



RESEARCH ARTICLE

THE SUSCEPTIBILITY TO GULLY EROSION OF BENIN CITY SOIL IN THE NIGER DELTA BASIN OF NIGERIA

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ARTICLE DETAILS

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ABSTRACT

Mechanical and chemical analyses of soil samples were applied in the study of soils in the gully erosion sites to determine their susceptibility to gully erosion. Mechanical analysis includes the determination of texture and sand + silt/clay ratio, while the chemical analysis includes the determination of pH, sodium adsorption ratio (SAR) and organic matter (OM) content values of topsoil and subsoil. The topsoil has percentages of sand > 76.85% and clay < 15.64% and is classified as sandy soil, while subsoil was classified as heavy clay soil with percentages of sand < 29.71% and clay > 59%. The pH of soils ranged from 4.34 to 6.42, indicating acidic soils. The sodium adsorption ratio (SAR) of topsoil and subsoil ranged from 2.08 to 2.25 and 2.33 to 2.53, respectively. Therefore, the soils can be described as saline and dispersive, with dispersiveness increasing from topsoil to subsoil. The total organic matter (TOM) and organic carbon (OC) ranged from 0.25 to 0.86 meq/100g and 0.16 to 0.56 meq/100g, respectively. The generally low values of OM content indicate unstable soil aggregates and poor structure that cannot resist erosion. The average monthly rainfall amount/intensity is enough to induce water saturation of soils. Slope level ranged from 4° to 6.4°. Therefore, based on high SAR, low OM, gentle slope and high rainfall amount/intensity, the topsoil and subsoil are susceptible to gully erosion when the former is exposed to the raindrops with vegetation removal and the latter is exposed to runoff with the erosion of the topsoil.

KEYWORDS

Benin city; Gully erosion; Soil texture; Soil erodibility; Rainfall erosivity

1. INTRODUCTION

For the past so many years, gully erosion has become a very serious environmental menace in Benin City. Houses have been lost, roads truncated, huge volumes of soil lost, rates of siltation of rivers increased and huge amounts of money spent by the government in fighting it. The quality of groundwater is being threatened by leachate from refuse dumped in some gullies as the gully depths gradually approach the water table. It is therefore considered a major factor in urban environmental degradation. Its initiation and development have been attributed to improper termination of drains and watercourses (Kayode-Ojo et al., 2019).

The study identified five gully erosion sites in Benin, which include the highly devastating ones at Constain Road in New Benin, behind Queen Ede School Compound in Ikpoba Hill, behind the University of Benin in Ugbowo and two minor ones at Iwogban and Powerline Road (Figures 1 and 2) (Oyanyan, 1999). As of 1999, the New Benin, Ugbowo, and Ikpoba Hill gully erosion sites had lost 58,889, 10,479.4, and 20,920.20 m³ of soils, respectively (Oyanyan, 1999). With the exception of the one at New Benin that the state government has worked on, the amount of soil loss due to gully erosion has been growing ever since. There has also been a rise in the number of gully erosion sites. There are 25 gully erosion sites in the city as of 2024, according to the Edo State Ministry of Environment (Olisa et al., 2024).

By the way, what is gully erosion? It is the highest level of erosion, after sheet and rill erosions (Morgan, 2005). Gully erosion occurs when erosion that was formerly sheet erosion is concentrated on definite rill erosion channels with flows at a velocity sufficient to detach and

transport large volumes of soil particles. When the channels eventually become deep with steep sides or walls having either rectangular or trapezium shapes, they are referred to as gullies. Generally, soil properties, rainfall and runoff intensity, wind action, geological, hydro-geochemical and geotechnical characteristics, and anthropogenic activities have been adduced as factors generating soil and gully erosion processes (Egboka and Orajaka, 1987).

Many studies have been carried out to determine why rill erosion channels are easily converted to gully erosion channels in the city. One of the studies, described Benin City soil as silty sands, poorly graded and non-plastic with an average of 17% plastic limit, 51 kPa of shear strength and 22° angle of internal friction and therefore concluded that the soil has the tendency to be eroded by water (Kayode-Ojo et al., 2019). Another study described the soil as loose soil that is highly prone to erosion because of 1.75 g/cm³ maximum dry density and 20.93 kN/m² maximum cohesion values (Ojeaga and Afolabi, 2022). A study of soils in one of the gully sites showed an average moisture content of 13.81% and a shrinkage limit as low as 7.14, making it easily water-saturated and causing a consequent reduction in shear strength and an increase in erosiveness (Eseigbe et al., 2012). As laudable as these findings are, there are other indexes of soil erosion that are based on physical and chemical properties of soil as well as the intensity of rainfall that still need to be investigated. Therefore, the aim of this paper is to present a veritable conclusion on the factors duly responsible for the susceptibility of Benin City soil to gully erosion by combining the further findings from the physical and chemical analysis of soil and erosivity of rainfall with

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the findings of the aforementioned researchers.

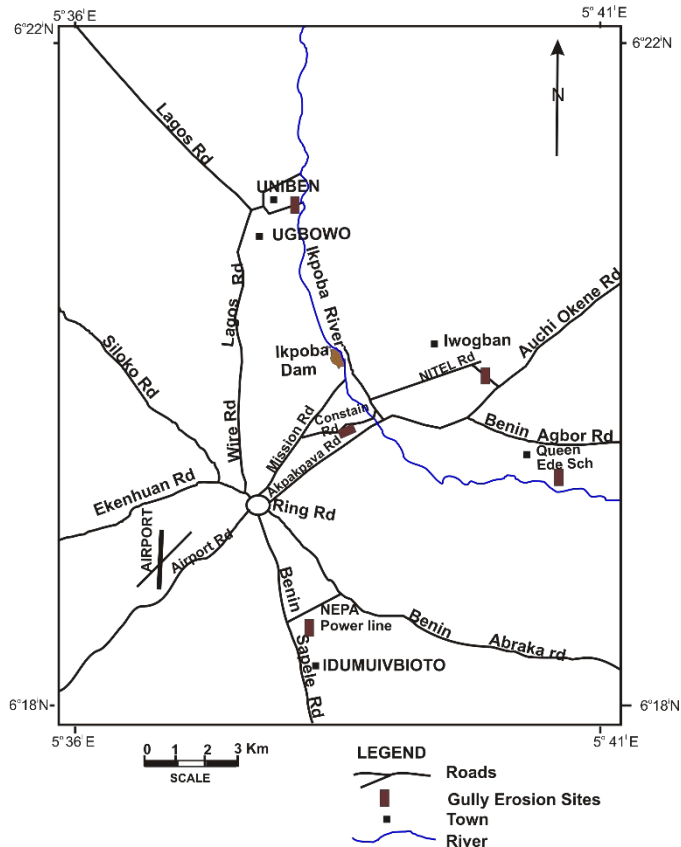


Figure 1: Map of Benin City showing major road network and some locations of gully erosion sites (Oyanyan, 1999).



Figure 2: Pictures of environmental degradation by gully erosion in Benin City. (a) Destruction of houses and groundwater pollution from leachate from refuse at Constain road, New Benin, (b) Loss of soil behind Uniben, Ugbowo, (c) and (d) Loss of soil and truncation of roads behind Queen Ede School, Ikpoba Hill.

1.1. Study Area location

The study area is Benin City, the capital of Edo State of Nigeria (Figure 3). The city is located between latitude 6° 18' and 6° 22' and longitude 5° 36' and 5° 41' (Figure 1), in the northern part of the Niger Delta basin of Nigeria. It is an ancient city of pre-colonial origin dating back to the twelfth century. It has a total landmass of about 1,204 square kilometres and a population of 1,496,000 (Wikipedia, 2025). It is therefore very obvious that the city population makes heavy demands on urban lands. The attempt by individuals, groups and government to meet the increasing demand for land for residential, industrial and institutional facilities resulted in the replacement of the soil's vegetal cover with impervious urban land surface, which increases surface runoff.

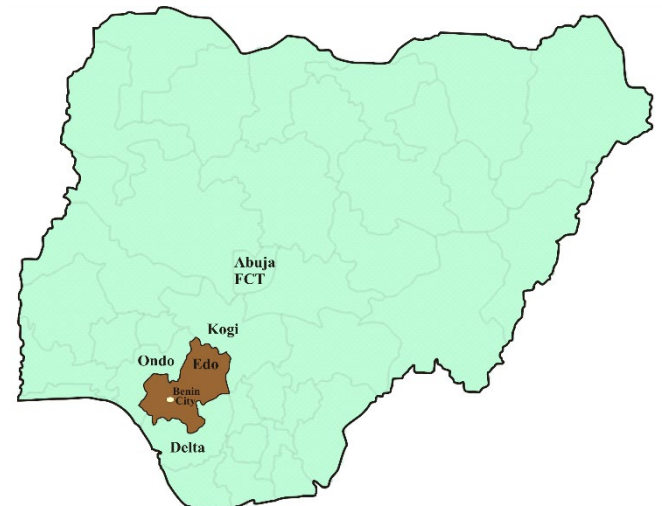


Figure 3: Map of Nigeria showing the location of Edo state and Benin City

1.2. Topography and Drainage Setting of the Study Area

The city's southwestern and southern regions have comparatively level elevations. However, in the city's northern and northeastern regions, the elevation progressively rises from 40 meters above sea level to roughly 177 meters. Because of this, Benin City's geography is often described as lowland with a plateau enclosing it in the north and northeast. The toe of slopes, or the bottom of river channels, ranged in elevation from 23 to 83 meters above sea level, while the peak of slopes, particularly those facing the northeastern river banks, ranged from 83 to 177 meters above sea level. Because of the impact of slope on surface runoff, the majority of gully sites are found in the city's northeastern region (Figure 1). In general, the city is a slanted plain that slopes southwest.

The Ogba and Ikpoba rivers serve as the primary drains for the study region. The Ogba River drains the gently sloping western region, while the Ikpoba River drains the northeastern/eastern region, which it typically tilts towards (Figure 4).

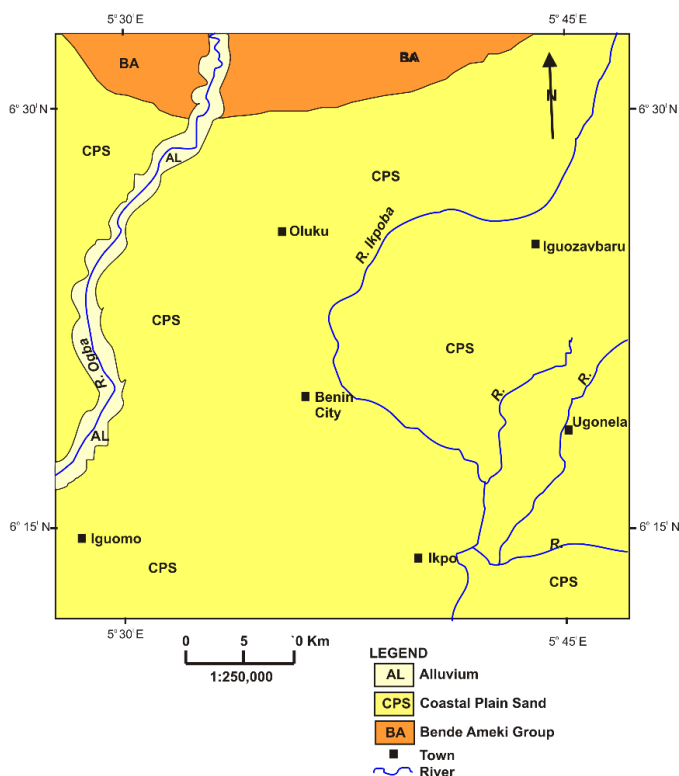


Figure 4: Map showing the geology and the natural drainage of Benin city (Based on information obtained from Reymont, 1965).

1.3. Geology of the Study Area

The study area is in the Northern Delta province of the Niger Delta basin (Doust and Omatsola, 1990). It is underlain by a deposit initially named coastal plain sand and later renamed Benin Formation (Figure 4) (Tattam, 1943; Short and Stauble, 1967; Reymont, 1965). The formation is Oligocene-Pleistocene in age and has a maximum thickness of 2000 m. It is characterised by reddish to reddish-brown lateritic massive clayey sand soil that caps the underlying continental fluvial sands/gravels and back swamp deposits. In the study area, the formation is bounded in the north by the Bende-Ameki Group of the Anambra basin but outcropped across the Niger delta basin in which it tops its three lithostratigraphic units: Benin, Agbada, and Akata Formations (Short and Stauble, 1967). Along the river's floodplains, especially the Ogba River, is the Quaternary alluvium deposit.

1.4. Climate

The study area is characterised by heavy rainfall in the months of April to October and a dry season from the month of November to March, with the months of December and January being the driest. The average monthly amount of rainfall ranged from 28.54 to 336.39 mm. As shown in Figure 5, the peak of the wet season, when most of the gullies developed, is between the months of June and August. It can be noticed from Figure 5 that the maximum peak rainfall occurs in the month of August, which means the term "the August break" is not usually

predominant in the city. Therefore, there is rainfall almost throughout the year, which is sometimes accompanied by strong wind.

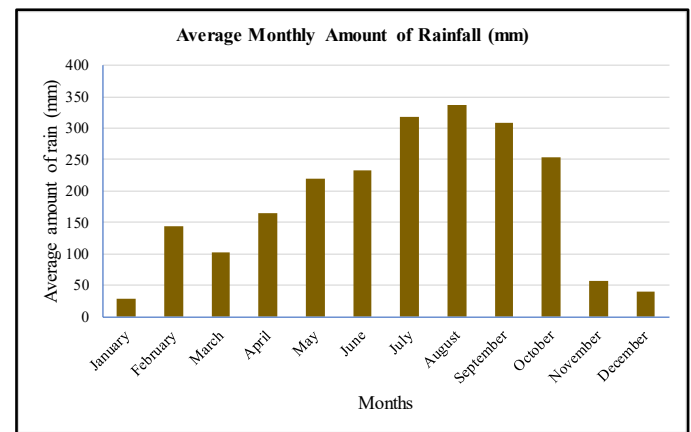


Figure 5: Average rainfall in Benin City between 2006 and 2023

2. DATA SETS AND METHOD OF STUDY

Equipment and data sets used for this study include a camera, geographic information system (GPS) device, hand auger, Abney level, average monthly amount of rainfall data for 17 years obtained from the Nigeria Meteorological Station, Benin City, and a map of locations of gully erosion-prone areas obtained from documented literature (Figure 1). Out of the gully erosion-prone areas, three of the most impacted locations, including the ones at the back of the University of Benin (Uniben) at Ugbowo, Constain Road at New Benin, and the back of Queen Ede School at Ikopba Hill, were selected for detailed study. The coordinates of the three gully erosion sites are shown in Table 1.

The susceptibility of soil to erosion depends on its erodibility, slope gradient, and the erosivity of rainfall (Morgan, 2005). Therefore, the method of study was chosen mainly for the determinations of the erodibility of soil and slope gradient in the three locations mostly affected by gully erosion. Rainfall intensity values documented in the literature and the average amount of monthly rainfall data obtained from the Nigerian Meteorological Station, Benin City, were used to evaluate the erosivity of rainfall in the city. Meanwhile, the GPS device was used to take the coordinates, the Abney level was used to measure the average amount of slope, and the camera was used to take the photograph of gully sites.

Table 1: The studied Gully Erosion Sites and Coordinates

S/n	Gully Erosion Sites	Coordinate
1.	Ikopba Hill (Behind Queen Ede School)	6°20'12.80"N, 5°40'39.87"E
2.	Ugbowo (Behind The University of Benin (Uniben))	6°24'23.76"N, 5°37'45.59"E
3.	New-Benin (Constain rd)	6°20'56.41"N, 5°38'15.69"E

2.1. Determination of Erodibility of Soil

Erodibility defines the resistance of the soil to both detachment and transportation by fluid (water or wind) (Morgan, 2005). It depends on the mechanical and chemical properties of soil (Dondofema et al., 2008). It is therefore a direct estimation of the susceptibility of soil to erosion (Bouyoucos, 1935). The mechanical properties of soil depend on the textural or grain size characteristics and properties derived from it, while the chemical properties are the sodium adsorption ratio (SAR) and organic matter and organic carbon content.

Soil aggregate stability, infiltration rate, run-off, and erosion depend on soil texture (Le Bissonnais and Singer, 1993). This analysis indicated the ratio of sand + silt/clay as an index of soil erodibility for water erosion (Bouyoucos, 1935). The higher the ratio, the higher the soil erodibility, and

the lower the ratio, the lower the soil erodibility or the lower the susceptibility of the soil to gully erosion. It has been indicated that there is a significant positive correlation between gully erosion development and SAR, which is the ratio of the Na concentration divided by the square root of one-half of the Ca + Mg concentration (Shahrivar et al., 2012; Servati et al., 2008; Rienks et al., 2000). The higher the Na content in soil, the higher its dispersiveness, and hence the higher its susceptibility to gully erosion (Mahangara, 2010). A research indicated that in tropical Africa, severely eroded soil contains less organic matter than soil less susceptible to erosion (While Lal, 1990). This is because the higher the organic matter and organic carbon content of the soil, the better the aggregate structure of the soil (Kemper and Koch, 1966; Shein and Milanovskii, 2003). Therefore, in consideration of the three factors of soil erodibility, top soil (A horizon) and lower or sub-layer soil (B horizon) were sampled with a hand auger at the head-cut of the gullies and labelled as sample 1 and about 4 to 5 m down the gullies' head-cut and labelled sample 2. The sampling spots were about 3 to 4 m from the edge of the gully walls. Each sample was packed in a polyethylene bag and appropriately labelled. The depth of topsoil ranged from 5 to 15 cm, while that of lower soil ranged from 15 to 30 cm. The soil samples were subjected to mechanical analysis for the determination of soil texture (the percentage of sand, silt, and clay in soil) and chemical analysis for the determination of potential of hydrogen (pH), exchangeable cation composition, and organic matter and organic carbon content.

20 g of an air-dried sample was sieved through a 2-mm sieve into a 50-ml beaker in order to measure the pH of the soil. After adding 20 millilitres of distilled water, the mixture was left to stand for half an hour, being periodically stirred with a glass rod that had been cleaned with distilled water. After rinsing the electrodes of the pH meter with distilled water, the soil sample's pH was measured.

The hydrometer method was used for the soil sample's mechanical analysis (Davidson, 1955). 100 cm³ of distilled water and 50 cm³ of 5.0 percent sodium hexametaphosphate, a dispersion agent, were added to 101 g of an air-dried soil sample that had been run through a 2 mm sieve in a "milkshake" mix cup. The mixture was stirred with a rod rinsed with distilled water and allowed to set for 30 minutes. The mix cup was then placed on the multimix machine for the mixture to be stirred into suspension for 15 minutes, after which the suspension was transferred to the control glass cylinder. The hydrometer was placed in the suspension, and distilled water was added gently to the upper line of the control glass cylinder. The hydrometer was removed, and the top of the glass cylinder was covered and inverted several times until all soil was in suspension. The cylinder was placed on the flat surface after the shakings and time was noted and immediately the soil hydrometer was slide slowly into the suspension until it was floating. The first reading on the hydrometer was

taken after 40 seconds after the cylinder was set down. The hydrometer was removed and the temperature in Fahrenheit of suspension measured with thermometer. The second hydrometer reading was taken 3 hours after the first reading, and the temperature was also measured in Fahrenheit. Hydrometer readings were corrected for temperature by adding 0.2 to every degree over 68°F and 0.2 was subtracted for every degree under 68°F. Also, to correct for salt as a result of the dispersing agent, 2.0 was subtracted from every hydrometer reading. The corrected hydrometer first reading multiplied by 2 gave the percentage of silt and clay, while the calculated percentage balance represents that of sand. The second corrected reading multiplied by 2 indicated the percentage of clay in the suspension. The subtraction of the sum of the percentage of clay and sand from 100 gave the percentage of silt.

To determine the cation compositions required to calculate SAR, 1 g of the soil sample was digested with combined mineral acids of 10 ml of concentrated nitric acid, 0.5 ml of concentrated sulphuric acid and 5ml of 52% perchloric acid. The solution was stirred to a clean one while being heated on an electro-thermal hot plate. The digest was then allowed to cool down to room temperature, after which it was diluted to 50 ml with distilled water. The solution was then filtered through Whatman filter paper number 541, which had been folded into a conical flask. An Atomic Absorption Spectrophotometer (AAS) was used to test the filtrate for metal ions. Among the metals examined are magnesium (Mg), calcium (Ca), and sodium (Na) and potassium (K).

The procedure used to determine the organic matter and organic carbon content of soil was by Walkley and Black (1934)

3. RESULTS AND INTERPRETATIONS

3.1. Mechanical Properties Of Soil Samples And Erodibility

Mechanical analysis of soil shows that the topsoil and lower soil have a sand + silt/clay ratio that ranged from 4.75 to 5.91 and 0.60 to 0.67 and the texture classified as silty clay sand or muddy sand and silty sandy clay, respectively (Table 2). The topsoil with percentages of sand > 76.85% and clay < 15.64% shows that it is a sandy soil expected to have good infiltration and drainage, but the converse is the case for the lower or subsoil classified as heavy clay soil with percentages of sand < 29.71% and clay > 59%. As a result, if the subsoil does not have well developed structure, it can easily be water-logged during periods of heavy precipitation, which will ultimately cause the topsoil to become saturated with water. On a ground with a long Abney slope level ranging from 4° to 6.4°, a sandy topsoil that is saturated with water will be extremely vulnerable to erosion, particularly if vegetation is removed. Also, when the subsoil is expose to the surface as a result of the erosion of the top soil and it becomes water-logged due to poor infiltration or percolation, it can be turned to surface water gley soils that have great risk of runoff and quick conversion of rill erosion channels to gully erosion channels.

Table 2: Average Slope and Mechanical Properties of Topsoil and Subsoil

Gully site	Abney Slope Level	Sample	Parameters and Units					Sand + silt)/clay Ratio
			Sand (%)	Silt (%)	Clay (%)	Textural Class	Soil Type	
Ikpoba Hill (Behind Queen Ede School)	4.4°	T1	78.00	6.36	15.64	Silty clay sand	Sandy Soil	5.394
		L1	27.6	10.27	62.13	Silty sandy clay	Heavy clay Soil	0.610
		T2	77.00	5.6	17.4	Silty clay sand	Sandy Soil	4.751
		L2	26.15	11.32	62.53	Silty sandy clay	Heavy clay Soil	0.600
New-Benin (Constain rd)	4°	T1	79.12	5.38	14.31	Silty clay sand	Sandy Soil	5.905
		L1	29.71	9.82	59.47	Silty sandy clay	Heavy clay Soil	0.665
		T2	78.50	7.25	14.34	Silty clay sand	Sandy Soil	5.980
		L2	25.85	9.85	64.3	Silty sandy clay	Heavy clay Soil	
Ugbowo (Behind Uniben)	6.4°	T1	77.98	6.54	14.89	Silty clay sand	Sandy Soil	5.676
		L1	28.86	10.25	59.92	Silty sandy clay	Heavy clay Soil	0.653
		T2	76.85	8.25	14.95	Silty clay sand	Sandy Soil	5.670
		L2	27.5	10.85	61.65	Silty sandy clay	Heavy clay Soil	0.622

T = Topsoil, L = Lower or subsoil

3.1.2. Chemical Properties Soil Samples and Erodibility

The chemical parameters of soil samples are provided in Table 3. The pH of topsoil ranged from 5.56 to 6.42, while that of subsurface ranged from 4.34 to 5.81. It suggests that Benin City soil is generally acidic, and the acidity increased from topsoil to lower or subsoil.

The sodium adsorption ratio (SAR) of topsoil and lower soil ranged from

2.08 – 2.25 and 2.33 – 2.53, respectively. The SAR values indicate general increase of SAR from topsoil to lower soil in line with Na concentration that also increased from topsoil to lower soil. A soil with pH < 8.5 and SAR square < 13 is classified as slightly saline to saline soil while the one with pH > 8.5 and SAR square ≥ 13 is classified as sodic soil (Waskom et al., 2006). It has been indicated in a case study in Africa that the threshold for soil dispersion is SAR value higher than 2 (Bell and Maud, 1994). Therefore, Benin city soil can be described as slightly saline to saline and dispersive soil, with dispersiveness increasing from the topsoil to the lower soil.

Table 3: Chemical composition of topsoil and subsoil

Gully site	Parameters and Units								SAR
	Sample	pH	Ca (Meq/100g)	Mg (Meq/100g)	Na (Meq/100g)	K (Meq/100g)	TOM (Meq/100g)	OC (Meq/100g)	
Ikpoba Hill (Behind Queen Ede Sch.)	T1	6.38	0.20	0.36	1.13	2.27	0.28	0.16	2.14
	L1	5.54	0.20	0.36	1.32	2.58	0.82	0.48	2.49
	T2	6.35	0.20	0.35	1.18	2.32	0.25	0.14	2.25
	L2	5.23	0.20	0.37	1.25	2.54	0.85	0.44	2.34
New-Benin (Constain rd)	T1	5.64	0.21	0.35	1.10	2.25	0.33	0.17	2.08
	L1	4.34	0.21	0.34	1.29	2.59	0.74	0.56	2.50
	T2	5.56	0.22	0.35	1.14	2.22	0.34	0.15	2.14
	L2	4.42	0.23	0.35	1.26	2.61	0.82	0.46	2.33
Ugbowo (Behind Uniben)	T1	6.42	0.20	0.37	1.15	2.29	0.38	0.21	2.15
	L1	5.21	0.20	0.37	1.35	2.57	0.84	0.53	2.53
	T2	6.35	0.20	0.36	1.19	2.31	0.42	0.23	2.25
	L2	5.81	0.20	0.34	1.27	2.59	0.86	0.48	2.44

T = Topsoil, L = Lower or subsoil

Potassium (K) concentrations ranged from 2.25 to 2.61meq/100g; and just like Na increased gradually from the topsoil to the subsoil. Potassium is like sodium in causing dispersion of clay soil in water resulting in the formation of soil with unstable aggregate and poor soil structure that lacks infiltration and good drainage (Marchuk and Marchuk, 2018). The dispersiveness of the soil caused by Na and K can be said to be exacerbated by the general low values of calcium (Ca) and magnesium (Mg) that ranged from 0.20 – 0.21 meq/100g and 0.34 – 0.37 meq/100g, respectively. This is because Ca and Mg ions generate the most rapid and stable coagulation bonds between soil minerals particles to form stable aggregates (Shein and Milanovskii, 2003).

The total organic matter (TOM) and organic carbon (OC) ranged from 0.25 to 0.86 meq/100g and 0.16 to 0.56 meq/100g, respectively. In all samples, organic matter (OM), though of low values, increased slightly from the topsoil to the lower soil. The general low values of OM content in the soil samples indicate unstable soil aggregates in water and consequently bad soil structure that cannot resist erosion. This is because organic matter is one of the glues that bind soil mineral particles together to form stable soil aggregates, resulting in increased water infiltration or percolation rate (Shein and Milanovskii, 2003; Alagöz and Yilmaz, 2009).

3.3. Rainfall Erosivity

The susceptibility of Benin soil to gully erosion cannot be completed without evaluating the erosivity of rainfall, which is the measure of the ability of raindrops to detach soil particles for mobilisation and transportation by flowing water. The erosivity of rainfall depends on the intensity of rainfall. The rainfall intensity is the force with which the rain droplets strike the surface of soil, and the force is converted to kinetic energy. Erosion is related to two types of rain events: the short-lived intense storm where the infiltration capacity of the soil is exceeded and the prolonged storm of low intensity that saturates the soil (Morgan, 2005). As indicated in section 1.3 and in Figure 5, the city experiences a high amount of rainfall between the month of April and November that are either short-lived intense storms or prolonged storms of low intensity. An intensity of rainfall greater than 25 mm/hour is enough to induce significant erosion (Hudson, 1981). Also, overland flow and slope wash can start during rainstorms of 50 mm with intensities greater than 30 mm/h (Morgan, 2005). In Benin City, the intensity of rainfall for amounts more than 32.73 mm range from 35.40 to 53.87 mm/hr (Nwoke and Okoro, 2013). That means the rainfall in Benin City has high erosivity to cause large-scale erosion if soil vegetal cover is removed, and geomorphological features and the geotechnical, chemical, and physical properties of the soil are favourable to the easy detachment and

movement of soil particles by raindrops and runoff.

4. DISCUSSION

Results and interpretations of the chemical properties of the soil samples show that both the sandy topsoil and heavy clay subsoil are characterised by low concentrations of Ca, Mg, and organic matter (TOM and OC) and SAR that has exceeded the threshold for soil dispersion in water. It is therefore expected that the soils consist of unstable aggregate that easily disperses in water and of poor structure that has a high risk of generating runoff. At the soil surface, crusting or capping that exacerbates runoff due to a drastic reduction in the rate of water percolation into the ground is also expected. This finding is very critical in ascertaining the factors responsible for the susceptibility of the subsoil to gully erosion. This is because subsoil has a greater influence on gully erosion volume and length development over the thin topsoil (Shahrivar et al., 2012).

The mechanical analysis of soil samples shows the topsoil is sandy soil with very low concentration of clay and therefore susceptible to erosion. This is in line with the findings of Kayode-Ojo et al. (2019); Ojeaga and Afolabi (2022). The characteristics of the subsoil classified as heavy clay soil is contrary to the findings of Eseigbe et al. (2012). This shows that the characteristics of subsoil is not uniform in the whole of the city.

The subsoils at the gully sites under investigation appear to be less erodible than the topsoil due to their low sand + silt/clay ratio, and their high proportion of clay that can provide enough cohesive strength to resist erosion. However, at least 58,889 m³ of subsoil has been eroded at several gully locations across the city (Oyanyan, 1999). This can be explained by the discoveries that with an increase in the soluble salts of soil such as Na, the negative impact of clay on aggregate stability will increase, and thus, erodibility of soil will increase as well (Kemper and Koch, 1966). It is also in line with the assertion that dispersive soils contain a moderate to high content of clay (Bell and Maud, 1994). Thus, even if the subsoil has a high clay percentage, its erodibility will be increased by the combination of high SAR, high potassium concentrations, a long, gradual slope, low organic matter content, and high moisture content from heavy rainfall.

The average monthly amount of rainfall and intensity in Benin City is high enough to induce water saturation of soil and significant erosion when the geomorphology of the ground and the chemical and physical properties of the soil are favourable to easy detachment and movement of soil particles by the force of raindrops and runoff. Therefore, water saturation of the sandy topsoil as a result of lack of infiltration and good drainage of the subsoil and its occurrence on a long gentle slope will enhance susceptibility to gully erosion, especially where vegetal cover is removed.

5. CONCLUSIONS

The topsoil and subsoils in the studied gully erosion sites are both acidic and are classified as sandy soil and heavy clay soil, respectively. Based on textural characteristics, the topsoil is more erodible than the subsoil. Due to the general high sodium adsorption ratio (SAR), high potassium, and low organic matter (OM), both topsoil and subsoil are saline and dispersive. This may have led to the formation of unstable soil aggregates and poor structure that are unable to withstand the detaching force of runoff and raindrops.

In Benin City, the average monthly rainfall and intensity are high enough to cause water saturation of soils and substantial erosion, particularly in areas with long and gentle slopes and a loss of vegetation cover. Therefore, with the general high SAR, high potassium content, low OM, long and gentle slope, and high amount and intensity of rainfall, both the topsoil and subsoil in the studied area are extremely vulnerable to gully erosion when the former is exposed to raindrops with vegetal removal and the latter is exposed to runoff with topsoil erosion.

To prevent the development of more gully erosion sites in the city, the exposure of the subsoil to the detaching force of raindrops and runoff must be prevented.

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Authors' contributions

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Competing interests

The author declare that he has no competing interests.

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