Spatial Multi-Criteria Analysis for Mapping of Flood Vulnerable Areas in Fagge Local Government Area of Kano State, Nigeria

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Abstract

Flood occurrences are common in various communities and efforts need to be doubled to abate the effect of flood on the populace. This paper used Multi-Criteria Analysis (MCA) in a Geospatial Information System (GIS) environment to identify and map areas vulnerable to flood in Fagge Local Government Area of Kano State. The causative factors of flood in the study area that include rainfall, soil, slope, elevation, geology, land use and drainage system were first identified and analysed using MCA to reveal the most effective factors of flood in the area. The results showed that elevation having the weight of 0.24 was the most effective factor contributing to flood in the area. This was followed by drainage (0.17), slope (0.168), soil (0.167) and Land Use Land Cover (LULC) (0.14). The result also revealed that, the least factors contributing to flood in the area were rainfall and geology having weights of 0.09 and 0.12, respectively. Vulnerability analysis showed that areas on the eastern parts of the study area were extremely vulnerable to flood while north-western and southern parts of the area were least vulnerable. It was therefore suggested that, the drainages should be constructed and the existing ones be cleared of blockages to allow free movement of storm waters away from the affected areas.

Keywords: Flood Vulnerability, Geospatial Information System, Mapping and Multi Criteria Analysis

INTRODUCTION

Natural hazards such as flood, tsunami, earth quake, volcanic eruption amongst others, have constituted many environmental problems in different parts of the world. Floods for instance, have claimed so many lives and property worth millions of dollars have been destroyed worldwide (Adedeji *et al.*, 2012; Guru and Jha, 2015). This has led to untold hardship as many have lost their sources of livelihood while some have to deal with series of health hazards such as diarrhoea, typhoid fever, malaria, dysentery, skin diseases and so on (Ahern *et al.*, 2005; Taylor *et al.*, 2011).

Flood is an overflow of large amount of water over areas that are normally dry (O'Connor *et al.*, 2002; Adeoye *et al.*, 2009; Azua, 2018). Bariweni *et al.* (2012), asserted that floods occur when ponds, lakes, dams, riverbeds, soil, and vegetation cannot absorb all the water which then runs off the land in quantities that cannot be carried within rivers and stream channels. Floods are the most frequent and most spatially distributed hazards across the globe (Mason *et al.*, 2014). Studies have shown that the frequency and intensity of flood events have increased worldwide in recent years (Jeb and Aggarwal, 2008; Balica, 2012). In Nigeria, cases of flood have become very common in almost all the states of the federation. This has destroyed homes, sources of livelihood and rendered the environment unsafe for habitation. It has also disrupted economic activities in the affected communities.

Many factors are responsible for the recurrent flood events in Nigeria. For instance, heavy rainfall lasting for several hours can lead to large volumes of water that overwhelm the infiltration capacity of the soil. This leads to surface runoff beyond the capacity of the drainages which are already filled with garbage due to poor maintenance. This in addition to unplanned settlements and farming activities amongst others, have caused flooding in different parts of the country. As a result of the recurring flood events, many research efforts have been made in Nigeria to mitigate the disaster; Adedeji *et al.* (2012) assessed the incidences of urban flooding and examined the role of spatial planning and land use management in building capacities in relation to flood hazards in Nigeria. The result revealed that inadequate spatial planning and land use management are the major causes of urban flood in Nigeria.

Ojigi *et al.* (2013), mapped the spatial distribution of flood disaster in central parts of Nigeria in 2012. The findings showed that Rivers Benue and Niger overflowed their banks inundating farmlands and settlements within the flood plain. The result also revealed that most of the communities affected were those who refused to leave the floodplain because of their ancestral land.

Nabegu (2014), assessed the vulnerability of households to flood in Kano State, Nigeria. The author made use of questionnaire surveys, infrastructure analysis and flood impact information of the most recent flood disaster in the area. The result of the study revealed that the coping strength and vulnerability are inconsistent across the various zones in the area.

Based on the literature reviewed, it appears however, that no such study has been carried out in Fagge Local Government Area (LGA) of Kano State which is prone to incessant flood cases. Therefore, the aim of this study is to map areas vulnerable to flood in Fagge LGA using MCA and GIS, to provide better understanding of the causes of flood in the area for effective planning and management. The objectives of this study are to; identify and map the various land use/land cover of the areas; determine the topography of the area using Shuttle Radar Topographic Mission (SRTM); map areas vulnerable to flood; and identify and map out safe areas for emergency situations.

MCA is a decision making tool developed for complex spatial analysis problems and land use planning and management (Vial *et al.*, 2018) of which flood vulnerability mapping is one of its many applications. It involves identifying the various factors called criteria that constitute the problem, analysing the significance of each of these criteria to the problem and integrating these factors in a logical way that will proffer solution to the problem under consideration (Owoh *et al.*, 2017). Details of its definition and application can be found in Guillermo *et al.* (1999), Yahaya (2008) and Stevens *et al.* (2013).

This method (MCA) is very relevant in flood vulnerability mapping because it selects the relevant criteria and rank them according to their importance to flood vulnerability in an area (Saaty, 2008) before using them to map flood vulnerable areas.

Study Area

Fagge LGA is located within latitude 11º59’ and 12°5’N and longitudes 8°28’ and 8°33’E (Figure 1). It has an area of approximately 21 km² having a population density in excess of 1000 per hectare, which is over 198,828 (NPopC, 2006). The LGA is blessed with two rivers namely; Jakara and Kwarin Gogau Rivers. These rivers flow through the area providing water for domestic and agricultural purposes. However, Nabegu (2014) asserted that River Gogau is the main cause of flooding in Fagge LGA.

The climate of the area is divided into wet and dry seasons. The wet season spans from June through September with annual rainfall of about 700 mm. The dry season spans from October through May with mean temperature of about 30°C (Olofin, 2008). The vegetation in the area is Sudan Savannah that consists of scattered trees on an expanse of land (Olofin, 2008).

The people in the area engage in more than one form of livelihood in order to meet with the high cost of living. Basically, the people engage in farming, trading and civil service amongst others. The farm produce include lettuce, tomatoes, onion, cabbage and so on which are consumed locally and transported to other parts of the country as well. The business men and women reside in the western parts of Fagge in which are migrants from the southern parts of the country.

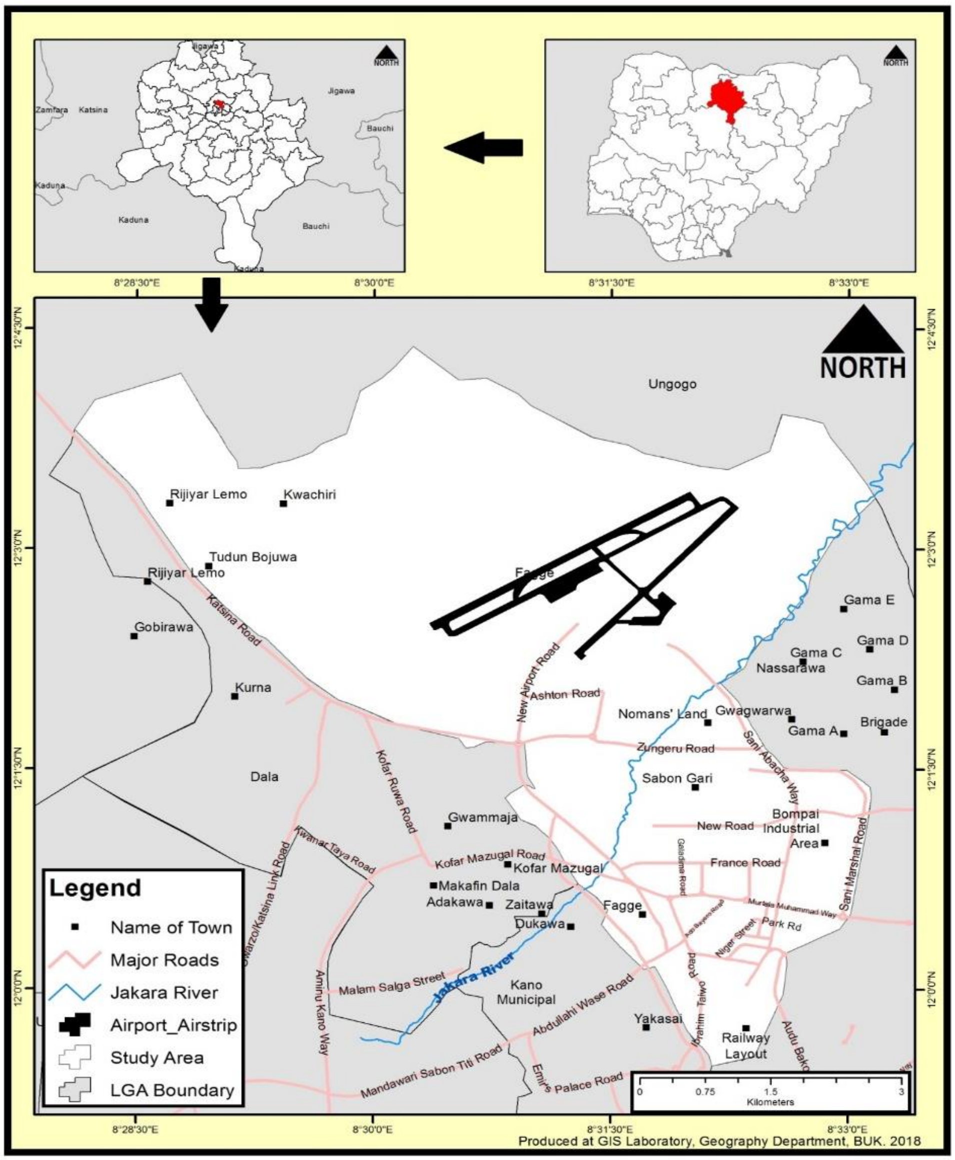

Figure 1: Map of the Study Area. Top right: map of Nigeria showing Kano State, topo left: Kano State, bottom is the study area. Modified after GADM (2018)

METHODS

Flood occurrence in any geographic location is based on many factors which include rainfall, land use, slope, soil type and drainage density. These factors often referred to as criteria by most researchers are the main causes of flood in an area. Thus, for one to be able to address the problem of flood, these criteria must be taken into consideration. The work flow diagram adopted in this study is shown in Figure 2.

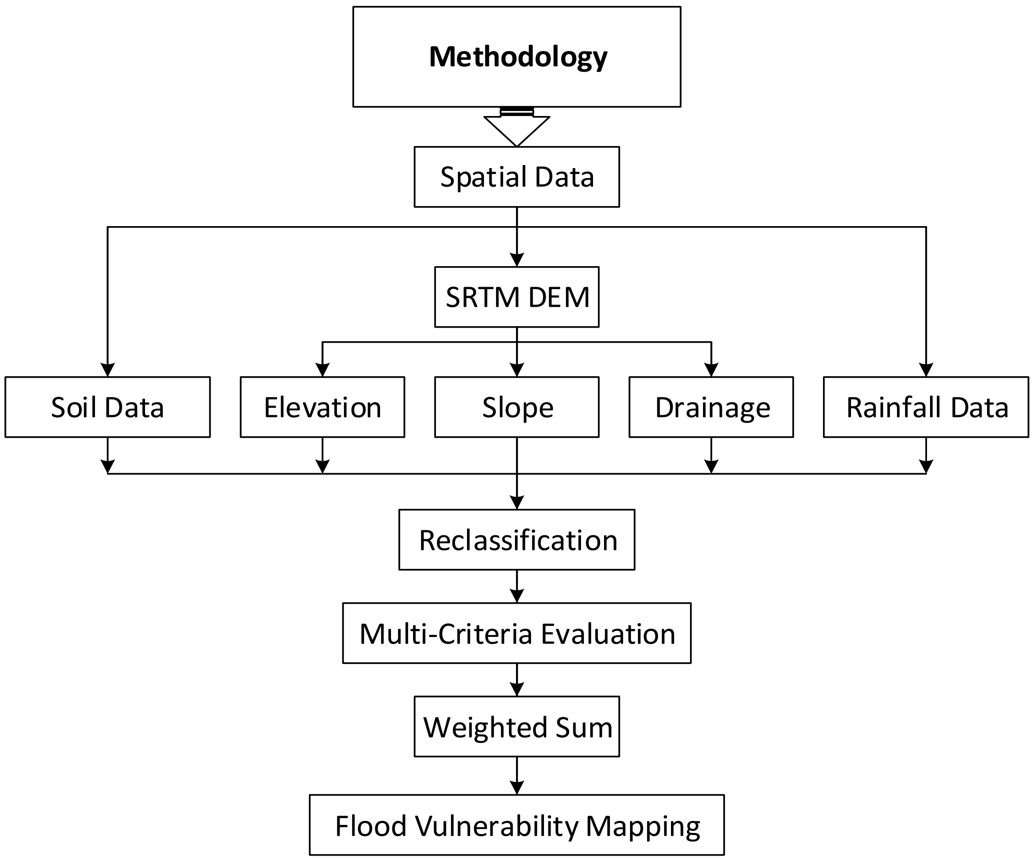

Figure 2: Work Flow Diagram. Modified from Andongma *et al.* (2017)

Data Sources

Various data types and sources were utilised in this study. Table 1 shows details of the data and their sources.

Table 1: Data Types and Sources

S/N	Data Type	Year	Resolution/Scale	Source
1	Landsat 8 OLI	2017	30m	USGS (www.glovis.usgs.gov)
2	SRTM	2016	30m (void filled)	USGS (www.glovis.usgs.gov)
3	Soil map	1990	1:1,200.000	Federal Department of Agricultural Land Resources (FDALR) Kaduna
4	Geology map		1:200,000	Geological Survey Agency
5	Rainfall Data	1986-2016		NiMET, Kano
6	Ground truth data	2018		Field observation

Data Processing

Landsat 8 OLI image was clipped to the study area and then subjected to digital image processing using histogram equalization to enhance the image contrast and to remove obscurity for proper identification. Supervised classification was carried out using maximum likelihood algorithm in Erdas Imagine 9.2 environment, to group the land uses into various classes based on their spectral reflectance characteristics. The accuracy assessment was carried out to ensure a high classification result.

The Shuttle Radar Topographic Mission (SRTM) Digital Elevation Data (DEM) which provides the pre-processed "Void Filled" version of the data was used to determine slope map and terrain characteristics such as flow direction, flow accumulation and network ordering maps of the area. The soil map was derived from the field soil survey done by the Soil Survey Division of the Federal Department of Agricultural Land Resources (FDALR) Kaduna in 1990. The geological map was extracted from the Geological and Mineral Resources map of Kano State which was obtained from the Nigerian Geological Survey Agency (NGSA). These maps were digitized into various layers using ArcGIS 10.3.

Rainfall distribution in the area under study was produced using the acquired rainfall records from 1986-2016. This was achieved using Inverse Distance Weighting (IDW) to create a continuous raster data of rainfall in the area.

Multi Criteria Decision Analysis (MCDA)

In this study, seven parameters including drainage system, rainfall, geology, land use, elevation, slope and soil were used in the analysis. These criteria were identified and chosen based on their relevance to flood vulnerability in the study area. The maps for these factors were created and used as layers in MCDA. The spatial data contained in each layer was ranked based on its susceptibility to flood and the pixels reclassed to reflect the ranks. The seven layers were then weighted using a combination of pairwise comparison matrix and Analytical Hierarchical Process (AHP) (Yahaya, 2008). Each factor was weighted using numbers ranging from 1 to 7 with 1 being the least important and 7 the most important factor to flood occurrence. Finally, weighted overlay was employed to identify areas vulnerable to flood in the area under study.

RESULTS AND DISCUSSION

Land Use and Land Cover

Land cover describes features such as forest and water body that covers the earth while land use refer to the various ways by which land is used (Azua, 2010). This could be for settlement and agriculture amongst others. Land use contribute to flooding especially where adequate planning for effective land use management is not considered. In such situations, houses are built haphazardly, vegetation indiscriminately removed and farmlands are cultivated without consideration for water ways and so on. These human activities amongst others create imbalance in the natural environment hence, causing flood in the area affected.

Classified results of land use in the study area are shown in figure 3. Four classes which include built up, vegetation, bare land and water body were identified and classified in the area. Built up area and bare land constitutes the largest proportion of land use in the area with a value of 33.6 and 27.9%, respectively. This is followed by dense and light vegetation having 20.4 and 18.2%, respectively, of the total area.

Table 2: Land Use and Land Cover Classes

LULC Type	No. of pixels	% of Pixels	Area (Sqkm^2)
Built up	14362	33.552	13.044
Dense Vegetation	8736	20.409	7.848
Bare land	11932	27.875	10.658
Light Vegetation	7775	18.164	6.95
Sum	*96312*	*100*	*38.500*

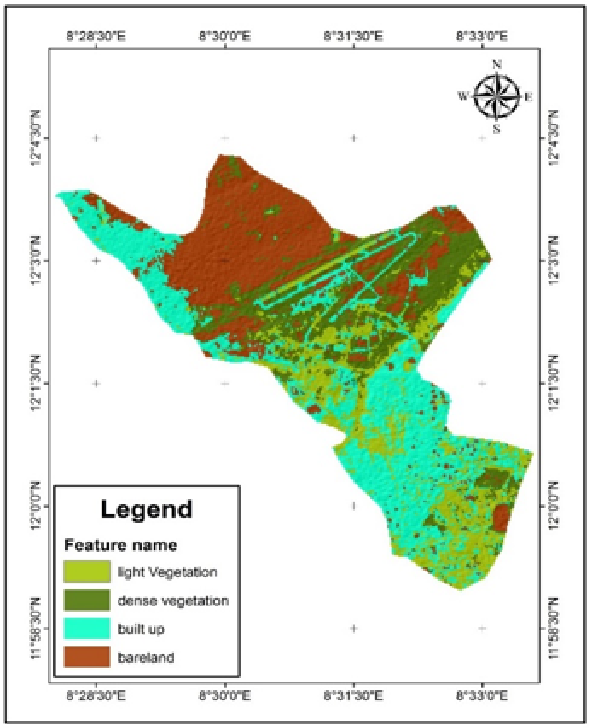

Figure 3: Land Use and Land Cover map

Table 3: Ranking of land use and Land Cover

Built-up	4
Vegetatio	2
Bare land	0

The accuracy assessment shows that the overall accuracy was 85% while the Kappa Coefficient was 79%. The land uses are ranked according to their contribution to flood in the area as shown in Table 3. Built up area is ranked 4 as the highest contributor to flood because houses built on water ways obstruct the movement of water during rainfall. This is followed by vegetation ranked as 2 and bare land 0. This is because bare land has no contribution to flood occurrence.

Rainfall in the Area

Floods occur because of excess water in an area. The rapid accumulation and release of runoff waters from upstream to downstream that is caused by rainfall contribute immensely to flooding in most areas. The amount of runoff is related to the amount of rain a region experiences. Hence, high rainfall indicates high vulnerability to flood and vice versa. Figure 4 depicts the rainfall map of the study area. The rainfall data in the study area was acquired from NiMET, Kano between 1986 and 2016. The average annual rainfall was computed to be about 696.4mm. The rainfall in the area is divided into high and low rainfall. The high rainfall was assigned the rank of 5 because it contributes more to flood vulnerability while low rainfall indicates low vulnerability and was assigned the rank of 3 (Table 4).

Drainage Density

The area upon which waterfalls and the network through which it travels to an outlet are referred to as a drainage system. The drainage map was generated in the ArcMap environment of ArcGIS using the Digital Elevation Model (DEM) of the study area. Figure 5 shows the map of the drainage system produced. The drainage density was grouped into four classes: very low, low, moderate, and high. Very low and low drainage density areas had little or no effect on flood occurrence and were ranked (1 and 2, respectively) as the least in the area (Table 5). Moderate drainage density contributes moderately to flood vulnerability and was ranked 3 while high drainage density areas indicate areas with high vulnerability to flood and were assigned the rank of 4 (Owoh *et al.*, 2017).

Table 4: Rainfall Ranking

Annual Rainfall (mm)	Ranking
0-39.21	3
39.21-40.66	5

Table 5: Drainage Ranking

Drainage density	Ranking
Very Low (0-0.8)	1
Low (0.8-2.17)	2
Moderate (2.17-4.10)	3
Very High (4.10-8.64)	4

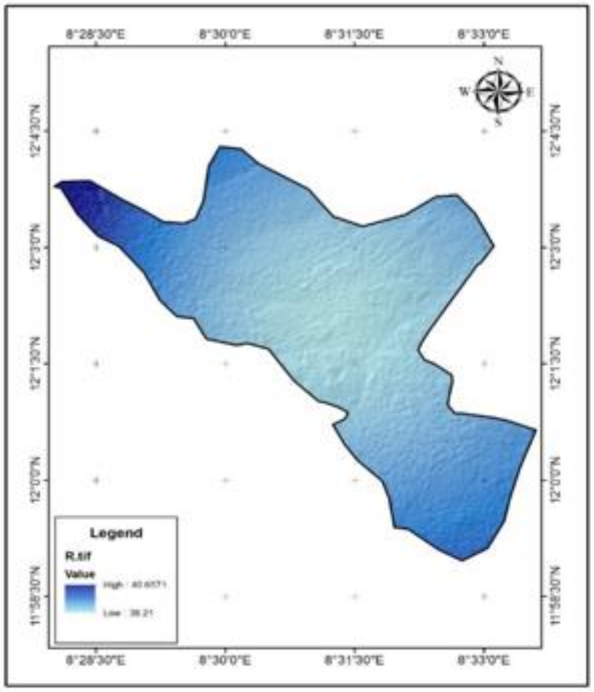

Figure 4: Rainfall Map

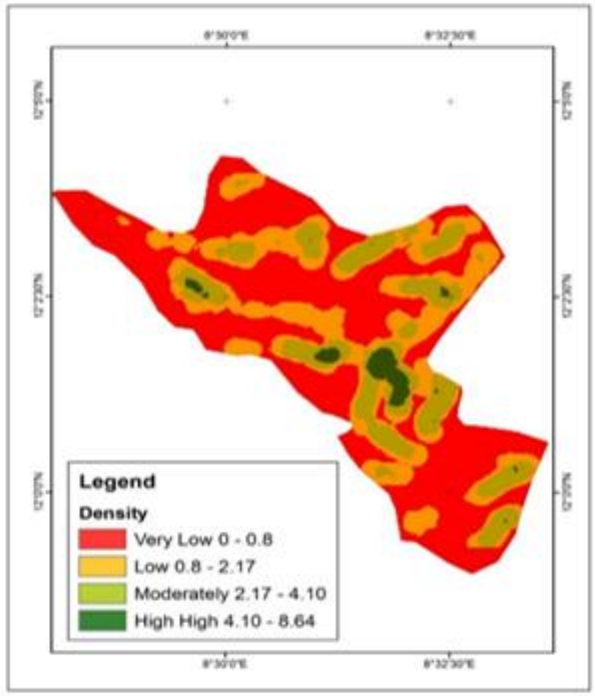

Figure 5: Drainage Density map

Geology

The presence of rocks creates impermeable surfaces that will be susceptible to rapid runoff. This allow easy movement of water thus having less impact on flood vulnerability. However, in a relatively flat terrain, water movement in rocky areas may be slow allowing water to accumulate which can result in flooding. Figure 6 shows the geology of the study area. The result revealed that the area is composed mainly of granite which had low contribution to flood. Hence, considering the nature of the terrain in the study area, geology was assigned a rank of 2 as shown in Table 6.

Soil

Figure 7 shows the soil map of the area. Soil types contribute to flooding by determining the amount of infiltration as well as surface flow in an area (Nicholls and Wong, 1990). For instance, if the soil has a low infiltration capacity, then, the amount of surface flow will be high thus leading to flooding and vice versa. The soil type found in the area was deep poorly drained sandy loamy surface which contribute to flood as the amount of infiltration is low, hence, it was ranked 4 as shown in Table 7.

Table 6: Ranking of Geology

Older Granite	2

Table 7: Ranking of Soil

Sandy Loam	4

Elevation

Elevation is an important element of flood because it determines the movement of water from upstream to downstream. The elevation of the study area was generated using SRTM DEM data (void filled) as shown in Figure 8. The height values ranged from 442 to 504m as depicted in the variation of colours. Based on this result, elevation was highest in the western and southern parts of the study area. The eastern parts of the area had the lowest elevation. High elevation which was ranked 2 allow easy water movement thus contributing less to flood. However, low elevation was ranked 4 because it allows water to accumulate thus contributing more to flood (Table 8).

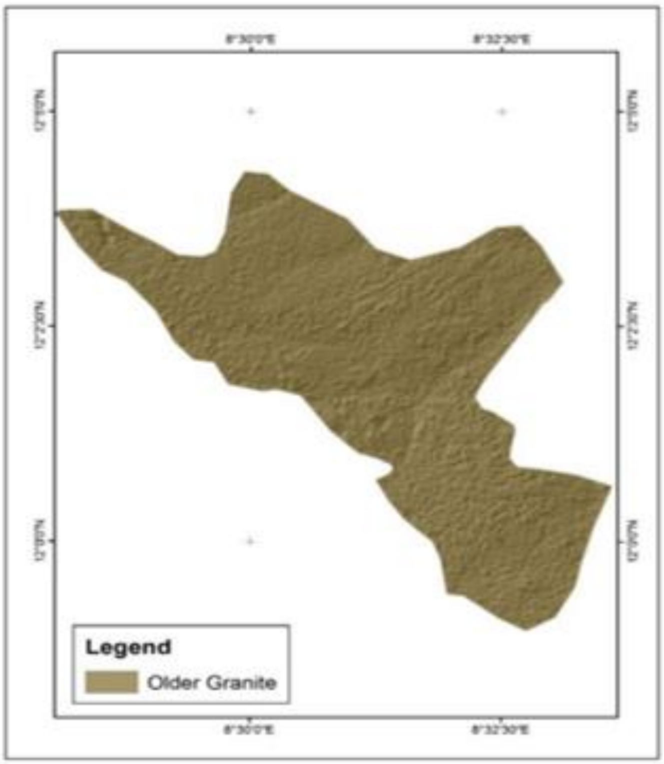

Figure 6: Geology map of the study area

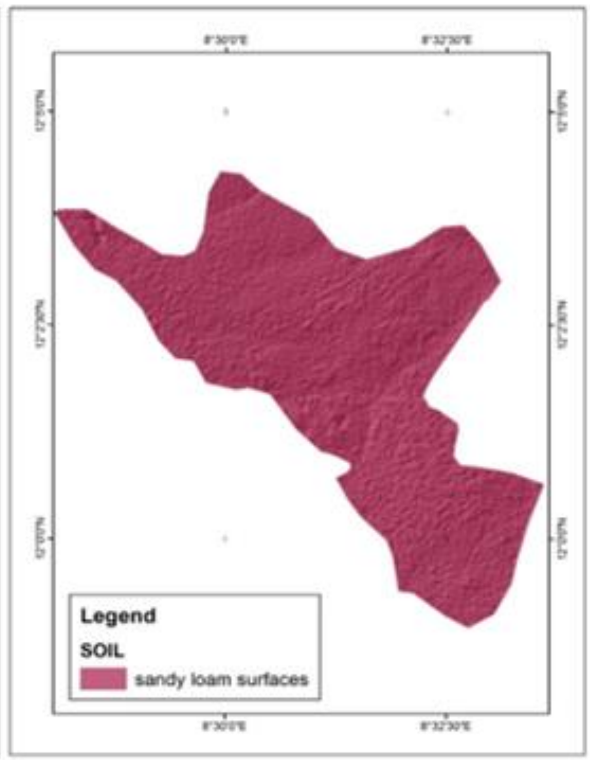

Figure 7: Soil map of the study area

Slope

Slope is an important element that contributes to flood occurrence in an area (Andongma *et al.*, 2017). A slope that is very steep allows free movement of water along the path while an area with a flat slope will allow gathering of water thus causing flood. The slope map was generated using SRTM data in the ArcHydro environment of ArcGIS (Figure 9).

The slope was classified into five classes; flat, gentle slope, sloppy, steep slope and extreme slope. The slope map shows the steepness of the slopes irrespective of the direction of the slope. A greater portion of the study area is relatively flat which may prevent the flow of surface water during rain.

This alone may trigger flood in the area. However, there may have been a free flow of water in areas close to the stream within the study area. Table 9 shows flat terrain having the highest rank of 4 while extreme slope has the least rank of 2.

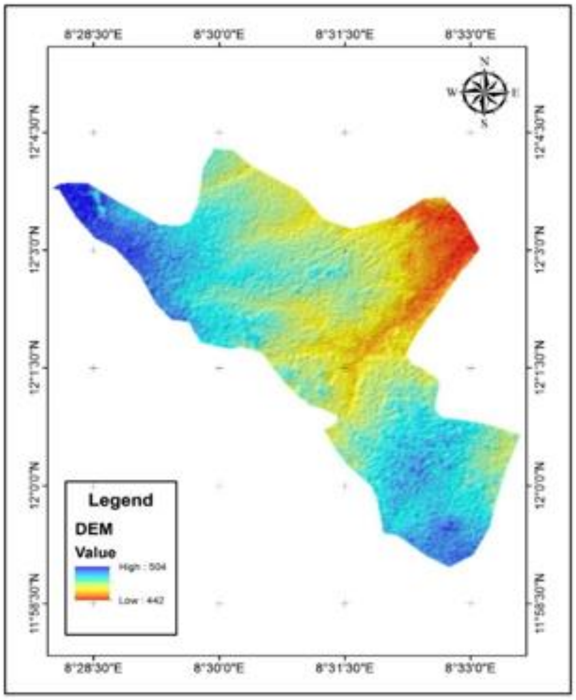

Figure 8: The 3-D DEM

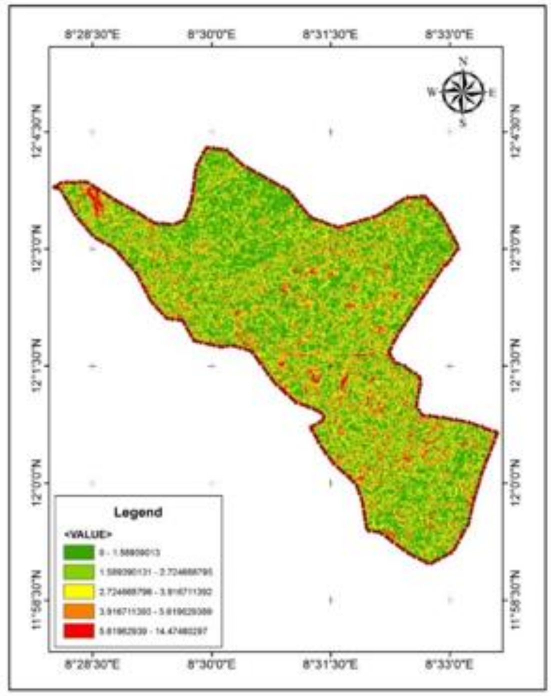

Figure 9: Slope map of the study area in percentage

Table 8: Ranking of Elevation

Elevation (m)	Rank
Low	4
High	2

Table 9: Ranking of Slope

Slope (m)		Rank
Flat Slope	(0.0-1.5)	7
Gentle Slope	(1.5-2.7)	6
Sloppy	(2.7-3.9)	5
Steep slope	(3.9-5.6)	4
Extreme slope	(5.6-14.5)	2

Vulnerability Analysis

A comparison matrix was first generated in Table 10 which was then normalized (Table 11) to obtain the overall results consisting of the weighted average for easy interpretation and understanding.

Table 10: Pairwise Comparison matrix with intensity judgment

Criteria	Drainage	Soil	Elevation	LULC	Rainfall	Slope	Geology
Drainage	1	5	1/2	3	7	1/2	1/7
Soil	3	1	1/2	3	6	1/4	1/2
Elevation	3	4	1	3	6	1	1/2
LULC	3	4	1/3	1	5	1/3	1/3
Rainfall	1/2	4	1/3	1/2	1	1/3	1/3

Slope	1/4	4	1/7	1/4	3	1	1/5
Geology	1/5	1/3	1/7	1/5	5	1/6	1
Total	10.95	22.33	2.95	10.95	33.00	3.33	3.01

Consistency Ratio (CR)

During MCA, it is expected that, the rating be randomly generated (Yahaya, 2008). Unfortunately, this is often not the case as the individual judgement would not agree absolutely, hence it is important to determine the degree of consistency attained using the Consistency Ratio (CR). CR has values that are equal to or less than 0.1.

Table 11: Normalized matrix

Criteria	Drainage	Soil	Elevation	LULC	Rainfall	Slope	Geology	Weights
Drainage	0.09	0.22	0.17	0.27	0.21	0.15	0.05	0.170
Soil	0.27	0.04	0.17	0.27	0.18	0.08	0.16	0.167
Elevation	0.27	0.18	0.34	0.27	0.18	0.03	0.16	0.240
LULC	0.27	0.18	0.11	0.09	0.15	0.01	0.11	0.140
Rainfall	0.05	0.18	0.11	0.05	0.03	0.01	0.11	0.090
Slope	0.02	0.18	0.05	0.02	0.09	0.03	0.07	0.168
Geology	0.02	0.01	0.05	0.02	0.15	0.05	0.33	0.120
Total	1	1	1	1	1	1	1	1.00

Values of CR above 0.1 implies that, the rating should be revisited. The CR was computed using the following expression:

$$CR = \frac{CI}{RI} \qquad 1$$

$$CI = \lambda_{max} - \frac{n}{n-1} \qquad 2$$

Where, *CI = Consistency Index*

RI=Random Consistency Index

N= Number of criteria

λ_{max}= Priority vector multiplied by each column total

From equations 1 and 2, the result of CR was computed to be 0.06 which fell within the acceptable limit of less than/equal to 0.1 indicating that, the ratings were consistent.

Vulnerability Map

The generated factor layers or resulting map layers were reclassified in ArcGIS and engaged in the production of flood vulnerability map using weighted AHP as located in IDRISI Selva 17.0. Weight values were taken into consideration in the vulnerability mapping. The vulnerability classes identified were: low, moderate, high, very high and extremely high as shown in Figure 10.

DISCUSSION

MCA was used to assess the relevant criteria that were responsible for flood occurrence in Fagge LGA. Table 8 revealed that among the seven criteria considered in the study area, elevation was the most important factor of flood in the area. This is shown in Figure 8 where elevation is very low in the eastern parts of the study area, decreasing towards the river from 502 to 442m above Mean Sea Level (MSL). This alone may have triggered flooding and also increased the risk of erosion within the study area.

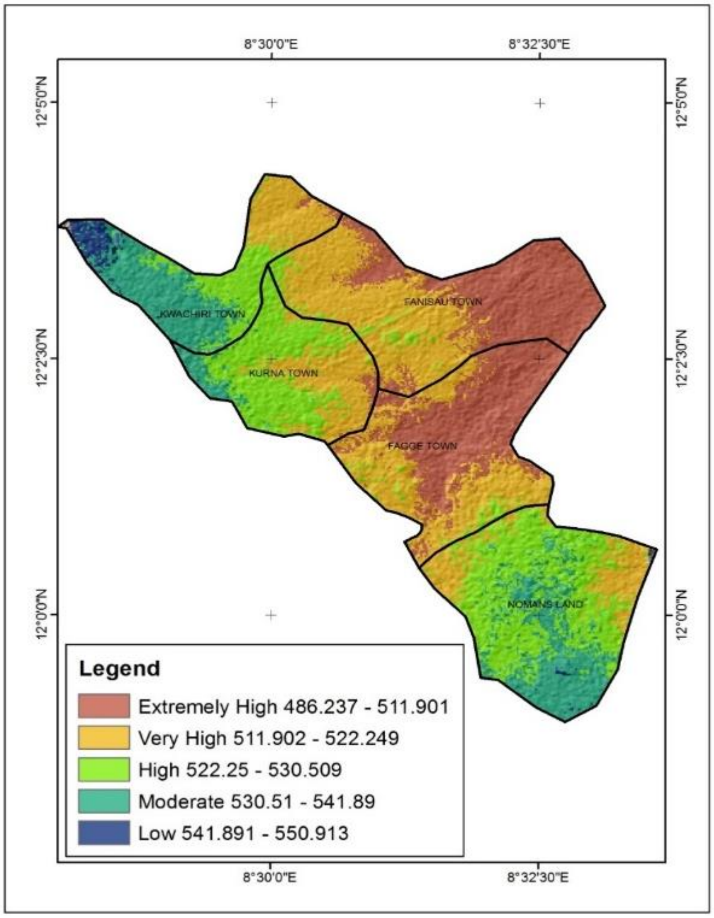

Figure 10: Flood vulnerability Map

Other criteria that contributed to flood in the area include drainage, soil and slope. The drainage density was extremely high in the central portion of the study area while other areas were moderate and low (Figure 5). The high drainage density observed was a contributing factor to flooding in the area. Poorly drained loamy soil (Figure 7) had low infiltration capacity thus allowing water to gather in some areas causing flooding. Slope in the area was relatively flat and gentle (Figure 9) which supported water gathering at different locations resulting in flood even when the rainfall was small. It was also observed in Table 8 that rainfall and geology were the least contributors to flood in the area. This means that rainfall in the area was not sufficient to cause flood but due to the nature of elevation as well as the poor drainage system, soil and slope, recurrent flood is evitable. This result agrees with Adedeji *et al.* (2012) who reported similar findings in Nigeria.

Figure 10 revealed that, the vulnerability in the study area is divided into five zones; extremely high, very high, high, moderate and low vulnerability zones. Extremely high vulnerability was observed in the eastern parts of the investigated area covering Fagge and Fanisau town. This meant that these areas were highly vulnerable to flood. On the other hand, the north-west and the southern parts of the area were least vulnerable to flood. These parts of the city are characterized by low building density largely occupied by kwachiri town at the northwest side and Nomans Land at the southern parts of the town.

The percentages of these vulnerability classes, in relation to the entire map area revealed that low vulnerability had 4.50%, moderate had 5.52%, high has 12.26%, very high had 23.26% and extremely high vulnerability had 54.50% of the total area under consideration. This implied that areas in Fagge LGA which are closer to riverine areas were highly vulnerable to flood hazard with hazard intensity decreasing towards the North-west and southern parts of the study area. In the event of a flood, the low vulnerable area may be used as a staging area for rescue operations.

CONCLUSIONS

The vulnerability of Fagge LGA to flood has been assessed. The result revealed that, the most important factors contributing to flood vulnerability of the local community resident in the study area included elevation (0.24), drainage (0.17), soil (0.167) and slope (0.168). However, the least contributing factors included rainfall (0.09), geology (0.12) and LULC (0.14). The results also revealed that areas on the eastern parts of the study area were more vulnerable to flood while areas on the north-western and southern parts of the study area were least vulnerable to flood occurrences.

In view of the results obtained in this study, it was suggested that, drainages should be constructed to channel storm waters and existing ones be cleared of blockages to allow easy movement of water in the affected areas.

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