Analysis of Gully Erosion in Tumfure, Gombe Urban, Gombe State, Nigeria

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Abstract

This paper analyzed gully erosion in Tumfure, Gombe Urban, Gombe State Nigeria. The specific objectives are: to identify and map out the areas affected, analyze the nature of the terrain, factors that influences the gully, its morphology, and the effects of the gully erosion in the study area. Data used in this paper were generated through field observation and measurements and satellite imageries. The data were analyzed through the use of ArcGIS10.2 software. The findings from the interpretation of satellite imageries of (2005) and (2016) as well as the results from field measurements showed that gully variables such as (length, depth and widths) have significantly changed in the last 12 years. The satellite image of 2005 revealed that urban growth in terms of settlement, market and administrative/offices was 0.14km^2 of the total land area. The 2016 image analyzed, revealed change in the urban expansion from 0.14km^2 to 4.26km^2 in 2016. This implied an increase of 4.13km^2 over 12 years. These infrastructures which were developed over the years are linked by footpaths along which runoff took advantage to in development of gullies. The finding further revealed that all the concrete surfaces and iron roofs increase runoff and consequent gully development. Falling of trees, cracks and falling of buildings into gullies are common features in the gully prone areas and several people are at the risk of losing their houses and livelihood to gully erosion if no holistic control measures are taken. The study therefore, recommended among others, that proper enlightenment campaign and educating the populace on the real causes of gully erosion, effective methods of controlling as well as preventing gully erosion be put in place by the government. Similarly, reforestation of catchment areas and eroded lands can be effective at reclaiming and controlling gully corridors in the affected areas.

Keywords: Gully erosion, GIS Software, Gombe urban, Tumfure, Nigeria

Introduction

Gully erosion is a dynamic geomorphic process operating on the landscape. It is defined as the process leading to the general degradation of the ground surfaces (Knapp, 1979; Morgan, 1980 and Blum, 1985). Similarly, Faniran and Areola (1980) defined soil erosion as a situation in which soil is removed at a rate faster than that at which new soil is formed. Jimoh (1999) defined soil erosion as the removal of soil materials and/or soil nutrients by surface run-off from different points of origin to other locations. The earth's landforms are closely inter-related and some of the observation which has been made with the passing of time shows that these landforms are acted upon by the processes of erosion causing the landforms to undergo a progressive change from initial forms sequentially to ultimate forms (Sparks 1995).

This geomorphic process may degenerate into sheet, rill or gully types of erosion (Cooke and Doornkamp, 1974 and Jimoh, 1999). Sheet erosion is essentially a process that involves the uniform removal of soil surfaces, which is when the soil surface is undergoing a uniform degradation. Rills are parallel grooves of little depth Scovering the land surface which can easily be filled through normal cultivation. Formation of rills is one of the consequences of flow water. Sheet and rill erosion are the fore runners of gully erosion, representing the incipient stage of the development of gully erosion.

Gully erosion is any erosional channel that is so deep that it cannot be crossed by a wheeled vehicle or eliminated by ploughing, unlike rills which can easily be filled through normal cultivation. In spite of technological advancement, erosion menace still remains a major problem in Nigeria. The annual heavy rainfall has very adverse impacts, altering existing landscape and forms. Such landforms create deep gullies that cut into the soil. The gullies spread and grow until the soil is removed from the sloping ground. Gullies when formed, expand rapidly, coupled with exceptional storm or torrential rainfall downstream by head ward erosion, gulping up arable lands, economic trees, infrastructures, lives, sacking of families, (Umudu, 2008) and valuable properties that are worth millions of naira.

An endemic problem in Gombe town is gully erosion, some measuring up to 15meters in depth (Mbaya, 2012). Vast tracts of arable land, buildings and roads have been destroyed by the gully erosion. The town is fast becoming hazardous for human habitation. Hundreds of people are directly affected every year and have to be re-located. Large areas of lands are becoming unsuitable for human settlements (Mbaya, 2012). The infrastructural development coupled with population increase, have heightened the problems of gully erosion in the State capital particularly in the study area (Tumfure) where there is a rapid physical growth of infrastructural facilities over the recent years. People have observed, some small rills, which were crossed with one-footstep, that have now developed into big gullies and those that have their houses at reasonable distances from such rills some years back are now helplessly observing their houses collapsing or with exposed foundations. This is also applicable to roads and other structures. When most available land in an urban area is built-up, increase pressure on land might lead to extension of urban land use to the stream channels, flood plains and restriction of streams to artificial channels. This is the situation being experienced in Tumfure.

However, despite the several studies reported in literatures such as study of gully phenomenon in Gombe town (Orazulike 1987), gully erosion master plan for Gombe town, interdependent mechanism between several factors that contribute to gully erosion, (Mbaya 2012) and rise in value of urban land due to population increase (Danladi and Ray 2014), there is still the need for more study on gully erosion in the study area, since there is no study carried out specifically in Tumfure and gully erosion is dynamic; every year new sites develop or existing ones increase. Mbaya (2012) carried out similar study; but then Tumfure was yet to be developed, as such it was not captured in his study. Therefore, considering the rapid physical development in the area, particularly with the emergence of the two recently built housing estates; Labour quarters and Investment quarters, there is the need for appraisal of the gully erosion problem in Tumfure, Gombe urban, Gombe State, Nigeria.

Aim and Objectives

The aim of this paper is to assess gully erosion in Tumfure in order to suggest adequate mitigation measures especially in the context of achieving sustainable development. Specifically, the paper has the following objectives: to identify and map out the gully erosion sites; analyze the nature of the terrain in the study area; measure the physical dimension of the gullies; and assess the effects of gully erosion in the study area.

Literature Review

Challenges of Gully Erosion

Gully erosion is a world-wide phenomenon. It is an enormous type of environmental degradation which leads to loss of valuable land used for agricultural, domestic, industrial and aesthetic purposes, as well as loss of property and even human lives (Obiadi, Nwosu, Ajaegwu, Anakwuba, Onuigbo, Akpunonu and Ezim, 2011). Over the last decade, there has been a growing interest in studying gully erosion and a lot of progress has been made with respect to understanding the soil degradation process and its controlling factors (Umudu, 2008). However, there are still several aspects of gully erosion that need to be studied more extensively. A few of these aspects are gully initiation, development and infilling, how hydrological and other soil degradation processes interact with gully erosion and measures for preventing and controlling gully erosion (Poesen, 2011).

In the early stages of settlement development of an area, the land is cleared of vegetation cover to make room for human occupancy. This leads to reduced infiltration capacity of the land (Sagua, 1988). As human settlement development progresses and construction work goes on, the landscape becomes more compacted, reduces infiltration capacity of the land, thereby increasing surface runoff. In the advanced stage of urban growth, much of the land is covered by man-made structures such as commercial, industrial, houses, pavement of street network, and building of gutters. When most of the available land in urban area is built-up, increased pressure on land might lead to extension of urban landuse to stream channels, flood plains and restriction of streams to artificial channels (Okoye, 1998).

Another factor in the development of gully is overgrazing. It removes much of the soil's protective vegetal cover and trampling, compact the soil; thus the infiltration capacity of the land is reduced. The increased run-off, caused by the insufficient water holding capacity of the soil, produces new gullies or enlarges old ones (Mbaya, Ayuba and Abdullahi, 2012). The role of vegetative cover is to intercept rainfall, to keep the soil covered with litter, to maintain soil structure and pore spaces, and to create openings and cavities by root penetration. This is best achieved under an undisturbed multistory forest cover. Under special conditions, however, a well-protected, dense grass cover may also provide the necessary protection to the soil. The relevance of plants in protecting the soil against fluvial processes on slopes lie in their ability to cover the surface and not their density. Nyanganji (1994) observed that apart from protecting the slope against the impact of raindrops and runoff erosion on slopes, it also opens up the soil for effective absorption of water into the ground thereby reducing runoff volume and energy on the slope; soil erodibility; slop angle, height and percent of vegetation cover explain the rate of soil wash. Therefore, the concept been adopted in this study is the concept of fluvial erosion.

Factors Affecting Soil Erosion

The rate of erosion depends on many physical and human factors. Physical factors include climate, geology, landform (slope), soil and vegetation. The amount and intensity of precipitation, the average temperature, as well as the temperature range, the wind speed, and storm frequency are some climatic elements that correlate with erosion (Ziebell and Leongtha, 1999) and (Cooke and Doornkamp, 1974). The geologic factors include the rock type; its porosity and permeability, the slope (gradient) of the land, and the rock structure such as are tilt, fault and weathered mantle. The biological factors include the ground cover by vegetation and the type of organisms inhabiting the area, and the land use.

Mapping of Gully Erosion

Gullies are mapped by extracting information from an image such as size, shape, shadow, tone and colour (reflectance), texture, pattern, and features (Zhang and Goodchild, 2002). In cases where the outline of the gully is not clear (i.e. vegetation cover) ground-truthing and stereographic viewing using air photographs or certain satellite imagery (e.g. SPOT) can minimize the problem because gullies are visualized from different perspectives. Gullies are delineated on a transparent plastic overlay over an air photo or digitized within a GIS (using air photos and satellite imagery), annotated and printed off as a map. Aerial photos are the most commonly applied instrument for mapping gully erosion because most gullies are visible using stereoscopic aerial photography (Thwaites, 1986;

Watson, 1997). Using 1:10,000 and 1:20,000 air photographs, Thwaites (1986) digitized gullies in the BRAR catchment (372 km^2) in South Africa, based on grey tones and feature. Morgan *et al*, (1997) identified gullies as linear features with a clearly defined depth. Most of the gully erosion research in southern Africa has used air photos to map gullies in Zimbabwe. Jones and Keech (1966) used air photo interpretation to measure gully size and therefore assess the severity of gully erosion at a scale of 1:25,000. In South Africa, Flugel, Marker, Moretti, Rodolfi and Sindorchuk, (2003) and Sindorchuk (2003) used air photos to map gully erosion based on the homogeneity of the erosion response and the heterogeneity of the structure, a concept called erosion response units (ERU).

These studies were slight modifications of the proposed method of terrain analysis which also extracts information from an image such as tone, texture, geometry and so on. This procedure enabled mapping of six different ERU, ranging from slightly eroded (1) to severely eroded (6), at a scale of 1:50,000. More recently and with relevance to the current study area, the study by Sonnevelds (2005) focused on digitizing gullies at the sub-catchment level, delineated as linear erosion features with confined flow. Many erosion studies applied in developing countries have used satellite imagery to digitize gullies (Dwivedi and Ramana, 2003;). Satellite imagery offers much broader spatial coverage than individual aerial photos and can be used to map gullies in remote areas due to additional spectral bands that help the interpreter distinguish gullies. Gullies are digitized based on tone, shape, pattern and their high reflectance in all. In Tanzania, Kiusi and Meadows (2006) delineated gullies based on colour, texture and pattern, using Landsat TM images at a scale of 1:100 000.

In India, Dwivedi and Ramana (2003) delineated three categories for gully erosion (shallow, medium and deep) using a false colour image from the Indian Remote Sensing Satellite. This imagery can improve on traditional methods of gully mapping at a local scale because major (>2.5 m) and minor (2.5 m) gullies are visible in the panchromatic band of SPOT-5 (2.5 m). In addition, SPOT imagery can improve on traditional mapping methods in South Africa on a regional scale by offering a seamless coverage. ERUs are defined as “distributed three-dimensional terrain units, which are heterogeneously structured and have homogeneous erosion process dynamics characterized by a slight variance within the unit, if compared with neighboring ones.” (Flugel *et al*, 2003). Although digitization of gullies from an air photo or satellite image has been used extensively, the method is limited to expert knowledge, its inconsistent, lacks quantitative information and can be a very time consuming and costly process as such for this paper, both the digitization and that of field investigation techniques are both adopted to and supplement the digitization method. This was considered more appropriate because through ground trothing, quantitative information about the coordinates of the gullies are obtained.

Description of Study Area

Tunfure is located in Akko Local Government Area which forms part of Gombe town and also the capital of Gombe State. It is located between latitudes 10°16'N to 10°17'N and longitude 11° 4'E and 11° 7'E (Fig. 1). It shares boundary with Wuro Billiri to the South, Shango to the North, Gombe town to the East and Lafiyawo to the West. It forms part of the capital city of Gombe State and occupies an area of about 12km^2 (Ministry of Lands and Survey, Gombe, 2008). Tumfure town is well linked by road to other regional centres like Gombe town, Kano road, Bauchi /Jos road and Yola /Jalingo road. Tumfure is located at the outskirt of Gombe urban as shown in Fig. 1.

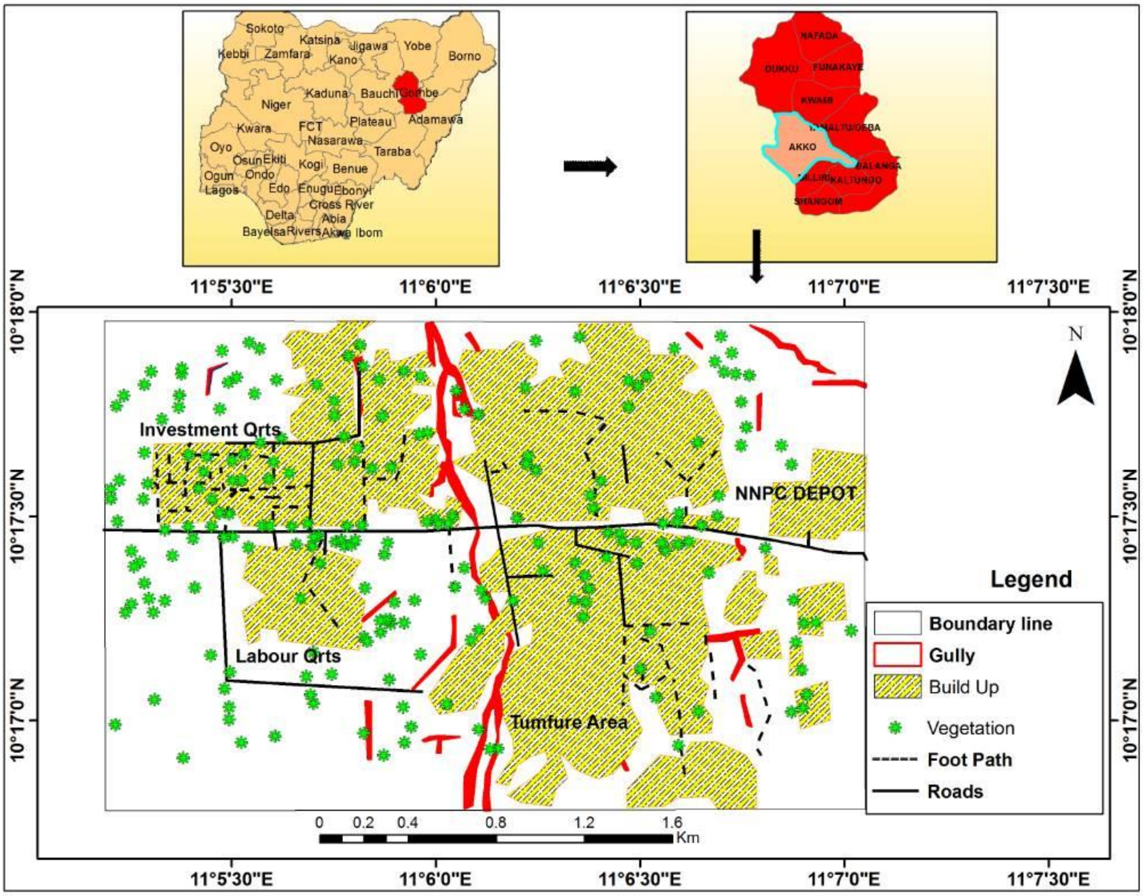


Fig.1: Akko LGA showing Tumfure (study area)
Source: Modified from Quick Bird Satellite Imagery (2018)

Materials and Methods

The study used google earth satellite imageries 2016, digital elevation data set from Shuttle Radar Topographical Mission (SRTM) with a special resolution of 90 meters, topo map sheet 152 of Gombe 2017. Thematic map of Gombe town was generated through creation module of ArcGIS software using digital elevation data set from SRTM obtained online, DEM image of the study area. Gully morphological characteristics including; length, width, depth and side slopes and data on the effects of gully erosion on the livelihood of the people in Tumfure was obtained from field investigations. Three procedures were adopted in the data collection exercise. These included: generation and interpretation of satellite imageries; (which includes, relief and drainage, elevation of the terrain, profile and slope of the stream and also the digital elevation model of the study area), fieldwork involving measurement of gully elements (length, width and breadth) as ground truth information and field investigations so as to ascertain the effects of gully erosion.

The Satellite imagery was obtained from google earth, landsat and archive, where the study area was downloaded and the image was exported to ArcGIS 10.3 and it was georeferenced and subsequently the affected areas were digitized and calculated from the attribute table using the field geometry in metres. The features were processed from DEM image and subsequent analysis. The data were analyzed through the use of ArcGIS software.

Results and Discussion

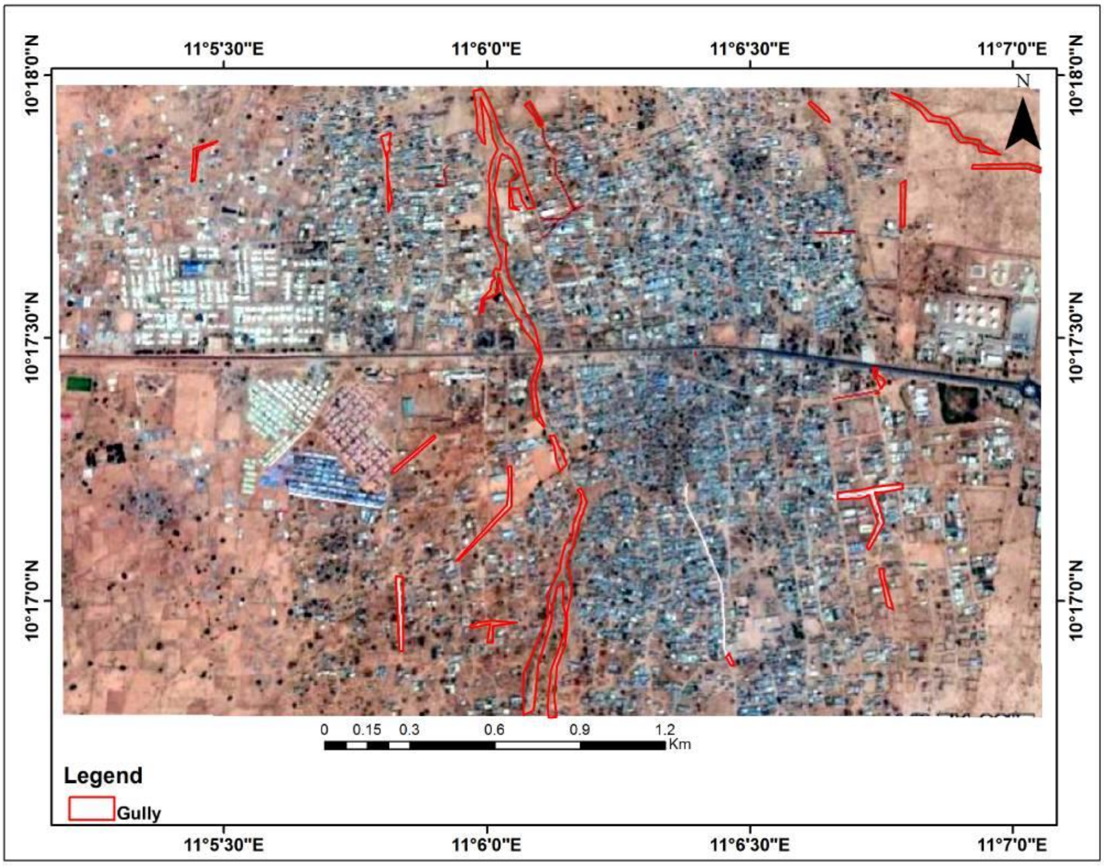
Identification and Mapping of Gully Erosion Sites in the Study Area

Table 1 presents the GPS coordinates of the locations of the areas affected by gully erosion in Tumfure. From Fig 2. it is pertinent to note that the main gully site is the Tumfure stream, which includes, parts of Farin-kasa, reservoir (adjacent labour quarters), Kasuwan gwari, (across Bauchi road), Longel and Hamma Idrissa. The gully is a second order gully with numerous first order gullies. The total length of the gully is 3.1km. The devastated areas can be seen from the imageries in Fig. 2. This continuous increase in gully development is mainly as a result of the observed human activities in the study area that ranges from the improper channeling of runoff water, haphazard erection of buildings on the undulating terrain and water ways, to dumping of refuse on waterways as observed by Danladi and Ray (2014). Other factors include, poor construction as evident by excessive runoff generated due to poor design of roads without drainages to channel the runoff into the nearby streams. The red colours in Fig. 5 shows areas affected and that are vulnerable to the gully erosion. The figure shows that many buildings, trees, open space as well as access roads falling within the perimeter marked by red colours are under threat of gully erosion. The total area affected by the gully as shown in Table 1 and calculated using ArcGIS software is 354405.8m^2 (0.354406km^2). Many buildings and vital infrastructure stand the risk of been destroyed within a short period of time if nothing serious is done.

Table 1: Coordinates of the Areas Affected by Gully Erosion in Tumfure

S/N	Latitude	Longitude
1	10^{0}17’12.219’’N	011^{0}05’37.462’’E
2	10^{0}17’18.405’’N	011^{0}05’39.174’’E
3	10^{0}17’28.097’’N	011^{0}05’55.073’’E
4	10^{0}17’14.841’’N	011^{0}05’57.090’’E
5	10^{0}17’13.173’’N	011^{0}06’05.515’’E
6	10^{0}17’20.383’’N	011^{0}06’02.954’’E
7	10^{0}17’28.744’’N	011^{0}06’13.264’’E
8	10^{0}17’17.338’’N	011^{0}06’11.960’’E
9	10^{0}17’17.729’’N	011^{0}06’13.651’’E
10	10^{0}17’19.868’’N	011^{0}06’20.317’’E
11	10^{0}17’12.691’’N	011^{0}06’18.723’’E
12	10^{0}17’19.056’’N	011^{0}06’42.235’’E
13	10^{0}17’14.268’’N	011^{0}06’45.515’’E
14	10^{0}17’27.315’’N	011^{0}06’45.564’’E
15	10^{0}17’42.095’’N	011^{0}06’38.838’’E
16	10^{0}17’44.687’’N	011^{0}06’10.101’’E
17	10^{0}17’49.039’’N	011^{0}06’08.360’’E
18	10^{0}17’56.060’’N	011^{0}06’05.150’’E
19	10^{0}17’41.218’’N	011^{0}06’06.798’’E
20	10^{0}17’34.704’’N	011^{0}06’00.427’’E
21	10^{0}17’48.319’’N	011^{0}05’55.159’’E

Source: Fieldwork, 2018

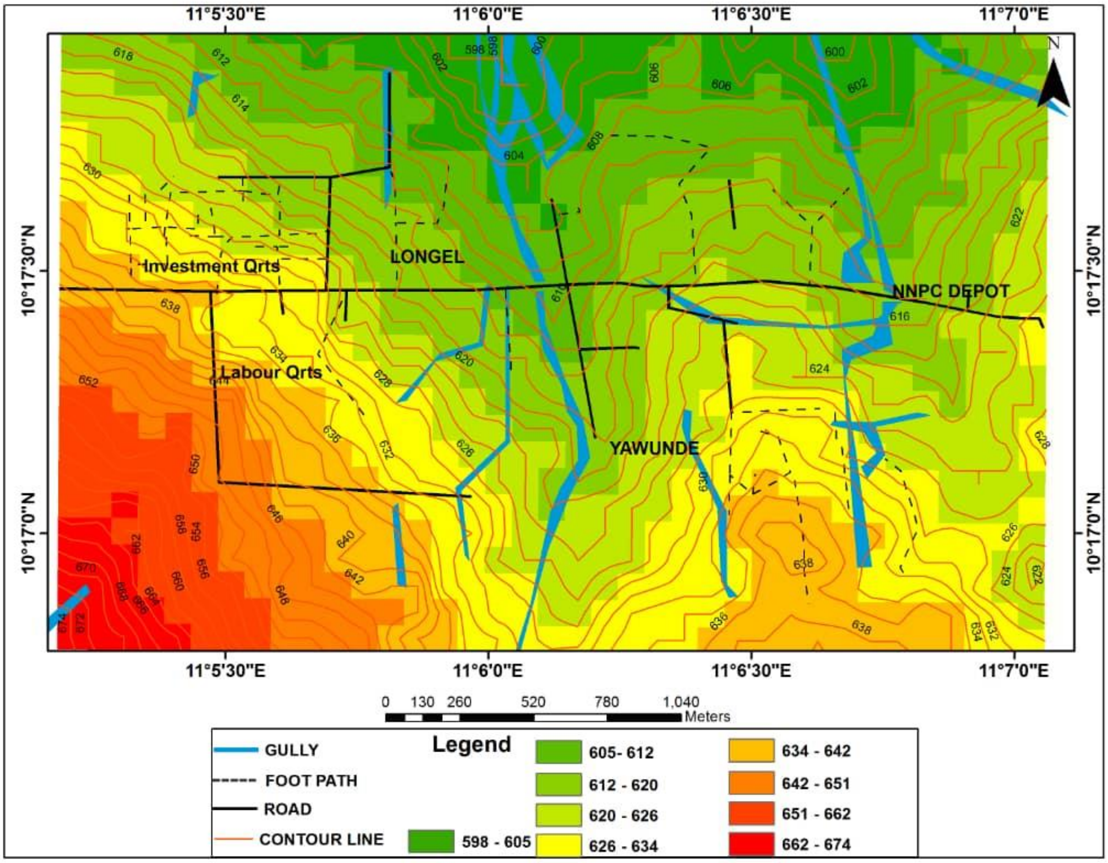


Source: Google Earth Image 2018

Fig. 2: Tumfure showing the areas affected by gully erosion

Influence of Relief and Drainage on Gully Erosion

Fig. 3 depicts the relief and drainage of the study area, where the different colours represents the elevation at different places within the study area. The area is generally undulating in nature. The lower part of the south-west (adjacent Labour quarters) represent the highest point in the study area (662m-674m) which is also close to where the Tumfure stream was initiated. Similarly, the lowest area (598m-605m) is in the northern part where the Tumfure stream continues to the outer part of Tumfure as all surface water flow down slope. As for the drainage, the area is mainly drained by seasonal streams flowing from south to north together with its tributaries. These water ways gradually transformed into gullies partly due to rapid demographic pressure on land and has affected the study area especially the infrastructures located close to the gully sites. The entire land is drained by the head waters of the River Dadin-Kowa which is a tributary of Gongola River (Balzerek, Werner, Jurgen, Klaus-martin, and Markus, 2003).

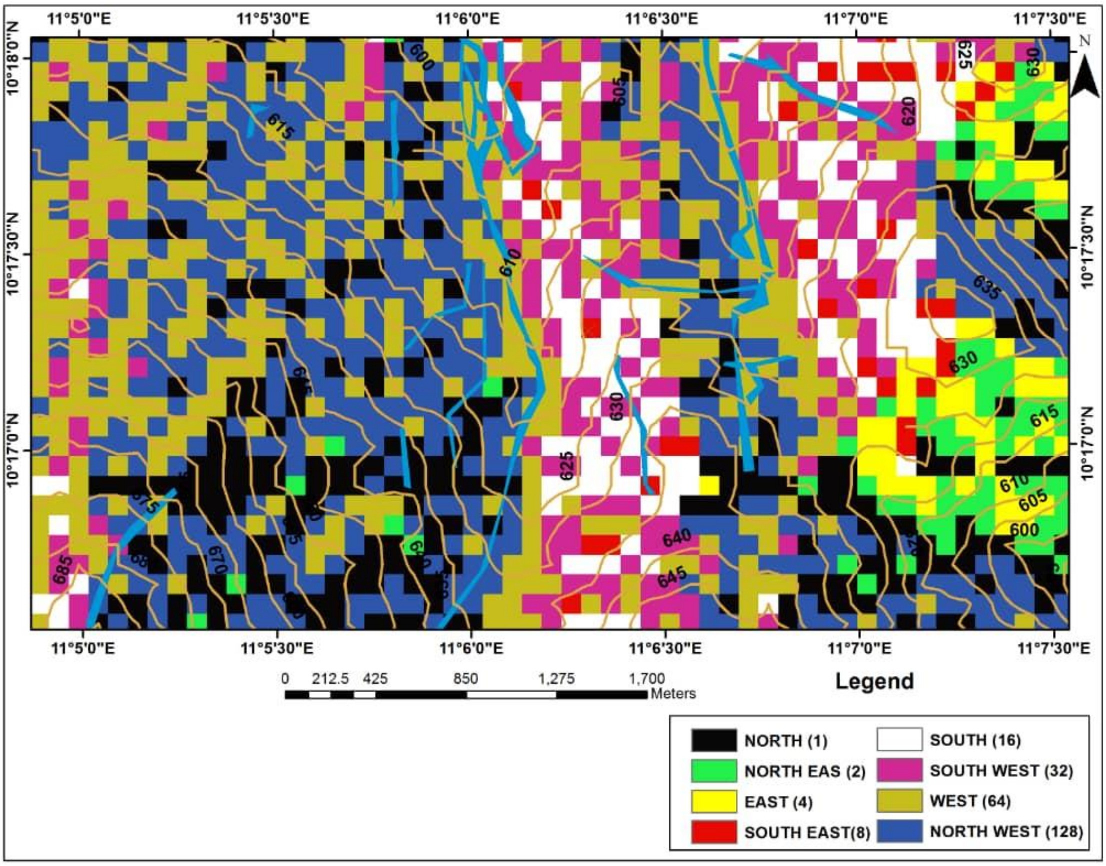


Source: Author's Analysis, 2017

Fig.3 Relief and drainage of the study area

Elevation and Stream Flow Direction

From fig. 4, one can easily deduce reasons why the stream is heavily subjected to gully erosion. The figure shows that the general topographic configuration of the area and how it influences the direction of flow of the runoff which is all directed towards the Tumfure stream. However, they are of different elevation (598m-674m) due to the undulating nature of the area as indicated from the legend, but they are all directed towards the Tumfure stream, as all water flows down slope.

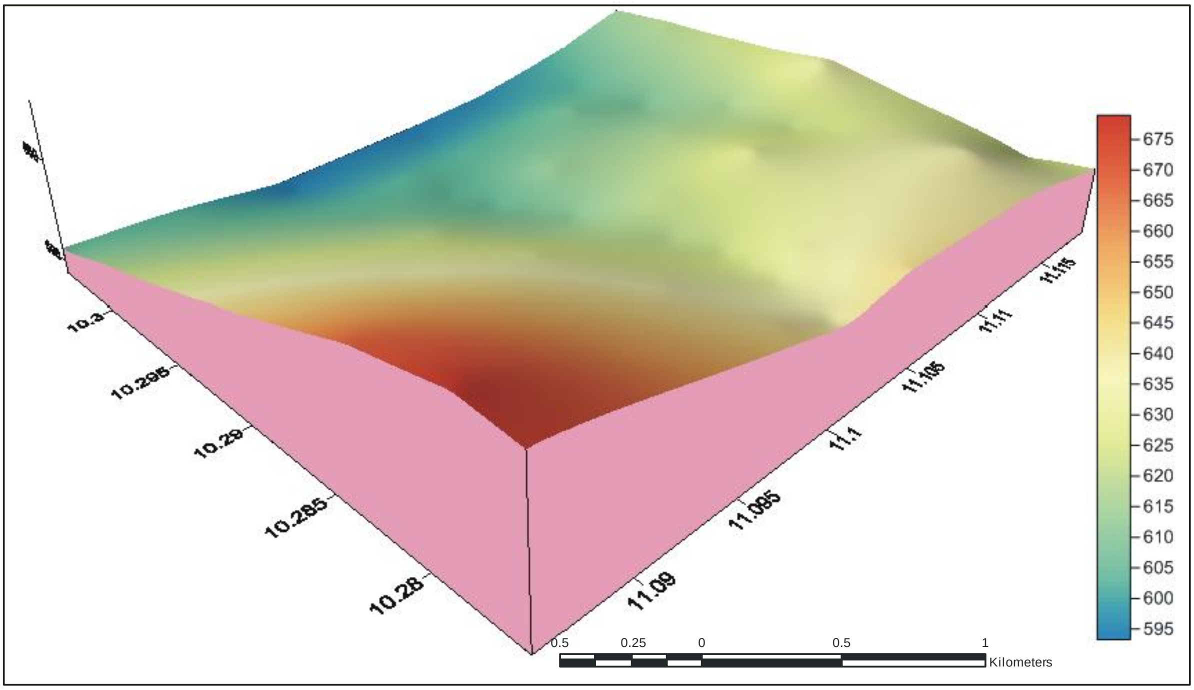


Source: Author's Analysis, 2018

Fig. 4: Elevation of the terrain and the direction of flow of the stream.

The Digital Elevation Model (DEM) of the Area

The DEM and the 3-Dimensional view of Tumfure as shown in Fig. 5 depict the general topography of the study area. Tumfure which also form part of Gombe town is generally a low lying area. The portrayed image on fig. 5 conforms to the description given by Max Lock, (1976) as an undulating area which comprises of a pronounced low lands which aid the high velocity of runoff water and hence encourages the gully erosion process in the area.



Source: Author's Analysis, 2018

Fig. 5: Three (3)-Dimensional view of the study area

Conclusion

This paper has analyzed the gully erosion in Tumfure. One of the major environmental problems in Tumfure is gully erosion. This is due to the complex interdependent mechanisms between rainfall pattern, soil erodibility, landuse and topography has reduced infiltration, which is generating higher runoff. This has increased deep cutting and has taken up valuable land. The situation is further worsened by rise in value of urban landuse due to population increase. These have forced people to erect buildings on floodplains, consequently increase in both magnitude and frequency of gully in response to high storm water runoff and channel concentration. The satellite imagery of the study area shows that the main gully site cut across Bauchi - Gombe road and was purposively used for the assessment of gully properties using satellite images of the year 2005 and 2016; topography and effects of gully erosion on residential and plants in the study area. The analyzed satellite image of 2005 shows that urban growth in terms of settlement, market and administrative/offices was $0.14km^2$ of the total land area. The 2016 image analyzed, revealed change in the urban expansion from $0.14km^2$ to $4.26km^2$ in 2016. This implied an increase of $4.13km^2$ over the 12 years. The impact of gully erosion in the study area includes destruction of roads, bridges; plots of land, houses, trees, and lowering of underground water. The incidence and existence of gully erosion in Tumfure therefore could be explained in terms of geological formations, deforestation and poor landuse practices in the area**.** There is need to protect the land from further degradation and continuous vulnerability without delay by appropriate counter measures.

Recommendations

Based on the findings of this study, the following recommendations were suggested

Firstly, construction of drainages should be adequate and implemented according to drainage sub-basin; the implementation should be performed from downstream to upstream.

Secondly, reforestation of catchment areas and eroded lands can be effective at reclaiming and controlling gully corridors in the affected areas.

Thirdly, planting deep-rooted perennial pastures, trees, or an appropriate mixture of both, such as *pitadeniastrum africanum*, can help maintain healthy and vigorous levels of vegetation.

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