Geospatial Assessment of the Impact of Topography on Flood Vulnerability in Maiduguri, Nigeria

[1]Shettima Mohammed Kaka, [1]Ikusemoran Mayomi and [2]Daura, M.M.

[1]Department of Geography, University of Maiduguri, Nigeria
[2] Center for Disaster Risk Management and Development Studies, University of Maiduguri, Nigeria

Abstract

In this paper, Remotely sensed data and Geographical Information System (GIS) techniques were used to assess the impact of topography on flood vulnerability of the terrain of Maiduguri. ASTER GDEM data were acquired online from which Triangulated Irregular Network (TIN) map of Maiduguri using contour 5 meters was generated. The TIN map was rasterized and classified into five flood liable zones: extremely liable, highly liable, liable, marginally liable and free flood zones. The flood vulnerability zone in each of the seventeen districts in Maiduguri was delineated and quantified. The study revealed that based on the topography of the city alone, eight (8) out of the seventeen districts in Maiduguri comprising Jabbamari, Dusuman, Maimusari, Old Maiduguri, Shehuri North, Tamsu Ngamdu and Yerwa constituting 21.88% of the Maiduguri land area, and holding the major population of the city, have their entire land area fall within either extremely liable or highly liable flood zones. Other districts with a high percentage of their land area within extremely or highly liable to flood zones are Gwange (80.72%), Mairi (68.78%), Bolori (56.55%). The result of the study also revealed that the impact of topography on excessive flooding in the core of Maiduguri (Yerwa, Shehuri North among others) as well as areas around the Jere Bowl is enormous. However, topography was found to play no role in the flooding of Bulumkutu area, which suggests that other factors other than topography are responsible for Bulumkutu floods. It was recommended that flood management and control should be prioritized based on how liable an area is. For instance, all the districts that were found to be highly liable to flooding should be given urgent attention before the ones with low possibility of being flooded. The integration of other factors, including topography for flood vulnerability of Maiduguri city as well as the causes of Bulumkutu floods is recommended for further studies.

Keywords: Digital Elevation Models, Flood Vulnerability, Geospatial, Maiduguri, Topography, Triangulated Irregular Network.

Introduction

In some decades back, Maiduguri urban was not part of the city that was always flooded in Nigeria because of the effect of its geographical location. However, in recent times, Maiduguri has been among the cities that were annually flooded. This sudden case of annual occurrence of the flood was reported by Agbonkhese, Yisa and Daudu (2013). Agbonkhese *et al* observed that in the early 1970s, Maiduguri used to be known as a place where rain hardly fell, and people were dying, due to dehydration caused by the harsh weather condition. But today, the situation is no longer the issue of inadequate rainfall in the city, but how to manage the excessive rainfall, which is always characterized by flooding, making some residents in the flood prone areas to annually count their losses. Human activities such as rapid industrialization and urbanization, population growth, exploitation of natural resources and location of infrastructures exacerbate the occurrence of floods. Causal factors of flood in Nigeria, which includes indiscriminate dumping of refuse on drainage channels to channel adjustment and poor drainage conditions have been observed. The topography of any place too has been identified as one of the factors resulting to urban floods (Ikusemoran, Dami and Maryah, 2013; Daura and Ikusemoran 2014).

In Nigeria, urban flooding occurs in towns located on flat or low lying terrain, especially where little or no provision has been made for surface drainage, or where existing drainage has been blocked with municipal waste, refuse and eroded soil or sediments. Ologunorisa (2006) observed that the flood may also be caused by the encroachment of hydraulic structures and cities on flood plains and by blocking of water channels and drainage networks. Maigari (2002) on the other hand, opined that these activities in one way or the other render streams or river channels incapable to accommodate fast running water from their catchment areas there by leading to flood. Maigari cited the case of August 1994 flood in Maiduguri, which resulted from the inability of Alau reservoir to accommodate the discharge from the diverted flow of Gombole/Sambisa swamp dyke on River Yedzaram.

The worst flood that has affected Maiduguri urban was the 1994 flood occurrence, and since then, the city has been recording annual flooding (UN DHA 1994). UN DHA (1994) also reported that the 1994 flood occurred between 12th and 13th September, 1994 due to excessive rainfall and the overflow from the Alau dam. Large number of people were displaced and made homeless; the government reported over 400,000 displaced/homeless persons, of which 180,000 were in immediate need for accommodation. The flood also destroyed a large number of mud houses, washing away nearly all personal belongings of stricken residents, paved roads were destroyed, cutting critical communication routes. Poultry and livestock production, farmlands and planted crops were seriously damaged.

Shetima (2018) stated that on September 11, 2007, Umar Abacha - a member of the Borno State House of Assembly representing Maiduguri Metropolis, donated food items worth thousands of naira to the victims of the flood disaster that ravaged no fewer than 96 homes at Gwange-Gangara area of Maiduguri. The items included bags of rice, groundnut oil and other relief materials. Shetima (2018) also reported that on July 6, 2012, torrential rains in Maiduguri displaced many residents from their homes. The report also stated that the heavy rains destroyed property worth millions, and also caused damage to the Jajeri Muslim Cemetery in Maiduguri where some dead bodies were washed up from their grave sites. One of the affected graves was that of a 10-year-old boy who was buried on Wednesday 4th July, 2012. It was also stated that the downpour was the heaviest in Maiduguri in that year. Residents living in the Bulumkutu, Ajillari, Jajeri, London Ciki, Polo, Bolori, Ummarari, Maduganari, Gomari Airport, Gwange and Mairi wards of the city were severely affected by the torrential downpour.

In the work of Shetima (2018), on August 2, 2014, no fewer than 100 persons were displaced in Maiduguri after their homes were flooded by a heavy downpour that started on Thursday 31st July, 2014 till Saturday 2nd Aug, 2014 leading to flooding in the city. Areas mainly affected include Ruwan-Zafi, London-Ciki, Ngomari, Simari, Mashamari, Zannari and Gwange, among others. In 2016, the Internally displaced persons (IDP) camps were not left out from flood as reported by Shetima (2018) that on July, 20th 2016, flood resulting from a downpour submerged 35 flats at Bakassi Internally Displaced Persons (IDP) camp in Maiduguri and IDPs occupying five of the worst affected flats were trapped for several hours. The Nigeria Hydrological Services Agency (NHSA) in early 2016 also warned that there would be flooding in 14 States in the country urging residents living in flood prone areas to relocate. According to NHSA, most cities would experience heavy floods due to the rise in sea levels and tidal surge, adding that some of the States that would have areas that are likely to be submerged include Lagos, Rivers, Benue, Sokoto, Anambra, Imo, Cross River, Yobe, Ogun, Osun, Kaduna, Oyo, Borno and Adamawa. The prediction came to pass as early as July, 2016. For instance, the officials of National Emergency Management Agencies reported that an early morning downpour in Maiduguri on Saturday 9th July 2016, flooded many areas like Jajeri, Ummarari, Ngarnam, Simari, London-Ciki, Customs, Dala, Gomari Airport, as well as Gomari Costain, Damboa road, Ruwan-Zafi (Shetima 2018).

Flood occurrence in Maiduguri has been studied by many authors. For instance, Odihi, (1996) asserted that floods are a seasonal occurrence in parts of Maiduguri and that flood hazard exert a heavy toll on their victims. He used human perceptions to identify Bulumkutu, Gomari, Gamboru, Bulabulin, Ngomari Abuja, Gwange, Mairi, Bolori, Wulari, and London Ciki as the wards or districts that were affected by flood in Maiduguri urban between 1988 and 1995. He concluded that flood problems can be reduced by formulation and enforcement of land use regulations and building codes that reduce flood damages among others. Bwala and Abdulwaheed, (2015) also carried out an assessment of the physical planning strategies and its challenges of combating flooding in Maiduguri Metropolis. They reported that Maiduguri urban flooding is a catastrophe that continued to threaten the inhabitants and inflicting serious damages to a man. Their findings revealed that flood is largely due to lack of drainages, blockages of water channels, depression and subsidence of the terrain, and high encroachment of the floodplain.

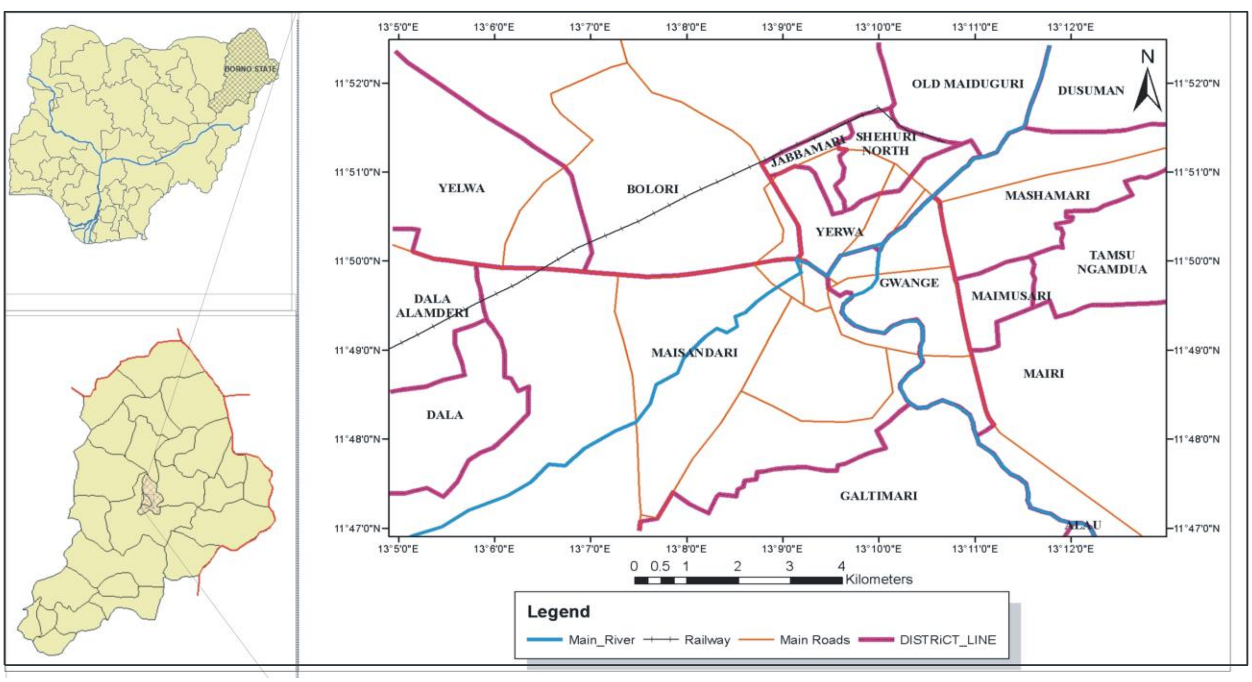
Other recent works on Maiduguri flood is that of Jimme, Bashir and Adebayo (2016) which examined the spatial pattern of urban flash floods and inundations, and the terrain characteristics in Maiduguri metropolis. Digital Terrain Model (DTM) was generated from the Shuttle Radar Topography Mission and was used to provide the basis for the terrain analysis to generate hydrological parameters such as elevation, flow accumulation and direction, drainage network and slope angle as well as classified elevation images and terrain wetness index to map out potential flood risk areas. The DTM identified potential areas liable to flash flood and inundation. Their findings revealed that Maiduguri was generally characterized by low lying areas with slope angles of less than 5 degrees covering an area of 144.4 km^2 out of 148 km^2 making it extremely difficult to drain.

In all the above previous studies, topography was always mentioned as one of the principal causal factors of flooding in Maiduguri city, but no existing study has been carried out to investigate the impact of topography on flood occurrence in Maiduguri. It is therefore based on this premise that the impact of topography on flood vulnerability in Maiduguri city was carried out. Though, Maiduguri consists Maiduguri Metropolitan Council (MMC) and parts of Jere, Mafa, Konduga and Magumeri Local Government Areas of Borno State, covering a total land area of 543km^2 and located between latitudes 11˚ 46' 03.88"N and 11˚55' 34.66"N and longitudes 13˚03' 41.56"E and 13˚16'01.22"E (Ikusemoran and Jimme, 2014). However, this study was carried out within the Maiduguri city located between latitudes 11˚47' 00"N and 11˚52' 30"N and longitudes 13˚4' 30"E and 13˚13' 00"E covering a total land area of 149.15km^2. This means that some parts of the city were not covered in this study. The selected area covered the entire land areas of Gwange, Jabbamari, Maimusari, Shehuri-North and Yerwa Districts as well as major parts of Bolori, Dala, Dala-Alamderi, Dusuman, Galtimari, Maisandari, Mashamari, Mairi, Old Maiduguri, Tamsu Ngamdua and Yelwa Districts (Fig.1). Only a small portion of Alau districts was captured in this study. Moreover, other likely factors of flood vulnerability such as availability and functionality of drainage networks, land use and proximity to the waterbody among others were not considered in this study.

The aim of the study is to identify and quantify areas that are liable to floods based only on the topography of the city. The results are expected to serve as reliable data and information on the flood liable areas due to the topography of Maiduguri using remotely sensed data and Geographic Information System (GIS) techniques. The study, therefore, will no doubt, not only provides accurate and reliable information on the current liable districts/areas to flood in Maiduguri based only on the topography, but will also be used for subsequent flood disaster prone assessments, planning and for mitigation measures. The generated baseline data will serve as a database to the government and all other stakeholders on flood and flood related issues in Maiduguri urban. It will also assist in decision making when it comes to location and allocation of resources within the urban.

Description of the Study Area

Maiduguri is located between latitudes 11º.42′N and 12º 00′ N and longitudes 12º.54′ and 13º 14′ E. The city is bounded in the North by Jere LGA, in the West, South and South-West by Konduga LGA, in the North-West by Mafa LGA. Maiduguri city comprised the entire MMC, some parts of Jere, Konduga, and Mafa LGAs.



Source: Modified from UN Office for the Coordination of Humanitarian Affairs, (2016)

Fig.1. The Study Area

Maiduguri is located on a vast open plain which is flat or gently undulating. The surface is covered by thick heterogeneous alluvial sand deposit with occasional alluvial sand deposits of degraded and remnant of sand dunes (Nwaka and Bababe, 1989). Maiduguri is generally drained by seasonally flowing rivers, whose peak flows are recorded during the rainy season in the month of July and August. Maiduguri is drained mainly by River Ngadda with Ngaddabul as its major tributary. The vegetation of Maiduguri is similar to Sahel Savannah surrounded by shrubby vegetation interspersed with tall tree woodland. Annual grasses form the vegetation cover of Maiduguri, especially during the rainy season. The grasses in most areas are thorny (Shetima 2018). The mean monthly maximum temperature is highest (40.2ºC) prior to the onset of the rains in June and the lowest (31.3ºC) during the peak of the rainy period of August. The area has an average mean annual of about $550mm^3$ (Shetima 2018). According to National Population Commission (NPC, 2006), the population of Maiduguri was 540,016 based on the 2006 census. Most of the people living along the floodplain are peasant farmers. Land use in the area is characterized by permanent rain fed cultivation of grain crops such as sorghum and millet. Dry season Fadama (market gardening) cultivation is practiced at some points, using Shaduf Irrigation System. Also cultivations are usually carried out right to the edge of gullies. Other land use activities include sand mining, grazing, urban house construction, garden and orchards.

Maiduguri urban comprises the entire populace of MMC, most of the inhabitants of Jere, as well as some population in Konduga, Mafa and Magumeri LGAs. The 2006 census and population results show that the population of MMC and Jere LGAs alone was about 18% of the total population of Borno State. This large population coupled with the fact that the city is the capital of Borno State has necessitated a thorough planning and mitigations for whatever hazards that the city encountered. Therefore, the study of this kind of the urban area becomes very necessary.

Materials and Methods

Data Requirements and Sources

The data and their respective sources that were used for this study is presented in Table 1.

Table 1. Data Requirements and Sources

Types of Data	Sources	Importance
Aster GDEM2 data (in tiles and in 30m resolution).	AsterGDEM2 data. Obtained from earthexplorer.usgs.gov.	The DEM data was processed to generate the elevation and the TIN map of the city through which the terrain of the city was analyzed for flood vulnerability
Global Positioning System (GPS)	Personal property	(i) The coordinates and heights (elevation) of places of interest, especially annual flood areas were obtained by the use of GPS. (II). The obtained elevations were also used for ground-truthing the heights of the Aster GDEM data. (iii) GPS data of some points that are frequently flooded during the raining season were obtained. The data were captured between 9th and 10th of July 2017.
Google Earth map of Maiduguri City	Google Earth Pro	Spatial locations of roads, rivers and other related features for flood assessment and vulnerability were derived from Google map in kilometer and added to the base maps and images in the ArcGIS environment.
Political map of Maiduguri	Obtained online from the United Nation's Office for the Coordination of Humanitarian Affairs	The different districts and their distinct boundaries were generated from the map for detecting the specific districts, features and institutions that fall into each of the categorized flood liable zones.

Methods

The methods employed in this paper involve the following activities:

(i) Generation of features, like profile graphs, 3D view and contour lines from the acquired DEM for assessments of the nature of the topography of the urban in terms of elevations, depressions, shapes, depth, and locations of places of interest such as depressions.

(iii) Creation of elevation map using Triangulated Irregular Network (TIN) (which has the capability of showing the heights, depth, depressions, shapes and the positions of features for the assessments of the impacts of the topography on flooding.

(iv) Rasterization and classifications of the elevation map into five floods liable classes: extremely liable areas, highly liable areas, liable areas, marginally liable areas and flood free zones

(v) Delineating the boundaries of the existing seventeen districts within Maiduguri by digitizing and overlaying the district boundary lines on the classified images.

(vi) Integration of flood points data, (that is, the points that were captured as samples of flooded areas during the 2017 raining season by the use of GPS) to the classified images in order to examine and compare the relationship between the areas that were mapped as liable to flooding and the actual areas that were captured (in-situ) as flooded areas during the raining season.

Presentation of Results

The topography of Maiduguri was geospatially generated with the use of a TIN map of the area as presented in Figures 2.

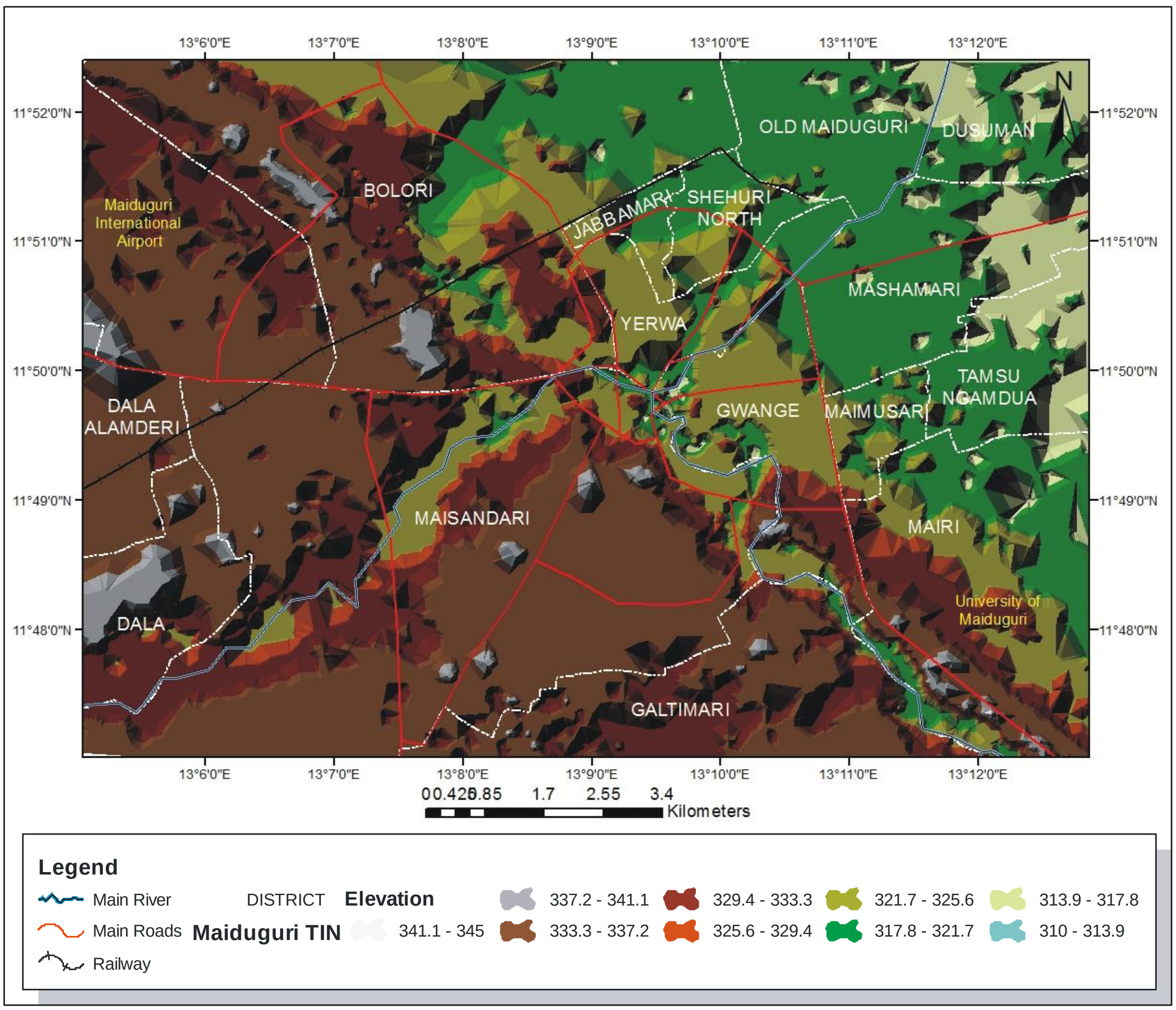


Fig. 2. Triangulated Irregular Network (TIN) of Maiduguri

A west-east longitudinal profile of the city was also generated to examine the nature of the topography of the city as shown in Fig. 3.

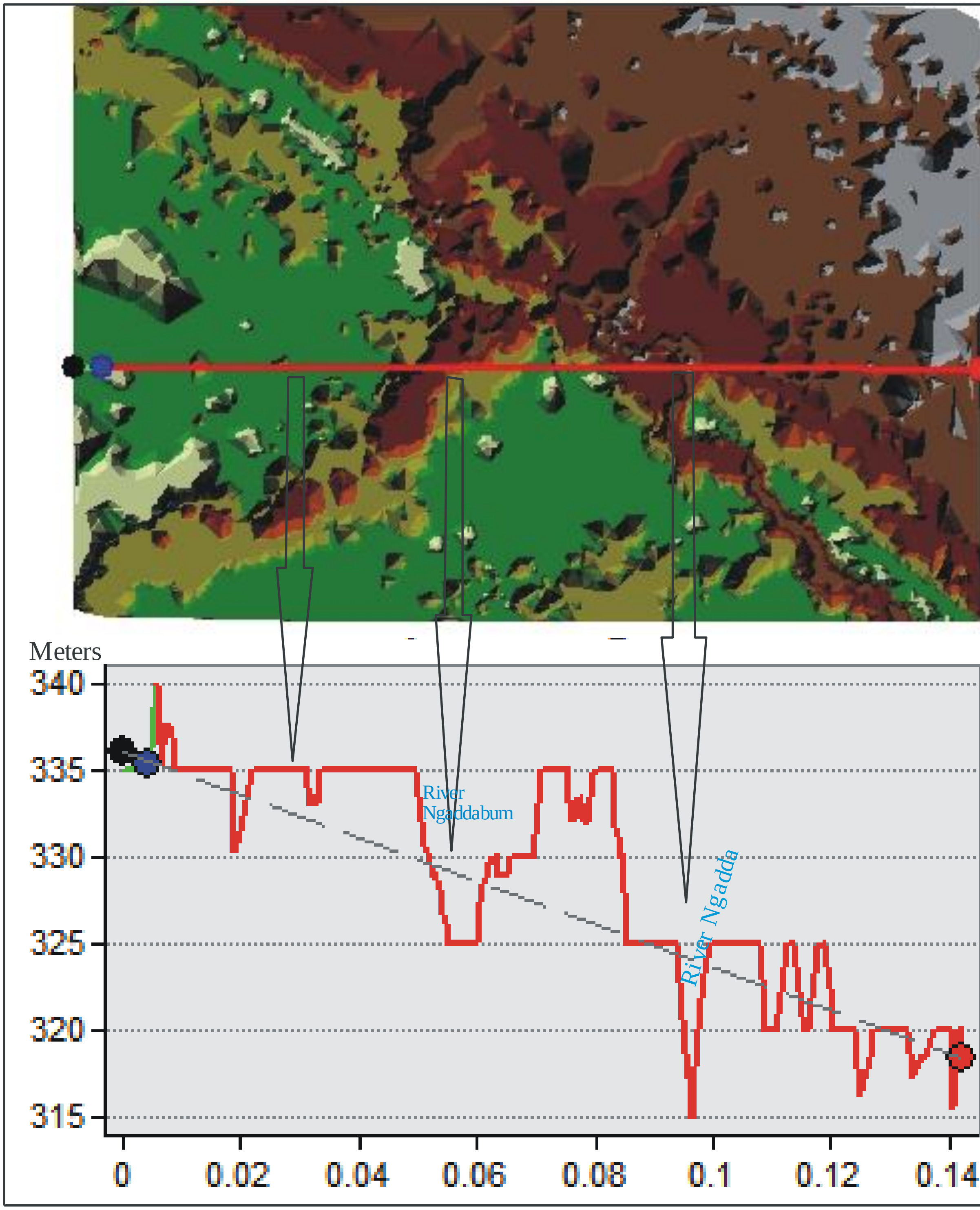


Fig. 3. West-East Longitudinal Profile of Maiduguri

Contour interval of 5 meters was used to generate the contour of Maiduguri, the low contour interval was chosen taking into consideration the relatively small and undulating nature of the area. The 3-dimensional view of the city was also mapped so as to ensure that areas or heights that are not discernable from the DEM are conspicuously seen on the 3D map. Both the contour and the 3D maps are shown in Figures. 4 and 5 respectively.

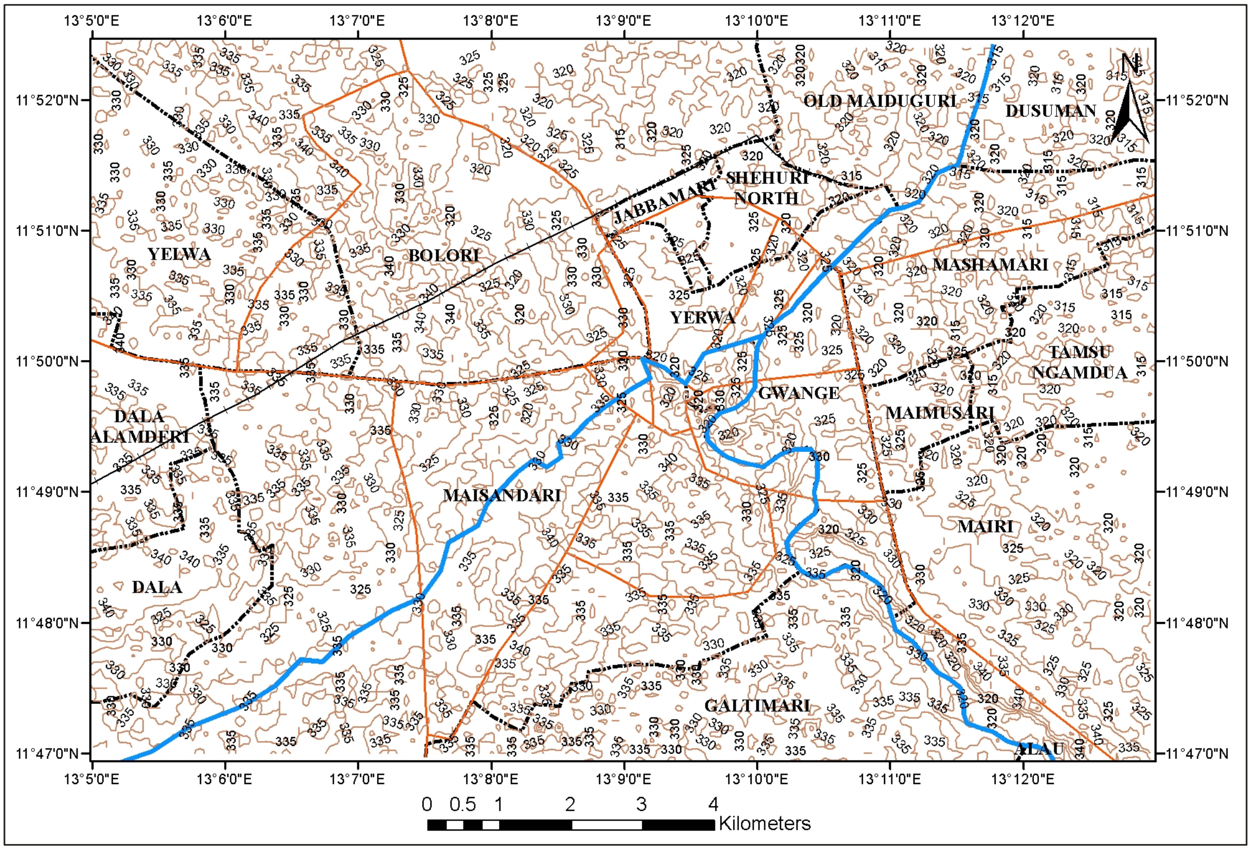


Fig. 4. Contour of Maiduguri

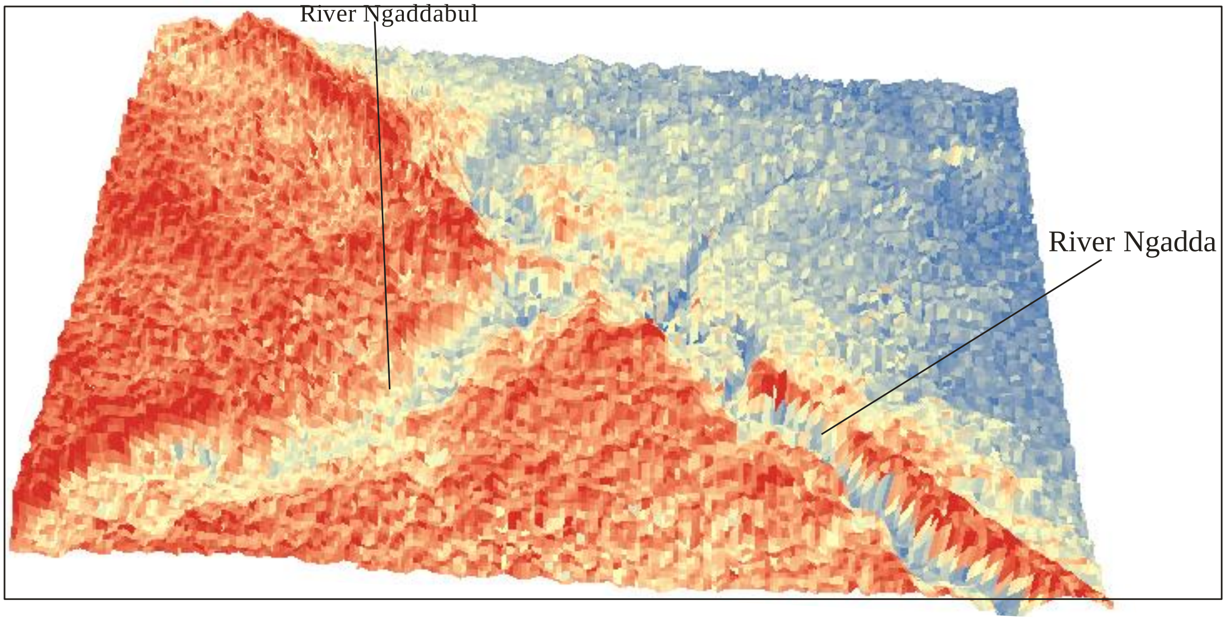


Fig. 5. 3D-View of Maiduguri (From South)

Discussion of Results

Analysis of the topography of Maiduguri

The occurrence and intensity of floods largely depend on the topography of the area (Ikusemoran *et al*, 2013; Daura and Ikusemoran, 2014). The effect of topography on flood occurrence cannot be overemphasized. The slope, the terrain, the plains, the heights and the general landuse determine how liable a place is to flooding. Therefore, the analysis of the topography of a place is essential for its assessments for flood prone or vulnerability.

The almost flat areas, the depressions, the slopes, and the nature of the valleys of Maiduguri were all clearly represented as shown in Figures 2 and 3. For instance, the wide and shallow valleys of River Ngaddabul and the narrow but deep valley of River Ngadda were visually visible, while the almost flat areas in the city were also delineated. The lower altitudes in the eastern part of the city and that of the highest elevation in the western region were conspicuously visible. The highest elevation in the east was 325m above the sea level while the western region has its highest heights at 340m above the sea level. The longitudinal profile in Figure 4 also revealed that based on the topography, water is bound to flow from the high western region in the lower terrain areas in the east, with possible accumulation in the two river channels.

Figure 5. shows the 3-D view of Maiduguri urban from the southern part of the city. An elongated upland between Bama road and River Ngadda was also conspicuously visible from the map. It was also revealed that the valley of River Ngaddabul is wider than that of River Ngadda, while River Ngadda is steeper and deeper than River Ngaddabul. The contour in Fig. 4 shows the elevation of the study area. It was revealed that areas above 340m are found in the central part of Dala district and other spots in Galtimari district. The use of numbers to show heights makes it easier for interpretation and spatial comparisons. For instance, Yerwa district is generally on 325m

above the sea level while the Shehuri North district is on 320m above the sea level, which means that the Shehuri North district is at lower elevation than Yerwa district.

Assessment of flood liable areas based on the topography of Maiduguri.

Having analyzed the topography of Maiduguri, it is necessary to relate the topography of the area to flood liable zones. In order to assess the parts of Maiduguri that are liable to flood through the analysis of the topography, the "elevation" of the city was generated. Elevation map combines the attributes of DEM and 3D for viewing an area as shown in Fig. 2. The elevation map shows the depressed areas in and around Jere Bowl, Dusuman, Tamsu Ngamdua, Mairi, Maimusari, Bolori as well as along the valleys of Rivers Ngadda and Ngaddabul. The slopes into the depressions were also conspicuous on the map. The relatively higher elevation on which some parts of Maiduguri is located such as parts of Galtimari, Maisandari, Bolori, Dala, Dala Alamderi and also 202 and 303 housing estates and New GRA were also revealed. The upland areas in Dala and Yerwa can be easily delineated as well as those spots of uplands in Bolori, Galtimari, Maisandari and Mairi Districts.

This elevation map also revealed why some areas are constantly flooded in the city. For instance, around the boundary between Yelwa and Bolori Districts is a depression (Fig. 2). Therefore, the runoff from Yelwa (from the west) and those from Bolori (from the east) all accumulate into this depression. Therefore, even if drainage channels are provided, it will be difficult to channel the runoff because the water will continue to circulate in the depression, because it is a depression without an outlet. Therefore, the area, until an outlet is constructed will continue to experience flood regardless of the numbers of drainage channel that are provided.

The reasons for excessive flooding in Yerwa and Shehuri North Districts in Maiduguri core, was also explained by the elevation map. For instance, the topography of Shehuri North makes the district to experience double tragedy of the flooding. Firstly, the eastern and northeastern parts of the district are along the depressed River Ngadda, hence, runoff from the river causes serious floods in this part of the district. Moreover, the western and northwestern parts of the districts are also within the Jere Bowl depression, separated from River Ngadda by upland which traps or forces runoff to return backward towards Jere Bowl or circulate around the area. This upland serves as a barrier for the runoff into River Ngaddabul. Therefore, an outlet must be constructed to channel the water from the district into River Ngaddabul for any meaningful flood control measures to take place.

Classification of the topography into flood liable classes

The elevation map in Fig. 2 was rasterized and classified into five flood liable classes. The classes are as follows:

(i) Extremely flood liable areas
(ii) Highly liable flood zones
(iii) Liable flood zones
(iv) Marginally liable flood zones
(v) Free zones

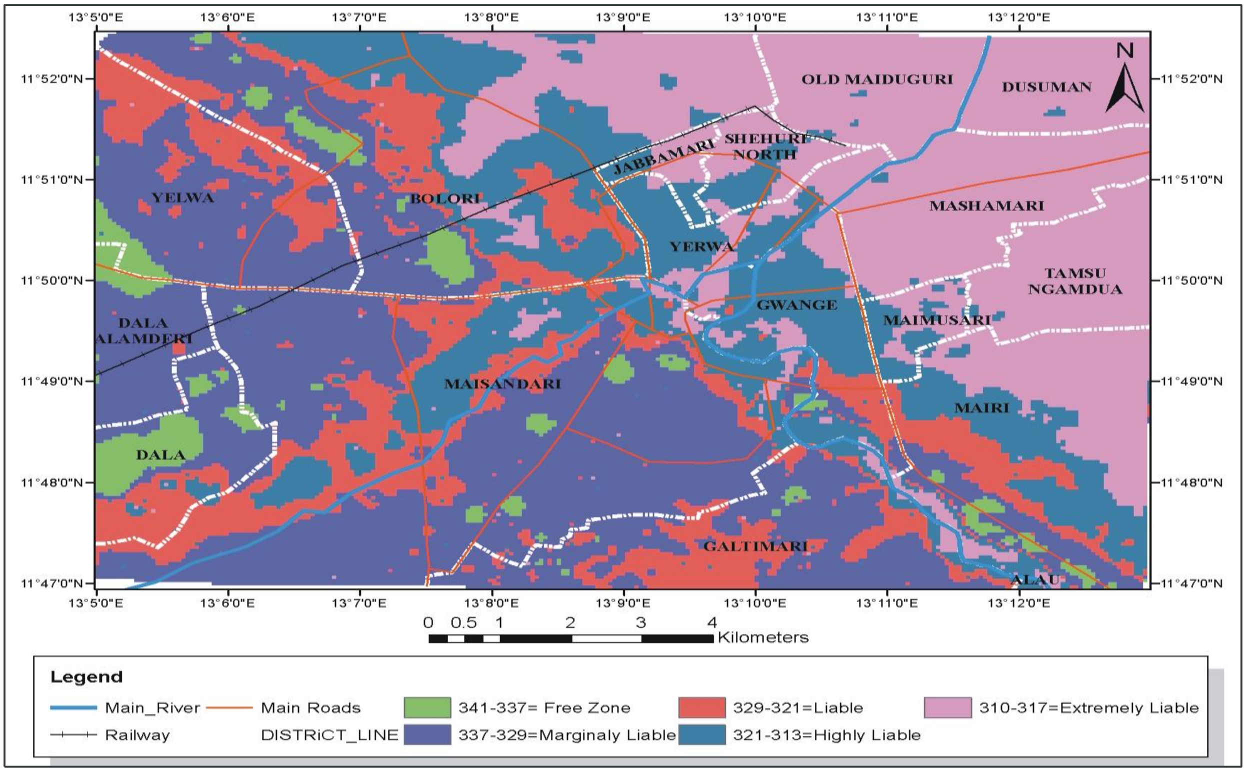


Fig.6. Rasterized TIN of Maiduguri

Extremely liable flood zone:

The extremely flood liable zone includes areas that are generally between the altitudes of 310 to 317m above the sea level. This zone includes almost the entire land areas of Old Maiduguri, Dusuman, Mashamari and Tamsu Ngamdua Districts. Some parts of Mairi, Yerwa, Bolori, Shehuri North and Mashamari Districts are also located within this zone. The total land areas of the swampy Jere Bowl, which is naturally liable to flood, and the valley of River Ngadda and some spots within Bolori and Maisandari Districts were also found to belong to this zone. It must be noted that (though the spatial extent was not determined as it was done in this study), but all these districts within these elevation zones have been constantly reported as being prone to flooding. For instance, Odihi (1996) listed Bulumkuttu, Ngomari, Gamboru, Bulabulin, Ngomari Abuja, Gwange, Mairi, Bolori, Wulari, and London Ciki as the wards that were affected by flood between 1988 and 1995. Jimme *et al*, (2016) also identified Maisandari II, Limanti, Bolori, Jabbamari, Mashamari, Goni Kachalari. Shehuri North, Mairi and Old Maiduguri as the wards that were prone to flooding.

Highly liable flood zone

These are areas that are also very prone to flooding. Though the terrain is a bit higher than that of the extremely liable flood zones, but the low altitude of the zone makes it very vulnerable to flooding. The elevation of this zone falls between 321 and 313m above the sea level (Fig. 6). Some parts of Mairi, Maimusari, Gwange, Yerwa, Shehuri North, Jabbamari, Bolori and Maisandari fall in this zone.

Liable flood zone

These are areas that are relatively prone to flood occurrence because of their low terrain. However, flooding in these areas are not as serious as that of the highly floodable areas. The classified regions fall between 313 and 329m above the sea level. This zone is found in Mairi, Gwange, Bolori, as well as the valley of River Ngaddabul running from Yerwa through Maisandari to Dala Districts. The valley of River Ngadda from Gwange downstream towards Alau is within the flood liable area.

Marginally flood liable zone

Marginally flood liable zone cover a larger part of the city. It is the zone that flooding can only occur in exceptional cases. The elevations of these areas fall between 329 and 337m above the sea level. 303 and 202 housing estates, western part of Bolori, some parts of Galtimari, Maisandari and Yelwa are all located within the marginally liable to flood areas. It is partly because of this reason that during heavy downpours, major parts of the University campus like Titanic Male Hostel, Distaster and MPH areas which all fall within the extremely flood areas are always flooded, while 303 and 202 housing estates that are only separated by road from the University hardly experience flooding.

Flood Free Zone

The areas that are not expected to be affected by flooding due to their high topography are termed in this study as the free flood zone. These areas are found on the highest elevation within the study area, with their heights ranging from 337 and 341m above the sea level**.** They are small land areas that are found in Dala, Yelwa, Bolori and Galtimari Districts. The free flood zone occupies a small fraction of the total land area of the city.

Assessments of liable zones of each district in Maiduguri urban

The aim of this study is to assess and quantify how liable a district is to flooding in Maiduguri based on topography alone. That is, mapping and quantifying the flood liable zones in each district. Each of the 17 districts was assessed in order to know the quantity of the land area that fall into each of the five classified flood zones: extremely liable, highly liable, liable, marginally liable and free zone. The result is presented in Table. 2.

Table. 2. Flood liable zones of each District in Maiduguri based on topography

S/N	Districts	Area (km^2)	% Area	Extremely Liable (km^2)	Extremely Liable (District %)	Highly Liable (km^2)	Highly Liable (District %)	Liable (km^2)	Liable (District %)	Marginally Liable (km^2)	Marginally Liable (District %)	Free Zone (km^2)	Free Zone (District %)
1	Alau	0.15	0.10	-	_	0.11	73..33	0.04	26.67	-	_	-	_
2	Bolori	27.24	18.26	6.96	25.55	8.43	30.95	4.76	17.47	5.89	21.62	1.20	4.41
3	Dala	5.55	3.72	0.01	0.18	0.21	3.78	1.44	25.95	2.15	38.74	1.74	31.52
4	Dala Alamderi	4.20	2.81	-	_	-	_	0.08	1.90	3.43	81.67	0.69	16.43
5	Dusuman	4.32	2.89	4.29	99.31	0.03	0.69	-	_	-	_	-	_
6	Galtimari	11.15	7.47	0.24	2.15	0.55	4.93	3.56	31.92	6.68	59.91	0.12	1.08
7	Gwange	6.42	4.30	1.31	20.41	3.84	59.81	0.89	13.86	0.33	5.14	0.05	0.78
8	Jabbamari	1.21	0.81	0.67	55.37	0.54	44.63	-	_	-	_	-	_
9	Maimusari	1.82	1.22	0.91	50.00	0.91	50.00	-	_	-	_	-	_
10	Mairi	14.73	9.87	5.63	38.22	4.35	29.53	2.37	16.09	1.85	12.56	0.53	3.60
11	Maisandari	36.70	24.60	0.76	2.07	5.46	14.88	7.49	20.41	22.30	60.76	0.69	1.88
12	Mashamari	8.20	5.49	8.11	98.90	0.09	1.10	-	_	-	_	-	_
13	Old Maiduguri	5.52	3.70	5.44	98.55	0.08	1.45	-	_	-	_	-	_
14	Shehuri North	2.43	1.62	1.62	66.67	0.81	33.33	-	_	-	_	-	_
15	TamsuNgamdua	5.23	3.50	5.16	98.66	0.07	1.34	-	_	-	_	-	_
16	Yelwa	10.51	7.04	-	_	0.02	0.19	3.14		6.74	64.13	0.61	5.80
17	Yerwa	3.77	2.52	1.44	38.19	2.33	61.80	-	_	-	_	-	_
	TOTAL	**149.15**		**42.55**	**28.56**	**27.83**	**18.68**	**23.77**	**15.84**	**49.37**	**33.14**	**5.63**	**3.78**

Source: Fieldwork (2017)

Table 2 revealed that eight out of the seventeen Districts in Maiduguri urban comprising Jabbamari, Dusuman, Maimusari, Mashamari, Old Maiduguri, Shehuri North, Tamsu Ngamdua and Yerwa constituting 21.88% of the study area have their entire land area fall within extremely and/or highly liable to flood areas. Other districts with high percentage of their land area within the extremely and/or highly liable areas to flooding are Gwange (80.72%), Mairi (68.78%) and Bolori (56.55%). This finding confirms that some districts that have been constantly reported as flood liable areas (Odihi 1996, Bwala *et al,* 2015 and Jimme *et al*, 2016). Flood free zones are found more in Dala (31.52%) and Dala Alamderi (16.55%) than in all other Districts of the city. However, only four Dala Alamderi (98.83%), Yelwa (69.93%), Maisandari (62.64%) and Galtimari (59.17%) out of the seventeen districts have more than 50% of their land areas within either marginally liable or flood free zone areas. These are the four LGAs with 50% of their land area located on a high topography without having to worry much about flood problems.

Having classified the topography of the urban into five different classes of flood, liability, the data that were collected in the field on hot spots of intense flooding through Global Positioning System (GPS) was added to the classified image so as to examine the impact of topography on flood occurrence by comparing the actual places with intense flood with the results (from the study based on the topography) of the areas of extremely or highly liable to flooding areas. The output map is displayed in Fig.7.

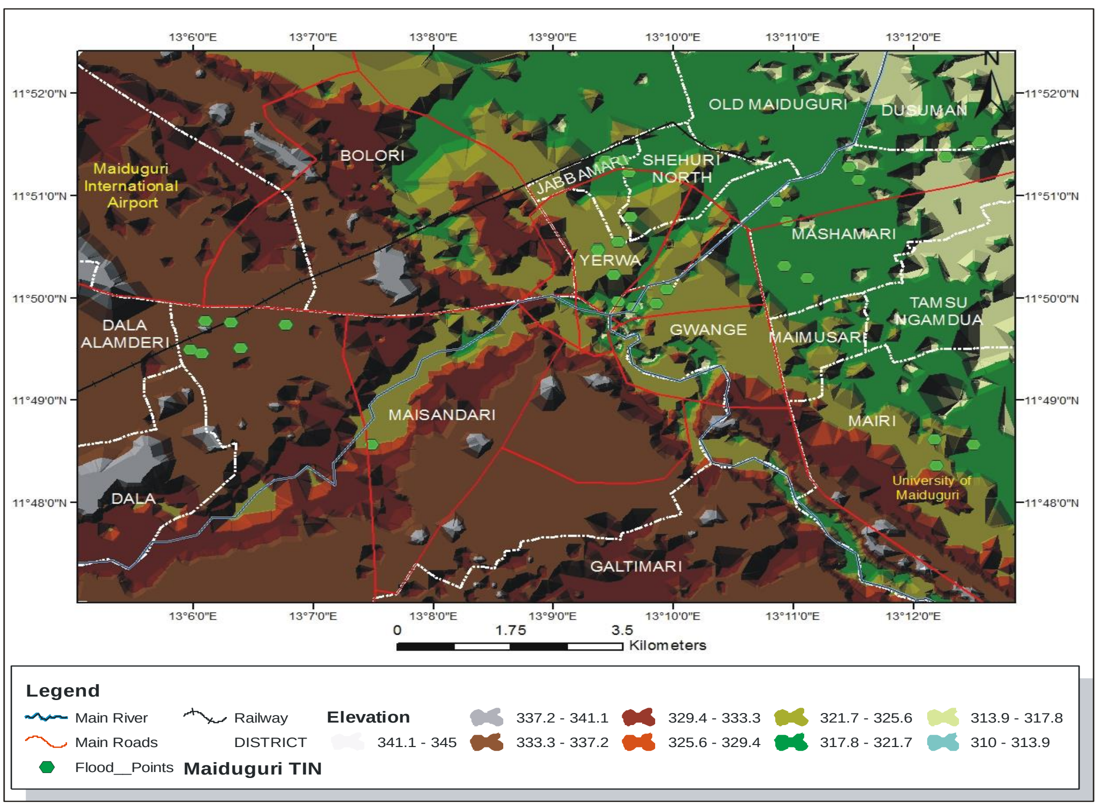


Fig. 7. Elevation map showing points of severe flood

Fig. 7. revealed that most of the land areas that were captured as liable to floods from GPS data during the rainy season also fall on the areas that were classified as either extremely or highly liable to flooding. However, some of the points, especially the flood prone areas in Bulumkutu area fell on areas

that were adjourned as marginally liable. The implications of this finding is that though the topography plays a major role in the occurrence and intensity of flooding in Maiduguri city, but flooding in Bulumkutu is not associated with topography, which means that other factors other than the topography which may be human induced are mainly responsible for flooding in Bulumkutu. Shettima (2018) reported that the major factor responsible for Bulumkutu floods is lack of drainage network and which the Borno State Government is already aware as many drainage channels have been constructed in the area within the last two years.

This finding confirms the report of Ologunorisa (2006) who observed that the flood may also be caused by the encroachment of hydraulic structures and cities on flood plains and by blocking of water channels and drainage networks. Maigari (2002) on the other hand observed that flooding is initiated by meteorological and anthropogenic factors which in one way or the other render streams or river channels incapable to accommodate fast running water from their catchment areas thereby leading to flooding. On Maiduguri urban, Jimme *et al* (2016) reported that the stream network of the area revealed that some parts of the urban were built on the natural stream channels or drainages. The effect on the terrain is that buildings and diversions lead to an obstruction of the natural course of water when it rains and especially as there are no effective drainages which make flooding inevitable.

Conclusion

The topography of Maiduguri urban has put the city in a disadvantage state when it comes to urban floods. This has made most parts of the urban area to experience frequent flooding. Eight districts (Jabbamari, Dusuman, Maimusari, Mashamari, Old Maiduguri, Shehuri North, Tamsu Ngamdua and Yerwa, Gwange, Mairi, and Bolori) out of the seventeen districts within the study area were found to require urgent actions for mitigation against flooding as major portions of these districts were found to be liable to flooding. Unfortunately, these districts comprised the core of the city (Yerwa, Shehuri North, Jabbamari) with a very high population. Moreover, major facilities (residential houses, roads, rail line) and institutions such as University of Maiduguri, University of Maiduguri Teaching Hospital (both in Mairi districts), College of Agriculture, (Mashamari district) and some housing estates like Abba Gana Terab Housing Estate (505) and Dikwa Lowcost, all fall within the flood liable areas. To save the population, facilities and institutions from these flood hazards, the use of modern technique such as remote sensing and GIS for assessments and monitoring of such hazards cannot be overemphasized. The lessons learned from this study can be applied to other cities or communities within and outside the country. Geospatial assessment of the totality of the land area of Maiduguri urban is recommended for further study. The integration of other factors, including topography for flood vulnerability of Maiduguri city as well as the causes of Bulumkutu floods is recommended for further studies.

Recommendations

Following the findings of this study, the following recommendations are made:

(i) Geospatial technique should be encouraged to be adopted for the assessments of urban flooding as the technique has been found to possess overwhelming advantages over the manual methods. Remote Sensing and GIS units with well trained staff should therefore be established in all the concerned ministries for proper monitoring of not only urban flood, but also other environmental hazards.

(ii) Flood management and control should be prioritized based on how liable an area is. For instance, all the districts that were found to be highly liable to flooding should be given urgent attention before other districts with low possibility of being flooded.

(iii) Functional drainage channels should be collectively designed by engineers and urban planners so as to control overland flow from resulting in urban flooding

(iv) Since flooding in Bulumkutu is discovered to have been caused by other factors other than topography, the State government as well as the associated ministries should as a matter of urgency look into the causes of floods in Bulumkutu.

References

Agbonkhese, O., Yisa, G. L., Daudu P.I. (2013). Bad drainage and its effects on road pavement conditions in Nigeria. *Civil and Environmental Research.* 3(10), 7-15.

Bwala, H.B. and Abdulwaheed, Y.A. (2015). Assessment of selected physical planning strategies and the challenges in combating flooding in Maiduguri, Borno State, Nigeria. *Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT) e-ISSN: 2319-2402, p- ISSN: 2319-2399.* 9(3), pp. 45-53.

Daura, M.M. and Ikusemoran, M. (2015). Geospatial assessments of flood vulnerability of Benue and Taraba States. *Academic Research International.* 6(6).

Ikusemoran, M., Anthony, D. and Maryah, U.M. (2013). GIS-based assessments of flood risk and vulnerability of communities in the Benue floodplains, Adamawa state. *Journal of Geography and Geology, Canadian Center for Science and Education.* 5(4), 148-160.

Ikusemoran, M. and Jimme, M.A. (2014). A decade Assessments of Maiduguri Urban Expansion (2002-2012). *Global Journal of Human Social Sciences*. 14(2), pp 1-8.

Jimme, M.A., Bashir, A. and Adebayo, A.A. (2016). Spatial distribution pattern and terrain analysis of urban flash floods and inundated areas in Maiduguri Metropolis, Borno State, Northeast, Nigeria. *Journal of Geographic Information System,* 8: 108-120. *http://dx.doi.org/10.4236/jgis.2016.81011*

Maigari A. I. (2002). *Introduction to environmental problems and management*. Wa'adallah environmental consults (WADEC) Kano State, Nigeria.

NPC (2007). *2006 Census.* Abuja: National Population Commission.

Nwaka, G. C. I. and Bababe, B. (1989). Soil studies of Ngaddabul floodplain within Maiduguri Metropolis for erosion control. *Annual Conference, Soil Society of Nigeria, Nsukka Nigeria.*

Odihi, J.O. (1996). Urban droughts and floods in Maiduguri: Twin hazards of a variable climate. *Berichte des Sonderforschungsbereichs 268, Band 8: 303-319*

Ologunorisa, E.T. (2006). *Flood risk assessment and management in Nigeria: Perspective from the Niger Delta.* Selfers Educational Books.

Shettima, K.M. (2018). Geospatial assessments of flood liable areas in Maiduguri. An unpublished M.Sc. dissertation. Department of geography, University of Maiduguri.

UN DHA (1994). *Nigeria Floods Sep 1994 UN DHA Situation Reports 1 – 3. Retrieved from* https://reliefweb.int/report/.../nigeria-floods-sep-1994-u-dha-situation-reports-1-3

United Nations' Office for the Coordination of Humanitarian Affairs (UN-OCHA 2016). Maiduguri and surrounds: Maiduguri city map, May, 2016.