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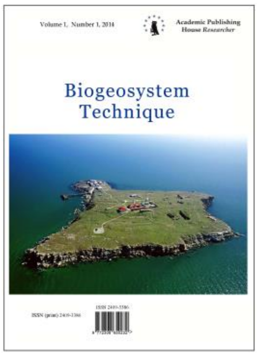

UDC 631

Flood Vulnerability Modelling Factors of Nafada Town, Gombe State, Nigeria Using Remote Sensing and GIS Techniques

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Abstract

This study employs the integrated approach of Remote Sensing and Geographic Information Systems (GIS) techniques in flood management with the goal of deriving flood vulnerability modelling factors. Flood vulnerability studies have become more efficient in recent years because of the availability of advanced computational facilities and use of GIS. Almost every year, Nafada Town has been experiencing repeated flooding during the rainy season (July to September). As a consequence, properties are lost or destroyed and sometimes lives are lost. The aim of this research is to develop factors that could be used in flood vulnerability modelling of terrain features that favored the incidence of the floods as part of the solution to the problem. The objectives were to process Shuttle Radar Topographic Mission (SRTM) Scene 186/052 with a resolution of 90m·90m which covered the study area, downloaded from United State Geological Surveys (USGS) and the factors were obtained. These fetors were fill sink (elevation), terrain wetness index, proximity to river and overland flow length using the Integrated Land and water information system (ILWIS 3.3) Software, the factors were then classified using Natural breaks extension of ArcGIS 9.3 software. Hence, GIS techniques were proved to be useful in deriving the flood vulnerability modelling factors in a time and cost effective manner. It is recommended that GIS methods should be incorporated in planning and management of floods in the study area and further study should be conducted to combine these factors to develop a flood vulnerability model of the area.

Keywords: Flood, Vulnerability, GIS, Remote Sensing, Mission, Nafada Town, Modelling, Proximity, Overland, Terrain wetness Index.

1. Introduction

In simple terms, flood is defined as temporary covering of land by water as a result of surface water escaping from their natural confines or as a result of heavy precipitation (Opolot, 2013). Perhaps, in contemporary times, it is the most consistent serious natural disaster affecting most countries of the world. For instance, Asian countries have been at the frontline of the incidence and severity of flooding in the world. It is estimated that the countries experienced 1/3rd of the 1562 floods that occurred in the world between 1994 and 2004 (Uddin et al., 2013; Bhatt et al., 2014).

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In Europe, flooding was reported in countries like Italy, Russia, Romania etc. (Ebi et al., 2003). It is even forecasted that the incidence of floods in Europe will double by 2050 while annual economic losses resulting from them will increase five folds (Conner, 2014). Thirty-two major floods occurred in the United States in the 20th Century (Perry, 2000).

Flooding is also wide spread in Africa (Emmanuel, 2013), Nigeria has had its own experience of flooding. Whitworth et al., (2015) classified the floods that occur in Nigeria into fluvial (along the plains adjoining rivers especially in the North), coastal (along the low lying coastal areas of the South) and pluvial (inundation of urban areas due to severe rainfall and poor drainage). The recent floods in the country include those of 2012 (30 States were affected, NEMA, 2012), 2013 (156 Local Governments in 31 States, NEMA, 2013), 2014 (35 cases across 8 States, NEMA, 2014), 2015 (7 States, NEMA, 2015). During the 2016 rainy season, the Nigerian Hydrological Services Agency (NIHSA) has highlighted the possibility of flooding in fourteen States (Nnodim, 2016). The incidence of flooding in Uyi Udele (Ebonyi State) (Davies, 2016), Lafiya (Nassarawa State) (Eleazu, 2016) and Hayin Gwarmai (Kano State) in June and July, 2016; attests to the potency of the forecast by NIHSA, and the need for serious mitigating action by stakeholders.

The destructive effects of floods on lives and properties and associated socio economic disruptions are also monumental. Globally, in the 20th century, 6.8 million deaths resulted from flooding and, between 1980 and 2009 2.8 billion people were affected by the disaster (Doocy et al., 2013). Opolot (2013) reported that between 2000 and 2008 flooding affected an average of 99 million people each year. A shortlist of some of the losses associated with floods in Nigeria since 2001were provided by Etuonovbe (2011). The 2012 floods, reported as the worst in forty years, displaced about 1.3 million people and killed 431 others (Emmanuel, 2012). It is obvious that the destructive effects of floods should qualify their mitigation to command priority in issues of environmental management, human and material safety. This is more so as the principal causes of flooding i.e. the incidence of high intensity rainfall, rise in sea levels associated with climate change, rapid urbanization and environmentally unfriendly land use practices (Dabara et al., 2012) all require the consistent deployment of required human, technological and material capacities to tackle.

Interactions with residents of Nafada town in Gombe State, Nigeria suggest that the town has been experiencing floods and their associated effects for a long period of time. The last major flood in the town was in 2013 whose consequence was the displacement of over 500 people, the injury of 112 people and the submerging and destruction of several houses and farmlands (NEMA, 2013). However, most of the floods have not commanded serious publicity and attention because of the rural character of the town coupled with the relative lower magnitude of the floods compared to others on the national scale. So far, efforts at addressing the problem has been restricted at the construction of about 16 km of drainage in 2004 and 2012 by the collaborative efforts of the Local and State Governments (Nafada LGA, 2013). The incidence of the 2013 flood suggests that this effort is not adequate for the problem. Therefore, it is imperative that more effective, knowledge derived measures be deployed. Specifically, knowledge about the factors, expected frequency, character, and magnitude of hazardous events in an area as well as the vulnerability of the people, buildings, infrastructures and economic activities in potentially dangerous areas is required (Van Western & Hosfstee, 2001). A combination of Remote Sensing and Geographic Information System (GIS) tools are effective for this purpose (Jayasselan, 2006). However, local capacities to deploy these tools for the purpose appear to be lacking. Hence, the purpose of this paper is to derive the physical factors that make the study area (Nafada town of Gombe State, Nigeria) vulnerable to flood. Remote Sensing and GIS techniques, specifically, the Shuttle Radar Topographical Mission (SRTM) Digital Elevation Model (DEM) and ILWIS software were used to evaluate four flood vulnerability factors: elevation, terrain wetness index, proximity to river and overland flow length.

2. Study area

The location of Nafada town is at latitude 110928mN and longitude 113289mE. It is the administrative headquarters of Nafada Local Government Gombe State, north eastern Nigeria (Fig. 1). It has an average altitude of 306 m and a largely agrarian population of 22,920 according to the 2006 population census. The town has distinct wet (rainy) and dry seasons whose incidence is governed by the movement of the inter-tropical convergence zone, a zone where warm and moist air from the Atlantic Ocean converges with hot, dry, and often dust-laden air from the Sahara

Desert known locally as the harmattan. The rainy season lasts for three months (July-September). The average rainfall varies from 760 mm to 1000 mm annually, with the highest rainfall recorded during the months of July and August. Temperatures are high throughout the year, averaging from 25 to 28 °C (77 to 82 °F).

The area has the Sudan Savannah vegetation that is characterized by predominantly tall and short grasses, with scattered trees and shrubs. The trees are mostly locust bean trees, baobabs and some other forms of deciduous trees. They are heavily cut by inhabitants to make firewood as a source of energy for cooking. The consequence of this is the increased tendency for runoff (and flood) due to the loss of the protection provided by the vegetation. While the geology of Nafada town is hilly and flat land with streams that runs from west to east, the geology of the area is made up of Fika shell that comprises blue-black gypsifereous with thin limestone bed. There is inadequate drainage system for the safe channeling and disposal of runoff within the area. Patches of ponds can be seen within the town especially during the rainy season. The Gongola River and its tributaries form the main drainage systems in the area, River Nafada is the prominent hydrological feature in the area (Abdul Kareem, 2014).

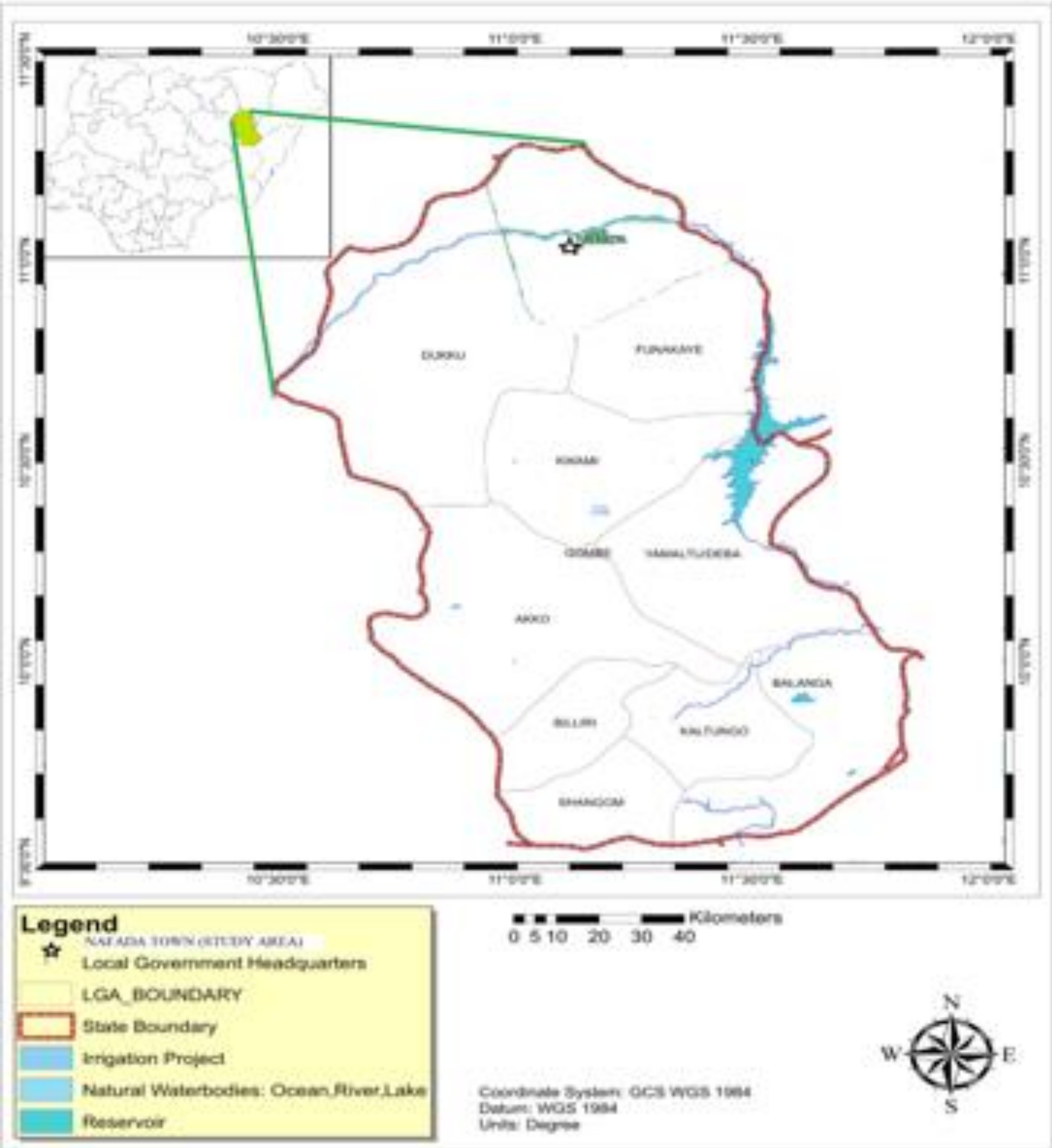

Fig. 1. The Study Area

3. Materials and methods

The Shuttle Radar Topographical Mission (SRTM) Digital Elevation Model (DEM), Scene 186/052 with a resolution of 90 m·90 m which covered the study area was obtained from (USGS, 2008). The ILWIS 3.3 was used for data processing. The flow chart in Fig. 2 describe how the DEM was processed to achieve the purpose of the study.

The SRTM DEM was imported into the ILWIS 3.3 environment and was process and the flood vulnerability criteria (fill sink/elevation, terrain wetness index, proximity, overland flow length) were obtained.

Classification is based on natural breaks using ArcGIS 9.3, classes are based on natural groupings inherent in the data. ArcMap identifies break points by picking the class breaks that best group similar values and maximize the differences between classes. The features are divided into classes whose boundaries are set where there are relatively big jumps in the data values. It is typical to use this type of thematic classification on continuous phenomena, such as slope, distance, or suitability, where you want to classify the range into a small number of classes and assign colors to those classes.

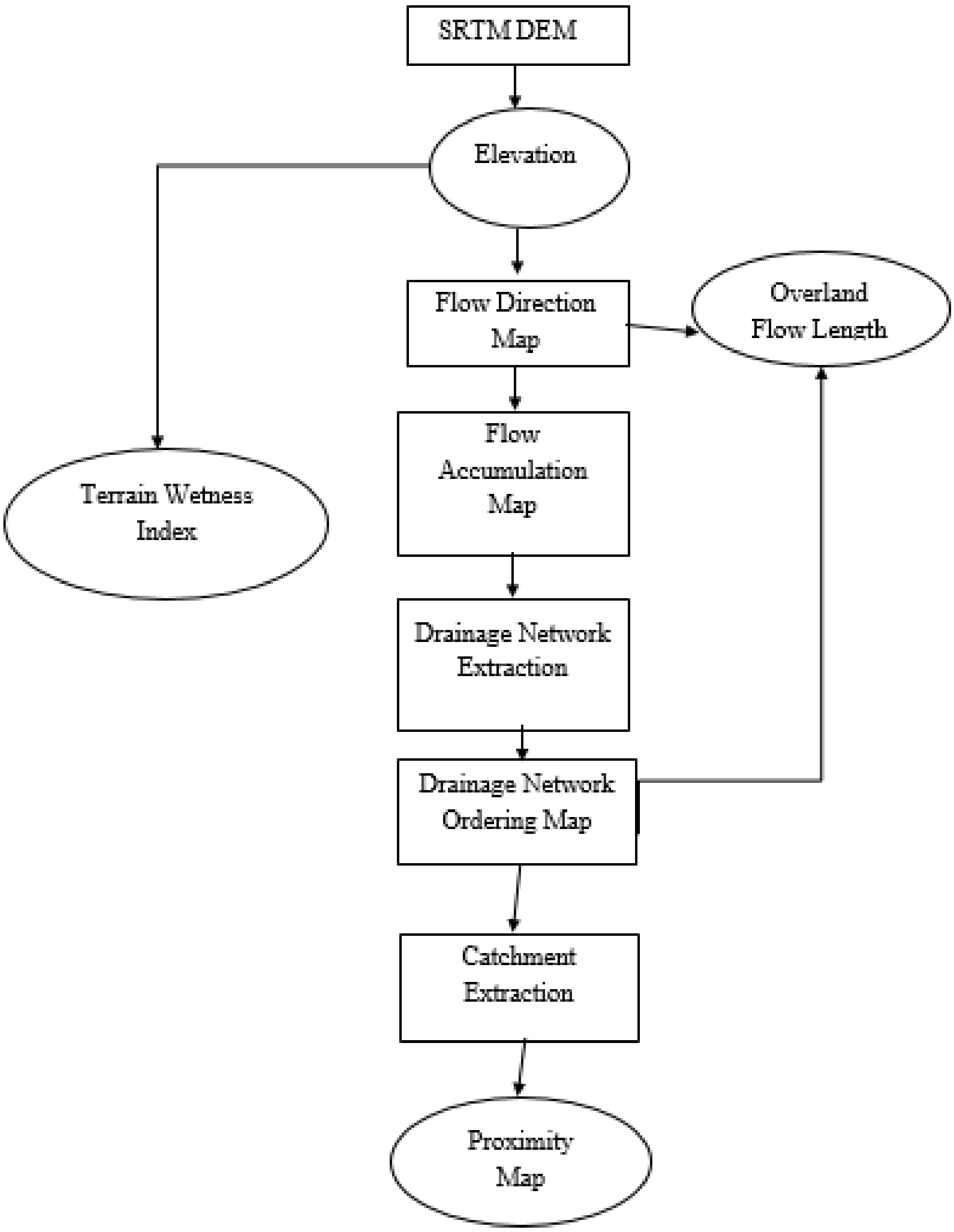

Fig. 2. Process of Deriving the Factors

Fill sink (elevation) is the process of cleaning the DEM so that local depressions (sinks) are removed from it; it will remove depressions that consist of a single pixel, i.e. any pixel with a smaller height value than all of its 8 neighboring pixels and depressions that consist of multiple pixels, when a depression of a single pixel is encountered: then the height value of this pixel will be increased to the smallest value of its 8 neighbor pixels, while if a depression of multiple pixels is encountered: then the height values of this depression will be increased to the smallest value of a pixel that is both adjacent to the outlet for the depression, and that would discharge into the initial depression. Elevation explains the height above the sea level. The height above the mean sea level of a particular place helps determine the level of vulnerability of such places to sea rising or flood occurrences, areas with low elevation can be vulnerable to flooding than areas with appreciable height. However, the factor holds that the height of a place determines the level that a place can be affected given a particular rise in the water body this was obtained through "ILWIS3.3>Operation>Dem Hydro Processing>Flow Determination>Fill Sink."

Terrain Wetness Index: The soil water volume/capacity helps in determining the saturation level of the soil within a given area. The wetness level of a terrain shows the amount of water that will be added to saturate the 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 hazards and vice versa. Terrain wetness index sets catchment area in relation to the slope gradient, it depicts the spatial distribution of soil-water in the study area, thereby showing surface saturation zones in the study area.

$$TWI = \text{In}\left(\frac{As}{T\tan\beta}\right)$$

A_s, is the specific catchment area (m^{-2}), T is the soil transmissivity when the soil profile is saturated, and β is the slope gradient (in degrees, I. D) (Moore et al., 1991).

This was obtained from "ILWIS3.3>Operation>Dem Hydro Processing>Compound Index Extraction>Compound Index Calculation." The input maps are Elevation and Flow accumulation map, the output map is terrain wetness index Map

Proximity to river: The Proximity toolset in the Analysis toolbox were used to discover proximity relationships. These tools output information with buffer features. Buffers are usually used to delineate protected zones around features, in this case, river or to show areas of influence. This factor was chosen to show the nearness or the distance of the study area to the river which is another factor that shows how vulnerable the area will be to flooding, this was achieved through "ILWIS3.3>Operation List>Double Click On Distance Calculate>Input Catchment Extraction Map>Ok or ArcGIS 9.3>Spatial Analyst Tools>Distance>Euclidian Distance>Input Raster>Ok".

Overland Flow Length: The Overland Flow Length operation calculates for each pixel the overland distance towards the 'nearest' drainage according to the flow paths available in the Flow Direction map, the operation produces a raster map that contains the overland down-flow distances towards the drainage into which a pixel will drain according to the flow direction map. This was obtained from "ILWIS3.3>Operation>Dem Hydro Processing>Compound Parameter Extraction>Overland Flow Length". The input maps are Drainage Network Ordering and Flow Direction Map while the output map is Overland Flow Length.

4. Results and discussions

The results obtained from the data processing described above are presented below.

Elevation

The graphical representation of the elevation values of the study area is shown in figures 3A and 3B. Fig. 3A show that the average geodetic height of the study area ranges from 246 m (lowest) to 499 m (highest elevation). Fig. 3B show that elevation is lowest (depicted in green) around the River and increases outwards to the height of about 499 m above sea level. This suggests a difference of 53 m between the lowest and highest elevations. This difference is large enough to ensure that in line with the law of gravity, the low lying river and its immediate vicinity is the destination of runoff from surrounding higher elevations.

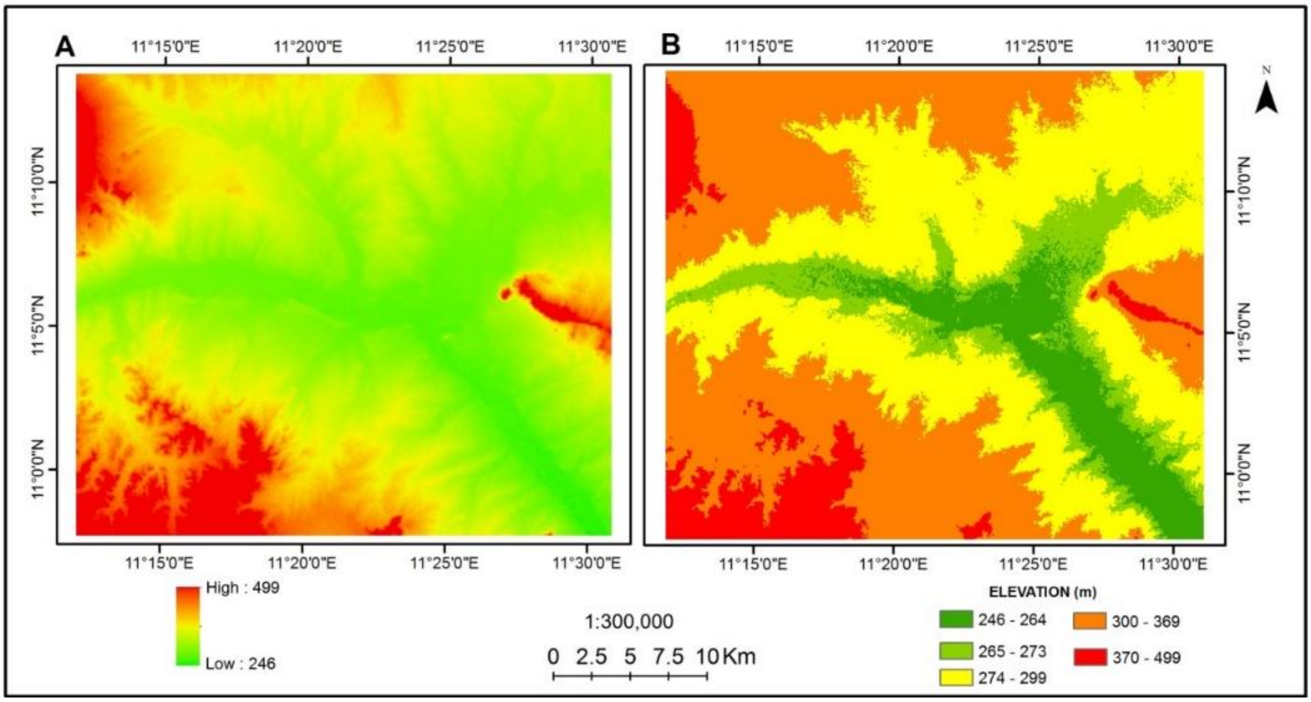

Fig. 3A. Elevation of the study area **Fig. 3B**. Classified Elevation of the study area

Using natural breaks, the DEM was classified into five classes as indicated in Table 1.

Table 1. Classified Elevation of the Study Area

S/NO	Elevation (m)	No of pixels	Area (%)	Vulnerability class
1	246 – 264	109195	31.14	Vulnerable to flood (VTF)
2	265 – 273	105057	29.96	Moderately vulnerable to flood (MVTF)
3	274 - 299	98447	28.07	Less vulnerable to flood (LVTF)
4	300 – 369	23360	6.66	Very less vulnerable to flood(VLVTF)
5	370 – 499	14623	4.17	Not vulnerable to flood (NVTF)
TOTAL		350682	100	

Table 1 shows that 31.14 % of the study area lies between 246-264 m and is therefore Vulnerable to Flood (VTF). Heights between 265-273 m occupy 29.96 % and are therefore, Moderately Vulnerable to Flood (MVTF). The heights between 300-386 m, classified as Less Vulnerable to Flood (LVTF) cover 28.07 %. And 6.66 % of the land have elevations between 274-299 m and is within the Very Less Vulnerable to Flood (VLVTF). Incidentally, the least portion of the study area 4.17 % with elevations of 370–499 m is Not Vulnerable to Flood (NVTF). Hence, the seriousness of efforts at flood prevention and mitigation should follow the vulnerability classification.

Raw and Classified Terrain Wetness Index

Terrain Wetness Index (TWI) provides an indication of how saturated a given cell will become during a rainfall event, and is therefore an indication of soil moisture. The higher the value of the index, the wetter the cell will be and vice versa. The results from the use of natural breaks suggests that the Terrain Wetness Index in the study area ranges from 9.45-28.00 (Fig. 4A). Fig. 4B shows the different classified colors used to indicate different wetness indices. Light blue for areas with high index and brown for those with low index. It can be observed that the wetter areas close to the river appear in light blue color whereas areas that are far-off are represented in brown color. The higher the wetness index the wetter the place becomes and the darker the light blue color becomes and apparently the more susceptible the place will become to flooding. Therefore, the low lying areas, extending from the river source are more susceptible to flooding than the highlands with dominant brown color.

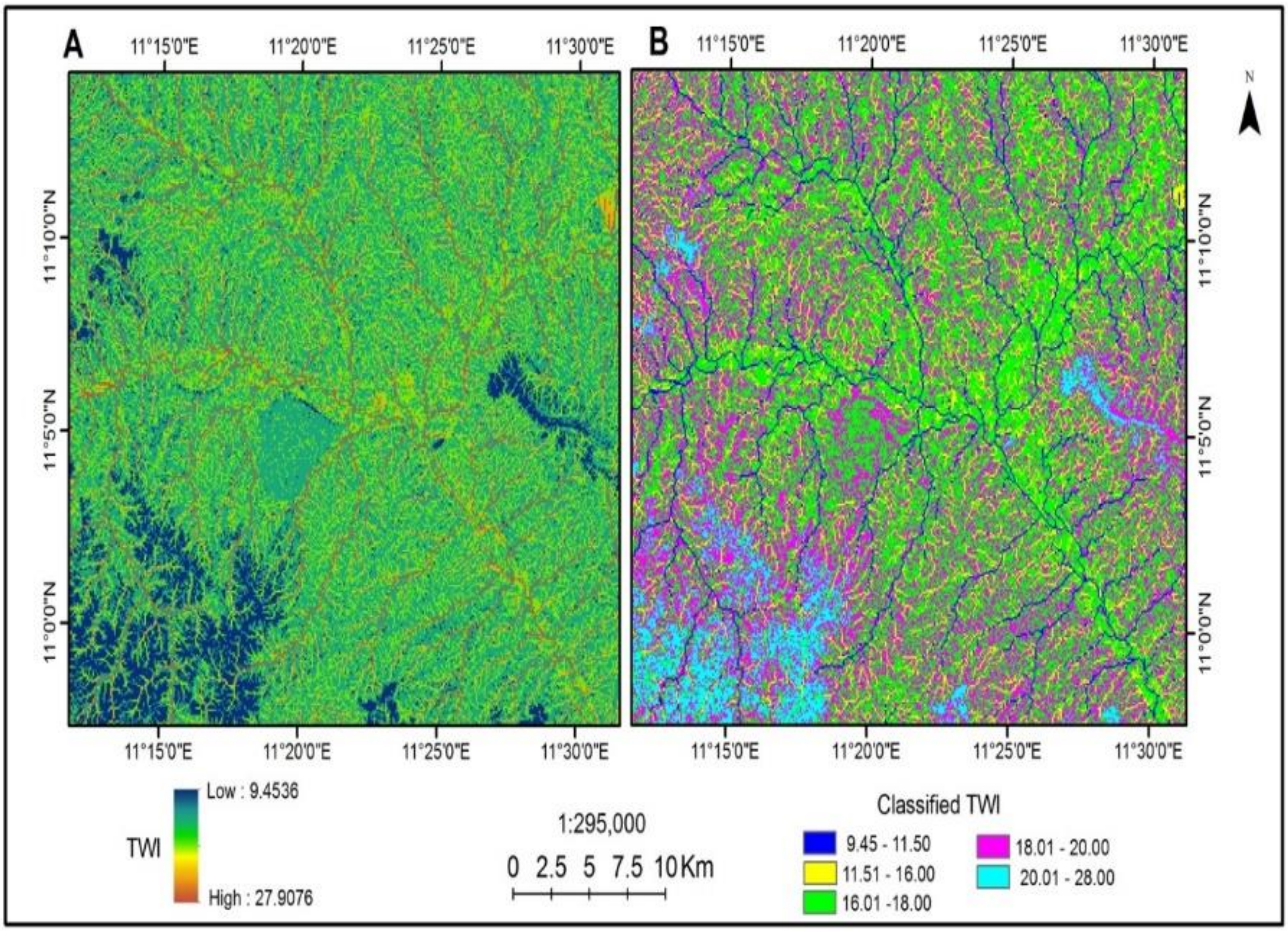

Fig 4A. Raw TWI Image **Fig 4B.** Classified TWI Image

The attribute data drawn from the Classified Image for terrain wetness (Figure 4B) is shown in the Table 2.

Table 2. Area Occupied by Various Terrain Wetness Index Classes

S/No	TWI Value Range	No Of Pixels	Area (%)	Vulnerability class
1	9.45-11.50	2397	0.68	Not vulnerable to flood
2	11.51-16.00	242784	69.23	Very less vulnerable to flood
3	16.01-18.00	58941	16.81	Less vulnerable to flood
4	18.01-20.00	38633	11.02	Moderate vulnerable to flood
5	20.01-28.00	7927	2.26	Vulnerable to flood
TOTAL		350682	100	

Table 2 shows that using the TWI factor, the TWI value range of 20.01-28.00 is occupied by about 2.26 % of the land in the study area. This area is Vulnerable to Flood. 11.02 % of the area is in the Moderately Vulnerable to Flood category while about 16.81 % is Less Vulnerable to Flood. The areas in the Very Less Vulnerable to Flood and Not Vulnerable to Flood categories are 69.23 and 0.68 % respectively.

Raw and Classified Proximity

The proximity/distance of the neighborhoods to the source of River is shown in Fig. 5A. In the Fig. 5A, it can be observed that the brown color used to indicate proximity to the river gradually fades with increasing distance away from it. Expectedly, inundation (and its effects) from the overflow of the river should affect areas with closest proximity to the river. Hence, the brown color is darkest in those areas. The risk of vulnerability decreases with increasing distance from the river.

The classified map (Fig. 5B) from which its attributes were derived and represented in the Table 3 indicates that the distance range of 0–399 m claims the highest percentage of about (49.9 %). The implication of this is that almost half of the neighborhood has close proximity to the river and is hence, susceptible to flood. While areas that are between 400–1250 m away from the river cover 29.61 %, those in the 1251–3000 m range occupy 15.15 % of the study area. Areas with the farthest proximity to the river are those that are >3000m from it. They cover 5.34 % and are the least vulnerable to the incidence of flood.

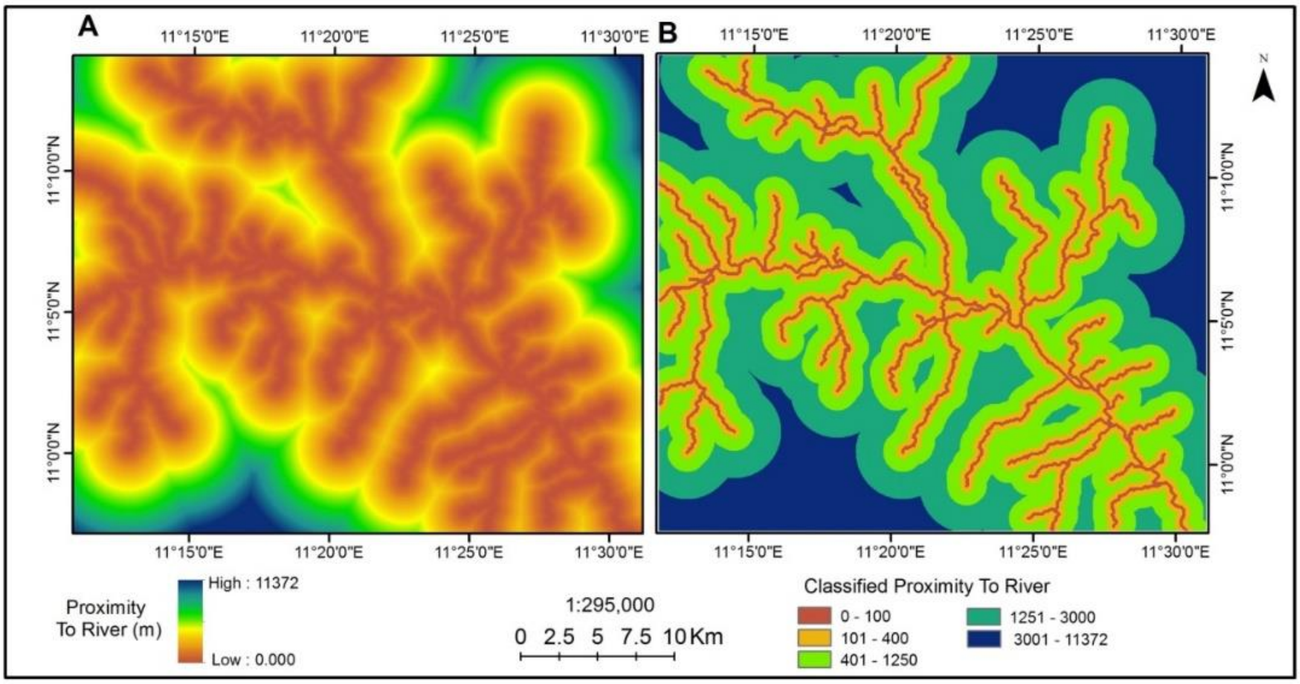

Fig. 5A. Raw Image of Proximity to River **Fig. 5B.** Classified Image of Proximity to River

Table 3. Percentages Covered by Various Heights of the Classified Proximity to River

S/No	Proximity (m)	No of Pixels	Area (%)	Vulnerability class
1.	0 – 100	24723	7.05	Vulnerable to flood
2.	101 – 399	150266	42.85	Moderate vulnerable to flood
3.	400 – 1250	103837	29.61	Less vulnerable to flood
4.	1251 – 3000	53126	15.15	Very less vulnerable to flood
5.	3001 – 1172	18728	5.34	Not vulnerable to flood
	TOTAL	350682	100	

Raw and Classified Overland Flow Length

Percentages derived by natural breaks, of the various Overland Flow Length (OFL) ranges of the neighborhoods to the nearest drainage shown on the Figure 6A indicates that areas colored in dark red are closer to the drainages which are closer to the river, the color faints away from drainages showing least overland flow length value to source of hazard, by implication the closer the overland flow length value, the higher the risk of being affected by flooding in the area. The classified map, Figure 6B and the attributes on Table 4 indicates that the overland flow length value between 0-300 m claims the lowest percentage about 6.57 % which classified as VTF, while the overland flow length value between 7001-26170 13.81 % shows the area that is NVTF while the remaining once fall in between.

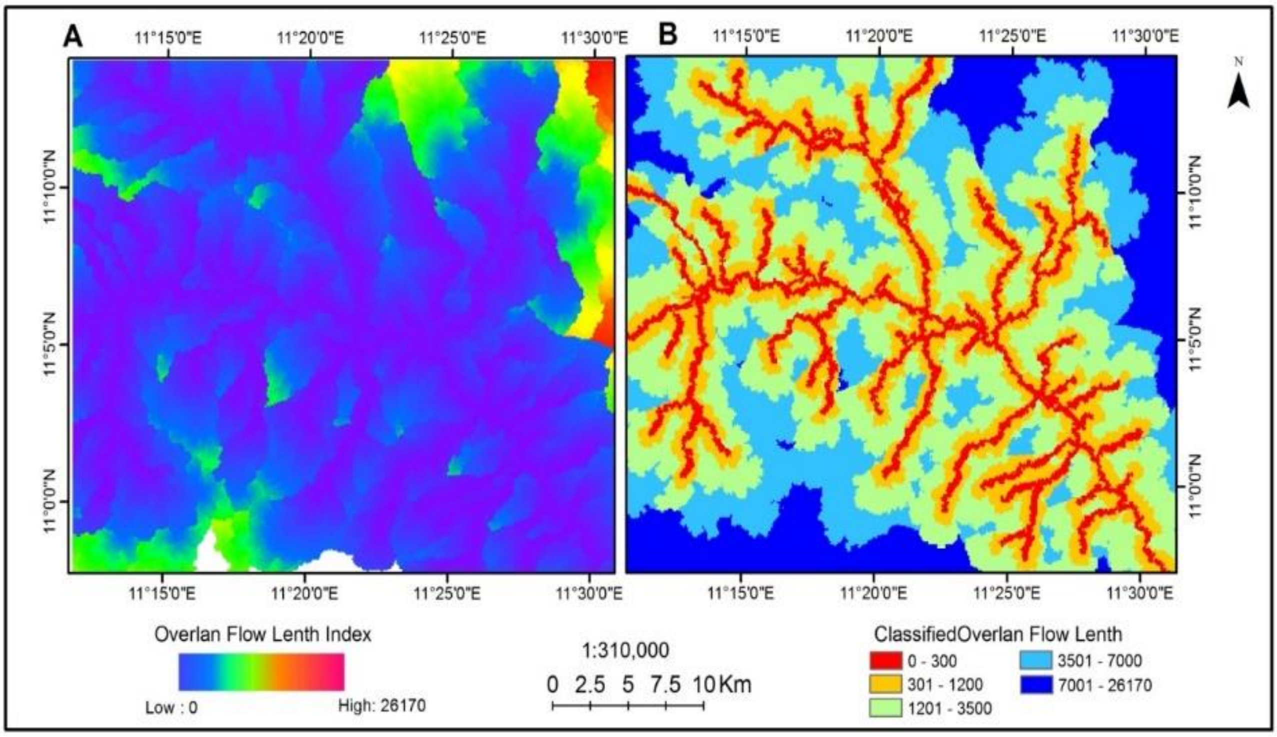

Fig. 6A. Raw Image of OFL **Fig. 6B**. Classified OFL

Table 4. Area Occupied by Various Overland Flow Length of the Study Area.

S/NO	Overland Flow Length	No of Pixels	Area (%)	Vulnerability class
1	0 – 300	23027	6.57	Vulnerable to flood
2	301 – 1200	38552	10.99	Moderate vulnerable to flood
3	1201 – 3500	116956	33.35	Less vulnerable to flood
4	3501 – 7000	123729	35.28	Very less vulnerable to flood
5	7001 – 26170	48417	13.81	Not vulnerable to flood
TOTAL		350682	100	

5. Conclusion and recommendations

Nafada town and its environment has been experiencing flooding over the years, this according to the research has been attributed to many factors amongst which are excess stage discharge, vulnerability, nature and rate of the Terrain Wetness Index, Proximity to the river and Geodetic Height of the area. High Terrain Wetness Index is recorded in areas around river Nafada, significant percentage of the area is low-lying, larger percentages of the people lives very close to the river, hence with close proximity to the river Nafada, the vulnerability and susceptibility of the people to flooding is very high. Hence, the application of this method (RS and GIS) in Nafada to developed flood vulnerability factors like Terrain Wetness Index, DEM, Proximity to the river and overland flow length, it is in no doubt a holistic approach in flood management in the Nafada town and its surroundings. This study was conducted under major constraint of limited data availability. Therefore, the following recommendations are made for the further studies in the future.

i. Topographical Data: For modeling flows in overbanks, topographic data should be of high resolution so that the topography of the floodplains could be properly represented.

ii. Use of new technology to generate TIN: TINs obtained using new technologies such as LIDAR (Light Detection and Ranging), which improves the quality of the digital terrain representations can be used for further study.

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