Indicators for Disaster Vulnerability to the Overflowing of the Niger River in Adjoining Settlements in the Confluence City of Lokoja, Nigeria

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Abstract

River overflow is one of the main causes of flooding and erosion. In Nigeria, flooding affects (loss and damage to properties and distortion of sources of livelihood) and displaces more people than any other disaster (loss and damage to properties and distortion of sources of livelihood). The 2012 overflowing of the River Niger and the subsequent flooding of Lokoja historically represent the most devastating natural disaster in the city. The study was based on the Geographic Information System's (GIS) Multi Criteria Analysis (MCA) and examined the risk and vulnerability of Lokoja's settlements adjoining the Niger River to flooding. The criterion considered were elevation, land cover, slope, curvature, flow accumulation, the Normalised Difference Water Index (NDWI) and the drainage density of the study area. The data used for this study was obtained from a secondary source United States Geological Survey (USGS).

The relationship between the NDWI and the precipitation in Lokoja showed that the NDWI and precipitation were inversely related. This implied that an increase in precipitation was consequential to the intensity of the water index in the study area. This study successfully showed the capability of remote sensing and the GIS to assess both pre- and post-disaster (flooding) vulnerability. It also revealed that high precipitation and increasing physical development due to urbanisation in lowlands increased the vulnerability of an area to flooding. The recommendation forwarded was the need for improved river basin management and flood disaster prevention.

Keywords: Niger River Overflow, Building Susceptibility and Vulnerability, Urban Flooding and Erosion, Flood Prone Areas, Spatio-temporal Analysis, Multi Criteria Analysis (MCA).

Introduction

Cities are centres of socio-economic opportunities. This attribute has contributed significantly to unprecedented increasing urbanisation, population movement and concentration in the cities[69]. Because of this, urban centres are becoming risky, disaster prone environments which threaten the residents (especially the poor and people residing in sub-standard housing in the most vulnerable locations)[57,69] and their livelihoods. Studies[2,7,9,13,59,66] report that natural hazards and emergency management are major issues in most cities. Forty million people across many cities are estimated to be vulnerable to natural hazards and by the year 2070, the total population of vulnerable people is estimated to be around 150 million[46].

In light of this, disaster management and its related issues (such as city exposure, susceptibility, resilience and vulnerability) have become a global topic of discussion among scholars over the past few decades[56,58,62,64]. This, perhaps, could be because it has been identified as an ongoing risk for human settlements all over the world and it has the potential to damage key urban infrastructure and threaten the well-being, safety and health of people[16,24,74]. As reported by UN-Habitat[70], disasters affect around 220 million of the global population and cause an economic loss of 100 million US Dollars per year. Of all the disaster types, flooding (which is defined as the unusually high rate of water discharge, resulting in temporary or complete inundation of the land adjacent to streams and rivers)[32] remains the most prominent and recurring disaster, with increasing impacts across the globe each year[78].

The World Health Organisation (WHO)[76] reinforces this by estimating that flooding affected more than two billion people globally between the years 1998 and 2017 and placed emphasis on the fact that people who live on floodplains (the concern of our study) in non-resistant structures, or people who lack proper awareness of flooding risks are highly vulnerable to disaster.

In Africa, cities in Egypt and Nigeria are claimed to be more vulnerable to flood risk, perhaps because of the population surge in those countries[46]. In Nigeria, the cities of Ibadan, Lagos, Kano and Lokoja are characterised by the increasing occurrences of flood disasters[12], which may possibly be connected to population growth and economic development which have perhaps warranted people residing along river overflow areas notwithstanding the consequences of such action. Long term data on natural disasters suggests that flooding and windstorms have been, by far, the most common causes of natural disasters worldwide over the past 100 years[27].

Flood hazards are natural phenomena, but the damages and losses from floods are the consequences of human action. In Nigeria's confluence town of Lokoja, two major flood events took place between the months of September and October 2012, namely the Ladgo dam flood and the Niger-Benue flood (Lokoja and the confluence of the Benue and Niger rivers from its adjoining states). The release of water from the Ladgo dam in Cameroun into the Benue River floodplain, coupled with the effect of global warming, was largely responsible for the 2012 flooding in Nigeria. The 2012 flooding in Nigeria remains the most prominent and destructive of all flooding experiences. It was estimated that roughly seven million people were affected.

A total of 597 476 housing developments were destroyed; 2.3 million people were displaced; 363 deaths were recorded; business infrastructure was destroyed; public health disease outbreaks increased, burdening the health system; agricultural land and animals were greatly affected and 500 000 barrels of crude oil output were lost per day because of the flooding[44,50,51]. While risk profiles from floods and other hazards differ among cities, the capacity to plan, prepare, respond and recover from disasters is a common need. This is often exacerbated by human activities such as the presence of riverside infrastructure (dams, piers and lands) and poor development practices including riverside development, excessive clearing, encroachment upon waterways and dredging, which may cause changes in the hydrological balance of the water ways involved[7,11,45,47,49,72].

Many of the anthropogenic activities have been traced to unplanned urbanisation, weak city planning ideology and poor floodplain management. Urbanisation (high population clusters and unplanned building layouts) aggravates the overflowing of rivers by restricting river flow. In an urban area, increased run-off, river flow and the obstruction of natural hydrology system drainage can be traced to city pavements, concrete infrastructure, lack of soft landscapes, impervious roofing materials and tarred roads[4,14,21,34,53,75]. In extreme cases, urban floods can result in disasters that set urban development back by years or even decades.

Given the high spatial concentration of people and values in cities, even small-scale floods may lead to considerable damages. While the natural causes (overflowing of rivers due to heavy rainstorms, hurricanes, or snow melt and dam failures) of floods are undoubted[32], the distribution of low-lying coastal areas and river floodplains remain major drivers for urban flooding. In Nigeria, Adelekan[5,6] reported that many communities in the coastal parts of Nigeria are vulnerable to flooding events.

The 2012 Lokoja flood in Nigeria pushed most of the country's rivers over their banks and submerged hundreds of kilometres of urban and rural lands[48], resulting in a loss of property and livelihood means. Against this experience, this study was interested in understanding the post-disaster vulnerability of the settlements located alongside the River Niger. This study focused on the overflowing of the Niger River and the rationale for the choice of this river in Lokoja was the confluence identity (meeting point of the Benue and Niger rivers) of the city. The Niger River passes through Lokoja, a confluence and capital city in Kogi state, Nigeria, with its source in the Guinea highlands and it runs through few West-African countries. In fact, the river has been identified as the third longest river in Africa with an estimated length of 4180km (2600 mi) and has the ninth largest river basin in the world[28]. This study sought to examine the risk dynamics of the Niger River on the adjoining settlements in the pre-overflow and post-overflow periods from 2012 to 2020.

The post-disaster vulnerability in the context of this study was the characteristics and circumstances of the human settlements adjoining the River Niger in the confluence city of Lokoja that made them prone or susceptible to the damaging consequences of a hazard such as the overflowing of the river with the subsequent flooding. The idea was that if these were carefully analysed, then measures could be put in place to reduce or avoid the resultant shock, as the inhabitants of these settlements would come to know well that post-disaster recovery could take decades and that the likelihood of these settlements never returning to their original state was high.

Studies[12,15,25,28,39,68] that were conducted on the River Niger have focused mainly on issues such as the physiochemical properties of the water, the hydro-geophysical composition of the river, aquatics in the river and on-the-spot disaster evaluation. Over the years there have been few studies on the comparative analysis of the pre-disaster, disaster and post-disaster vulnerability of the settlements along the River Niger's floodplain.

The study was designed in such a way as to contribute to the body of knowledge on the systems to enhance the environmental sustainability of settlements along river courses which are vulnerable to disaster from overflow and flooding. Farhan and Lim[26] affirm that one of the methods to assess sustainability is vulnerability assessment and this study looked more at problem solving than problem identification and emphasis. Problem solving in the context of this study meant identifying pragmatic ways for this settlement to absorb, resist and recover from potential exposure to overflow and flooding risk, while problem identification meant the chance of these settlements being exposed to such hazards.

The study employed the conceptualisation of the word 'resilience' by UN-Habitat[70] to develop the research question adopted for this study. According to them, resilience is "the ability of any urban system to maintain continuity through all shocks and stresses while positively adapting and transforming towards sustainability”[70]. The study therefore sought to answer the question on how vulnerable the settlements were, with a focus on the River Niger’s post-2012 overflow that led to urban flooding.

Concept of Urban Resilience

The word ‘resilience’ has gained recognition and dominated discourses (academic and policy) on management strategies of hazards and risks that are linked to climate change, disasters and insecurity among many others[41,55]. Resilience as a concept in ecology is seen as the ability of any system to bounce back and move forward[65]. Specifically, Meerow et al[41] defined it as “a measure of the persistence of systems and their ability to absorb changes and disturbances and maintain the same relationships between populations or state variables which are supported by two fundamental variables: stability and regeneration”. The arguments in ecology present it as the ability of a system to absorb a shock while being capable of moving to another regime[63].

Looking at the concept of resilience in the lens of climate change, the Intergovernmental Panel on Climate Change (IPCC) attributes resilience to adaptation, response, learning and transformation mechanisms owing to hazard-related events. However, a critical examination of the different arguments on what resilience connotes informs us that the concept captures the possible pre- and post-hazard preventive measures for people in vulnerable zones.

The technical, practical and policy-oriented responses to vulnerability owing to environmental shocks and stresses (such the Lokoja flood) represent the applicability of the concept of resilience[37]. Studies[36,37,54] have alluded that urban resilience addresses the vulnerability of communities pragmatically by attempting to identify the risks, mitigating them, preparing for possible risk events and ensuring a swift recovery after the incidence might have occurred.

The urban resilience concept has been experimented with in many cities[29], most especially in the developed world, looking at strategies to reduce possible shocks and even prevent environmental disasters. This study drew perspective from the concept of resilience to understand how resilience could be used to mitigate flood occurrences in Lokoja. It is estimated that 98% of properties are vulnerable to flooding in Nigeria[3] and over 118 million poor people across Africa will be exposed to floods and extreme weather conditions by 2030, with implications for urban land scarcity[30,35,38,73]. The need for improved disaster management towards resilient cities cannot be downplayed. This reveals the need for a flood resilient framework and institutional systems in our cities to respond to flood risks and other possible natural hazards.

The concept of resilience in flood management emphasises the need for vulnerable communities to learn how to live with flooding and not seek to avoid it as a whole. The assumption is that when residents of vulnerable communities learn how to live with flooding, then the possible havoc of disaster will be minimal and the communities will be able to bounce back from the shock. These narratives made this concept more applicable and relevant to describe our study on the vulnerability of communities in the confluence city of Lokoja, Nigeria that live along the Niger River to river overflow and flooding. Our aim was to suggest innovative approaches to enhance the environmental sustainability of the settlements along the river’s course because of their heightened vulnerability to this type of disaster.

Study Area

The Niger River and the Benue River which divide Nigeria into three geographical regions converge in Lokoja and this gives this city its accolade as a ‘confluence city’. The confluence of the Niger and Benue rivers in the Lokoja study area makes it susceptible to flooding. The study area is located at latitude 7° 40’ 0”N and 7° 50’ 0”N and longitude 6° 40’ 0”E to 6° 50’ 0”E (Figure 1). Settlements located around the confluence often bear the full impact of flooding[19].

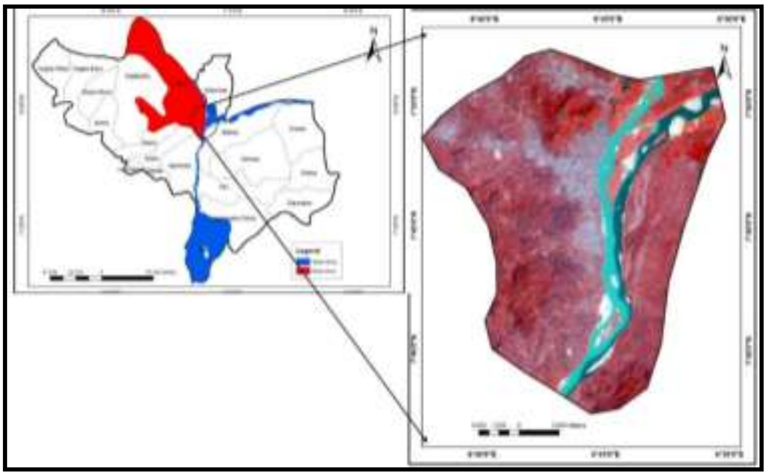

Figure 1: Map of the Study Area
Source: Authors’ Construct (2021)

Materials and Methods

To map out the flood risk area in the study area, a GIS multi-criteria approach was adopted. Seven thematic variables were considered because one variable cannot singly account for flooding in an area. These thematic variables, which included land use/land cover, a digital elevation model (DEM), drainage density, curvature, slope, the NDWI and flow accumulation were classified and weighted using the ArcGIS software, as observed in various studies[20,22,33,42,60,61].

Spatio-temporal analysis plays an important role in identifying the causality relationships in space and time within the object of an event studied[17,77]. As such, this study employed a spatio-temporal analysis technique to evaluate the change over time (2012-2020) in the study area. The aim was to track the encroachment level on the flood plains in the study area. The dataset employed to generate these thematic maps was obtained from the archives of the USGS. The Landsat datasets were used to produce the land use/land cover maps and the NDWI and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) datasets were used to generate the curvature, slope, drainage density, digital elevation model and flow accumulation datasets of the study area (Figure 1).

To achieve a natural colour for the land cover analysis, bands 4,3 and 2 on Landsat 8 and bands 3,2 and 1 on Landsat 7 were combined using the composite bands on the ArcMap software. Thereafter, a maximum likelihood classification was carried out after highlighting the built-up areas, marginal land, vegetation and water bodies in the study area.

The NDWI was used to delineate the surface water bodies in the study area. It was derived using the formula 'green – NIR/green + NIR', with the raster calculator on the ArcGIS software[40]. The DEM of the study area was extracted from the ASTER dataset using the 'extraction by mask' tool on the ArcGIS software. Thereafter, the 'fill tool" was used to correct the missing data. The 'slope tool' and the 'curvature tool' were used to generate the slope and curvature respectively. When generating the flow accumulation, the DEM was initially used to generate the flow direction, using the 'flow direction' tool. The flow direction was used to generate the flow accumulation raster by using the flow accumulation tool.

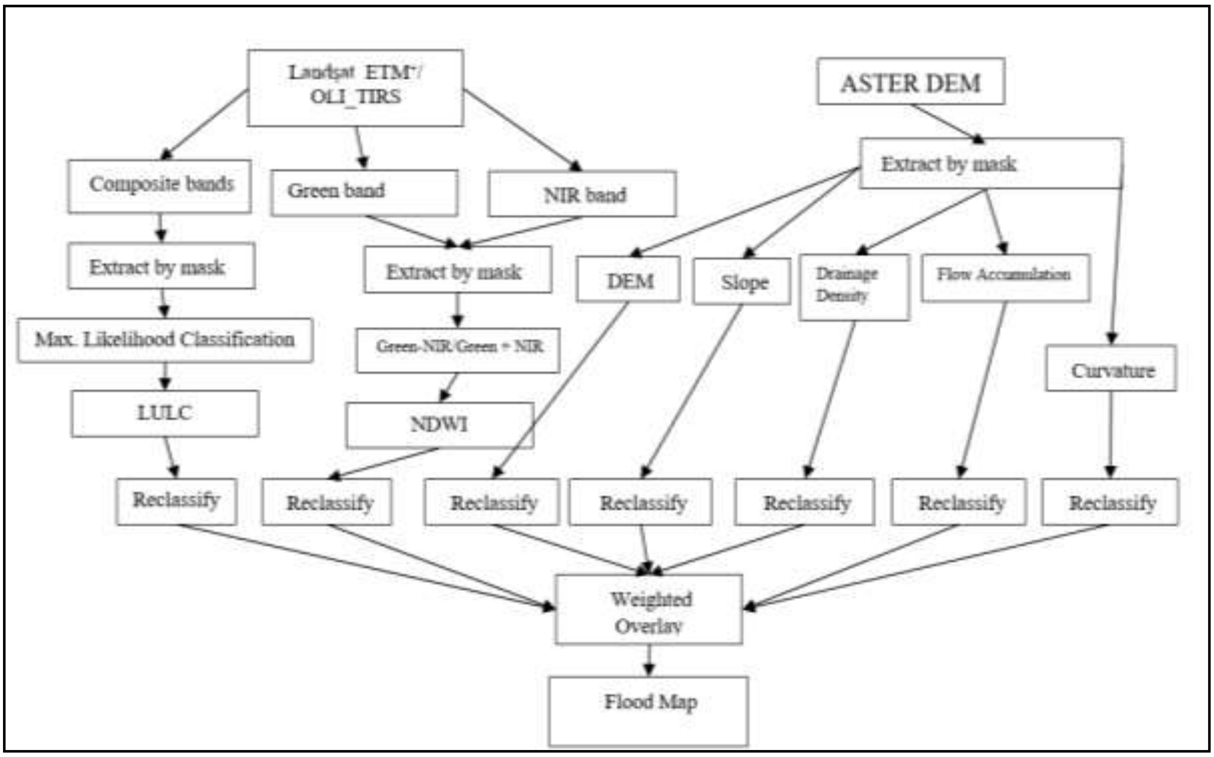

Figure 2: Methodology Flow Chart Construct Adopted in the Study
Source: Authors' Construct (2021)

Table 1
Landsat Dataset Metadata of the Study Area

S.N.	Satellite Sensor	Resolution	Sensor Type	Capture Date	Path and Row	Band Combination
1	Landsat 7 (2012)	30M	ETM$^+$	12/15/2012	189_055	3,2,1
2	Landsat 8 (2020)	30M	OLI_TIRS	12/31/2017	189_055	5,3,2
3	Landsat 8 (2020)	30M	OLI_TIRS	01/06/2020	189_055	5,3,2

Source: Field survey (2021)

Thereafter the flow accumulation raster was used to generate the stream order raster. This was then converted to a polyline by using the ‘stream to feature tool’. The polyline shapefile was further analysed to generate the drainage density of the area using the ‘line density’ tool.

To assign all these thematic maps to a common variable, the ‘reclassify’ tool on the ArcGIS software was used. Each map variable was divided into 5 classes, with equal intervals in the ArcGIS environment, as used in the study of Das[22]. Table 2 shows that the thematic layer class ranked as number 5 had a very high risk of getting flooded. This was followed by rank number 4, which was at high risk. Furthermore, rank numbers 3, 2 and 1 were at moderate, low and very low risk of getting flooded respectively.

The precipitation data used for this study was downloaded from the archive of the World Climatic data (https://www.worldclim.org/).

Table 2
Ranking of Thematic Layers’ Influence on Flooding

<table>
<tr><th>Thematic Layer</th><th colspan="2">Class</th><th>Rank</th><th>Risk Vulnerability</th><th>Weight %</th></tr>
<tr><td rowspan="5">Elevation (m)</td><td colspan="2">25.61 - 94.016</td><td>5</td><td>Very high risk</td><td rowspan="5">20</td></tr>
<tr><td colspan="2">94.017 - 162.422</td><td>4</td><td>High risk</td></tr>
<tr><td colspan="2">162.423 - 230.828</td><td>3</td><td>Moderate risk</td></tr>
<tr><td colspan="2">230.829 - 299.234</td><td>2</td><td>Low risk</td></tr>
<tr><td colspan="2">299.235 - 367.64</td><td>1</td><td>Very low risk</td></tr>
<tr><td rowspan="4">Land Cover</td><td colspan="2">Water body</td><td>5</td><td>Very high risk</td><td rowspan="4">17</td></tr>
<tr><td colspan="2">Built-up area</td><td>4</td><td>High risk</td></tr>
<tr><td colspan="2">Marginal land</td><td>3</td><td>Moderate risk</td></tr>
<tr><td colspan="2">Vegetation</td><td>2</td><td>Low risk</td></tr>
<tr><td rowspan="5">Slope (degree)</td><td colspan="2">0.001 - 1.136</td><td>5</td><td>Very high risk</td><td rowspan="5">15</td></tr>
<tr><td colspan="2">1.137 - 2.993</td><td>4</td><td>High risk</td></tr>
<tr><td colspan="2">2.994 - 5.572</td><td>3</td><td>Moderate risk</td></tr>
<tr><td colspan="2">5.573 - 9.08</td><td>2</td><td>Low risk</td></tr>
<tr><td colspan="2">9.081 - 26.309</td><td>1</td><td>Very low risk</td></tr>
<tr><td rowspan="5">Drainage Density(km/km^2)</td><td colspan="2">7.761 - 9.7</td><td>5</td><td>Very high risk</td><td rowspan="5">15</td></tr>
<tr><td colspan="2">5.821 - 7.76</td><td>4</td><td>High risk</td></tr>
<tr><td colspan="2">3.881 - 5.82</td><td>3</td><td>Moderate risk</td></tr>
<tr><td colspan="2">1.941 - 3.88</td><td>2</td><td>Low risk</td></tr>
<tr><td colspan="2">0 - 1.94</td><td>1</td><td>Very low risk</td></tr>
<tr><td rowspan="5">Flow Accumulation</td><td colspan="2">29,000 - 37,700</td><td>5</td><td>Very high risk</td><td rowspan="5">10</td></tr>
<tr><td colspan="2">13,300 - 28,900</td><td>4</td><td>High risk</td></tr>
<tr><td colspan="2">5,780 - 13,200</td><td>3</td><td>Moderate risk</td></tr>
<tr><td colspan="2">1,490 - 5,770</td><td>2</td><td>Low risk</td></tr>
<tr><td colspan="2">0 - 1,480</td><td>1</td><td>Very low risk</td></tr>
<tr><td rowspan="6">NDWI</td><td>2012</td><td>2020</td><td rowspan="2">5</td><td rowspan="2">Very high risk</td><td rowspan="6">13</td></tr>
<tr><td>0.21 - 0.55</td><td>0.01 - 0.07</td></tr>
<tr><td>0.05 - 0.2</td><td>-0.06 - 0</td><td>4</td><td>High risk</td></tr>
<tr><td>-0.05- 0.04</td><td>-0.11 - -0.07</td><td>3</td><td>Moderate risk</td></tr>
<tr><td>-0.14- -0.06</td><td>-0.14 - -0.12</td><td>2</td><td>Low risk</td></tr>
<tr><td>-0.39 - -0.15</td><td>-0.25 - -0.15</td><td>1</td><td>Very low risk</td></tr>
<tr><td rowspan="5">Curvature</td><td colspan="2">0.126 - 0.621</td><td>5</td><td>Very high risk</td><td rowspan="5">10</td></tr>
<tr><td colspan="2">0.0243 - 0.125</td><td>4</td><td>High risk</td></tr>
<tr><td colspan="2">-0.0427 - 0.0242</td><td>3</td><td>Moderate risk</td></tr>
<tr><td colspan="2">-0.156 - -0.0428</td><td>2</td><td>Low risk</td></tr>
<tr><td colspan="2">-1.09 - -0.157</td><td>1</td><td>Very low risk</td></tr>
</table>

Source: Authors’ Analysis (2020)

Results and Discussion

Land Use Land Cover (LULC): The continuous activities of humans, such as deforestation on the earth's surface, led to land use and land cover changes[1,23]. Furthermore, human activities such as buildings and roads reduced the ability of soil to absorb water. As such, these activities led to an increase in the surface runoff, but vegetated areas enhanced the infiltration of water into the soil[43,52]. As this study tracked the spatio-temporal changes in land use in the study area, the land uses were classified into four classes which are: the built-up area, water body, disturbed vegetation and undisturbed vegetation.

Table 3 explains the LULC of Lokoja between 2012 and 2020. The analysis revealed that the built-up area covered 38.40km^2 (10.16%) in 2012. As a result of the rapid urbanisation and increase in population growth experienced in Lokoja, the areas had a significant increase in land area occupied. The size of the built-up area increased from 38.40km^2 in 2012 to 55.13km^2 in 2020. The increase in built-up areas in Lokoja within the study period (2012-2020) was responsible for the changes recorded in the undisturbed and disturbed vegetation.

Owing to the increase in anthropogenic activities in Lokoja, in 2020, a total of 104.55km^2 of undisturbed vegetation was either cleared or transformed for other uses. The continuous clearance of undisturbed vegetation as land cover will regularly worsen the threat of flooding in an area[8].

analysis also revealed that as built-up areas increased, more vegetation cover was also disturbed. A total of 65.62km^2 of land cover was disturbed between 2012 and 2020. The alteration of land use and land cover (LULC) in Lokoja continued to expose the environs to the impending danger of flooding.

Normalised Difference Water Index between 2012 and 2020: The NDWI measured the liquid water molecules in vegetation canopies that interacted with the incoming solar radiation[18]. The NDWI is a tool used to identify and monitor the difference between water-bearing and non-water bearing features and helps identify flood-prone[61] areas. The result of the spatio-temporal analysis of the NDWI in table 4 shows that the water containing index in the study area ranged between -0.3 to 0.55 in 2012. A slight decrease was recorded in the index in 2017 with a range of -0.38 to 0.14.

The decrease in the range of the NDWI in 2017 was attributed to a decline in the precipitation of that year (Figure 6). In 2020, an increment was seen in the water containing area as the NDWI increased with a range of -0.25 to 0.7. The variation in the NDWI meant that the water-bearing features increased in the study area and this was an element of flood susceptibility. There was thus an increase in the number of water-bearing features in 2012 and 2020, according to the NDWI, which could be ascribed to the 2012 and 2020 flooding in Lokoja[19,48].

Assessment of the DEM, Slope Analysis, Drainage Density and Flood Analysis: The DEM of Lokoja explains that the elevation of the study area ranged from 25.61 meters to 367.64 meters above sea level (Figure 3). The study revealed that 216.37 km^2 of the total area lay between 25.61 m to 94 m above sea level. This implied that 57.24% of the land areas in Lokoja were flood prone.

The slope analysis also showed that 57.24% of the land area at low elevation had a slope of less than 2^o (Figure 4), consequently resulting in the area retaining water after heavy precipitation runoff. This occurrence was also accountable for the 2012 and 2020 flooding in Lokoja. The slope analysis revealed that the slope in the study area ranged between 0.001^o to 26.309^o.

Table 3
Land Use Land Cover Analysis of Lokoja between 2012 and 2020

Year	2012		2020	
Sample Set	**Land Area (Km^2)**	**%**	**(Km^2)**	**%**
Built-up Area	38.40	10.16	55.13	14.59
Water Bodies	45.97	12.16	68.17	18.03
Disturbed Vegetation	94.76	25.07	160.38	42.43
Undisturbed Vegetation	198.86	52.07	94.31	24.95
Total	377.99	100	377.99	100

Source: Author's Analysis (2021)

Table 4
Normalised Difference Water Index for Lokoja between 2012 and 2020

NDWI	2012	2017	2020
Minimum Index	-0.39	-0.38	-0.25
Maximum Index	0.55	0.14	0.70

Source: Authors' Analysis 2021

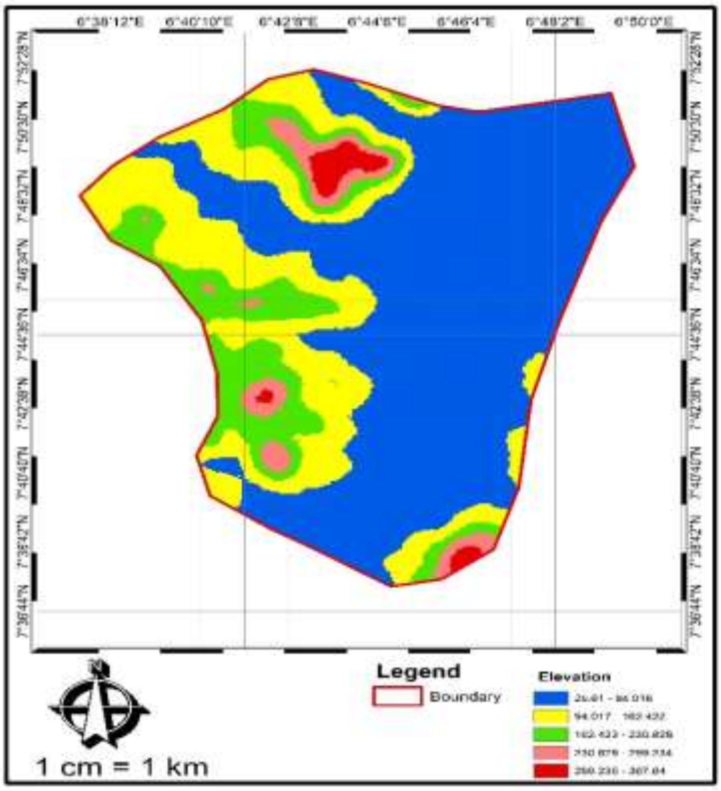

Figure 3: Digital Elevation Model of Lokoja.
Source: Authors' Analysis (2021)

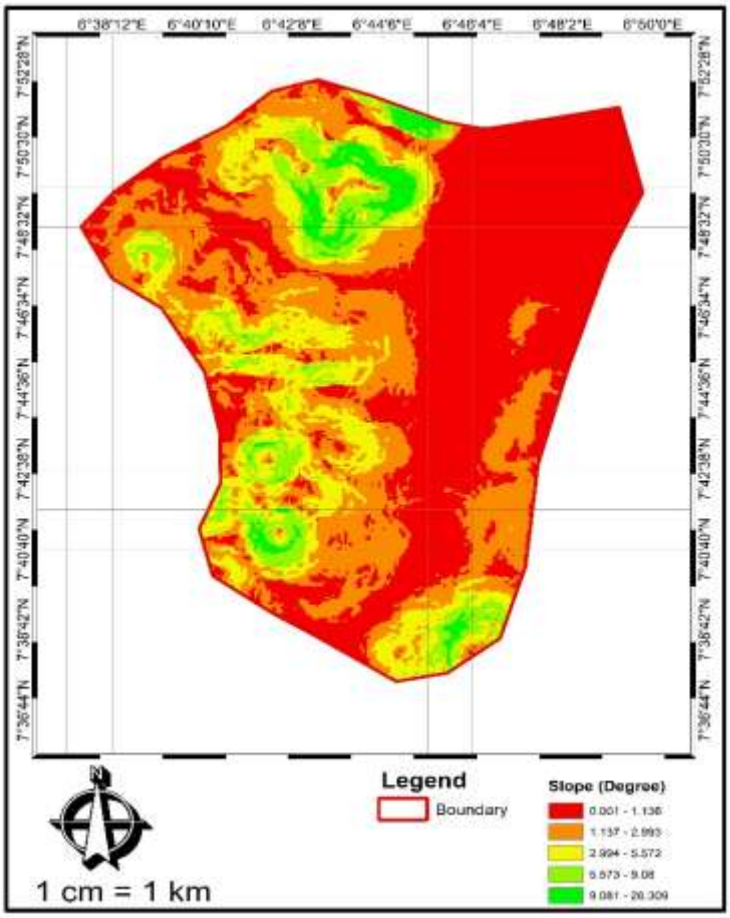

Figure 4: Slope Analysis of Lokoja.
Source: Authors' Analysis (2021)

The perimeter survey for this study revealed that new drainage was under construction in the study area to curtail the runoff from heavy precipitation and the water bodies (Niger and Benue rivers). The survey further revealed that the existing drainage in the study area was either silted or blocked by plastic bags and bottles. The drainage density analysis revealed that areas of higher drainage density were prone to flooding because a high drainage density is directly proportional to higher surface runoff and vice-versa[52]. The drainage density for the study area ranged from 0 - 9.7 km^2 and the area most vulnerable to flooding in Lokoja ranged between 7.7 - 9.77 km^2 (Figure 5). The settlements that fell within this area were Gaduma, Jingbe, Elete, Ganaja, Adankolo, Sarkin Noma, Galilee, Lokogoma and Kpata. The residents of these settlements were victims of flooding in 2012 and 2020[19,71].

The flood map for 2012 and 2020 was produced using the seven flood parameters earlier discussed. The flood maps for 2012 and 2020 showed that there were variations in landmass among the areas highly, moderately and lowly flood-prone in each year. As shown in figure 6, in 2012 the lowly flood-prone area was 92 km^2 (24.33%), while in 2020 it has declined to 89 km^2 (23.54%) of the total 378 km^2 of the study area. Also, the area prone to moderate flooding was 241.14 km^2 (63.80%) in 2012, while in 2020 the area prone to moderate flooding had declined to 222.78 km^2 (58.94%) of the total 378 km^2. The area highly prone to flooding in 2012 was 44.86 km^2 (11.87%) and in 2020 the highly flood-prone area had increased to 66.22 km^2 (17.52%). The flood map analysis also indicated that the highly flood-prone area was increasing and more areas are likely to be flooded in the future.

Relationship between Precipitation and the Normalised Difference Water Index: The precipitation data for the study epochs revealed that the highest precipitation value was recorded in 2012, with a maximum precipitation value of 103.86 mm and an average of 101.53 mm (Figure 7). This implied that high rainfall was recorded in Lokoja in this period. Sotunde[67] opined that the heavy tropical rains recorded in 2012 were responsible for the flooding in this period. The 2012 scenario was repeated in 2020, with high precipitation in Lokoja in 2020 which resulted in a flash flood. This flash flood displaced residents and cut Lokoja off from some parts of the country; Ajaokuta Road, which leads to the South-East and some South-South parts of Nigeria[71] was impassable.

An average of 97.88 mm of precipitation was recorded in 2020. In this same epoch, a maximum precipitation value of 100.25 mm was recorded. The high precipitation values recorded in 2012 and 2020 were reflected in the index values of the NDWI of the study area. The NDWIs of 2012 and 2020 were high at 0.55 and 0.70 respectively.

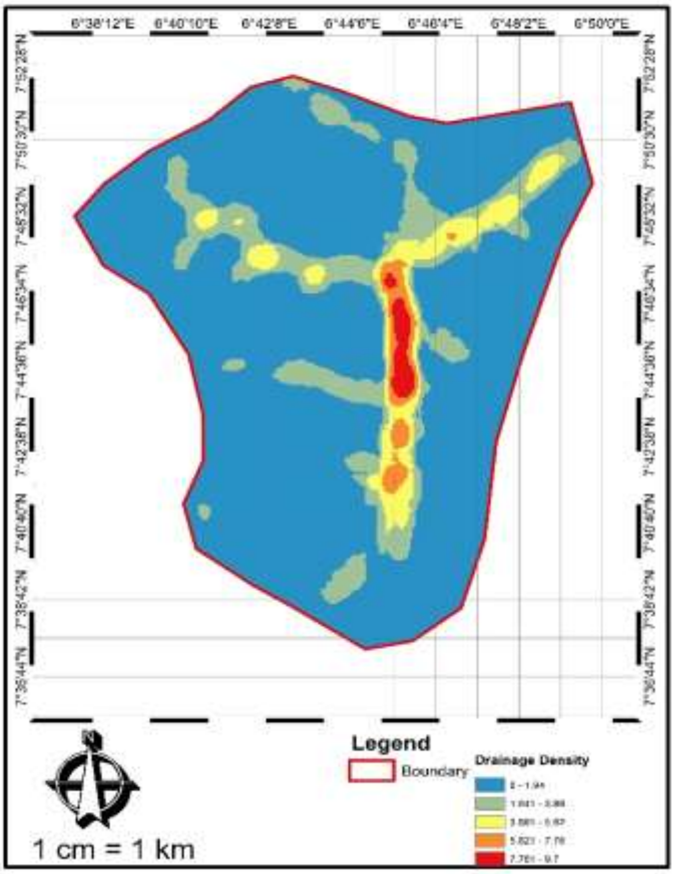

Figure 5: Drainage Density Map of Lokoja.
Source: Authors' Analysis (2021)

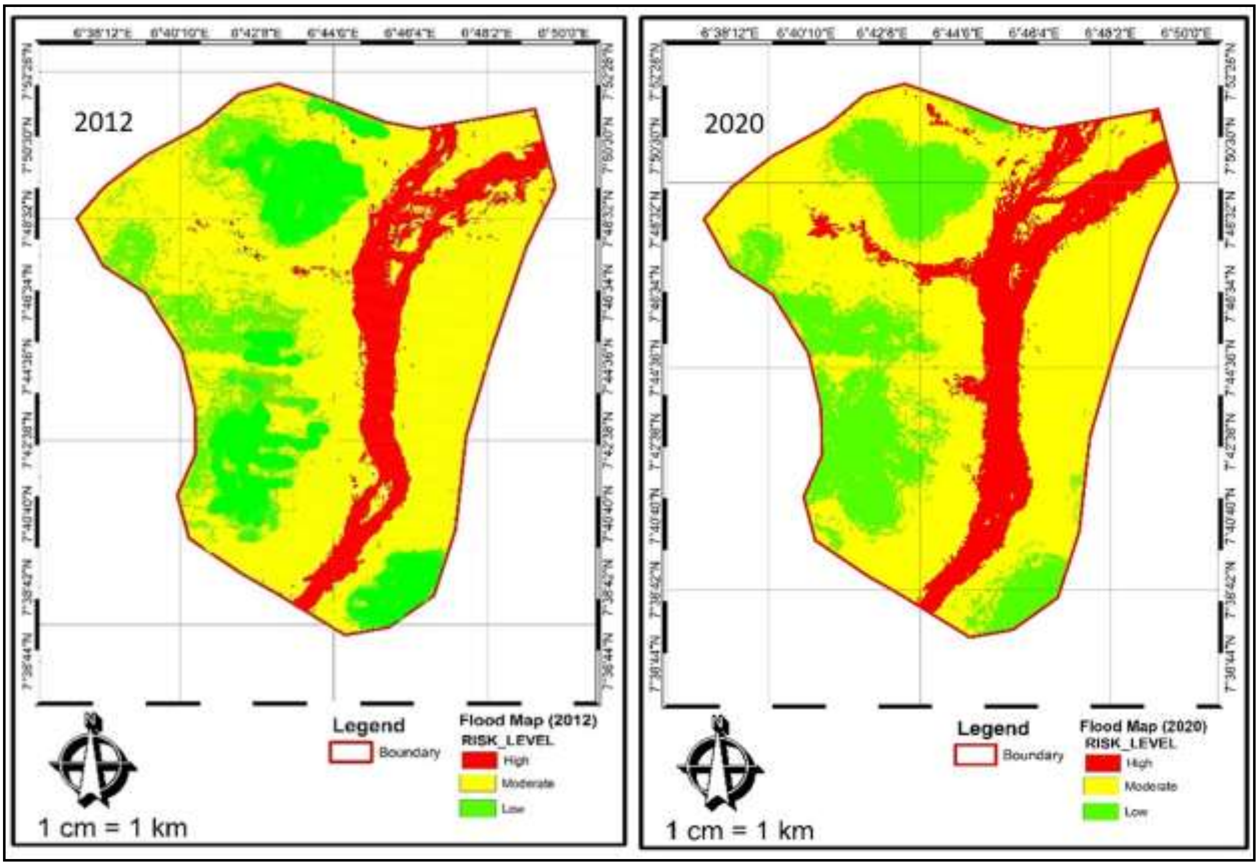

Figure 6: Slope Analysis of Lokoja.
Source: Authors' Analysis (2021)

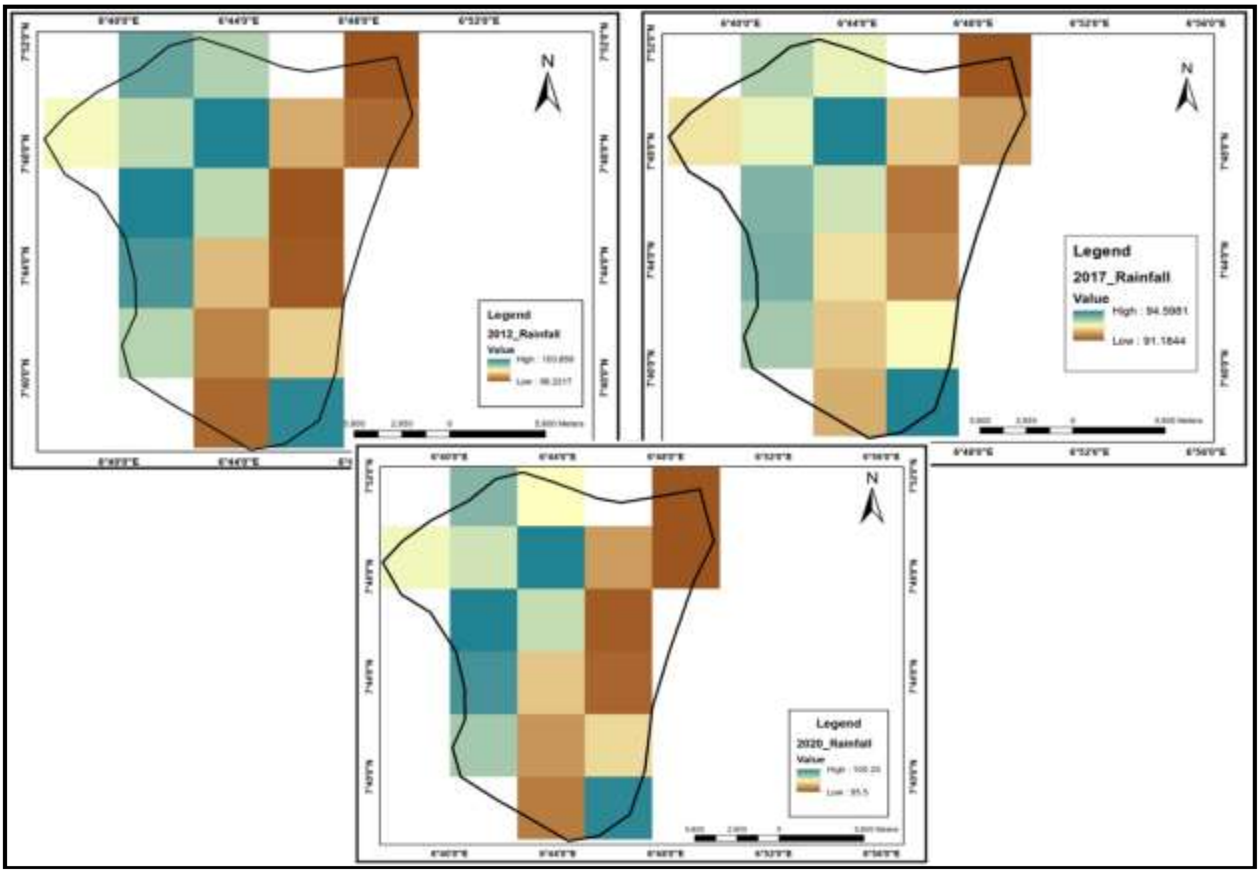

Figure 7: Precipitation Maps of Lokoja between 2012 and 2020
Source: WorldClim (2021)

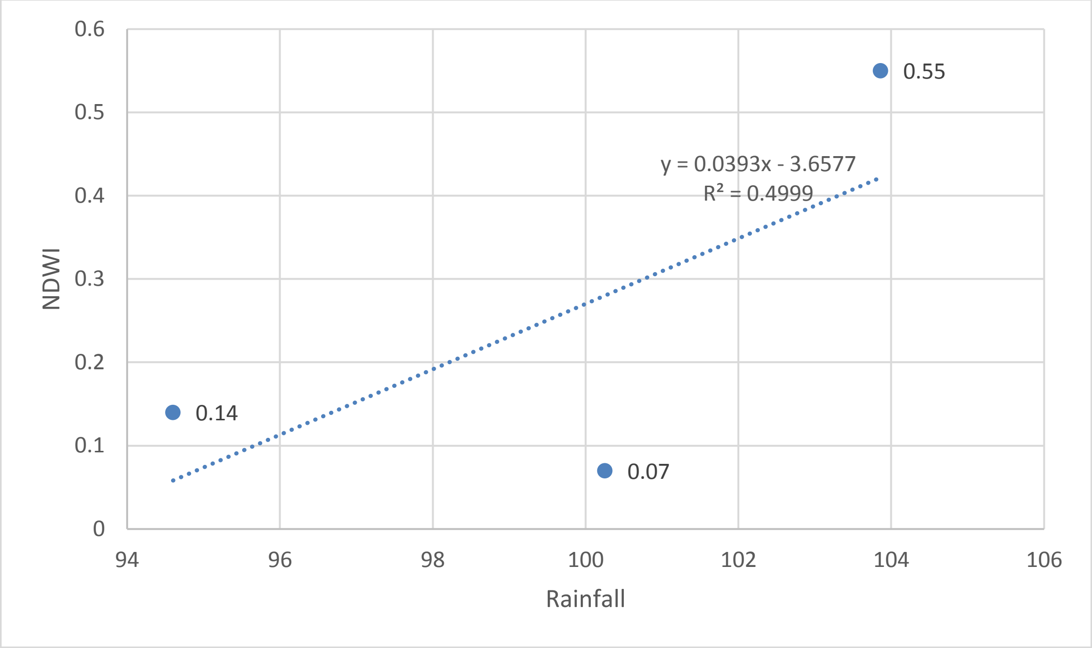

Figure 8: Relationship between NDWI and Precipitation.
Source: Authors' Analysis (2021)

The relationship between the NDWI and precipitation in Lokoja showed that the NDWI and precipitation were related. This implied that an increase in precipitation was consequential to the intensity of the water index of the study area (Figure 8).

Conclusion and Recommendations

This study successfully showed the capability of using remote sensing and the GIS to assess both pre- and post-disaster (flooding) vulnerability. This study revealed that high precipitation levels and the increasing physical development due to urbanisation in lowlands increased this area's vulnerability to flooding. This study thus concluded that the confluence of the Benue River and the Niger River at Lokoja made the residents of the area more susceptible to flooding annually.

This study recommends that an early warning system approach be adopted by the Nigerian Meteorological Agency (NIMET) encouraged and supported by other sister organisations such as the Kogi State Disaster Management Agency and the National Emergency Management Agency. These two agencies (the Kogi State Disaster Management Agency and the National Emergency Management Agency) should be more proactive, rather than just dealing with the distribution of relief management and the management of flooding after it has occurred. These agencies should be provided with equipment and machines to enable them to carry out assessments and issue early warnings in vulnerable areas. This approach will help raise alerts and pass the relevant information on to the residents who reside in the flood-prone areas, so as to mitigate some of the adverse effects of any imminent flooding. Periodic clearing of silted and blocked drainage systems should be mandated by the Government and defaulting communities should be fined heavily. This measure will serve as a proactive measure in checking impending flooding in Lokoja. The study also forwards the need for improved river basin management and flood disaster prevention in the lowlands. The view is that the terrain analysis will support pre- and post-disaster response, planning and monitoring which are critical to sustainable city and integrated flood management. This study further recommends a geo-spatial investigation of disaster-prone areas after a flood disaster has occurred.

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(Received 15th October 2021, accepted 28th December 2021)