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Variability of Selected Physico-chemical Properties of Soil Overlying Different Parent Materials in Odukpani, Cross River State

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Authors' contributions

This work was carried out in collaboration between all authors. Author SMA designed the study, involved in data collection and critically revises the article. Author IAI managed the literature searches, drafted the article, performed the statistical data analysis and interpretation. Author EEA supervised field survey, involved in data collection, critical revision of the article. All authors read and approved the final manuscript to be published.

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ABSTRACT

This research investigated variability among soil properties in soils overlying shale, sandstones and limestone parent materials. The result showed variability in percent sand, silt and clay content in both surface and subsurface soil. The texture ranged from clay, loam, sandy clay to sandy clay loam. The soils were acidic except those developed on limestone. The organic carbon contents of the soils were low to moderate. Total nitrogen was low while available phosphorus was high. In all parent materials exchangeable bases consistently decreased with geomorphic surfaces and were in the magnitude of Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}. The result of the study also showed that landscape position (crest, middle slope and valley bottom) significantly influences sand and clay content, available phosphorus, and exchangeable acidity (H^{+}) and the crest had the highest sand content, middle slope had the highest clay content, valley bottom had highest available phosphorus while the crest and valley bottom had the highest exchangeable H^{+}. Also, parent materials (shale, sandstone and limestone) significantly influences sand and clay content, pH, organic carbon, available phosphorus, exchangeable Ca and Mg, exchangeable acidity (Al and H), ECEC and BS. pH and base saturation within and across the three parent materials consistently had low variability

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class (CV< 15%) whereas soil texture particularly percent silt and Al^{+++} consistently had high variability class (CV >35%). This result suggest that uniform management practices for soil properties with high variability alongside with those having low variability in Odukpani soils can leads to failure of crops to response to such management practices and yield loses are inevitable.

Keywords: Shale; sandstones; limestone; variability.

1. INTRODUCTION

Most farmers in Nigeria, especially those that are not conversant with soil pedogenetic processes often regard soils to be the same in all aspect especially when such soils are in the same geographical location. It is against this backdrop that Onweremadu [1] aptly stated that soils even those formed on the same parent materials differ greatly in their physico-chemical properties. Irmak et al. [2] also affirmed that different parent materials give rise to differences in morphology, physical and chemical properties of soils, even under the same agro-ecological conditions.

Hence, soil variation is a gradual change in soil properties as a function of landforms, geomorphic elements, soil forming factors and soil management [3]. Soil properties vary spatially within and across a field even in soil developed under the same parent material. This differences could be attributed to both intrinsic (soil forming factors) and extrinsic factors (soil management practices, fertilization, and crop rotation) [4].

Now that emphasis is being tailored to precision farming in Nigeria in order to meet up with food requirement of rapidly growing population, investigations on properties of soils on different parent materials and landscape positions is absolutely necessary. Potentials of soils can readily be tapped when this information are available. In view of the importance of soil as a critical resource for meeting the diverse needs of mankind, including serving as a medium for plant growth and also providing food for the populace, it has become imperative to take account of the variability of soil properties especially when intending to design a suitable soil management system to be used in selecting appropriate agronomic practices for such soils. This is so because a basic knowledge of spatial distribution of soil properties within and across landscape are important in refining agricultural management practices [5], as this will enable the users to minimize environmental damage while utilizing the soil.

Soils of Cross River State are developed from diverse parent materials including basalt, shale, sandstones, limestone, coastal plain sand, alluvial and basement complex [6]. However, soils in Odukpani Local Government Area of Cross River State (both the upland and flood plain soils) are exclusively developed on limestone, shale and sandstones [7]. This area is one of the major crops producing area in Southern Agricultural Zone of Cross River State. Thus, information on variations in soil properties within and across soil overlying diverse parent materials in Odukpani LGA will enable potential users to appreciate the behaviour of this soil and also enable farmers to rationally plan the development and use of the lands accordingly, so as to put available agricultural lands to their best uses for sustainable food production. This has, therefore necessitated this study with the objective of assessing the variability in physical and chemical properties within and between soils developed on limestone, shale and sandstones parent materials.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

This research was carried out in Odukpani Local Government Area, Cross River State. The area lies between latitude 05°34' North and longitude 08°50' East. The study area has tropical climate with two seasons; the rainy season which lasts from April to October and dry season which is from mid-November to March. The area receives average rainfall of 2,134 mm per annum and daily temperature ranges from 21℃ to 34℃ [8]. The relative humidity reaches a minimum of 60% in January (at the peak of the dry season) and rises to 70 - 85% in July (at the peak of the rains). The area originally had rainforest vegetation, but has been altered due to population increase and attendant conflictive land use including subsistence agriculture. Soils of the area are derived from limestone, shale and sandstones.

2.2 Field Studies

A free survey technique guided by the geological map of Cross River State was used in situating soil profile pits. Three (3) parent materials (Shale, Sandstone and Limestone) were selected and on each parent materials three landscape positions were identified using Abney Level. In each identified landscape positions, three (3) profile pits were dug and described according to FAO guidelines for soil description [9]. Samples from genetic horizons were taken to the drying shade for air-drying and subsequently to laboratory for analysis.

2.3 Laboratory Analysis

The air-dried samples were crushed gently and passed through 2 mm sieve to separate gravel from fine earth fraction. The fine earth fraction (< 2 mm) was subjected to routine soil analysis: Particle size fraction analysis was determined by mechanical analysis technique of Bouyocous modified by Gee and Or [10] using sodium hexa-metaphosphate as a dispersant. Soil pH was measured potentiometrically in a soil: water suspension (mixed at a ratio of 1:2.5 soil: water) using glass electrode pH meter following procedure described by Hendershot et al. [11]; organic carbon was determined by the dichromate wet oxidation method of Walkley and Black as outlined in Nelson and Sommers [12] and converted to organic matter by multiplying by a factor of 1.742 (Van Bemmelen factor); total nitrogen was determined by micro-Kjeldahl digestion method; available phosphorus (P) was extracted by Bray-1 method and the colour was developed in soil extract using ascorbic acid blue method [13]; exchangeable bases (Ca^+, Mg^+, Na^+, and K^+) were extracted by saturating soil with neutral 1*M* NH_4OAc [14] and Ca and Mg in the extract was determined using atomic absorption spectrophotometer (AAS) while K and Na were determined by flame photometry; exchangeable acidity was determined by extracting the soil with 0.1*N* KCl solution and titrating the aliquot of the extract with 1*N* NaOH following the procedure outline by Udo et al. [15]. Effective cation exchange capacity (ECEC) was calculated by the summation of exchangeable bases (Ca^{2+}, $Mg2^+$, K^+, Na^+) and exchangeable acidity (H^+ and Al^{3+}). Base saturation was calculated as the sum of total exchangeable bases divided by ECEC and expressed as a percentage [16].

2.4 Statistical Analysis

The generated data for different soil properties were analyzed using mean and Coefficient of Variation (CV), two sample t-tests and Analysis of Variance (ANOVA). Soil properties were assessed for their variability using Coefficient of Variation (CV) and compared with variability classes following Wilding and Dress, [17] ratings, where CV ≤ 15% = low variation, CV > 15 ≤ 35% = moderate variation, CV > 35% = high variation. Significant differences in soil properties between surface and sub-surface sample were determined using unpaired t-tests. The analysis of variance (ANOVA) procedures for Randomized Complete Block Design (RCBD) was used and the significant means were separated using Duncan's Multiple Range Test (DMRT) at 5% level of probability.

3. RESULTS AND DISCUSSION

3.1 Particle Size Distribution

As shown in Tables 1, 2 and 3, there were considerable differences in soil particle size distribution under the three landscape positions in the three parent materials studied. Percent sand content was the most dominant particle fraction in the three parent materials considered. Soil texture showed variability in percent sand, silt and clay content in both surface and subsurface soil. Soils developed on shale predominantly exhibited sandy clay loam to sandy clay texture (Table 1). This revealed that the shale parent material exhibited fine texture. The texture was almost similar to soils developed on sandstone and it ranged from sandy loam, sandy clay to sandy clay loam. In contrast, the soils derived from limestone parent material were finer of all the three soils and its texture ranges from clay, loam to sandy clay loam. This result is consonant with the report of Babalola et al. [18] that topography and parent materials have influence on pattern of soil distribution over landscape. The trend in percent sand, silt and clay movement along the landscape positions were irregular.

The result of the findings also showed that in shale and limestone, there were no significant differences in sand and silt contents between the surface and subsurface soil (Table 4), whereas sandstone showed significant decrease in sand ($t = -2.01$; $p < 0.1$) and silt ($t= -2.47$; $p < 0.05$) content between the surface and subsurface soil. The results also showed that in shale ($t = 7.24$; $p < 0.01$), sandstone ($t = 2.37$; $p < 0.05$) and limestone ($t = 2.65$; $p < 0.01$) parent materials the value of percent clay on the surface soils were significantly ($p<0.05$) lower than those on subsurface soil (Tables 1, 2, 3, and 4). This indicates that clay increases with depth, perhaps due to the pedogenic process of illuviation. This result is an indication of the translocation of clays from the surface downward by argilluviation process. Boul and Hole [19] has aptly stated that an argillic horizon must contain a minimum clay increase relative to the eluvial horizon or an underlying horizon, and show evidence of clay movement. As a consequence, the texture observed irrespective of physiographic position and parent materials can be favourable for agricultural cultivation. Most field crops could grow well in soils having sandy clay and sandy clay loam textural class as these soils have a potentially well-balanced capacity to retain water, form a stable structure and provide adequate aeration [20].

3.2 Silt/Clay Ratio

The mean silt/clay ratio values for soils developed under shale were 0.61 (surface soil) and 0.26 (subsurface soil) and in soil developed under sandstone it were 1.7 (surface soil) and 0.84 (subsurface soil) whereas in limestone it were 1.15 (surface soil) and 0.26 (subsurface). The mean silt/clay ratio in soil developed under shale was less than unity, signifying low weatherbility of the soil and pedogenesis under this parent material, whereas those developed under sandstone and limestone were more than unity especially those on the surface soil, this indicates high weatherbility of the soil developed under sandstone and limestone parent materials. On the whole a silt/clay ratio values > 0.25, a critical limit [21] is used in defining the intensity of weathering of parent materials. The results obtained for this study therefore showed that the studied soils have considerable amount of weatherable minerals in them.

3.3 Nutrient Status of the Soils

<u>3.3.1 pH</u>

The mean values of pH at the surface and subsurface soil were 4.27 and 4.34 respectively for soil developed on shale parent material. However, comparing these values with critical nutrient limit (5.6 - 6.5) stipulated by Landon [22] for most arable crops, the result showed that soil overlying this parent material is acidic in soil reaction. Also, mean pH values were not significantly different between the two geomorphic surfaces (surface and subsurface soils) ($t = -0.97$; $p>0.05$), and its variation across the three landscape position was low (Table 4). Consequent upon the observed pH value, if farmers in the area are to use the soil for crop cultivation, provision should be made for liming. Nevertheless, the low pH recorded on these soils might be as a result of the acidic nature of the parent rock coupled intensive leaching of exchangeable cations. Similarly, the mean values of pH at the surface and subsurface of soil developed on limestone were 7.23 and 7.01 respectively, and the value was not statistically significant ($t = 0.37$; $p >0.05$), whereas in soil developed on sandstone the mean surface and subsurface soil pH were 5.13 and 5.23 respectively and was significantly different ($t= -2.49$; $p<0.05$) between the two geomorphic surfaces. This is in conformity with the findings of Babalola et al. [18] who did similar work on soil properties and slope position in a Humid forest and observed same trend of pH.

3.4 Organic Carbon, Organic Matter, Total Nitrogen and C/N Ratio

The organic carbon contents of the soils were low to moderate. Soils developed on shale and sandstone had moderate organic carbon content while those developed on limestone parent material had low value based on critical rating of Landon [22] and by direct implication this soils are also low or moderate in organic matter content. The low values of organic matter content of soil developed on limestone would encourage a rapid leaching of cations into the sub-soils from the surface. The values of organic carbon content obtained in all parent materials were consistently higher in surface soil than subsurface soil, and shale ($t = 4.13$; $p < 0.05$) and limestone ($t = 3.53$; $p< 0.05$) showed a significant difference between surface and subsurface soils values while sandstone ($t = -1.54$; $p >0.05$) shows no significant difference between surface and subsurface organic carbon content. Addition of leaf litter or crop residue to the soils will be beneficial for crop production in the area especially on those parent materials that is inherently had low pH values. Organic matter is known to produce high percentage of net negative charges in exchange site [23]. High quantity of organic matter reported in similar studies on soils developed from Bende-Ameki Shale by Chikezie et al. [24] and Ahukaemere et al. [25] could be explained by the protection of organic carbon by clay.

Table 1. Physico-chemical properties of soil developed from shale parent material

	Horizon	Depth (cm)	Particle size			Texture	Silt/clay ratio	pH (H_2O)	OC	OM	TN	C/N ratio	AV. P ($mgkg^{-1}$)	Exch. cations				Exch. acidity		ECEC	BS (%)
			Sand	Silt	Clay									Ca	Mg	K	Na	Al^{+3}	H^+		
			→ % ←						→ % ←					→ $cmol^+kg^{-1}$ ←							
Crest	Ap	0-12	52.0	19.0	29.0	SCL	0.65	4.3	3.39	5.91	0.13	26.18	22.16	6.4	3.2	0.19	0.08	1.56	0.42	11.85	83.29
	Bt1	12-39	69.0	7.0	24.0	SCL	0.29	4.4	1.86	3.24	0.11	16.91	10.42	5.2	1.4	0.11	0.07	1.34	0.28	8.40	80.71
	Bt2	39-79	58.0	7.0	35.0	SC	0.20	4.6	0.98	1.71	0.10	9.80	8.51	4.6	0.4	0.08	0.06	1.28	0.18	6.40	77.18
	Ctr	79-145	57.0	7.0	36.0	SCL	0.19	4.7	0.88	1.53	0.05	17.60	7.21	3.0	0.2	0.06	0.05	1.14	0.10	4.55	72.74
Middle	Ap	0-10	54.0	17.0	29.0	SCL	0.59	4.2	2.25	3.92	0.12	18.75	17.14	6.4	2.2	0.14	0.07	0.98	0.60	10.39	84.79
slope	Bt1	10-50	59.0	10.0	31.0	SCL	0.32	4.2	0.79	1.38	0.08	9.88	8.02	4.2	0.4	0.10	0.07	0.96	0.04	6.13	77.81
	Bt2	50-95	58.0	11.0	31.0	SCL	0.35	4.2	0.76	1.32	0.08	9.50	8.00	4.1	0.2	0.07	0.06	0.09	0.38	5.71	77.58
	Ctr	95-138	61.0	9.0	30.0	SCL	0.30	4.2	0.19	0.33	0.04	4.75	6.10	3.1	0.1	0.04	0.03	0.86	0.24	4.47	75.39
Valley	Ap	0-10	54.0	17.0	29.0	SCL	0.59	4.3	3.3	5.75	0.13	25.38	16.87	6.4	3.2	0.19	0.07	0.56	0.42	10.84	91.0
bottom	Bt1	12-39	59.0	10.0	31.0	SCL	0.32	4.4	1.9	3.31	0.11	17.27	9.0	7.2	0.4	0.11	0.08	0.34	0.60	8.73	89.2
	Bt2	39-79	58.0	11.0	31.0	SCL	0.35	4.0	1.0	1.74	0.10	10.00	3.7	5.6	0.1	0.10	0.09	0.28	0.66	6.73	86.0
	Ctr	74-145	61.0	9.0	30.0	SCL	0.30	4.4	0.9	1.57	0.05	18.00	2.8	4.2	0.6	0.06	0.06	0.88	0.46	6.26	78.5
Surface sample																					
Mean			52.67	25.0	22.30		0.61	4.27	2.98	5.19	0.13	23.40	18.72	6.4	2.86	0.17	0.073	1.03	0.48	11.03	86.34
SD			13.43	14.57	1.73		0.035	0.058	0.63	1.10	0.006	4.045	2.98	0	0.57	0.029	0.006	0.50	0.10	0.75	4.06
CV (%)			25.50	58.20	7.8		5.74	1.40	21.3	21.3	4.6	17.30	15.9	0	20.1	16.70	7.9	48.6	0.22	6.8	4.7
Ranking			M	H	L		L	L	M	M	L	M	M	L	M	M	L	H	L	L	L
Sub-surface sample																					
Mean			36.67	11.36	51.96		0.26	4.34	1.03	1.79	0.08	12.63	7.08	4.57	0.42	0.081	0.063	0.79	0.32	6.26	81.47
SD			9.30	7.87	11.92		0.058	0.21	0.54	0.94	0.027	4.85	2.48	1.29	0.40	0.025	0.017	0.45	0.21	1.57	6.19
CV (%)			25.40	69.3	22.9		22.31	5.00	52.4	52.4	34.2	38.4	35.02	28.2	95.3	31.1	27.3	57.2	65.9	25.0	7.6
Ranking			M	H	M		M	L	H	H	M	H	H	M	H	M	M	H	H	M	L

SCL = sandy clay loam; SC =sandy clay; OC = organic carbon; OM = organic matter; TN = total nitrogen; AV. P = available phosphorus; BS = base saturation; ECEC effective cation exchange capacity; CV; coefficient of variability; L = low variability; M =moderate variability; H= high variability; SD = standard deviation

Table 2. Physico-chemical properties of soil developed from sandstone parent material

	Horizon	Depth (cm)	Particle size			Texture	Silt/clay ratio	pH (H_2O)	OC	OM	TN	C/N ratio	AV. P ($mgkg^{-1}$)	Exch. cations				Exch. acidity		ECEC	BS (%)
			Sand	Silt	Clay									Ca	Mg	K	Na	Al^{+3}	H^{+}		
			→	%	←				→	%	←			→				$cmol^{+}kg^{-1}$	←		
Crest	Ap	0-20	75.0	17.0	8.0	SL	2.12	5.4	2.30	4.01	0.16	14.37	16.0	3.0	2.8	0.10	0.07	1.30	0.24	7.51	79.49
	Bt1	20-60	75.0	7.0	18.0	SL	0.38	5.6	0.42	0.73	0.03	14.00	7.75	3.0	1.2	0.08	0.06	1.26	0.16	5.76	75.34
	Bt2	60-90	66.0	16.0	18.0	SL	0.89	5.7	0.22	0.38	0.02	11.00	7.50	2.8	0.4	0.08	0.06	1.12	0.14	4.60	72.60
	Ctr	90-139	65.0	11.0	24.0	SCL	0.46	5.8	0.12	0.20	0.01	12.00	7.50	2.0	0.2	0.07	0.05	1.10	0.12	3.54	65.53
Middle slope	Ap	0-16	74.0	12.0	14.0	SL	0.86	4.6	1.12	1.95	0.01	112.00	6.88	3.4	1.6	0.11	0.08	1.6	0.17	6.96	74.56
	Bt1	16-50	53.0	5.0	42.0	SC	0.12	4.8	0.68	1.18	0.05	13.6	7.75	2.8	0.8	0.08	0.06	1.2	0.09	5.03	74.35
	Bt2	50-81	49.0	7.0	44.0	SC	0.16	4.9	0.48	0.84	0.03	16.00	7.63	2.7	0.7	0.07	0.06	1.2	0.08	4.81	73.38
	Ctr	81-134	48.0	11.0	41.0	SC	0.27	5.0	0.28	0.49	0.01	28.00	6.50	2.1	0.4	0.04	0.03	1.0	0.04	3.61	71.19
Valley bottom	Ap	0-16	75.0	17.0	8.0	SL	2.12	5.4	0.2	0.35	0.06	3.33	16	3.0	2.8	0.1	0.07	1.64	0.24	7.85	76
	Bt1	16-50	75.0	7.0	18.0	SL	3.89	5.7	0.42	0.73	0.03	14.00	7.75	3.0	1.2	0.08	0.06	1.16	0.0	5.5	79
	Bt2	50-81	66.0	16.0	18.0	SL	0.89	5.6	0.22	0.38	0.02	11.00	7.5	2.8	0.4	0.09	0.07	2.56	0.28	6.2	54
	Ctr	81-134	65.0	11.0	24.0	SCL	0.45	4.0	0.12	0.21	0.09	1.33	7.5	3.0	1.2	0.07	0.05	2.4	0.32	7.04	61
Surface sample																					
Mean			74.33	15.33	10.0		1.7	5.13	1.21	2.10	0.077	43.23	12.96	3.1	2.4	0.10	0.073	0.51	0.22	7.44	76.71
SD			0.58	2.89	0.73		0.73	0.46	1.05	1.83	0.076	59.81	5.26	0.23	0.69	0.0058	0.0058	0.18	0.04	0.45	2.53
CV (%)			0.78	18.85	7.3		9.00	8.96	86.8	87.1	98.7	138.4	40.59	7.42	28.75	5.8	7.9	3.5	18.2	0.60	3.3
Ranking			L	M	M		L	L	H	H	H	H	H	L	M	L	L	L	M	L	L
Sub-surface sample																					
Mean			62.44	10.11	27.44		0.84	5.23	0.32	0.57	0.03	13.43	7.48	2.60	0.72	0.07	0.056	1.44	0.13	5.12	69.65
SD			10.19	3.98	11.45		1.18	0.60	0.18	0.32	0.02	6.89	0.38	0.37	0.39	0.014	0.011	0.59	0.10	1.15	7.83
CV (%)			16.30	39.37	41.70		141.0	11.5	56.5	56.5	77.2	15.3	5.20	14.1	55.3	19.3	20.3	41.1	76.9	22.4	11.2
Ranking			L	H	H		H	L	H	H	H	M	L	L	H	M	M	H	H	M	L

SL =sandy loam; SCL = sandy clay loam; SC = sandy clay; OC = organic carbon; OM = organic matter; TN = total nitrogen; AV. P = available phosphorus; BS = base saturation; ECEC effective cation exchange capacity; CV; coefficient of variability; L = low variability; M =moderate variability; H= high variability; SD = standard deviation

Table 3. Physico-chemical properties of soil developed from limestone parent material

	Horizon	Depth (cm)	Particle size			Texture	Silt/clay ratio	pH (H_2O)	OC	OM	TN	C/N ratio	AV. P ($mgkg^{-1}$)	Exch. cations				Exch. acidity		ECEC	BS (%)
			Sand	Silt	Clay									Ca	Mg	K	Na	Al^{+3}	H^{+}		
			→ % ←						→ % ←					→ $cmol^{+}kg^{-1}$ ←							
Crest	Ap	0-15	68	8.70	23.3	SCL	0.37	6.9	2.2	3.83	0.18	12.22	23	8.2	3.2	0.11	0.9	0.16	0.92	14.49	91.99
	Bt1	15-65	54	17.7	28.3	SCL	0.62	6.5	0.8	1.39	0.07	11.43	18.9	8.0	3.2	0.11	0.08	0.52	0.92	12.83	88.78
	Bt2	65-104	46	9.70	44.3	SC	0.22	7	0.6	1.04	0.05	12.00	19.3	6.0	2.6	0.09	0.07	0.52	0.80	10.08	86.90
	Ctr	104-180	44	7.70	48.3	C	0.16	6.5	0.5	0.87	0.04	12.50	18.8	5.8	3	0.08	0.06	0.32	0.56	9.82	91.04
Middle slope	Ap	0-10	43	36.7	20.3	L	1.81	6.9	2.3	4.01	0.19	12.11	20.8	6.4	2.8	0.09	0.07	0.48	0.2	10.78	93.23
	Bt1	10-54	34	4.70	61.3	C	0.077	7.4	0.5	0.87	0.04	12.50	18.0	7.2	2.4	0.1	0.08	0.44	0.28	10.5	93.14
	Bt2	54-80	29	4.70	66.3	C	0.071	7.9	0.4	0.69	0.03	13.33	22.0	5.4	2.6	0.09	0.06	0.84	0.36	9.35	87.17
	Ctr	80-121	31	14.70	54.3	C	0.27	6.9	0.9	1.56	0.08	11.25	22.8	8.0	1.8	0.1	0.08	0.4	0.40	10.78	92.58
Valley bottom	Ap	0-14	47	29.70	23.3	L	1.27	7.9	0.8	1.39	0.07	11.43	29.6	6.0	2.2	0.08	0.06	0.44	0.60	9.38	88.91
	Bt1	14-54	27	28.70	44.3	C	0.65	6.3	0.6	1.04	0.05	12.00	39.2	5.8	2.4	0.08	0.05	0.48	0.36	9.17	90.84
	Bt2	54-95	29	8.70	62.3	C	0.13	6.8	0.3	0.52	0.02	15.00	29.4	5.6	2.2	0.09	0.06	0.56	0.72	9.23	86.13
	Ctr	95-168	36	5.70	58.3	C	0.098	7.8	0.3	0.52	0.02	15.00	33.3	5.4	2.4	0.08	0.07	0.56	0.4	8.91	89.23
Surface sample																					
	Mean		52.66	25.03	22.30		1.15	7.23	1.76	3.07	0.14	11.91	24.46	6.86	2.73	0.09	0.34	0.36	0.57	10.97	91.38
	SD		13.42	14.57	1.73		0.73	0.57	0.83	1.46	0.06	0.43	4.58	1.17	0.50	0.015	0.48	0.17	0.36	2.21	2.22
	CV (%)		25.5	58.2	7.80		62.9	8.0	47.5	47.5	45.5	3.6	18.7	17.1	18.4	16.4	140.4	48.4	62.9	20.01	2.40
	* Ranking		M	H	L		H	L	H	H	H	L	M	M	M	M	H	H	H	M	L
Sub-surface sample																					
	Mean		36.66	11.36	51.96		0.26	7.01	0.54	0.95	0.04	12.77	24.63	6.35	2.51	0.09	0.068	0.52	0.53	10.07	89.53
	SD		9.30	7.87	11.91		0.23	0.57	0.21	0.36	0.021	1.40	7.58	1.07	0.41	0.011	0.011	0.14	0.22	1.21	2.53
	CV (%)		25.4	69.3	22.90		87.90	8.2	38.0	38.0	46.0	11.00	30.80	16.9	16.5	11.6	16.1	28.1	42.8	12.0	2.8
	Ranking		M	H	M		H	L	H	H	H	L	M	M	M	L	M	M	H	L	L

*SCL =sandy clay loam; L =loam; C = clay; OC = organic carbon; OM = organic matter; TN = total nitrogen; AV. P = available phosphorus; BS = base saturation; ECEC effective cation exchange capacity; CV; coefficient of variability; *L = low variability; M =moderate variability; H= high variability; SD = standard deviation*

Table 4. Two sample t-test of surface and sub-surface horizons differences among parent materials

Parent materials	Particle size			Silt/clay ratio	pH (H_2O)	OC	OM	TN	C/N ratio	AV. P ($mgkg^{-1}$)	Exch. cations				Exch. Acidity		ECEC	BS (%)
	Sand	Silt	Clay								Ca	Mg	K	Na	Al^{+3}	H^+		
	→	%	←			→	%	←				→		$cmol^+kg^{-1}$	←			
Shale	1.92^{NS}	1.55NS	7.24***	2.11NS	-0.97NS	4.13**	0.058NS	-5.68***	7.15***	8.59***	4.21***	-3.81***	4.07***	2.00NS	-0.74NS	3.69**	3.78**	4.00**
sandstone	-2.01*	-2.47**	2.37**	16.65***	-2.49**	-1.54NS	-2.76**	1.19NS	-1.86*	28.30***	-0.39NS	-1.63NS	-0.71NS	13.58***	-17.00***	28.13***	52.54***	-22.31***
Limestone	1.91^{NS}	-0.47NS	2.65***	1.25NS	0.37NS	3.53***	2.15NS	-1.40^{NS}	4.04***	3.44***	0.27NS	-0.59	0.23NS	0.98NS	-0.77NS	-0.79^{NS}	0.038^{NS}	1.41^{NS}

****, **, and * means significant at 1, 5 and 10% respectively*

Table 5. Grouping of coefficient of variation into variability classes for different parent materials

	Coefficient of variation (CV)		
	Low (CV<15%)	**Moderate (CV 15 -35%)**	**High (CV >35%)**
Shale			
Surface soil	Clay, silt/clay ratio, pH, TN, Ca, Na, H^+, ECEC, **BS**	Sand, OC, OM, C/N ratio, avail. P, Mg, K,	Silt, Al^{+++}
Subsurface soil	pH, BS	Sand, clay, silt/clay ratio, TN, Ca, K, Na, ECEC	Silt, OC, OM, C/N ratio, avail. P, Mg, Al^{+++}, H^+
Sandstone			
Surface soil	Sand, silt/clay, pH, Ca, K, Na, Al^{+++} ECEC, BS	Silt, clay, Mg, H^+	OC, OM, avail. P, TN, C/N ratio,
Subsurface soil	Sand, pH, avail. P, Ca, BS	C/N ratio, K, Na, ECEC	Clay, Silt, silt/clay, H^+, OC, OM, TN, Mg, Al^{+++}
Limestone			
Surface soil	Clay, pH, C/N ratio, BS	Sand, avail. P, Ca, Mg, K, ECEC	Silt, silt/clay ratio, OC, OM, TN, Na , Al^{+++}, H^+
Subsurface soil	BS, ECEC, K, C/N ratio, pH	Sand, clay, Ca, Mg, Na, Al^{+++}	Silt, Silt/clay ratio, OC, OM, TN, H^+,

Table 6. Distribution and variation of physico-chemical properties influenced by landscape position and parent material

	Particle size			Silt/clay ratio	pH (H_2O)	OC	TN	C/N ratio	AV. P ($mgkg^{-1}$)	Exch. cations				Exch. acidity		ECEC	BS (%)
	Sand	**Silt**	**Clay**							**Ca**	**Mg**	**K**	**Na**	**Al^{+3}**	**H^+**		
	→	%	←			→	%	←		→			$cmol^+kg^{-1}$	←			
Parent materials																	
Shale	40.7b	14.8a	44.5a	0.48a	4.3b	1.52ab	0.092a	15.3a	9.99b	5.03	1.03a	0.10a	0.066a	0.86b	0.37b	7.46b	82.70b
Sandstone	65.5a	16.7a	23.1b	1.05a	5.2b	0.55c	0.052a	20.7a	8.86b	2.80c	1.14a	0.081a	0.060a	1.46a	0.16b	5.7b	71.42b
Limestone	40.7b	14.8a	44.5a	0.48a	7.1a	0.85bc	0.07a	12.6a	24.59a	6.48a	2.57a	0.92a	0.14a	0.48b	0.54ab	10.30a	89.99a
F-value	32.36***	0.08^{NS}	8.03***	2.25^{NS}	127.29***	4.40**	1.88^{NS}	0.79^{NS}	46.57***	41.31***	10.06****	1.55^{NS}	1.13^{NS}	30.83***	22.55***	18.61***	33.12***
Landscape position																	
Crest	58.8a	11.5	29.7c	0.55a	5.6	1.19	0.079a	14.2a	13.92bc	4.83	1.82a	0.097a	0.13a	0.97a	0.40a	8.25a	80.53a
Middle slope	41.5b	13.0	45.4ab	0.49a	5.4	0.89	0.063a	20.7a	12.63c	4.65	1.33a	0.086a	0.063a	0.84a	0.24b	7.21a	82.69a
Valley bottom	46.6b	21.6	37.0bc	0.97a	5.5	0.84	0.071a	15.3a	16.88ab	4.83	1.59a	0.094a	0.066a	0.99a	0.42a	8.00a	80.89a
F-value	12.37***	1.96^{NS}	3.25*	1.44^{NS}	0.56^{NS}	0.65^{NS}	0.29^{NS}	1.10^{NS}	2.87*	0.13^{NS}	0.80^{NS}	0.37^{NS}	1.02^{NS}	0.84^{NS}	6.02***	1.02^{NS}	0.51^{NS}
Parent materials x Landscape position																	
Shale x crest	53.0a	10.9a	36.0a	0.34a	4.5d	1.78a	0.097a	17.6b	12.07c	4.8a	1.30a	0.11a	0.065a	1.33b	0.25c	7.85a	78.66a
Shale x middle slope	34.2a	15.2a	50.5a	0.56a	4.2d	1.00a	0.08a	10.7b	9.81c	4.45a	0.72a	0.088a	0.058a	0.72c	0.32c	6.36a	83.17a
Shale x valley bottom	34.8a	18.2a	47.0a	0.54a	4.2d	1.77a	0.097a	17.7b	8.09c	5.85a	1.07a	0.12a	0.075a	0.52c	0.5b	8.16a	86.26a
Sandstone x crest	70.2a	12.8a	17.0a	0.97a	5.6b	0.77a	0.055a	12.8b	9.69c	2.70a	1.15a	0.083a	0.060a	1.19b	0.17c	5.35a	73.25a
Sandstone x middle slope	56.0a	8.8a	35.2a	0.35a	4.8cd	0.64a	0.025a	42.4a	7.19c	2.75a	0.88a	0.075a	0.057a	1.25b	0.095	5.10a	73.38a
Sandstone x valley bottom	70.2a	28.5a	17.0a	1.84a	5.2bc	0.24a	0.075a	6.9b	9.69c	2.95a	1.40a	0.085a	0.063a	1.94a	0.21c	6.65a	67.63a
limestone x crest	53.0a	10.9a	36a	0.34a	6.7a	1.02a	0.085a	12.0b	20.0b	7.00a	3.00a	0.098a	0.28a	0.38c	0.80a	11.5a	89.68a
Limestone x middle slope	34.2a	15.2a	50.5a	0.56a	7.3a	1.02a	0.085a	12.3b	20.90b	6.75a	2.40a	0.095a	0.073a	0.54c	0.31c	10.17a	91.53a
limestone x valley bottom	34.8a	18.2a	47.0a	0.54a	7.2a	0.50a	0.04a	13.4b	32.88a	5.70a	2.30a	0.082a	0.060a	0.51c	0.52b	9.17a	88.78a
F-value	1.58^{NS}	0.52^{NS}	0.34^{NS}	1.31^{NS}	2.69*	0.78^{NS}	0.96^{NS}	2.33*	4.38***	1.98^{NS}	0.28^{NS}	0.4^{NS}	1.05^{NS}	7.05***	5.69***	1.25^{NS}	1.47^{NS}

3.4.1 Total nitrogen

Based on the rating of total nitrogen set by Tekalign [26], the total nitrogen content in both the surface and subsurface layers of the soils were low. Therefore, the soils must be fertilized with external N inputs for sustainable production as N is dynamic and subject to leaching and volatilization losses. But these applying inputs should be in accordance with specific site requirements of specific soils and crops.

3.4.2 C/N ratio

Based on the rating adopted by Gavilak [27], C: N ratio <10 is very good, 10--14 moderate and >14 is poor. In line with this author, the surface of soils developed under shale (C:N ratio =23.40) and sandstone (C:N ratio = 43.23) were poor in C:N ratio, whereas soil developed under limestone (C:N ratio = 11.91) had moderate C:N ratio. Generally, the C/N ratio in sandstone was below C/N ratio of 25 being the separating index for mineralization and mobilization of nitrogen as established by Paul and Clark [28].

3.5 Available Phosphorus

Based on the critical rating of Landon [22], the available phosphorus content of all the surface soils in the three parent materials were high (avail. P > 15 mg/kg) whereas those of the subsurface soils except soil developed on limestone were low (avail. P < 8 mg/kg). The values of available phosphorus content obtained in all parent materials were consistently higher in surface soil than subsurface soil, and shale (t = 8.58; p <0.01), sandstone (t = 28.30; p< 0.01) and limestone (t =3.44; p< 0.01) showed significant different between surface and subsurface soils values. The decline in phosphorus content with depth might be attributed to the increment of the clay content which was found to increase with the depth and clay type which can cause fixation of phosphorus [29]. This is in agreement with the findings of Tekalign et al. [26] who reported that top soil phosphorus is usually greater than sub-soil due to sorption of the added phosphorus, greater biological activities and the accumulation of organic matter on the surface soil.

3.6 Exchangeable Cations and Base Saturation

The exchangeable bases exhibited regular trends with depth. In all parent material exchangeable bases consistently decreased with geomorphic surfaces (i.e from surface to subsurface soil). This result agree with the decreasing cation magnitude, that is Ca2+ > Mg2+ > K+ > Na+. The result further showed that among the exchangeable bases, the exchange complex of the soils was dominantly occupied by Ca and followed by Mg, whereas K and Na were very fewer compared to the former two divalent cations. The mean exchangeable calcium content of the surface soil (Ca = 6.4 cmol/kg) developed on shale was higher than those of the subsurface soil (Ca = 4.57 cmol/kg) and was significantly different (p < 0.01). Also, the mean exchangeable calcium content of the surface soil (Ca = 6.86 cmol/kg) developed on limestone was higher than those of the subsurface soil (Ca = 6.35 cmol/kg) and there was no significant different (p> 0.05). The value of the surface and subsurface soils were within the moderate (5-10 cmol/kg) critical limit of Landon (1991). In contrast, the mean exchangeable calcium content of the surface soil and subsurface soil developed on sandstone was low and there was no significant different (p >0.05). Bases rating suggested by FAO (9), in all the parent materials and surface soils exchangeable Ca and Mg were moderate except exchangeable Ca content in sandstone which had low Ca content while exchangeable K and Na content had low values. Similarly, in the subsurface soil, all the exchangeable bases Ca, Mg, K and Na were low except Ca content in limestone parent material which falls within the moderate class (> 5.0). The high levels of the divalent cations may be related to the high clay and relatively high organic matter content of the soils. Even though the soil developed on shale parent material is acidic, the exchangeable Ca and Mg adsorbed to the surface of high organic matter content of the soil and remains in the soil with few chance of leaching for this cations has made the exchangeable bases to be high that has also resulted to the formation of high base saturation of this soil. Therefore, all the soils developed under the three parent materials have greater propensity for increased fertility for K+ if supplied with adequate amounts of K_20 fertilizer based on soil test.

3.7 Exchangeable Acidity

The exchangeable acidity value was low in soils developed under diverse parent materials. The exchangeable acidity values (Al^{+3}) was higher in subsurface horizons especially in soil developed under sandstone and limestone, suggesting pronounced pedogenic processes of leaching and eluviation in surface horizons and consequent illuviation of translocated basic cations in deep subsurface soils.

3.8 Effective Cation Exchange Capacity

The Effective Cation Exchange Capacity (ECEC) of soils was generally low. The highest value obtained for this study was 11.03 cmol/kg and was for soil developed under shale. It has been reported elsewhere that the soils of South-eastern Nigeria had low ECEC and basic cations [30]. The low ECEC have been attributed to the fact that soils in this region are strongly weathered, have little or no content of weathered materials in sand and silt fractions and have predominantly Kaolinite in their clay fractions. This finding is also in agreement with that of Korieocha et al. [31] who worked on inland valley soils of south eastern Nigeria and observed low ECEC.

3.9 Base Saturation

As per BS rating developed by Landon [22], BS values greater than 60% are rated as high; between 20 and 60% medium and less than 20% as low. Therefore, the BS of the surface and sub–surface horizons of soil pedons was rated as high. These high BS values recorded in the soils of the study area could be the results of high clay and organic matter content, both of which represent the colloidal matter of a soil. Generally, high value of BS in the soil pedons indicates the presence of high nutrient reserves.

3.10 Variability and Distributions of Soil Physical and Chemical Properties across the Three Parent Materials

The studied soils were evaluated for their variability using coefficient of variation (CV). Tabi and Ogunkule [32], Olorunlana [33] and Asongwe, et al. [34] have similarly used the thresholds of CV to group variability in soil properties. Based on the criteria stipulated by Wilding and Drees (17) CV values ≤15% is considered low, 15-35% moderate, < 35% are considered high. The extents of variability of the 18 physico-chemical properties determined in the study area were presented in Tables 1, 2, 3 and 5.

Of all the physical and chemical properties studied, only clay, silt/clay ratio, pH, TN, Ca, Na, H^+, ECEC and BS had low variability (CV<15%) in surface soil developed under shale while pH and BS had low variability in subsurface soil. In contrast, high variability (CV > 35) was observed in silt and Al^{+++} for surface soil and silt, OC, OM, C/N ratio, avail. P, Mg, $Al^{+++}$and H^+ for subsurface soil respectively.

Similarly, in soil developed under sandstone low variability (CV<15%) were observed in sand, silt/clay, pH, Ca, K, Na, Al^{+++}, ECEC and BS for surface soil and sand, pH, avail. P, Ca and BS for subsurface soil respectively, whilst high variability (CV <35%) were observed in OC, OM, TN, C/N ratio and avail. P for surface soil and silt, clay, silt/clay ratio, OC, OM, TN, Mg, H^+ and Al^{+++} for subsurface soil.

Also, in surface soil developed under limestone clay, pH, C/N ratio and BS had low variability (CV<15%) while variability in BS, ECEC, K, C/N ratio, and pH for corresponding subsurface soil was also low. Nevertheless, high variability was observed for Silt, silt/clay ratio, OC, OM, TN, Na, Al^{+++} and H^+ in surface soil whereas subsurface soil had high variability in Silt, Silt/clay ratio, OC, OM, TN and H^+.

In soil overlying the different parent material pH and BS consistently had low variability (CV<15%) than other soil properties while silt and Al^{+++} consistently had high variability (CV>35) in the studies soils than other soil properties. Similar variability in soil pH was also reported by Tabi and Ogunkunle [32] for Alfisols in Southern Nigeria and Phil-Eze [35] in soil under vegetation cover in a tropical rainforest landscape. Although the variability reported for pH in this study is small, but minor changes in pH units can have significant effects on nutrient availability. This is so because soil pH is a very important property that influences many physico-chemical properties of soils including the availability of nutrients [36]. In all parent materials soil texture particularly percent silt and Al^{+++} were consistently high (CV >35). Gami et al. [37] also reported similar variability in soil texture in their study. This result suggest that uniform fertilizer recommendation on soils in Odukpani can leads to over or under fertilization in cultivated areas which in return may causes severe yield losses. Similar results in spatial variability in soil physico-chemical properties and nutrient levels has been obtained and documented by Liu et al. [38], Patil et al. [39] and Ahmed et al. [40]. The moderate and high extent of variability of properties of soils on the lithosequence was attributed to variation in landscape positions within the study area.

3.11 Effect of Landscape Position and Parent Materials on Soil Properties

Landscape position (crest, middle slope and valley bottom) significantly influences sand and clay content, available phosphorus, and exchangeable acidity (H^+) and the crest had the highest sand content, middle slope had the highest clay content, valley bottom had highest available phosphorus while the crest and valley bottom had the highest exchangeable H^+ (Table 5). Similar studies also indicated that landscape positions influences soil texture [41] and acidic cations [42]. Similarly, parent materials (shale, sandstone and limestone) significantly influences sand and clay content, pH, organic carbon, available phosphorus, exchangeable Ca and Mg, exchangeable acidity (Al and H), ECEC and BS. This result is not surprising as previous studies [43] indicated similar results. Therefore the study indicated that different parent materials and landscape positions can create remarkable differences in soil properties.

However, considering the landscape positions and the three parent materials as a whole (Table 5). The result showed that soils overlying limestone in the crest, middle slope and valley bottom significantly had the highest pH value compare to other parent materials and landscape positions. Also soils overlying limestone in the valley bottom significantly had the highest available P content compare to other parent materials and landscape positions. In contrast, soils overlying sandstone in the middle slope had a highest significant C/N ratio than other parent materials and landscape positions. The result further showed that the exchangeable acidity (Al^{+++} and H^+) was significantly different in landscape positions across the three parent materials with soils overlying sandstone in the valley bottom having the highest value of exchangeable Al^{+++} and soils overlying limestone crest having the highest exchangeable H^+ value.

4. CONCLUSION

Currently, Odukpani Local Government Area is facing food security problem of which its impacts are being reflected in the form of famines. This study has made considerable efforts to study the characteristics and the spatial variation of soil properties in the soils of the area as it is essential for sustainable agriculture, environmental assessment of soil quality, risk of soil pollution and erosion.

Thus, with the value of pH obtained, it can be asserted that soil developed on limestone is more fertile and preferred for farming followed closely by sandstone in relation to shale. This is further buttressed by the values of their effective cation exchange capacity, percent base saturation, organic matter and available P. Hence, limestone has superior chemical properties which indicated good chemical edaphology for crop productivity. In this regards therefore, it would require minimal fertilizer input when compared to shale and sandstone.

The result of this study has showed that the variation in soil properties in this area is cause by both parent materials and landscape positions and this is one of the reasons for variation in crop yield under the same management regime. Therefore, the knowledge of spatial variability of soil properties is very important for precision farming, site-specific management and sustainable crop production by applying inputs in accordance with specific site require.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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