The Influence of Drainage Basin Morphometry and Runoff Rate on Vulnerability to Gully Erosion in Wadata Catchment Area, Makurdi Local Government, Benue State

Godwin Akaayar Songu[1], Salemkaan Aloysius Iorkua[2], Ph.D,
Emmanuel Efobe Ndoma and Samaila Buba[1]
[1]Department of Geography, Federal University of Kashere, Gombe State.
[2]Department of Geography, Benue State University, Makurdi.
Correspondence Email: godwinsongu22@gmail.com

Abstract

Gully erosion is one of the world's biggest environmental problems which results in the destruction of buildings, roads, farmlands, human death among others. This paper, therefore, assesses the influence of Demekpe Drainage Basin morphometry and runoff rate on vulnerability to gully erosion in Wadata catchment area, Makurdi Local Government Area of Benue State, Nigeria with a view to aiding the design of soil erosion control structures. The square method was used to delineate topographic maps of the study area at intervals of 5cm for extraction of drainage basin parameters. Parameters measured include stream density, stream frequency, stream intensity, stream length, stream area, stream order, bifurcation ratio and length of over land flow. Also Erdas Imagine, ArcGIS, and Surfer 9.0 Softwares were used to generate a Digital Elevation Model of Wadata catchment area to depict spatial vulnerability to gully erosion and determine size of the catchment area for estimation of peak rate of runoff in the study area using the rational method. The Digital Elevation Model shows that Old Government Reservation Area and Benue Crescent Area in Makurdi have moderate drainage intensity (≥ 0.5) and are relatively more vulnerable to gully erosion as compared to other areas like New Garage Area and Wadata Area with lower drainage intensities of ≤ 0.2 and ≤ 0.3 respectively. The results also show that Demekpe Drainage Basin has moderate drainage density ($0.78km^{-1}$), drainage intensity (0.63) and overland flow of (1.68km) with tendency of influencing the extent to which the earth surface is being lowered by agents of denudation in the area, predicting the likelihood of gully incision by runoff. Wadata catchment area has a high peak rate of runoff ($83.05\ m^3/sec$), which is capable of influencing gully development in the area. The paper, therefore, recommends that a storm drain with size of 60m embankment and reservoir capacity of $4{,}000\ m^3$ should be designed and constructed to help contain excess runoff in Wadata catchment area for atleast ten years; and contour trenches can also be dug and rubble used to reduce channelised flow and sediment entrainment along slopes for controlled gully development in the area.

Keywords: **Basin morphometry, gully erosion, runoff rate, vulnerability, Wadata catchment area.**

Introduction

Drainage basin is the entire area providing run-off to, and sustaining part or all of the stream flow of the main stream and its tributaries (Gregory and Walling, 1973). The drainage basin morphometry in terms of density, intensity, frequency, bifurcation ratio among others, have influence on how a catchment area yields to the process of gullying (Udosen, 2008). According to Soufi (2015) morphometry is the measurement and quantitative analysis of the configuration of the earth's surface, shape and dimension of its landforms. Hence, there is a relationship between drainage basin morphometric parameters and gully erosion potentials. This is based on the fact that drainage basin parameters influence the amount of discharge in a catchment area as well as, the amount of runoff that can be channelised, capable of initiating gully erosion. For instance, it has been discovered that the higher the drainage density, the faster the runoff and the more significant the degree of channel abrasion is likely to be, for a given quantity of rainfall (Soufi, 2015). Also, drainage density provides a link between the form attributes (morphometry) of the basin and its erosional process (Udosen, 2008).

Surface runoff is one of the most critical factors influencing the rate of gully development in the humid tropical environments where rainfall intensities and frequencies are often high. It is on this basis that Poesena, Nachtergaelea, Verstraetena and Valentinb, (2013) considered gully erosion as a process whereby runoff water accumulates and often reoccurs in narrow channels, and over short periods, removes the soil from this narrow area to considerable depths. Gully erosion is a destroyer of farmlands, buildings, roads and soil depletion, which culminates in environmental degradation as also observed in the study area. Because of the effects of gully erosion on the environment, literature on gully erosion globally, is replete with studies on the causes, effects, morphology, growth mechanisms and rates of gully erosion (Udosen, 1991; Iorkua,1999 and 2006; Adediji, Ibitoye and Ekanade, 2009; Songu, Oyatayo and Iorkua, 2015).

Different geographical environments produce different assemblage of geomorphologic processes and mechanisms of soil erosion, especially accelerated erosion in form of gullies. Thus, studies relating to impact of drainage basin and runoff rate on soil erosion initiation and sustenance have been reported in different parts of the world. See for instance Udosen (2000) in Akwa Ibom State, Mc Mahom and Cuffney (2016) in United States of America, Eze and Effiong (2010) in Calabar, Essien and Okon (2011) in Uyo, Kavvas and Govindargu (2017) in India, Pareta and Pareta (2017) in India. However, literature review indicates deficiency with regards to the influence of drainage basin parameters and runoff rate, on vulnerability to gully erosion in an urban settings of Benue State. This specifically involves the quantification of peak rate of runoff or maximum discharge, overland flow and the intensity of drainage dissection employing Digital Elevation Models (DEMs) within the framework of Geographic Information System (GIS). This study therefore, examined the influence of drainage basin morphometry and runoff rate on vulnerability to gully erosion in Wadata catchment area, within the Demekpe Drainage Basin as input measures; capable of initiating and sustaining gully erosion in the area.

The Study Area

The study was conducted in the Demekpe Drainage Basin, in Wadata catchment Area, South bank of Makurdi LGA, Benue State, Nigeria. The study area is located between longitude 8º 36' 0'' E and 8º 36' 12'' E, as well as between latitude 7º 47' 02''N and7º 47' 15'' N (Ministry of Lands and Survey Makurdi, 2017). The study area experiences wet and dry climate, classified as "Aw" by Koppen's climatic classification scheme (Tyubee, 2005). This type of climate is also called the tropical humid savanna climate. The wet season which last for seven months, usually starts in April and ends in October. Conversely, the dry season starts from November and ends in March. The climate is usually associated with torrential rainfall and high temperature. The annual total rainfall ranges from 900mm to 1800mm, with an average annual intensity of 44.85mm/hr (NIMET, 2017). In terms of geomorphologic 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 27ºC to 31ºC; though, it may occasionally rise to 37ºC in some days in March and April (Tyubee, 2005). It is important 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 10º. The general topography in the study area varies between 65m – 125m within the Wadata catchment area (Songu, Oyatayo and Iorkua, 2015). The River Benue is the major drainage system. The Demekpe Drainage Basin is a 3rd order drainage basin, with a total of eight 1st order streams, five 2nd order streams and one 3rd order stream. 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 in the study area.

Materials and Methods

Data for this paper were sourced from GIS, field observation and map-based analysis. The morphometric properties of the Demekpe Drainage Basin namely: stream length, drainage density, drainage intensity, drainage frequency, stream order, bifurcation ratio and length of overland flow were measured from topographic maps of the study area (Makurdi 251 NE, 251 SE and 251 SW). The Demekpe Drainage Basin morphometry were determined as follows:

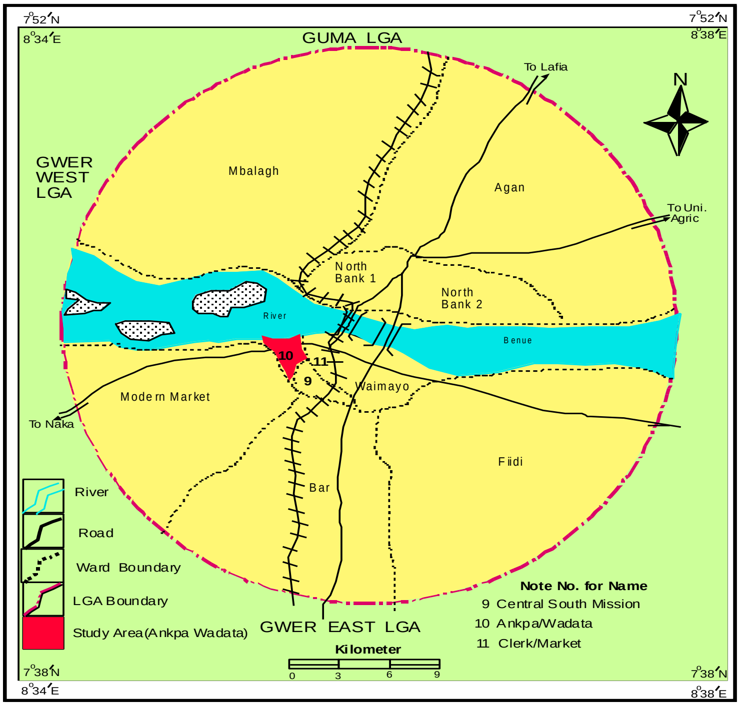

Fig. 1: Map of Makurdi Local Government Area showing study area
Source: Ministry of Lands and Survey, Makurdi, 2017.

(i) Stream length. The length of streams was determined by dividing the topographic map of the study area into grid cells of 5cm interval. Thread was then used to measure the distance of each stream from headwaters to the mouth of the water way on the map to be converted to ground distance. The dimensions of the streams were then converted to ground distance in kilometer using the map scale. The formula used was: $Ground\ distance = Map\ distance \times Scale \frac{factor}{100,000}$........(1). Hence, stream lengths were expressed in kilometers (Gregory and Walling, 1973).

(ii) 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 (Gregory and Walling, 1973).

(iii) Stream frequency which is the number of stream segment per unit area was

determined using the formula: $Ds = \frac{Ns}{Ab}$................. (2).

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 (Gregory and Walling, 1973).

(iv) Drainage density. Drainage density of streams in the studied basin was determined using the formula: $Dd = \frac{L}{Ab}$………………… (3).

where Dd is the drainage density. L, is length of stream and Ab is the basin area of each stream (Gregory and Walling, 1973).

(v) Drainage intensity. It was determined as a product of drainage density and stream frequency in the studied basin (Gregory and Walling, 1973).

(vi) 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:

$Lo = \frac{1}{Dd}$…………….. (4).

where Lo, is the length of overland flow. Dd is the drainage density (Gregory and Walling, 1973).

(vii) Generation of DEM. To generate a DEM of the study area to depict spatial vulnerability to soil erosion, the entire area of order 1 and 2 streams in the Demekpe Drainage Basin contributing to stream discharge in the Wadata catchment area were delineated on the topographic maps of the study area, and coordinates of the area were derived from the maps for GIS analysis. The Digital Elevation Model of the sub-catchment area was extracted from Shuttle Radar Topography Mission (SRTM) obtained from LANDSAT (MSS) with 25m resolution. The method of extracting the information was achieved using Erdas Imagine, ArcGIS, and Surfer 9.0 Software. The SRTM was imported into the Erdas Imagine; the study area was extracted using the sub setting tool. The contour was then created using the surfacing tool and saved in Tile File Format (TIFF). ArcGIS (Arcscene) and Surfer 9.0 Software were then used to obtain 3D display of the study area. The size of Wadata catchment area was measured from the DEM in ArcGIS (ArcMap) using the measuring tool (Pareta and Pareta, 2017; Ghaffari, 2013). The Area was calculated to be 76 hectares or 190 acres for determination of the maximum or peak rate of runoff in the study area using rational method.

(viii) Peak Rate of Runoff: The peak rate of runoff or discharge in the study area was determined using the rational method. The rational method is used to estimate the peak surface runoff rate for design of a variety of drainage structures, such as a length of storm sewer, a storm water inlet, or a storm water detention pond. It is most effective in urban areas with area of not more than 200 acres (Gregory and Walling, 1973). The method is used to determine size of storm drains, detention basin and other drainage structures or to determine the size of the detention basin required for erosion and flood control. The peak rate of runoff was determined in the study area using the formula:

$Q = \frac{CiA}{Z}$………………. (5)

where, Q is the peak rate of runoff in m^3/sec.

C, is an empirical coefficient representing a relationship between rainfall and run-off.

i, is the average intensity of rainfall for the time of concentration(Tc) for a selected design storm.

A, is the drainage area

Z, is the metric conversion factor.

The rainfall intensity (i) in the study area was determined using the formula: $i = \frac{Pd}{tc}$………………(6)

where:

P_d = Depth of rainfall (mm)

t_c = drainage area time of concentration (hr.)

Moreso, tables were used to code the data and descriptive statistics (i.e. percentage, mean, standard deviation (S.D) and coefficient of variation were used to ascertain variation in the data set.

Percentage was computed using the formula: $\frac{n}{\sum N} x\ 100$……………… (6). In the formula, 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 $\frac{\sum N}{n}$………….. (7)

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

Standard deviation was determined using the formula:

$$S = \sqrt{\frac{\sum(x - M)^2}{n}} \text{ …………….. (8)}$$

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

Coefficient of variation was determined by dividing mean by standard deviation and multiplying by 100 as thus:

$$CV = \frac{M}{SD} X\ 100 \text{ ……………………… (9)}$$

where, CV is coefficient of variation
M, is mean
SD, standard deviation

Results and Discussion

Demekpe Drainage Basin Morphometry and Vulnerability to Gully Erosion in Wadata Catchment Area.

The Demekpe Basin is a 3rd order basin that contributes significantly to water discharge in the study area. Catchment analysis was conducted to ascertain the extent to which the Demekpe drainage basin parameters have influenced spatial vulnerability to gully erosion in the area. The study shows some morphometric parameters of the Demekpe Drainage Basin as presented in Table 1.

Table 1: 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).
1	5.73	9.50	0.31	0.60	0.17	1.67
1	6.22	15.10	0.87	0.41	0.36	2.44
2	6.31	16.2	0.40	0.39	0.16	2.56
2	9.55	5.90	1.13	1.61	1.81	0.62
2	7.74	8.30	0.72	0.89	0.64	1.12
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: Analysis in Topo Map, 2017

The mean length of streams in Wadata catchment area was 7.11 km, with a standard deviation (SD) of 1.39 and a coefficient of variation (CV) of 19.55%. The total area of Demekpe basin within Wadata catchment was 55km^{2,} and a mean basin area of 11.0 km^2 with SD of 3.98 and CV of 36.18%. The mean stream frequency was 0.69, with SD of 0.29 and a CV of 42.03%. The mean Drainage Density in the study area was 0.78 km^{-1}, with a SD of 0.45 and CV of 57.69%. The average drainage intensity in the study area was 0.63, with a SD of 0.61 and CV of 96.83% (Table 1). The drainage intensity was moderately low, implying that the drainage density and frequency have effect on the extent to which the surface has been lowered by agents of denudation like surface runoff, which is capable of initiating gully erosion especially along steep slopes and impervious areas. This is because running water may not be quickly removed from the surface.

The spatial pattern of erosion vulnerability in the study area as revealed in Figure 3 was largely influenced by the drainage density, drainage intensity, soil type and topography of the areas. Earlier studies by Udosen (2008) revealed a coarse drainage intensity of 0.52 in the Ikpa river basin, which was found to have influenced the pattern of erosion in the area. Compare also the studies of Udosen and Essiet (2012) in South Eastern Nigeria; Onu *et al*, (2012) in Okigwe-Umuahia erosion belt and Mac Mahon and Cuffney (2016) in United States of America who discovered that the drainage density of $0.6km^{-1}$ was moderately high and influenced gully development in the study areas. The findings of this study confirmed those of Eze and Efiong (2010) in Calabar, Pareta and Pareta (2017) in MegaYamuna basin in India, who discovered that low drainage intensities influences soil erosion.

The moderately coarse drainage intensity in the study area could be attributed to the permeable nature of the unconsolidated sandy soils and sandstone that forms the geology of the area, gently sloping relief with terrain heights averaging 65 meters in the study area. Like other coarse catchment areas, the Demekpe Drainage Basin which is moderately coarse with its permeable landscape is as well, prone to gully erosion especially along steep slopes and impervious areas due to poor drainage systems capable of initiating and sustaining gully development in the area (Mallo, 2015). This situation is exemplified in the study area where gullies have been incised especially along community secondary school road, Makurdi and this poses severe traffic hazard to nearby roads and dwellings.

The mean length of overland flow in the Demekpe Drainage Basin was 1.68km, with an SD of 0.75 and CV of 44.64%. The mean length of overland flow (1.68km) in a permeable landscape, with drainage density of $0.78km\text{-}^{1}$ and moderately dissected catchment like the Demekpe Basin implies that surface runoff along stream channel will be moderately high and relatively faster on steep slopes and impervious areas downstream. It is apparent to note that, the mean length of over land flow influences both the shape of the drainage basin as well as time of the concentration of runoff on valley side slopes. The moderately high rate of overland flow observed in the study area was considered a major determinant factor influencing channelised flow and gully development in the area. Previous studies have also confirmed the influence of mean length of overland flow on basin form, channelised flow and time of concentration downstream (Udosen 2000; Mallo, 2009; Udosen and Essiet, 2012; Kavvas and Govindargu, 2017). Figures 2a and 2b provide further field evidence of a gully channel that has been incised along community secondary school road Makurdi, in the Wadata catchment area.

Fig. 2a: Culvert being destroyed by a gully in Wadata area.

Source: Authors' field work, 2017

Fig. 2b: Lateral expansion of the gully due to mass wasting

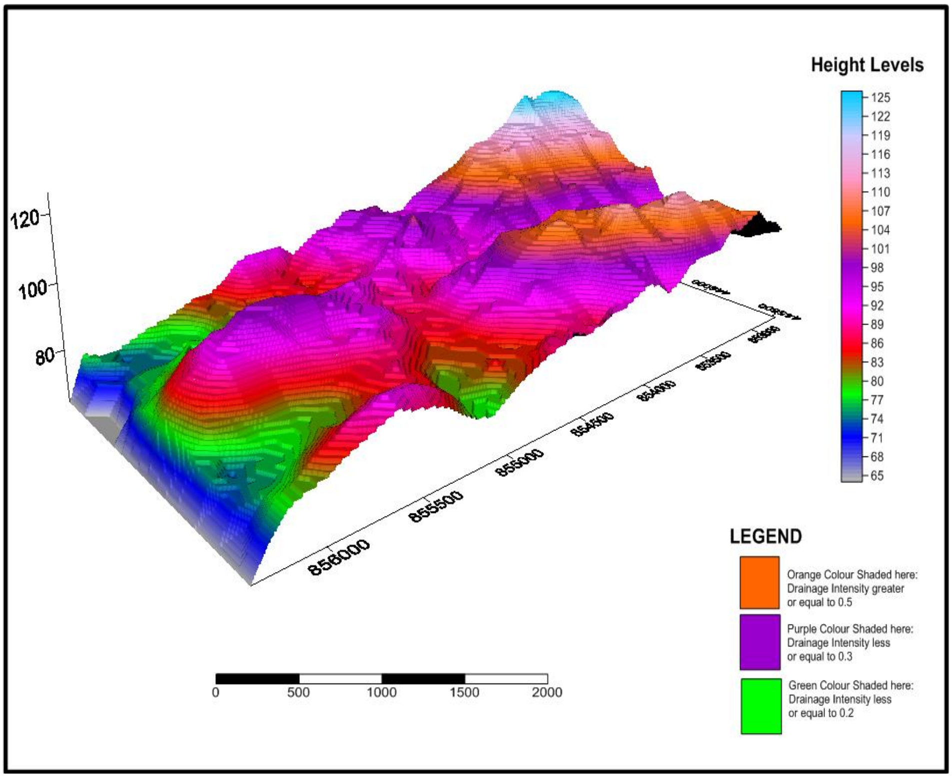

Fig. 3: Digital elevation model of Wadata catchment area showing variation in drainage intensity and vulnerability to Soil erosion.

Source: Authors' field work, 2017

Figure 3 is a DEM of the Wadata catchment area in the Demekpe Drainage Basin showing drainage intensity vis-à-vis erosion prone areas. The DEM displayed the physiographic attributes of the catchment area in terms of its gently steep gradient which hardly exceed 10^0 and topography of the area ranging from 65m to 125m above sea level. This section of the Demekpe Drainage Basin, a 3rd order basin drains in the south west part of Makurdi contributing to stream discharge in the watershed. The DEM revealed that Wadata catchment area is characterized with areas of moderate drainage intensity ($\geq$ 0.5) and low drainage intensities ($\leq$ 0.2, $\leq$ 0.3). The areas with moderate drainage intensity shaded orange colour covers part of Old Government Reservation area (GRA) and Benue crescent area in Makurdi and are fairly vulnerable to soil erosion (Fig. 3).

The areas with low drainage intensities shaded purple and blue covers part of Ankpa ward area, New Garage area and Wadata area where a gully system has been incised. The areas with low drainage intensities are less prone to soil erosion, but highly prone to flooding; which can as well initiate the process of gullying, especially in times of intense rain storms in the study area due to runoff on steep slopes and impervious areas. This is because surface runoff may not be quickly removed from the watershed making it susceptible to flooding and erosion. The varying levels of vulnerability to soil erosion in Wadata catchment area could be attributed to the gently steep slope gradient in Old GRA and part of New Garage area which influenced high rate of runoff in those areas. The soil type which is predominantly sandy loam, the topography of the area and abandoned excavated gutters resulting from engineering works. Gully channels are mostly incised at the stream source points or areas that have steep slopes and high elevation enhancing downstream overland flow concentrated in channels, with the low lying areas highly prone to flooding. The gently steep slope in Old GRA and part of New Garage area is capable of initiating gully development especially on hill side slopes and abandoned excavated gutters by road sides. These factors have impacted on the initiation and development of the observed gully system in Wadata Area in the Demekpe Drainage Basin.

The use of DEMs within the framework of Geographic Information System**s** can assist planning authorities and environmentalists to identify the most vulnerable erosion-prone areas of a catchment as exemplified in the study area and select appropriate management practices. Also, hydrological modeling in river basin management commonly requires investigation of landscape and hydrological features such as terrain slope, drainage networks, basin area and catchments boundaries to model precisely the direction and magnitude of runoff (Ghaffari, 2013). The size of Wadata catchment area was measured from the DEM of the study area for determination of peak rate of runoff, which is seemingly the leading factor in gully incision and development in the study area.

Runoff and Soil Erosion Estimation in the Wadata Catchment Area.

The rational method was used to determine the peak rate of runoff in Wadata catchment area within the Demekpe Drainage Basin and it was determined using the formula:

$$Q = \frac{CiA}{Z}$$

The runoff coefficient (C) for the combination of land use and soil/surface types in the study area was determined as the ratio of the rate of runoff to the rate of rainfall at an average intensity using the runoff coefficient table and values are shown in Table 2.

Table 2: Runoff coefficients of urban watershed in the study area.

Type of Drainage Area	Runoff Coefficient (C)
Residential area	0.33
Streets	0.42
Concrete pavements	0.97
Parks	0.10
Sandy loam soil	0.22
Roofs	0.75
Grass land	0.71
Total	**3.5**
Mean	**0.5**
S.D	**0.3**
C.V (%)	**60**

Source: Authors' field work, 2017.

The total runoff coefficient in the area was computed as thus:

$C = Cr + Cs + Cc + Cp + Csa + Crf + Cg$……………. (1.1)

where:

C = total runoff coefficient in the watershed

Cr = component of coefficient accounting for residential area

Cs = component of coefficient accounting for streets

Cc = component of coefficient accounting for concrete pavements

Cp = component of coefficient accounting for parks

Csa = component of coefficient accounting for sandy loam soil

Crf = component of coefficient accounting for roofs

Cg = component of coefficient accounting for grassland

Therefore, the total runoff coefficient in the watershed = 3.5, with a SD of 0.3 and CV of 60%.

The rainfall intensity (i) in the study area was determined using the formula: $i = Pd/tc$

where: P_d = Depth of rainfall (mm); t_c = drainage area time of concentration (hr.)

Table 3 shows computed annual rainfall intensity for selected storms with time concentration of not less than ten minutes for a period of ten years in the study area.

Table 3: Annual rainfall intensity in the study area from 2007-2016.

Year	Rainfall Amount(mm)	Rainfall Duration (hr)	Rainfall Intensity (mm/hr).
2007	1335.9	39.69	33.66
2008	1556.9	35.42	43.95
2009	1618.0	29.01	55.77
2010	1173.7	30.95	37.92
2011	1532.5	31.09	49.29
2012	1584.0	33.90	46.72
2013	1470.5	44.94	32.72
2014	1343.0	26.36	50.94
2015	1375.6	30.11	45.69
2016	1594.8	30.12	52.95
Mean	**1458.49**	**33.16**	**44.96**
S.D	**138.3**	**55.27**	**7.53**
C.V (%)	**9.49**	**15.89**	**16.75**

Source: NIMET, 2017

The mean rainfall amount in the study area was 1458.49mm, with an SD of 138.49 and CV of 9.49%. Mean rainfall duration was 33.16hr, with an SD of 5.27 and CV of 15.89%. The mean rainfall intensity was 44.96mm/hr, with an SD of 7.53 and CV of 16.75%. Hence, the mean rainfall intensity (i) in the study area used in the rational method for determination of peak rate of runoff = 44.96mm/hr. The area (A) of Wadata catchment determined from the Digital Elevation Model of the study area (Fig. 3) using ArcGIS is 190 acres (76 hectares). Hence, the maximum or peak rate of runoff in the study area was determined using the formula: Q = CiA/Z

C = 3.5
i = 44.96 mm/hr,
A = 190 acres
Z = 360 (metric conversion factor)

$$Q = \frac{CiA}{Z}$$

Q = (3.5)(44.96)(190) / 360

Q = 83.05 m^3/sec

The peak rate of runoff in the study area as determined from selected storms of not less than 10 minutes for a period of ten years was 83.05m^3/sec; implying an average annual peak rate of 8.305m^3/sec. This meant that averagely an annual peak rate of 8.305 m^3/sec is envisaged from storms that last for 10 minutes and above. With the determined peak rate of runoff in the study area, erosion control structures like storm drains or detention basin can be designed to help control excess overland flow in the study area. Pertinently, runoff is the leading factor in the incision and development of gullies and flood disasters. The implication is that a designed storm drain in the area is expected to control erosion and flooding at least for a period of ten years before a new design can be sought.

To control soil erosion and flooding using the estimated runoff rate in the study area, a storm drain or detention basin can be designed with size of 60m embankment and reservoir capacity of 4,000m^3, which could be effective for at least ten years. The fairly high peak rate of runoff (83.05m^3/sec) in the study area has a significant impact on hydrological characteristics of the watershed especially in terms of erosion and flooding, if not properly contained.

Conclusion

The influence of Demekpe basin morphometry and runoff rate on vulnerability to gully erosion in Wadata catchment area was examined in this study. It was observed that high rate of runoff (83.05m^3/sec) in the study area has significant impact on the initiation and development of gullies especially along hillside slopes. It was also inferred that due to the moderate drainage density (0.78km^{-1}) and drainage intensity (0.63) in the gully catchment, which influenced a considerable amount of overland flow (1.68km), gully channels are likely incised and developed in the study area; if control measures are not adopted. The study, therefore, concludes that landform development especially the incision and growth of gullies in the study area are largely influenced by the high rate of runoff, moderately coarse drainage density and intensity in the study area.

Recommendations

The following recommendations based on findings of the study, are hereby made:

(i) Soil erosion development in Wadata catchment area could be controlled by designing a storm drain with size of 60m embankment and reservoir capacity of 4,000 m^3 which will be used to contain excess runoff in the study area.

(ii) Contour trenches can be dug and rubble used to reduce channelised flow and sediment entrainment along slopes in Wadata catchment area for controlled gully development in the area.

(iii) There should be well connected drainage network in form of gutters in the study area to help channel overland flow downstream and reduce its effect on erosion initiation and sustenance, especially in concentrated channels.

(iv) There should be a refocus on watershed management in the area, especially a reduced interest in concreted surfaces that rather influences runoff, but more of green areas which enhance infiltration.

Reference

Adediji, A., Ibitoye, M. O. and Ekanade, O. (2009). Generation of digital elevation models for gullies in Irele Local Government of Ondo State. *African Journal of Environmental Science and Technology,* 3(3): 067-07

Essien, O.E. and Okon, E. G. (2011). Rainfall characteristics, runoff rate and traffic flow on gully morphometric parameter growth and soil loss in sand-mined peri- urban, Uyo, Nigeria. *Journal of Geology and Mining Research*, 3(7):180-187.

Eze, E.B. and Effiong, J. (2010). Morphometric Parameters of the Calabar River Basin: Implication for Hydrologic Processes. *Journal of Geography and Geology*, 1(2):18-26.

Ghaffari, G. (2013). *The Impact of DEM Resolution on Runoff and Sediment Modelling* results. Retrieved from http://scialert.net/fulltext on 3rd May, 2018.

Gregory, K. J. and Walling, D. E. (1973). *Drainage Basin Form and Processes: A Geomorphologic Approach*. Norwich: Fletcher and Son Ltd, pp 22-58.

Iorkua, S. A. (2006). A Study of Inter-Relationship among Gully Elements in North Bank, Makurdi. *A Journal of Geography and Development* (1): 32-51.

Iorkua, S. A. (1999). A Gully in North Bank Area of Makurdi Benue State. Unpublished M.Sc. Dissertation, University of Ibadan, Ibadan, pp. 35-48.

Kavvas, M. L. and Govindargu, R. S. (2017). *Hydrodynamic Averaging of Overland flow and Soil erosion over Rill Hill Slopes*. Retrieved from http//www.iahs.info/redbooks on10th march, 2016.

Mallo, I.Y. (2009). Inter-relationships between Barnawa River Catchment Parameters of Northern Nigeria. *Journal of Environmental science*, 3(2):10-22.

Mallo, I.Y. (2015). Morphometric Characteristics of the Barnawa River Catchment in Kaduna Metropolis, Northern Nigeria. *Journal of Environmental science*, 4(1):26-35.

Mc Mahom, G. and Cuffney, T. F. (2016). Quantifying Urban Intensity in Drainage Basins for Assessing Stream Ecological Conditions. *Journal of the American water resources Association*, 36(6):1247-1261.

Ministry of Land and Survey, Makurdi (2017). Base Map on State and Local Government boundaries.

NIMET Weather Office, Nigerian Air Force Base Makurdi (2017). Rainfall Intensity, Frequency and Amount in Makurdi. Retrieved on 3rd April, 2017.

Onu, N. N., Opera, A. I and Ehirim, C. N. (2012). Delineation of active Fractures in a Gully erosion area using Geophysical methods: Case study of the Okigwe-Umuahia erosion belt, Southeastern Nigeria. *International Journal of Science and Technology*, 4(2):1- 20.

Pareta, K. and Pareta, U. (2017). Quantitative Morphometric Analysis of a Watershed of Yamuna Basin, India using ASTER (DEM) Data and GIS. *International Journal of Geomatics and Geosciences,*1(2):1-14.

Poesena, J., Nachtergaelea, J., Verstraetena, G. and Valentinb, C. (2013). Gully erosion an Environmental change: Importance and research needs. *Catena* 50, pp. 91 – 133.

Songu, G. A., Oyatayo, K. T. and Iorkua, S.A. (2015). Impact of Gully Erosion Stream Sedimentation in Demepke Drainage Basin. *American Journal of Water Resources*, 4(3): 100-108.

Soufi, M. (2015). *The Impact of Land Use and Soil Characteristics on Gully Formation in an Arid Ecosystem, Southwest of I.R. Iran*. Retrieved from http://www.sciencedirect.com/science on 13th November, 2017.

Tyubee, T.B. (2005). Spatial Organization of Daily Rainfall in the Middle belt of Nigeria. *The Benue Valley (41):69-71.*

Udosen, C. E. (2000). Thresholds of Gully erosion in the Coastal Plain Sands of Eastern Nigeria A Case Study of Ikpa River Basin. Unpublished Ph.D Thesis, University of Ibadan.

Udosen, C. E. (1991). A Morphometric Analysis of Gullies in Obotme Area of Akwa Ibom State. Unpublished M.Sc. Dissertation, University of Ibadan, pp. 43-55.

Udosen, C. E. (2008). *Gully Erosion in Ikpa River Basin: A Threshold Phenomenon*. Lagos: Time Communications, pp. 10-212.

Udosen, C.E. and Essiet, A. A. (2012). Digital Elevation Models as a Tool for Monitoring and Evaluating Gully Development in a Humid Tropical Environment. *Online Journal of Earth Sciences*, 6(2):6-14.