

FACTORS AND IMPACTS OF GULLY EROSION IN GOMBE METROPOLIS

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Abstract

Gully erosion is one of the most serious and extensive environmental degradation problems in Gombe, north eastern Nigeria. The development of effective strategies of prevention and mitigation of this hazard requires an understanding of the factors and controls of its initiation and intensification from a catchment-scale perspective. A combination of socio-economic, hydro-geomorphic, terrain, soil, land use land cover and rainfall data was employed to investigate the factors, impacts and controls of gully erosion in Gombe metropolis. The results showed that inappropriate farming and land management practices, logging, deforestation, overgrazing, road building, poorly terminated drainage works, urbanisation and increasing rainfall are key triggers of gully erosion processes in the metropolis. Strategies to combat and prevent gully erosion in Gombe metropolis should be holistic and include a combination of appropriate land management and soil conservation measures, reforestation, regulated developments and road/drainage construction works that adheres to recommended design standards, taking into consideration the hydrologic, geomorphic and terrain conditions of the area.

Keywords: Gully erosion, Erosion control, NEWMAP, Gombe

Introduction

Gullies are formed due to a complex of erosion processes by which concentrated runoff water acts upon the landscape to create incised channels through which solutes and sediments are transported to a down-slope watercourse during and immediately after heavy storms (Soil Science Society of America, 2001; Valentin et al., 2005). Whilst the threshold for gully initiation and development could be the result of subtle natural processes related to slope gradient and the geomorphological configuration of the landscape, extrinsic drivers like anthropogenic pressures and climatic variability have accelerated erosion processes operating at the catchment scale. In this regard, increased human exploitation of land resources in the upper parts of catchments has widely been recognised as a key factor perpetuating extensive gully development in otherwise stable landscapes (Poesen et al., 2003). Although improper land use including inadequate provision of drainage system for constructed roads, livestock overgrazing, deforestation, and destructive logging are key man-made factors driving gully formation, physical factors like topography, soil properties, geology, rainfall distribution, duration, intensity and runoff significantly influence the rate and susceptibility of land to gully. In Nigeria for example, the

spatial and temporal differentials in soil erodibility is not only a reflection of anthropogenic activities, but a function of the diverse lithological formations at local and regional scales within the country (Igwe, 2012; Mbaya et al., 2012).

A review of literature on gully erosion in Nigeria suggests that all other drivers being equal, gully erosion is more likely to be prevalent in sedimentary terrains than in the Basement Complex (igneous and metamorphic) formation of Nigeria (Abdulfatai et al., 2014). This may help explain the concentration of extensive gullies in certain parts of the country (Egboka and Okpoko, 1984; Igwe, 2012). In northern Nigeria, Gombe State has a particularly unique lithology that engenders the formation of gullies when coupled with other extrinsic factors operating at various catchment scales. Consequently, gully erosion has emerged as one of the most serious environmental degradation problem in the state, threatening entire communities and rural livelihoods (Mbaya et al., 2012; Danladi and Ray, 2014). To effectively mitigate this environmental hazard, there is need to understand the antecedent history of this landscape and how it has shaped the spatial pattern of processes driving gully initiation and intensity in the state in general and Gombe metropolis in particular. There is a dearth of research on the controls of gully erosion that demonstrates catchment-scale hydro-geomorphic relationships to enable the design and adoption of effective gully erosion prevention/mitigation strategy in Gombe State. This study seeks to fill this gap by examining the impacts, factors and control of gully erosion in Gombe metropolis. The findings will help refine existing mitigation measures and develop new strategies for gully erosion control in the state.

Materials and Methods

Study Area

This study was carried out in Gombe (Figure 1), the capital of Gombe State, in north eastern Nigeria. The administrative area occupies a landmass of 52 km² with fairly steep to gently undulating landscape. It is bounded by Kwami Local Government Area (LGA) to the North, Akko LGA to the South and West, and Yamaltu/Deba LGA to the East. The area is drained by multiple ephemeral streams and the tributaries of the River Gerkwami basin; the southernmost sub-basin of River Gongola with an average elevation of approximately 495 m above sea level. The vegetation is of the Sudan savanna type composed mainly of wooded shrubland and other scattered trees and plant species including *Adansonia digitate* (African Baobab), *Anogeissus leiocarpus* (African Birch), *Azadirachta indica* (Neem) and *Vitellaria paradoxa* (Shea Tree). The climate of the area is characterised by a dry season (November to mid-April) and a wet/rainy season (late-April to October) with a single peak in August. The average annual rainfall is about 886 mm and mean monthly temperature range between 18 – 39°C. The bedrock geology of the area is dominated by sandstone, clay and shale with highly weathered, well-drained ferruginous soils.

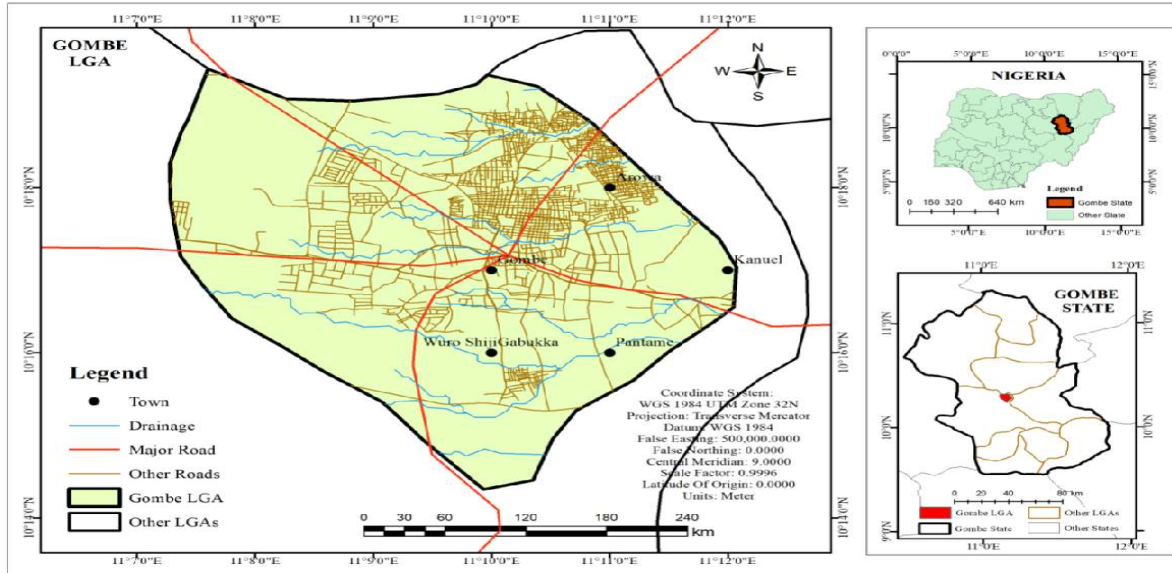


Figure 1: Study area

Methods

Multiple datasets including socio-economic data, hydro-geomorphic data, elevation data, soil data land use/cover data and rainfall data were used in this study. Direct photographic field observation of the physical environment was also undertaken to provide a better understanding of the realities of key drivers and impacts of gully erosion in the study area.

Socio-economic data

Socio-economic data was gathered using a structured questionnaire and interviews with key informants. This made it possible to assess the extent to which major economic activities in the study area are drivers of gully erosion. A hundred and ten (110) questionnaire (ten for each of the 11 wards) were administered to the adult population in the study area. The questionnaire was used to obtain information on economic structure and land productivity. Random sampling technique was applied in the questionnaire administration. All questionnaires were retrieved and cross-checked for inconsistency and errors. A structured interview guide was used to moderate the interviews. Questions were asked orally and responses manually recorded.

Hydro-geomorphic data

The hydro-geomorphic extent of the area was delineated using Remote Sensing and Geographic Information System (GIS) tools. The data requirement included Landsat Operational Land Imager (OLI) satellite imageries, Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM), field observation data and Nigeria 1:50,000 topographical map sheets (Gombe Sheets 152 N.W. and S.W.; Duku Sheets 151 N.E. and S.E.) of the area obtained from the Federal Ministry of Lands and Survey. The tributaries of River Gerkwami representing the southernmost sub-basin of River Gongola is the main drainage system in the study area. The morphometric characteristics of the sub-basin divided into three categories, viz: general relief aspects (basin relief, relief ratio and relative relief), linear aspects (stream order, stream number, stream length, basin length, bifurcation ratio, mean bifurcation ratio) and areal aspects (stream frequency, drainage density, circularity ratio, elongation ratio and form factor) were derived from Environmental Systems Research Institute (ESRI) ArcGIS software or analysed using established mathematical equations presented in Table 1. The hypsometric integral (*HI*) which reflects the spatial variations in relative

heights across a drainage network and is strongly related to the flood response and erosional maturity of a basin (Strahler, 1952; Singh et al., 2008) was calculated as:

$$HI = (E_{Mean} - E_{min}) / (E_{max} - E_{min})$$

Where *HI* is the hypsometric integral; E_{mean} is the mean elevation of the basin; E_{min} and E_{max} are the minimum and maximum elevations within the basin.

Table 1: Summary of investigated morphometric parameters

S/N	Morphometric parameter	Abridged form	Formula	Description	References
1	Area (km ²)	<i>A</i>			
2	Perimeter (km)	<i>P</i>			
3	Basin relief	<i>B_h</i>	$B_h = H_{max} - H_{min}$	H_{max} = highest point within the basin; H_{min} = lowest point	Patton and Baker (1976)
4	Relief ratio	<i>R_r</i>	$R_r = \frac{H}{L_b}$	H = basin relief L_b = basin length	Schumm (1963)
5	Relative relief	<i>Rhp</i>	$Rhp = \frac{R}{P}$	R = basin relief P = basin perimeter	Huggett and Cheesman (2002)
6	Stream order	<i>U</i>			Strahler (1964)
7	Stream number	<i>Nu</i>			
8	Stream length (km)	<i>Lu</i>			Horton (1945)
9	Basin length	<i>L_b</i>			
10	Bifurcation ratio	<i>R_b</i>	$R_b = \frac{N_u}{N_u} + 1$	N_u = number of streams of any given order	Strahler (1964)
11	Mean bifurcation ratio	<i>R_{bm}</i>	Average of R_b		
12	Stream frequency	<i>F_s</i>	$F_s = \frac{\sum N_u}{A}$	N_u = total number of streams A = area of watershed	Horton (1945)
13	Drainage density	<i>D_d</i>	$D_d = \frac{\sum L}{A}$	L = total length of stream A = area of watershed	Strahler (1964)
14	Drainage texture	<i>T</i>	$T = D_d \times F_s$	D_d = drainage density F_s = stream frequency	Smith (1950)
15	Circularity ratio	<i>R_c</i>	$R_c = \frac{4\pi A}{P^2}$	A = area of the basin P = area of circle having the same length of perimeter as the basin	Strahler (1964)
16	Elongation ratio	<i>R_e</i>	$R_e = \frac{(2\sqrt{\frac{A}{\pi}})}{L_b}$	A = area of the basin L_b = maximum length of the basin parallel to the main stream	Schumm (1956)
17	Form factor	<i>R_f</i>	$R_f = \frac{A}{L_b^2}$	A = area of the basin L_b = maximum length of the basin	Horton (1932)

Elevation data

The topographic configuration of the landscape was obtained from SRTM DEM of the study area.

Soil

Soil samples were collected from systematically determined 2m x 2m square area in proximity to major gully sites (Federal College of Education (Technical), Gombe Univeristy, Mallam Inna, Navi-Nawa, Bogo) in the study area using stainless steel auger with an internal diameter of 5 cm. The soil samples were then analysed for texture, consistency, bulk density, aggregate stability and total porosity using notable methods described in Carter and Gregorich (2008).

Land use/cover data

Land Use Land Cover Change (LULCC) data was derived from medium resolution Landsat OLI satellite imagery obtained from the USGS for 1984, 2002 and 2015, respectively. The acquired multi-date satellite imagery were imported in the GeoTIFF data format and pre-processed in ERDAS IMAGINE. A false colour composite consisting of band 4, 3 and 2 were selected and layer stacked after which image subsets were created using the area of interest vector frame in ESRI ArcGIS 10.2. Bands 4, 3 and 2 of the Landsat image were loaded for red, green and blue, respectively. The LULCC data were then generated from the multi-date satellite images which were classified using supervised and maximum likelihood classification techniques with an overall Kappa accuracy of 97%. Prior to classification, ground truth data obtained through field campaigns was used to create 'training areas' for designated land cover types/class which included agriculture/farmlands, settlements/built-up areas, vegetation, water bodies, highland vegetation, bare surfaces/rock outcrop and riparian vegetation. A total of fourteen ground control points were selected based on the uniqueness of the spectral signatures visible on the satellite imageries. The classified image was subsequently vectorised and class statistics extracted for further descriptive statistical analysis.

Rainfall data

Rainfall data for the area was obtained from the archives of the Nigerian Meteorological agency (NiMet). The data covered a twenty-year period spanning 1980 – 2014. Daily rainfall data was aggregated to generate monthly rainfall data for the rainy season months of April to October. The departure of monthly rainfall from the long-term climatological average (i.e. rainfall anomaly) were computed and used to identify the years of dryness and wetness within the period.

Results and Discussion

Impacts on Gully Erosion in Gombe

Human Impacts on Gully Erosion

Agriculture is a key economic activity of the population in Gombe metropolis. A majority of the respondents (65%) are engaged in farming as a primary occupation whilst it is a secondary occupation for another 31%. The major crops grown include maize, sorghum, groundnut, soya beans and millet. Whilst, 16% of the respondents assert that their farm yields have increased in the last five years, 56% indicate a decline in farm yields. Loss of soil fertility and farmlands due to soil erosion (24%), flooding (25%) and gully erosion (34%) were prominent reasons adduced for the declining farm yields. However, farming systems may also play a key role in soil fertility depletion/loss as mixed cropping (63%) and sole cropping (22%) are the common crop management practices adopted by the respondents. Both cropping systems could lead to

significant soil nutrient loss particularly in the absence of fertilizers treatments and incorporation of legumes (e.g. Haynes and Francis, 1990; Bashagaluke et al., 2018). Although loss of soil fertility due to the prevalent farming system may occur gradually over a period of time, a sudden and significant removal of topsoil by erosion processes would have more radical impact on crop productivity and likely lead to complete loss of available land when gullies develop. Most of the respondents (69%) engaged in agriculture have no knowledge of contour cropping as a conservation farming method for soil erosion control on slopes. Field visits and interviews with key informants reveal that as a matter of convenience or lack of knowledge, crops are sometimes planted up and down the slope instead of across, thus creating furrows that accelerate runoff and encourage slope dissection and gully erosion (Plate 1). After a period of cultivation (5 – 10 years) some of the respondents (36%) relocate to new and relatively more fertile lands at the forest margins. This practice in addition to logging for fuel wood has led to massive deforestation and high runoff velocity on the exposed surface with increased potential for gully initiation and intensification. The respondents contend that logging (26%), deforestation (26%), high density cattle grazing (22%) and building/construction activities (18%) contributes to ground cover exposure that accelerates gully erosion in Gombe metropolis.

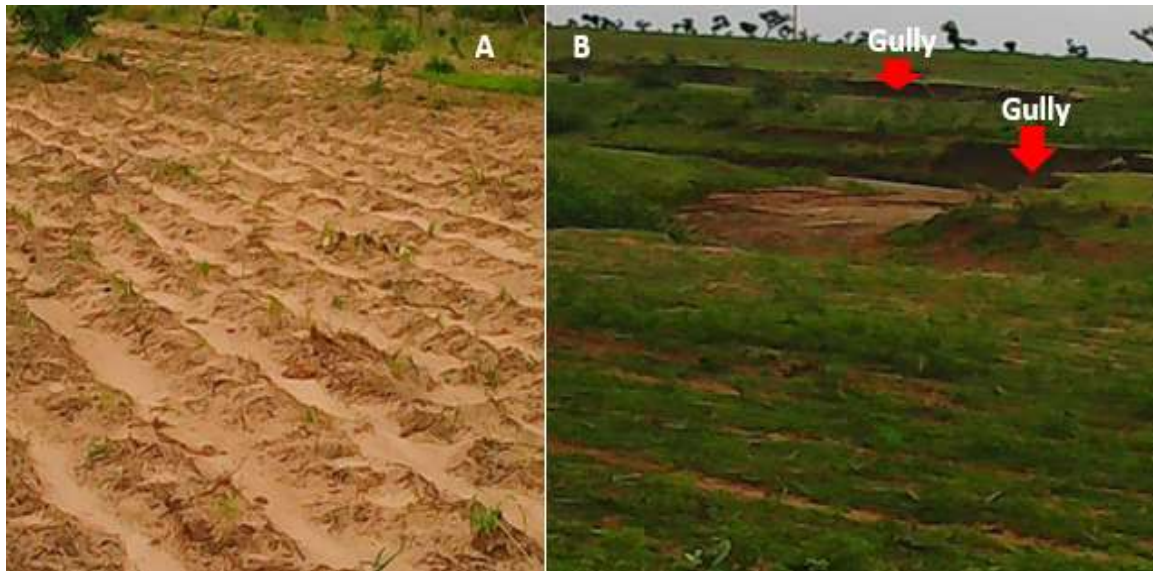


Plate 1: Farmlands on slope with features of rill (A) and gully erosion (B) in Gombe metropolis

Hydro-geomorphic/Environmental Impacts on Gully Erosion

Gullies are often influenced by the hydro-geomorphic characteristics of the landscape on which they occur. As a process, gully erosion is governed by the concept of geomorphic threshold where the detachment of soil mass occurs when the combined energy from rainfall and overland flow exceeds soil resistance to erosion (Udosen, 2009). This process is usually multivariate and involves a number of hydraulic indicators including total discharge, flow energy or velocity of runoff, catchment shape and size, as well as length and slope gradient. Gombe metropolis is drained by the tributaries of River Gerkwami, a sub-basin of the River Gongola Basin that covers a total area of approximately 981 km² with an elevation range of 237 – 733 m and a basin relief of 496 m which is within the typical range for catchments with high surface runoff and low rate of infiltration.

The fairly high drainage density (0.46) is also an indication of high relief, thinly distributed vegetation (Figure 2) and low infiltration capacity. Although the entire sub-basin is of a fourth order, the tributaries draining Gombe metropolis are of first and second orders with a combined stream number of 98 and stream length of 338 km (Table 2). The elongation ratio, form factor, and circulatory ratio (Table 2) suggests that the basin is more elongated than circular and is expected to experience moderate peak flows of longer duration. However, the frequent occurrence of short duration high-intensity rainfall during the wet season often results in peak flows of shorter duration with greater environmental devastation.

The hypsometric integral (Table 2) (Strahler, 1964) indicates that Gombe metropolis is within a mature catchment with active erosional processes and sediment transport capacity. The steepness and ruggedness of the terrain especially in the upper part of the basin has facilitated the widespread development of gullies and drainage enlargement within inter-gully areas such that the distinction between rivers and flattened gully bottoms as water transmission sources in the drainage basin is significantly diminished. These findings in addition to the observed dendritic drainage pattern is indicative of a fairly homogenous lithology with little structural control that invariably increases the influence of geomorphic factors on gully formation in Gombe metropolis. The morphological impression of the observed gullies appears to be partly controlled by the distribution of runoff channels within the catchment area. The gully forms are characteristically dendritic, composed of many important branching tributaries. The small (depth <1m) and medium (depth of 1 – 5m) gullies are mostly discontinuous whilst the large gullies (depth >5m) such as those behind Federal College of Education (Technical) (Plate 2) and the state university are continuous, consisting of a network or multiple networks of interconnected gullies with a main channel and branch gullies that have evolved on the landscape from concentrated overland flow.

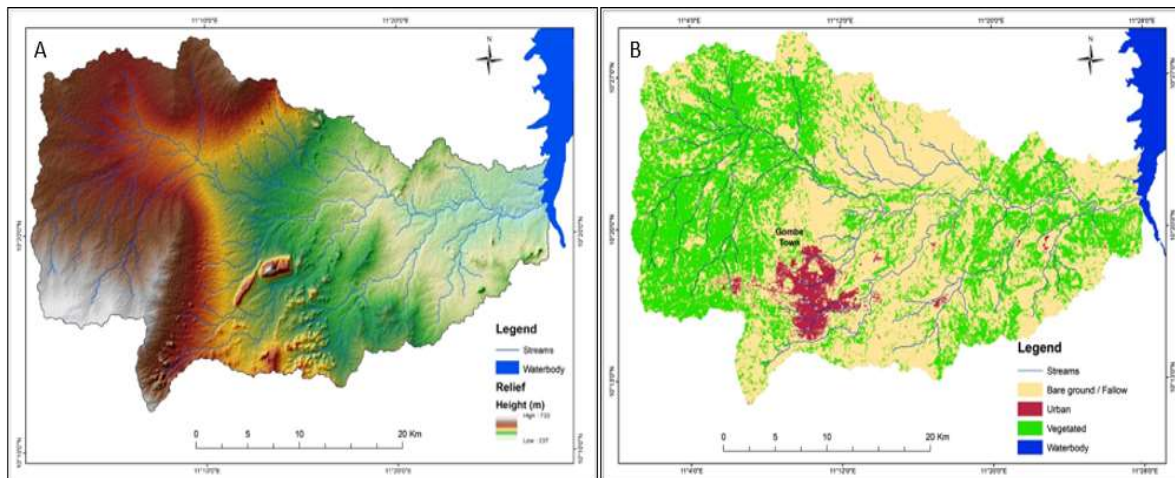


Figure 2: Gerkwami River basin showing general relief, drainage (A), and land use/cover with Gombe metropolis (B)

Table 2: Morphometric characteristics of Gerkwami Basin

Morphometric Parameters								
Area (km ²)	Perimeter (km)	Basin Relief (m)	Relief Ratio	Relative Relief	Hypsometric integral	Elongation Ratio	Form Factor	Texture Ratio
981	182	496	9.96	2.73	0.50	0.71	0.40	0.41

No. of stream of each Order (N_u)				Bifurcation Ratio (R_b)			Mean R_b
Order 1	Order 2	Order 3	Order 4	R_b I-II	R_b II-III	R_b III-IV	R_{bm}
75	23	7	1	3.3	3.3	7.0	3.39

Stream Length of each Order (km)				Stream Length (km)	Basin Length (km)	Stream Frequency	Drainage Density	Circulatory Ratio
Order 1	Order 2	Order 3	Order 4					
228	110	57.9	51.6	447	49.8	0.11	0.46	0.37



Plate 2: Gully erosion behind Federal College of Education (Technical), Gombe

Factors Controlling Gully Erosion in Gombe Metropolis

Topography

Slope gradient is an important factor in the formation of gullies, which are characteristic features of high terrain areas with steep slopes (Valentin et al., 2005). From a basin perspective, Gombe metropolis is situated on a main drainage line with a slope of 31.4° , that is, a drop of 1m for every 163m horizontal distance. Although this falls within the classification of an extreme slope, the gradient is much steeper at the upper course (Figure 2A). Steep slopes encourages high runoff velocity and the initiation of gullies with downslope transportation of considerable sediment volume during rain storm events (Edokpa, 2017). The volume of runoff generated is however dependent on the climatic condition of rainfall in the catchment.

Soil/lithologic properties

Gully patterns and forms are to a large extent controlled by lithologic properties and soil resistance to erosion (Abdulfatai et al., 2014; Edokpa, 2017). Gombe metropolis is underlain by the *Gombe Sandstone Formation* characterised by friable sandstones, siltstones and shale. This soft friable sandstone and siltstone lithology is less resistant to the erosive energy of runoff which explains the prevalence of extensive gullies in the metropolis that sometimes exceeds 40 m and 18 m in width and depth, respectively. The configuration of the gullies is mostly 'U-shaped' indicating that the top and sub soils have similar resistance to detachment by runoff. Fresh lithologic outcrops are usually light grey in colour but become dark red following exposure to (oxidation) weathering. Laboratory and field analysis reveal that the soils are friable, and mostly sandy at depths of 0 – 200 cm beyond which some texturally sandy-clay-loam soils are observed.

The sandstone lithologic units with some clay and high iron content appears to be relatively more resistant to the erosive force of runoff, although constantly high temperatures and high-intensity rainfalls create cracks or fractures in the soil, which are structurally weakened starting points of erosion particularly on moderate to high topographic gradients. The high velocity of runoffs generated on steep slopes facilitates the detachment and transportation of soil particles which constitute significant sediment load when gullies integrate with the existing river/stream channel network. The soil bulk density range was 1.45 – 1.49 g/cm³ with an average porosity of 44.5% indicating that the soils are well-conditioned for plant growth. However, the soils are of low to medium physical quality with respect to their aggregate stability of 48 – 58%. This implies that the soil aggregates are fairly unstable and susceptible to disintegration during rainstorms leading to blockage of soil pores, reduction in infiltration capacity, crusting and increased surface runoff and erosion.

Land use/cover change

Land use/cover change is a key factor influencing the acceleration of natural gully processes in Gombe metropolis. Agriculture and built environment (settlements) are the most critical land uses responsible for land cover changes in the study area (Figure 3). In 1984, the coverage area of vegetation was 34.3% whilst built-up area and agricultural land uses were 4.22% and 52.4%, respectively (Figure 4). By 2002, the percentage cover of built-up area and agriculture had increased to 81.1% and 10.5%, respectively, whilst vegetation decreased significantly to 6%. However, by 2015 the area coverage of agriculture was 27.4%, representing a 66% decrease between year 2002 and 2015. This was due to a significant increase (>280%) of built-up area in 2015 and an increase in the total area coverage of bare surfaces from 2% in 2002 to 26% in 2015.

The intensification of farming in the absence of appropriate soil management practice affects soil structural stability by depleting soil organic matter which in turn promotes crusting, runoff generation and gully erosion (Valentin, 2004). Some farmlands in the area have been lost to gully intensification. This may partly explain the observed reduction in the total area coverage of agricultural lands and the increase in exposed/bare surface in 2015. There is also evidence of agricultural land conversion for urban development. Urbanisation often require extensive road building which concentrates runoff on the paved roads and associated side drains to other catchment areas. Poorly constructed and improperly terminated drains (Plate 3) are critical drivers of the most devastating gullies in Gombe metropolis. During torrential rains, runoff rapidly concentrates in the drains which are mostly directed straight onto unprotected mid slopes resulting in gully initiation and intensification.

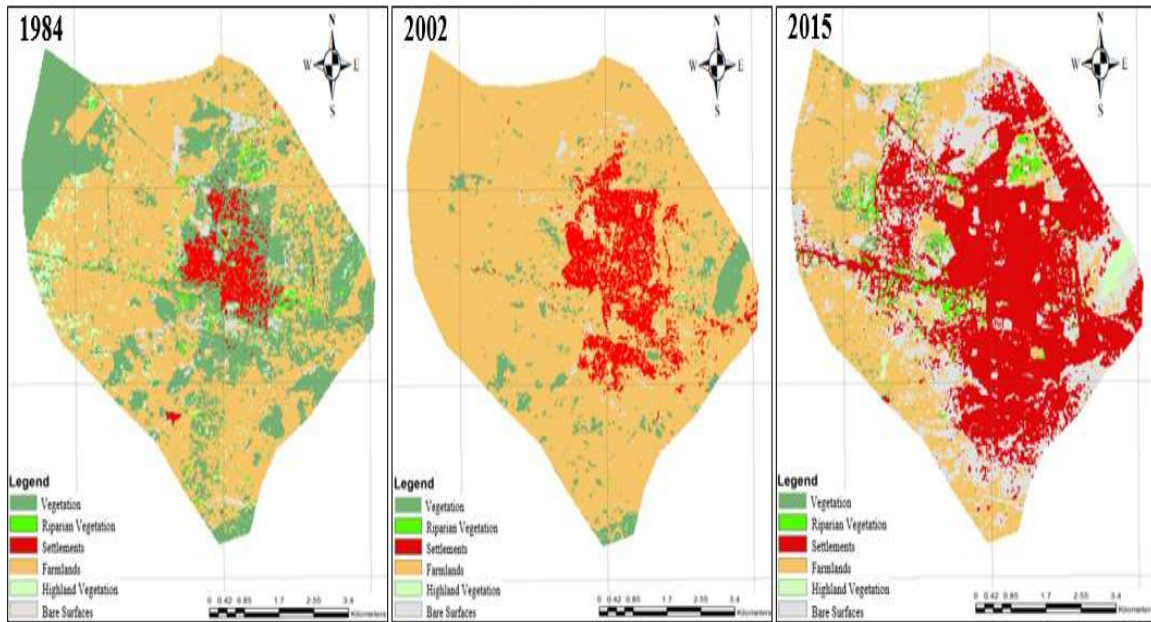


Figure 3: Land use/cover in Gombe Metropolis in 1984, 2002 and 2015

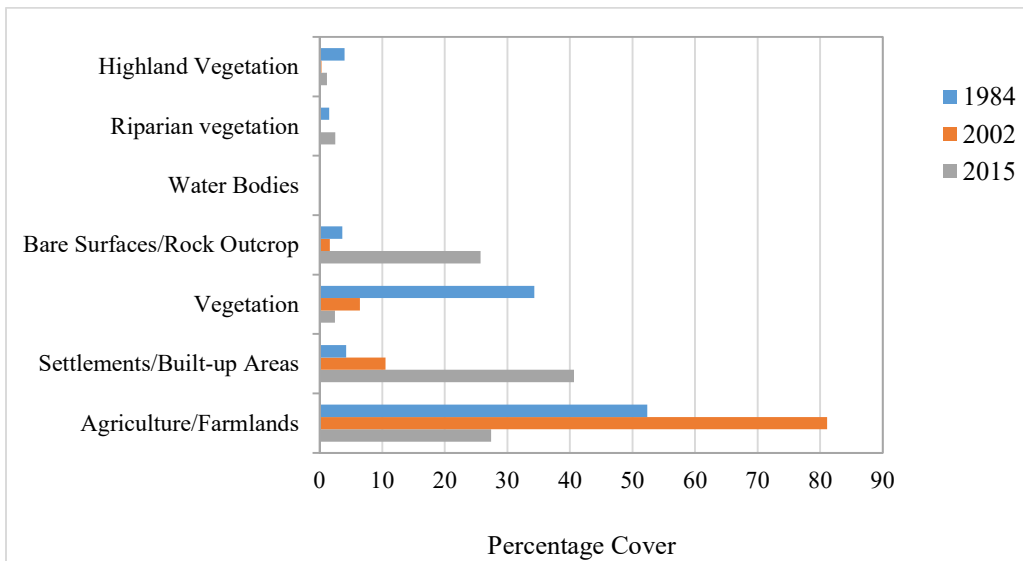


Figure 4: Total area percentage for classified LULC categories in Gombe metropolis in 1984, 2002 and 2015



Plate 3: Improperly terminated drain system at the head of the extensive gully behind the Gombe State University

Climate and climate change

The climatic parameter of rainfall/precipitation is a key driver of erosion, supplying the energy required for the detachment and transportation of soil particles by overland flow. Rainy season in Gombe metropolis commences in mid-April and last until October with an annual average of 868 mm during the period under investigation. The average monthly rainfall amount range between 26 mm in April and 235 mm in August (Figure 5). About 67% of rainfall in the rainy season occur between July and September, thus increasing the potential for the occurrence of flood disaster similar to that recorded in the study area in 2004, 2012 and 2014. Overall, with the exception of years 2010 and 2011, the standardized rainfall anomaly (Figure 6) show that rainfall has consistently increased above the climatological average since the turn of the 21st century. The decade-on-decade rainfall totals reveal an increase of 876 mm and 551 mm respectively, between 1980-89 and 1990-99, and 1990-99 and 2000-09 indicating an overall increase of 1427 mm between 1980-89 and 2000-09. There were more wet (20) than dry (15) years, with 40% of wet years occurring in the last decade (2005 – 2014) of the period under investigation. This suggests a general increase in rainfall trend in Gombe metropolis with serious implication for runoff, flooding and gully erosion particularly in an environment with severely degraded vegetation cover, steep slopes and poorly terminated drains.

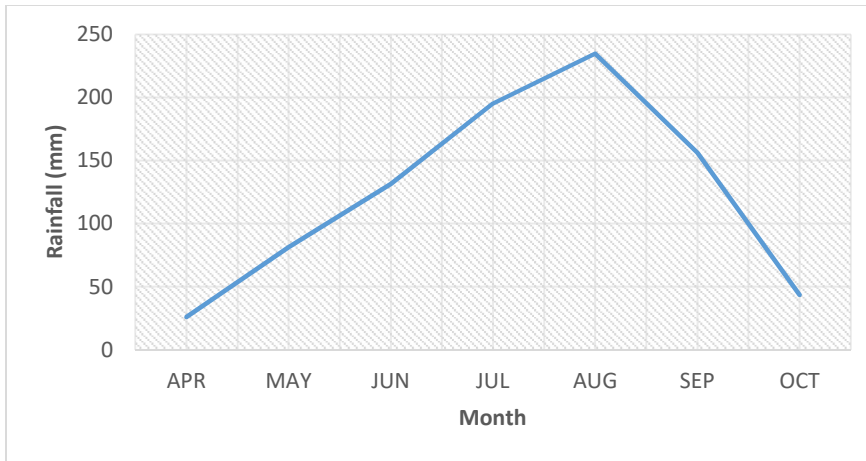


Figure 5: Monthly average rainfall in the rainy season (1980 – 2014)

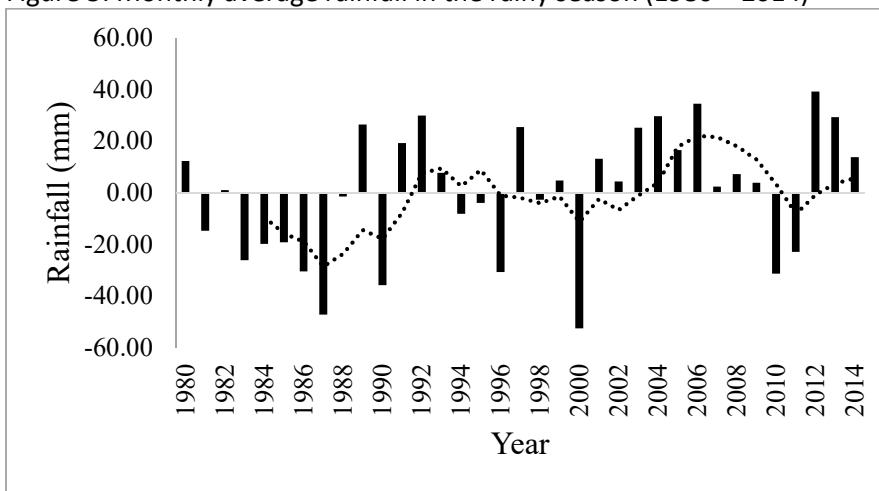


Figure 6: Standardized rainfall anomaly for the rainy season (1980 – 2014). The dashed line represents 5-year moving average

Conclusion and Recommendations

Gully erosion processes in Gombe metropolis is accelerated by a combination of anthropogenic and physical factors including farming practices, urbanisation, land use/cover changes, road/drainage construction, soil/lithologic properties, topography, climate and hydro-geomorphic characteristics of the landscape. Strategies to combat and prevent gully erosion in the area should be holistic and include a mixture of appropriate land management and soil conservation measures, reforestation, regulated developments and road/drainage construction works that adheres to recommended design standards, taking into consideration the hydrologic, geomorphic and terrain analysis of the area. The following are the specific recommendations of this study:

1 Soil conservation

Catchment-scale conservation work in the gully and inter-gully areas is required to check the intensity of gully erosion in Gombe metropolis. Widespread construction of check dams across gullies, particularly in upslope areas will help reduce the velocity of water flow and counteract high gully erosion rates in the catchment. Access to hillslopes for livestock grazing should be

restricted or closed off to improve water conservation and reduce soil exposure to accelerated erosion rates due to loss of vegetal cover. The establishment of water and sediment control basins is encouraged in areas where farmlands on hillslopes are widespread. This will help reduce or eliminate the downslope erosive action of runoff and lessen the potential of gully erosion by trapping and storing sediments. Mulching and compost addition to croplands should be encouraged to improve soil aggregate stability and resistance to erosion.

2 Vegetation cover

Vegetation play a key role in protecting the soil from erosion by improving soil infiltration capacity and structural stability. The gully erosion problem in Gombe metropolis is reinforced by unprecedented deforestation that has seen the percentage total area coverage of vegetation reduce from 34.3% in 1984 to about 6% in 2015. Whilst the trees are cut for firewood and charcoal production, the understorey component is relentlessly grazed or cleared for arable farming. An extensive programme of reforestation specifically on steep land or highland areas should be urgently implemented to mitigate gully erosion and reduce sediment generation and downstream transfer. To be effective, tree planting should be accompanied with planting of shrubs and grasses to create a near surface layer of vegetation that will help reduce the kinetic energy of drops intercepted by the trees.

3 Drainage construction works

As an area experiencing rapid urbanisation, road construction and other building activities is a key feature in Gombe metropolis. Whilst side drains are in most cases constructed alongside the roads, there is usually the problem of runoff carrying capacity and abrupt termination of the drains at mid slopes which has resulted to widespread flooding, gully initiation and intensification in the area. To reduce the role of road construction in promoting and accelerating gully initiation and development in Gombe metropolis, the road design and associated drainage works should take into consideration the characteristics of the natural drainage pattern, hillslope morphology (slope gradient, shape, length etc.) as well as hydrologic and hydraulic factors. This will reduce the risk of road and drainage failures that exacerbates gully erosion by concentrating runoff along failed and exposed cuts or fills. It will also help in determining the most appropriate sites for location of roads that will reduce the financial and environmental cost by leveraging on the natural dimension of the existing hillslope drainage rather than attempting to construct drains that alter it, albeit improperly, resulting in frequent road and built drainage failure that exposes adjoining areas to exponential velocity of runoff and gully initiation and intensification.

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