ASSESSMENT OF SOIL WASH AND SOIL ERODIBILITY INDICES ON MINIATURE BADLANDS AT GADA BIYU, ABUJA, FEDERAL CAPITAL TERRITORY, NIGERIA

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Abstract

Gada Biyu is located within the *Federal Capital Territory of Nigeria. The Federal Capital Territory is located between latitudes 8° 25´and 9° 25´ North of the Equator and longitudes 6° 45´ and 7°45´ East of Greenwich Meridian in the savanna region with Aw type of climate. The study site at Gada Biyu is located within the following coordinates: point A1 at 8°36' N, 6°54' E, point A8 at 8°36' N, 6°54' E, point E1 at 8° 36'N, 6°54' E and point E12 at 8° 36'N, 6° 54'E. Erosion pins and a soil auger were used during the 2010 rainy season to obtain data for assessment of soil wash and soil physical properties. Soil textural grades and organic matter content were determined in the laboratory by the hydrometer and Walkely-Black methods respectively. Rates of ground lowering were computed from exposed parts of the pins installed in the field after the 2010 rainy season, while erodibility indices were determined from textural grades and soil organic matter. Results of soil wash show a mean ground lowering of 17.32mm/yr over a mean slope of 27° at Gada Biyu Badlands implying a great loss of soil in the study site. Soil erodibility indices show mean values of 2.29% for critical level of soil organic matter content, 2.26 for clay ratio, 2.10 for modified clay ratio and 78.79% for dispersion ratio. These results imply that there was a great loss of soil structure and high susceptibility of the soils to erosion during a single rainy season. These findings suggest that the soils of the study site and those of the Federal Capital Territory in general are undergoing rapid degradation. Thus, it is recommended among other things, that the authority of the Federal Capital Territory should checkmate and control indiscriminate grazing, poor farming practices and construction activities on potential sites and areas already known to be susceptible to erosion, in an attempt to forestall rapid ground lowering and the future occurrence of badlands within the Federal Capital Territory and its environs.*

Key words: *Badlands, Soil Degradation, Soil erodibility, Soil Particle Size, Soil structure, Soil wash*

Introduction

The clearing of vegetation cover especially due to human activities can set in motion certain negative geomorphic processes such as accelerated soil erosion, increase siltation of rivers, and flood among other land degrading processes. For example, Meginnis (1935), Ologe and Leow (1982), Mallo (1988, 1999, 2010), have demonstrated that there is a strong relationship between erosion rates and the density of vegetation cover. Similary, the findings of Campbell (1970a and b), Way (1973), McKnight (1990), Clarke and Rendell (2003) and Mallo (2007), have buttressed the fact that concentrated runoff consequent to rainstorms of high intensity and short duration on devegetated surfaces can exacerbate soil erosion and consequent evolution of badlands. Badlands are semi arid severely eroded landscapes where a maze of gullies, ravines, valleys and saw tooth ridges dissect a devegetated land surface as typified of Gada Biyu badlands under study.

In the Federal Capital Territory (FCT) of Nigeria, the vegetated areas are severely being destroyed and replaced by built up areas. Not only is the natural environment of the FCT changed to built-up areas, but some of the areas have been transformed into bare surfaces caused by excavation of soil and related earth moving activity during construction of roads, buildings, and other structures. Some of the affected sites were used for moulding mud bricks and burnt bricks. Such areas were hitherto covered by vegetation but are now bereft of vegetal cover, while some have been badly damaged by severe gullying. As earlier observed, such land uses and

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land cover change can trigger eco-geomorphic processes such as erosion (Clarke and Rendell, 2004).

Evidence of intense human activities such as deforestation (Mallo and Ochai, 2009) and construction among others, abound throughout the territory's landscape in the form of bare surfaces and miniature badlands. In many parts of the FCT, soil erosion on bare surfaces of excavated land, abandoned quarries and construction sites and over cultivated farmlands is already a menace. Where surface disturbance has occurred, information about present and possible future erosion rates provide a basis for planning and checking the adverse effects of accelerated soil erosion. For example, measurement of erosion resulting from agricultural disturbance poses a challenge for developing a technology that can minimise loss of topsoil and maximise crop productivity over extended periods (www.cartage.org.lb/, 2011; www.gcrio.org, 2011).

Badlands offer a near ideal opportunity for study of processes and rates of weathering and erosion and the associated patterns of change in surface morphology (Campbell, 1982; Loughran, 1989; McKenna, 2002; Clarke and Rendell, 2006). Hitherto, information on land use and land cover change in the FCT is partly available like in the work of Ejaro (2009), but the environmental impact of this on the eco-geomorphic processes that have been triggered have not been investigated. This work therefore, is a pioneer study in an attempt to quantify rates of erosion on bare surfaces, and miniature badlands within the FCT of Nigeria that has resulted due to destruction of the vegetation cover. The results obtained will provide a clue on both present and possible future erosion rates in the FCT since such studies have never been conducted in the area in question.

The aim of the work therefore, is to provide baseline data and information for experts and the government, to enable them check the adverse effects of accelerated soil erosion that is currently threatening the geological norm of the land surface of the FCT. The incessant disturbance of the land surface is as a result of influx of people from all over the country to the new Federal Capital City where most Nigerians believe offers better job opportunities.

Deascription of Study Area

Brief History

The FCT of Nigeria was created on 3rd February 1976 through the promulgated Federal Capital Territory decree No. 6, 1976. The decision was taken due to the growing unsuitability of Lagos as Nigeria's Federal Capital City as result of the problem of peripheral location, dual and conflicting role as both federal and state capital, acute shortage of land for further expansion, and inadequacies for further infrastructural development among other reasons, right from the late 1960s (Okechukwu, 1974; Obateru, 1987)

Location

Lying between latitudes 8° 25´and 9° 25´ north of the Equator and longitudes 6° 45´ and 7°45´ east of Greenwich Meridian, Abuja the FCT is geographically located in the centre of the country with a landmass of approximately 8000 km² of which the actual city that is, the Federal Capital City(FCC) occupies 250 km^2.

Gadabiyu badlands is a landscape intricately rilled and barren, characterized by a multiplicity of short, steep slopes underlain by horizontal strata of shale and clay formation that are poorly consolidated when exposed to overland flow after occasional rains. Innumerable tiny rills develop over the surface which rapidly evolves into ravines and gullies that severely dissect the land. A maze of short but very steep slopes are etched in filigree of rills, gullies and gorges with a great many ridges, ledges and many other erosion remnants scattered throughout the study area.

Geology

The underlying rocks of the FCT consist basically of Basement Complex and sedimentary rocks. The Basement Complex rocks made up of igneous and metamorphic rocks cover about 48 % of the total area and in some places the land is occupied by hills and dissected terrain (Mabogunje, 1977). The rocks consist mainly of schists, gneiss and older granite. The mountain ranges together with some isolated inselbergs are believed to have been poured out of volcanoes within the Tertiary period. The areas underlain by the sedimentary rocks cover about 52 % of the total area of the Federal Capital Territory and largely constitute the undulating plains. These plains form present day remnants of erosional processes of the Quaternary period (Figure 1). Towards the south west of the Federal Capital

Territory there exist sand ridges with outliers of sandstone capings. Sandstone and clay also occur in significant proportions of parts of Abaji and Kwali Area Councils. These areas are easily dissected and indeed exhibit very glaring evidences of severe gully erosion (Balogun, 2001). Okechukwu (1974) and Kogbe (1978) also described the geology of the Federal Capital Territory as almost predominantly underlain by high grade metamorphic and igneous rocks of Precambrian age. These rocks consist of gneiss, migmatites and granites and schist belt outcrops along the eastern margin of the area. The belt broadens southwards and attains a maximum development to the south-eastern sector of the area where the topography is rugged and the relief is high. In general, the rocks in the FCT are highly sheared (Figure 1).

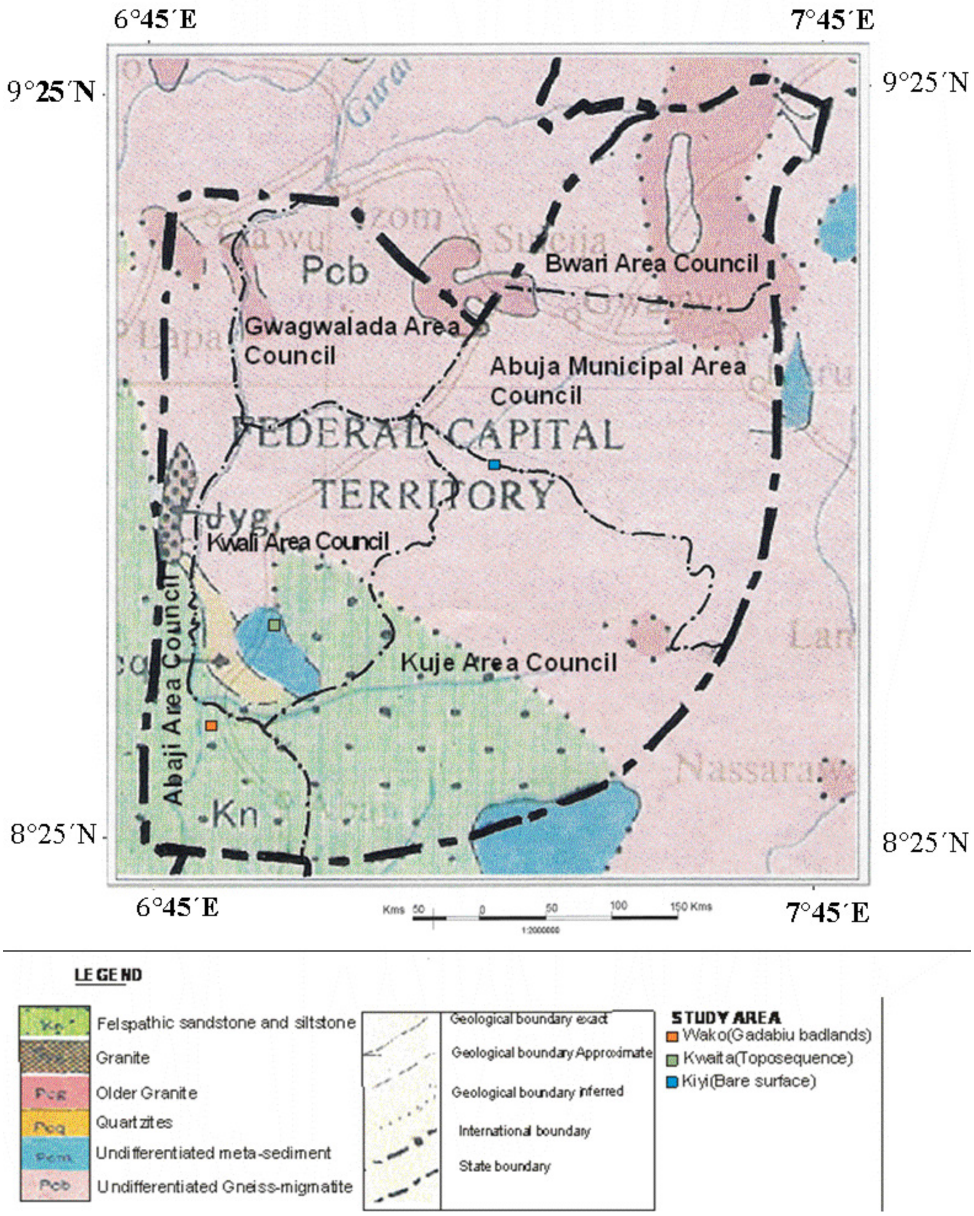

Figure 1 The Geology of Abuja, the Federal Capital Territory of Nigeria.
Source: Geological Map of Nigeria (1984)

Soils, Climate and vegetation

On the aforementioned rock types, Zonal Tropical Ferruginous soils have developed through the process of laterisation. The FCT experiences Aw or Tropical Continental climate according to Trewartha's modification of Koppen's climatic classification (Money, 1976). The Aw climate is characterised by six months dry season from November to April and six months rainy season from May to October. The vegetation is southern Guinea Savanna biome characterised by deciduous trees scattered among grasses. However, some of the areas are forested because they have not suffered much devegetation while some of the forests fringe the streams which are relatively wet all over the year.

Methodology

Samples Collection

At Gada Biyu badlands, transects were chosen and points along them were named as A, B, C and D from one slope point to another from the crest through the middle to the basal slope positions. In situ soil samples were collected randomly along the transects with a soil auger. The soil samples were then stored in polyethylene bags, labelled and transported to the laboratory for analysis.

Laboratory Analysis

The samples were air dried and passed through a 2 mm sieve mesh and prepared for analysis of particle size, organic carbon and organic matter, using Standard Analytical Procedures (Jou, 1983), in the following procedure. Organic carbon was estimated by wet digestion method after Walkley and Black (1934), and the values obtained were multiplied by 1.729 to derive the percentage organic matter value. Analysis of soil particle size distribution was carried out using Bouyoucos (1951), hydrometer method.

Measurement of Soil Wash

Erosion pins were used to measure rate of wash as it is the conventional technique for studying erosion on badlands. Erosion pins after Haigh (1979), Tatah (1984) and Nyanganji (1986), were used to record rates of ground lowering during the 2010 rainy season. The erosion pins were made of iron nails of 15.24 cm (6 inches) length and were inserted on the crest, middle, and base slope positions on randomly selected slope profiles of the badlands. The top 3.00 cm lengths of the pins were painted and deliberately exposed at the insertion period to allow easy visibility of the pins on the land surface (Schumm, 1956). Exposed parts of the pins were painted so that the lengths of the exposed unpainted part of the pins after the rainy season indicated the amount of soil loss. The measurement of ground lowering at a point started from the end of the painted 3 cm top portion of the nail downwards. Small erosion pins(nails) of about 5 mm in diameter were preferable since thicker stakes could interfere by causing scour, stoppages of soil particles and related materials that were conveyed by surface runoff hence exaggerating the amount of soil wash and deposition around the pins. Erosion pins were installed in March/April at the onset of the rains and left in the field till the end of the rainy season in October/November 2010, when the readings were taken to compute mean rates of erosion. The rate of ground lowering was obtained by averaging the lengths of the exposed unpainted parts of the pins measured from each pin location.

Computation of Soil Erodibility Indices

The susceptibility of soil to erosion was quantified partly by computing the erodibility indices of the soils. The effect soil physical properties should always be evaluated more precisely to determine the erodibility of soil which depends on the mechanical composition of soil such as sand, silt and clay (Bouyoucus, 1935). Erosion indices viz clay ratio(CR), modified clay ratio(MCR), critical level of soil organic matter concentration(S_t) and dispersion ratio(DR) were calculated using the following formulae:

Clay Ratio (CR) $= \frac{\%Sand + \%Silt}{\%Clay}$ as proposed by Bouyoucus (1951)....Equation 1

Modified Clay Ratio (MCR) $= \frac{\%Sand + \%Silt}{\%Clay}$ as proposed by Mukhi (1988)...Equation 2

Critical Level Of Soil Organic Matter (S_t) $= \frac{SOM}{Clay + Silt Content}$ as proposed by Pieri (1991)....Equation 3

According to Pieri (1991), when the value of the critical level of soil organic matter concentration (S_t) is equal to or less than 5% (i.e. $S_t \leq 5\%$), then there is loss of soil structure and high susceptibility to erosion, but when it is within 5% to 7%, the structure of soils are unstable and face the risk of soil degradation. Furthermore, the value of $S_t \geq 9\%$ implies stable structure of the soils.

$$\text{Dispersion Ratio (DR)} = \frac{(\%Silt+\%Clay)\ in\ undispersed\ soil}{(\%Silt+\%Clay) in\ dispersed\ soil}$$

as proposed by Middleton (1930).....Equation 4

According to Middleton (1930), when the DR value is above 15% the soils are erodible, but when it is below 15% the soils are not readily susceptible to erosion.

Results AND Discussion

Soil Erodibility Indices

Certain soil erodibility indices namely critical level of soil organic matter content, clay ratio, modified clay ratio and dispersion ratio were used to assess the degree of susceptibility of soils of the study area to erosion as previously discussed; the results are presented in the following subsections.

Critical Level of Soil Organic Matter

The critical levels of soil organic matter concentration (S_t) are presented in Table 1. The mean values of S_t on the crest, middle, and basal slope positions at Gada Biyu are 2.22%, 2.31%, and 2.37% with coefficients of variation (CV) of 18.96%, 29.94% and 21.99 % respectively.

Table 1 Soil Erosion Indices Recorded at the Gada Biyu Badlands

	Gada Biyu Badlands Slope positions									Mean For the three positions		
	Crest slope			Middle slope			Basal slope			Mean		
	Mean	CV	δ	Mean	CV	δ	Mean	CV	δ	Mean	CV	δ
%St	2.22	18.96	0.42	2.31	29.94	0.69	2.37	21.99	0.52	2.29	23.25	0.53
CR	2.14	23.30	0.50	2.13	27.46	0.59	2.25	18.64	0.42	2.17	22.93	0.50
MCR	2.08	22.88	0.48	2.07	27.10	0.56	2.18	18.23	0.40	2.10	22.55	0.47
DR	77.59	65.70	50.98	75.12	62.69	47.10	76.99	48.79	37.56	78.79	68.15	53.69

An overall mean critical level of soil organic matter concentration (S_t) index recorded at Gada Biyu badlands is 2.29% with a standard deviation of 0.53% and coefficient of variation of 23.25%. This result shows that there is great loss of soil structure and high susceptibility of the soil to erosion , since according to Pieri (1991), when the value of the critical level of soil organic matter concentration (S_t) is equal to or less than 5% (i.e. $S_{\leq}5\%$), there is loss of soil structure and high susceptibility to erosion.

Clay Ratio

The mean values of CR for the crest, middle, and basal slope positions are 2.14, 2.13 and 2.25 with standard deviations of 0.50, 0.59, and 0.42 and coefficients of variation of 23.30%, 27.46%, and 18.64 % respectively (Table 1). The overall mean value of CR for the study area is 2.17. Decrease of CR in the soil content from crest through the middle to the base slopes reflects an increase in resistance of the soil to erosion toward the valley floors (Tarafdar and Ray, 2005). However, a careful look at the results show that the differences in the values CR are not significantly different at the 0.05 level on the three slope positions implying that the soil structure is almost uniform on the slopes.

Modified Clay Ratio

The results in Table 1 reveal that the MCR index of soil erosion has a mean of 2.10, and coefficient of variation of 22.55%. At Gada Biyu badlands crest, middle, and basal slope positions, MCR index have mean values of 2.08, 2.07, and 2.18 with coefficients of variation of 22.88%, 27.10% and 18.23 % respectively. A mean MCR value of 2.10 for Gadabiyu is close to the clay ratio value of 2.17 suggesting that organic matter content of the soil is low and could not assist the soils in resisting erosion by binding the soil aggregates together. The small variation between the mean values of MCR and CR could be attributed to the presence of organic matter incorporated in the MCR formula. Erosion rates recorded in the study site is still high despite the organic matter content, because the quantity of the later is very small. Higher organic matter content could have remedied the problem of high soil entrainment. According to Mukhi (1988) and Tarafdar and Ray (2005) the results of correlations among soil properties revealed that modified clay ratio could be a better index of soil erodibility than clay ratio, particularly in soils having high content of organic matter.

Dispersion Ratio

Table 1 shows that the mean values of DR are 77.59%, 75.12% and 76.99% with coefficients of variation of 65.70%, 62.69%, and 48.79 % at the crest, middle, and basal slope positions respectively. A DR mean value of 78.79% was recorded at the Gada Biyu badlands implying that the soils are highly erodible. When the DR value is above 15% the soils are erodible, but when it is below 15% the soils are not readily susceptible to erosion (Middleton, 1930). Mukhi (1988) among others relied on the DR for understanding soil susceptibility to erosion.

Rates of Soil Wash

At Gada Biyu Badlands a mean soil wash value of 17.32mm/yr was recorded (Table 2). This rate of soil entrainment per rainy season is high and can be attributed to the low values of clay ratio, modified clay ratio and dispersion ratio recorded in the study as already discussed above. All things being equal, that is, the landscape, vegetation and climate being constant, the mean ground lowering at Gada Biyu Badlands will be 173.2 mm (17.32cm) in ten years, 1732 mm (173.2 cm) in a hundred years or 17,320 mm (1,732cm) or 17.32metres in a thousand years.

The high rate of ground lowering implies that there is a great loss of soil on which the farmers depend upon for crop cultivation and hence a threat to the sustainability of agriculture and food security. The mean rate of ground lowering of 17.2 mm yr^{-1} recorded at Gada Biyu which is located in the Southern Guinea Savanna of Nigeria is lower than the result recorded by Tatah (1984) in Yola and Gusau which are located in the Northen Guinea Savanna. Tatah (1984) recorded a rate of soil wash of 33mm/yr and 28mm/yr for the badlands of Yola and Gusau respectively.

The lower rate of ground lowering recorded in the FCT compared to the works of Tatah (1984) can be attributed to denser vegetal cover in the Southern Guinea Savanna than the Northern Guinea Savanna bioclimatic zone. For the same reason the result is also lower than that of Leow *et al.* (1982a) under Northern Guinea savanna climate in Zaria, Northern Nigeria. The works of Leow *et al.* (1982a), Tatah (1984), Nyaganji (1986) and Mallo (1988) all agreed to the aforementioned trend. It can be deducted from these findings that in the savanna environment, rates of soil wash decrease from the Sudan savanna bioclimatic zone down to the Guinea savannna bioclimatic zone. This increase in rates of soil entrainment from the Guinea Savanna to the Sudan Savanna bioclimatic zone can also be attributed to the decrease in rainfall amount and consequent decrease in the density of vegetation cover which greatly determine rates of soil wash in these bioclimatic zones.

Table 2 Rate of Soil Wash Monitored through Erosion pins at Gada Biyu Badlands

Location	Transects	Slope length(m)	Slope degree (°)	Wash ($mmyr^{-1}$)
Gada Biyu Badlands	Transect A	6.4	50°	28
		1.99	27°	14
		2.00	20°	10
	Transect B	4.30	17.5°	16
		1.69	25°	17
		1.6	11°	8
		3.37	30°	20
		1.05	35°	25
	Transect C	2.63	47°	28
		2.4	35°	25
		1.8	25°	17
		1.26	12°	10
		1.21	16.5°	12
		1.37	34°	24
	Transect D	4.50	45°	26
		2.0	17°	10
		1.42	11°	7
		1.50	25°	12
		1.80	35°	20
	Mean	2.33	27.26	17.32
	Standard deviation	1.39	12.02	7.09

Conclusion

Erosion, an eco-geomorphic process has been triggered on the study site due to negative change in land use and land cover or management practices. Results of soil wash by erosion pins and erodibility indices or erosion indices on the site leads to the conclusion that the farmlands of the FCT are actually undergoing rapid degradation. For example the critical level of soil organic matter concentration index has shown that soils of the study sites have lost soil structure and are highly susceptible to erosion.

Recommendations

i. Evolution of badlands should stimulate serious concern about the environment in general and instigate a planned ecological intervention on the landscape. Anthropogenic activities responsible for exacerbating geomorpological processes should be banned in areas so degraded. The authorities concerned should check and control indiscriminate grazing, farming and construction activities on potential sites and those already known to be susceptible to erosion**.**

ii. The information in the present study about present and possible future erosion rates should be used as a basis for reducing the adverse effects of accelerated soil erosion and providing the means for developing measures to minimise the loss of topsoil as well as encourage good farming practices.

iii. For the purpose of remediation and rehabilitation of the sites, organic matter should be resurrected in the study area by re-vegetating the affected areas and by encouraging the use of organic manure. This will gradually supply organic matter content needed to bind soil aggregates and create good soil structure that can no longer be easily susceptible to erosion.

iv. Geomorphologist should begin to take advantage of the 'near ideal opportunity' offered by these bare surfaces and miniature badlands for the study of processes, rates of weathering and erosion, and the associated patterns of change in surface morphology of Nigeria's FCT and its environs.

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