	**470**	**96**	**434**		**0.24**	**1.36**	**48.75**	**4.57**	**0.225**	**0.102**	**0.123**
CV		**28.83**	**55.77**	**35.48**	**40.07**	**37.92**		**54.19**	**12.51**	**13.15**	**86.08**	**0.16**	**1.39**	**0.36**
						NKPORO(profile 04)								
A	0-17	300	270	570	260	170	SL	1.52	1.27	52.07	7.71	0.216	0.099	0.117
AB	17-48	310	230	540	170	290	SCL	0.58	1.36	48.6	5.16	0.217	0.1	0.117
Bt1	48-99	300	210	510	120	370	SC	0.32	1.45	45.28	2.21	0.219	0.103	0.116
Bt2	99-125	288	242	530	130	340	SCL	0.38	1.52	42.02	0.91	0.218	0.103	0.115
Bt3	125 - 174	240	240	480	130	390	SC	0.33	1.61	39.24	0.8	0.222	0.105	0.117
mean		**287.6**	**238.4**	**526**	**162**	**312**		**0.63**	**1.44**	**45.44**	**3.36**	**0.218**	**0.102**	**0.116**
CV		**9.64**	**9.12**	**6.39**	**35.83**	**28.16**		**81.58**	**9.22**	**11.23**	**89.39**	**1.05**	**2.40**	**0.17**
						OWERRINTA(profile 05)								
A	0-11	550	300	850	60	90	LS	0.66	1.18	55.47	22.61	0.214	0.092	0.122
AB	11-31	460	290	750	70	180	SL	0.38	1.29	51.32	10.21	0.214	0.092	0.122
Bt1	31-70	420	370	790	30	180	SL	0.16	1.31	50.56	6.16	0.215	0.1	0.115
Bt2	70-106	400	300	700	20	280	SCL	0.07	1.35	49.05	2.08	0.215	0.1	0.115
Bt3	106 -196	550	260	810	30	160	SL	0.18	1.48	44.15	1.02	0.216	0.099	0.117
mean		**476.00**	**304.0**	**780.0**	**42.00**	**178.00**		**0.29**	**1.32**	**50.11**	**8.42**	**0.21**	**0.10**	**0.12**
CV		**14.90**	**13.28**	**7.37**	**51.62**	**38.19**		**81.31**	**8.21**	**8.17**	**103.70**	**0.19**	**4.37**	**3.02**
						UZUAKOLI(profile 06)								
A	0-18	230	230	560	230	210	SCL	1.09	1.22	23.96	7.01	0.222	0.102	0.12
AB	18-46	300	210	510	180	310	SCL	0.58	1.34	49.43	4.17	0.223	0.103	0.12
Bg1	46-116	294	196	490	160	350	SCL	0.45	1.41	46.79	3.1	0.225	0.103	0.122
Bg2	116-190	286	184	470	100	430	SC	0.23	1.57	40.8	0.23	0.225	0.104	0.121
mean		**277.5**	**205**	**507.5**	**167.5**	**325**		**0.59**	**1.39**	**40.25**	**3.63**	**0.22**	**0.10**	**0.12**
CV		**11.60**	**9.64**	**7.61**	**32.10**	**28.14**		**62.10**	**10.55**	**28.43**	**77.25**	**0.17**	**0.19**	**0.19**

Coarse sand (CS), fine sand(FS), total sand(TS), silt (Si), clay(Cl), Textural class(TC), sand (S), sandy loam (SL), loamy sand (LS), sandy clay (SC), sandy clay loam (SCL), Silt clay ratio(SCR), bulk density (Bd), total porosity (TP), moisture content (MC), saturated hydraulic conductivity (Ksat), field capacity(FC), permanent wilting point(PWP), available water content(AWC).

3.2 Physical properties of the soils studied in Abia State

Presented in Table 2 are the results of the physical properties of the soils studied in Abia State. As shown, there was variation in coarse sand (CS) of the soils with higher values recorded at the endopedons of most pedons. The CV values were 4.63%, 9.17%, 28.83%, 9.64%, 14.90%, and 11.60% for Akwaette(profile 01), Alayi(profile 02), Ibeku(profile 03), Nkporo(profile 04), Owerrinta(profile 05) and Uzuakoli(profile 06) respectively. According to Wilding *et al*. (1994), coefficient of variability (CV) of ≤15%, >15≤35% and >35% are rated low, moderate and high respectively. Thus, all the soils apart from profile 03 were homogenously distributed since they had CV≤15%. Coarse sand was also shown to be irregularly distributed in all the soils but profile 02 that showed steady increase with soil depth. Moreover, its range was 440-490 (mean= 468 g/kg), 500-620 (mean= 558g/kg), 120-300 (mean= 236g/kg), 240-310 (mean= 287.6g/kg), 400-550 (mean= 476.0g/kg) and 230-300 (mean= 277.5 g/kg)

in profile 01, 02, 03, 04, 05 and 06 respectively, indicating that on average basis, CS was higher in profile 02 than others.
Similarly, fine sand displayed low CV (≤15%) in profiles 04 to 06, moderate CV (>15≤35%) in profiles 01 and 02 and high CV (>35%) in profile 03. Its range was as follows: 160 to 390 with average value of 298 g/kg in profiles 01; 220 to 390 with average value of 294 g/kg in profile 02; 120 to 400 with average value of 234 g/kg in profile 03; 210 to 270 with average value of 238.4 g/kg in profile 04; 260 to 370 with average value of 304.0 g/kg in profile 05 and 184 to 230 with average value of 205 g/kg in profile 06. Furthermore, it was observed that similar to coarse sand, fine sand was indistinctly distributed in all the pedons except profile 01 and 06 where there was progressive decrease with depth. The higher fine sand in surface horizons of most pedons might be due to the detachment of finer particles from the soil body, which were translocated to deeper layers by percolating water and surface depletion (Buol *et al.* 1998). Similar results of decrease in the sand content with depth were also reported by Sharma *et al.* (2001).

Total sand particles ranged from 830-650, 890-820, 660-240, 570-480, 850-700 and 560-470 $gkg^{-1}$with mean values of 766, 850, 470, 526, 780 and 507.5 gkg^{-1} in soils from Akwaette (profile 01), Alayi(profile 02), Ibeku(profile 03), Nkporo(profile 04) Owerrinta(profile 05) and Uzuakoli(profile 06) respectively, suggesting that greater (850) and least (470) sand fractions in Abia State were recorded in profile 02 and 03 respectively. Sand-sized particle especially coarse sand dominated other particle sizes in all the soils and was also observed to decrease irregularly down the soil profiles. There was also homogenous (CV=3.11-9.53%) distribution of sand particles in all these soils apart from Ibeku with moderate coefficient of variability (CV=35.48%). The dominance of total sand indicates fragility and low content of colloidal materials like clay giving rise to the susceptibility of the soil to erosion (Ejikeme *et al*., 2021).

Silt content showed high variation (CV=35.8-61.2%) in all the soils with the exception of profile 01 and 06(CV=>15≤35%) that showed moderate variation. Across the sites, a range of 160-70(mean= 110gkg^{-1}), 40-20(mean= 20gkg^{-1}), 160-60(mean= 96gkg^{-1}), 260-120(mean= 162gkg^{-1}), 70-20(mean= 42gkg^{-1}) and 230-100(mean= 167.5gkg^{-1}) in profile 01, 02, 03, 04, 05 and 06 respectively. In particle size distribution, sand was followed by clay content. This is consistent with report of Igwe and Stahr (2004) while silt-sized particles were lower in content (Igwe *et al*., 1995). Unlike sand fractions, clay particles increased irregularly with soil depth irrespective of sampling site. It had mean value of 124, 128, 434, 312, 178 and 325 and ranged from 190-100, 170-90, 680-240, 390-170, 280-90 and 430-210gkg^{-1} in profile 01, 02, 03, 04, 05 and 06 respectively, demonstrating that clay fraction was highest in Ibeku(profile 03) than other sites in Abia State. Moreover, its distribution pattern was low in all the soils except Ibeku and Owerrinta(profile 05) (CV= >35%). The clay increase in most B-horizons especially the kandic horizons is a confirmation of reports from other studies. It has been reported that clay increase in most kandic horizons is as a result of clay migration-accumulation or illuviation, clay destruction, selective erosion, sedimentation or lithological discontinuity (FAO, 1988; Van Wambeke, 1989; Driesen and Dudal, 1991). The fact that clay minerals are unstable and break down under intense chemical weathering especially in humid and sub-humid climates further buttressed the claim. This was also reported in Alemayehu *et al*. (2014) for some Ethiopian soils. Based on the result of particle sizes determined in the laboratory, the texture of the soils were dominated by sand, loamy sand and sandy loam in Akwaette (profile 01), Alayi(profile 02) and Owerrinta(profile 05) respectively whereas it was mainly sandy clay loam in both Ibeku (profile 03) and Nkporo (profile 04).

Silt-clay ratio (SCR) plays a critical role in assessing clay movement, the degree of weathering and the age of both parent material and soil (Yakubu & Ojanuga, 2013). The highly weathered soils are associated with lower silt fraction. In the present study, there was wide (CV=62-82%) distribution of silt clay ratio in all the soils of Abia State exception being profile 01 (CV=14%). Within the soil depth, it also showed unspecific pattern of distribution. Averaged over soil profiles, it was highest (0.89) in soils of profile 01 followed by profile 04(0.63), profile 06(0.59), profile 05(0.29), profile 03(0.24) and profile 02(0.17). Ayolagha (2001) posits that old parent materials usually have a SCR below 0.15 while SCR above 0.15 is indicative of young parent materials. Interestingly, results of this study showed that all the soils except profile 14 had mean silt-clay ratios above 0.15 indicating a high degree of weathering potentials in all the soils.

Bulk density of the soils also varied amongst the profiles in Abia State with increasing distribution pattern down the depths of all the soils and wide coefficient of variation being low (CV=8.2-12.51%)in all the soils, indicating uniform distribution pattern. It varied from 1.55-1.23 (mean=1.38), 1.58-1.25 (mean=1.39), 1.58-1.21 (mean=1.36), 1.61-1.27 (mean=1.44), 1.48-1.18 (mean=1.32) and 1.57-1.22 (mean=1.39) in Akwaette (profile 01), Alayi(profile 02), Ibeku(profile 03), Nkporo(profile 04) Owerrinta(profile 05) and Uzuakoli(profile 06) respectively, implying that amongst the soils from Abia, highest and lowest compaction were in profile 03 and 04 respectively. These values were lower than 1.6 Mg/m^3 which according to Landon (1991) is the upper threshold above which root growth can be hampered.

Total porosity was shown to follow inverse trend wit bulk density by decreasing with depth in all the soils. Besides, its distribution with the soil depths was low in all the soils irrespective of sampling site (CV=8.17-28.43%). Total porosity like other physical properties varied with a decreasing mean of 50.11, 48.75, 47.92, 47.69, 45.44 and 40.25 in profile 05, 03, 01, 02, 04 and 06 respectively. The higher values of total porosity in the topsoil than subsoil for the respective profiles are probably caused by relatively high soil OM content and the disturbances of the topsoil due to continuous cultivation. Also the low total porosity in the subsoil may be attributed by higher clay content (Karuma *et al.,* 2015). The porosity was > 40% in all the horizons, thus they are not liable to restrict crop growth since they indicate no soil compaction, roots penetration without difficulty, adequate aeration and water storage within the soil (Gachene *et al*., 2003).

There were also differences in saturated hydraulic conductivity (Ksat) of the soils in Abia State with higher values recorded at the epipedons compare to the endopedons. The CV values were 39.70%, 25.80 %, 86.08%, 89.39%, 103.70%, and 77.25% for profile 01, 02, 03, 04, 05 and 06 respectively, demonstrating it was widely distributed in all the soils of Abia apart from profile 02 with moderate variation. Equally, its distribution within the soil depth was progressive decrease with depth in profile 03 to 06, irregular and unspecific in profile 01 and profile 02 respectively. However, ranges of Ksat include 10.34-3.11 cm/hr (profile 01), 10.22-5.12 cm/hr (profile 02),9.21-0.81cm/hr (profile 03),7.71-0.8cm/hr (profile 04), 22.61-1.02cm/hr (profile 05) and 7.01-0.23cm/hr (profile 06) with the highest mean of 8.42 cm/hr recorded in profile 05 and equal lowest value (3.63 cm/hr) recorded in soils profile 04 and 06. Progressive decrease with depth in profile 03 to 06 could be attributed to decreased porosity, macro-porosity and micro-porosity within the profiles (Nwite, 2015).

Mean values of field capacity (FC) content of soils were distributed as follows: 0.22, 0.220, 0.225, 0.218, 0.21 and 0.22(Cm/m) for profile 01,02, 03, 04, 05 and 06, respectively, implying no obvious difference that was also supported by the low CV recorded in all the soils. Permanent wilting point (PWP) also showed very low CV(≤4.5) in all the soils of Abia. It however ranged from 0.1 to 0.102 Cm/m with a mean value of 0.10Cm/m in profile 01 and 02; 0.1 to 0.104Cm/m with a mean value of 0.102Cm/m in profile 03; 0.099 to 0.105 Cm/m with a mean value of 0.102 Cm/m in profile 0; 0.092 to 0.1 Cm/m with a mean value of 0.10 Cm/m in profile 05 and 0.102 to 0.104 Cm/m with a mean of 0.10Cm/m in profile 06. It was also observed that PWP increased insignificantly in most endopedons

Similar to PWP, available water capacity (AWC) of soils differed among soils formed in Abia State. It was also observed insignificantly higher in most endopedons. The values of CV were 0.16%, 1.38%, 0.36%, 0.17%, 3.02% and 0.19% for Akwaette (profile 01), Alayi (profile 02), Ibeku(profile 03), Nkporo(profile 04) Owerrinta (profile 05) and Uzuakoli (profile 06) respectively, Accordingly, minimum and maximum values of AWC were 0.117 to 0.119 cm/m(mean=0.12), 0.117 to 0.121 cm/m(mean=0.119), 0.123 to 0.124 cm/m(mean=0.123), 0.115 to 0.117 cm/m(mean=0.17), 0.115 to 0.122 cm/m(mean=0.12) and 0.12 to 0.122 cm/m(mean=0.12) in profile 01,02, 03, 04, 05 and 06 respectively, suggesting that PWP was slightly higher in profile 03 than others.

4.0 Spatial study of unsampled locations using Krigin and Semivariogram

The bulk density of the unsampled location was predicted with the regression function 0.20*x + 1.130, and it revealed a coefficient of variation $R^2$of 0.2, ME (-0.0008) that is very close to zero, RMSE (0.04) that is very close to ASE (0.041), RMSSE that is very close to 1 and a blue line (Figure 2) close to 1:1 line. This suggest that the Gaussian model made a good prediction of the unsampled area and also the appropriateness of the sample point spacing. The performance of the Exponential model was cross validated for Total porosity. The regression function 0.0497*x + 48.52 was adopted. The R^2 of 0.0497, the ME of 0.082, the RMSE of 2.389, the ASE 0f 2.49, the RMSSE of 0.959 and the distance between the blue line and the 1:1 suggest that the model made a moderate prediction of the unsampled location. The spatial variability of the hydraulic conductivity (KSat) was also monitored with the Exponential model and the performance of this model was evaluated. The regression function 0.568*x + 2.364was used to predict the unsampled location. The R^2 (0.568) greater than 0.5 was observed indicating a good fit (Harisuseno *et al* 2020; Ikuemonisan, *et al*., 2020). The ME (0.69), RMSE (2.628), ASE (13.27), the RMSSE (0.445) and the closeness of the blue line to 1:1 line (Figure 4) suggested that the model made a good prediction of the unsampled location.

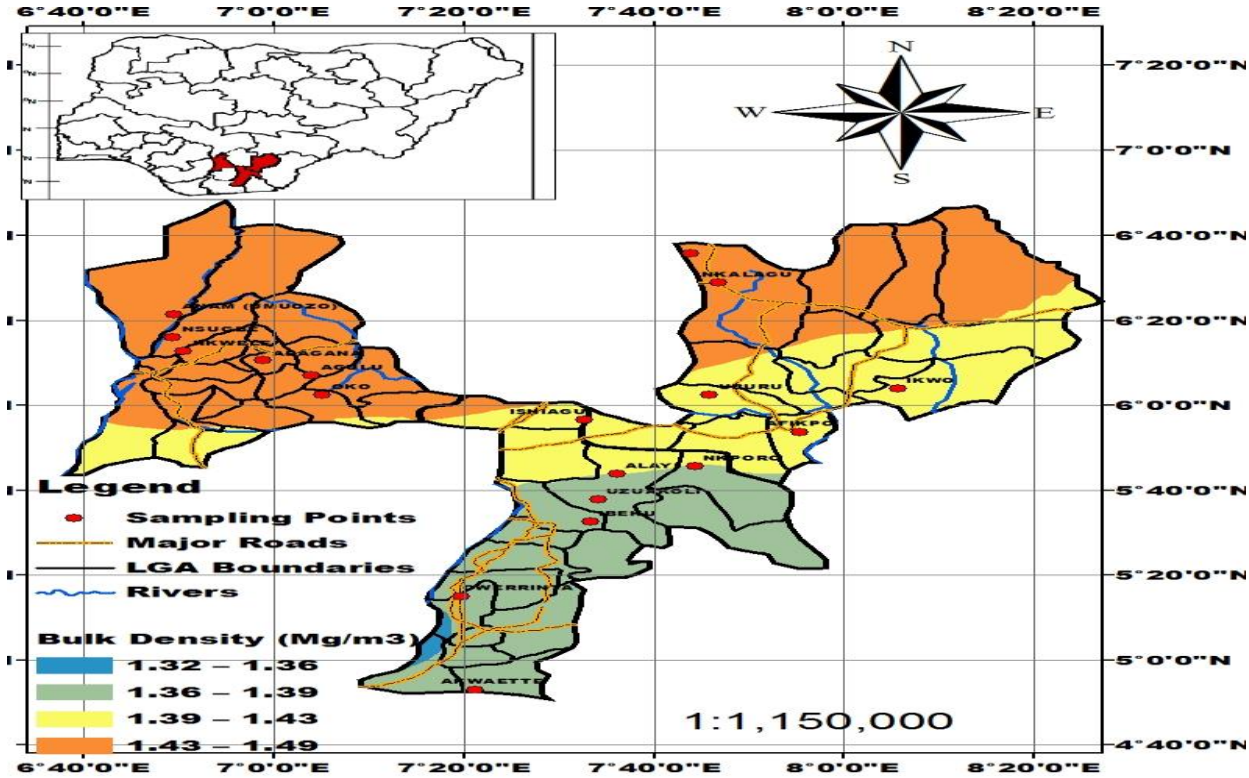

Figure 2: The Kriged Map for the Bulk Density

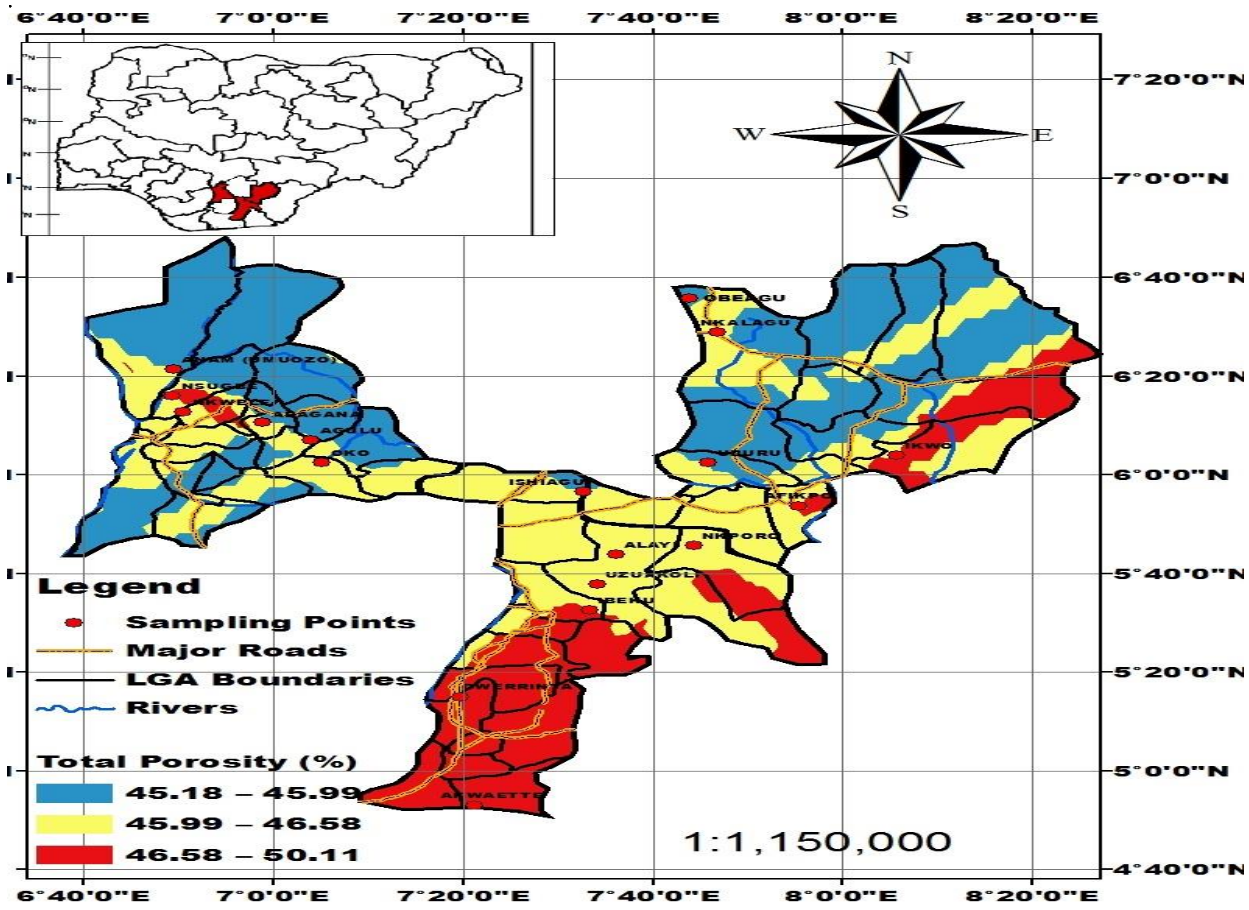

Figure 3: The Kriged Map for the Total Porosity

The spatial distribution of 230.1 -294.9g/kg followed similar pattern. The difference in clay content across the study area could also be attributed in the different parent materials existing in the study area.

The silt clay ratio (SCR) Kriged map reveals an observable pattern for the SCR of the study area. The highest SCR is observed in soil around Ikwo and Uburu in Ebonyi State indicating low degree of weathering processes around this region (Ayolagha *et al* 2012). This could also be attributed to the geological formation. The lowest SCR of 0.102- 0.214 are observed at different points across the study area. The SCR of 0.41 -0.744 covered most of the study area.

The Kriged map for bulk density base on the semivariogram analysis displays an observable pattern (Figure 2). The bulk density of about 1.43 – 1.49Mg/m^3 covered most soils in Anambra State and the northern part of Ebonyi State. The bulk density of about 1.39 – 1.43 Mg/m^3 covered most of the soils in Ebonyi State, northern part of Abia State and a little part of southern part of Anambra State. The bulk density of about 1.36-1.39 Mg/m^3 covered most soils of Abia State and a small patch of 1.32 -1.36 Mg/m^3 are also observed in this state. The bulk density capable of restricting root development (above 1.6 Mg/m^3) are observed in the study area from the map (Arshad *et al*., 1996).

The Kriged map for the total porosity is displayed in Figure 3. The map followed almost the same pattern with that of bulk density. The highest total porosity of about 46.58 – 50.11% were observed in southern part of Abia State while the least total porosity of about 45.18 – 45.99% are observed in northern part of Anambra and Ebonyi State. The total porosity of about 45.99 – 46.58% are observed in northern part of Abia State and in patches across the other states. These differences in the total porosity could be attributed to the differences in the lithological material and the undulating nature of some places in the study area.

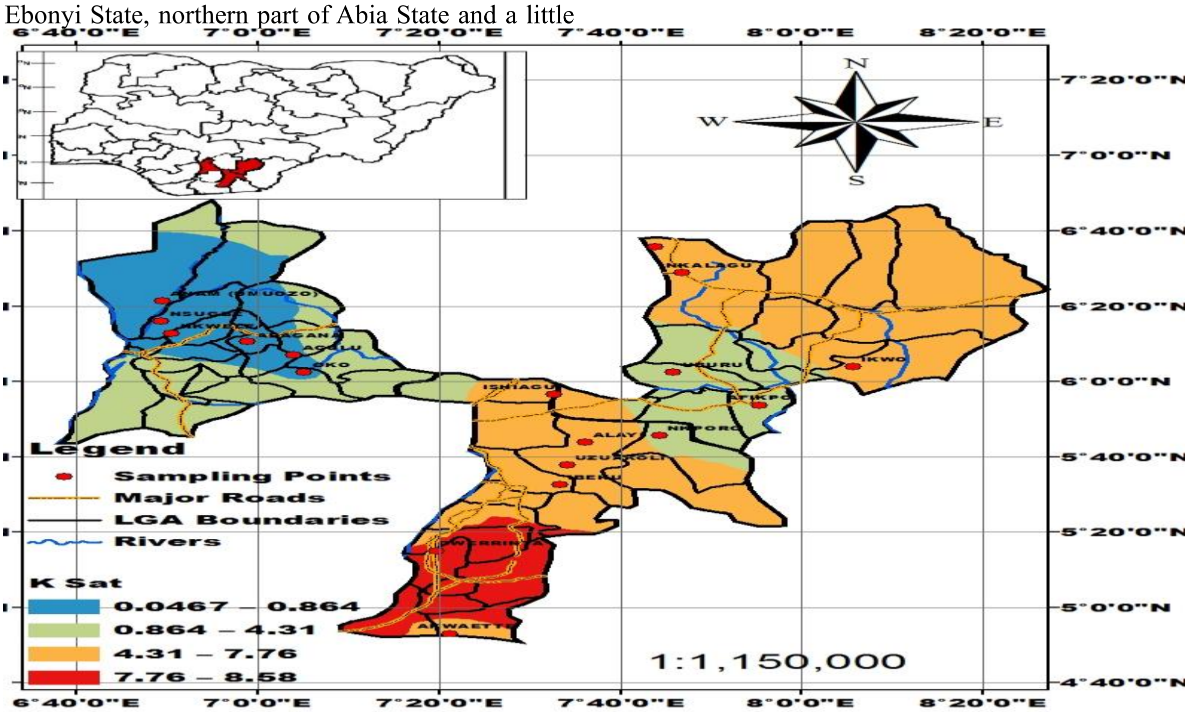

Figure 4: The Kriged Map for the Hydraulic Conductivity (K Sat)

Conclusion

This study demonstrated that the physical properties of soils in Abia State, Nigeria, vary significantly with parent material, landscape position, and soil depth. Soils developed over false bedded sandstone, coastal plain sands, and shale exhibited notable differences in texture, bulk density, porosity, and hydraulic conductivity. Coarse-textured soils with high sand content dominated the surface horizons, while finer textures and increased clay content were more prominent in deeper layers, especially in shale-derived profiles. Bulk density increased and porosity decreased with depth, indicating compaction in subsurface layers. The use of geostatistical techniques, particularly ordinary kriging, effectively mapped spatial variability and predicted values for unsampled locations with acceptable accuracy. These findings underscore the importance of integrating pedological and geospatial tools in land resource evaluation. The spatially explicit information generated can guide site-specific soil management practices, enhance crop productivity, and support sustainable land use planning in the region. It is therefore recommended that future land development efforts in Abia State should consider the inherent variability of soil properties to improve land suitability assessments and precision agriculture interventions.

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