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Impact of Gully Erosion Stream Sedimentation in Demepke Drainage Basin

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Abstract This study examined gully development in Demekpe drainage basin, Makurdi Local Government Area of Benue State of Nigeria; with a view to determine the volume and amount of sediment loss from a 3rd order gully system. The systematic sampling technique was used to segment the gully which measured 220m long at intervals of 20m. Parameters measured include among others gully length, gully depth, gully shoulder and bed widths, slope gradient, cross sectional area, stream density, stream frequency and stream intensity. Cartesian coordinates, spot heights and core soil values were also determined. Digital Elevation Model was used to model gully form, direction of runoff and sediment delivery ratio in the gully system. The result showed that the volume of sediment loss from the gully system with a cross sectional area of $91.7m^2$ is $931.5m^3$ using the End Area method of soil loss determination. The amount or weight of sediment loss from the gully system is estimated to be 12,575.28 tonnes. The Digital Elevation Model of the gully system indicates a trapezoidal form and slopes with summital convexity. The convexity of the slope shape implies that runoff is generated from all sides of the slopes, influencing a considerate amount of sediment loss at the gully sides and floor. It is therefore recommended that planting of cover crops should be intensified to enhance infiltration and concreted surfaces should be minimised to reduce surface runoff and sediment loss along slopes.

Keywords: *gully, sediment loss, digital elevation model, Demekpe drainage basin, Makurdi local government area*

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1. Introduction

Gully erosion is a serious environmental problem, in its entire ramification [5]. The initiation and development of gully erosion in any part of the world, is dependent on some factors: these include among others climatic parameters (rainfall erosivity, wind, temperature), soil characteristics (mainly erodibility), geology, vegetation, topography and anthropogenic activities [26]. According to Udosen [23], a gully is any eroded channel so wide that it cannot be crossed by a wheeled vehicle or eliminated by ploughing. Gully erosion has been reported in different parts of the world by a number of researchers, including, Udosen [21,22,23,24,25] in Akwa Ibom State; Iorkua [12] in Makurdi; Eze and Effiong, [4] in Calabar; Soufi and Isaie [21] in Iran; Ionita [11] in Romania and Ebisemiju [2] in Guyana. It is imperative to emphasise that gully erosion lead to destruction of farmlands, buildings, roads as well as the development of bad land topography and soil depletion [26]. In the study area, one of the major observable consequential processes of gully erosion is stream sedimentation. According to Ionita [10] stream sedimentation is a fluvial process through which sediments (sand, silt and clay) are carried in stream flow in a drainage basin due to runoff and other sub-aerial processes occurring in the basin downstream.

Worthy of note is that a few studies have been carried out in Makurdi on gully form and development. See for instance Iorkua [11,12]. However, there are observed deficiencies in literature on gully development in the study area, with paucity of knowledge on the volume and amount of sediment loss from gully catchments due to stream sedimentation. Also, because loss of soil due to erosion removes useful farmland, adds to sediment loads, and can help transport anthropogenic fertilizers into the river system, and thereby poisoning the river, a phenomenon known as eutrophication occurs [10]. These consequences of stream sedimentation pose threats to aquatic lives and other water resources, as well as the surrounding environment. Despite the socio-economic and environmental consequences of gully erosion stream sedimentation in the Benue valley, the studies of gully development are deficient in literature. This study therefore, examined gully development in Demekpe drainage basin in Makurdi Local Government Area, with a view to determine the volume and amount of sediment loss from a 3rd order gully system; to enhance controlled gully development and soil degradation in the study area.

1.1. The Study Area

The study was conducted in the Demekpe drainage basin, in Wadata catchment Area, South bank of Makurdi LGA, Benue State. The study area is located between longitude 8^{0} 36^{1} 0^{11} and8^{0} 36^{1} 12^{11}, as well as between latitude 7^{0} 47^{1} 02^{11} and7^{0} 47^{1} 15^{11} (Ministry of Lands and Survey Makurdi, 2014). The area experiences wet and dry climate, branded “Aw” by Koppen’s climatic classification scheme. This type of climate is also called the tropical humid savanna climate. The wet season which last for seven months starts from April to October. Conversely, the dry season starts from November and ends in March. The climate is usually associated with torrential rainfall and high temperatures. The annual total rainfall ranges from 900mm to 1800mm, with an average annual intensity of 44.85mm/hr [11]. In terms of geomorphological processes, the most important feature of the climate is the long duration and intensity of rainfall. Soil type in the area is predominantly sandy loam with high percentage of sand particles. Temperatures are high throughout the year, averaging 27^{0}c to 31^{0}c. Though, it may occasionally rise to 37^{0}c in some days in March and April. It is probable to note that, high temperatures harden the exposed soil and enhance surface run-off.

In terms of relief and drainage, the study area has an undulating terrain with slope angle hardly exceeding 10^{0}. Its general topography varies between 65m – 110m within the Wadata catchment area [20]. The river Benue provides the major drainage system. The Demekpe drainage basin is a 3^{rd} order drainage basin, with a total of 8 1^{st} order streams, 5 2^{nd} order streams and 1 3^{rd} order stream analysed from topographical maps of the study area. The Demekpe drainage basin has an average bifurcation ratio of 3.3. The moderate bifurcation ratio could be attributed to the sedimentary rock which underlies the basin and moderate rainfall intensities. See Figure 1.1 for location and Figure 1.2 for relief and drainage maps of the study area.

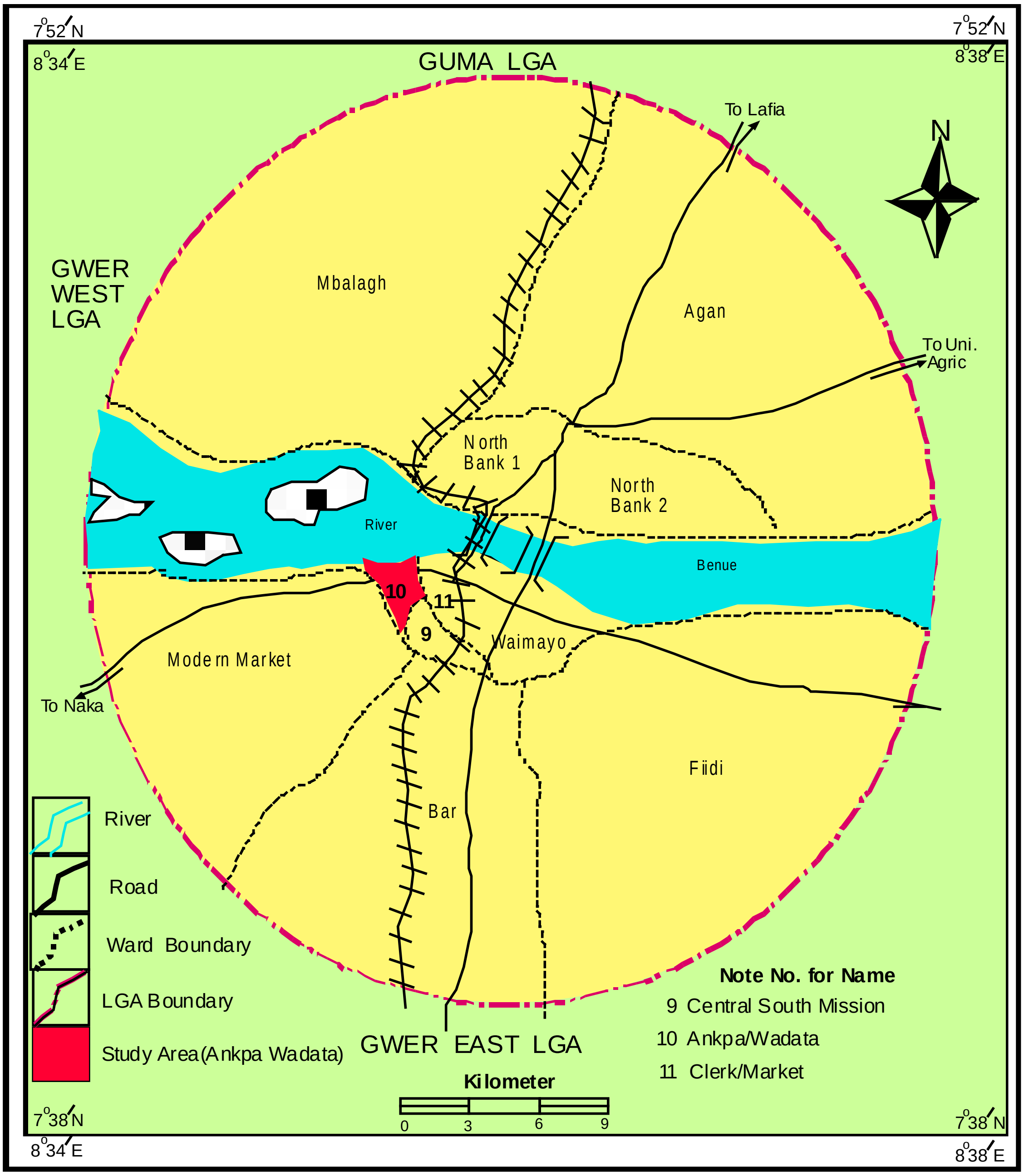

Figure 1.1. Location of the study area on Map of Makurdi Local Government Area (Source: Ministry of Lands and Survey, Makurdi, 2014)

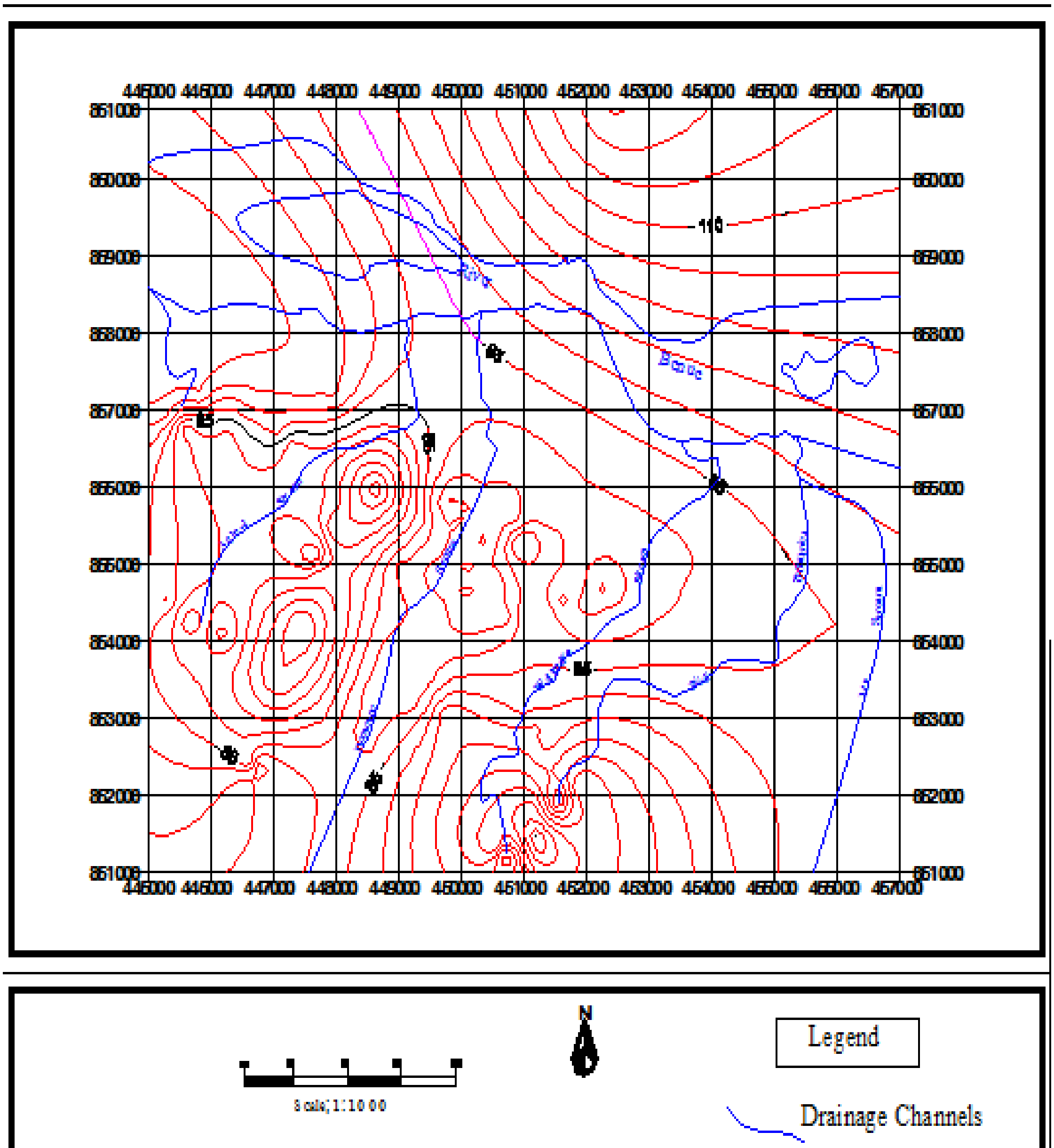

Fig 1.2 Relief and Drainage Map of the Study Area

Source: Ministry of Lands & Survey, Makurdi.

Figure 1.2.

1.2. Theoretical Framework

This study emphasised the complex systems theory. Walonick [28] noted that complex systems theory is an aspect of general systems theory that consider elements with diverse components that are interrelated and interdependent. The complex systems theory therefore is applied on systems that are made up of subsystems, either open and closed systems or components which are dependent on one another [28]. The open system is a system that receives input from the environment and releases output to the environment. Whereas, a closed system is one which only receive inputs without given output [6]. A system's input is therefore defined as the movement of matter or energy from the environment into the system. Output is the movement of matter or energy from the system to the environment. Both input and output involve crossing the boundaries that define the system [28]. The gully system is an open system that is made up of different components like shoulder and bed widths, slope gradient, depth, length among others which continually depend on one another and exist in a state of dynamic equilibrium with the prevailing environmental conditions and processes [26]. There are also inputs into the system in form of precipitation and runoff; and output in form of discharge and sediment yield (i.e. sand, silt and clay) from a gully system [13]. This study determined the volume and amount of sediment loss in a gully system within the Demekpe drainage basin as an output measure; influenced by adjustments in the gully parameters resulting from precipitation, runoff and other sub-aerial processes occurring in the drainage basin.

2. Materials and Methods

The study employed field method design and systematic sampling procedure, which enabled gully parameters like shoulder width, bed width, length, slope gradient, depth, semi-circularity ratio and cross sectional area to be measured from the field using some survey equipment namely: measuring tape, level and leveling staff, ranging poles, a tripod stand and six inches nails served as erosion pins. Also, morphometric properties of the Demekpe drainage basin namely: stream length, drainage density, drainage intensity, drainage frequency, stream order and length of overland flow were measured from topographic maps of the study area. To measure the morphometric parameters of the gully channel from field for analysis, the method of using erosion pins was adopted. Field measurements were done using some survey equipment as described below:

(i) Gully Length: This was measured using the linen tape and ranging poles, starting from the gully head. It was measured at 20m interval. Another 20m stretch was taken from the ranging pole that marked the end of the first stretch, downstream the gully, again at the most centre. This process continued to the mouth of the gully. This was done to determine the length of the gully channel.

(ii) Bed width and shoulder width. These were measured at each of the sampled points of the 20m intervals. At each of these points, the tape was stretched across the gully bed and shoulder to the opposite bank and readings in meters were obtained. The process was repeated at all the 12 sampled points. The bed and shoulder widths are the major cross sectional variables of the gully system and therefore, help to determine the width at the top and bottom of the gully.

(iii) Gully Depth: To measure the gully depth, the ranging poles and the linen tape were used. One of the poles was fixed at the deepest part of the gully bottom along the same line where bed and shoulder widths were measured. The tape was stretched across the gully over the ranging pole. A third person standing near the ranging pole on the gully bottom noted where it met the tape. The pole was removed and measured (from the ground up to the point where it met the tape) and the reading recorded as the depth. The depth is essential in determining the extent to which the gully has been incised into the underlying geological materials.

(iv) Slope Angle: Slope angle was measured using Abney level and leveling staff. Readings were taken at stretches of 20m interval. At each stretch, a reader stood in the middle of the pole to take readings both ways, focusing on the line in the Abney level, through the sight at the marked point on the pole. The difference in the two readings gave the angle of that particular stretch. The slope angle is insightful on the gradient along the gully side walls and the extent to which it has influenced sub-aerial processes in the gully system.

(v) Shoulder width/bed Width Ratio: This was determined at all the 12 sampled points by dividing the values of the shoulder width by the bed width. The shoulder width/bed width ratio is important for determining the adjustment between the two cross sectional variables (bed and shoulder width) with the prevailing gully development mechanisms. **(vi) Shoulder width/depth Ratio:** This was determined at all the 12 sampled points by dividing the values of the shoulder width by the depth of the gully system at those points.

The shoulder width/depth ratio helps in determining the developmental dimension of the gully system, in terms of widening and deepening in relation to the prevailing processes and mechanisms.

(vii) Cross Sectional Area: This was determined at all the 12 sampled points by multiplying the shoulder width at those points by the depth of the gully system at those points and expressed in m^2. The cross sectional area is imperative to determining the total area covered by the gully channel extending from the watershed to the extent to which it has been incised.

Data on stream length, stream density, stream frequency, drainage intensity and stream area of basins in the gully catchment were derived from topographic maps of the study area as described below. The drainage basin parameters were essential in determining the level of drainage dissection in the study area and the extent to which it has influenced gully development and morphology.

(viii) Semi-circularity ratio. Semi circularity ratio of gully head scarp was determined using the formula:

$$RSc = L / W \tag{1}$$

where, RSc is the semi- circularity ratio.
L, is the minimum length of gully head measured from a point equidistant from the two shoulders of gully head base to the most distant on gully head rim.
W, is the maximum width of gully head. All measurements at the gully head were done using a measuring tape

(ix) Stream length. The length of streams were determined by dividing the topographical maps of the study area at scale 1:50 000, of topographic sheets, Makurdi 251NE, Makurdi 251SE and Makurdi 251 SW into grids of 5cm interval and measuring the streams and converting their dimensions into kilometer using the map scale. The formula used was:

$$\begin{aligned} &\text{Ground distance} \\ &= \text{Map distance} \times \text{Scale factor} / 100,000. \end{aligned} \tag{2}$$

Hence, stream lengths were expressed in kilometers.

(x) Stream Area. The individual stream area was determined using the square method. The entire basin area was divided into series of squares, and individual stream area was computed and expressed in km^2 using the map scale [26].

(xi) Stream frequency which is the number of stream segment per unit area was determined using the formula:

$$Ds = Ns / Ab \tag{3}$$

where Ds, is the stream frequency. Ns, is the number of stream segments per km^2 in the basin. Ab, is the area of each stream segment.

(xii) Drainage density. Drainage density of streams in the studied basin was determined using the formula:

$$Dd = L / Ab \tag{4}$$

where Dd is the drainage density. L, is length of stream and Ab is the basin area of each stream.

(xiii) Drainage intensity. It was determined as a product of drainage density and stream frequency in the studied basin.

(xiv) Length of overland flow or runoff. The length of overland flow in the gully Catchment was determined as the reciprocal of drainage density using the formula:

$$Lo = 1 / Dd \quad (5)$$

where Lo, is the length of overland flow. Dd is the drainage density [7].

(xv) Moreso, to map the gully catchment, Global positioning system (GPS) receiver (Garmin GPS 12) was used to extend controls for the gully catchment to determine 100 spot heights and their corresponding Cartesian coordinates. Erdas Imagine, Arc GIS and Kriging analysis in Suffer 9.0 software were used to model the gully form, direction of runoff and sediment delivery in the gully channel.

(xvi) Soil Samples. To analyse the soil property from the gully system, 12 core soil samples were taken from the gully floor by using a McCauley corer of approximately 5.5cm in diameter and 4cm in height for determination of physical characteristics and bulk density. The textural properties of the soil samples were determined in the laboratory using the separation by sieving method. The soil bulk density of core soil samples was determined in the laboratory using the formula:

$$P_b = M_s / V_t \quad (6)$$

where P_b is the bulk density, M_s is the mass of oven dried soil and V_t is the total volume of soil (see [9]). Cross Sectional Area of the gully catchment was determined using a formula adopted by Ofomata [18] in South Eastern Nigeria. The formula is given as:

$$A = wd \quad (7)$$

where, A = Cross Sectional Area (m^2)
w = depth of the gully

The values of the cross sectional area was then used in the End Area formula to determine the volume of soil loss from the gully system using the formula:

$$\text{Volume of soil loss} = {}^{1/2}\left(Y_1 + Y_2\right)d \quad (8)$$

where d, is the distance between cross sectional areas, Y_1, is the first sectional area and Y_2, is the second sectional area. The weight or amount of sediment loss from the gully catchment was estimated by multiplying volume of soil loss with the soil bulk density (see [13]). Moreso, tables were used to code the data and descriptive statistics (i.e. mean and standard deviation (S.D)) were used to ascertain variation in the data set.

The percentage, mean and standard deviation were used to ascertain the variation in the data set. Percentage was computed using the formula:

$$n / \sum N \text{ x } 100 \quad (9)$$

In the formular, n, is the value of each individual score and ∑N is the sum of the all the scores multiplied by 100. Mean was determined using the formula

$$\sum N / n \quad (10)$$

where ∑N, is the sum of all the observation and n, is the number of observation.

Standard deviation was determined using the formula:

$$S=\sqrt{\frac{\Sigma(x\text{-}M)^2}{n}} \quad (11)$$

where x, is individual observation, M, is the mean and n, is the number of observation.

3. Results and Discussion

3.1. Gully Morphometry and Development in the Demekpe Drainage Basin

Drainage basin characteristics obviously influence the manner and the rate by which water is transmitted through the system, and the local characteristics determine exactly how a basin responds to a particular climatic input to produce output in stream flow [26]. Sediment yield from a basin, which is indicative of gully's rate of development and morphology is equally influenced by the drainage basin characteristics and by the way in which the basin generate stream flow. Thus, the sediment can be visualised as composed of a number of subsystems, particularly the channel subsystem, encompassing erosion and deposition, especially in a gully channel, which is seemingly an open system [16]. See Table 1 below for the morphometric parameters of the gully.

Table 1. Morphometric properties of the Gully catchment

	Distance from Gully Head (m)	Gully Depth (D) (m)	Bed Width (BW) (m)	Shoulder Width (SW) (m)	Slope Angle (SA) Degree	Shoulder Width/Depth ratio	Shoulder Width/Bed Width Ratio	Cross Sectional Area SWxD (m^2)
	0	1.1	8.0	9.0	3	8.18	1.13	9.90
	20	2.2	6.5	7.5	2	3.14	1.15	16.50
	40	1.58	5.2	6.0	3	3.79	0.12	9.48
	60	1.0	4.0	4.3	2	4.30	1.08	4.30
	80	1.4	4.7	5.3	1	3.79	1.13	7.42
	100	1.4	5.9	6.7	1	4.79	1.14	9.38
	120	1.3	5.0	5.9	5	4.54	1.18	7.67
	140	1.3	4.7	5.0	1	3.85	1.06	6.50
	160	1.2	4.5	5.0	1	4.17	1.11	6.00
	180	1.0	5.3	5.9	1	5.90	1.11	5.90
	200	1.0	5.3	5.6	3	5.60	1.06	5.60
	220	0.8	3.2	3.8	1	4.75	1.19	3.04
Total		15.3	62.3	70.0	24.0	56.8	12.5	91.7
Mean		1.27	5.19	5.83	2.00	4.73	1.04	7.64
S.D		0.37	1.23	1.41	1.28	1.34	0.29	3.48

Source: Authors' field work, 2014.

From the results obtained through field measurements, it was discovered that the gully has a mean depth of 1.27m, mean bed width of 5.19m, mean shoulder width of 5.83m, mean slope angle of 2^0, mean shoulder width/depth ratio of 4.73m, mean shoulder width/bed width ratio of 1.04m and mean cross sectional area of 7.64m^2 (see Table 1). In terms of variability, shoulder width/bed width ratio revealed the lowest variability with standard deviation of 0.29; implying that the gully's shoulder width and bed width did not vary remarkably from its head down stream. The level at which shoulder width and bed width of the gully degrades concurrently accounts for the trapezoidal form assumed by the gully channel in space as revealed in Figure 1. By contrast, the cross sectional area of the gully showed the highest variation with a deviation of 3.48; which is indicative of the fact that the rate at which the shoulder width of the gully and the depth are degrading differs in time and space. This has severe impact on the amount of stream flow and sedimentation in the gully channel; as well as other process occurring in the gully system [20]. These cross sectional variables of the gully channel reflects the different processes occurring at the gully sides, head, floor and mouth. The low mean depth (1.27m) of the gully shows that the gully is shallow in depth and still undergoing the process of deepening. The widths of the gully tend to show more expansion and tendency of degrading, consequent upon lateral recession of gully side walls at work. This kind of gully wall expansion was also noticed in the study of gully erosion in North Bank area of Makurdi by Iorkua [12]. It is apparent that gully erosion development in the study area is influenced by factors like runoff, man's activities of cultivation and deposition, sandy loam soil type in the area and the geology which is predominantly sandstone [20]. The semi circularity ratio of the gully head scarp was determined to be 0.4; indicating that it has a broadly looped head scarp. This confirms the work of Essien and Okon [3] in Uyo were this kind of gully heard scarp was discovered and attributed to high intensity of rainfall and slope gradient. In the Demekpe drainage basin were the gully has been incised, the determinant factors of the broad looped gully head scarp remains the gently steep gradient at the gully head, moderate intensity of rainfall. This therefore, shapes the gully form by enhancing velocity of overland flow, sediment concentration and transport capacity of runoff in the gully system especially along the gully head were gully slope gradient is relatively steeper (see Table 1).

In a related vein, the mean length of streams in the Demekpe drainage basin, within the studied gully catchment area is 7.11km, with a mean basin area of 11.0km^2. The mean stream frequency is 0.69 and mean drainage density in the study area is 0.78km^{-1}. The drainage intensity in the study area is 0.63. The mean drainage density of streams in the gully catchment (0.78km^{-1}), with a moderate drainage intensity of 0.63 are capable of initiating gully development especially down slopes and impervious areas. See Table 2 for some morphometric properties of the Demekpe drainage basin contributing to stream flow in the gully catchment.

Table 2. Some morphometric properties of the Demekpe drainage basin.

Stream Order	Stream length (km)	Stream basin area(km^2)	Stream frequency	Drainage density (km^{-1})	Drainage Intensity	Length of overland flow(km).
2	6.31	16.2	0.40	0.39	0.16	2.56
2	7.74	8.30	0.72	0.89	0.64	1.12
1	5.73	9.50	0.31	0.60	0.17	1.67
2	9.55	5.90	1.13	1.61	1.81	0.62
1	6.22	15.10	0.87	0.41	0.36	2.44
Total	**35.55**	**55.00**	**3.43**	**3.90**	**3.14**	**8.41**
Mean	**7.11**	**11.00**	**0.69**	**0.78**	**0.63**	**1.68**
S.D	**1.39**	**3.98**	**0.29**	**0.45**	**0.61**	**0.75**

Source: Computed from 1: 50 000 topographic maps, Makurdi 251 NE, 251 SE and 251 SW.

The moderate drainage intensity of streams in the Demekpe drainage basin presupposes that drainage density and frequency have effects on the extent to which the surface has been lowered by agents of denudation like surface runoff. The findings of this study confirm those of Eze and Efiong [4] in Calabar, Pareta and Pareta [19] in MegaYamuna basin in India, who discovered that low drainage intensities influences flooding and erosion. The mean length of overland flow in the Demekpe drainage basin is 1.68km. This length of overland flow in a permeable landscape like Demekpe implies that surface runoff along stream channels is moderately high and relatively faster on steep slopes with little time of concentration downstream, as well as, influence the shape of the drainage basin. Hence, a determining factor to the broadly looped head scarp of the gully channel and degrading gully widths due to lateral recession at work. This poses a severe traffic hazard on the road at the foot of the slope were the gully is incised. Previous studies have also confirmed the influence of mean length of overland flow on basin form, flow and time of concentration downstream [14,15,23,27].

The Digital Elevation Model of the gully system in the study area revealed that the gully has a trapezoidal-shape (See Figure 2). The DEM also shows that the slope shapes from the gully are dominantly convex, implying that overland flow and sediment loss are generated from all sides of the slope in a northwest direction. This implies that runoff and sediment delivery ratio along the gully channel affects mostly the shoulder or top width and bed width due to the shearing effects and lateral recession along the gully channel. The implication is that sediment delivery ratio from the gully channel due to these gully processes is likely to increase over time as a result of the expansion of the gully wall sides and therefore posing severe effect to close-by dwellings, roads, farmlands and increased nutrients and oxygen depletion in river Benue. This is because runoff is collected in the gully channel alongside sediments, especially during rainy season and discharged into river Benue. This confirms the study of Ionita [10], who discovered in Moldarian Plateaus of Romania that gully development is associated with removal of materials through stream sedimentation. Also, it enhances the process of eutrophication; which implies overabundance of nutrients and oxygen depletion in river system. Thus, sediments are largely transported by stream flow into a river system and making it unsuitable for certain uses and sometimes pose as threats to aquatic lives; especially in situations where gullies are ephemeral and empty into a river system, like the gully in the study area. Also, a study by Adediji et al [1] in Irele local government of Ondo state using DEMs revealed dominantly convex slopes with V-shaped gullies. The gully form and convexity were attributed to the slope gradient in the study area, enhanced by raindrop impact and poor soil aggregates. In Wadata area of the Demekpe drainage basin, the trapezoidal form assumed by the studied gully system and the convexity of its slope shape are attributed to the gently steep slopes in the gully catchment especially along stream source points as in the case of gully head scarp (≥ 3^0), unconsolidated sandy soils in the study area and high amount of runoff which intensifies slumping of materials and sediment entrainment downstream.

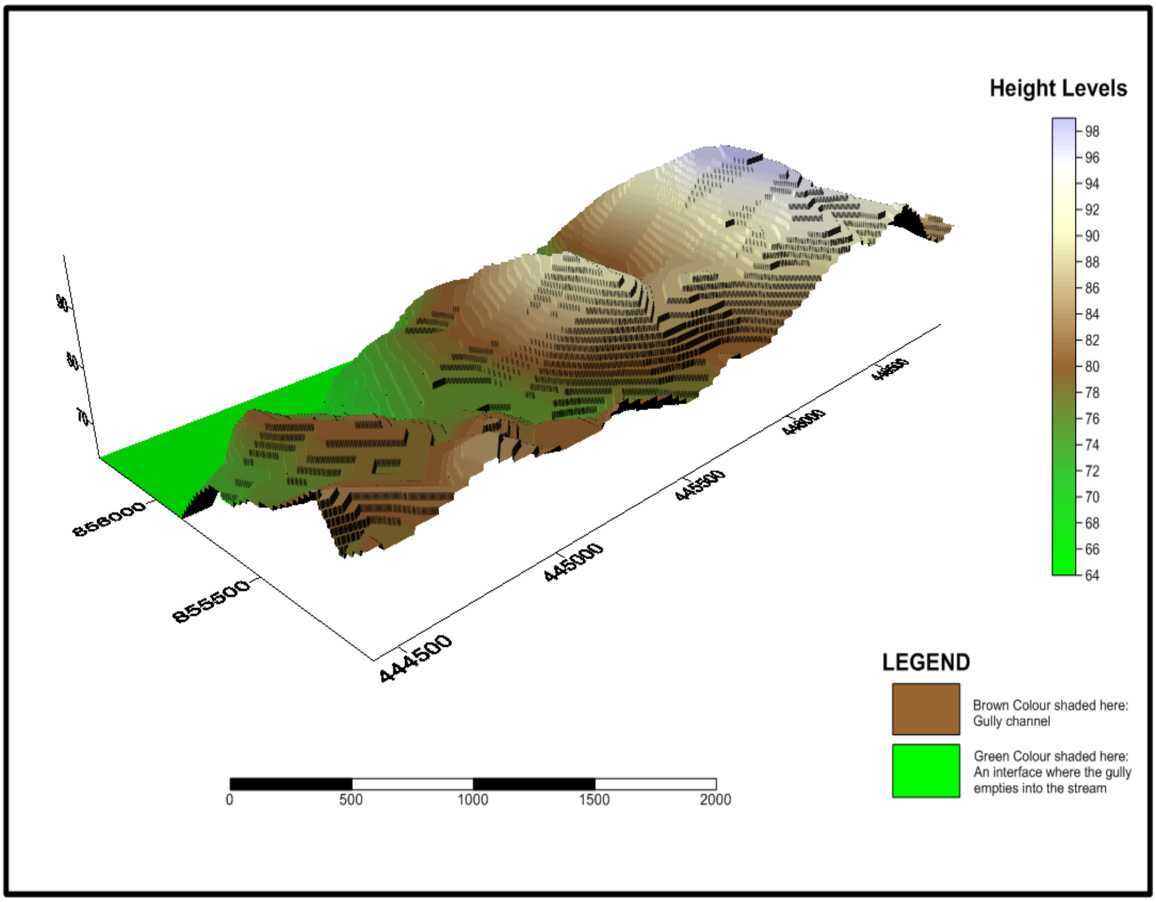

Figure 2: Digital elevation model showing morphology of the studied gully system

3.2. Soil Characteristics and Sediment Loss from the Gully Catchment

Soil textural characteristics and estimated volume of soil loss from the gully channel are shown in Table 3 below.

Table 3. Soil Textural Properties and Volume of Sediment Loss in the Gully catchment

Soil Properties	Sand (%)	Silt (%)	Clay (%)	Bulk density g(cm^3)	Volume of Sediment Loss (m^3)
	69.40	7.60	21.10	1.10	264.00
	68.50	12.50	20.30	1.11	
	58.30	12.80	28.90	1.01	137.80
	69.20	11.70	19.20	1.12	
	66.90	12.50	21.90	1.15	168.00
	62.80	9.90	27.30	1.27	
	65.30	11.20	23.50	1.16	141.70
	58.40	15.10	27.60	1.02	
	59.40	17.90	23.10	1.12	119.00
	66.60	11.90	22.10	1.13	
	61.30	15.90	23.20	1.08	101.00
	62.80	9.90	27.30	1.19	
Total	**768.9**	**148.9**	**285.5**	**13.5**	**931.50**
Mean	**64.08**	**12.41**	**23.79**	**1.12**	**155.25**
S.D	**4.14**	**2.82**	**3.21**	**0.07**	

Source: Authors' field work, 2014.

The soil textural properties of the studied gully catchment shows a high proportion of sand particles with mean value of 64.08%, mean silt value of 12.41%, mean clay value of 23.79% and a mean bulk density of 1.12cm^3 (see Table 3). It is imperative to note that the gully catchment is endowed with erodible soils, which are predominantly deep, sandy and are derived from alluvial deposits. The soil is well drained and so the water holding capacity is limited; and can as well be easily removed because of the coarse nature of the soils, and carried in stream by runoff. The gully system studied cuts through the thick layer of alluvium deposits to the relatively resistant sandstone bedrock. However, due to the uneven distribution of these mineral particles (i.e. sand, silt and clay) in the soil, it necessitates a great variation in their surface and sub-surface horizons; with sandy loam soil dominating the surface horizons and sandy clay at the sub-surface horizons. The soil structure of the gully catchment is mainly crumb at the top soil and sub-angular blocky at the subsoil. The properties of the soils in the gully catchment pre-supposes that gully initiation and development are likely due to the unconsolidated nature of the sandy loam soil at the surface horizons of the soils; which are easily detached and entrained by raindrop impact. Worthy of note is that, the soil properties positively predict the rate at which sediment is loss from the gully catchment.

Figure 3a. Culvert being destroyed by the gully

Figure 3b. Lateral expansion of the gully due to sediment loss

Figure 3c. Sediments carried in stream flow along gully bed

Figure 3d. Interface where the gully empty its sediments/load into river Benue

Source: Authors' field work, 2014.

Similarly, the volume of sediment loss from the gully catchment is shown in Table 3. The total volume of sediment loss from the gully catchment is 931.50m^3 with a mean value of 155.25 m^3. The estimated amount or weight of sediment loss from the gully catchment is 12,575.28 tonnes (i.e. Volume of sediment loss X bulk density) (see [1,13]. The amount of sediment loss in the gully catchment confirms the findings of Jeje [13] in South Western Nigeria and Adediji et al [1] in Ajagba Area of Ondo State in South Western Nigeria from a 1st order gully system. However, higher amounts of sediment loss were discovered from Ode-Irele Area (25, 996.83 tonnes), Idogun quarters (31, 700.16 tonnes) and Ado quarters (24, 973.04 tonnes) from 3rd order and 2nd order gully systems respectively by Adediji et al [1]. The differential amount of sediment loss from the 3rd order gully system in the study area could be attributed to the permeable and loose nature of the soils in the gully catchment and gently steep slopes in the gully catchment, hardly exceeding 4^0. Also, the 931.50m^3 of sediment removed from the 3rd order gully system with a total area of 91.7m^2 in the Demekpe drainage basin, though lower, but compares with 6, 900m^3 of soil loss from 7-8 hectares of gully system in the North Island East region, New Zealand by Harley et al [8]. Worthy of note is that the volume of materials eroded from the gully catchment in the study area has severe impact on the rate of accelerated erosion in the area as well as, attendant consequences on the environment. With this volume of sediment loss (931.50m^3) and amount of sediment loss (12,575.28 tonnes) from a 3rd order gully system with an area of 91.7m^2, the long term effect on farmland removal, river nutriment and destruction of roads due to lateral expansion of gully side walls are quite exacerbating. Moreso, the concurrent degrading of the gully's shoulder width and bed width, as well as the summital convexity of its slope shape as revealed by the digital elevation model shows that the interdependence or form-form adjustment of the gully properties influences the rate at which sediment is loss from the gully catchment, especially from all sides of the slope, giving the gully a trapezoidal form. See figures 3a, 3b, 3c and 3d for effects of the gully system in Demekpe drainage basin.

4. Conclusion and Recommendations

The development of a gully in the Demekpe drainage basin in Makurdi Local Government Area of North Central Nigeria was studied with a view to determine the volume and amount of sediment loss from the gully system. The gully system has a trapezoidal form resulting from a form-form adjustment, with concurrent degrading of the shoulder width and the bed width acted upon by lateral recession and slumping of materials due to mass wasting. The volume and total amount of sediment loss in the gully system are moderate as compared to those obtained elsewhere (see for instance [1,8,13] showed higher values). It is therefore concluded that sediment loss from the gully system in the study area is influenced by high amount of runoff from the concreted surrounding surfaces and roads; abandoned excavated gutters which enhances drainage density in the area and thereby, enhancing transportation and concentration of sediment downstream. Also, because of the coarse nature of the sandy loam soil in the study area which are easily detached and carried by overland flow, gullies are likely incised and stream sedimentation enhanced, which impacts the amount of sediment loss at any given time. Therefore, to curb gully development and reduced amount of sediment loss from gully systems in the study area, infiltration should be encouraged by planting cover crops and grasses between buildings rather than cement pavements to reduce the velocity and amount of runoff in the area and sediment loss along slopes.

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