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Study of Some Watershed Characteristics Associated with Gully Erosion Development Using Google Elevation Services in Girei Basin Adamawa State, Nigeria

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ABSTRACT

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A field study was conducted in 2020 to characterize watershed features and digital terrain attributes of the Girei area. Digital mapping tools were applied to assess altitude, basin size and number, slope gradients, drainage channels, and topographic elements. Results showed that altitude ranged from 152 m in lowland areas to 488 m at hilltops. Four basins (watersheds) were identified, with areas of 2,288.1 km², 190.6 km², 41.1 km², and 13.7 km². Vegetation was dominated by grasses and shrubs typical of the savannah, with scattered shea-butter, acacia, eucalyptus, and locust bean trees. Land use was largely rice and sorghum cultivation, often practiced interchangeably. Drainage patterns reflected the relief, with streams and rivers originating from highlands and channel lengths totaling 355.8 km, comprising trunk routes A and B as well as service routes connecting communities. The slopes were classified as level (<2%), gentle (2–6%), moderate (6–13%), steep (13–25%), and very steep (>25%). The long slope distance from the highest elevations to gully areas facilitated runoff, accelerating gully headcut formation and expansion. These findings highlight the susceptibility of Girei to gully development driven by slope gradient, slope length, runoff velocity, and water volume. Management interventions such as runoff barriers and slope stabilization are recommended to mitigate erosion risks.

INTRODUCTION

Productivity impacts of land degradation are due to a decline in land quality on-site where degradation occurs (e.g. erosion) and off-site where sediments are deposited. Soil erosion is a destructive environmental problem that affects social and economic development, agricultural production and sustainable use of natural resources (Ma *et al.*, 2014 and Vanmaercke, *et al.*, 2021). Gully erosion is one of the most serious types of soil erosion, especially in mountainous areas. Gully erosion is the process of overland flow converging into what are initially, interconnected micro-depressions that form a natural drainage-way (Liu, *et al.*, 2021).

Gully erosion is the result of a series of interrelated processes that depend on the environment (Anderson, *et al.*, 2021). Topographic factors were widely focused on because the erosive effects of water flow are related to the topography (Jiang, *et al.*, 2021; Chowdhuri, *et al.*, 2021). The combined influence of hydrology and topography affects soil stability by reducing the shear strength and soil anti-erodibility (Amare, *et al.*, 2019). The influence of topography on the development of gullies is reflected in the slope length, slope gradient and catchment area (Tang, *et al.*, 2021). Slope length provides sufficient runoff for the development of the gullies, indirectly enhancing the erosive power of water. Slope is the key factor affecting runoff shear stress, and



it is also the key topographic factor of gully formation (Liu, et al., 2021). The characteristics of gullies vary with the topographic position and slope gradient (Zhang, et al., 2016). The critical conditions and spatial pattern of gully erosion have been determined by studying the correlation between the catchment area and other topographic factors (Yang, et al., 2019; Munoz, et al., 2010). In addition, the varied land use and management practices in different countries over different time periods have led to different effects, so human influences are often one of the driving forces in the evolution of gully (Castillo and Gomez, 2016).

The description of topographic features based on digital elevation models (DEMs) is the focus of current topographic research (Zhang, et al., 2020; Arabameri, et al., 2021). To study the development of gullies and to establish gully erosion models, topographic maps and large-scale satellite images (Landsat, Modis, Terrain data of SRTM, etc.) were usually used as data sources of remote sensing and geographical information system technologies (Zhou, et al., 2021). Based on these data and combined with field surveys (Wang, et al., 2016), the topographic factors (e.g., altitude, slope gradient, aspect, relief and dissection) and spatial distribution of gullies were analyzed effectively, the relationships between topography and the distribution of gullies was also established (Arabameri, et al., 2019), and the formation and development of gullies can be revealed. The impact of land use on the development of gullies (Xia, et al., 2022 and Chen, et al., 2021), the development and distribution of roadside gullies, the development of gullies under different watershed conditions (Kong, et al., 2022), and the impact of gullies on Eco-environmental quality (Li, et al., 2022). These works were of great significance for the evaluation of gully erosion control (Gao, et al., 2021).

An exploration of the effects of topography on the development of gully helped to understand the characteristics and formation of gullies, and provide a scientific basis for the evaluation, prevention and control of the hazards caused by gullies in mountainous areas. Quantitative analysis of gully development in different geomorphic units and the influence of topographic factors on gully system development were rarely reported. The superposition effect of different factors on gully development and the effect of different geomorphic units on gully evolution needed to be further studied. Therefore, the research objectives of this study were to reveal the relationships between topographic factors and gully development, and find out the

topographic conditions with the most serious gully erosion using digital model services in Girei LGA.

MATERIAS AND METHODS

The Study Area

Girei Basins Area is located between latitude 9°00' and 9° 32' N and Longitude 12°10' and 12°48'E and situated at an altitude of 158.5m above sea level with a total landmass of 1,848 km² in Adamawa State (Gundiri, 2023). It is bounded to the north by Song Local Government Area, to the south and West by Yola North and South Local Government Area and to the east by Fufore Local Government Area. Figure 1.

The climate of the area comprised typical wet and dry seasons with average annual rainfall ranges from 700-1000mm. The temperature ranges from 15°C to 39°C. The amount of sunshine hours' ranges from 2500 in the south to 3000 hours in the extreme north (Adebayo et al., 2020).

The vegetation in the area comprised few grasses and shrubs, which is typical of savannah region with scattered trees mainly shear-butter, acacia, eucalyptus and locust bean tree, while the dominant grass species include *panicum maximum*, *aristida longiflora* and *andropogon gayanus* (Gundiri, 2023; Tekwa and Usman, 2006; Adebayo, 2004). All the gully sites occurred on both cultivated and non-cultivated lands, while some occurred on cattle route path, and there were fewer grasses, shrubs and trees observed at all the sites. The Geology of Girei according to Nigerian Geological Survey Agency [NGSA] (2006) is described as upper cretaceous rocks, Precambrian basement complex a mixture of rock types and minerals. Most of the area is underlain by Magmatite and some Porphyritic Granite especially in the Eastern part of the Local Government area. Some medium to coarse granite biotite are also found. The relief of Girei LGA comprises flat, relatively flat and rugged terrain with hills and mountains spread across all the districts. Hydrology of the area is dependent on the rainfall pattern and the underground reservoir mostly in areas underlain by sedimentary rock formations. According to Adebayo (1999), the water resources available in the State (Adamawa) including Girei Basins are adequate if utilized properly. The rivers in the area are seasonal in nature. The parent materials are heterogonous and comprised predominantly loamy sand, clay and sandy clay of a range of colors (Vahyala, et al., 2018). Which are also predominantly alfisols, luvisols, vertisols, and lithosols having lithic and paralithic horizon (Vahyala et al. 2018).



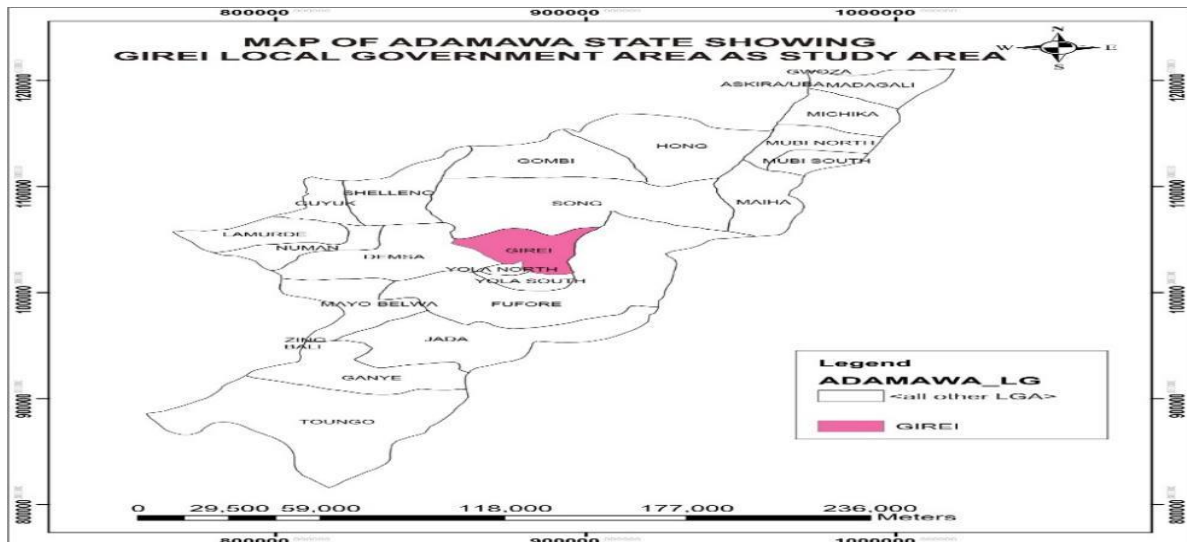


Figure 1: Map of Adamawa State Showing Girei LGA

Site elevation and topography

A semi-detailed survey of selected gully erosion sites was conducted in the field in order to develop the digital terrain model (DTM). A global positioning system (GPRS) was used to obtain elevation above sea level of each gully system as suggested by Vandekerckhove et al. (1998); Nachtergaele et al. (2001b); Nasri et al. (2008). The study area has a rolling topography with rock outcrops in some places. The altitude of the study area reaches a maximum of 488 m (the hill top) above sea level in the hilly areas, while the lower grounds have altitude of about 152 m above sea level. The hilly grounds however, ranged in altitudes from 213-274 m above sea level, while the lower grounds vary in altitudes from 144 – 280 m above sea. The relief of Girei LGA comprises flat, relatively flat and rugged terrain with hills and mountains spread across all the districts.

Watershed area (A)

The administrative map of the study area was scanned, geo-referenced and digitized. Also, the boundaries of the existing drainage network and watersheds were digitized. The different layers of the digitized administrative map, watersheds and drainage network were overlaid in ArcGIS 9.3 environment leading to the determination of the locations and areas of the watersheds.

Determination of Watershed Characteristics of Girei Local G. A.

In this study the maps of the gully sites were prepared using GIS software. Some of the fields visited in 2014 were also revisited. Gullies were digitized by determining the location of each gully in the watershed using a hand-held GPS with a horizontal accuracy of about 3 m on August 2020, after which its coordinates were imported into Google Earth to situate all gullies on the imagery. The gully edges were then digitized using

Google Earth's square segment mapping tool, satellite images were accurate to about 30m. Therefore, square segments measured 300 m×300 m was used.

To study watershed characteristics, an online tool was developed using Google Maps API and Google Elevation Service. The Google Elevation Service provided elevation data for locations on the surface of the earth which was useful to find the gross slope of the terrain being one of important factors affecting runoff. Other characteristics such as size, shape, drainage density of watershed was analyzed using Google Maps API.

The input data used for this analysis was downloaded from Open Data Archive (CartoDEM) of ISRO's Bhuvan website. Thematic maps such as watershed boundary, drainage network, and contour maps were prepared from the DEM data using ArcGIS 10 Hydrology tools. Other common biophysical features of the different watersheds were described using the standard procedures. Among the watershed features measured were the area, axial length, and length of the streams slope, irrigation facilities, land use and Forest cover, areas within Girei and the proposed Girei, and the various municipalities within each watershed.

Girei local government contains basically four basins which all originated from the same source, which is the mountain top. The sizes of the four basins are as follows: basin one, which is the largest has a surface area of 2288.1 Km² and also contains all the gully points scattered, the next basin is the basin two with surface area of 190.6 Km², but does not contain any gully point. It is followed by basin three with the surface area of 41.1 Km² which also does not contain any gully point. The last basin has surface area of 13.7 Km² without any gully point. Consequently, all these four basins originated from the mountain top and flows into the same river (Benue River) (Figure 2 and Table 2).

Basin I: all the erosion activities took place in this basin; it is the largest of all the other basins. Its characteristics are found in Table 4.

RESULTS AND DISCUSSION

Morphology of Some Watershed Characteristics of the Study Area

The data on drainage pattern, land use, geology, slope rate and vegetation of the study area were generated morphologically. The results showed that by slope rating the terrains at Jabbilamba, Safini, Sangere, Madalu, Lamido Farm, Hona, Professorial Quarters, Federal Housing, Damare, Labodo River, Kangling, Ndikajam, Amsami, Jera, Dundu, Jatau, Ngawa, Modibbo, Kaftarare, Sani and Mashi were gently sloping (2-6%), as they were located at relatively lower altitude. However, those at Daware Junction, Girei River, Hona 1 and University Farm being situated at higher altitude were categorized as moderately sloping (6 – 13%) (Table 1 and figure 3). Generally, the study area was observed to be poorly drained which could be the reason why there was accumulation that led to ponding on the surface, subsequently generated runoff. Few locations were regarded as imperfectly drained such Sangere 6, Lamido Farm, Daware Junction 1, Girei River 1 and Dundu. The drainage pattern and run-off speed across study sites revealed that sites situated on higher topography had higher run-off intensities compared to sites lying on lower topography, whose run-offs were similar. This result correlated with the report of Tekwa (2014) who observed at Mubi watershed that topography was perhaps responsible for run-speed on the watersheds. This also agrees with the reports of Foster (1986) that topography influences run-off generation and peak discharge of concentrated flow channels.

The results also revealed that the common land-use in the study area were Rice and sorghum cultivation, which were carried out interchangeably. These two were the dominant cultivated crops in the area during the period of study. The gully at this location might be attributed to the nature of the soils and their drainage pattern, which was in line with the study of Vahyala et al. (2018), who stated that soils with erodible characteristics tends to be more vulnerable to erosion than non erodible soils. Some of the study locations, such as Daware Junction 1 and 2, were uncultivated being cattle routes (brutali), which might be the supporting factor of the erosion apart from the downward flow of runoff water from the high hills, even as reported by Gundiri, (2023). They locations were characterized by sparse trees and shrubs close to main road, school buildings and electrical poles, these

gullies were a threat to economic and social activities in the area. Girei River 1 and 2 located close to a school building, which was also becoming a threat to the structures. Hona 1 also located close to a bridge, which inevitably was becoming a threat too. Sangere too was close to high way, electric poles, communication network and underground piping (Table 1) were also affected by the menace, which the gully development was attributed to anthropogenic activities through the installation of communication lines which has created easy routes for water to flow and as a result, soils are eroded and transported down the slope, even as supported by Sidle et al. (2018), who reported that pipping communication network lines, exposed cut and fill slopes, embankments, associated with road construction, mining operations, and residential or commercial construction sites, are susceptible to gully erosion in dry regions with episodic high-intensity rainfall. Valentin et al. (2005), also observed that, unprotected soil surfaces are vulnerable to raindrop impact and, as run-off generates and coalesces down-slope, rills and eventually gullies form. Long, steep exposed slopes with silty soils are more susceptible to gully development. Highly interconnected road and trail networks concentrate surface run-off on landscapes and initiate gullies and cause head cutting of incipient channels due to drainage discharge

The Geology of Girei according to Nigerian Geological Survey Agency [NGSA] (2006) is characterized by and described as upper cretaceous rocks, Precambrian basement complex, a mixture of rock types and minerals. However, the dominant vegetation in Girei area comprised few grasses and shrubs, which is typical of Savannah region with scattered trees mainly shear-butter, acacia, eucalyptus and locust bean tree, while the dominant grass species include panicum maximum, aristida longiflora and andropogon gayanus. The results of this study coincide with the report of Adebayo and Tukur (1999); Tekwa and Usman (2006). The relief of Girei LGA comprises flat, relatively flat and rugged terrain with hills and mountains spread across all the districts. This type of relief may be the responsible factor for the significance of altitude and runoff in impacting gully development. The drainage of the area is a function of the existing relief condition as the streams and rivers originate from the highland areas. Another study conducted in Adamawa state also described the relief of Girei as observed in this study that overland flow is the upper reaches of the hydraulic length, shallow flow begins where overland flow converges to form gullies while channel flow is manmade drains (Idowu et al., 2013).

Table 1: Geology and Site Characteristics of the Study Area

S/N	Location Coordinates	and	Slope	Drainage	Land use	Geology	Vegetation
1	Jabbilamba1 9.516994° 12.572850°		Gently Sloping (2-6%)	Poorly drained	Rice cultivation	Basement complex	Few grasses and trees
2	Jabbilamba 2 9.516785° 12.572633°		Gently Sloping (2-6%)	Poorly drained	Rice cultivation	Basement complex	Trees, shrubs and grasses
3	Jabbilamba 3 9.516532° 12.572671°		Gently Sloping (2-6%)	Poorly drained	Rice cultivation	Basement complex	Few grasses and trees
4	Jabbilamba 4 9.515722° 12.571830°		Gently Sloping (2-6%)	Poorly drained	Rice cultivation	Basement complex	Trees, shrubs and grasses
5	Safini 1 9.494569° 12.580054°		Gently Sloping (2-6%)	Poorly drained	Sorghum	Basement complex	Trees, shrubs and grasses
6	Safini 2 9.492304° 12.579205°		Gently Sloping (2-6%)	Poorly drained	Sorghum	Basement complex	Few grasses and trees
7	Safini 3 9.491582° 12.579420°		Gently Sloping (2-6%)	Poorly drained	Sorghum	Basement complex	Trees, shrubs and grasses
8	Madalu 1 9.489809° 12.573925°		Gently Sloping (2-6%)	Poorly drained	Sorghum	Basement complex	Trees, shrubs and grasses
9	Madalu 2 9.488658° 12.572122°		Gently Sloping (2-6%)	Poorly drained	Sorghum and Rice	Basement complex	Trees, shrubs and grasses
10	Sangere 1 9.491006° 12.579733°		Gently Sloping (2-6%)	Poorly drained	Sorghum	Basement complex	Few grasses and trees
11	Sangere 2 9.489868° 12.577256°		Gently Sloping (2-6%)	Poorly drained	Sorghum	Basement complex	Trees, shrubs and grasses
12	Sangere 3 9.487100° 12.584712°		Gently Sloping (2-6%)	Poorly drained	Coco, cashew, dibino	Basement complex	Few grasses and trees
S/N	Location Coordinates	and	Slope	Drainage	Land use	Geology	Vegetation
13	Sangere 4 9.489209° 12.583842°		Gently Sloping (2-6%)	Poorly drained	None cultivated (tamarintree) tsamiya	Basement complex	Trees, shrubs and grasses
14	Sangere 5		Gently Sloping (2-6%)	Poorly drained	Sorghum	Basement complex	Few grasses and trees

	9.489617° 12.582738°						
15	Sangere 6 9.485488° 12.582840°	Gently Sloping (2-6%)	Imperfectly drained	None cultivated	Basement complex	Trees, shrubs and grasses	
16	Lamido' farm 9.448463° 12.571184°	Gently Sloping (2-6%)	Imperfectly drained	Sorghum	Basement complex	Trees, shrubs and grasses	
17	Daware Junction 1 .9.413492° 12.561109°	Moderately Sloping (6- 13%)	Imperfectly drained	None cultivated (Brutalin) cattle route	Basement complex	Few grasses and trees	
18	Daware Junction 2 9.411194° 12.560670°	Moderately Sloping (6- 13%)	Poorly drained	None cultivated (Brutalin) cattle route	Basement complex	Trees, shrubs and grasses	
19	Daware Junction 3 9.407352° 12.560460°	Moderately Sloping (6- 13%)	Poorly drained	Rice cultivation	Basement complex	Trees, shrubs and grasses	
20	Girei river 1 9.374170° 12.543849°	Moderately Sloping (6- 13%)	Imperfectly drained	Close to School building	Basement complex	Few grasses and trees	
21	Girei river 2 9.375064° 12.543743°	Moderately Sloping (6- 13%)	Poorly drained	Close to School building	Basement complex	Trees, shrubs and grasses	
22	Hona 1 9.351638° 12.523953°	Moderately Sloping (6- 13%)	Poorly drained	Close to a bridge	Basement complex	Trees, shrubs and grasses	
23	Hona 2 9.348662° 12.526076°	Gently Sloping (2-6%)	Poorly drained	Sorghum	Basement complex	Few grasses and trees	
S/N	Location and Coordinates	Slope	Drainage	Land use	Geology	Vegetation	
24	Professorial Quarters 9.335798° 12.498308°	Gently Sloping (2-6%)	Poorly drained	Cattle route, close to bridge and university wall.	Basement complex	Trees, shrubs and grasses	
25	Federal Housing 9.316944° 12.483758°	Gently Sloping (2-6%)	Poorly drained	Sorghum and close to bridge	Basement complex	Few grasses and trees	
26	Damare 9.318070° 12.454001°	Gently Sloping (2-6%)	Poorly drained	Sorghum, rice and mango trees	Basement complex	Trees, shrubs and grasses	
27	Labondo river 1 9.399577° 12.398064°	Gently Sloping (2-6%)	Poorly drained	Rice cultivation	Basement complex	Few grasses and trees	

28	Labondo river 2 9.396890° 12.402543°	Gently Sloping (2-6%)	Poorly drained	None cultivated	Basement complex	Few grasses and trees
29	Kangling 9.382482° 12.389676°	Gently Sloping (2-6%)	Poorly drained	None cultivated	Basement complex	Trees, shrubs and grasses
30	Ndikajam 9.459885° 12.334563°	Gently Sloping (2-6%)	Poorly drained	Rice	Basement complex	Few grasses and trees
31	University farm 1 9.354971° 12.505632°	Moderately Sloping (6-13%)	Poorly drained	University farm	Basement complex	Trees, shrubs and grasses
32	University farm 2 9.358256° 12.505026°	Moderately Sloping (6-13%)	Poorly drained	University farm	Basement complex	Few grasses and trees
33	Jatau 9.472115° 12.392833°	Gently Sloping (2-6%)	Poorly drained	Sorghum and close to bridge	Basement complex	Few grasses and trees
34	Amsami 9.525381° 12.526645°	Gently Sloping (2-6%)	Poorly drained	Sorghum, rice and mango trees	Basement complex	Few grasses and trees
S/N	Location and Coordinates	Slope	Drainage	Land use	Geology	Vegetation
35	Dunde 9.474111° 12.391489°	Gently Sloping (2-6%)	Imperfectly drained	Rice cultivation	Basement complex	Trees, shrubs and grasses
36	Jera 9.544892° 12.435604°	Gently Sloping (2-6%)	Moderately drained	None cultivated	Basement complex	Few grasses and trees
37	Sani 9.510375° 12.508201°	Gently Sloping (2-6%)	Moderately drained	None cultivated	Basement complex	Trees, shrubs and grasses
38	Kaftarare 9.491526° 12.469397°	Gently Sloping (2-6%)	Moderately drained	Rice	Basement complex	Trees, shrubs and grasses
39	Mashi 9.495313° 12.458301°	Gently Sloping (2-6%)	Poorly drained	Sorghum and maize	Basement complex	Few grasses and trees
40	Modibbo 9.380195° 12.490674°	Gently Sloping (2-6%)	Poorly drained	Sorghum, rice and trees	Basement complex	Few grasses and trees
41	Ngawa 9.492952° 12.445485°	Gently Sloping (2-6%)	Moderately drained	Rice cultivation	Basement complex	Trees, shrubs and grasses

Key: Lamido Farm =LF, Professorial Quarters = PQ, Federal Housing = FH, Kangling = KLG, Damare = Dam, Jatau = J, Amsami = A, Sani = S, Mashi=M, Modibbo = M, Girei River = GR, Jabbilamba = Jabbi, Daware Junction = DJ, Hona = H, University farm = UF, Labondo River = LR.

Watershed Characteristics of Girei LGA

The results of the study showed that Girei watershed comprises of 4 basins of various sizes; Basin 1 (2,288.1 Km²), Basin 2 (10.6 Km²), Basin 3 (41.1 Km²) and Basin 4 (13.7 Km²) (Table 2). Results revealed that all the study areas were located in Basin 1 having the highest surface area. The total surface area of all the basins was 2,533.5 km² (Figure 2)

The drainage of the area was a function of the existing relief condition as the streams and rivers originated from the highland areas. Due to the nature of the topography of the area, the slope was categorized in to: level slope <2%, gentle slope 2-6%, moderate slope 6 – 13%, steep slope 13 – 25% and very steep slope >25%. As observed in (Figure 3), all the gully locations were located at the category of the gentle slope (2 – 6%) with only few



located at moderate slope rate (6 - 13%). This observation was the same with that of the morphological description in (Table 1). The slope played a vital role in surface water runoff, For instance, places with high slope rate had high runoff rate compared to places of relatively flat terrain (Table 1). Due to the nature of the slope rate, gully activities were able to accelerate, because most human activities were carried out at the lower slope, while the streams and rivers originated from the highland areas. According to the report of Otim *et al.* (2019) and Idowu *et al.* (2013) who stated that both runoff volumes and rates increases as watershed size increases; however, both rates and volume per unit of watershed area decreases as the runoff area increases. Watershed size might have contributed to the gully development too, because, the season at which high runoff may be expected to occur were equally determined by the watershed size. According to Idowu *et al.* (2013), overland flow is the upper reaches of the hydraulic length, shallow flow begins where overland flow converges to form gullies while channel flow is available man-made drains.

The study area comprised of both trunk routes A, trunk routes B and Service routes linking one community to another as shown on (Figure 4). The trunk A route was linking one state, local government to another (Mubi road), while the trunk route B and C linked one community to another. The service route was used to link one farmland to the other (Figure 4). the various trunk routes might also contributed in the expansion of the gullies, even as evident in some of the gully locations where travel routes turned to erosion sites as a result of compaction due repeated trampling by human and some other transient movement which inhibited water infiltration but increased runoff flux. This finding was also supported by Vahyala *et al.* (2018) who reported that dislodged soil particles tend to silt and block surface pores, contributing to the development of surface crust, that restrict water movement into the soil surface as a result of compaction due to livestock, human and equipment traffic, especially on wet soils.

Results of the study showed that the drainage of the area was a function of the existing relief condition as the streams and rivers originated from the highland areas then flowed down streams and distributed within the study area, some of the major gully points might be attributed to the high volume of runoff flowing down the mountain top. Table 3 revealed 4 major sums of channel lengths: row labels 7 (188.6 km), row labels 8 (81.7 km), row labels 9 (71.1 km) and row labels 10 (14.4 km) (Figure 5). The total channel length of all the channels was 355.8 km. These channels were distributed across the study areas (Table 3). However, it was out of these various channel's gullies are easily formed due to relatively high flow gradient and water movement at great velocities (Figure 5). these channels also contributed in the development and expansion of the gullies as a result of bank and heat-cut collapse when

water is running off into the channels. This was also in line with the finding of Gundiri, (2023) which revealed that active side wall of a channel with thick depth and whose floor was restricted from deepening by rock basement could generate bank collapse and perhaps due to the wide drainage area which further concentrated run-off that increased side wall erosion in the channel. Also reported by Capra *et al.* (2004) that channel incision could consistently occur when the soil depth is high, which was also in accordance to this study.

The Digital Terrain Models of watersheds in the study area revealed the following topographic order of magnitude in altitude; Jabbilamba (273 m) > Sangere, Amsami, Sani, Lamido Farm, Hona, Girei River, and Professorial Quarters (244- 213 m) > Jera, Modibbo, University Farm, and Federal Housing (213 – 183 m) > Damare, Ngawa, Mashi and Kaftarare (183 – 152 m) > Dundee, Jatau, Labondo River, Kangling and Ndikajam (152 m) (Figure 6). The DTM suggest that Jabbilamba is situated at a higher altitude (273 m) compared to the other locations, especially Dundee, Jatau, Labondo River Kangling and Ndikajam which were sited on a lower altitude (≤ 152 m) (Figure 6). These differences in topographic points have actually been evident in the sizes of the gullies, where the larger gullies were mostly located at higher altitude than others, especially locations like; Jabbilamba, Daware Junction, Sangere and Safini. Slope was the key factor affecting runoff shear stress, and it was also the key topographic factor of gully formation even as supported by Liu *et al.* (2021), that the characteristics of gullies vary with the topographic position and slope gradient. Also, Zhang *et al.* (2016) and Obasi *et al.* (2011) observed that the influence of topography on the development of gullies is reflected in the slope length, slope gradient and catchment area. Which were all in accordance with these findings.

Table 2: Basin Surface Area of the Study Area

NO	NAME	Surface Area (sq km)
4	Basin 4	13.7
3	Basin 3	41.1
2	Basin 2	190.6
1	Basin 1	2,288.1

Total study area: 1039.600 m²=2,533.5 Km²



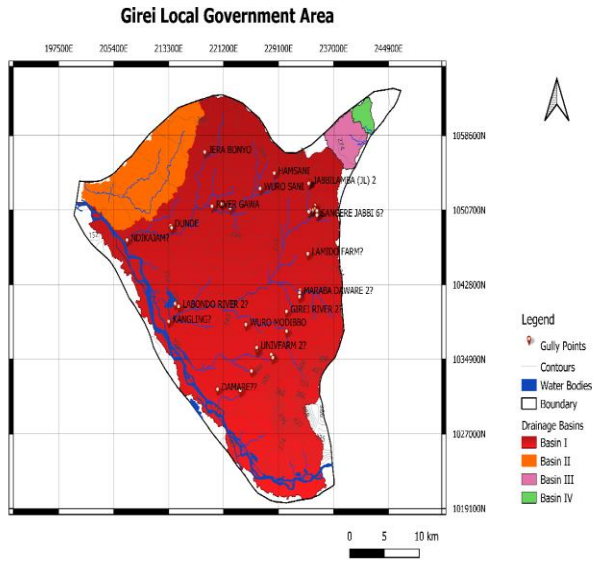


Figure 2: Map of Girei Showing the Drainage Basins (Watershed) and Gully Points

Table 3: Channel Length of the Study Area

Row Labels	Sum of Length (km)
7	188.6
8	81.7
9	71.1
10	14.4
Grand Total	355.8

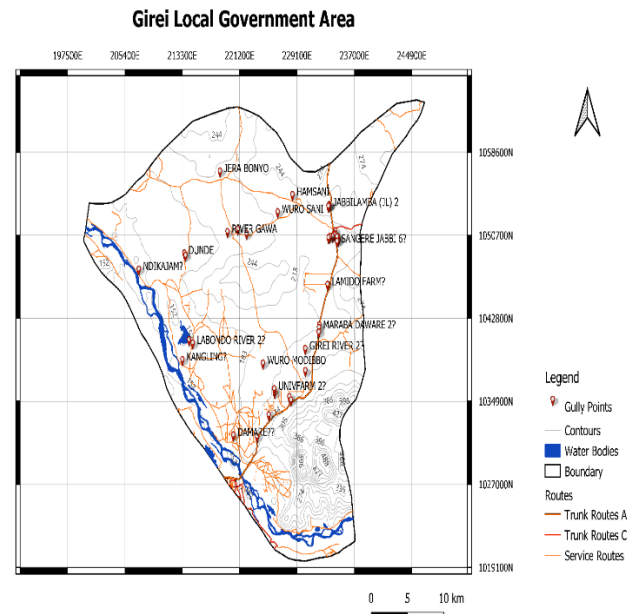


Figure 4: Map of Girei Local Government Showing the Travel Routes and the Gully Points

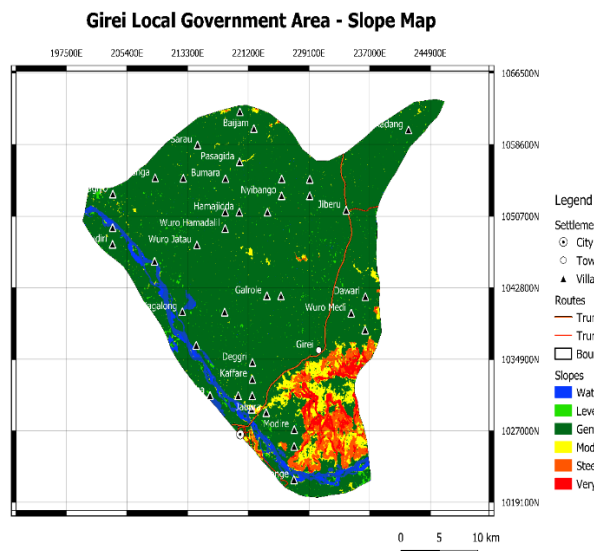


Figure 3: Map of Girei Local Government Showing the Slope Rate

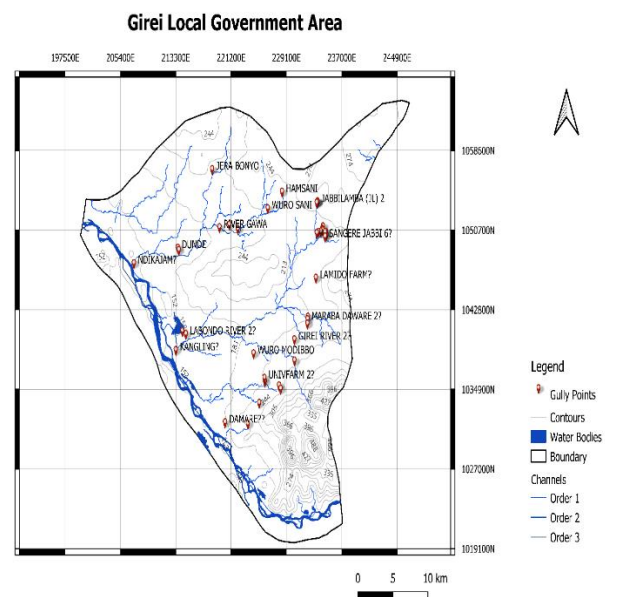


Figure 5: Map of Girei Local Government Showing the Water Channels and the Gully Points

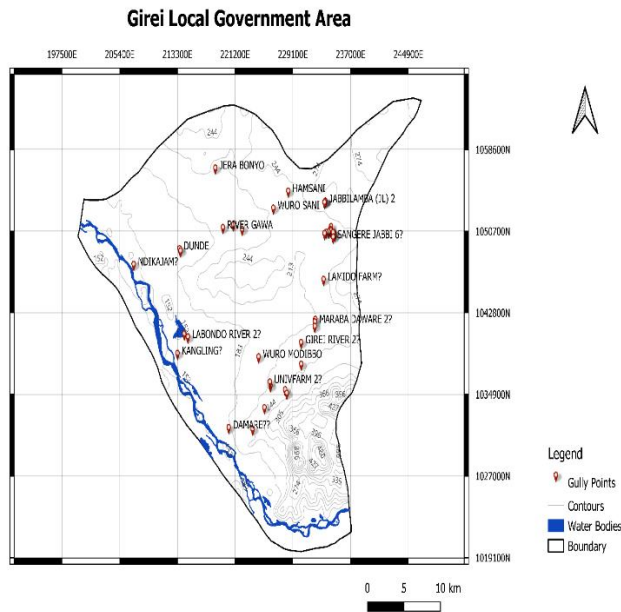


Figure 6: Map of Girei Local Government Area Showing the Topography and Gully Points

CONCLUSION

Due to the nature of the topography of the area, the slope was categorized into: level slope <2%, gentle slope 2-6%, moderate slope 6 – 13%, steep slope 13 – 25% and very steep slope >25%. As observed in figure 5, all the gully locations are located at the category of the gentle slope (2 – 6%). This observation was the same with that of the morphological description in Table 2. The slope plays a vital role in surface water runoff. For instance, places with high slope have high runoff rate compared to places of relatively flat terrain. Watershed size may determine the season at which high runoff may be expected to occur. Due to the nature of the slope rate, gully activities were able to accelerate, because most human activities are carried out at the lower slope, while the streams and rivers originates from the highland areas. The study area comprised of both trunk routes A, trunk routes B and Service routes linking one community to another. The results of the study showed that Girei watershed comprises of 4 basins, such as: Basin 1 (2,288.1 Km²), Basin 2 (190.6 Km²), Basin 3 (41.1 Km²) and Basin 4 (13.7 Km²). Observation showed that all the study locations were located in Basin 1 having the highest surface area. The total surface area was (1,039.6 km²). The distance from the highest level (488 m) down to the points of the gully areas was long enough for water to flow along the slope as runoff cutting the gully headcut capable of influencing gully development. Effort should be made to reduce; slope rate, slope length and runoff speed and volume, by applying runoff barriers.

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