Journal of Innovative Agriculture: 9(2) : 12-20, 2022
DOI: 10.37446/jinagri/rsa/9.2.2022.12-20
Research paper

Characterization of the morphological, physical and chemical properties of gully eroded soils

Nwosu Tochukwu Victor*, Anene Basil, Ezeobi Mmesoma, Madueke Chike

Department of Soil Science and Land Resources Management, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.

Received: 12 May 2022
Accepted: 13 June 2022
Published: 30 June 2022

***Correspondence**
Nwosu Tochukwu Victor
tv.nwosu@unizik.edu.ng

Characterization of the nature and properties of soils is fundamental to effective land use planning, land allocation and land management. A study was conducted in a gully eroded site at Ugwuoba, in Enugu State-Southeast, Nigeria. The study area runs on a toposequence of about 195m in length and was divided into three units of upslope, midslope and downslope for ease of study. A soil profile was dug 15m away from the upslope to serve as the control. Prior to soil sample collection, the horizons were first delineated. Soil samples were then collected from the soil profile, starting from the bottom horizon. Before soil sample collection from the upslope, midslope and downslope sections of the gully, the gully walls were first cleaned by scraping off the exposed surface to expose the undisturbed underlying layer. The horizons were then delineated and soil samples collected, starting from the bottom horizon. Collected soil samples were analyzed for selected soil properties; data obtained were subjected to statistical analysis and treatment means were separated using Duncan's post hoc test at 5% probability level. The results obtained showed a colour differentiation that ranged from dark brown, dark yellowish brown, yellow red to dark red with a crumby structure. The textural class of the studied area was predominantly sandy loam. Soil pH was generally acidic. The control, upslope, midslope and downslope had average available phosphorus concentration of 19.48 mg/kg, 18.92 mg/kg, 22.03 mg/kg and 22.08 mg/kg respectively. Average Total Nitrogen concentrations of 1.28%, 0.09%, 0.09%, and 0.11%, were obtained respectively at the control, upslope, midslope and downslope. Soil organic carbon ranged from 0.72%-1.42% at the upslope, 0.78%-1.63% at the midslope and 0.96%-1.17% at the downslope. Effective cation exchange capacity (ECEC) of the studied area ranged from 5.95 cmol/kg to 10.02 cmol/kg. Calcium concentration ranged from 3.00 cmol/kg to 4.40 cmol/kg at the control, 2.80 cmol/kg-4.40 cmol/kg at the upslope, 2.80 cmol/kg to 4.00 cmol/kg at the midslope, 3.60 cmol/kg to 5.20 cmol/kg at the downslope. Potassium concentration ranged from 0.08 cmol/kg to 0.14 cmol/kg. Magnesium concentration ranged from 1.20 cmol/kg to 3.20 cmol/kg, Sodium concentration ranged from 0.10 to 0.21. Exchangeable soil acidity of the studied area ranged from 0.80 cmol/kg to 1.60 cmol/kg. Soils of the studied area are classified as Typic Udipsamments and Arenosols according to USDA soil taxonomic system and World

Reference Base respectively. The soils can support perennial crops when left under natural vegetation.

Key words: *arenosols, gully, land use, toposequence, typic udipsamments, Ugwuoba*

INTRODUCTION

Soil erosion is a natural process whose impacts are felt across all landforms (Ritter, 2012). Dunjó et al*.* (2018) reported that erosion sorts the soil by removing a major proportions of the clay and humus, leaving behind the unproductive coarser fractions like coarse sand, gravel, and stones. This ultimately impairs the quality and productivity of the residual topsoil. The loss of this organic matter and clay degrades the soil, resulting in changes in the structure, texture, plant nutrient dynamics and biological diversity and sustainability of the soil. This further aggravates the prevailing situation, by making the soil even more susceptible to erosion and other forms of land degradation. Indeed, erosion alters the physical, chemical, and biological properties of the soil by degrading its aggregate stability and nutrient availability (Abdullahi, 2018).
Soil erosion by water can be differentiated into sheet, rill, and gully erosion. The most problematic type of erosion in southeastern Nigeria is gully erosion. Gully erosion is a product of concentrated overland flow of runoff in channels which progressively become larger and deeper until they become extensive enough to disrupt tillage operations in a farm (Gilley, 2005). Obalum et al*.* (2012) reported that the size, shape, slope length and slope gradient of the catchment area plays a crucial role in affecting the infiltration rate, which in turns affect the runoff rate and volume. Gully erosion and soil degradation are linked as they interact through a series of feedback loops. Soil degradation leads to soil erosion while gully erosion drastically reduces the form, quality and productive capacity of the soil (Wen et al., 2013). Gully erosion is one of the greatest environmental disasters in Southeastern Nigeria where more than 1,000 gully sites are currently in existence (Abegunde et al., 2006). In the region, large proportion of the agricultural lands have been lost or rendered unproductive, ancestral lands have been washed away, homes and properties destroyed and human life lost (Abegunde et al., 2006; Adelaku et al., 2007; Ezezika and Adetona, 2011; Obiadi et al., 2011; Igwe, 2012; Madueke et al., 2021a). The situation has become so critical that the World Bank (1990) put the annual cost of gully erosion in the region at one hundred million dollars ($100,000,000.00). According to Obidimma and Olorunfemi (2011), the preponderance of gully erosion in Southeastern Nigeria may be attributed to the inherent geotectonic, geologic, and geo-hydrologic characteristics of the area. Other factors include unplanned sand mining and urbanization, shortened fallow length/continuous cropping, inadequate biomass turnover, cultivation along slopes, numerous (compacted) footpaths, etc. (Osuji et al., 2002; Madueke et al., 2021b). These issues are exacerbated by the very high rainfall amount and intensity in the region necessitating effective land evaluation, land use planning and land allocation. Therefore, the characterization of the nature and properties of soils is a fundamental requirement for sustainable land use planning. Unfortunately, the most up-to-date data on the soils of Nigeria (Federal Department of Agricultural Land Resources, 1985) is very inadequate for effective land use planning and soil management (Fagbami and Ogunkunle, 2000; Esu, 2004; Madueke et al., 2021a). This necessitates the characterization of the degraded soils of Agugwu community in Ugwuoba, Oji-river LGA of Enugu as a necessary first step towards effective management been one of such gully sites where soil data is inadequate for sustainable soil management.

MATERIALS AND METHODS

Study areas

A farm land of about six hectares, located at Ugwuoba, Oji-river Local Government Area, Enugu State, Nigeria, was used for the study. The land has been under a serious gully erosion that runs across a toposequence; and it lies within latitude 6^{0}15” to 6.25” N and longitude 7^{0}14” to 7^{0}23” E.

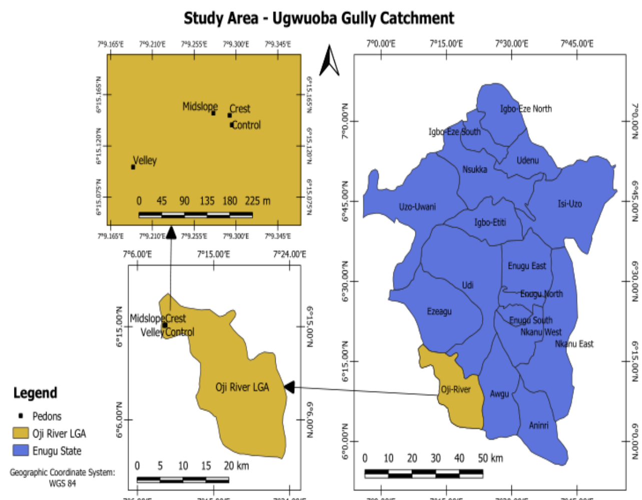

Figure 1. Map showing the studied area

The location of the study area is shown in Figure 1. Oji River has an annual rainfall of about 1800 mm and an average annual temperature of 27.1℃. The average annual relative humidity of the area is 66%. The hottest months are between January and March while the coolest months are between July and September and moderate in the month of November. The vegetation of the area is derived savanna and is made up of some species of plants and food crops like oil palm (*Elaeis guineensis*), oil been tree (*Peathelethra macrophylla*), cassava (*Manihot esculenta*), Bamboo (*Phyllostachys aureosillcota*), yam (*Dioscorea spp.*) stubborn grass (*Sida acuta*) etc. as physically observed. Agriculture is the major occupation in the study area as most of the inhabitants are farmers. The major food crops produced in this area are; yam, maize, oil palm, vegetables, cassava and cocoyam.

Figure 2. A photograph of the gully site

Field study/soil sampling

A reconnaissance survey was conducted prior to soil sampling and this was to ascertain some morphological features of the study area. The site is about 130m away from the Ezu River, running on a toposequence of about 195m in length. Figure 2 shows a photograph of the gully site. The area was divided into three units of upslope, midslope and downslope. Before soil sample collection from the upslope, midslope and downslope sections of the gully, the gully walls were first cleaned by scraping off the exposed surface to view the undisturbed underlying layer. The horizons were then delineated and described using the method described by FAO (2006). Soil samples were then collected from the gully face, starting from the bottom horizon. A soil profile was also dug 15m away from the upslope to serve as the control site. The horizons were also delineated and described, and soil samples taken for laboratory analysis.

Laboratory analysis

The soil samples were air-dried under room temperature, crushed with a wooden roller and passed through a 2mm mesh sieve. They were then subjected to the following routine laboratory analysis.

Particle size distribution (mechanical analysis)

Particle size distribution was determined by calgon dispersion using Bouyocous Hydrometer method as modified by Gee and Or (2002).

Soil reaction (pH): Soil reaction was determined by glass electrode pH meter method in 1:2.5 soil water ratio as reported by Handershot *et al.* (1993).

Organic carbon: Organic carbon was determined by chromic acid oxidation method of Walkley and Black modified by Nelson & Sommers (1982).

Total nitrogen: Total nitrogen was determined by the semi-micro Kjeldahl distillation method of Bremner & Mulvaney (1982).

Available phosphorous: Available phosphorous was determined by Bray II Extraction and Spectrophotometer method of Bray and Kurtz (1945).

Exchangeable bases: Ca^{2+}, Mg^{2+}, K^+, Na^+ were extracted by 1 Normal Ammonium acetate (1N NH_4AOC) saturation method. Ca^{2+} and Mg^{2+} were determined by the EDTA complexometric titration method while K^+ and Na^+ were determined by the flame photometric method (Jackson, 1962).

The exchangeable acidity: H^+ and Al^{3+} were determined by 1 Normal potassium chloride (1N KCl) extraction method and titrated with 0.05N sodium hydroxide (0.05N NaOH) (Mclean, 1982).

Statistical analysis

Data collected from the laboratory were subjected to analysis of variance (ANOVA). Duncan's post hoc test was used to separate the treatment means at 5% probability level.

Soil classification

The soils were classified using the USDA Soil Taxonomy (Soil Survey Staff, 2014) and the World Reference Base (WRB) for Soil Resources (IUSS Working Group WRB, 2015). The land use recommendations were then made with respect to these classifications and the physico-chemical properties of the soils.

RESULTS AND DISCUSSION

Morphological features/properties of soils of the study area

The study area is located in an undulating terrain with slope generally above 2%. It is underlain by the Imo Shale Group and weathered Coastal Plain Sands. Active gully erosion currently exists on the site (Figure 2). The soils of the study area have colour differentiation that range from dark brown, dark yellowish brown, yellowish red to dark red. The topsoil generally has a loose crumb structure. The upper soil surface at the upslope had a dark yellowish brown colour (10YR ¾) while at the midslope and valley bottom it was dark brown (7.5YR $^3/_2$). Dark reddish colour as observed at the subsoil of midslope and downslope could be attributed to the presence of sesquioxides as reported by Nnabuihe et al. (2022). Soil consistency ranged from non-sticky to very friable when moist; the boundaries of the horizons were wavy, smooth, irregular and regular. Table 1 details the morphological properties of soils of the study area.

Physical soil properties

Particle Size Distribution: The results of particle size distribution of soils in the studied area are shown in Table 2. The upslope had a mean sand, silt, and clay contents of

Table 1. Morphological features of the site at different depths

Location	Horizon	Depth (cm)	Texture	Moist colour	Consistence	Structure	Horizon boundary
CONTROL	A	0-22	S	db (7.5YR ¾)	np, ns	Lc	W
	AB	22-53	S	db (7.5 YR ¾)	np, ns, l, f	Lc	W
	AB	53-143	S	yr (5 YR $^{4}/_{6}$)	fr, ns, np	Lc	S
	B	143-200	S	yr (5YR $^{5}/_{6}$)	fr, ns, np	Lc	S
UPSLOPE	Ap	0-25	S	dyb (10YR ¾)	fr, ns, np,	Lc	IR
	A	25-45	LS	dyb (10YR ¾)	ns, np	L	W
	AB	45-72	S	db (7.5YR ¾)	fr, ns, np	L	S
	B	72-110	LS	drb (5YR ¾)	fr, ns, np	L	S
	B_1	110-200	LS	drb (5YR ¾)	ns, np	L	S
MIDSLOPE							
	Ap	0-10	LS	db (7.5YR $^{3}/_{2}$)	vfr, ns, np	Lc	IR
	Ap	10-28	LS	db (7.5YR $^{3}/_{2}$)	vfr, ns, np	Lc	W
	AB	28-50	LS	db (7.5YR $^{3}/_{2}$)	fr, ns, np	L	R
	B	50-102	S	dr (5YR ¾)	fr, ns, np	L	S
	B_2	102-200	LS	dr (2.5YR $^{3}/_{6}$)	fr, ns, np	L	S
DOWNSLOPE							
	Ap	0-15	LS	db (7.5YR $^{3}/_{2}$)	vfr, ns, np	Lc	IR
	Ap	15-32	LS	db (7.5YR $^{3}/_{2}$)	vfr, ns, np	Lc	W
	AB	32-53	LS	db (7.5YR $^{3}/_{2}$)	fr, ns, np	L	R
	B	53-102	S	dr (5YR ¾)	fr, ns, np	L	S
	B_2	102-200	LS	dr (2.5YR $^{3}/_{6}$)	fr, ns, np	L	S

Key: (i)S= sandy (ii)LS= loam sand (iii) db= dark brown (iv) yr= yellowish red (v)dyb= dark yellowish brown (vi)) drb= dark reddish brown (vii) dr= dark red (viii) fr= friable (ix) ns= non-sticky(x) np= non-plastic (xi) vfr= very friable(xii)l= loose(xiii)lc= loose crumbs, (xiv)S= smooth, (xv)R= regular (xvi)IR= irregular (xvii)W= wavy.

87.10%, 4.00%, and 86.00% respectively; the midslope had 88.70% of sand, 6.70% of silt, and 4.60% of clay; while the downslope had 92.20% of sand, 3.85% of silt and 3.95% of clay. The upper soil surface at midslope and downslope had more of sand content when compared with upslope and the control. As generally observed, sand content was more at the downslope when compared to upslope and midslope and could be attributed to the deposition process that occurred. Soils at the upslope, midslope, and control belong to the textural class of sandy loam while the soil at the downslope was more of sandy. Textural classes are relatively permanent and it represents the inherent soil properties that characterize the soil physical composition. Similar results were reported by Madueke et al*.* (2021a) for soils formed from the coastal plain sands of the humid tropics.

Chemical properties of soils of the studied area

The chemical properties in the soils of the studied area are shown in Table 3. The pH of soil at the upslope ranged from 5.00-5.50, 4.80-5.19 at the midslope and 4.86-5.10 at the downslope. Generally, the soil were found to be acidic, as also reported by Madueke et al*.* (2021a) for soils underlain by the coastal plain sands in the tropical rainforest belt of southeastern Nigeria. This could be attributed to the effect of the parent material (coastal plain sands) as reported by Nwosu et al*.* (2020), as well as the very high annual rainfall recorded in the region. The intense rainfall facilitates extensive leaching of basic cations, leaving behind an impoverished soil predominated by acidic cations (Onweremadu, 2007; Chikezie et al*.*, 2010).

The mean available phosphorus contents were 22.08 mg/kg, 19.48 mg/kg, 18.92 mg/kg and 22.03 mg/kg respectively at the control, upslope, midslope and downslope. The control and downslope had more of available phosphorus content than the upslope and midslope. This may be attributed to the fact that the control was not eroded, whereas, the downslope received the available phosphorus within the sediments eroded from the upslope and the midslope. As such, the higher available phosphorus content at the downslope could be the outcome of deposition process. The difference was however, not statistically significant.

The mean Total Nitrogen content at the control was 1.28%, while the upslope, midslope and downslope had mean Total Nitrogen contents of 0.09%, 0.09% and 0.11% respectively. At the Upslope, Total Nitrogen in the soil ranged from 0.06%-0.11% while at the midslope, downslope and control it ranged from 0.06%-0.14%, 0.10%-0.13%, 0.07-3.08% respectively. Total Nitrogen content of soils at the upslope, midslope and downslope was low when compared to the control. The relatively low Total Nitrogen content in the gullied sites is an indication that soil erosion has a major impact on the nitrogen content of the soil. It is also noteworthy that nitrogen content was generally low, which could be attributed to predominant sandy texture, the high annual rainfall and the extensive leaching, an indicator of nutrient loss at the epipedon (Nwosu et al*.,*2020*)*. Similarly, according to Madueke et al*.* (2021a), low Total Nitrogen is a common occurrence in southeastern Nigeria, and it may be attributed to the high solubility and mobility dissolved nitrates, which are subsequently leached beyond the plant roots by excess rainfall.

Table 2. Particle size distribution of soil samples in the studied Area

Profile pits	Horizon	Sand (%)	Silt (%)	Clay (%)	Textural class
CONTROL	0-15	86.70	5.20	8.10	LS
	15-32	86.70	3.10	10.20	LS
	32-53	87.00	2.30	10.70	LS
	53-102	88.00	7.40	4.60	Sand
	102-153	87.70	3.10	9.20	LS
	Mean	**87.10**	**4.30**	**8.60**	
	SD	**1.673**	**1.789**	**3.286**	
UPSLOPE					
	0-10	88.70	5.10	6.20	LS
	10-28	86.70	3.10	10.20	LS
	28-50	84.70	3.10	12.20	LS
	50-102	88.70	7.10	4.20	Sand
	102-153	86.70	3.10	10.20	LS
	Mean	**87.10**	**4.00**	**8.60**	
	SD	**1.673**	**1.689**	**3.286**	
MIDSLOPE	0-25	92.70	3.10	4.20	Sand
	25-45	86.70	9.10	4.20	LS
	45-72	88.70	7.10	4.20	Sand
	72-110	88.70	5.10	6.20	LS
	110-190	86.70	9.10	4.20	LS
	Mean	**88.70**	**6.70**	**4.60**	
	SD	**2.449**	**2.608**	**0.894**	
DOWNSLOPE	0-22	92.70	3.10	4.20	Sand
	22-53	92.70	3.10	4.20	Sand
	53-143	90.70	5.10	4.20	Sand
	143-180	92.70	4.10	3.20	Sand
	Mean	**92.20**	**3.85**	**3.95**	
	SD	**1.000**	**0.957**	**0.500**	
	P-v	0.01	0.10	0.01	
	Remark	S	NS	S	

The soil organic carbon concentration at the upslope ranged from 0.72% - 1.42% with a mean value of 1.01%, Midslope had soil organic carbon concentration that ranged from 0.78% - 1.63% with mean value of 1.00%. The downslope had organic carbon concentration that ranged from 0.96% - 1.17% with a mean value of 1.14%. Soil organic carbon concentration at the control ranged from 0.73 – 1.42%, with a mean value of 1.21%. Highest amount of organic carbon concentration was obtained within 0-25cm soil depth in the studied area. This is due to the continuous addition of plant litters to the surface soil. The generally low organic carbon may be attributed to the very high temperature in the humid tropics which results in the rapid degradation of organic matter. The effective cation exchange capacity (ECEC) of soils had mean values of 6.84cmol/kg, 6.81 cmol/kg, 6.74 cmol/kg and 8.22 cmol/kg respectively at the control, upslope, midslope and downslope. The highest ECEC was recorded in the subsoil of the downslope. This is attributable to the deposition of sediments eroded from the higher terrain and the subsequent leaching of the basic cations due to the integrated impacts of high rainfall amount and sandy soil texture.

Calcium concentration in the soils of the studied area ranged from 3.00-4.40 cmol/kg, 2.80-4.40 cmol/kg, 2.80-4.0 cmol/kg and 3.60-5.20 cmol/kg respectively at the control, upslope, midslope and downslope. There was increase in calcium concentration down the slope. This is attributable to the loss of calcium due to erosion at the higher terrain and the gain downslope due to the deposition of the eroded sediments. Potassium concentration in the soils of the studied area ranged from 0.08-0.14 cmol/kg; this was generally found to be less than 1.00 cmol/kg. The low potassium concentration could be attributed to a low potassium reserve in acid sands of the humid tropics, which is in turns, due to the high solubility and mobility of exchangeable potassium and its eventual loss through leaching (Alfaro et al., 2017). Magnesium concentration in soils generally ranged from 1.20-3.20 cmol/kg.

Sodium concentration ranged from 0.11-0.18 cmol/kg at the control, 0.10-0.18 cmol/kg at the upslope, 0.10-0.16 cmol/kg at the midslope and 0.10-0.21 cmol/kg at the downslope. It was observed that topography seemed not to have affected the spatial distribution of sodium. This may be the resultant effect of the parent material (coastal plain sands), which is highly leached, with low inherent sodium reserves. Exchangeable soil acidity in the studied area generally ranged from 0.80-1.60 cmol/kg. It was low (<1.00 cmol/kg) at the topsoil of the

Table 3. Chemical properties of soils in the studied Area

Profile pits	Horizons	pH (H_2O)	AVP (mg/kg)	TN (%)	OC (%)	OM (%)	Ca	Mg	K	Na	EA	ECEC
							(cmol/kg)					
Control	0-15	5.50	20.20	2.11	1.30	2.24	3.70	2.00	0.12	0.18	0.90	6.90
	15-32	5.10	20.60	3.08	0.95	1.64	3.60	1.50	0.12	0.14	1.50	6.86
	32-53	5.47	21.90	1.06	0.73	1.26	4.10	1.30	0.11	0.11	1.44	7.06
	53-102	5.50	23.40	0.07	0.76	1.31	4.40	1.70	0.11	0.12	1.12	7.45
	102-153	5.00	24.30	0.11	1.42	2.45	3.00	1.60	0.13	0.11	1.13	5.97
	Mean	**5.31**	**22.08**	**1.286**	**1.21**	**1.78**	**3.76**	**1.62**	**0.11**	**0.33**	**1.28**	**6.84**
	SD	**0.244**	**4.102**	**0.023**	**1.092**	**0.398**	**6.593**	**1.283**	**0.614**	**0.024**	**3.9315**	**0.646**
Upslope												
	0-10	5.00	23.20	0.11	1.20	2.08	3.60	2.00	0.13	0.18	0.80	6.72
	10-28	5.10	18.60	0.08	0.90	1.56	3.60	1.60	0.11	0.13	1.60	7.04
	28-50	5.47	15.90	0.06	0.72	1.25	4.00	1.20	0.11	0.10	1.52	6.94
	50-102	5.50	15.40	0.07	0.81	1.40	4.40	1.60	0.10	0.12	1.20	7.42
	102-153	5.00	24.30	0.11	1.42	2.44	2.80	1.60	0.10	0.17	1.28	5.95
	Mean	**5.00**	**19.48**	**0.09**	**1.01**	**1.75**	**3.68**	**1.60**	**0.11**	**0.14**	**1.28**	**6.81**
	SD	**0.223**	**5.102**	**0.014**	**0.292**	**0.498**	**0.593**	**0.283**	**0.014**	**0.034**	**0.315**	**0.545**
Midslope												
	0-25	5.14	32.00	0.14	1.63	2.80	3.60	2.40	0.11	0.16	0.80	7.07
	25-45	5.19	16.80	0.10	0.84	1.45	4.00	2.40	0.14	0.12	1.04	7.70
	45-72	4.80	17.50	0.08	0.96	1.66	2.80	1.60	0.09	0.14	0.96	5.59
	72-110	4.90	16.10	0.07	0.78	1.35	3.20	2.00	0.08	0.11	0.96	6.35
	110-190	4.93	12.20	0.06	0.78	1.35	3.60	2.00	0.08	0.10	1.20	6.99
	Mean	**4.99**	**18.92**	**0.09**	**1.00**	**1.72**	**3.44**	**2.08**	**0.10**	**0.13**	**0.99**	**6.74**
	SD	**0.166**	**7.595**	**0.032**	**0.361**	**0.616**	**0.456**	**0.335**	**0.024**	**0.021**	**0.145**	**0.801**
Downslope												
	0-22	5.00	25.40	0.13	1.17	2.03	4.80	2.80	0.11	0.17	1.04	8.93
	22-53	4.86	21.00	0.11	1.42	2.44	5.20	3.20	0.13	0.21	1.28	10.02
	53-143	5.10	19.10	0.10	0.96	1.66	4.00	2.00	0.08	0.14	0.96	7.18
	143-180	5.00	22.60	0.10	1.02	1.76	3.60	2.00	0.08	0.10	0.96	6.73
	Mean	**4.99**	**22.03**	**0.11**	**1.14**	**1.97**	**4.40**	**2.50**	**0.10**	**0.15**	**1.06**	**8.22**
	SD	**0.099**	**2.666**	**0.013**	**0.205**	**0.349**	**0.730**	**0.600**	**0.026**	**0.048**	**0.151**	**1.533**
	P-v	0.03	0.68	0.35	0.74	0.74	0.09	0.02	0.71	0.49	0.15	0.09
	Remark	S	NS	NS	NS	NS	NS	S	NS	NS	NS	NS

Note: S= Significant; NS= Not significant

control, upslope and midslope. The higher concentration in the downslope is attributable to sediment deposition, while the generally low values in the studied area may be due to the integrated impact of parent material, sandy soil texture, high rainfall and extensive leaching.

Soil classification

The soils were classified according to USDA Soil Taxonomy and the World Reference Base for Soil Resources (WRB)

Soil taxonomy

Order: Across the toposequence, the soils showed evidence of fluctuating clay content with depth and a predominantly sandy soil texture which precluded the existence of argillic or kandic horizons. This consequently indicated that the soils could not be classified as Ultisols, Oxisols or Alfisols. Furthermore, the Poor structural development – the soils were either single-grained or granular in structure – the predominantly sandy texture, and colour development only differentiating topsoil from subsoil indicate that cambic horizons are not yet fully developed. As such, the soils could not be classified as Inceptisols. They were therefore classified as Entisols.

Sub-order: There is no evidence that the soils have ever been submerged as indicated by the absence of mottles or hydromorphic conditions, or other signs of fluctuating water table. They could consequently not be classified as Wassents or Aquents. Due to the preponderance of less than 35 percent rock fragments and a textural class of loamy sand or coarser in all layers, the soils were classified as Psamments.

Great group: The absence of cryic soil temperature regime and aridic (or torric), ustic or xeric soil moisture regime means that the soils could not be classified as Cryopsamments, Torripsamments, Ustipsamments or Xeropsamment. They were therefore classified as Udipsamments due to the prevalence of an udic soil moisture regime.

Sub-group: Absence of lithic contact, aquic moisture regime, illuvial organic matter accumulation or changes as a result of large-scale artificial application of organic matter, eliminates the Lithic Udipsamments, Aquic Udipsamments, Oxyaquic Udipsamments, Spodic Udipsamments, Lamellic Udipsamments and Haploplaggic Udipsamments sub-groups. The soils were consequently classified as Typic Udipsamments.

WRB classification

Major soil group: Due to a soil texture ranging from loamy sand to sand along the toposequence and less than 40% (by volume) of coarse fragments in all horizons, the soils were classified as Arenosols. Furthermore, the soils had Base saturation that was above 50 % in all horizons and were therefore classified as Eutric Arenosols. Compared to other soil classification systems around the world, the soil class could be correlated to the following: Arenic Rudosols/Tenosols (Australia), Psamments (United States of America), Psammozems (Russia), Neossolos (Brazil), and Sols minéraux bruts and Sols peu évolués (France) (FAO, 2001; IUSS Working Group WRB, 2015).

Land use recommendation

These Arenosols should have been left under their natural forest vegetation. This is due to the highly weathered sandy nature, poor structural stability and low productivity of Arenosols, which, given the prevalent high rainfall intensity and amount in the tropical rainforest, is easily degraded. Also, the nutrients are concentrated in the forest biomass and soil organic matter. As such, the loss of the forest eliminates the naturally rejuvenating capacity of the soils; the rapid degradation of the organic matter due to the high temperature makes the nutrients readily available in inorganic forms; the intense rainfall and the sandy soil texture makes the dissolved nutrients easily leached and lost; the loss of the ground cover (forest and forest understory), litter falls and organic matter takes away the protection of the soil from the direct impact of rainfall and other environmental factors, leading to intense land degradation, like gully erosion. This invariably leads to the infertile badlands with no productive, ecological or socioeconomic value (FAO, 2001; IUSS Working Group WRB, 2015), like the gully in the study area (Figure 2). If left under its natural forest cover, the land can still yield timber, wood, fiber, pulp, fruits and forest foods, and medicinal herbs. If the land is to be cleared, it may be used for the production of such perennial crop as rubber, coconut, cashew, and pine, etc. This capacity is boosted by the fact that the area is located in the rainforest where plants can access water all-year-round. It is noteworthy that the soils can be used for intensive agricultural production, but to be sustainable, this would require the implementation of extensive management/conservation practices that may not be economically justifiable. Nevertheless, with proper management, root/tuber crops, like cassava, which can thrive on relatively infertile soils, as well as ginger, groundnut and Bambara nuts, all of which require loose soils for ease of root penetration and harvesting can thrive on these soils (FAO, 2001; IUSS Working Group WRB, 2015).

CONCLUSION

The predominant soils in the area are Typic Udipsamments (USDA) and Eutric Arenosols (WRB). The soils of the studied area are depleted of nutrients owing to the devastating effect of erosion. Consequently, even with careful management, the soils can only sustain a limited range of crops. Therefore, to ensure sustainable agricultural yield, the soils should either be left under their natural forest cover or used for plantation agriculture or agroforestry. To support arable crop production, appropriate land management practices aimed at conserving the soil, controlling the rate of runoff, preventing soil erosion, and retaining ground cover, organic manure and plant nutrients, need to be implemented.

AUTHOR CONTRIBUTIONS

Nwosu, T.V.: Organized the data, wrote and edited the manuscript. Anene, B.C.: Designed the experiment and the methodology. Ezeobi, M.N.: Helped in sample collection and laboratory analysis. Madueke, C.O.: Characterized the soil and helped to proof read the manuscript.

COMPETING INTERESTS

The authors have declared that no conflict of interest exists.

ETHICS APPROVAL

Not applicable

REFERENCES

Abdullahi, A. (2018). Erosion effect on soil physical properties in selected farmlands in Gidan Kwano, Niger State. *Journal of Horticulture and Plant Research*, *2*, 10-22.

Abegunde, A. A., Adeyinka, S. A., Olawuni, P. O., & Oluodo, O. A. (2006, October). An Assessment of the Socio Economic Impacts of Soil Erosion in South-Eastern Nigeria. In *Shaping the change XXIII FIG Congress Munich, Germany*.

Adekalu, K. O., Olorunfemi, I. A., & Osunbitan, J. A. (2007). Grass mulching effect on infiltration, surface runoff and soil loss of three agricultural soils in Nigeria. *Bioresource technology*, *98*(4), 912-917.

Alfaro, M., Rosolem, C., Goulding, K., Johnston, J., & Wang, H. (2017, January). Potassium losses and transfers in agricultural and livestock systems. In *Frontiers of potassium science conference* (Vol. 25, pp. O166-O173). Rome: Italy.

Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil science*, *59*(1), 39-46.

Bremner, J. M., & Mulvaney, C. S. (1982). Total nitrogen. In. AL Page (ed.) Methods of Soil Analysis. Part 2. Chemical and Microbiological Methods.

Chikezie, I. A., Eswaran, H., Asawalam, D. O., & Ano, A. O. (2010). Characterization of two benchmark soils of contrasting parent materials in Abia State, Southeastern Nigeria. *Global Journal of Pure and Applied Sciences*, *16*(1).

Dunjó, G., Pardini, G., & Gispert, M. (2003). Land use change effects on abandoned terraced soils in a Mediterranean catchment, NE Spain. *Catena*, *52*(1), 23-37.

Esu, I. E. (2004). Soil characterization and mapping for food security and sustainable environment in Nigeria. A Keynote address was presented at the 29th Annual Conference of the Soil Science Society of Nigeria held at the University of Agriculture, Abeokuta Nigeria. *Abeokuta Nigeria*.

Obidimma, C. E., & Olorunfemi, A. (2011). Resolving the gully erosion problem in Southeastern Nigeria: Innovation through public awareness and community-based approaches. *Journal of Soil Science and Environmental Management*, *2*(10), 286-291.

Fagbami, A. A., & Ogunkunle, O. O. (2000). Soil survey, land evaluation, and agronomy: The Nigerian case study. *Agronomy of Nigeria*, 165-173.

Driessen, P., Deckers, J., Spaargaren, O., & Nachtergaele, F. (2000). *Lecture notes on the major soils of the world* (No. 94). Food and Agriculture Organization (FAO).

FAO (2006). Guidelines for soil description (4th ed.). Food and Agriculture Organization (FAO) of the United Nations, Rome, Italy.

Federal Department of Agricultural Land Resources (1985). The Reconnaissance Soil Survey of Imo State (1: 250, 000). Federal Department of Agricultural Land Resources (FDALR), Owerri, Nigeria.

Gee, G. W., & Or, D. (2002). 2.4 Particle-size analysis. *Methods of soil analysis: Part 4 physical methods*, *5*, 255-293.

Gilley, J. E. (2005). Erosion: Water-Induced. In: Hillel, D. (Ed.) Encyclopedia of Soils in the Environment. Elsevier, Amsterdam, The Netherlands. Pp. 463-469. DOI: https://doi.org/10.1016/B0-12-348530-4/00262-9

Hendershot, W. H., Lalande, H., & Duquette, M. (1993). Soil reaction and exchangeable acidity. *Soil sampling and methods of analysis*, *2*.

Igwe, C. A. (2012). Gully erosion in southeastern Nigeria: role of soil properties and environmental factors. *Research on soil erosion*, *10*, 51020.

IUSS Working Group WRB (2015). World Reference Base for Soil Resources 2014: International soil classification system for naming soils and creating legends for soil maps. *World Soil Resources Reports* No. 106. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 192 pp.

Jackson, M.L. (1962). Soil Chemical Analysis, Prentice-Hall Inc., New York, USA.

Mclean, E.O. (1982). Aluminum. In: Black C.A (ed.) Methods of soil analysis. Agronomy Part 2. American Society of Agronomy (No. 9), Madison, Wisconsin, USA. Pp. 978-991.

Nelson, D. A., & Sommers, L. (1983). Total carbon, organic carbon, and organic matter. *Methods of soil analysis: Part 2 chemical and microbiological properties*, *9*, 539-579.

Nnabuihe, E.C., Onweremadu, E.U., Uzoho, B.U. & Aririguzo, B.N. (2022). Characterization and classification of selected floodplain soils for arable crop production in Abakaliki southeastern Nigeria. *International Journal of Agriculture and Environmental Research 8*(1), 114-136. DOI: https://doi.org/10.51193/IJAER.2022.8108

Obalum, S. E., Buri, M. M., Nwite, J. C., Watanabe, Y., Igwe, C. A., & Wakatsuki, T. (2012). Soil degradation-induced decline in productivity of sub-Saharan African soils: the prospects of looking downwards the lowlands with the Sawah ecotechnology. *Applied and Environmental Soil Science*, *2012*.

Madueke, C. O., Okore, I. K., Maduekeh, E. C., Onunwa, A. O., Okafor, M. J., Nnabuihe, E. C., ... & Nwosu, T. V. (2021). Characterization and land evaluation of three tropical rainforest soils derived from the coastal plain sands of southeastern Nigeria. *Agro-Science*, *20*(2), 25-36.

Maduekea, C. O., Okorea, I. K., Maduekehb, E. C., Onunwaa, A. O., Johnbosco, M., Okafora, E. C. N., & Nwosua, T. V. (2021). Comparative assessment of tropical rainforest soils formed from different geologic formations in southeastern Nigeria. *Environment & Ecosystem Science (EES)*, *5*(1), 47-57.

Nwosu T.V. Nnabuihe E.C, Okafor M.J., & Ekpe I.I (2020). Chemical properties of a watershed prone to erosion along Nworie river Banks in Owerri, Imo state, southeast Nigeria. *Proceedings from the 44th conference of Soil Science Society of Nigeria. Colloquia SSSN* 44(2020):228-236 https://doi.org/10.36265/colsssn.2020.4433

Obiadi, I.I., Nwosu, C.M., Ajaegwu, N.E., Anakwuba, E.K., Onuigbo, N.E., Akpunonu, E.O., & Ezim, O.E. (2011). Gully Erosion in Anambra State, South East Nigeria: Issues and Solution. *International Journal of Environmental Sciences 2*(2), 795-804.

Obidimma, C. E., & Olorunfemi, A. (2011). Resolving the gully erosion problem in Southeastern Nigeria: Innovation through public awareness and community-based approaches. *Journal of Soil Science and Environmental Management*, *2*(10), 286-291.

Onweremadu, E. U. (2007). Pedology of near gully sites and its implications on the erodibility of soils in Central South Eastern Nigeria. *Research Journal of Environmental Sciences, 1*(2), 71-76.

Osuji, G.E., Eshett, E.T., Oti, N.N., & Ibeawuchi, I.I. (2002). Land Use Practices and the Predisposition of Selected Watersheds in Imo State to Erosion in: Proceedings of the 36th Annual Conference of the Agricultural Society of Nigeria held at Federal University of Technology, Owerri, Nigeria.

Ritter, J. (2012). Soil erosion: Causes and effects. OMAFRA Factsheet – ORDER NO. 12-053, AGDEX 572/751. Ministry of Agriculture, Food and Rural Affairs, Ontario, Canada.

Soil Survey Staff (2014). Keys to Soil Taxonomy, 12th ed. Natural Resources Conservation Service, United States Department of Agriculture (USDA), Washington, D.C., USA.

Tang, W. J., Liu, H. H., & Liu, B. Y. (2013). Effects of gully erosion and gully filling on soil degradation in the black soil region of Northeast China. *Journal of Mountain Science*, *10*(5), 913-922.

World Bank (1990). Towards the development of an environmental action plan for Nigeria. World Bank, Washington, D.C., USA. 139 pp..