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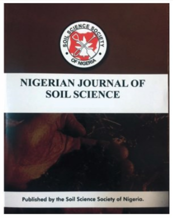

Evaluation of soil development on an erosional landscape of the Nigerian Guinea Savanna

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ABSTRACT

Soil landscape relationship is an essential tool for evaluating soil development. This study was carried out to evaluate soil development on an erosional landscape of the Nigerian guinea savanna. Field studies were carried out by augering to a depth of 105 cm and by studying soil profiles along gully walls and stream channels in selected locations. Profile description and soil sampling were done following guidelines in the soil survey manual. Standard laboratory procedures were employed in analysis of soil physical and chemical properties. Soils of the area have developed from basement complex rocks under a tropical continental climate. Ongoing soil erosion in the area range from sheet to gully and stream bank erosion. Soil types identified on the landscape were Entisols on summit to upper footslope slope positions, whereas Inceptisols were observed on middle to lower footslope positions. Soils productivity index ranged from less than 0.10 to between 0.11 to 0.30 on Entisols and Inceptisols respectively. A horizons were poorly developed as indicated by the low profile darkness index and have very high soil erodibility index (> 0.04 (t.ha.h)/(MJ.mm)). The parent materials coupled with leaching and erosional processes have significantly influenced the fertility and productivity of the soils.

1.0 Introduction

Soils are products of the integrated effect of climate and living matter acting upon the parent material, as conditioned by topography, over periods of time (Brady and Weil, 1999). Soils form a three-dimensional continuum on the landscape, and thus do not exist in isolation, but are organized within the landscape. Furthermore, studies by Norton et al. (2003) indicates that soil development varies systematically in lateral and vertical directions as a function of the landscape position, the soil- forming factors, and/or soil management practices. An appraisal of the influence of topography on such soil properties as 1, thickness and organic matter content of A-horizon, 2, depth of solum, 3, drainage condition of soils, 4, type and relative abundance of clay minerals, 5, chemical properties of soils, etc, are needed to complement the present knowledge of soil-forming processes in the landscape of the study area. Soil-landscape relationships are a potent tool for the study of soil-distribution patterns and soil genesis.

The Study area is located in Langtang North area of Nigeria's Guinea Savanna. The area has a tropical continental climate. However, not much is known about soil characteristics of the area. Consequently, the objective of this study is to evaluate soil development in the study area.

2.0 Materials and methods

2.1 Field studies

The area of the study site is 31, 608 ha. The system for automated geographic analysis (SAGA) GIS software was used for fundamental terrain analysis of the study area. Representative sampling points were located in each slope unit. At each sample point observations were made on signs of soil erosion and deposition. Soil samples were obtained by drilling with a soil auger in selected locations to a depth of 105 cm. Also, soil profile observations representing average conditions for each landscape unit containing it were made along gully channels and stream banks. Morphological properties of soil profiles were determined using the Soil Survey Manual (Soil Survey Division Staff, 1993) and soil samples collected from genetic horizons. The profile darkness index (PDI) was determined as described by Schaetzl and Thompson (2015): Soil productivity was determined using the method of Delgado (2003).

2.2 Laboratory analysis

Soil samples were air-dried in the laboratory, crushed with porcelain pestle and mortar and sieved to remove material more significant than 2mm (gravel and other coarse fragments). The following analyses of the less than 2mm fraction were carried out: Particle size analysis was determined using the hydrometer method as described by Gee and Bauder (1986). Soil erodibility factor was determined using the procedure described by van der Knijff et al (2000). Bulk density was described using the clod method as described by Estefan et al (2013). Soil pH was determined in 0.01M $CaCl_2$ solution at a 1:2.5 soil/water or solution ratio.

Exchangeable bases (Ca, Mg, K and Na) were determined using NH_4OAc saturation method as described by Thomas (1982). Exchangeable acidity was determined by leaching with 1M KCl solution. The exchangeable acidity was determined from the extract by titration with a standard NaOH solution (Thomas, 1982). Cation exchange capacity at pH 7 (CEC-7) was determined by the NH_4OAc saturation method (Rhoades, 1982). Organic carbon was determined by the Walkley-Black dichromate wet oxidation method as described by Nelson and Sommers (1982). This was determined following the procedure described by IITA (1979) using the Bray-1 extraction method whereas Nitrogen was determined by the Kjeldahl method as described by Haluschak (2006).

2.3 Soil classification

The data generated from this study was used to classify the different soil types present in the landscape. The Keys to Soil Taxonomy (Soil Survey Staff, 2014) was used to classify the soils.

3.0 Results and Discussion

3.1 Soil physical properties

Soil colours of the study area have hues ranging from 7.5 to 10YR with values and chroma ranging from 3 to 4, and 2 to 5 respectively. Soil structures were poorly developed and single grained especially in the surface soils. Furthermore, surface soils of the study area are sandy in texture whereas subsurface soils have loamy sand to sandy loam textures. These is in contrast to finer soil textures in the subsurface reported by Ande (2010) and Eshett et al. (1990) for some basement complex soils. The pronounced coarse textures of soil of the study area could be due to increased rate of weathering occasioned by past tectonic processes as the area is located in a fault zone. Secondly, the noticeable sandy textures especially of surface soils, may be further accentuated by loss of clay due to soil-forming factors such as elluviation and erosion. This possibility was noted by Maribeng (2007) for soil derived from granite. Furthermore, Aki et al (2014) observed sandy textures in surface soils derived from biotite-hornblende-gneiss under warm humid tropical climate. The consistence of the soils was loose to very friable, non-sticky and non-plastic. This was reflected in the low bulk densities (mean: 1.30 g/ cm^3; Standard deviation: 0.27) of surface soils of the area. Similar values for bulk density was obtained by Uwingabire (2016) for soils developed over gneiss. Soil erodibility in the area is very high (> 0.04 (t.ha.h)/(MJ.mm)) as shown in Table 1. This is not unlikely due to the sandy nature of the soils (Brady and Weil, 1999).

3.2 Soil development

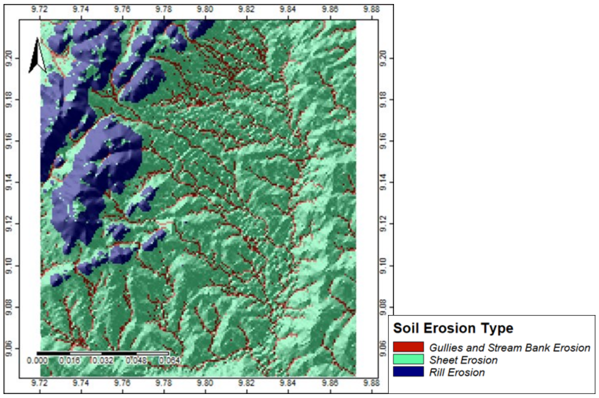
The geology of the study area is comprised of basement complex parent materials. This consist of migmatite, granite gneiss, porphyroblastic gneiss and rhyolitic rock intrussions. Slope angles are usually very steep mostly on the shoulder to backslope positions. Topography has played a significant role in modifying soil development in the area by: influencing the quantity of precipitation absorbed and retained in the soil, influencing the rate of removal of the soil by erosion; and directing movement of soil materials in suspension or solution from one area to another. Furthermore, colluvial materials are washed down by runoff to footslope positions from which further soil development has taken place.

Soil erosion ongoing in the study area ranges from sheet to gullies and stream bank erosion, as shown in Figure 1. Consequently, the influence of topography on soil depth is shown in Figure 2 with rock out crops being a major feature of the summit to backslope positions. Shallow soils occur over unconsolidated deposits at the upper foot slope position, whereas moderately deep to deep soils at occurs at the middle to lower footslope positions. The profile darkness index of Thompson and Bell (1996) was used to assess the development of the A horizon in soils of the study area. Values greater than 12 is regarded as very high while values less than 3 are regarded as very low in this study. The low organic matter contents (mean and standard deviation of 1.18 and 0.71%) reflected in the distribution of profile darkness index of soils of the area (Figure 4). PDI values were low (< 3.0) indicating poor A horizon development.

The trend in distribution of soil depth also reflected in the classification of the soils (Figure 3). Hence, Entisols were observed on crest to upper footslope, whereas Inceptisols were observed at the middle to lower footslope positions. In a study of hillslope soils derived from biotite-granite, a similar finding was made by Olowolafe and Dung (1999) who reported that Entisols were found on the crest, side slope and upper footslopes where rates of soil erosion are faster than rates of other pedogenic processes. In contrast, Carter and Ciolkosz (1991) noted that the thickness of the O, A, and E horizons was neither related to slope gradient nor aspects for sand stone derived hillslope soils. They further asserted, that this indicates that the present rate of soil formation is greater than erosion, and that the influence of erosion on steep slopes could be offset by lateral movement of through-flow water above the B-horizon.

3.3 Soil Fertility and Productivity

The productivity characteristics of the soil as shown in Figure 3 indicates that soils classified as Entisols and Inceptisols in the study have low and medium productivity indexes respectively. Similarly, Lobo et al (2005) had noted for some Alfisols that soil productivity was highest on lightly eroded soils and lowest on severely eroded soils. Furthermore, the soils have low fertility as indicated by low levels of ECEC (mean: 3.03 cmol/kg; standard deviation: 0.14), organic matter, and base saturation (Table 2). Besides, nitrogen and available phosphorus contents in the soils were low being less than 0.15% and 10 mg/kg respectively. The low fertility status of the soils could be due to higher quartz and lower of soluble cations content in the parent materials (Maribeng, 2007). The sandy nature of the soils could have encouraged more significant leaching, there by resulting in low soil fertility



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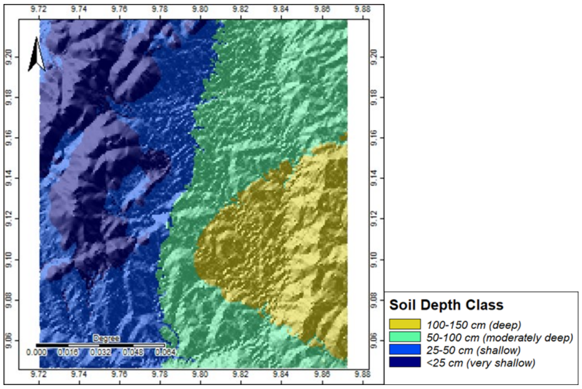

Figure 2: Distribution of soil depth in the study area

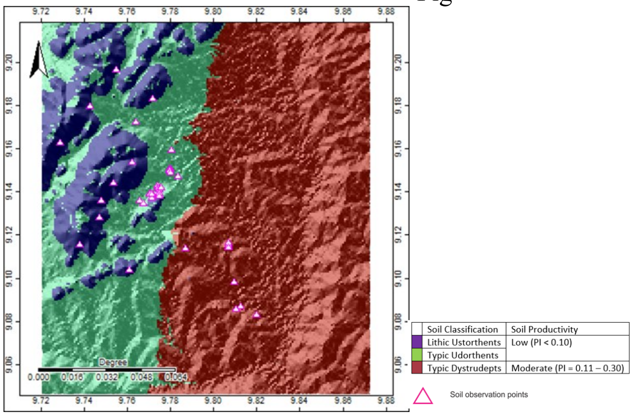

Figure 3: Soil Classification and productivity

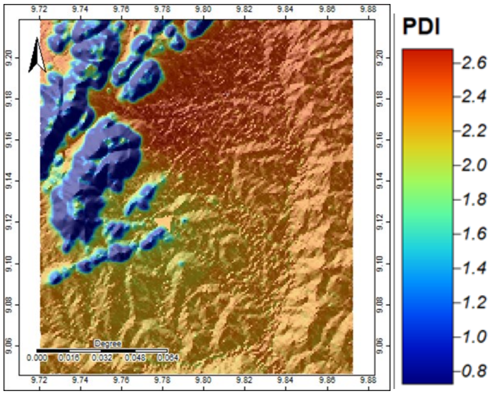

Figure 4: Profile Darkness Index (PDI)

Table 1: Soil physical properties

Profile	Horizon	Depth (cm)	Sand (%)	Silt	Clay	Texture	K factor
1	A	0 - 12	90.0	8.0	3.0	Sand	0.621
	AC	12 - 30	91.6	6.0	2.4	Sand	0.696
	C	30 - >75	90.0	5.4	4.6	Sand	0.611
2	A	0 - 15	79.2	10.8	10.0	Loamy sand	0.345
	C	15 - 65	81.0	11.0	10.0	Sandy Loam	0.342
3	A	0 - 40	69.2	26.8	4.0	Sand	0.290
	C	90 - >130	89.4	4.8	5.8	Sand	0.575
4	A	0 - 45	91.0	3.0	6.0	Sand	0.606
	C	45 - 280	78.0	5.4	16.6	sandy loam	0.266
5	A	0 - 30	92.0	5.4	2.6	sand	0.702
	C	30 - >110	89.4	8.0	2.6	sand	0.638
6	A	0 - 45	95.5	24.7	1.8	Sand	0.367
	B	45 - 55	77.0	9.0	16.0	Sandy loam	0.243
	BC	55 - 200	93.0	5.0	2.0	Sand	0.743
7	A	0 - 45	89.0	5.0	6.0	Sand	0.563
	BA	45 - 65	78.0	9.0	15.0	Sandy loam	0.260
	B1	65 - 95	79.0	7.0	14.0	Sandy loam	0.300
	BC	95 - 110	91.0	5.0	4.0	Sand	0.646
	C	110 - 250	82.0	6.0	12.0	loamy sand	0.358
8	A1	0 - 25	93.0	4.4	2.6	Sand	0.728
	A2	25 - 40	89.0	5.0	8.0	Loamy sand	0.490
	B1	40 - 80	76.0	6.0	18.0	sandy loam	0.236
	B2	80 - 110	77.0	5.0	18.0	Sandy loam	0.245
	C	110 - 200	84.0	4.0	12.0	sandy loam	0.385
9	A	0 - 30	91.0	7.0	2.0	Sand	0.690
	B1	30 - 55	81.0	10.4	8.6	sandy loam	0.385
	B2	55 - 80	78.0	4.0	18.0	Sandy loam	0.254
	B3	80 - 160	77.0	5.0	18.0	Sandy loam	0.245
	BC	160 - 200	70.0	9.2	21.8	sandy loam	0.161
10	A	0 - 22	87.6	7.0	5.8	Sand	0.530
	B	22 - 55	87.0	7.2	5.8	loamy sand	0.526
	C	55 - 210	74.0	18.4	1.6	Loamy sand	0.466

Table 2: Soil chemical properties

Profile	Horizon	Depth	pH	Organic Matter	Ca	Mg	Na	K	EA	ECEC
		(cm)		(%)	cmol/kg					
1	A	0 - 12	6.58	1.7	1.1	0.5	0.0	0.1	1.6	3.3
	AC	12 - 30	6.46	1.3	1.0	0.4	0.0	0.0	1.6	3.2
2	A	0 - 15	6.46	3.3	1.0	0.4	0.0	0.1	1.6	3.1
3	A	0 - 40	5.47	2.1	1.0	0.4	0.0	0.0	1.6	2.9
4	A	0 - 45	7.07	1.8	1.0	0.4	0.0	0.1	1.6	3.1
5	A	0 - 30	6.66	1.5	0.9	0.4	0.0	0.0	1.6	2.9
6	A	0 - 45	6.87	0.2	0.9	0.4	0.0	0.0	1.6	2.9
	B	45 - 55	7.65	0.4	1.0	0.4	0.0	0.0	1.6	3.0
	BC	55 - 200	3.08	0.2	1.0	0.4	0.0	0.1	1.6	3.2
7	A	0 - 45	6.57	0.8	1.1	0.5	0.0	0.1	1.6	3.3
	BA	45 - 65	6.46	0.9	1.0	0.5	0.0	0.1	1.6	3.2
	B1	65 - 95	8.08	1.0	1.0	0.4	0.0	0.1	1.6	3.0
	BC	95 - 110	7.15	1.0	0.9	0.3	0.0	0.1	1.6	2.9
8	A1	0 - 25	6.87	0.8	1.0	0.4	0.0	0.0	1.6	3.0
	A2	25 - 40	6.67	1.7	0.9	0.4	0.0	0.0	1.6	2.9
	B1	40 - 80	6.46	1.3	1.0	0.4	0.0	0.0	1.6	3.0
	B2	80 - 110	7.04	0.9	1.0	0.4	0.0	0.0	1.6	3.0
9	A	0 - 30	6.67	1.8	1.0	0.4	0.0	0.0	1.6	3.1
	B1	30 - 55	6.36	0.7	0.9	0.4	0.0	0.1	1.6	2.9
	B2	55 - 80	6.87	0.9	1.0	0.4	0.0	0.1	1.6	3.1
	B3	80 - 160	6.97	1.1	1.1	0.4	0.0	0.1	1.6	3.2
	BC	160 - 200	6.36	0.4	0.8	0.3	0.0	0.0	1.5	2.8
10	A	0 - 22	7.35	1.9	1.0	0.3	0.0	0.1	1.6	2.9
	B	22 - 55	6.97	0.6	0.9	0.4	0.0	0.0	1.6	2.9

4.0 Conclusion

Soils of the study area have developed through the sequence of Lithic Ustorthents, Typic Udorthents, to Typic Dystrudepts. Soils are very coarse in texture especially in the A horizon. Furthermore, soils are very friable, loose, non-sticky and non-plastic in consistency. Surface horizons are poorly developed as indicated by low organic matter content and consequently low PDI values. Soils have low fertility. Soil productivity is lowest on Entisols whereas low to medium productivity were located on Inceptisols. For a comprehensive understanding of soil development in the study area, it is imperative that future research should be carried out on the mineralogical properties of the soils. This will furnish greater insight into the type and amount of minerals that have developed over time in the soils. Furthermore, it will enable further classification of the soils to the family level of the Soil Taxonomy System and provide greater information into management requirement of the soils.

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