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MODELLING OF FLOOD PRONE AREAS IN BAUCHI METROPOLIS, BAUCHI STATE, NIGERIA USING REMOTE SENSING AND GIS TECHNIQUES

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Abstract:
Increase in frequency of flooding in Bauchi metropolis is a major cause for concern during rainy season. The research was aimed at Modelling of Flood Prone Areas in Bauchi Metropolis, Bauchi State, Nigeria and this was achieved through the processing of Shuttle Radar Topographic Mission (SRTM) of 90 meters resolution and Pleiades image of 0.5 meter resolution. The factors were generated are fill sink (elevation), Flow direction, Flow accumulation, Terrain Wetness Index, and creation of buffer zones around the rivers to show the proximity. The results shown that 573 meters is in lowland areas while 760 meters is in highland areas, Flow direction map shown the various ways by which water flows as indicated with different colours, flow accumulation map shown the cumulated number of each cell which is the lowest volume of water is 1 m^3 and the highest volume is 9285 m^3, and the Terrain Witness Index map shown the value of 24.45 as a more saturated in a given cell which the values of 9.29 are less saturated. The flood-prone map shown that 7.6% of the areas at 30 meters buffered around the rivers were classified as vulnerable to flood, 13.4% of the areas at 60 meters buffered around the river were classified as moderate vulnerable to flood, 19.5% of the areas at 90 meters buffered around the rivers were classified as less vulnerable to flood, 26% of the areas at 120 meters buffered around the rivers were classified as very less vulnerable to flood, while 33.5% of the areas at 150 meters buffered around the rivers were classified as not vulnerable to flood respectively. It is recommended that further research should be conducted using Matrix Laboratory (MATLAB) software in mapping of flood-prone areas and a predicting model should be produced for future occurrence of flooding. It is also recommended that LIDAR as a new technology

should be used to improve the quality of digital terrain representation in order to generate TIN and recommended that Areas that are vulnerable to flooding be relocated.

***Keywords**: Modelling, Flood, Prone, Bauchi Metropolis, Remote Sensing, GIS, Techniques, Flow direction, Flow accumulation, Terrain Wetness Index, Buffer, Proximity, Shuttle, Radar, Mission, Vulnerable.*

Introduction

Flooding is the most common and most spatially distributed natural hazard across the world, and every year flood causes considerable damage in various parts of the world. Chang *et al.* (2006) reported that heavy convective rainfall often results in flooding in urban areas. Urbanization results into conversion of agricultural land, natural vegetation and wetlands to built-up environments and construction on natural drainages as well increase in the population of those living in flood vulnerable areas such as flood plains and river beds. Perhaps, floods are probably the most recurring, widespread, disastrous and frequent nat ural hazards affected most of the country of the world (Bhankaurally, Nowbuth, and Bhavara; 2010). For instance, Asian countries over 30 years ago, floods are the most frequent and devastating natural disasters for the total of about 40% compared to other continents and in European countries, the occurrence of floods is about 14% (Dushmanta and Srikantha; 2004).

According to (United Nation Environmental Program (UNEP, (2002) the major environmental disasters in Africa are recurrent droughts and floods. Their socio-economic and ecological impacts are devastating to African countries, because most of them do not have real time forecasting technology or resources for post-disaster rehabilitation. In Nigeria, Flooding usually occurs as a result of high levels of water in the rivers, concentration of overland flow following heavy rainfall, limited capacity of drainage systems and blockage of waterways and drainage channels (Olajuyigbe *et al.* 2012). Flooding incidences are becoming a more frequent occurrence in Nigeria. Between 2011 and 2012, there were a number of reported cases of flooding in several parts of the country. The major floods were occurred in most parts of Kogi, Delta, Bayelsa, and Onitsha in 2012. According to experts, the floods were caused by excess rainfall which resulted in the over flooding of Rivers Niger and Benue and their tributaries, from Taraba to Adamawa all the way to the southern states of Nigeria and over 600,000 residents were rendered homeless, farmlands were lost and many people were killed (Nkeki, Henah, and Ojeh; 2013). In the year 2012 also, Nigeria witnessed the highest flood disaster in 100 years, where over ten States of the Federation came greatly under water (Okonkwo, 2013). This incident was predicted by the Nigerian Meteorological Agency. Some of the causal factors of flood disasters in Nigeria include land inundation from heavy rainfall, climate change, and blockage of drainages with refuse, construction of buildings across drainages, inadequate drainage networks, and population increase in urban areas (Adeoye *et al*., 2009).

Although flood events are not new in Bauchi metropolis, the state capital, previously rainy season has caused an unprecedented flooding of abnormal magnitude and damage. Apparently, this is, for the large part, due to heavy rainfall for long period. The rain have caused most drainage basin to swell and overflow their courses, submerging the surrounding 'flat' fields or floodplains, which are mostly located in the outlying areas of the metropolis. However, it is evidence that the problem of flooding in Bauchi metropolis is getting more and more acute due to anthropogenic activities of the people around the lowland areas of the metropolis.

Study Area

Bauchi metropolis is bounded by seven local governments comprising of Kirfi, Ganjuwa, Alkaleri, Tafawa Balewa, Dass and Toro respectively. Bauchi metropolis falls within latitudes 10° 19′ 55′′ N and 10° 20′ 58′′N and longitudes 9° 50′ 50′′E and 9° 51′ 29′′E. It is the capital of both Bauchi Local Government Area and Bauchi State and covers an area of about 3,687km^2 (Bauchi-Wikipedia February, 2017). The prominent mountains are the Wambai and Warinje hills located at the northeast of the metropolis, the Jahun and Gudum hills in the south and the Kobi hill that dominates the center of the old walled town of the metropolis. The population figure, according to 2006 National population census result, stands at 493,810 (NPC, 2006). Bauchi is situated within the belt of open Sudan savannah, characterized by sparse trees of up to 6.096m and above. It has been subjected to considerable human interference through cultivation, grazing and burning; thereby most of the vegetation has been reduced to acacia shrub of less than 35% vegetation cover at micro level. The vegetation is less uniform and grasses are shorter than what grows. The rivers have numerous headwaters and tributaries within the metropolis. This pattern of drainage has produced productive clay and loam soil from Fadama land that surrounded the metropolis. The Gubi dam lies to the northeast of the metropolis and provides a good source of water for urban uses. Bauchi experiences its rainy season right from mid-June to mid - October, with August recording the highest amount of rainfall of 340 mm. The total mean annual rainfall stands at 1,091.4 mm (BASG, 2012).There are two major seasons in Bauchi i.e. rainy and dry seasons. The rainy season months are May to September, when humidity ranges from about 37% to 68%. The onset of the rains has been often in March and they end virtually October while the dry season starts from November to May (Shuaibu *et al.*, 2015).

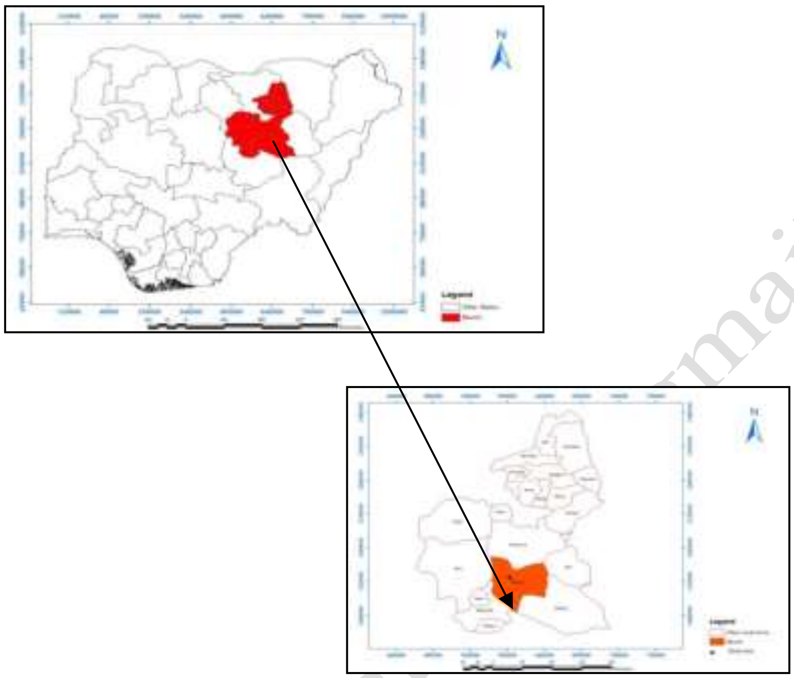


Fig. 1. The Study Area
Source: Department of Surveying and Geoinformatics, ATBU, Bauchi (2016).

Materials and methods

The Shuttle Radar Topographical Mission (SRTM) Digital Elevation Model (DEM) with a 90m resolution which covered the study area was obtained from (USGS), Pleiades Satellite image with a 0.5m resolution obtained from Bauchi Geographic Information System (BAGIS, 2012); and the official name of the areas were collected from the district head office of Bauchi. The flowchart of the methodology is shown in figure 2.

ILWIS3.3 was used to obtained the factors such as fill sink/elevation, flow direction, flow accumulation, terrain wetness index, and ArcGIS 10.1 was also used to obtained the areas that are proximity to the river.

The area were classified in to five classes (that is Vulnerable, Moderately, Less, Very Less and Not Vulnerable to flood) respectively.

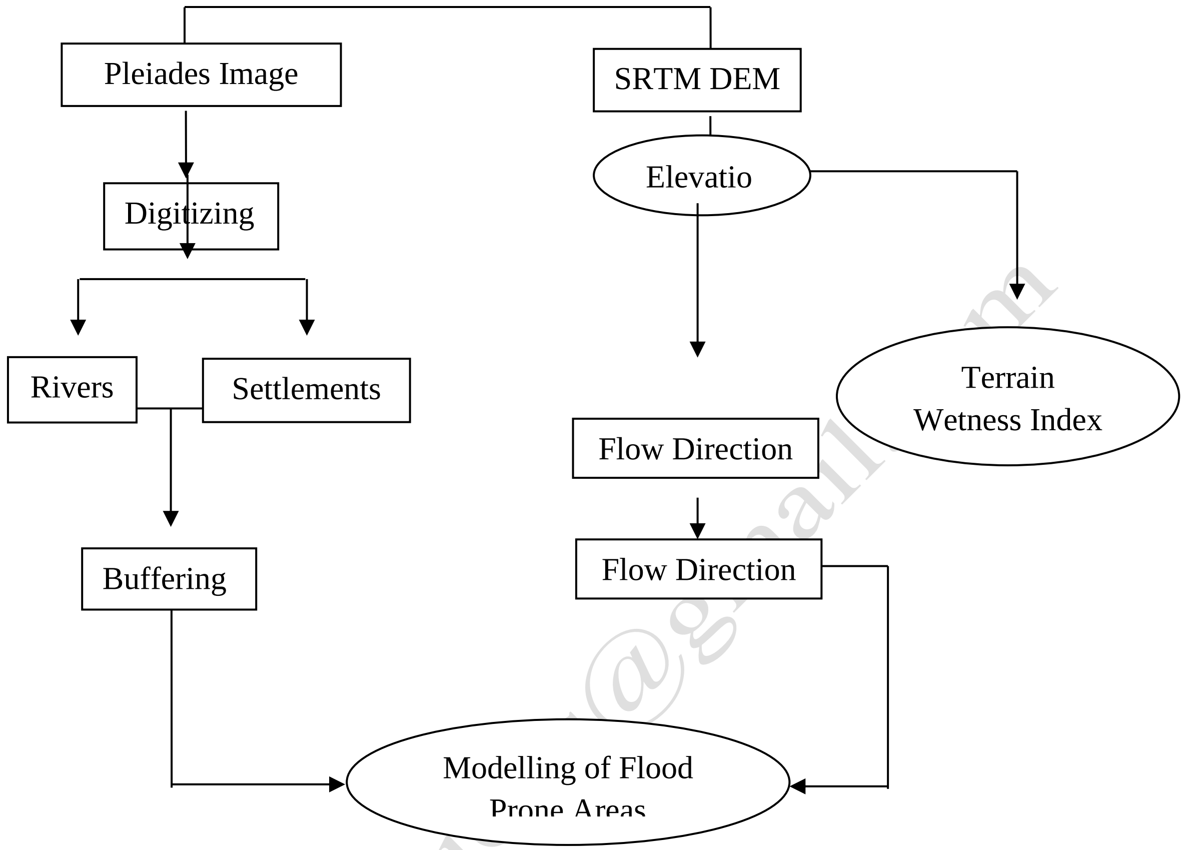


Fig. 2. Flowchart of the methodology
Source: Author's Laboratory Work.

Fill sink is the removal and filling of small imperfection (such as lake, pond etc that are found to stop flow of water from high to low altitude) from satellite data. It also allows water to flow from the higher elevation to lower elevation instead of settling in sink areas for the successful hydrological analysis. Fill can also be used to remove peak while peak is a cell where no adjacent cells are higher. Therefore, the process of fill sink can be obtained is "ILWIS3.3>Operation>Dem Hydro Processing>Flow Determination>Fill Sink".

Flow Direction was generated from the spatial analyst tools and selecting the hydrology tool followed by flow direction tool; and filled out the information required to produce. The mathematical expression used to determine how much flow goes to each adjacent cell thus:

$$\mathrm{Fi} = \frac{Li\ tan\alpha i}{\sum_{i=1}^{n} \mathrm{Li\ tan}\alpha \mathrm{i}}$$

Where: Fi is the proportional flow to a neighboring cell

Li is the flow width

αi is the slope angle of the cell Muhammad *et al.*, (2016).

Flow accumulation map was generated to shows how much water performs a cumulative count of the number of pixels that naturally drain into outlets and find out drainage pattern of the terrain. Pattern of the rivers was shown with different colours and the colours were classified into six such as first, second, third, fourth, fifth and sixth order rivers that carry water from catchment areas to final destinations. It was also generated to determine the areas where large volume of water accumulated during rainfall because of its potential to cause flooding.

Terrain wetness index (TWI) was generated using ILWIS 3.3 software, the input raster was Fill sink and Flow accumulation map while the output map was Terrain Wetness Index. TWI was generated in order to show soil water volume/capacity that helps in determining the saturation level of soil within a given area. The wetness level of a terrain also shows the amount of water that will be added to the saturated soil and eventually dispense as surface flow when percolation must have taken place and soil is over saturated. Higher wetness index (values) signifies places of high flood risk and vice versa. This factor was chosen to check the level of soil wetness in the study area and the relative reaction if there is an addition at a given time. TWI can be express mathematically as:

$W_T = 1n\ (A_s/T\tan\beta)$

Where A_s, is the specific catchment area (m^2m^{-1}), T is the soil transmissivity when the soil profile is saturated, and p (betta) is the slope gradient (in degrees, I. D) (Moore, Grayson and Ladson, 1991).

Pleiades imagery of the study area was used for the vectorization of the features around the area. During the digitization, homogeneous areas and the scattered built-up areas were digitized separately for better accurate proximity analysis while rivers were digitized using polygon feature instead of traditional conventional cartographic System of using line.

Proximity to the river was created by buffering in order to show graphic symbolic representation of the significant features of part of surface of the earth. In this study, buffers around the rivers was created in order to map out areas that are vulnerable to flooding base on their proximity to the river at 30 meters, 60 meters, 90 meters, 120 meters and 150 meters respectively. Mayomi *et al.*, (2013) said that, flood intensity all over the world depends on the proximity or the closeness of any location from the main causal water body, hence, the higher the risk of the flooded areas, though, depending on the topography of the area. In such case, flood vulnerability was classified into five classes as (1) vulnerable to flooding, (2) Moderately vulnerable to flooding, (3) Less vulnerable to flooding, (4) Very less vulnerable to flooding and (5) not vulnerable to flooding respectively. Finally, an overlay analysis tool was used under intersection option to clip out the total areas of the study that encroached water bodies based on the vulnerability classes.

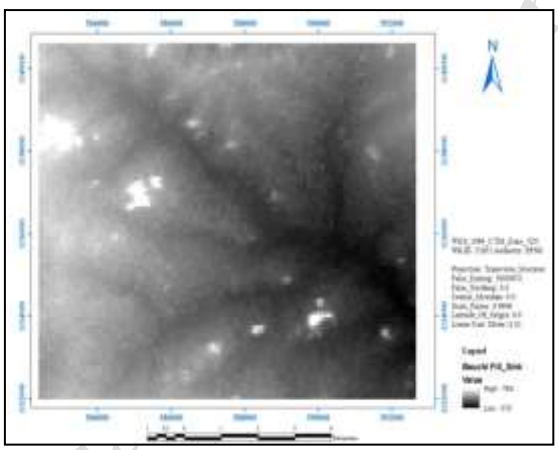
Results and discussions

The results obtained from the processing data described above can be presented below:

Elevation

This shows the graphical presentation of the value of elevation of the study area as shown in figure 3a and figure 3b. It is also show the average height of the elevation in the area slice from 573 meters (lowland) to 760 meters (highland). Meanwhile, in fill sink, white colour is indicates the highest point while black colour is the lowest point while in Digital Elevation Model, red colour indicated the highest point while blue colour is the lowest point. The difference between the lowland and the highland areas is 143 meters. As a result of that the difference is greatly large.

a **b**



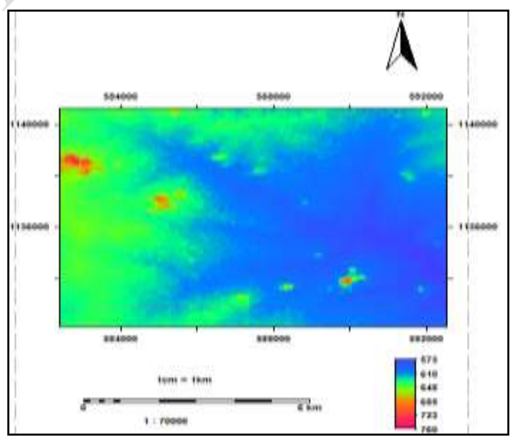


Fig. 3a. Elevation of the study area **Fig. 3b.** Classified Elevation of the study area

Source: Author's Laboratory Work.

By considering the natural break, DEM of the study area were classified into five as shown in Table 1 below.

Table 1. Vulnerability classes from the Classified Elevation of the Study Area

S/N	Elevation (m)	Vulnerability Classes
1.	573 – 609	Vulnerable to Flood (VTF)
2.	610 – 642	Moderately Vulnerable to Flood (MVTF)
3.	643 – 684	Less Vulnerable to Flood (LVTF)

4.	685 – 722	Very Less Vulnerable to Flood (VLVTF)
5.	723 – 760	Not Vulnerable to Flood (NVTF)

Source: Author's Laboratory Work.

Table 1 above shows that area falls at height of 573-609 (m) are classified as Vulnerable to Flood (VTF). All area lays between the heights of 610-642 (m) are classified as Moderately Vulnerable to Flood (MVTF). The area lies between the heights of 643-684 (m) were classified as Less Vulnerable to Flood (LVTF). The heights of elevation of 685-722 (m) were classified as Very Less Vulnerable to Flood (VLVTF). While area haven the highest number of elevation of 723-760 (m) were classified as not vulnerable to flood (NVTF). Consequently, the vulnerability classification of flood should be use in prevention and mitigation.

Flow Direction

This shows the direction of water flow if the Output drop raster option is chosen, an output raster is created showing a ratio of the maximum change in elevation from each cell along the direction of flow to the path length between centers of cells. It can be useful for determining neighboring pixel; any water in a central pixel will flow naturally from various places within the study area as presented with different colours.

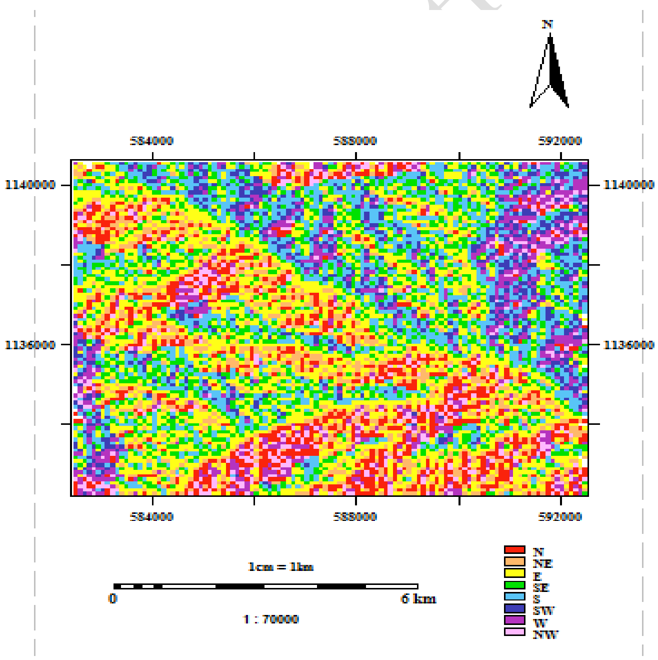


Fig. 4. Flow Direction

Source: Author's Laboratory Work.

By considering the direction of water flow, the area covered per each pixel is indicated in table 2 below,

Table 2. Flow Direction and the area in percentage per pixels with colours

S/N	FLOW DIRECTION	COLOUR	NO. OF PIXEL	AREA
1.	N	Red	1232	11.96
2.	NE	Orange	1146	11.13
3.	E	Yellow	2585	25.09
4.	SE	Green	1387	13.46
5.	S	Light-Blue	1826	17.73
6.	SW	Navy-Blue	691	6.71
7.	W	Violet	895	8.69
8.	NW	Pink	539	5.23
TOTAL			10301	100%

Source: Author's Laboratory Work.

Table 2 above shows that 11.96% of the area with Red colour, the water is flows toward North direction, 11.13% of the area that appeared with Orange colour shows that water is flows toward North-East direction, 25.09% of the area with Yellow colour shows that the water is flows toward East direction, 13.46% of the area with Green colour shows that the water is flows toward South-East direction, 17.73% of the area with Light-Blue colour shows that the water is flows South direction, 6.71% of the area with Navy-Blue colour shows that the water is flows toward the direction of South-West, 8.69% of the area with Violet colour shows that the water is flows toward the West direction, while 5.23% of the remaining area with Pink colour shows that the water is flows toward the direction of North-West.

Flow accumulation

It calculates accumulated flow as the accumulated weight of all cells flowing into each down slope cell in the output raster. If no weight raster is provided, a weight of 1 is applied to each cell, and the value of cells in the output raster is the number of cells that flow into each cell.

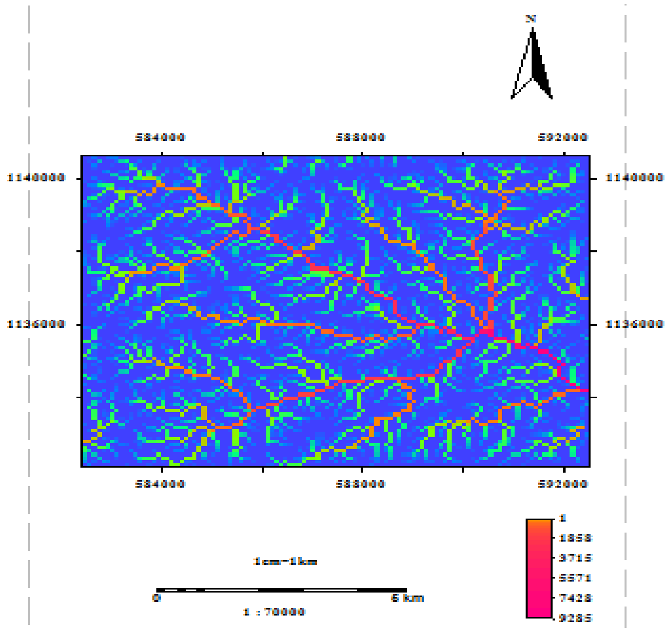


Fig. 5. Flow accumulation
Source: Author's Laboratory Work.

Figure 5 above, shows that the rivers pattern was indicated with different colours and the colours were classified into six such as first, second, third, fourth, fifth and sixth order rivers that carry water from catchment areas to final destinations.

Terrain Wetness Index

Terrain Wetness Index (TWI) was generated in order to show the soil water volume/capacity that helps in determining the saturation level of soil within a given area. The wetness level of a terrain also shows the amount of water that will be added to the saturated soil and eventually dispense as surface flow when percolation must have taken place and soil is over saturated. The factor was chosen to check the level of soil wetness in the study area and the relative reaction if there is an addition at a given time. It's also shows the values separated by natural break ranges from 9.29 - 24.45. This was classified according to the range and colours separation. Therefore, the high index areas were appeared with purple colour while the low index areas were appeared with blue colour. The wetter area close to the river is appearing with blue colour while areas with blue colour are far-away from flooding. Therefore, the lower areas close to the river source are more affected by flooding than those in high areas.

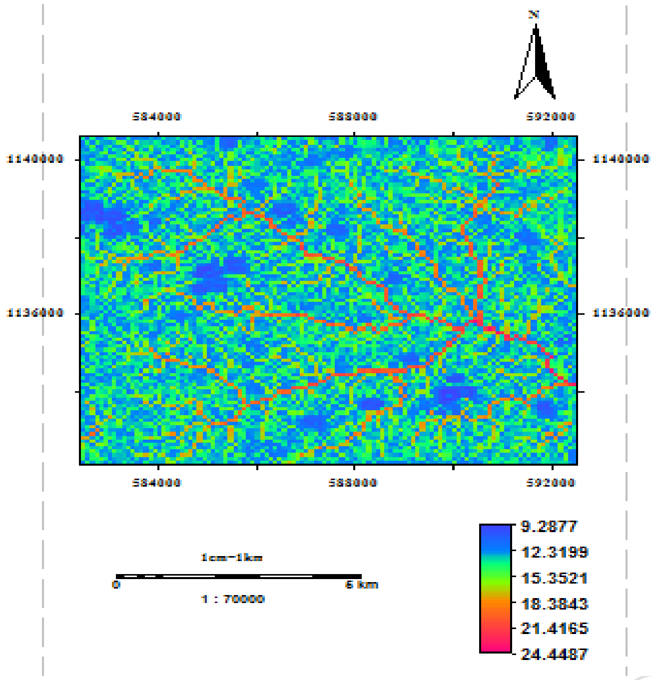


Fig. 6. Terrain Wetness Index (TWI)

Source: Author's Laboratory Work.

Table 3. TWI Range of values and Vulnerability Classes

S/N	TWI Range of Value	Vulnerability Classes
	1. 9.29-12.32	Not vulnerable to flood
	2. 12.33-15.35	Very less vulnerable to flood
	3. 15.36-18.38	Less vulnerable to flood
	4. 18.39-21.42	Moderate vulnerable to flood
	5. 21.43-24.45	Vulnerable to flood

Source: Author's Laboratory Work.

Table 3 above shows the TWI factor, the range of value from 9.29-12.32 of areas saturated were classified as Not vulnerable to flood, the range of TWI value from 12.33-15.35 of the area were classified as Very less vulnerable to flood, The range of TWI value from 15.36-18.38 were also classified as Less vulnerable to flood, the TWI range of value from 18.39-21.42 were classified as Moderate vulnerable to flood while the range of value from 21.43-24.45 of the area were classified as Vulnerable to flood.

Proximity to the river

Proximity is one of the methods of determining the relationship between selected geographical elements by identifying the location of other elements within a specified distance. Creation of buffer zone is the most common method used in proximity analysis. The buffer zone was grouped into five zones at regular interval of 30 meters. As in Mayomi *et al.,* (2013) used buffer of 3 kilometers to show the settlements that are within the buffer to be affected. The classified buffer zones are at 30meters, 60meters, 90meters, 120meters and 150meters respectively. Each zone has shown the amount of encouragement in hectares and percentages. The rivers were indicated by deep blue, the buffer zones were also indicated by light blue while the settlements were indicated by light brown.

Fig. 7: thirty meters buffer zone

Fig. 8: sixty meters buffer zone

Fig. 9: ninety meters buffer zone

Fig. 10: one hundred and twenty buffer zone

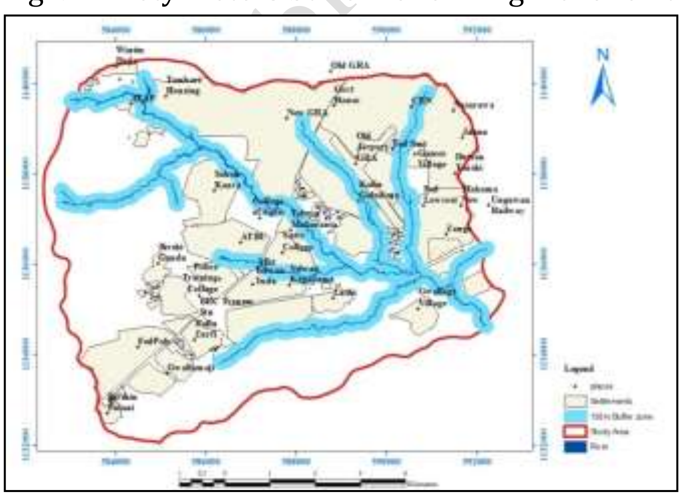


Fig. 11: one hundred and fifty buffer zone

Source: Author's Laboratory Work.

Table 4. Flood-prone zones and amount of encouragement to the river banks

S/N	Vulnerability classes	Buffered zone in meters	Areas in hectares	Area in %
1	Vulnerable to flood	30	280	7.6
2	Moderately Vulnerable to Flood	60	498	13.4
3	Less Vulnerable to Flood	90	723	19.5
4	Very Less Vulnerable to Flood	120	964	26
5	Not Vulnerable to Flood	150	1244	33.5
	TOTAL		3709	100%

Source: Author's Laboratory Work.

Table 4 above shows the flood-prone zones and amount of encouragement to the river banks. Every areas within 30 meters buffer zone are encouraged to river at about 7.6% were classified as Vulnerable to flood, the areas within 60 meters buffer zone are encouraged to the river at about 13.4% were classified as Moderately Vulnerable to flood, the areas within 90 meters buffer zone are encouraged to the river at about 19.5% were classified as Less Vulnerable to flood, the areas within 120 meters buffer zone are encouraged to the river at about 26% were classified as Very Less Vulnerable to flood while areas within 150 meters are encouraged to the river at about 33.5% were classified as Not Vulnerable to Flood. All the areas that are within each zone have their name written on the map for easy interpretation.

Conclusion and recommendations

Some areas within Bauchi metropolis has been experienced flooding for many years as according to the research, this has been attributed to many factors such as excess stage discharge, vulnerability, nature and rate of the Terrain Wetness Index, Geodetic Height of the area and Proximity to the river. The high Terrain Wetness Index is recorded around the affected areas within metropolis; significant range of value of the area is in low-lying. Hence the proximity of the areas that is very close to the river, the vulnerability and likely of the people to be affected by flooding is very high. The application of Remote Sensing and Geographic Information System method in developing the flood vulnerability factors such as DEM, Terrain Wetness Index, and Proximity to the river are bring the historical approach in flood management within Bauchi Metropolis and its environs. Therefore, the following are recommendation that can be used for further future studies:

i. To have a properly representation of the topography of the floodplains areas, a high resolution of topographical data should be made available.
ii. Matrix Laboratory (MATLAB) software should be used in mapping of flood-prone areas.
iii. A predicting model should be produced for future occurrence of flooding.
iv. There is a need to test the sampling of soil for determine the water content in the floodplain areas.
v. LIDAR as a new technology should be used to improve the quality of digital terrain representation in order to generate TIN.
vi. Areas that are vulnerable to flooding be relocated.

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