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A Geospatial Approach to Flood Vulnerability Mapping for Disaster Management in Lokoja and Environs

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Abstract: - Geographic information on flood vulnerability is essential for preparing for flood disasters. This study applies Geographical information System Techniques to produce flood vulnerability map of Lokoja and environs and its potential to cause devastating effect in the area. This study is aimed at mapping flood vulnerable areas within Lokoja, for an effective flood disaster management and proper planning. Satellites imageries MODIS of 2011and 2012, SPOT 5 of 2011, location map of Lokoja Metropolis, SRTM DEM, rainfall data, water discharge/gauge data, and GPS coordinates; acquired during field survey were integrated to map areas vulnerable to flooding. The study is limited to environmental factors such as hydrology, slope, soil type, drainage density, landform and land use/land cover. Different maps were generated; composite map of the study area, flood extent map, flood plain map, slope map, flow direction map, flow accumulation map, Triangular irregular network, flood vulnerability map and also pie chart showing percentage area impacted, histogram showing the pattern of rainfall within Lokoja metropolis was generated. The approach resulted in four classes of flood vulnerability ranging from not vulnerable, less vulnerable, more vulnerable and most vulnerable areas. The area not vulnerable accounted for 18.22%, less vulnerable area accounted for 35.15%, more vulnerable area accounted for 26.22%, and the most vulnerable area accounted for 20.41%. The study concludes by proffering a number of recommendations aimed at addressing the issue of flooding within Lokoja metropolis. The recommendations includes; construction of levee along areas that are vulnerable to flooding, widening and construction of standard drainages around Lokoja metropolis, dredging of surrounding water bodies to deepen their depth, among others.

Keywords: Flood, vulnerability, hazard, vulnerability, GIS, geospatial

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I. Introduction

It has been observed that the more accessible the parts of drainage basin and river courses are, the more severe the conflict between lands uses types than the erstwhile remote areas. This is exactly the case of the Niger-Benue rivers right from their sources outside Nigeria down to the delta area on the Atlantic Ocean in Nigeria. The Niger-Benue river confluence is of major interest in this study as it relate to urbanization activities in Lokoja town and river encroachment.

Floods are major disasters affecting many countries of the world annually, especially in most flood plain areas. Floods do not only damage properties and endanger the lives of human and animals but also produce other secondary effects like outbreak of diseases such as cholera and malaria as well. Flooding is commonly caused by heavy downpours of rains on flat ground, reservoir failure, volcano, melting of snow and or glaciers etc. Flood risk is not just based on history; but on a number of factors: rainfall, river flow and tidal-surge data, topography, flood control measures, and changes due to construction of building and development on flood plain areas.

Flooding is caused by several factors and is invariably preceded by heavy rainfall. The other causes of flooding are moderate to severe winds over water, unusual high tides, tsunamis due to undersea earthquakes, breaks or failures of dams, levees, retention ponds or lakes, or other infrastructure that retains surface water.

Although flooding is a natural occurrence, man-made changes to the land can also be a factor.

Development does not cause flooding but can make it worse. In cities and suburbs, pavement and rooftops prevent some rainfall from being absorbed by the soil. This can increase the amount of runoff flowing into low lying areas or the storm drain system.

The town of Lokoja as a settlement on a river bank is not an exception. It has witnessed several devastating floods, occurring almost on an annual basis, in its recent history, especially from 1991, due to rapid and uncontrolled urbanization of the town (Mabel, 2014). The release of waters from Ladgo dam in Cameroon into the River Benue flood plain, and similar releases from Kainji, Jebba and Shiroro dam on the Niger River were largely responsible for the 2012 flooding in Nigeria, of which Lokoja, a confluence town of Rivers Niger and Benue was adversely affected.

Flood disaster management like other disasters management can be grouped into phases;

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i. The preparedness phase where activities such as prediction and risk zone identification or vulnerable mapping are taken up long before the event occurs,
ii. The prevention phase where activities such as forecasting, early warning, monitoring and preparation of contingency plans are made before or during the event, and
iii. The response and mitigation phase where activities are undertaken after the disaster and this includes damage assessment and relief management (Van Western *et al.*, 1993).

Mitigation of flood disaster can be successful only when detailed knowledge is obtained on the expected frequency, character, and magnitude of events in an area as well as the vulnerability of the people, buildings, infrastructures and economic activities in a potential dangerous area (Van Western and Hosfstee, 1993). However, Ifatimehin *et al.* (2009, Ifatimehin and Ufuah (2006) reported that this detailed knowledge is always lacking in most urban centers of the developing world especially Nigeria.

One way to mitigate the effects of flood is to ensure that all areas that are vulnerable are identified and adequate precautionary measures taken to ensure adequate preparedness, effective response, quick recovery and effective prevention. Before these could be done, information is required on important indices of flood risk identification which are elevation, slope orientation, proximity of built-up areas to drainages, network of drains, presence of buffers, extent of inundation, cultural practices as well as attitudes and perceptions (ICPR, 2002).

To get information on most of these, and identify areas that are vulnerable to floods, reliable techniques of collecting and analyzing geospatial information are required. In this regard, an integrated approach of the knowledge of remote sensing and GIS can be used to investigate and map out areas that are less or more vulnerable to flooding.

The periodic flood events in the study area therefore necessitated the need for proper monitoring and evaluation of its causes of flood and solutions to the problems. The objective of this study is to apply Geospatial techniques in mapping flood risk and vulnerable areas of Lokoja town for disaster management.

Statement of Research Problem

Lokoja is located at the confluence of the main Niger River and the Benue River in central Nigeria. The communities along the banks of the river cultivate in the floodplain and surrounding land and also do some fishing. The farmers in Lokoja and environs are affected by regular floods, which in some years caused considerable damage to their crops and houses. Erosion of the river banks is also a significant problem to these communities. Predictive Modelling of Floods in Nigeria using Cellular Automaton Evolutionary Slope and River Model (CAESAR) has also been carried out; a predictive model was applied to predict flood inundation extents in three different zones (Adamawa, Ibadan and Kogi State) in Nigeria [Olayinka, 2017]. The results were validated with actual flood extent measurements to determine if the natural floodplain was actually exceeded. Another study was carried out on vulnerability mapping and resettlement for Baratang Island, Andaman, India [Arunbaj et al, 2006]. They considered seven parameters such as elevation, geology, geomorphology, sea level trends, horizontal shoreline displacement, tidal ranges and wave heights to demarcate the vulnerability line all along the coast. They observed that the tsunami affected areas were within the 0-20 m contour region and suggested that settlements within this region should be moved away. They integrated thematic layers such as land use / land cover, transport, Slope and Disaster prone areas in ArcGIS to suggest sites for resettlement. Application of flood makes management system to establish rehabilitation plan of reducing natural disaster in South Korea. They utilized the height and true elevation of the flood to create flood mark map and flood hazard map to establish rehabilitation plan of reducing natural disaster [Ha 2012]. Geospatial analysis of flood disaster with a view to determining the flood disaster impacts (physical and economic) on the life and property of the residents of the affected areas in Lokoja was also carried out, but they did not look at settlement relocation for flood victims. Research into resettlement of any type has focused on the direct economic costs and benefits expected from the projects and, to a lesser extent, their environmental and social ramifications [Tan Yao, 2006]. There has been comparatively limited research undertaken on the potentially far-reaching and long-term social impacts of the resettlement processes. In this study area, however, no research work was conducted regarding the suitability of the environment for human settlement. Therefore, there is serious need to determine suitable sites for relocation in case of further severe flood disaster.

Aim and objectives of the Study

The aim of this study is to map Flood Risk and Vulnerability areas for Disaster Management of Lokoja and Environs, Using Geospatial Techniques Based on the aim, the specific objectives are to:

1. Delineate the flood vulnerable zone of the study area;
2. Carry out terrain analysis for Lokoja environs; and
3. Determine areas that are vulnerable to flooding in Lokoja and environs
4. To assesses the urbanization pattern and its effect on flood vulnerability of the developed areas bordering the river bank.

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Study Area

The study area, Lokoja lies between latitudes 7°45´27.56´´ and 7°51´04.34´´ N of the equator and longitude 6º41´55.64´´ and 6º45´36.58´´E of the Greenwich Meridian. Lokoja is the administrative headquarters of Kogi State in Nigeria. It is well connected and accessible through state and federal highways. It is also located close to confluence of the River Niger and Benue; the area is sandwiched between a water body and a hill i.e. River Niger and Mount Patti respectively which had streamlined the settlement to a linear one and has a modifying effect on the climate. The annual rainfall in the area is between 1016 mm and 1524 mm with its mean annual temperature not falling below 27°C. The rainy season lasts from April to October when the dry season lasts from November to March. The land rises from about 300 metres along the Niger-Benue confluence, to the heights of between 300 and 600 metres above the sea level in the uplands, Nkalubo, (2012). Lokoja is drained by Niger and Benue rivers and their tributaries. The confluence of the Niger and Benue rivers which could be viewed from the top of Mount Patti is located within the study area.

The general relief is undulating and characterized by high hills. The Niger-Benue trough is a Y-shaped lowland area which divides the sub-humid zone into three parts. It has been deeply dissected by erosion into tabular hills separated by river valleys. The flood plains of the Niger and Benue river valleys in Lokoja have the hydromorphic soils which contain a mixture of coarse alluvial and colluvial deposits, Arulraj et al (2006). The alluvial soils along the valleys of the rivers are sandy, while the adjoining laterite soils are deeply weathered and grey or reddish in colour, sticky and permeable. The soils are generally characterized by a sandy surface horizon overlying a weakly structured clay accumulation.

The main vegetation type in Lokoja is Guinea savanna or parkland savanna with tall grasses and some trees. These are green in the rainy season with fresh leaves and tall grasses. The different types of vegetation are not in their natural luxuriant state owing to the careless human use of the forest and the resultant derived deciduous and savanna vegetation. Agriculture serves as the main occupation of the people. However, the status of the Lokoja as an administrative headquarters brought some institutions into the area, which put many people in the public institutions like the Kogi State Polytechnic, Specialist Hospital and other governmental offices.

River confluence areas all over the world are known to offer spectacular environmental attractions to people and have therefore been the focus of varied aspects of human activities. This is one of the major reasons why the former colonial administrator, Lord Lugard, had to locate his administrative headquarter at Lokoja. But that the founding and growth of cities rest on physical resources is axiomatic, and so the rise and development of a city depend not only on the natural resources of its site and environs but also on the regional framework of its physiographic which either aids or hinders its internal and external functional efficiency, Obateru (2004). In the last seven years, urbanization activities has become complex in Lokoja town which can be attributed to her Kogi state capital status in 1991 with much pressure on the available land spaces. More so, the core area of the town is sandwiched between the Niger River valley and the elongated Patti Hill to the west. But Obateru (2004) opine that topography of the site and environs of a capital should not be rough or rugged, or else there would be insufficient building space which would result in high land values and inhibit efficient land use organization and economical provision of social infrastructure and public utilities system. This paper aims to take stock of geospatial capabilities which are particularly relevant to mapping flood vulnerability using a vulnerability analysis.

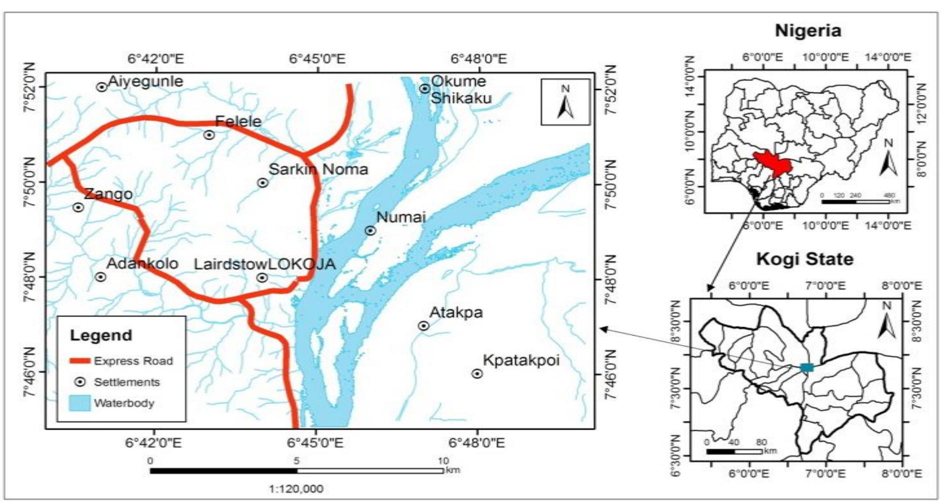

Figure 1.1: Map of Kogi Showing the Study Area.

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II. Review of Literature

In developed countries, a large part of the literature concerned with flooding has focused on topics such as impact of flooding in relation to various hurricanes, its effects on megalopolitan land prices, coastal inundation, sea level rise and its impact on property values. Effects and flood damages to various economies have also been recurrent themes. From a geological perspective, floods are a natural consequence of stream flow in a continually changing environment. Floods have been occurring throughout earth history, and are expected so long as the water cycle continues to run. Streams receive most of their water input from precipitation, and the amount of precipitation falling in any given drainage basin varies from day to day, year to year, and century to century (Khalequzzaman, 1994). The author went ahead to identify the causes of flood as; sea level rise, subsidence and compaction of sediments, riverbed aggradation, soil erosion due to tilling, excessive development, damming of rivers, seismic (earthquake) and neotectonic activities and greenhouse effects. Ojo (2011) identifies causes of flood in developing nations as unregulated developments, invasion of public areas, lack of institutional capacity at municipal level, unrealistic regulations, economic pressures from developers, ineffectiveness of planning regulation by allowing development on flood plains and poor and lack of standard drainage system on roads. In his own paper, Omisore (2011) grouped the causes as natural causes (heavy torrential rains or storm, ocean storms and tidal waves, usually along the coast and blockade of river or drainage courses by waste) and human causes (lack of meteorological data for weather forecasting, burst of main pipes, dam burst/levee failures, dam spills, property development along river setbacks and indiscriminate waste disposal). Atere (2000) examines the causes of floods in Ikoyi and Victoria Island, Lagos. The author identifies causes of flood in these areas as excessive rainfall, faulty drainage designs, and blocked drainage channels by refuse and sediments, obstruction by buildings and inadequate drainage heads to make the drainages efficiently drain off storm water.

III. Research Methodology

i Data such as Satellite imageries, Satellite Radar Topographic Mission (SRTM) data, Topographic maps, and Global Positioning Satellites (GPS) points was utilized for this study. The MODIS images to be used would comprise of visible and infrared channels to better distinguish between water and land. The Geodetic/Geographical data, the settlement and Road route map was extracted from the Administrative Map using Georeferencing and Digitization Procedures.

ii Image Processing was carried out using the Earth Resource Data Analysis Software (ERDAS) 9.2 to mosaic the Landsat ETM+ Path 189 Row 54 and Row 55 respectively. The Arc GIS 10.1 was used to perform the Supervised Classification of the Study Area to determine the Land Use and Land Cover of the terrain before flood.

iii The Arc hydro tools of the Environmental Systems Research Institute (ESRI) was used to preprocess the Digital Elevation Image of the Study Area by producing the agreed Digital Elevation Model (DEM) and other Operation as Sink and Flow Accumulation, Data Projection and Georeferencing. Images preprocessed in other software's were imported in the Arc GIS 10.1 software where the area of interest was extracted via the clipping process in the Arc tool box. The AOI raster and Vector feature of the Lokoja town was then re-projected to WGS 1984 Universal Transverse Mercator (UTM) Zone 32 N. Mercator (UTM) and Georeference.

iv **Field Data Integration.** Geodetic data was collected to validate the flood extent obtained from the Satellite imagery of the Study Area. This was carried out to validate the flood extent as captured by the Satellite imageries. The point data was collected by a Garmin GPS - Map 76 Mark Receiver, Canon digital Camera, Printed Copies of Satellite imageries and Base Maps was used as the field tools to identify and delineate inundated areas.

v (e) Spatial Analysis Techniques. The analysis of the inundated areas was conducted via query by location i.e. Proximity Analysis. This was done by selecting some of river channel, and shape files of the settlement to determine areas that were adversely affected by floods. The Buffering was categorized into various ranges along the basin to represent the highly vulnerable, moderately vulnerable and safe-zone regions of the Study Area (Ojigi, 2013). This operation was carried out in ArcGIS software by loading all features layer (Point, Line and polygon) that cover the flood Inundated region to determine the actual spatial coverage and extent of the flood. The zoning of flood vulnerable areas was categorized into three zones (highly vulnerable, moderately vulnerable and safe-zone regions). This zoning was based on the proximity of communities along the River basin as well the elevation of the terrain of the study area.

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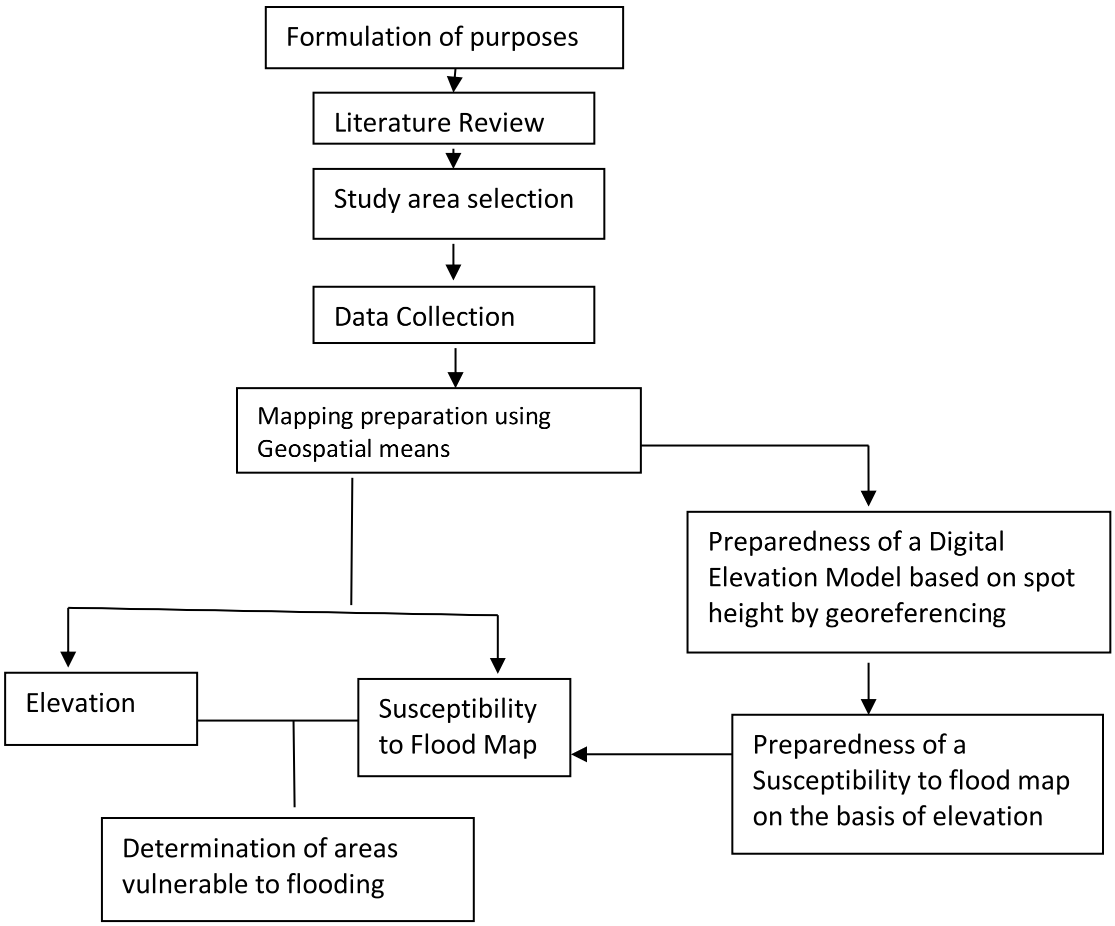

Figure 1: Research workflow

IV. Results and Discussion

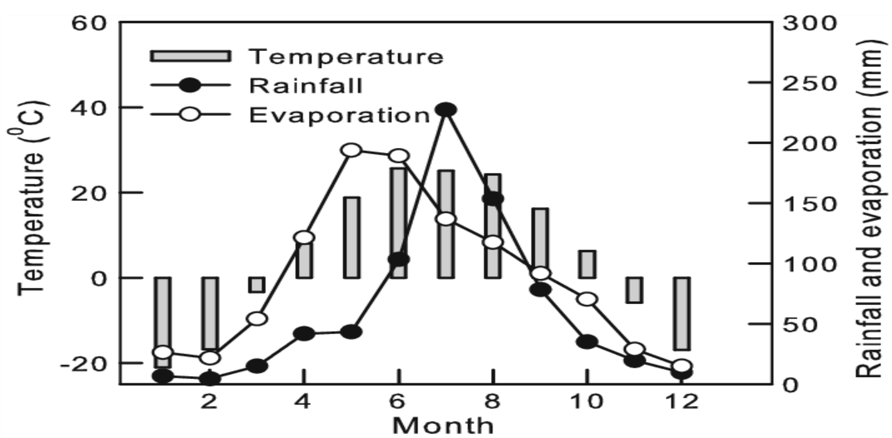

Figure 2: Mean Monthly Rainfall and Evaporation Statistics of Lokoja

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Table 1. Annual peak discharge record of Lokoja station between 1995 and 2012.

Year	Minimum discharge (m^3/s)	Maximum discharge (m^3/s)	Range discharge (m^3/s)	Highest water level (m)	Lowest water level (m)	Mean water level (m)
1995	3628	17713	14085	8.8	2.45	4.91
1996	2811	19914	17103	9.4	2.77	3.87
1997	2700	15548	12848	8.2	2.91	4.25
1998	2664	23491	20827	10.5	2.01	4.78
1999	3756	23090	19334	10.36	2.1	4.52
2000	3201	18225	15024	8.94	2.08	4.43
2001	2616	18885	16269	9.12	2.04	3.86
2002	2592	17012	14420	8.62	2.05	3.81
2003	2290	19025	16735	9.16	2.05	3.22
2004	2915	16098	13183	8.36	1.85	2.55
2005	1919	13792	10534	7.66	2.04	3.51
2006	1844	19389	17545	9.26	2.12	1.87
2007	2227	19941	17714	9.38	2.35	4.42
2008	1535	20426	18891	9.34	1.99	4.28
2009	2101	20534	18433	9.58	1.95	4.49
2010	2164	19108	17870	9.79	2.33	4.45
2011	1835	16912	15077	8.65	1.96	4.22
2012	-	31696	-	12.84	9.28	6.05

Source: Extracted from NIWA's gauge record in Lokoja.

Table 1 and Figure 2 indicate that highest rainfall is normally recorded in the month of August/September. Correspondingly, evaporative losses are much lower between May and October and thus signifying moisture surplus. Figure 3 illustrate the seasonal variation in the moisture availability over Lokoja. The months of November to April of any hydrological year also suffers moisture deficit. These are dry season months in the Study Area. About 6 months; May to October are also characterized by moisture surpluses corresponding with wet season period at Lokoja.

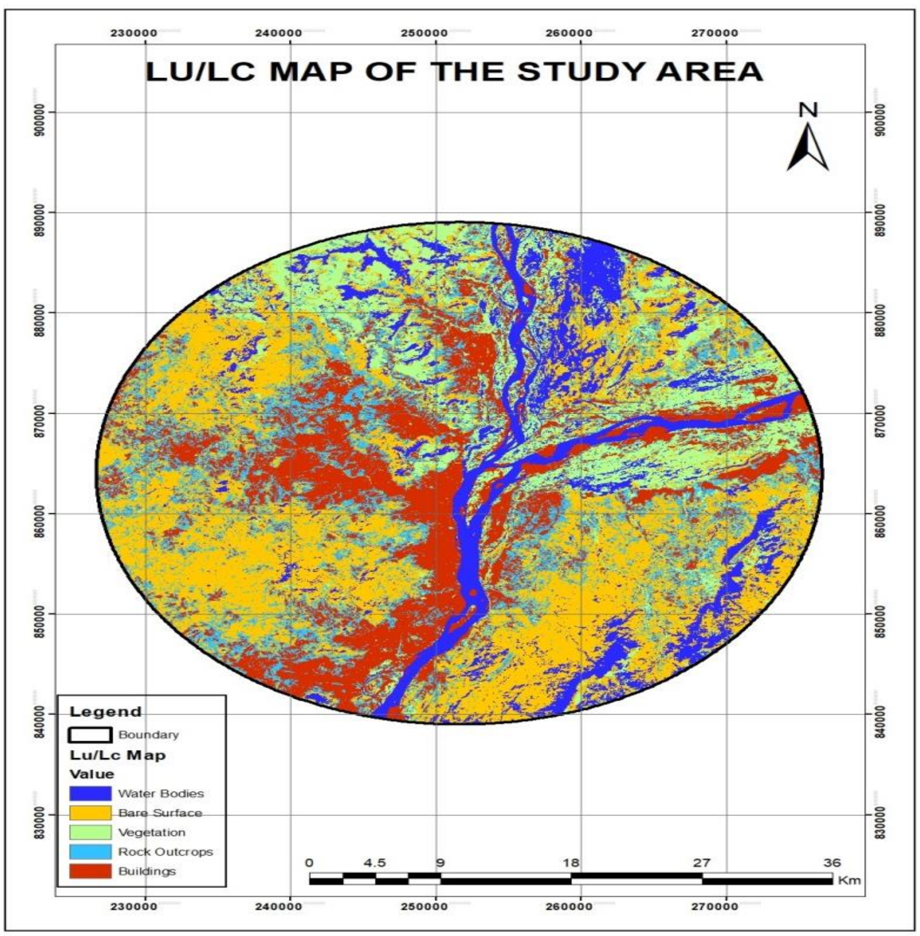

Figure 3: Classified Land use / Land cover of the Study Area

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Figure 3 illustrates land use / land cover classification of Lokoja and environs. Six major features were Identified; namely Bare Soil, Settlement, Wetland Vegetation, Crops, and Forest/trees.

Table 2: Showing Data of the Land use/Land cover of the Study Area

Land Cover	Number of pixels	% of pixels	Area (m^2)
Roads and Pavement	928	1.39%	753768.0
Urban Area	29413	44.04 %	23890709.3
Vegetation & Farmlands	27614	41.35%	22429471.5
Water	3761	5.63 %	3054872.3
Flood plain Vegetation	5064	7.58%	4113234.0
Total	66780	100 %	54242055.1

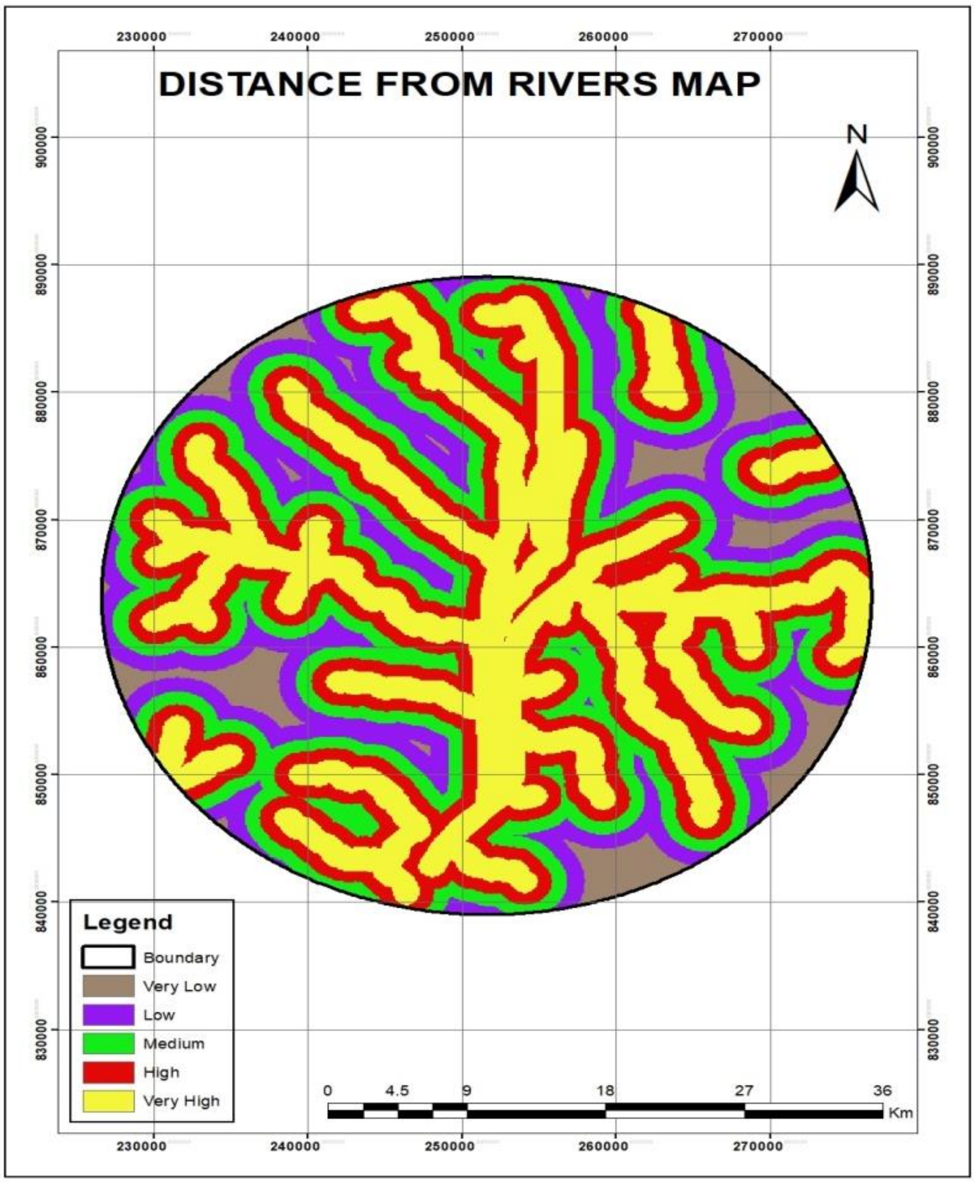

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Figure 4: 1,500 Meter Buffer Distance along Drainage Lines

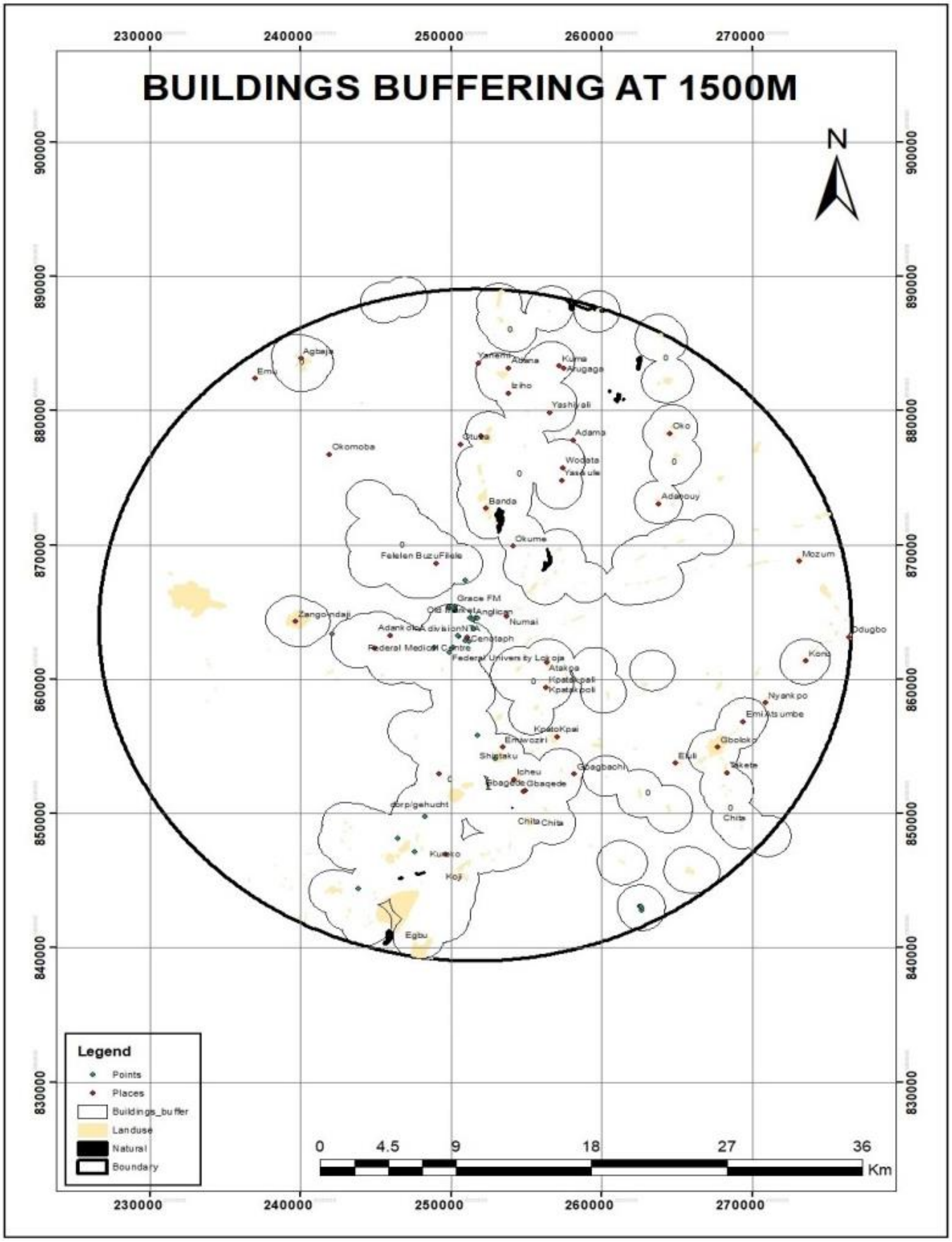

Figure 5: 1,500 Meter Buffer Distance from Buildings

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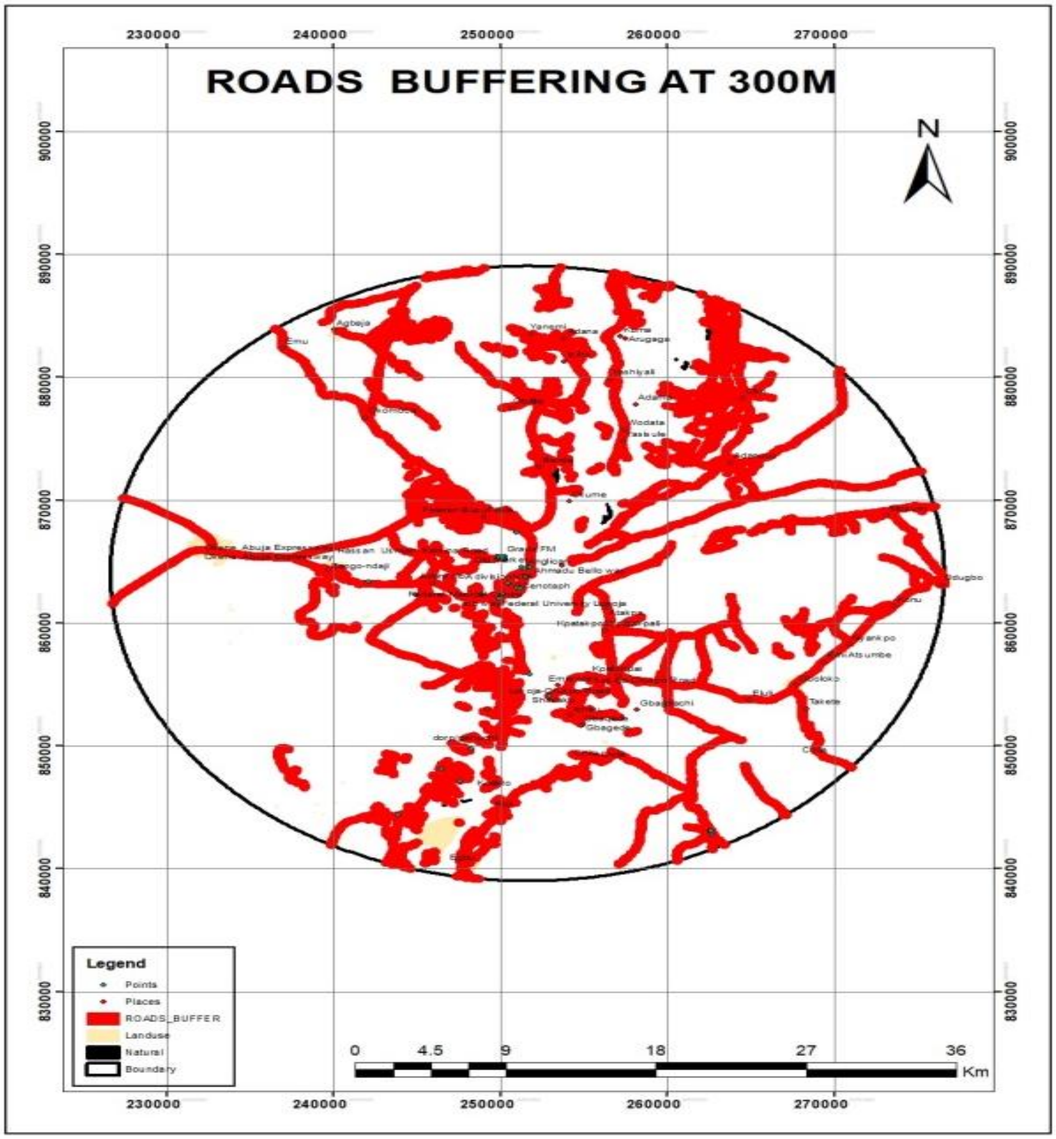

Figure 6: 30 Meter Buffer Distance from Roads

Figures 5, 6 and 7 shows a multiple ring buffer of the drainage basin in the following criteria 300 m, 500 and 1,500 m respectively. This was performed to determine flood risk extent in accordance with Space Standards for Urban Development and areas liable to flood along the river channel in the Study Area.

Table 3.1: Areal extent of land use/land cover in 2012

Value	Pixel count	Class Name	Area (m^2)	Area (%)
1	3681	Flood Extent	230062500	40.19
2	501	River	31312500	4.06
3	5716	Land	357250000	55.75
Total			618625000	100

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Table 3.2: Wet and Dry Area in Lokoja and environs

Class name	Area in 2020 (m^2)	**Area in 2021(m^2)**	**Area in 2020(%)**	**Area in 2021(%)**
Wet	31312500	258000000	4.91	39.47
Dry	606187500	379500000	95.09	60.53
Total	637500000	637500000	100	100

Table 3.3: Flood vulnerability in Lokoja and environs

Vulnerability	Weight	Pixel count	Area (m^2)	Area (%)
Not Vulnerable	1	132833	119549700	20.25
Less Vulnerable	2	226770	204093000	34.57
More Vulnerable	3	187389	168650100	28.57
Most Vulnerable	4	108932	98038800	16.61
Total			590331600	100.00

The Triangular Irregular Network (TIN) of the study area shown in Figure 3.8 further buttressed on the fact that some areas are more vulnerable than the other. From the map, the areas ranging from 35-83.889m are considered to be the most vulnerable areas to flooding, areas with height ranging from 83.889-132.778m are considered to be more vulnerable to flooding, areas ranging from 132.778-181.667m are considered as areas less vulnerable to flooding, while areas with heights ranging from 181.667 and above are considered as areas not vulnerable to flooding. More also, the presence of excess water may be as a result of reduction in capacity of natural water course, this obstruct the natural water flow and deregulate topography thereby leading to local depression.

The Pre and during flood mapping as well as the analysis of the study area using the MODIS Satellite imageries (2020 and 2021) serves as reality check. Almost all the areas considered to be dry in 2020 were converted to wet areas in 2021. It can be seen in Table 3.2 that the wet area accounted for 4.91% in 2020 which is the size of part of River Niger and Benue increased to 40.47% in 2021. These clearly show that the flood took over the area and therefore reduced the dry area from 95.09% in 2020 to 59.53% in 2021. This result attest to the fact that there was a very serious flood disaster in 2021 which took over areas considered to be dry by the communities living in such zones. The rainfall data analysis carried out shows that over the years, the rainfall amount in the study area is inconsistence. There has been a variation in the rainfall pattern over the years. The mean monthly rainfall is 104.2cm while the mean annual rainfall is 1224.11cm.

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Plate 1,2 and 3: Flood situation in Lokoja and environs

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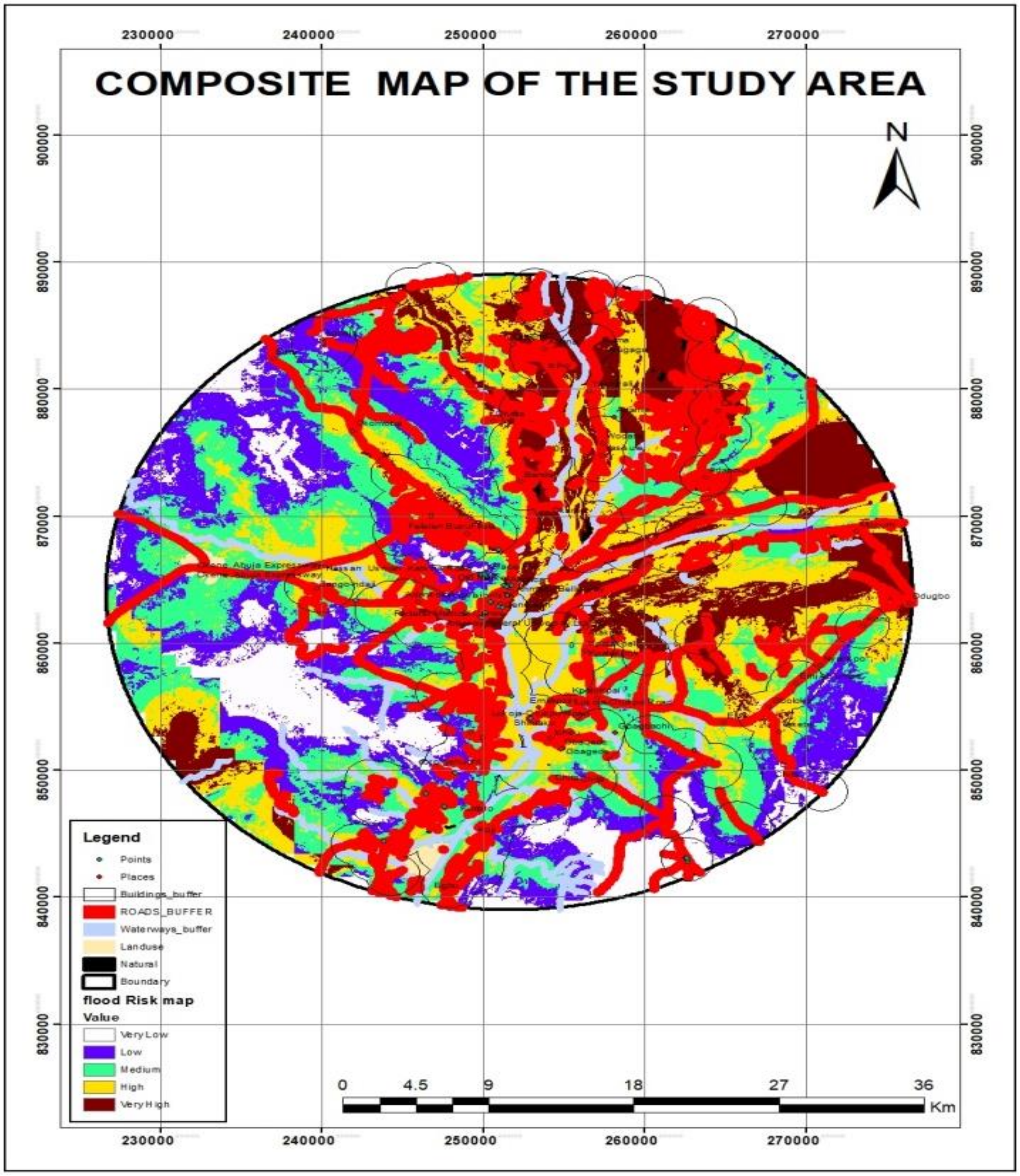

Table 3: Vulnerability Level of Locations within Lokoja

Vulnerability Level	Number of Locations	% of the Total
Highly Vulnerable	24	57.14
Moderately Vulnerable	14	33.33
Safe Zone	4	9.53
Total	42	100

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Table: 2. Area of flood vulnerability zones of study area

Flood risk zone	Flood plain	Flood risk zones	Area (hectares)
Very high flood risk	Low plain	Very High Flood Risk Zone	130.23
High food risk	High plain	High Flood Risk Zone	199.8
Moderate flood risk	Lowland	Moderate Flood Risk Zone	235.71
Low flood risk	Upland	Low Flood Risk Zone	231.03
Very low flood risk	Highland	Very Low Flood Risk Zone	60.21

The incidence of floods in the study area is caused by a combination of natural and human induced activities along the floodplains. Lokoja happens to be the confluence of the two largest rivers in Nigeria; Rivers Niger and Benue. The size and importance of these rivers coupled with increasingly growing human activities like building, dam construction, and excavation of sand along the river bank increase the risk of flood disasters.

A buffering operation was carried out to assess the effect of floods and how far away from the river channel people could erect their buildings. The result indicates that at 50 meters from the river many households were flooded. At 80 meters buffer, several other households were susceptible and at 100 meters buffer from the river, many more households are at risk. This signifies that houses should not be built less than 100 meters from the river banks.

After this operation, the communities were then grouped using the standard flood risk zoning method. At the end we have highly vulnerable areas, moderately vulnerable and safe zones. From the analysis, those safe zones are areas of elevated landform; they are relatively high and can hardly be inundated by flood waters in case of excess discharge from the river drainage. The safe areas are recommended for people to live to avoid the risk of flood disaster.

V. Conclusion and Recommendations

The DEM generated and the image drape shows that Lokoja town is not only a river side settlement but also a hill side settlement. It is a fast growing settlement owing to its status as the administrative and commercial nerve centre of Kogi State, Nigeria. It is also the 'gateway' settlement to the highly populated southeast and southwest Nigeria and as such serves as both a resort and stop over settlement for most travelers and business people. This is resulting in increased physical planning problems as buildings are constructed on every available space including the marginal flood plains and river banks. This results in the blockage of river channels and drainage lines; and investigation of surface runoff leading to floods. Coupled with urban development problems is the variability of climate resulting in the increased rainfall and inflow into the hydropower dam reservoirs.

This, most often is beyond the capacity of these dams to cope with excess water in their reservoirs. To save the dam structures from collapse, massive water releases are made with devastating flood consequences to the downstream environment. Lokoja being at downstream settlements is therefore at high risk of floods. Careful appraisal of the flood events and the affected environment using Geospatial techniques becomes expedient for effective flood disaster management.

It is therefore recommended that dredging of the Niger River at Lokoja be carried out to allow free flow of water, strict adherence to urban development laws and procedures particularly in the choice of sites be enforced and there should be continuous monitoring of the hydro-climatic variables at the hydropower dam reservoirs to issue early warnings and safeguard downstream environments from devastating extreme weather events like floods.

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