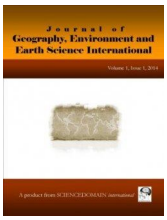

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Geospatial Techniques for Terrain Analysis of Gombe State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author IM designed the study, generated the digital maps and wrote the first draft of the manuscript. Author BBW conducted field studies on the entire state for enquiry and confirmation of names of features such as highlands, rivers etc. Author LAM managed the literature searches. Analyses of the study were carried out by all the authors. All authors read and approved the final manuscript.

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ABSTRACT

Terrain analysis is useful in so many areas ranging from military operations to landuse and agricultural planning, urban planning, forestry management, drainage, hydrology and site suitability assessment of agricultural, settlement, industrial and transportation projects. Gombe State is one of the newest states in Nigeria; they need industrial growth, agricultural development, transport planning and development and most especially sustainable use of the general environment, hence, the state is in need of reliable spatial information of the terrain. SRTM DEM data acquired online was used in conjunction with other complimentary maps of Gombe State to analyze the terrain of the State in ArcGIS environment. The raster surface modules of ArcGIS 9.3 was used in this paper to generate, classify and analyze the Digital Elevation Models (DEM) using the SRTM data of the state into four classes: highlands, uplands, plains and river basins. Cultural features such as settlement and transportation were also analyzed, while various topographical features such as DEM, slope, hill-shading and contour lines were derived from the DEM data for the analysis of the

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terrain of the state. The 2013 NIGER_SAT image of the state was classified into six landuse and landcover classes through the classification modules of ERDAS IMAGINE 9.2 for the analysis of the vegetation and landcover of the state. The study revealed that 33.06% and 34.81% of the land area of Gombe State comprised of the River Basin and plains respectively, while 26.65% and 5.48% are of uplands and highland areas respectively. Yamaltu/Deba, Funakaye and Balanga LGAs have more than half of their land area located within the Basin of River Gongola, while Kaltungo, Balanga and Shongom have more highland areas than the other LGAs. It was recommended that remotely sensed data and GIS techniques be used for terrain analysis because of its accuracy and reliability of data output, and its time saving over conventional methods.

Keywords: DEM; GIS; terrain; topography; Gombe State.

1. INTRODUCTION

The need for analysis of the terrain of any area for environmental monitoring and sustainability cannot be overemphasized as [1] have noted that “a proper understanding of the terrain characteristics is essential for any scientific pursuit”, while [2] also observed that the vast scientific and technical literature accumulated over the years has examined every possible aspect of terrain influence on natural and human processes on this planet. Terrain analysis has been found useful in so many areas ranging from military operations to land use and agricultural planning, urban and residential planning, forestry management, drainage and hydrology assessment as well as site suitability assessment of agricultural, settlement, industrial and transportation projects [3]. Digital Elevation Modeling (DEM) as used by U.S. Geological Survey (USGS) in [4] is the digital cartographic representation of the elevation of the terrain at regularly spaced intervals in x and y directions, using z-values referenced to a common vertical datum. [5] underlined the significance of digital terrain modeling and computerized technology in practical applications, and numerous publications have emphasized the role of terrain in hydrologic modeling, sediment transport, soil erosion estimation, drainage basin morphology, vegetation, and ecology. A DEM is a quantitative, three-dimensional representation of the earth surface derived from elevation data; it provides basic information regarding terrain characteristics. According to [4] it is called a "model" because computers can use such data to model and automatically analyze the Earth's topography in 3-dimensions, minimizing the need for labour-intensive human interpretation). It does not include only the representation of the relief itself but also its descriptions, as slope, aspects, contour lines, break lines, peaks, and the other characteristics. According to [6] several methods have been applied for DEM generation such as photogrammetry using stereo data, interferometry, airborne laser scanning and interpolation of contour maps. However, in this paper, DEM was generated from Shuttle Radar Topography Mission (SRTM) data to analyze the surface configuration of Gombe State.

In the early 60’s when Nigeria got her independence, the need for national mapping arose which led to the generation of aerial photographs of the country between 1969 and 1970 [3] Subsequent topographical maps based on the aerial photographs were derived and from then till now, no any form of national aerial photography has been embarked upon. Other than the non-coverage of the 1960s aerial photographs of some parts of the country, information generated from these aerial photographs that were captured in more than four decades ago are usually regarded as obsolete because so many activities on the terrain must have taken place within the long periods, hence, the need for recent data on such areas. Gombe State is one of the newest states in Nigeria; they need industrial growth, agricultural development, transport planning and development and most especially sustainable use of the general environment, Therefore, the question that arose are: Is the terrain of the new state adequately analyzed? Are the existing data on the terrain of the state current and reliable?. The need for digital terrain analysis of Gombe state had already been highlighted by [7] that “most Nigerian states have robust multipurpose cadastral system, they have gone digital and Gombe State cannot be an exception”. This calls for the need for terrain analysis of the state with the use of modern techniques such as remotely sensed data and GIS. They concluded that the fuel, driving the engine of growth and sustainable development of any state or nation, is a reliable and up-to-date geoinformation. GIS according to [3] has the capability to receive, update, manipulate and condense digital terrain data to

through terrain analysis. Therefore, this paper demonstrates the use of remotely sensed data and GIS techniques for the analysis of the terrain of Gombe State for planning and decision making and for future developmental programs such as transportation and environmental assessment and monitoring. It could also serve as data bank that can be reliably used for future projects.

1.1 Aim and Objectives

The aim of this study is to analyze the terrain of Gombe State using remotely sensed data and GIS techniques. The main objectives are:

(i) To generate and classify the terrain of Gombe State into various topographical classes, using remotely sensed data and GIS techniques.
(ii) To generate and demonstrate the application of terrain features such as slope, contour, hill-shading and image classifications in the analysis of the terrain of Gombe State.
(iii) To assess the impact of the terrain on the patterns of some natural and man-made features such as drainage, settlement and transportation.

1.2 The Study Area

Gombe State which is popularly referred to as the 'Jewel in the Savannah' was carved out from the former Bauchi State by the Federal Military Government of Nigeria on 1st October, 1996. Hence, since no new state has been created since then, Gombe State has always been referred to as one of the newest States in Nigeria. Gombe State shares boundaries with Yobe State to the north, Adamawa and Taraba States to the south, Borno State to the east, and Bauchi State to the west (Fig. 1).The State comprises the following tribal groups: Tangale, Terawa, Waja, Kumo, Fulani, Kanuri, Bolewa, Jukun, Paro Shonge, Tula, Cham, Lunguda, Dadiya, Banbuka, Hausa and Kamo Awak. According to [8] Gombe has two distinct climates, the dry season (November–March) and the rainy season (April–October) with an average rainfall of 850 mm. The mean annual temperature is about 32°C, the soil of Gombe state comprised of sandstones, clay and silt, while the vegetation of the state is that of savanna woodland comprising scattered shrubs and trees such as *Butyrospermum, paradoxum, Tamarin indica, Parkia biglibosa, Aflexia Africana* and grasses. The National Population and Housing Census of Nigeria [9] put the total population of the State as 2,365,040 people out of which 1,244,228 were males and 1,120,802 were females. [10] reported that the main occupation of the people in the state is small-scale farming and the major crops grown include rice, maize, cowpea and vegetables, and that the Upper Benue River Development Authority (UBRBDA) which is in charge of Dadinkowa Dam in Yamaltu-Deba Local Government Area of Gombe State which was commissioned on June 15, 1988 was to serve the following purposes: irrigation agriculture of about 44,000ha, hydroelectric power generation of up to 34 mw, fishing and fishery development (over 20, 000 metric tones of fish annually), flood control and flow regulation, domestic water supply to the State capital and environs and recreational and other socioeconomic benefits. He however concluded that however, the generation of hydroelectric power is the only activity that is yet to commence but the historic irrigation of agricultural lands has been massively going on in the area and rice farmers have been the major beneficiaries.

2. MATERIALS AND METHODS

The following materials were acquired for this study:Digital Elevation Dataset from Shuttle Radar Topographical Mission (SRTM) with spatial resolution of 90metres, Niger-sat image of 2013 obtained from National Space Research and Development Agency (NASRDA) Abuja, Nigeria, Global Positioning System (GPS) Germin 76, Thematic Maps of Gombe State as well as ArcGIS 9.3 software. Digital Elevation Modeling (DEM) of Gombe was generated through DEM creation module of ArcGIS software, using Digital Elevation Dataset from SRTM obtained on line (Fig. 2). The raster DEM was polygonized and classified into the following four classes using the conversion and the symbology classification modules of ArcGIS 9.3 respectively:

(i) River valleys: with heights ranging from 184-351 m above the sea level
(ii) Plains with heights ranging from 352-462 m above the sea level
(iii) Uplands with heights ranging from 463-590 m above sea level
iv) Highlands with heights ranging from 591-1158 m above the sea level

The areas in square kilometers of each of the classes in each LGAs of the state were derived and calculated through the extraction and area

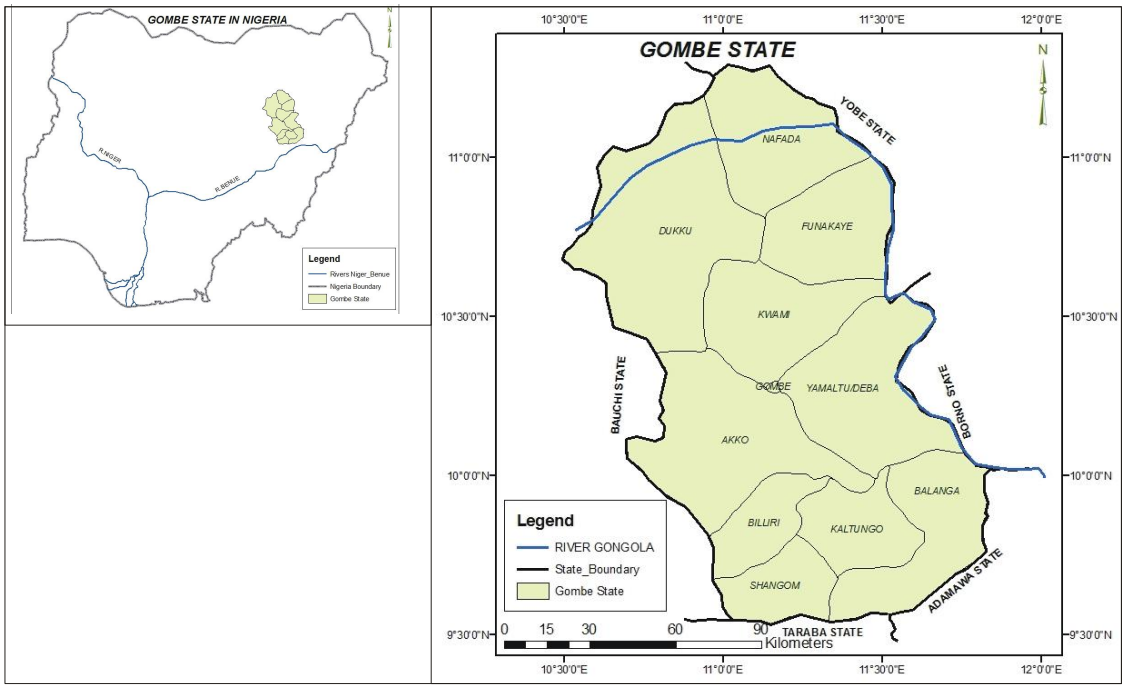

Fig. 1. The study area

calculation modules respectively of ArcGIS 9.3 software. Other features such as contour lines, slope, aspect, and hill shading were processed from the DEM image for subsequent analysis (Figs. 2a -2d). The landuse and vegetation cover of the state was also assessed through the classification of the NIGER-sat image of 2013. The image was classified into six classes; agriculture, urban settlement, grazing land, woodland, swamps and settlement. The area coverage of each of the classes was derived by the use of the area calculation menu of ArcGIS 9.3 software. For the assessment of the relationship between the terrain and other features such as transportation, settlement and drainages, the following operations were performed:

(i) Thematic map of the state containing the transportation features (road, rail line and airport) of the state was acquired and referenced to the DEM image, the features were then digitized and overlain on the DEM images.

(ii) Following the difficulty in accurately discerning the rural settlements on imageries, GPS was used to obtain the coordinates of 165 settlements which were linked to the DEM image for easy assessment of the locations of the rural settlements.

(iii) The rivers in the state were generated from the flow accumulation module of the hydrological analysis of the ArcGIS, the generated rivers were then digitized and overlain on the DEM image (Fig. 4).

3. RESULTS AND DISCUSSION

3.1 Relief of Gombe State

The DEM map in Fig. 2a showed the four terrain classes as well as their heights. The DEM image in Fig. 2a showed that Gongola basin has the least elevation in the state with 184 m above sea level, while the highest elevation is found on the highland areas with an altitude of 1184 m above sea level. This finding is however contrary to the hitherto estimate of the land area of the state which has been grossly underestimated. For instance, [11] reported that the elevation of the plain is at about 600 m above sea level, while, the hills reach between 700 m and 800 m. This paper has shown that the highest elevation of the state which is 1184 m is well above 800m above sea level. A closer look at the hill shade image in Fig. 2b revealed the valleys, the slopes, the uplands and the highlands as well as the dome-shaped hills. The 50 m contour interval of the State in Fig. 2c which was generated from the DEM also clearly differentiated the plains from

the highland with wide and close contour lines respectively. Moreover, the steep slope areas such as immediate western part of Dadinkowa dam as well as the mountain ranges in the south were conspicuous on the map with clustered contour lines, while the shapes of some of the hills such as conical and dissected hills were also clearly identified. Finally, the slope image (in percentage rise) of the State in Fig. 2d which was also generated from the DEM image could be used to assess the steepness of the terrain of the State. The slope image revealed that some parts of the Faliya-Burak-Dadiya mountain range in the southern part as well as some highland areas such as the famous Tula plateau in Kaltungo LGA, the Kulani-Degri-Jikkar hills in Balanga LGA, Kilang hill in Shongom LGA and the Dogon Dutse hill in Kaltungo LGA are found to be steep sided, while the plains and even most parts of Dukku hills are not steep in slope as shown in Fig. 3C. The 3D image in Fig. 3 also clearly revealed the steepness of these mountain ranges and hills in the state.

The relief of the state as revealed in Figs. 2a-2d conforms with the description of [11] that the topography of Gombe State is made up of mainly mountainous, undulating and hilly to the south-east and flat opens plains in the central, north and north-east, west and north-west. The 3-Dimensional view of the Gombe State DEM as shown in Fig. 3 revealed the fascinating terrain of Gombe State as ealier described by [12] that the terrain of the hills of Gombe State has beautiful dome-shaped rock formations with fascinating scenery which are ideal for climbing and camping. The Famous Tangale dome shaped rock/hill formation, Tula Hills, the Bima hills as well as Filiya – Dadiya hills and the Ndinijam Kargo hill are some of the hills in these mountainous region.

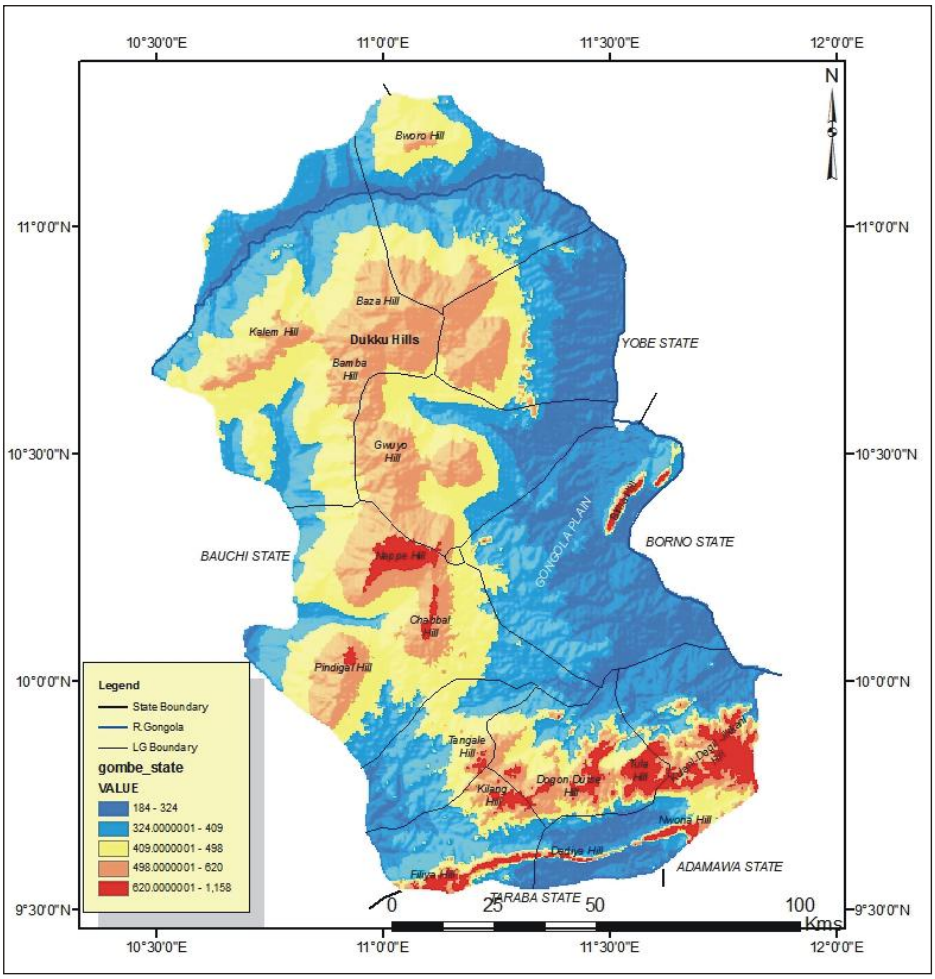

Fig. 2a. The DEM of Gombe State

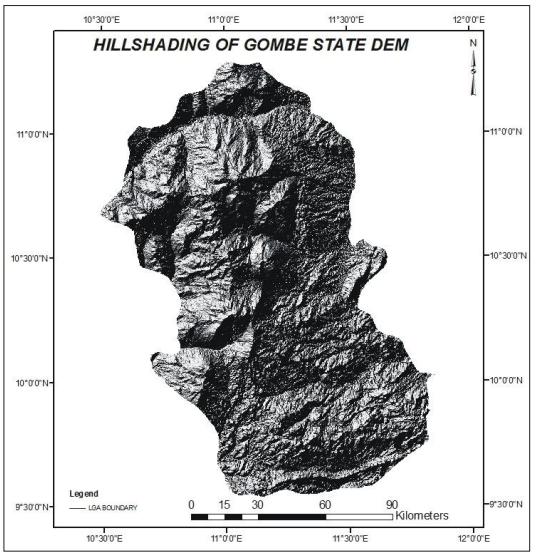

Fig. 2b. The shadow of Gombe State

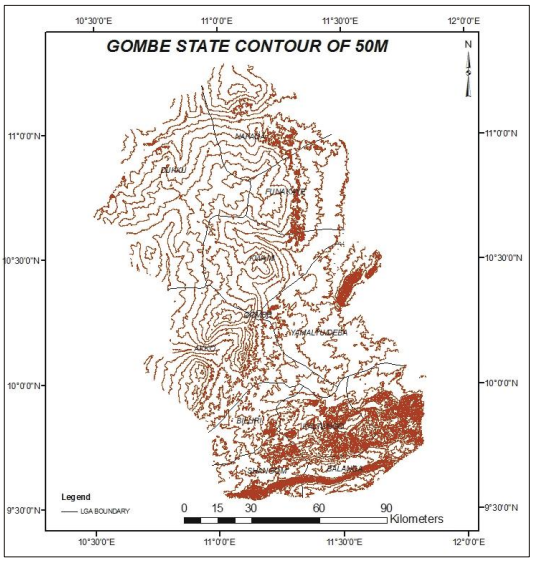

Fig. 2c. The contour of Gombe State

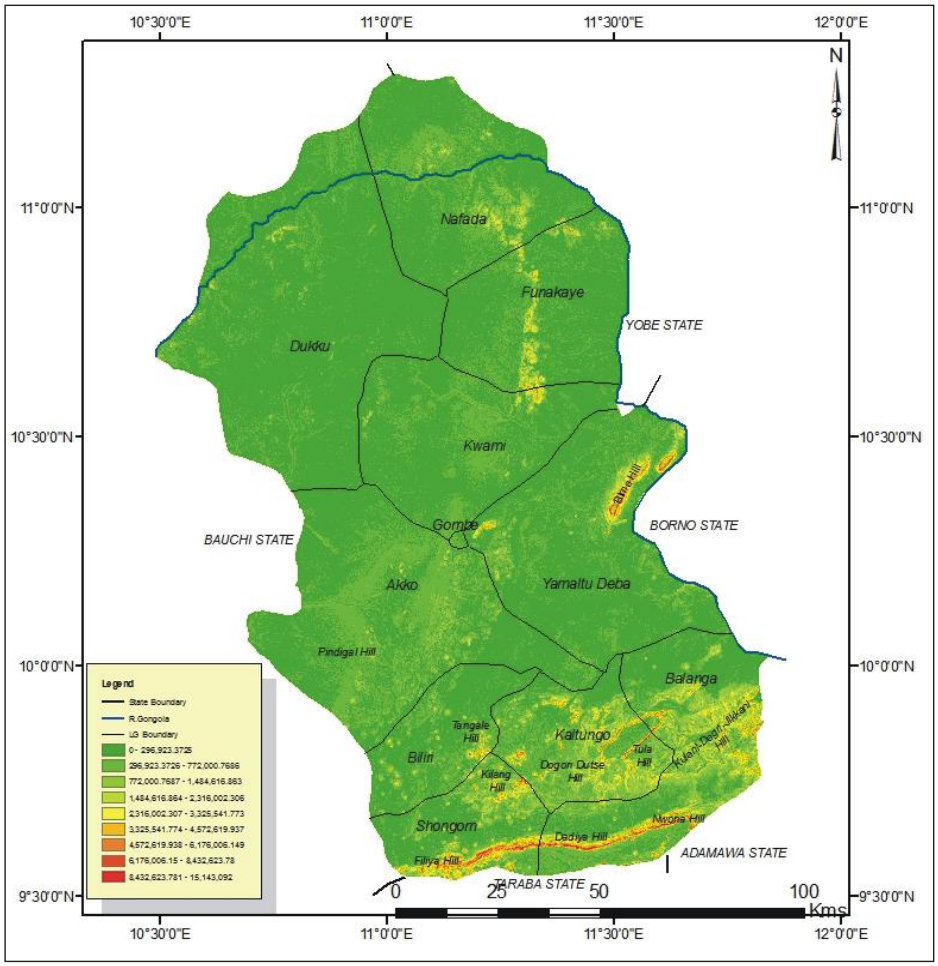

Fig. 2d. The slope image of Gombe State

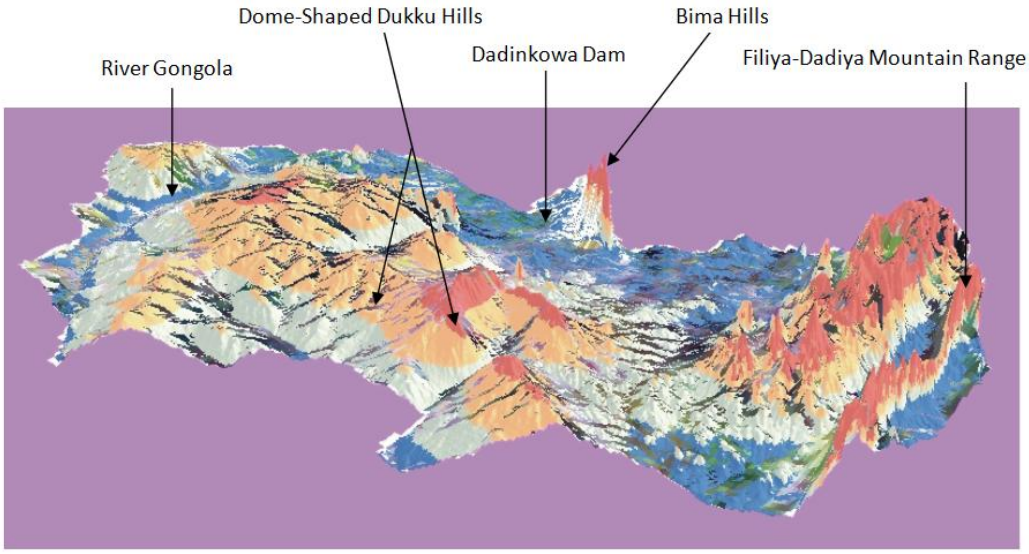

Fig. 3. 3D view from the Western Side of Gombe State

The generated Digital Elevation Models (DEM) of Gombe State was used to classify the terrain of the state into four types: River Basin, Plains, Uplands and the Highlands. The automated extraction and area calculation of the ArcGIS software which was used for area calculation in this paper gave a more accurate actual size of Gombe State to be 17,58.6 km^2 as against the previous conflicting figures by different authors. For instance, [11] gave the size of the state as 20,265 km^2, while [12] cited it as 18,768 sq km^2.

The land area coverage in square kilometers of each of the terrain classes as well as in each of the LGAs in the State is presented in Table 1.

The following are the analysis of each of the four terrain classes of the state.

(i) River Basin: This comprised mainly the River Gongola Basin, it formed an east-west narrow land area in Dukku and Nafada LGA at the extreme northern part of the State, and except the intrusion of Kulani-Degri-Likkar hills in the southern part of the state, the entire western border of the state comprised the river basin (Fig. 2a). The northern part of Dukku LGA, the central portion of Nafada, the western part of Funakaye and Kwami LGAs, major parts of Yamaltu LGA and the north and southern parts of Balanga LGA are all situated in Gongola Basin. Table 1 revealed that a total land area of 5705.99 km^2 representing 33.06% of the state were located in river basin areas. The river basin is a generally lowland area with altitudes ranging from 184 to 351 m heights above sea level (Fig. 2a). River basins are generally utilized for agricultural activities in Nigeria. For instance, rice is believed to be suitable in river basin areas [13]. More than 33% of the land of Gombe State comprised of river basin which are mainly found in Yamaltu-Deba, Balanga and Funakaye LGAs and which can be utilized for rice production. The establishment of the Upper Benue River Basin Development Authority (UBRBDA) at Dadinkowa in Yamaltu-Deba LGA for irrigation (mainly rice) agriculture is a clear evidence of the suitability of the terrain.

(ii) The Plains: The plains comprised land areas with altitudes ranging from 351-462 m above sea level. In Table 1, the plains of Gombe state covered a land area of 5999.05 km^2 which is 34.76% of the total land area of Gombe State. The plains generally separate the river basins from the upland areas. Table 1 revealed that Biliri LGA has most (61.72%) of its land area in the plains, while, Akko, Dukku and Nafada LGAs have more than 40% of their land area as plains. The plains are generally utilized for agricultural, residential and industrial purposes.

(iii) The Uplands: The upland areas are the land areas with minimum of 462 m and maximum of 590 m above sea level (Fig. 2a). These areas are generally higher

in altitudes than the plains. Table.1 showed that the upland areas occupy 26.70% of the total land area of Gombe State. Gombe LGA, the LGA with the least land area (13.79 km^2) in which Gombe town (the State capital) was situated, had 79.77% of its land area as uplands. Apart from Gombe LGA, only Kwami LGA has more than 40% land area as uplands due to the extension of massive part of Dukku hills into the LGA. The doomed-shaped features of Dukku hills are mainly upland areas, while the southern mountain ranges are also surrounded by upland areas.

(iv) The Highlands: The highlands comprised of high mountain ranges and hills with altitudes above 590 m above sea level (Fig. 2a). The highest peak of the highlands in Gombe State is 1158 m (Fig. 2a). Only 5.8% of the land areas of Gombe State are of highlands, with Kaltungo Balanga and Shongom LGAs having more than 10% of their land area as highlands (Table 1). The major highlands areas include the thin mountain range at the extreme southern part of the state, where they are known as Filiya and Burak hills in Shongom LGA and Dadiya and Mwona hills in Balanga LGA. Other highland areas include: Kulani-Degri-Jikkar hills in Balanga LGA, Tula plateau mainly in Kaltungo LGA but extends to Balanga LGA, Dogon Dutse hills in Kaltungo LGA, Tangale hill in Biliri LGA (which extends to Shongom LGA), Pindiga, Lamba and Chabbal hills in Akko LGA, Dukku and Baza hills in Dukku LGA, and Bima hills in Yamaltu Deba LGA.

3.2 Drainage

The drainage of Gombe State can be categorized into two: the artificial dams and the surface rivers.

3.2.1 Artificial dams

3.2.1.1 Dadinkowa Dam

The Dadinkowa dam is a man-made lake that is situated in Yamaltu-Deba Local Government Area. According to [12] the Dam was constructed along the Upper Benue River Basin, with the purpose of irrigation and hydroelectric power generation by the former National Electric Power Authority in 1959. Construction of the dam commenced in January 1981 and was commissioned on June 15, 1988. UBRBDA is a Nigeria federal government's organization in charge of Dadinkowa Dam in the area and it supplies irrigation water to registered rice farmers. The Dam was constructed to serve the following purposes: Irrigation agriculture of about 44, 000 ha, hydroelectric power generation of up to 34 mw, fishing and fishery development (over 20, 000 metric tones of fish annually), flood control and flow regulation, domestic water supply to the State capital and environs, recreational and other socioeconomic benefits. However, the generation of hydroelectric power is the only activity that is yet to commence but the historic irrigation of agricultural lands has been massively going on in the area and rice farmers have been the major beneficiaries.

3.2.1.2 Balanga Dam

Balanga dam is currently under construction. It is located in Balnga LGA. When completed, the dam is expected to supplement electricity supply in the state, increase land area for irrigation agriculture and supply of domestic water to major towns in Balanga and Kaltungo LGAs among other benefits.

3.2.1.3 Cham Dam

The dam was constructed by the state government authority through direct labour between 1984 and 1992. This dam is located in Cham village of Balanga Local Government Area which is about 130 km south of Gombe town-the state capital. According to the [14], the crest width of the dam was 8.0m with crest length of 1200 m and crest elevation of 522.0 m. The maximum dam height was said to be 15 m with reservoir capacity of 8 million m^3 and spillway discharge of 72 m^3/sec. The dam was constructed in order to provide portable water to the people of Cham town, the livestock in the area as well as provision of water for irrigation. The dam was commissioned in 1992. As at then the dam was irrigating 250 ha of rice and vegetables and also providing water supply to Cham. Unfortunately the dam collapsed in September 1998 as a result of unprecedented flood disaster and since then the dam has not been reconstructed, hence providing only skeletal services to the people since the collapse.

3.2.2 Surface rivers

Fig. 4 showed the locations of the two artificial dams as well as the important rivers in Gombe State.

Table 1. The land area coverage of the terrain classes in each of the LGAs in Gombe State

S/N	LGAs	Land area (Km^2)	%	River basin (Km^2)	%	Plains (Km^2)	%	Uplands (Km^2)	%	Highlands (Km^2)	%
1	Akko	2553.57	14.80	191.35	7.49	1199.35	46.97	908.92	35.59	253.95	9.94
2	Balanga	1666.48	9.66	897.17	53.84	258.50	15.51	256.74	15.41	254.07	15.25
3	Biliri	774.02	4.48	221.16	28.57	477.75	61.72	61.63	7.95	13.48	1.74
4	Dukku	3364.48	19.49	566.65	16.84	1561.58	46.41	1181.65	35.12	54.60	1.62
5	Funakaye	1475.68	8.55	759.19	51.45	258.11	17.49	452.57	30.67	5.81	0.39
6	Gombe	13.79	0.08	-	-	2.79	20.23	11.00	79.77	-	-
7	Kaltungo	997.66	5.78	111.97	11.22	325.95	32.67	368.95	36.98	190.79	19.12
8	Kwami	1632.49	9.46	362.75	22.22	456.49	27.96	790.34	48.41	22.91	1.40
9	Nafada	1766.55	10.24	630.87	35.71	728.95	41.26	390.75	22.12	15.98	0.90
10	Shangom	818.88	4.74	239.77	29.28	315.35	38.51	156.36	19.09	107.40	13.12
11	Yamaltu/Deba	2195	12.72	1725.11	78.59	414.23	18.87	29.08	1.32	26.58	1.21
	Total	17,258.6	100	5705.99	33.06	5999.05	34.76	4607.99	26.70	945.57	5.48

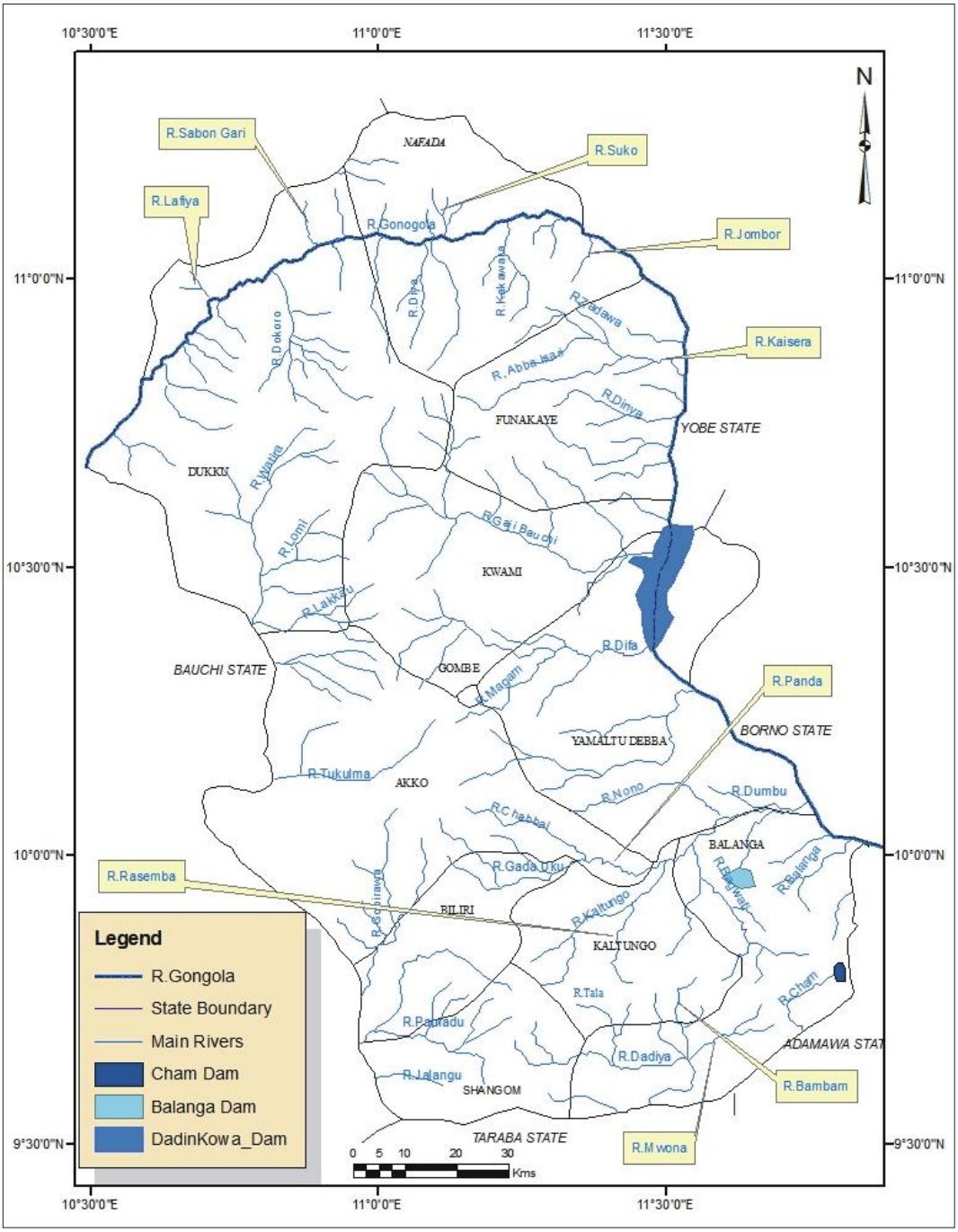

Fig. 4. The drainage of Gombe State

Among the surface rivers are:

(a) River Gongola: According to [10] and as evidenced in Fig. 4, River Gongola is the largest river that flows through the state. The River enters the State in the north-west through Bauchi State and flows eastward through Dukku, and Nafada LGAs. At Nafada, the Gongola bends in a loop southward forming natural boundary between the state and Borno and Adamawa states in the eastern parts before it joins River Benue at Numan, outside the state.

(b) Tributaries to River Gongola:

(i) River Lafiya: River Lafiya enters Gombe State through Bauchi State and flows southward in Dukku LGA before joining River Gongola in the south of Lafiya settlement.

(ii) River Sabon Gari: Like River Lafiya, River Sabon Gari is one of the major tributaries of River Gongola. River Sabon Gari also enters Gombe State through Bauchi State and flows southward through Dukku LGA before joining River Gongola at the northern part of the river.

(iii) River Suko: River Suko is a short course river joining the northern part of River Gongola in Nafada LGA.

(iv) River Dokoro: River Dokoro is a river with larger basin than all other tributaries to River Gongola. River Dokoro takes its course from Dukku hills and flows northward before it joins River Gongola at the southern part in Dukku LGA.

(v) River Diji: River Diji takes its course from Dukku hills and flows northward through Dukku and Nafada LGAs, it joined River Gongola in Nafada LGA.

(vi) River Kakawaro: River Kakawaro began from Dukku hills and flows northward between Barwa and Kukawaro villages in Nafada LGA before it joins River Gongola.

(vii) River Jombor: River Jambor is located n Nafada LGA at the north-eastern corner of Gombe State. It is a short-course river that joins river Gongola at the western part, where Bojoga-Potiskum road crosses River Gongola.

(viii) River Kaisera: River Kaisera is found at the extreme northern part of Dadin Kowa dam. It takes its source from Dukku hills and flows eastward through Funakaye LGA to join River Gongola. River Abba Isari and River Zadawa are the main tributaries to River Kaisera, but while River Abba Isari joined River Kaisera at the southern part of the river near Bajoga town, River Zadawa flows southward through Nafada LGA before joining River Kaisera in the north-western part of Bajoga town.

(ix) River Dinya: River Dinya is another short-course tributary to River Gongola. It flows easterly between Bajoga town and Jillahi village and joined River Gongola in Funakaye LGA.

(x) River Difa: River Difa was an initial tributary to River Gongola, but when Dadin Kowa dam was constructed, River Difa becomes one of the feeding rivers to the dam. River Difa takes its course from Kwami LGA, it has several tributaries among which is River Magma which flows through Gombe LGA and north-east ward before joining River Difa in the north-western of Zamkum town in Yamaltu Debba LGA.

(xi) River Dumbu: River Dumbu is a major tributary to River Gongola. It is located between Tallase and Deba Habe towns. River Dumbu takes its source from Kilang hills located between Shangom and KaltungoLGAs and flows north-eastern ward to join River Gongola in Yamaltu Deba LGA. River Nono is one of the tributaries to River Dumbu at the northern side. It is located in Yamaltu Debba LGA.

(xii) River Balanga: River Balanga drains larger areas than the other rivers in the southern part of the State. The river drains major parts of Balanga, Kaltungo and southern part of Yamaltu-Deba LGA. The River took its source from the mountain range in Kaltungo LGA and flows north eastward towards Adamawa State. It has several tributaries among which are:

(a) River Panda: This river is located in Biliri LGA. It has two main tributaries, that is, (i) River Chabbal which takes its source from Chabbal hills in Akko LGA and flows south westerly through Kumo town to join River Panda. (ii) River Gada Uku. The northern tributaries of River Gada Uku took their sources from Chabbal hills in Akko LGA, while the southern ones took their sources from Biliri hills in Biliri LGA.

(b) River Kaltungo: River Kaltungo took its source from Kilang hills and flows north western wards, draining some parts of Kaltungo and Biliri LGAs before joining River Dumbu. River Rasemba which is located in Kaltungo LGa is a major tributary to River Kaltungo.

(c) River Bagwati: River Bagwati which took its source from Tula plateau in Balanga LGA, flows northwards and

drains some parts of Balanga LGA before joining River Dumbu.

(c) Other Rivers

(i) River Watira: This river takes its source from Bamba hills (extension of Dukku hills) and flows southward through Dukku LGA into Bauchi State. Infact, River Watira is a major tributary to River Gaji in Bauchi State. River Watira has several tributaries among which are River Lomi in Dukku LGA and River Lakkau in Akko LGA.

(ii) River Tukulma: River Tukulma is located in Akko LGA of Gombe State. It flows south-western ward into Bauchi State.

(iii) River Pamadu: This river takes its course from the central part of Shamgom LGA and flows westerly into Bauchi State. The river is located between Shangom and Biliri LGA. River Gobirawa in Biliri LGA is the largest tributary to River Pamadu.

(iv) River Jalangu: This is a short-course river located in Shangom LGA. It is the main river at the extreme south-western part of Gombe State.

(v) River Dadiya: River Dadiya is located at the southern part of Gombe State. The river flows from east to west with several tributaries draining some parts of Shangom and Balanga LGAs. Among the tributaries are Rivers Bambam, Taba and Mwona

Fig. 5 showed the relationship or the effect of the topography of the state and the pattern of drainage system. Fig. 5 also revealed that the nature of the terrain of Gombe state gives rise to radial drainage pattern, that is, a pattern where the rivers flow to different directions away from a hill, highland or mountains.

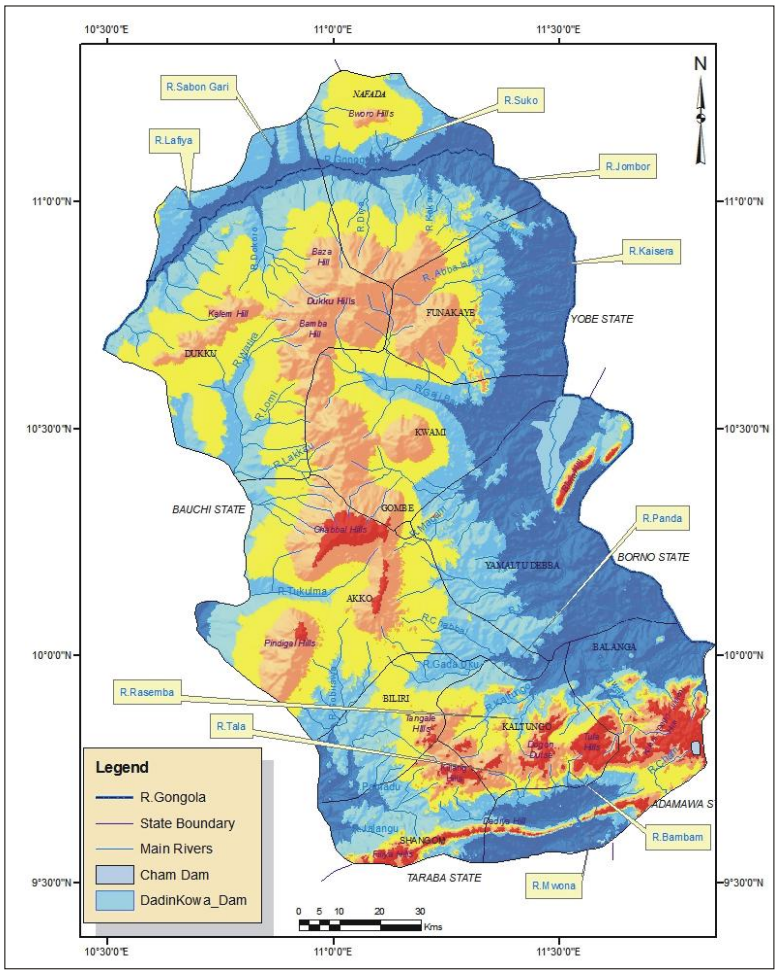

Fig. 5. Drainage on the relief of Gombe State

At the extreme north of the State are rivers with short courses most of which are tributaries to River Gongola. The north-south domed shaped hills in Dukku, Kwami, Akko and Biliri LGAs serve as major watershed for some rivers such as River Dokoro, Watira, Diji, Lomi, Lakkau, Tukulma, Chabbal, Gaji Bauchi among others. The mountain range comprising Kulani-Degri-Jikkar hills, Tula plateau, Dogon Dutse and Kilang hills in Balanga and Kaltungo LGAs in the southern part of the State also serve as watershed to some rivers such as Rivers Jalangu, and Pamadu which flow westward towards Bauchi State, as well as Rivers: Balanga, Puto, Rasemba, Bagwati and Kaltungo which all flow eastward towards Adamawa State. These rivers are very important to the inhabitants of the state in terms of water provision for domestic and irrigation purposes especially during the dry season when rainfall amount is scanty due to the geographical location of the state as expressed by [15] that the climate of Gombe is characterized by a dry season of six months, alternating with a six months rainy season.

3.3 Landuse and Landcover

[7] on the landuse of Gombe state commented that the landuse is crucial for economic, social, political and environmental advancements. Hence, administrators, resource planners and policy makers need digital land information. The detail classified area coverage of the landuse and landcover of the state from the 2013 Niger_sat image of Nigeria is presented in Fig. 6.

Table 2 shows the area coverage in square kilometers as well as in percentages of the six classified landuse/landcover classes of the State.

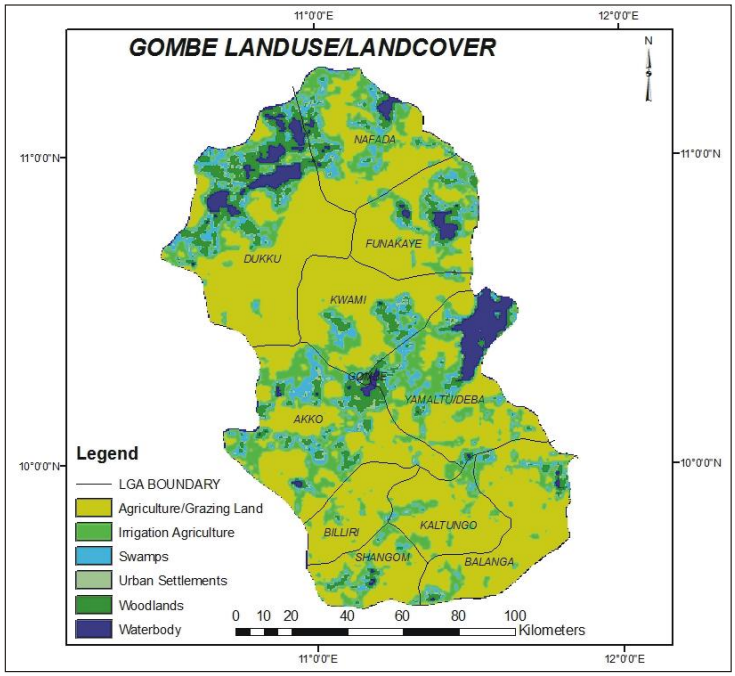

Fig. 6. Landuse and landcover of Gombe State

Table 2. Areas and percentages of landuse and landcover in Gombe State

Landuse and vegetation cover	Area (km2)	Percentages
Agriculture/Grazing land	10285.82	59.60
Irrigation agriculture	3047.83	17.66
Swamps	1551.27	8.99
Settlements	365.79	2.12
Woodlands	1285.19	7.45
Waterbody	722.69	4.19
Total	17,258.6	100

Table 2 revealed that more than half (59.60%) of the state area landmass is covered with grasses and shrubs that are mainly used for agriculture and animal grazing. This confirms the assertion of [11] that the vegetation in Gombe State is predominantly shrub land in the central part which might be due to the fact that over half of the state (central) that is underlain by the Kerri Kerri Formation has shallow to moderately shallow impoverished soils, with sandy loams on iron pan which aids the growth of grasses and shrubs. These grasslands/grazing lands (Fig. 6) which are mainly concentrated at the central parts of the state extend from southern Dukku through northern Kwami to western and southern Funakaye and Nafada LGAs. At the southern parts, major portions of Biliri, Kaltungo and Balanga are also made up of grasses/grazing lands, with patches of land areas in Shangom, Akko and Yamaltu-Deba. The grassland are in no doubt home of animal grazing as reported by [16] that the people of Gombe state are predominately farmers, and also rear cattle. Therefore, considering the vegetation cover of the state, more than half of the land area of the state are suitable for animal rearing especially at central region of the state where the presence of highland areas (Fig. 2a) allows transhumance; because the grasses that are burnt shortly after the rainy season quickly regenerate fresh grasses that serve as food for the animals during the dry season when the grasses in the lower altitudes are been burnt, hence leading to migration of these animals to highlands area in search of pastures during the dry season. Some parts of these grassland areas are also used for cultivation of some crops especially cotton, maize, sorghum and beans. The presence of a large vast of suitable land for agriculture especially grain cultivation, has made Gombe state one of the leading producers of grains in the country as reported by [11] that the famous grains depot whose history is old and legendary is not only the raw grains market in Gombe State; it is also the single existing grains depot in the entire North eastern sub-region of Nigeria. At this depot, large quantities of maize, sorghum, millet, beans, groundnut oil (peanuts), and benniseed, among others are brought to the depot daily from various markets in the State for onward purchases and shipment to all the major towns and cities of Nigeria for both domestic and industrial uses. This assertion was supported by the findings of [17] that Gombe State is the leading north-eastern region in cowpea marketing in Nigeria, at the peak period of cowpea sales, an average of 935.5 tons of cowpea leave Gombe daily to Lagos, Port Harcourt, Enugu and other parts of southern Nigeria and another 240 metric-tons to Kano in the north and Nigeria neighboring countries.

Irrigation agriculture covered a total land area of 17.66% (Table 2) Irrigation agricultural activities are mainly carried out around the swamps of the valleys of River Gongola at the northern parts comprising Dukku and Nafada LGAs as well as Funakaye and Yamaltu-Deba in the eastern parts of the state. The southern extreme with patches of wetland areas (Fig. 6) are also found to be utilized for agricultural activities. In summary, the land area of some parts of Dukku, Nafada, Funakaye, Yamaltu-Debba, Shangom, Akko Kwami and Gombe LGAs could be essentially utilized for irrigation agriculture and crops that could thrive well in waterlogged environment. No wonder Festus et al. [13] reported that Gombe State is one of the leading states in rice production in Nigeria due to the presence of two irrigation dams at Dadin Kowa and Balanga which ensure all year round rice production. [11] on land availability and suitability for agriculture in the state asserted that agriculture engages well over eighty per cent (80%) of the State's active population. The State is blessed with abundant agricultural land, and it is estimated that sixty-five per cent (65%) of the total land area is cultivable. They produce agro-based raw materials including cereals - maize, sorghum, rice and wheat; legumes – cowpeas, groundnuts, soya beans and bambara-nuts; fruits - orange, lemon, mango, guava, paw-paw and grapes; vegetables - tomatoes, pepper, onions, okra, pumpkin and melon; tree crops - gum arabic, sugar-cane, sunflower, ginger and fisheries. [10] reported that the main occupation of the people of Yamaltu-Debba LGAs is small-scale farming and the major crops grown include rice, maize, cowpea and vegetables. This condition is similar to other LGAs with extensive river basin areas such as Dukku, Funakaye and Nafada. It was observed in Fig. 6 that the downstream of Dadinkowa Lake especially at the central part of Yamaltu-Deba LGA, are also used for agriculture.

The collective coverage of 13.18% of the land area of Gombe state for swamps and waterbody (swamps covering 8.99% and waterbody 4.19%) in Table 2 could be attributed to the presence of River Gongola in the State. It was revealed from Fig. 6 that major swamps and waterbody areas were found along the basin of River Gongola.in Dukku, Nafada and Funakaye LGAs, as well as

around the Dadinkowa dam in Yamaltu-Deba LGA. There is a large expanse of water at the central portion of the state been shared by Gombe, Yamaltu-Deba and Akko LGA. These areas that are covered by waterbody and swamps in the savanna vegetation belts in Nigeria are commonly referred to as the "fadama". According to [17] the dire need for rapid food production in Nigeria led among others to the implementation of numerous Agricultural Development Programmes like National Fadama Development Project I (Fadama I) between February, 1993 to March, 31 1999 which aimed at improving the productive capacity of Fadama users. National Fadama Development Projects II (Fadama II) was established as a result of the success story and lessons from Fadama-I. The main thrust of Fadama-II Project was to sustainably increase the incomes of Fadama users (fisher folk, farmers, pastoralist, hunters, gatherers and service providers), through empowerment of the community to take charge of their development agenda. They concluded that Gombe State is one of the beneficiary states from these fadama projects because of the large area landmass of fadama area in the state.

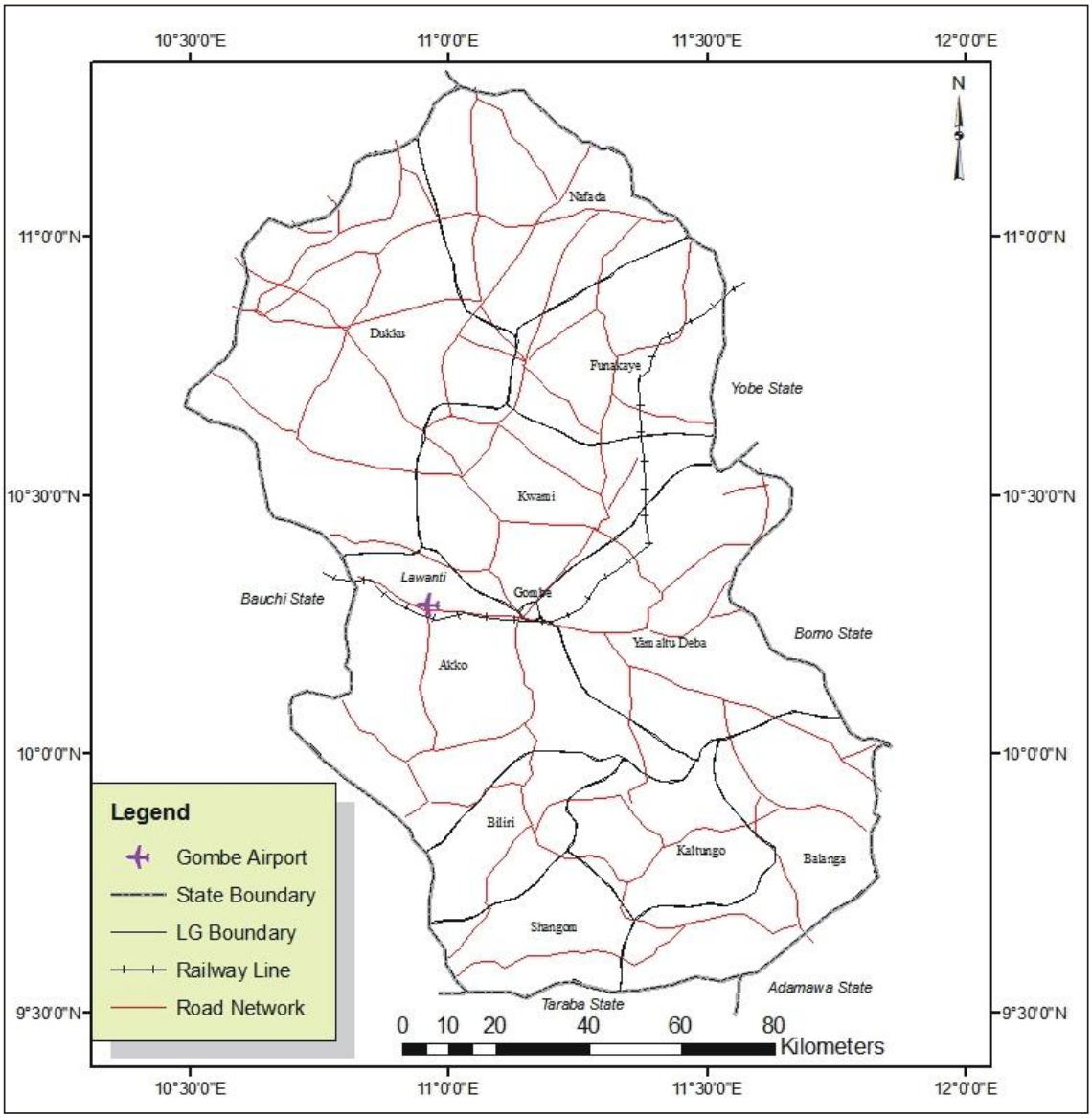

Fig. 7. Transportation network of Gombe State

3.4 Transportation

Gombe State has three major means of transportation; road, rail and air. Road transportation is the most important means of transportation in almost all the developing countries. Road transportation has been described as the most important, probably because of its flexibility and its low cost in terms of construction, maintenance and usage [18]. Unlike some states, regions or countries that have some of their roads running in a particular alignment (north-south, west-east etc), the road networks in Gombe State are not in any specific alignment but instead they are cobwebs in nature (Fig. 7). The reason for the nature of the roads could be attributed to the nature of the terrain of the state as some of the roads were made to avoid the highlands especially in the southern part (Fig. 8) as well as the cone-shaped hills that are found in the central region of the state (Fig. 8). The only railway line in the State enters the state through Bauchi State and runs eastward through Akko-Gombe-Yamaltu-Deba-Kwami-Funakaye LGAs before entering Borno State at the north eastern part of Gombe State. This means that while about sixteen states out of the thirty six states in Nigeria are not connected to railway lines, [19] five out of the eleven LGAs in Gombe state are connected. A domestic airport was also constructed at Lawanti in Akko LGA (Fig. 7).

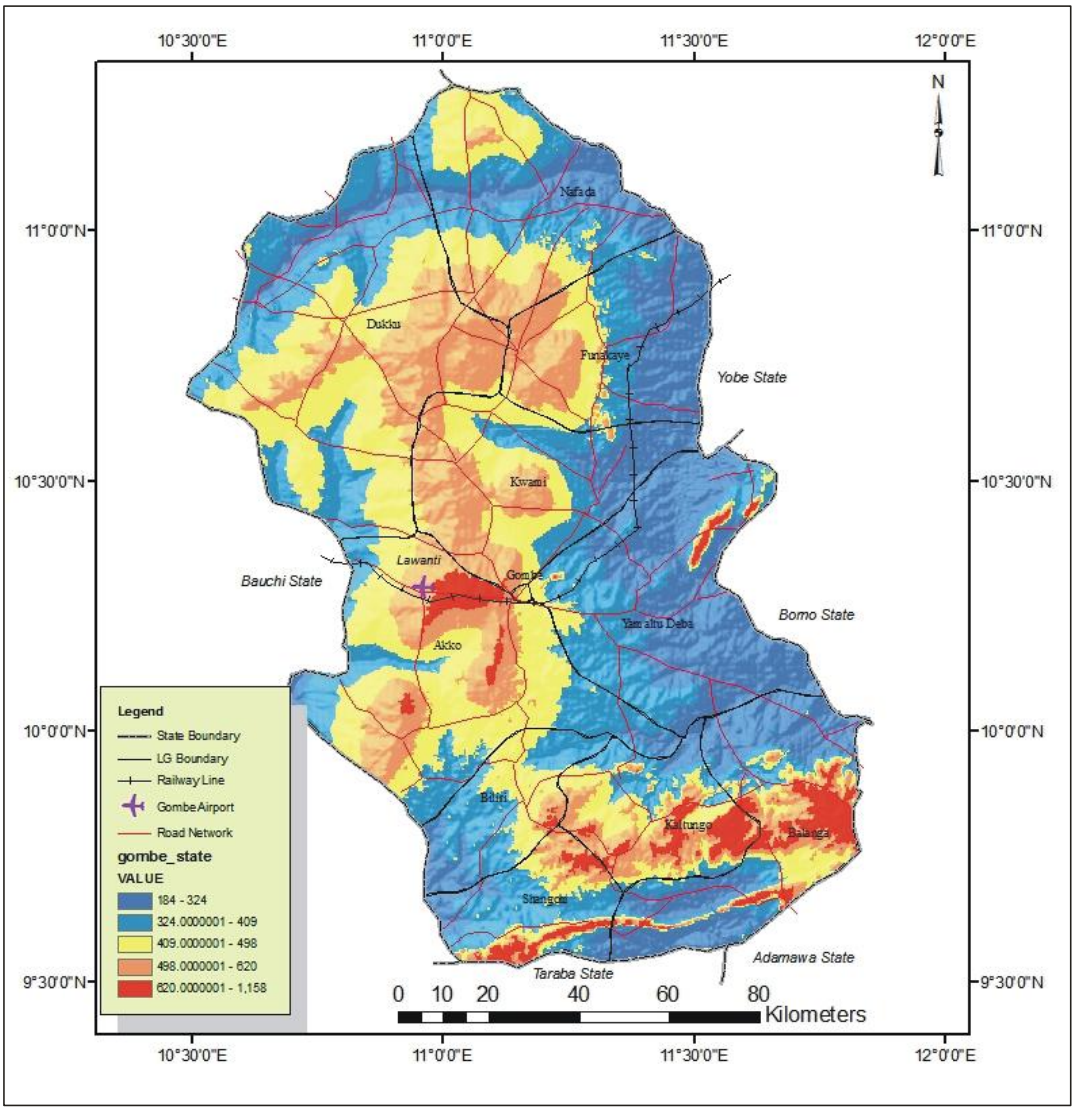

Fig. 8. Road on the DEM of Gombe State

On the assessment of the impact of the topography on transportation, Fig. 8 revealed that more roads were constructed in the plains and upland areas than the river basin which might be because of the swampy nature of the basin area. The extreme eastern parts and the extreme southern parts which are mainly highland areas have few road networks. Moreover, it was also revealed that most of the road networks around the cone-shaped hills at the central parts of the state were constructed on the valleys of the dissected cones (Fig. 8). In order to connect the more compacted rural settlements on the uplands and highland areas, many roads were constructed on the highlands which makes some of the roads to contain bends and very steep in some areas as noted by [18] that in Nigeria, road transportation is considered to be the most dangerous means of transportation because of their bad nature such as sharp bends, narrow bridges, steep slopes and other related problems which are associated with the terrain where these roads are constructed.

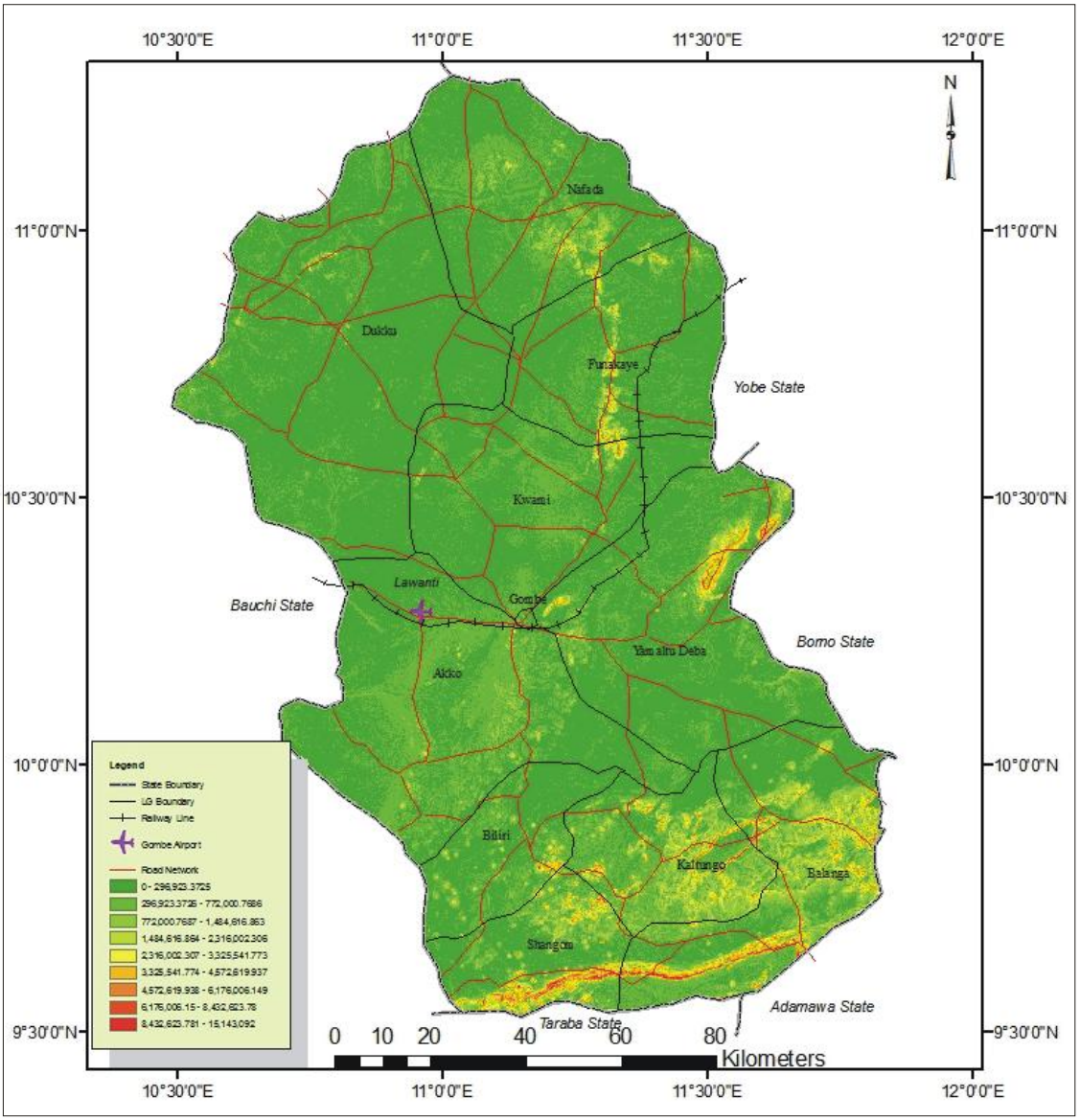

Fig. 9. Slope image of Gombe State

Another important effect of the relief on road transportation development is the presence of sharp slopes in some areas in the state. For instance, the Faliya-Dadiya mountain range in the southern part of the state which is characterized by very steep slope (Fig. 9) almost cut off the extreme southern part from other regions of the state because only few roads were constructed across the steep mountain range as shown by the slope image (Percentage Rise) of the State in Fig. 9. In river basin areas, average slope areas (yellow colour areas) were used as good sites for road construction (Fig. 9). A good example is the road that runs northward from Gombe town through Kwami and Funakaye to Nafada LGA in the North were constructed on medium slope areas especially in Funakaye LGA.

Finally, DEM and slope images will assist road developers to have ideas on where the roads would be constructed with minimal cost by avoiding mountainous areas as well as areas where rivers are numerous in order to minimize cost on bridge construction.

3.5 Settlements

The Gombe State settlement pattern (except Gombe city which is the State headquarters) is mainly of rural settlement as shown in Fig. 10.

Fig. 10 revealed the nature and spatial distribution of some of the rural settlements in the state. The river basins as well as the plains of the state were revealed to be more habited than the upland and the highland areas. This finding is supported by the results of the last population census results [20] which revealed that only four LGAs (Kaltungo, Kwami, Nafada and Shomgom) have less than 200,000 people. Fig. 2a and Table 1 revealed that except Nafada LGA, the other three LGAs have large portions of their land on uplands or highlands areas.

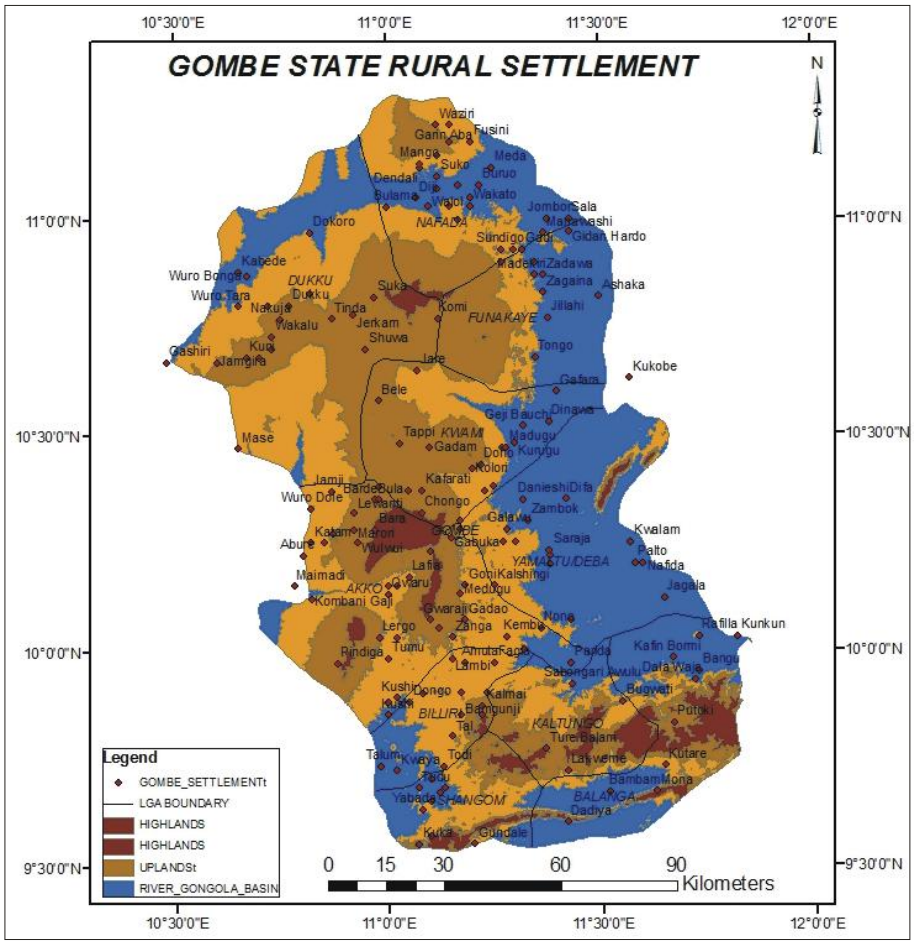

Fig. 10. Rural settlements on the DEM of Gombe State

4. CONCLUSION

Gombe state, which is one of the six states in the north-east geopolitical zone cover a total land area of only 17,258.6 km^2 (6.3%) out of the 272,395 km^2 of the total land area of the north-east geopolitical zone. Being one of the newest states, series of land developmental projects and activities are put in place to ensure rapid development of the state, hence, the need of judicious and sustainable utilization of the terrain which can be achieved through automated terrain assessment in order to minimize improper landuse and environmental degradation. No doubt, the adoption of this technique over the use conventional maps and methods such as manual interpretation of the existing 1967 aerial photographs (from which topographical maps were generated in 1970) for terrain analysis in the state will definitely reduce the problem of lack or inadequate data (especially in some areas that were said not to be covered by the 1967 aerial photographs in Nigeria). Moreover, with the techniques, one can easily generate desired information of any given area provided all the necessary data such as DEM, thematic maps, and satellite images with high spatial resolutions are available. Such generated maps can easily be stored and frequently edited as desired. However, the need for quality training and the low spectral and spatial resolutions of some DEM data are some of the limitations of the use of DEM for terrain analysis. It is therefore suggested that high resolution DEM data should be provided for end user either free or at low cost for researchers all over the world.

5. RECOMMENDATIONS

Gombe state government should embark on automated terrain analysis for her land development so as to maintain and sustain the land area of the state through sustainable utilization. The terrain of any area marked for large developmental projects should be adequately analyzed using automated techniques so as to minimize environmental degradation. For the state government to achieve this, remote sensing and GIS centers and institutes must be established for the training of technical staff and provision of adequate and current data for terrain analysis. All government ministries and parastatals that deal with the environment such as ministry of environment, ministry of agriculture, environmental protection agencies among others should embrace remote sensing and GIS technique for data and information generation and move away from the conventional methods which are more prone to human error, difficult to update and problem of storage of data.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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