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Malum Japhet Flayin,
Martins Okechukwu Udochukwu

SOIL ASSESSMENT AND MITIGATION OF FLASH FLOOD EROSION USING IPOMOE CARNEA IN GOMBE TOWN, GOMBE STATE, NIGERIA

In many parts of the world floods occur more often and increase in size. In the tropics, it is partly or wholly caused by climatological factors, in-situ soil types (as soils with low infiltration rate are vulnerable to flooding); inadequate drainage network, topography and human factors. Gombe town is situated within an elevation of 628 m and 361 m above sea level (a.s.l). Topography is mainly mountainous, undulating and hilly with open plains and mean slope gradient of 5°, considered to be a high gradient for unprotected soils. This causes high surface runoff leading to excessive flooding and formation of gullies, cutting deep trenches that result in the destruction of residential houses and environmental disasters throughout Gombe town. The research work assessed gully erosion from high vulnerable sections in Gombe town affected by high fluvial floods. Field measurement was done using 50 m tape, GPS, satellite images and laboratory analysis. Laboratory analysis of soil particles sizes showed that mean particle sizes were 74.9 %, 14.1 % and 11.0 % for sand, silt and clay respectivly; the textural class for the entire study site was sandy clay. Porosity from the entire study area contains low volume of voids relative to the volume of solids. Bulk density was slightly high compared to the standards values. The soil chemical properties of the soil pH for the entire site mean (ESM) was 6.42. This indicates that the soils are slightly acidic which affect microbial activities on organic matter that enhance the binding of soils to resists erosivity of fluvial floods. People resorts to using vegetative cover of Ipomoe Carnea plant as mitigation measures to protect their vulnerable houses and farms from gully erosions because the stems interweaves and forms a thick cover that diffuses the high velocity water flow into laminar flow. The weaved stems traps, blocks and prevents the flood transported materials (soil, humus, gravels) in between the stems thereby prevents and slows soil erosion to the nearest minimum.

Keywords: *flash floods, soil porosity, gully erosion, mitigation, Ipomoe Carnea, Gombe town.*

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1. Introduction

Flood is a large amount of water covering an area. It is an over flowing of a great body of water over land not usually submerged. Flood may be described in various ways according to the type and magnitude [1]. Floods are defined as any abnormal high water stage or overland flow, in a stream, flood way, lakes or coastal areas that result in significant detrimental effects. Flood occurs in rivers when flow exceeds the capacity of the river channel, at bends or as a natural hazard that occurs as an extreme hydrological event [2]. It is also defined as large volume of water, which arrives at and occupies the stream channel and its flood plain in a time too short to prevent damage to economic activities including homes [3–5].

Floods kept occurring more often and increasing in size. People move from rural areas to cities or within cities and often settle in areas that are highly exposed to flooding, thereby making them highly vulnerable if there is no flood defense mechanism [6, 7].

In the tropics, it is partly or wholly climatological in nature [8]. In-situ soil types with low infiltration rate are vulnerable to flooding [9]. Inadequate drainage network, low lying terrain, the buildup of the vulnerable areas, and human factors are other causes of flooding [10].

Flooding can be divided into different types according to their duration, namely: slow-onset, rapid-onset and flash floods [11, 12]. Categories of flooding are also identified as riverine flood, coastal flood, urban flooding, arroyos floods, small-area floods and large-area floods [13–15].

In Nigeria, serious floodings have been occurring much more frequently in the last four decades, which dated back to the 1940s [16, 17]. It has continued to occur in the forms of: Coastal flooding, river flooding, flash floods and urban flooding, dam burst levee failures, dam spills [14, 18]. It normally occurs between June and October in urban and rural areas. Devastating flood disasters occurred in 1963, 1978, 1980, 1985, 1987 and 1990 [19]. Some of the recent flooding disasters include those of 2010, 2011 and 2012

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that were highly devastating. Since then, there is no year that flooding disaster did not occur in Nigeria [20–22].

Incidences of flooding disasters occurred between 2010 and 2015 in Nigeria [19]. In Gombe town occurs due to fluvial and pluvial and sometimes by combination of the two kinds of floods. Fluvial (river related) flood occurs when the discharge of a river exceeds the capacity of the river channel to contain it, while pluvial flood takes place when the rainfall rate exceeds the capacity of storm water drains to evacuate the water and the capacity of the ground to absorb water [23]. Pluvial flooding often occurs unexpectedly in locations not obviously prone to flooding and with minimal warning, referred to as «invisible hazard» [24]. Pluvial flooding is a characteristic of urban areas where large areas of impervious ground exist and inadequate drainage systems abound. As urban growth increases, the impervious surface area also increases; thereby rendering populations vulnerable to water inundation as natural streams and man-made drainage systems fails to cope with increased run-off subsequent to heavy rainfall [25].

Urban pluvial flooding frequency also increases due to urbanization and climate changes [26, 27]. It has the potential to cause significant damage and disruption of highly urbanized areas, with high density of properties, critical infrastructure and population [28].

The nearly yearly occurrence of flood disasters in Gombe necessitated the need for continuous mitigation measures to curtailing the dangers of sudden floods to protect the environment, farmlands, public health and safety in residential houses. The use of *Ipomoe Carnea* (Choisy plant) as mitigation measures against erosion caused by flash floods is getting much attention as an immediate interim measure.

Ipomoe Carnea is popularly called «Ana Kwari» meaning «preventer of river formation» in Hausa languarge, Northern Nigeria. As the name implies, choisy plant grows and spread in form of cover crops in fields especially along water courses and wetlands. *Ipomoea Carnea Jacq*. (Family: *Convolvulaceae*) commonly known as Bush morning glory, blue dawn flower or bindweed and popularly called Choisy plant named after Choisy J. D. who researched extensively on *Ipomoea* plant species in 1833. The scientific name of Choisy plant is *Ipomoeo* and belong to about 60 genera and about 2000 species [29], of mostly herbaceous perennial shrub plant with vines that climb upto 15 m stretch. More than one-third of the species are included in two major genera, *Ipomoea* and *Convolvulus*.

It grows originally from the tropics of South America, North America (USA), Asia, parts of Africa, Australia, New Zealand and some pacific islands [6, 30], in dense populations along river beds, river banks, canals and other wetland areas [31]. Many tropical species are use as valuable ornamentals, medicinals, and food crop. *Ipomoea* is the largest genus in the family with over 500 species, among which; is *Ipomoea Carnea Jacq*. species. In natural habitats, they are mainly found in watercourses where it threatens riparian vegetation. Farmers use it as ornamental and hedge plant along the banks of irrigation and drainage canals in the Nile Delta, Eqypt [32].

Choisy shrubs are fast-growing plant and drought-resistant once established [33]. They reproduce vegetatively through stem fragments and root easily within a few days. The stems sprout vigorously after being cut. The leaves of many species are fleshy, three lobes, cordately tapered, with 9–18 cm. Flowering starts from June to November and are also tapered, large, with 6–8 cm, very flashy, frequently blue, but sometimes white, pink or multi-coloured. The fruits are capsules with 10–13 mm diameter, with 4–6 seeds inside [6]. The leaves of the Nigerian species (*Ipomoe Carnea*) are fleshy and single lobed (Fig. 1).

Fig. 1. *Ipomoe Carnea* plant: *a* – during dry season; *b* – during rainy season; *c* – flowers in rainy season

Impacts on environments: *Ipomoeo* forms impenetrable mats that smother (suppress) trees, shrubs and grasses (ivasive) of other species, leading to their death and preventing the development of native vegetation [6].

They sprout vigorously and can within two months grow, spread, and cover a wider area (Fig. 2, *a*). Stem branches sprout from the ground level rapidly in all directions forming a very thick mat cover (Fig. 2, *b*).

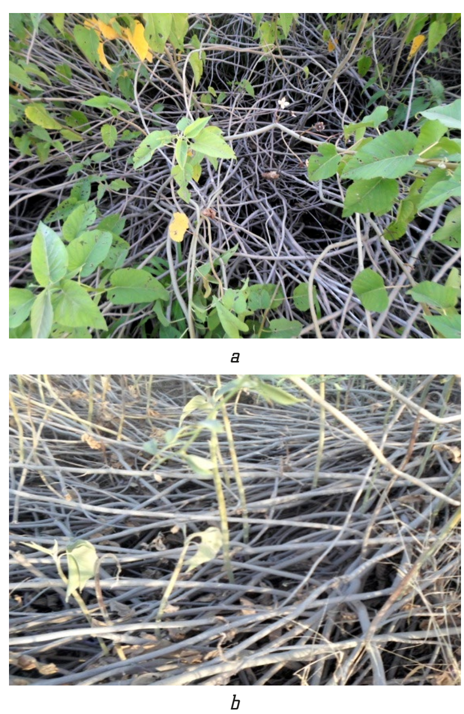

Fig. 2. *Carnea* stems: *a* – grow in all directions; *b* – form thick mat cover at the base

The interweaves stems forms a thick cover that diffuses the high velocity water flow into laminar flow. The weaved stems traps, blocks and prevents the flood transported materials (soil, humus, gravels) in between the stems thereby preventing soil erosion to the nearest minimum.

The aim of the study is to assess the characteristics of soils from gully erosion Sites in part of Gombe town; the use of *Ipomoe Carnea* plant as mitigation measures against fluvial flood in the area and to proffer solutions in curtailing the problem.

2. Materials and Methods

2.1. The study area (Gombe, Nigeria). Gombe is the capital of Gombe State, Nigeria, located between latitude 9°30′ and 12°30′N and longitudes 8°45′ and 11°45′E of the Greenwich Meridian. The town is located between latitudes 10°18′25.0″N and longitude 11°10′29.6″E, in the Sudan Savannah region of the country at the North-east of river Benue, bordering with Adamawa, Bauchi, Borno and Yobe states (Fig. 3, 4). Topography is mainly mountainous, undulating and hilly to the Southeast and open plains in the central Northeast, West and Northwest. The altitude of Gombe ranges between 628 m and 361 m. Larger part of the existing town is at the foot of the Akko escarpment of sand and on a shallow dish-like site [34]. The town also expanded westward towards hill escarpment called Bima mountain and Lijji hills. Gombe occupies an area of about 45 km^2 (Ministry of Land and Survey Gombe) [35]. Presently, all the areas around Bima mountain, Doma and Lijji hills are occupied by residential houses.

Fig. 3. Map of Gombe State in Nigeria

Fig. 4. Map of Gombe State showing Gombe Town

The climate of Gombe is characterized by a dry season of six months, alternating with six months rainy season. Rainy season starts around April or May; heavy rainfalls sometime may start in June or July to September. Weather tends to be very hot between November and March with mean annual temperature of about 32 °C or higher whereas relative humidity patterns to 90 % in August and dropping to less than 10 % during the Harmattan period [36].

The stratigraphy consists of the alluvium, the Cretaceous Sedimentary Formations of Kerri Kerri Formation, the siltstone, sandstone and ironstone of the Gombe Formation, the shale and characteristics of limestone of the Pindiga and Yolde Formation, Bima Formation and the basement rocks [37].

The World Bank, in its effort to assist the State in solving the menace of flood through engineering approach, constructed drainages in 2005 and 2006, in residential areas ravaged by the flood that occurred in the year 2000. Despite all these efforts annual flooding of Gombe metropolis still persists [34, 38].

Flooding persists in Gombe metropolis because flash and fluvial types of flooding do occur at the same time (Fig. 5) [39]. The other reason is that Gombe town is situated at a higher altitude, which makes the sloping terrain of water flow through the constructed drainage channels to build up high run off coefficient. Thus, the high velocity of water leads to overflow in channels causing soil erosion along the drainages and gully erosion within and around the environs houses.

a *b*

Fig. 5. Some flood Scenes in Gombe: *a* – in residential houses; *b* – in a major street road

2.2. Erosion Study Sites. Survey of the erosion sites was investigated and study areas selected were: Bogo, BCGA, Kaniel and Doma seasonal streams/erosion sites, designated as A, B, C and D respectively (Fig. 6).

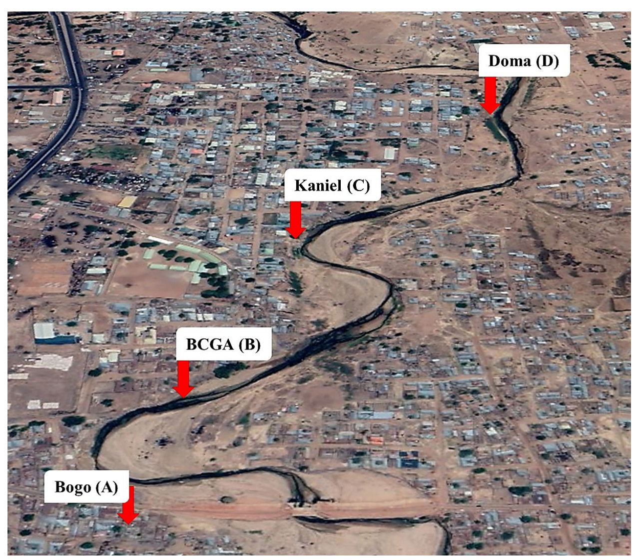

Fig. 6. Gully Erosion Sites of the Study Area

Sites location, field measurements of erosion depths and bed width were carried out and recorded using relevant standard field instruments. The distance between the erosion sites areas of study spans 3.54 km.

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2.2.1. Sample collections and analysis. Soil samples were collected from the mapped site (A to D) (Table 1) along the stream/erosion side walls. Soils from each site were taken from top, middle and bottom.

Depths were not based on predetermined precision depths because vertical depths of erosion varied in each site. Soil samples were collected using Augur, hand-held shovel, into polythene bags, labeled and named before taking to laboratory for analysis.

Table 1

Erosion Sites of the Study Area

S/N	Location (Site)	Elevation (m, a.s.l.)	Latitude, °N	Longitude, °E	Erosion Depth (m)	Bedwidth (m)	Nature of Erosion
1	A (Bogo)	391	10°16′22.9692″	11°12′18.9868″	4.3	45.2	Gully
2	B (BCGA)	387	10°16′18.6240″	11°12′33.3360″	5.23	47.4	Gully
3	C (Kaniel)	386	10°16′10.8120″	11°12′51.2712″	8.00	43.0	Gully
4	D (Doma)	361	10°16′21.0936″	11°13′32.6964″	8.26	39.12	Gully

Note: a.s.l. – above sea level

3. Results and Discussion

The erosion characteristics of the study area with respect to the gully length, width, depth and nature of the erosion are shown in Table 1. The grain size analysis, bulk density, porosity, sand percentage composition, clay and silt and textural class are as shown in Table 2, and chemical properties of the soils, shown in Table 3.

3.1. Soil physical characteristics

Porosity: Porosity is the ratio of the space taken up by pores in a soil to its total volume. The porosity of soils from the study areas ranged from 40 to 48 % with a mean of 44.5 %. The highest porosity of 48 % was observed in site D (Doma) and lowest observed in Site A (Bogo) having 40 % (Table 1). Porosity from the entire study area contains low volume of voids relative to the volume of solids. Soils of low porosity are more porous and less cohesive, this prone soils to erosive forces [40].

Table 2

Soil Textures of Study Sites

Parameters	Bogo	BCGA	Kaniel	Doma Mean
Bulk Density ($g \cdot cm^{-3}$)	1.8	2.0	1.4	1.6–1.7
Porosity (%)	40	46	44	48–44.5
Sand (%)	78.3	72.8	73.2	75.1–74.9
Silt (%)	9.0	16.2	11.3	4.9–14.1
Clay (%)	12.7	11.0	15.5	20.0–11.0
Textural class	Sandy clay	Sandy silt	Sandy clay	Sandy clay

Table 3

Chemical Parameters of Soils from the Study Sites

Site	Depth	pH	P	K	Ca	Mg	Na	OM	CEC
					mg/kg			Cmol/kg	
A (Bogo)	Top	6.30	17.0	3.50	8.20	2.30	0.80	0.70	5.20
	Middle	6.80	15.4	4.10	6.70	2.50	0.70	1.10	6.10
	Bottom	6.40	16.0	2.20	6.50	1.40	0.40	0.50	5.80
	Mean	*6.50*	*16.1*	*3.27*	*7.13*	*2.10*	*0.63*	*0.77*	*5.70*
	S.D±	0.264	0.808	0.971	0.929	0.585	0.208	0.305	0.458
B (BCGA)	Top	6.50	18.5	3.50	7.90	1.80	0.60	1.20	2.80
	Middle	6.02	19.1	2.40	8.10	2.60	0.50	1.00	3.10
	Bottom	6.20	17.8	1.90	8.70	2.80	0.10	0.60	4.20
	Mean	*6.24*	*18.50*	*2.60*	*8.23*	*2.40*	*0.40*	*0.93*	*3.37*
	S.D±	0.242	0.650	0.818	0.416	0.529	0.264	0.305	0.737
C (Kaniel)	Top	6.40	19.4	4.50	9.50	3.50	0.60	0.60	6.70
	Middle	6.60	18.9	3.80	8.80	3.10	0.80	0.90	7.20
	Bottom	6.20	18.3	2.70	7.80	2.70	0.50	0.40	7.80
	Mean	*6.40*	*18.9*	*3.67*	*8.70*	*3.10*	*0.63*	*0.63*	*7.23*
	S.D±	0.200	0.550	0.907	0.854	0.400	0.152	0.251	0.550
D (Doma)	Top	6.70	20.0	4.10	10.0	1.50	0.20	1.20	5.90
	Middle	6.50	18.7	3.20	8.90	1.70	0.40	0.80	6.50
	Bottom	6.10	18.5	2.30	7.80	1.20	0.10	0.60	5.69
	Mean	*6.43*	*19.1*	*2.30*	*8.90*	*1.47*	*0.23*	*0.87*	*6.03*
	S.D±	0.305	0.814	0.900	1.100	0.251	0.152	0.305	0.420
	E.S.M	*6.40*	*18.15*	2.96	8.24	2.27	0.47	0.80	5.58

Notes: pH – Hydrogen Potential; P – Phosphorus; K – Potassium; Ca – Calcium; Mg – Magnesium; Na – Sodium; OM – Organic Matter; CEC – Cation Exchange Capacity; S.D – Standard Deviation; E.S.M – Entire Site Mean

Bulk density: Bulk density is a property that determines the hydrological functions of the soil and determines the rate at which rainfall is absorbed. The infiltration of water into the soil is also affected by soil bulk density. Soils bulk density ranged from 1.4–2.0 g/cm^3 (Table 2). This is slightly high compared to the average standards values of 1.33 g/cm^3 [41], where the bulk density is high, infiltration reduces and increases overland flow that results into erosion [42]. This is also aggravated by the topographical gradient of Gombe town, which is situated at a height of 628 m above sea level. The height reduces downwards towards the drainage basins into river Gongola at Dadinkowa area boundary with Borno State having a mean slope gradient of 5°. This is considered high gradient for unprotected soil surface [37].

Slope angle that inclined at 3° to 50° represents a slope gradient of about 63 % of the spatial variations; causing low infiltration and high runoff conditions which weakens soil structure thereby making it vulnerable to the intensity of gully erosion [43], and in a site causes severe gullies [44].

Soil textures: The mean soil particle size analysis from the study showed the percentage constituents comprised of 78.3 % sand, 9.0 % silt and 12.7 % clay. Site (A) Bogo, (C) Kaniel and (D) Doma all falls under sandy clay textural class, while sites (B) BCGA, falls under sandy silt soil. This means the soils in the three areas (A, C and D) are highly sandy in nature. This agrees with earlier study on the characteristics of the Gombe town soils, Gombe soils that averaged of 70 % sand proportion at the top layers and lesser percentage clay content at the bottom layers [37, 45]. High proportion of sandy soils, leads to high water percolation and infiltration due to high proportion of clay content at the bottom layer [46]. This leads to increase in the collapsing and slumping of gully walls as witnessed at Bogo, BCGA and Doma (site A, B, D), Fig. 7, 8. The sandstones and shales (Gombe Sandstone and Pindiga Formations dominated Gombe town geology and have been accelerating gully erosion through rock fracture and weathering [46–48].

Characteristics of the longitudinal profiles of the gullies throughout the study area alternate along the 3.54 km length span. Some areas are deeper in length; others have wide bed and top width. This is possibly due to variation in nature of soil composition and geology of the study area as it either resists erodibility or easily eroded.

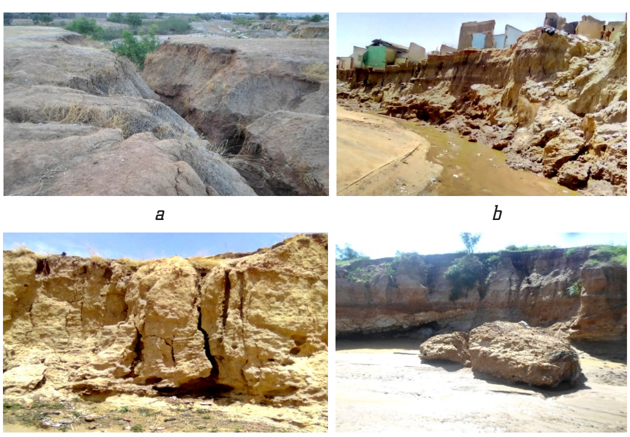

Fig. 7. High percentage of sandy soils leads to collapse of gully walls along study site axis: *a* – gully at site A; *b* – gully walls & houses at site B; *c* – gully walls at site C; *d* – gully walls at site D

Fig. 8. Washing, scouring and undercutting of sandstones around houses at: *a* – site A; *b* – site C axis

Studies on changes in bed widths over a period showed an increase from 6.2 m to 52.5 m in ten years, implying a mean annual increase of 210 m^2 [37]. This study found out that over 70 % of the gully sites top and middle bed width layers are sandy soils, while the bottom bed width layers in BCGA, Kaniel and Doma sites (B, C, D) are all under laid by sandstones, this helps to prevent excessive bed width erosion leading to undercut of residential, commercial structures and farms.

3.2. Soil Chemical Characteristics

Soil pH: The mean soil pH values from the sites were 6.60, 6.24, 6.40, 6.43 (Table 2). This indicates the soils are slightly acidic (between 6 and <7). Acidity in soils affect microbial activities on organic matter which might enhance the binding of soils to resists erosivity of rain runoff effect [49, 50], otherwise high acidity dissociates soils which might be prone to erodibility.

Metallic concentrations: The mean concentrations of phosphorus (P) from the sites were 16.1, 18.5, 18.9, and 19.1 mg·kg^{-1} for sites (A–D) respectively. Concentration tends to increase down the slope of the seasonal river and falls within medium standard ratings [51] (Table 4), but falls under high concentration [47, 50]. Potassium (K) concentrations fluctuate between 3.27, 2.60, 3.67 and 2.30 mg·kg^{-1}. These concentrations are higher by standard rating with range of (0.15 to >0.30) and values of >1.2 mg·kg^{-1} as «very high» [50]. Exchangeable K is a part of the cation exchange capacity of soils and is adsorbed on the soil colloids [52].

Table 4

Standard Rating for Interpreting Levels of Soil Analytical Parameters

Parameter	Low	Medium	High
Ca^{2+} (Cmol·kg^{-1})	<2.00	2.00–5.00	>5.00
Mg^{2+} (Cmol·kg^{-1})	<0.30	0.30–1.00	>1.00
K^{+} (Cmol·kg^{-1})	<0.15	0.15–0.30	>0.30
Na^{2+} (Cmol·kg^{-1})	<0.10	0.10–0.30	>0.30
CEC (Cmol·kg^{-1})	<6.00	6.00–12.00	>12.00
OC (%)	<0.40	0.40–1.40	>1.40
N (%)	<0.08	0.10–0.20	>0.20
P (mg·kg^{-1})	<3.00	3.00–20.00	>20.00
OM (%)	<1.50	1.50–2.50	>2.50
Bulk Density (g/cm^3)	<1.50	1.50–5.00	>5.00

Notes: OM – Organic Matter; OC – Organic Carbon; N – Nitrogen; P – Phosphorus; Na – Sodium; K – Potassium; Ca – Calcium; Mg – Magnesium; CEC – Cation Exchange Capacity

For Calcium (Ca), the mean values were 7.13, 8.23, 8.70, 8.90 mg·kg^{-1}. All the values are classified as being «high» ratings of soils. Ca strives on soil with pH range 6 to 10 and above referred to as an alkaline metal. Magnesium (Mg) mean values for the sites were 2.10, 2.40, 3.10, 1.47 mg·kg^{-1}. All the values are above the standard values (Tables 3, 4). Both Ca and Mg are secondary nutrients givers in soils, hence they bind soil particles together [53]. If calcium and magnesium are the predominant cations in a soil, exchange complex, tends to be easily permeable, thereby leaving the soils in granular structure [54–56] and therefore susceptible to erosion.

Sodium (Na) mean values from sites (A–D) ranged between 0.63, 0.40, 0.63 and 0.23 mg·kg^{-1} (Table 3). All the values are far above the standard ratings (Table 4). Na readily reacts with other substances in chemicals processes in soils. High sodium concentration contributes to the weakening of soil aggregates and their dispersion under rain drop impact [57].

The results of soil Organic Matter (OM) showed that the mean values were 0.77, 0.93, 0.63, 0.87 %. All the field values are below the values of <1.50, 1.5–2.50 and >2.50 representing low, medium and high rates respectively. Earlier studies in the area indicated that top soils which inhabit most plant nutrients and organic matter are removed by erosion leaving soils with low nutrient status, poor structure and low water holding capacity [37]. Organic matter content in soils should be in the range of 1.9–3.0 % to bind the soil and attain productivity [58].

The mean values of CEC for the five gully sites range from 5.99–7.02. This means the CEC is slightly at medium level in the soils when compared to standard ratings [51] (Table 4). Cation Exchange Capacity (CEC) is the total capacity of a soil to hold exchangeable cations. It influences the soil's ability to hold onto essential nutrients and provides a buffer against soil acidification and erosion.

High CEC value (>25) is a good indicator that a soil has a high clay and/or organic matter content and can hold a lot of cations. A soil with a low CEC value (<5) is an indication that a soil is sandy with little or no organic matter that cannot hold many cations [59].

Thus, from this study, the soil properties of the gully erosion sites were found to be sandy loam and slightly acidic. This means the binding medium of the soil are less cohesive, hence, easily dissolved and washed away by flood. This explains why the gully sites are widened on yearly basis by collapsing from sides.

This research is limited to studying the characteristics of the erosion site soils, relationship with flood water and its negative effect on the immediate environment. It is expected that the results of the soil texture, chemical and the metallic properties of the area soils will be further helpful in planning on how to proffer solution to the problem of gully erosion in the study area.

3.3. Mitigation measures to prevent further widening of the gullies. The frequent occurrence of the flash and fluvial floods necessitated the people in Gombe and environs to adopt various methods of curtailing the gully menace against the environment, houses and farms; one of such measures is the use of vegetative cover as mitigation against the soil erosion. The most suitable cover plant used by the people is the *Ipomoe Carnea*.

The plant reproduces vegetatively through stems and root very fast. The plant stems are cut and transplanted during early rainfall in edges of water ways where they sprout out rapidly, provided there is enough moisture in the soil; to protect excess flood into farms (Fig. 9) and gullies (Fig. 10).

a

b *c*

Fig. 9. Transplanted *Carnea: a* – during dry season; *b* – sprouting from both sides of a seasonal river during rainy season

a

b

Fig. 10. *Carnea* transplanted at the base of the gullies: *a* – to stop expanding into a farm; *b* – to prevent gully expansion

To prevent expansion of water flow from flash flood that leads to collapse of gullies banks in streams and rivers, the plants are transplanted some meters away from the stream bank towards the river flow beds (Fig. 11).

In farms the plants are either transplanted on the small rills noticed on the farm or across the river (Fig. 12). For prevention against gully wall collapse that affects houses, are *Carnea* is planted at some distance from the house foundation, fence or wall towards the riverbeds (Fig. 13). Research showed erosion widens in similar areas where *Carnea* was not planted (Fig. 14).

Fig. 11. *Carnea* transplanted away from the stream bank to curtail expansion of fluvial erosion

a

b

Fig. 12. Grown *Carnea* in:
a – farm rills; *b* – stream bank to prevent soil erosion on farms

a *b*

Fig. 13. *Carnea* planted along: *a* – riverbeds; *b* – erodable area, to protects houses affected by fluvial erosion

a *b*

Fig. 14. Erosion widens in Areas where *Carnea* was not planted:
a – into Residential houses; *b* – gully cutting below houses

The use of *Ipomoe Carnea* plant as mitigation measures against flash and fluvial flood, has proved effective especially in the farms and house fencing. Government should encourage people to participate in organize planting of the *Ipomoe Carnea*. Less privilege and farmers should be supported on the continuous and massive planting of *Ipomoe Carnea* in all the required areas.

However, the study sites throughout its 3.54 km length are all within residential areas. Over the years efforts have been made to proffer engineering solution to the menace of the gully erosion in Gombe town, standard engineering construction of drainage system channels to convey the high fluvial floods from the tributaries into a main course are not properly constructed.

The best measure to prevent further widening of the gullies, which have been destroying houses in the near future, is general landscaping of the affected areas, followed by construction of gabion floors, gabion retaining walls, gabion baskets, and concrete drainage channels depending on area suitability. The best-recommended type of drainage channel suitable for gully erosion of this magnitude is trapezoidal drainage channels [60, 61].

It is recommended that before construction of engineering erosion control structures such as the gabions and drainage channels inform of terraces, waterways, drainage systems, porous barriers and concrete structures, are done, detail soil, hydraulic, geological and topographic studies of the area should be properly investigated. This is because gullies in the study area (Gombe) need proper and standard design considerations like width of structure, depth of water flow, soil water holding capacity, velocity of water flow to enable for the construction of durable discharge channels that will convey volumes of flash flood water out safely with minimum damage to the environment.

4. Conclusions

The assessment of soil properties from the study sites were mostly found to be dominated by loosed and very porous sandy constituents with low proportion of silt and clay. The textural class of the entire site soil is sandy-loam. Over 70 % of the gully sites top and middle bed width layers are sandy soils, while the bottom bed width layers in BCGA, Kaniel and Doma sites (B, C, D) are all under laid by sandstones, this helps to prevent excessive bed width erosion, but undercut residential, commercial structures and farms.

Physical properties of the site soils showed that bulk density is relatively high, while porosity was highly permeable. The chemical property of organic matter is low; potassium, sodium, calcium, magnesium and phosphorus were found to be high. The hydrogen potential (pH) showed that, the soil is slightly acidic, the exchangeable cations capacity was medium. Development of deep and wide gullies that keep occurring in the study site is facilitated by the above reasons. This explains why some of the earlier gully control effort by government in the area failed; because soil properties around the gullies were not properly studied before erecting the control measures.

Conflict of Interests

The authors declare that there is no conflict of interest, including financial, personal, authorship or other anything that could affect the research and its results presented in this article.

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Data availability

The manuscript has no associated data.

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✉***Malum Japhet Flayin,*** *Postgraduate Student, Department of Agricultural and Environmental Engineering, Joseph Sarwuan Tarka University, Makurdi, Benue State, Nigeria, ORCID: https://orcid.org/0000-0002-9400-2546, e-mail: jmflayin@gmail.com*

Martins Okechukwu Udochukwu, *Professor, Department of Agricultural and Environmental Engineering, Joseph Sarwuan Tarka University, Makurdi, Benue State, Nigeria, ORCID: https://orcid.org/0000-0002-8691-561X*

✉*Corresponding author*