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GIS BASED FLOOD VULNERABILITY ASSESSMENT ALONG ASA RIVER, ILORIN NIGERIA

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ABSTRACT

Asa river basin is under threat of seasonal flood hazard. The flood problem has impacted lives and properties of people living within the vicinity. This study seeks to investigate flood vulnerability levels and assess infrastructure and population at risk along Asa River, Ilorin, using Geographic Information System (GIS). Five criteria which include elevation, bedrock, drainage density, land use and land cover, and rainfall were analysed and flood vulnerability factor layers were generated. AHP was used to evaluate and weight individual flood factors on the basis of their level of influence to flood vulnerability. Necessary reductions were made and permissible consistency ratio value of 0.072 was obtained. The percentage weights gotten from the reductions were further inputted for each factor to perform the Weighted Sum Analysis in ArcMap environment. Buildings at risk along Asa river channel were manually extracted using on-screen digitizing from high resolution satellite imagery derived from SAS Planet. Analysis of weight assigned to each factor considered indicated that rainfall ranked highest in terms of contribution to flooding with 36.43% when compared to other factors. Vulnerability map produced shows that highly vulnerable, vulnerable, less vulnerable and not vulnerable area account for 14.53%, 30.81%, 30.55%, and 24.12% respectively. Overlay analysis of the vulnerability map and map of existing infrastructure revealed that at least 425 buildings were at risk. The implication is that 2,125 people are prone to risk using the household figure of 5. The study concludes that, there is need for further study that will develop strategy that could catch flood and prevent jump to reduce the impact of flooding or its effects on the people and environment.

Keywords: Asa River**,** Flood vulnerability, GIS, AHP, Infrastructure at risk.

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1.0 INTRODUCTION

Floods account for approximately one third of global natural hazards and more people are adversely affected by flooding than any other geophysical phenomenon (Smith and Ward, 1998). On average, 20,000 people lose their lives due to flooding each year and it affects 75 million people globally, most of whom become homeless (Smith, 2001). Floods are one of the most common, costly natural disasters worldwide. For example, in the US, floods caused 8.17 billion in damages and 89 deaths annually over the period 1983 to 2012 (NWS, 2012). Nwilo *et al.* (2012) explained that floods are among the most devastating natural disasters and cost many lives every year. It is reported that flood disasters account for about a third of all natural disasters (by number and economic losses). Nigeria is no exception to countries that experienced flood hazard in recent time. Many communities have suffered losses due to flood problem. Adamawa State experienced flood disaster which destroyed farmlands and claimed lives and properties.

During the last two decades, many damaging floods have occurred in West Africa (Di Baldassarre *et al.*, 2010). In 2014, Asa river basin in Ilorin Kwara State experienced heavy flooding caused by intense rainfall. The worst affected areas were Unity road, Lower Taiwo road, Amilegbe/Emir's road, Aduaralere, Duma and Harmony Estate axis. Flooding along the Asa River in Ilorin is an annual occurrence and the unsafe condition of lives and properties along the river reaches has over the years become an issue of serious concern to individuals, Local, State and the Federal Government. Properties amounting to billions of naira are damaged yearly.

Source: (Ahmed Shittu THISDAY News Journal, May 28, 2017): ***Image of 2017 flooding at the downstream axis of Asa River: the area is one of the most affected by seasonal flooding***

The aim of this study is to analyze flood vulnerability along Asa river basin with a view to proffer more options in the management and control of flood hazard. The specific objectives are to: assess the various flood vulnerability factors, generate a flood vulnerability map for Asa river basin and assess the infrastructure and population at risk.

2.0 LOCATION OF THE STUDY

The study focuses on Asa river basin which has its source in Oyo State, South-West Nigeria and it flows through Ilorin, capital of Kwara State, Nigeria in a South-North direction forming a dividing boundary between the eastern and western parts of Ilorin metropolis. Asa River major tributary is River Awon, which continues to form one of the tributaries of River Niger at approximately 12.2 km North of Ilorin. River Asa is joined by River Oyun to the East and to the West by River Imoru. Afidikodi, Ekoro, Obe are among the earliest tributaries of Asa River while its tributaries in Ilorin include River Agba, Aluko, Atikeke, Mitile, Odota, Okun and Osere (Ojo, 1998 and Ibrahim *et al.,* 2013). The Asa Dam is located between latitudes 8°36´N and 8°24´N and longitudes 4°36´E and 4°10´E in Ilorin. The River is approximately 56 km long with a maximum width of approximately 100 meter within the dam site. Its total catchment area is approximately 1037 km^2 lying within Kwara State and Oyo State of Nigeria with about one third of the basin area located in Oyo State (Okekunle, 2000).

Asa River is a very significant source of water in terms of economic, agricultural and environmental purposes in the city as it is used in homes and industries (Ahaneku and Animashaun, 2013). There are farmlands, residential and industrial buildings along the banks of the river upstream and downstream of the dam. The geology of the area is described as undifferentiated basement complex. The substantial area is underlain by sedimentary rock which contains both primary and secondary lateritic and alluvial deposit (Oyegun, 1983).

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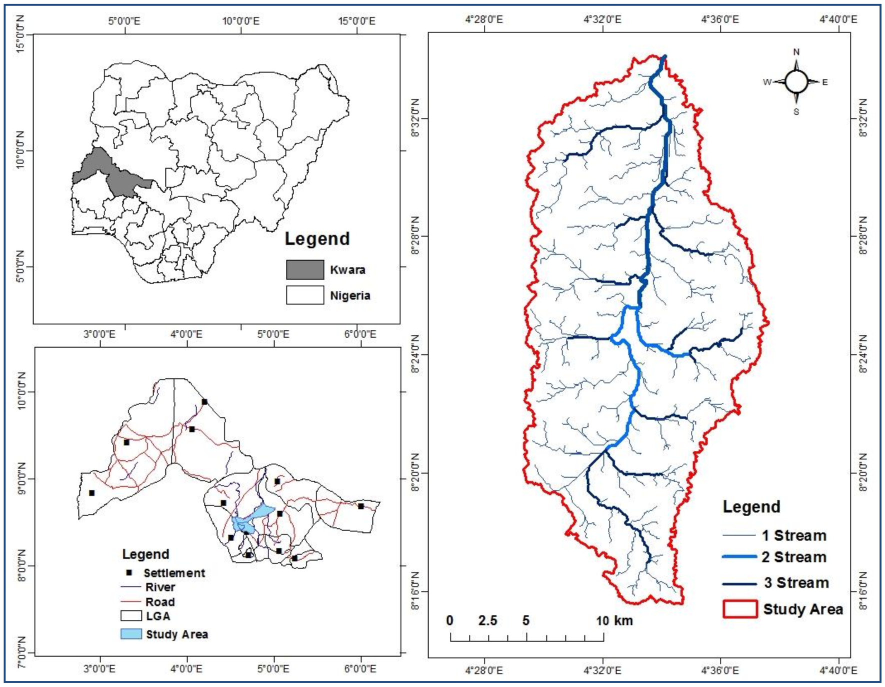

Figure 1: Location Map of Asa River Basin in Ilorin metropolis.
Source: Author's Laboratory Analysis, 2018

3.0 MATERIALS AND METHODS

Table 1: Data Types and Sources

Data Types	Sources	Resolution/Scale
LandSat OLI-TIRS	USGS Earth Explorer (2017)	30m
SRTM DEM	USGS Earth Explorer (2017)	30m
Rainfall	Food and Agriculture Organization of the United Nations FAOClim 2 World-Wide AgroClimatic Database (2017)	long, lat and variable (rainfall) prepared in excel file
Bedrock Map	Geological Map of Kwara State, (2017)	1:100,000
SAS Planet Imagery	SASPlanet Software Informer	30m

Flood vulnerability analysis is conducted in this study using two-steps process: assessment of various flood vulnerability factors and assignment of weights to the various factors. The work is based on Multi-criteria Decision Analysis with AHP (MCDA-AHP). Data such as LandSat (30m resolution), SRTM DEM, and Rainfall from FAOClim 2 World-Wide AgroClimatic Database, Geological map, and SAS Planet imagery (30 m) were sourced and utilized in the generation of various flood vulnerability factors. The layers derived are described hereunder.

3.0 GENERATION OF FLOOD VULNERABILITY FACTORS

3.1.1 Drainage density

Drainage density is the total length of all the rivers in a drainage basin divided by total area of the drainage basin. The drainage length density as explained by Greenbaum (1985) is the total drainage length per unit area. Drainage extracted from the SRTM data is expressed as the density map for easy characterization of rainfall runoff and accumulation of rain water in the catchment area. The drainage density map was analyzed in ArcMap 10.2 using the kernel density tool.

3.1.2 Elevation

Shuttle Radar Topographic Mission (DEM) data with 30 meters resolution was obtained from USGS (earthexplorer.usgs.gov) website. DEM was reclassified according to susceptibility to flood, color shades were applied, and equal interval was used and manually given range values. The basin shapefile which delineates the study area was used to mask out (with spatial analysis tool, extract by mask module) the area under investigation.

3.1.3 Land Cover Map

The land cover map was produced from the LandSat 8 OLI-TIRS image data using supervised classification (maximum likelihood classifier). False color combination, band 5, 4, 3, was composited and the bands were stacked for image classification operation. With proper knowledge of the study site and strict adherence to Anderson Level 1 classification scheme, the training sites were selected (region of interest – roi) and the various land use classes were diligently defined. Four LULC classes were identified and defined which are built-up, bare land, water body and vegetation (riparian, which are the flood plain zones). Post processing assessment was carried out to show the statistical analysis of the classification results, the overall accuracy and kappa coefficient was derived in Envi classic software.

3.1.4 Bedrock

The bedrock of the area is undifferentiated basement complex with loam sand surfaces. Oyegun (1983) reported that Ilorin is underlain by Precambrian Igneous metamorphic rock of a basement complex, which is neither porous nor permeable except in places where they are deeply weathered or have zone of weakness. Substantial area of the town is also underlain

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by sedimentary rock, which contains both primary and secondary lateritic and alluvial deposit. As reported by Oloru (1998), low permeability level of the old Precambrian rocks in the city increases surface water accumulation and run off after rainfalls which in turns lead to a flood. The bedrock map was scanned and georeferenced and digitized out on ArcMap and was further converted to raster and reclassified (preparation for usage).

3.1.5 Rainfall

Precipitation is a major hydrological parameter in flood vulnerability analysis. The mean rainfall data was extracted from the FAOClim World-Wide AgroClimatic Database, 32 station data in Nigeria was pre-processed in Excel Spreadsheet, imported and interpolated using inverse distance weighted (IDW) on ArcMap to produce the rainfall map as a major input data set.

3.2 Procedure for Flood Vulnerability Map Using Sum Overlay (AHP)

The mapping of the flood vulnerability zones within the study area was done by weighted sum overlay method in the ArcMap 10.2. The generated flood vulnerability factors were reclassified before overlay analysis. This was done by assigning the new weight values to the maps' sub-units (sub criteria) computed from the AHP using the reclass tool. The flood vulnerability map of the study area was produced by overlaying all thematic layers (i.e. drainage density, elevation, bedrock, land cover and rainfall) using the weighted sum overlay.

Flood Vulnerability Zone Map (FVZM) = $\sum_{i,j=1}^{n} WiXj$

Where Wi = % weight for each thematic map and Xj = reclassified map

3.3 Assessment of Infrastructure and Population at Risk

Satellite Imagery with 30 meter resolution from SAS Planet was used to digitize the infrastructure (buildings, roads, etc) along the water channel to know the infrastructure and population that are prone to flooding. Overlay operation was performed in ArcMap software using the flood vulnerability map and vectorized map of infrastructure to estimate the number of buildings and roads located in areas prone to flooding and the degree of vulnerability. Finally, a flood risk map (FRM) was produced and the population at risk was estimated by using the average number of household (H/H figure = 5) obtained from National Population Census. This value was multiplied by the total number of building at flood risk zones.

4.0 RESULTS AND DISCUSSION

Various flood vulnerability factor layers were generated and integrated with the use of GIS tool to produce flood vulnerability map in this study. These factors are: Drainage Density, Elevation, Soil, Bedrock, Rainfall and Land Cover Features. Watershed analysis was performed to determine the flow accumulation, flow direction, major basins and the drainage network (Figure 2). The obtained result describes the study area and shows the common sets of streams and rivers that all drain into a single larger body of water.

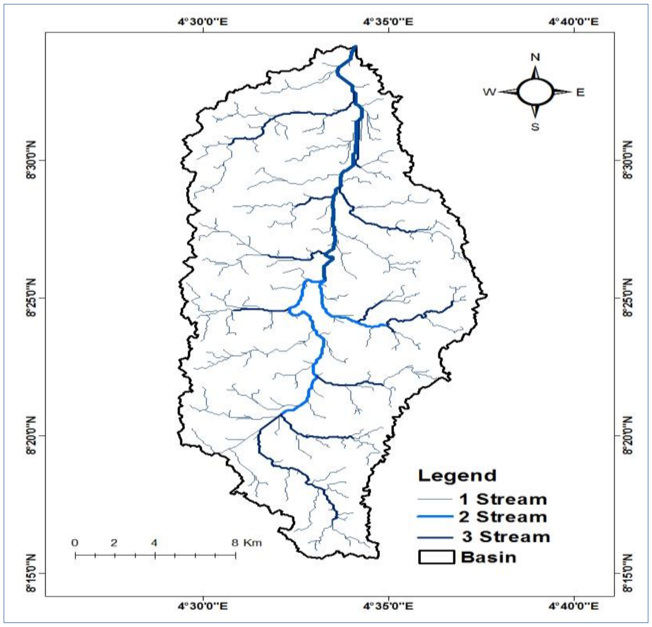

Figure 2: Drainage Network
Source: Author's Laboratory Analysis, 2018

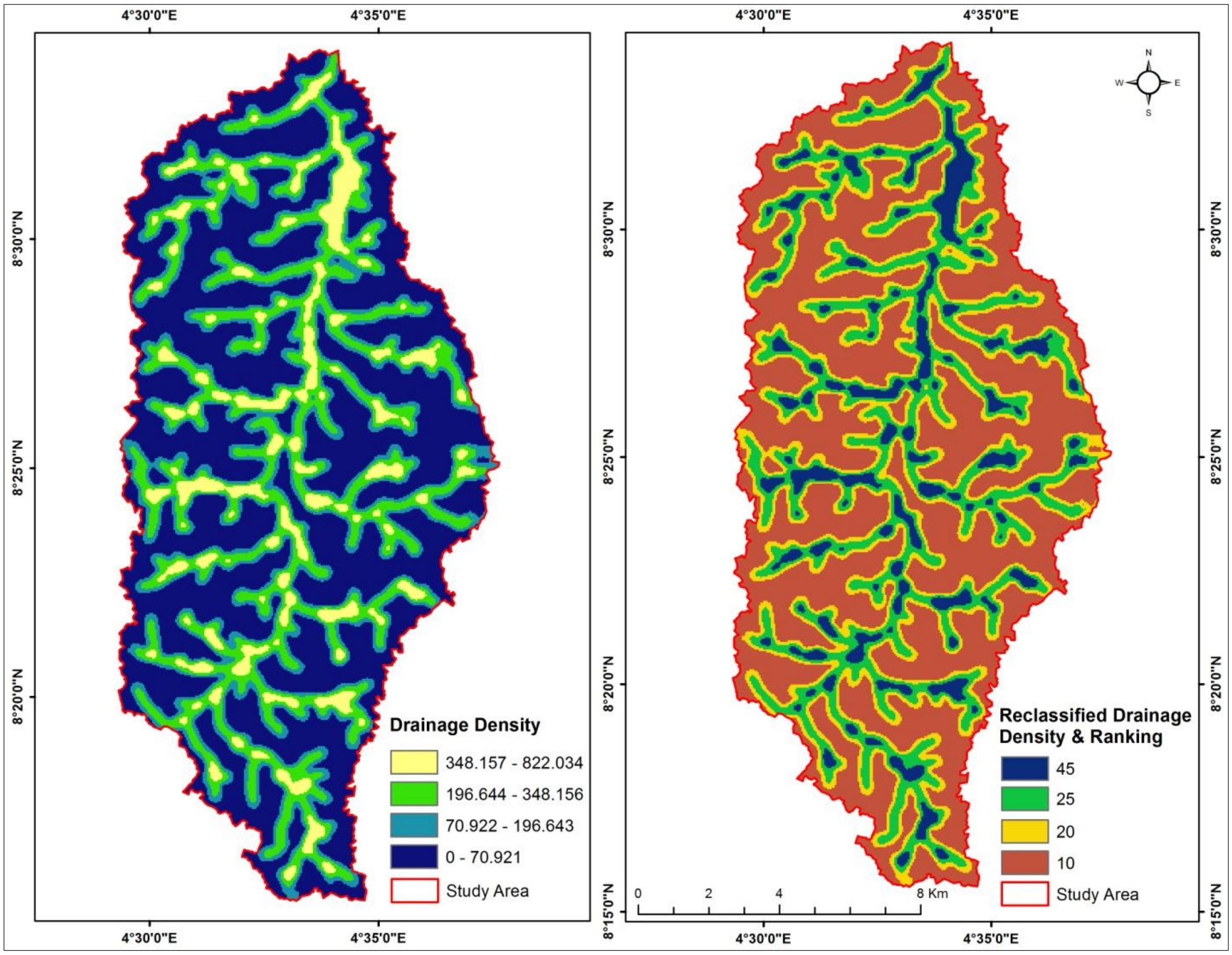

Figure 3: Drainage Density and the Reclassified.
Source: Author’s Laboratory Analysis, 2018

The drainage density system of the study area was observed to be influenced by the low relief of the area, which indicated dendritic and less parallel pattern of the drainages in South to North direction, the Asa river flows in South direction to North, having its upstream from the Dam axis towards the heart of Ilorin metropolis. Drainage density is a measure of how well or poorly a drainage system is drained by stream channels.

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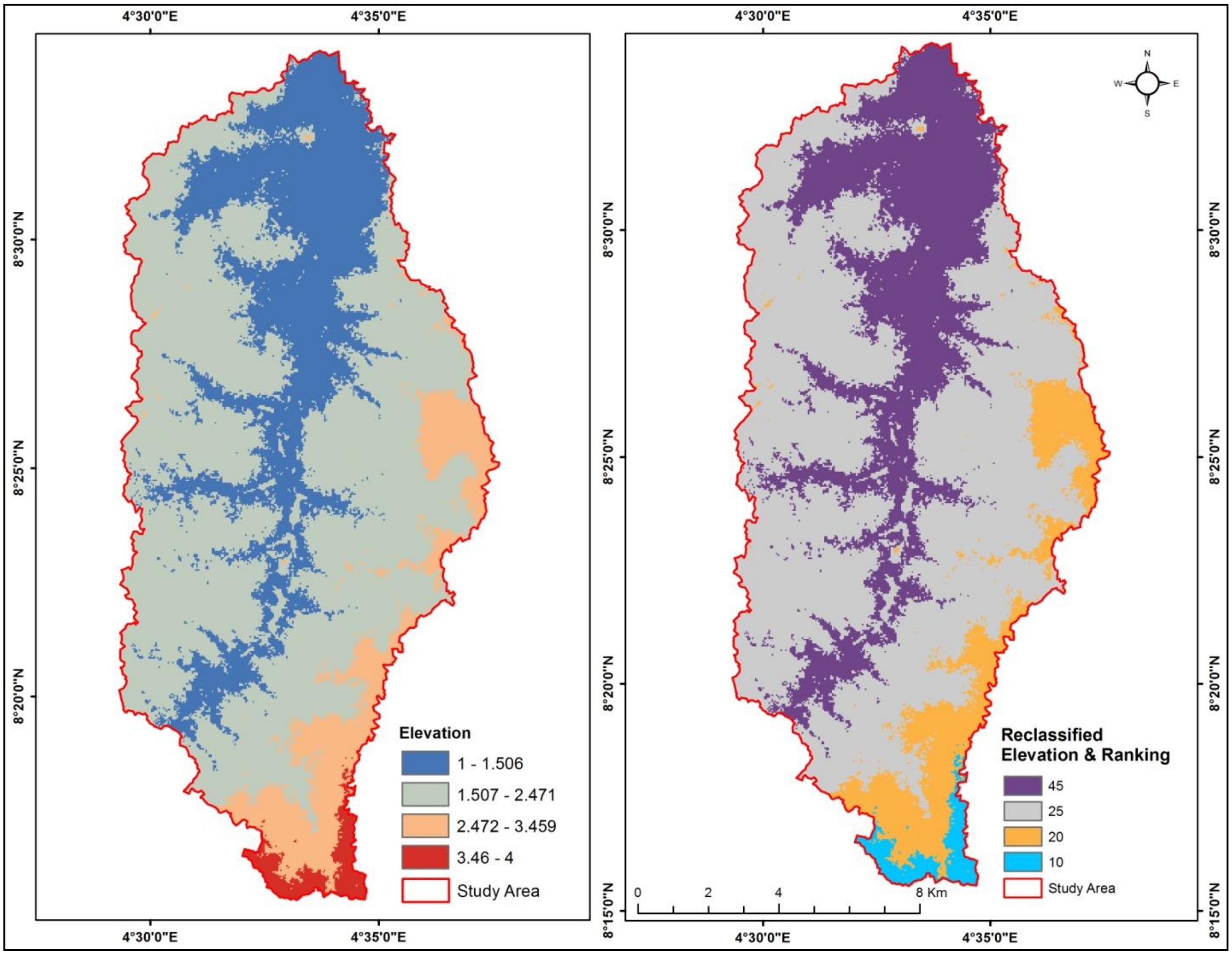

Figure 4: Elevation Map and the Reclassified
Source: Author's Laboratory Analysis, 2018

The DEM or surface analysis of the study area reveals the terrain information. The relief range 1 – 1.506 is the lowest and this shows the steepness of the area which is along the water channel. The steepest area is the highly vulnerable area because of the steep depth. The Southern part has a relatively higher elevation which is not vulnerable to flood.

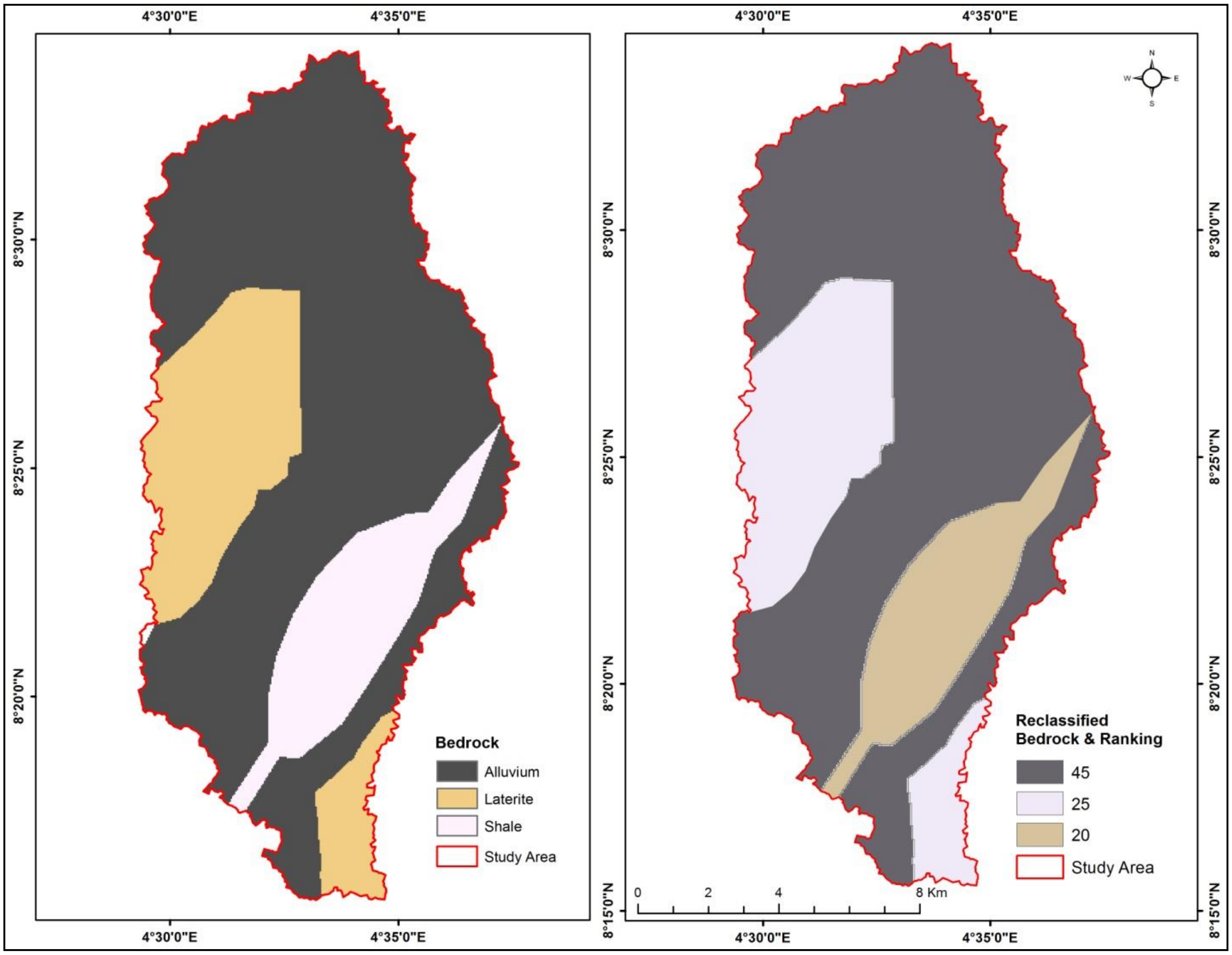

Figure 5: Bedrock Map and the Reclassified
Source: Author's Laboratory Analysis, 2018

The bedrock of the area is described as undifferentiated basement complex. The substantial area is underlain by sedimentary rock which contains both primary and secondary lateritic and alluvial deposit. The area covered by alluvium and laterite is high in the study area and described by Oloru (1983) as low permeability level of the old Precambrian rocks in the city which increases surface water accumulation and run-off after rainfalls which in turns lead to flooding.

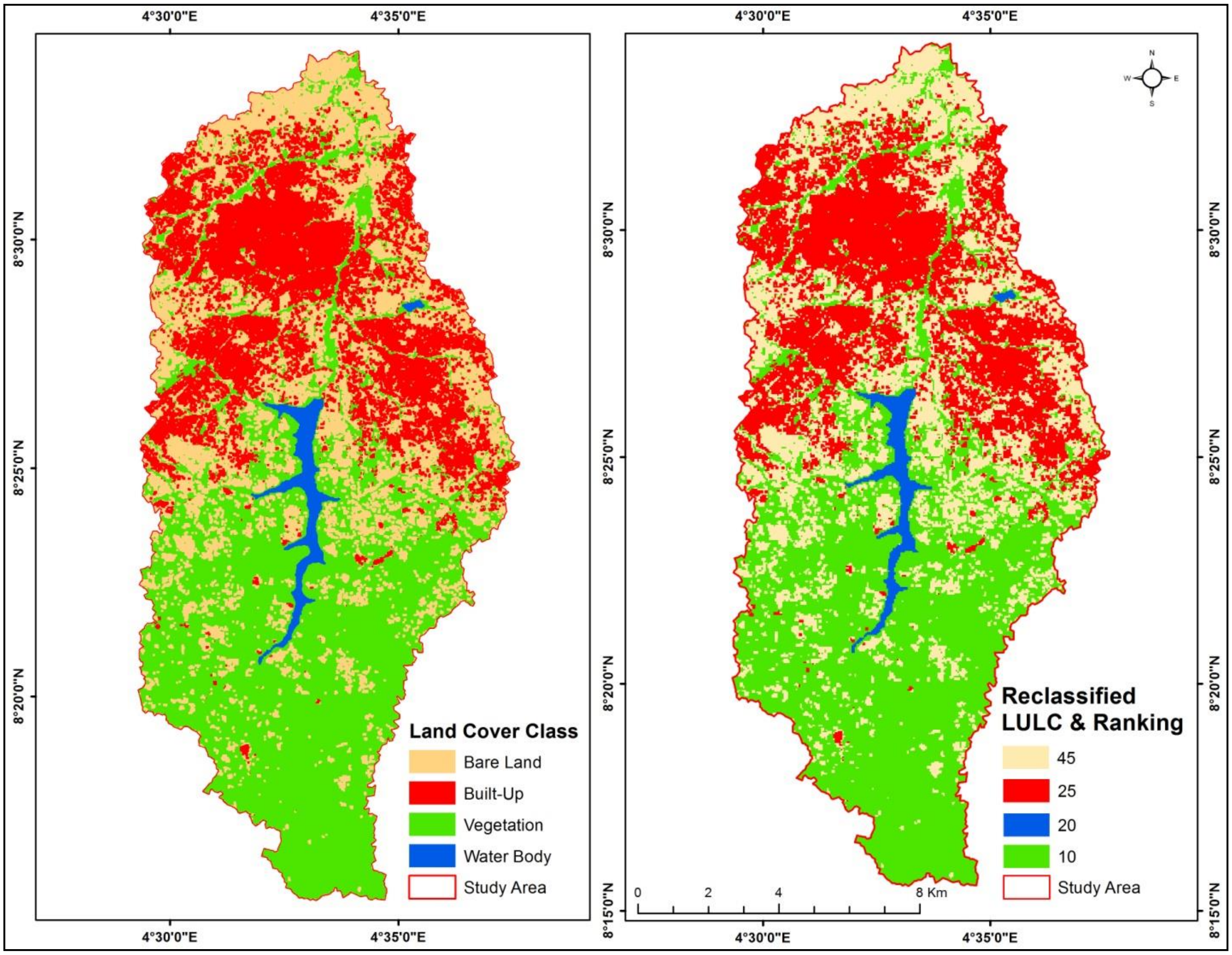

Figure 6: Classified Land Use Land Cover Map of the Study Area
Source: Author's Laboratory Analysis, 2018

Figure 6 is a classified Operational LandSat Image (OLI-TIRS) for the year 2017; the image was classified into 4 classes of land use land cover of the study area. The classification was done with Envi (Image processing software) and Anderson Level-1 classification scheme was adopted. The red class represents the built-up area, yellow indicates the bare land areas, green is the vegetation cover and blue is the water body. Vegetation and forests increase the infiltration and storage capacities of the soils. Further, they cause considerable retardance to the overland flow. Thus the vegetal cover reduces the high flood. This effect is usually very pronounced in small catchments of area.

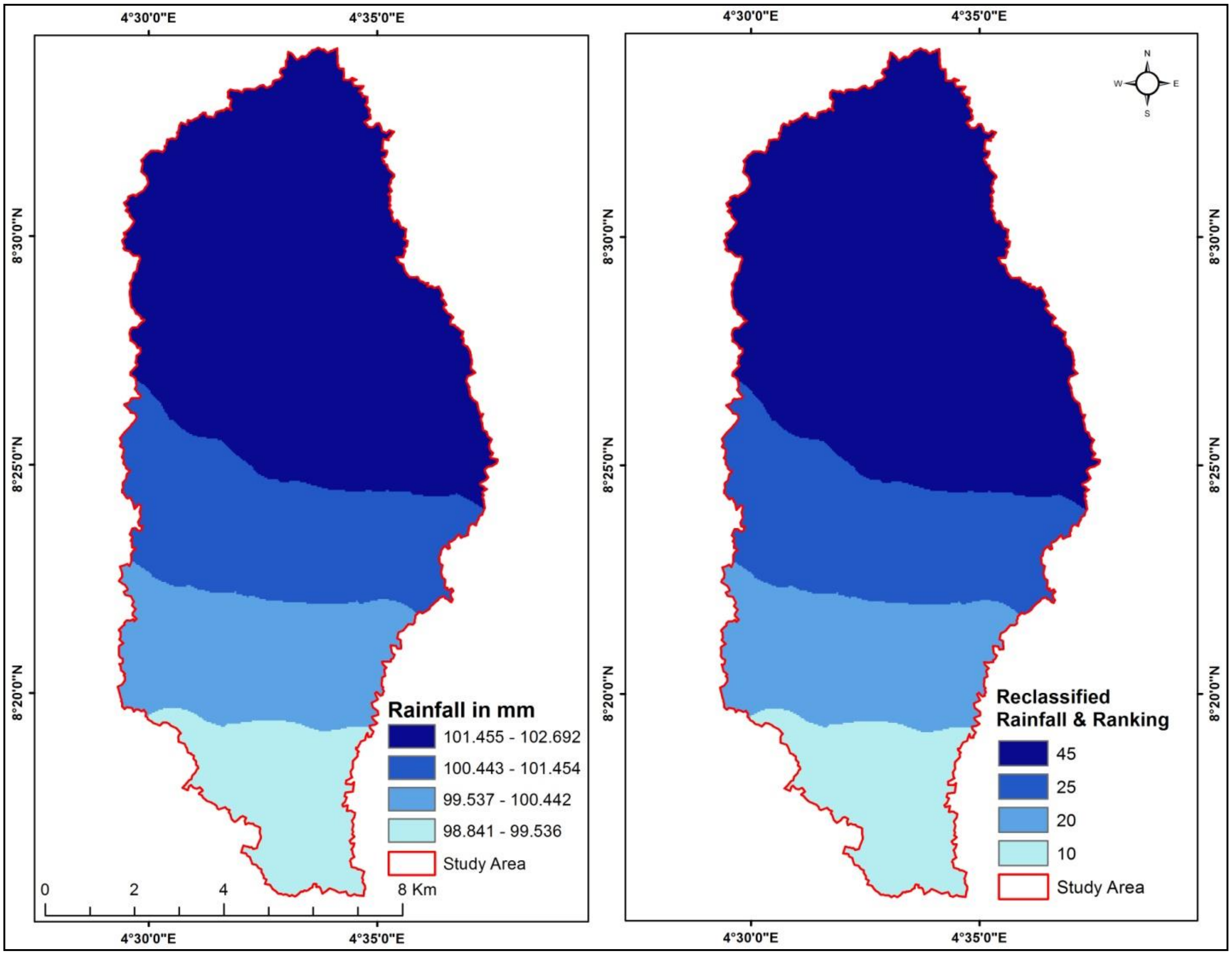

Figure 7: Rainfall Map and the Reclassified
Source: Author's Laboratory Analysis, 2018

Rainfall map was reclassified to show spatial variability of rainfall in the area under investigation. The downstream i.e. the Northern part of the study area has high rainfall relative to the Southern part, but the amount of rainfall as shown from the variability map explains that rainfall is major factor influencing flooding. Highly vulnerable area is at the heart of Ilorin metropolis (downstream) with high torrential rainfall and these area has high population with dense infrastructure around the water channels, this area is highly vulnerable to flooding, only the farming activities are carried out around the Asa river may not be affected due to less rainfall and high elevation if it experiences high torrential rainfall due to less infrastructure.

4.1 Weights of Criteria Computation Using Analytical Hierarchical Process (AHP)

AHP is used to calculate weight of criteria for decision making, the relative importance of features of each individual parameter to flood vulnerability mapping was critically determined. Each of the flood vulnerability factors was weighted using AHP. Processes involved for the assignment of weights to criteria are: A pair wise comparison matrix, computation of consistency index and consistency ratio.

Table 2: Normalized Weight Assessment by Ranking Sum Method

Criteria	Rank (order of preference)	Weight (w)	Normalized Weight (Wj)	Weight in %
Rainfall	1	5	0.03	39.62
DD	2	4	0.17	27.85
Elevation	3	3	0.28	17.23
Bedrock	4	2	0.12	11.85
Land Cover	5	1	0.40	3.45
Sum		**15**	**1**	**100**

Source: Author's Laboratory Analysis, 2018

Consistency Index = $\dfrac{\lambda max - n}{n-1}$

n = total no of factors

$\frac{5.323-5}{5-1} = 0.080$

Therefore Consistency Ratio = $\frac{0.080}{1.12} = 0.072$

Since CR 0.072 < 0.10, we can conclude that our matrix is reasonably consistent and hence decisions can be taken with derived weights of the criteria.

4.2 Sensitivity Analysis

Based on AHP method weights are calculated for bedrock, drainage density, elevation, land cover and rainfall of the catchment as 11.85%, 27.85%, 17.23%, 3.45%, and 39.62% respectively. The consistency ratio (CR) is found as 0.07. This indicated a reasonable level of consistency in the pairwise comparison of the factors. Raster layer in grid format of each parameter is multiplied by their given weight and summing them together using arithmetic weighted sum overlay tool in ArcMap 10.2 software.

4.3 Production of a Flood Vulnerability Map and Flood Risk Map

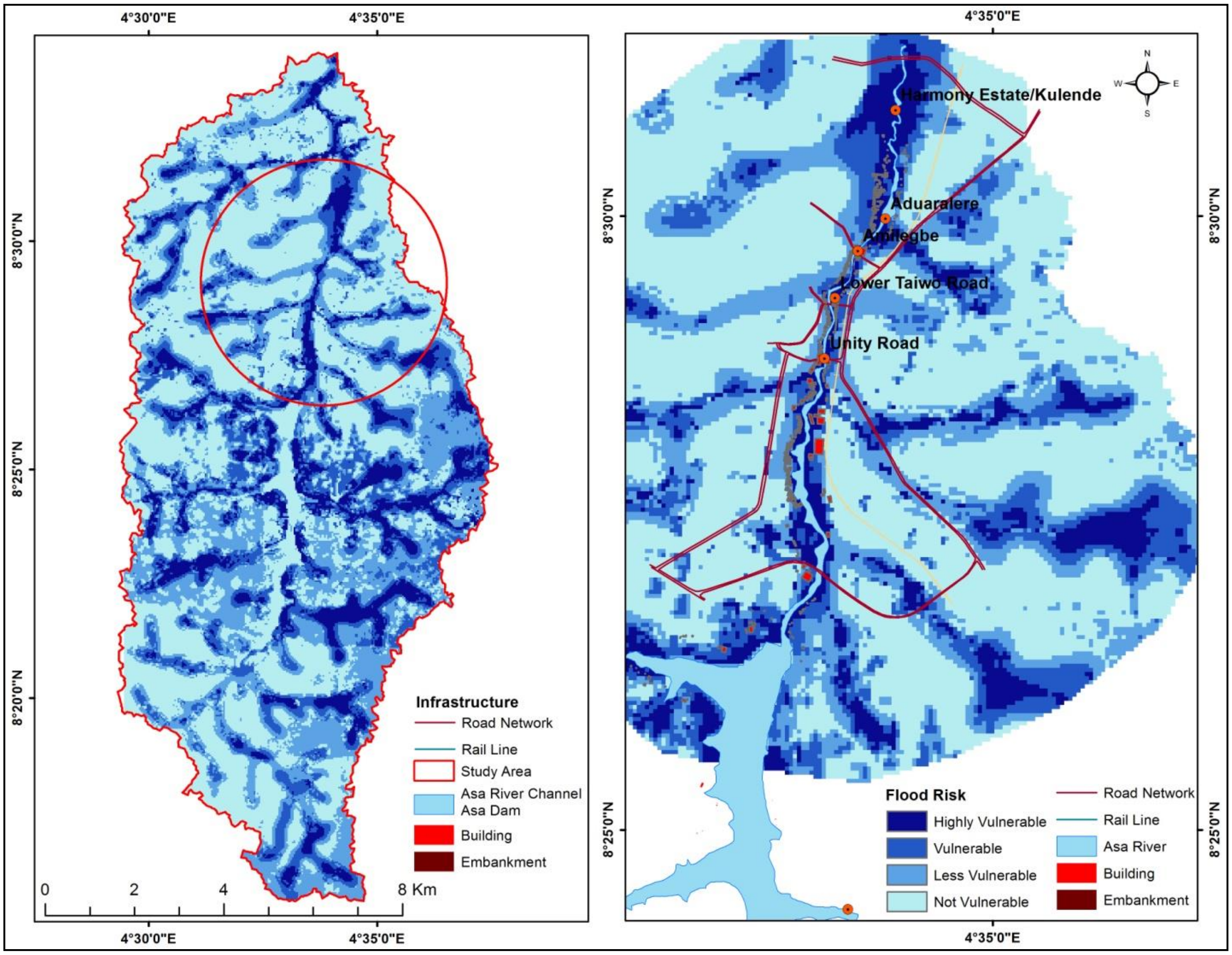

Figure 8: Flood Vulnerability Map and Superimposition of Vectorized Map on Flood Vulnerability Map for Flood Risk

Source: Author's Laboratory Analysis, 2018

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Table 3: Weights for Thematic Layers and Classes' Areas and Percentages Cover

Factors	Sub-Classes	Ranks	Weights	Area (km^2)	Area (%)
Bedrock	Alluvium	45	11.85	70.316	20.837
	Laterite	25		41.755	12.373
	Shale	20		225.385	66.789
Drainage Density	348.16 - 822.03	45	27.85	28.960	8.523
	196.64 - 348.16	25		181.251	53.343
	70.92 - 196.64	20		62.168	18.296
	0 - 70.921	10		67.400	19.836
Elevation	1 - 1.506	45	17.23	91.280	26.864
	1.507 - 2.471	25		207.124	60.958
	2.472 - 3.459	20		34.881	10.265
	3.46 - 4	10		6.495	1.911
Land Cover	Bare Land	45	3.45	90.885	26.75
	Built-up	25		100.135	29.47
	Vegetation	20		141.73	41.72
	Water body	10		7.008	2.06
Rainfall	101.46 - 102.69	45	39.62	37.355	10.900
	100.44 - 101.45	25		69.321	16.226
	99.54 - 100.44	20		55.151	20.396
	98.84 - 99.54	10		178.047	52.476

Source: Author's Laboratory Analysis, 2018

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Table 4: Flood Vulnerability Zones with Area and Percentage Coverage

Flood Vulnerability Zones	Area Coverage (Km^2)	Percentage Extent (%)	Areas within the zones
Highly Vulnerable	48.277	14.527	Coca Cola road, Unity, Lower Taiwo road, Amilegbe, Aduaralere, Harmony Estate, Duma, Mandate Housing Estate
Vulnerable	102.389	30.808	Emir's road, Ipata, Niger
Less Vulnerable	101.518	30.547	Station, Emirs Road
Not Vulnerable	80.153	24.118	Post Office, Taiwo, Gambari, Zango

Source: Author's Laboratory Analysis, 2018

Table 5: Sub-themes/Classes Contributing to the Five (5) Flood Vulnerability Zones

Zones	Sub themes/Classes
Highly Vulnerable	Alluvium, Bare Land, high drainage density, lower elevation, high rainfall.
Vulnerable	Laterite, Built-up areas, moderate drainage density, gentle elevation, moderate rainfall.
Less Vulnerable	Shale, Vegetation, medium drainage density, low elevation, low rainfall.
Not Vulnerable	Water body, lower drainage density, high elevation and lower rainfall.

Source: Author's Laboratory Analysis, 2018

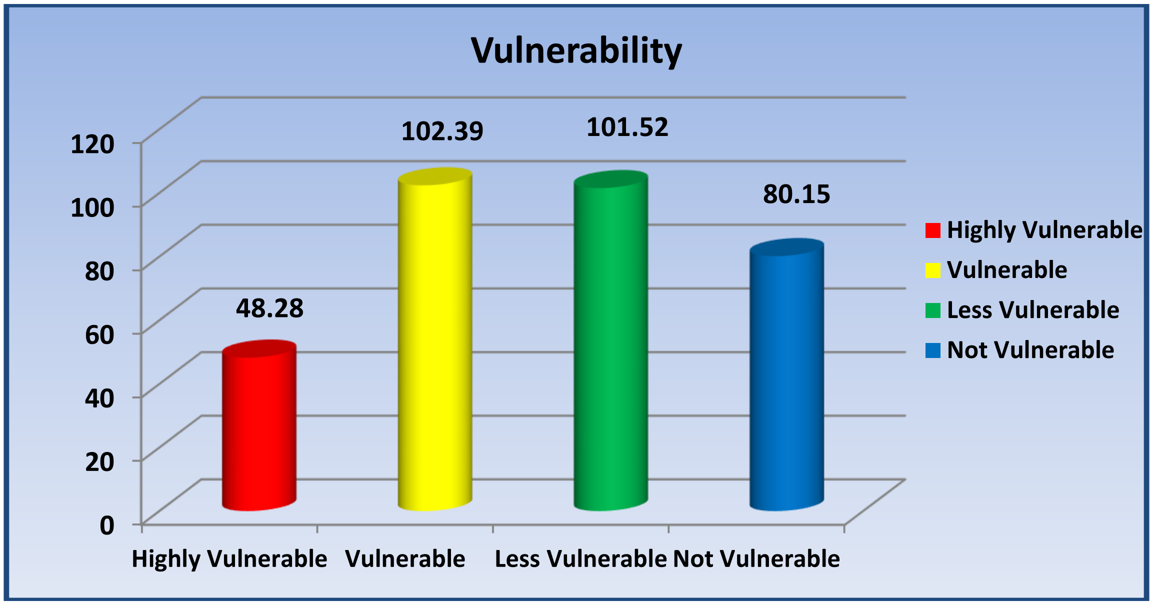

Figure 9: Bar Chart Showing Flood Vulnerability Distribution and Extent

4.4 Discussion of Results

In terms of class distribution and area extent, the study area occupies total area of 339 km^2. Highly vulnerable area occupies 48.277 km^2, vulnerable area occupies 102.387 km^2, less vulnerable area occupies 101.518 km^2, and not vulnerable area occupies 80.153 km^2.

The result of the vulnerability map shows four classes for the whole study area. This provides quick information about the vulnerable areas in Asa river catchment. These classes include highly vulnerable zones, vulnerable zones, less vulnerable zones and not vulnerable zones. The not vulnerable zone occupies an area of 24.118%, less vulnerable zone occupies an area of 30.546%, the vulnerable zone occupies 30.808% and highly vulnerable zone occupies 14.527%.

The different zones are delineated with graduated color depending on the degree of vulnerability.

Existing infrastructure (buildings, embankment, roads, and rail line) was digitized from SAS Planet imagery. A total of 550 buildings were digitized along the river basin for overlay.

The digitized map was overlaid on flood vulnerability map to assess infrastructure at risk. The total numbers of buildings that fall within the highly vulnerable zones are 425. The numbers of infrastructure within vulnerable zone, less vulnerable zones were not estimated because of the workload involved in heads-on digitization of the existing features.

Some major road networks also fall within the highly vulnerable zones which is the reason why some roads within Asa river basin are always eroded during torrential rainfall amongst poor drainage system. The Federal Government of Nigeria built embankment around Lower Taiwo Road/Emir's road which has highly contributed to the reduction of flooding in the downstream axis (built-up) of the study area.

4.5 Infrastructure and Table of Attributes

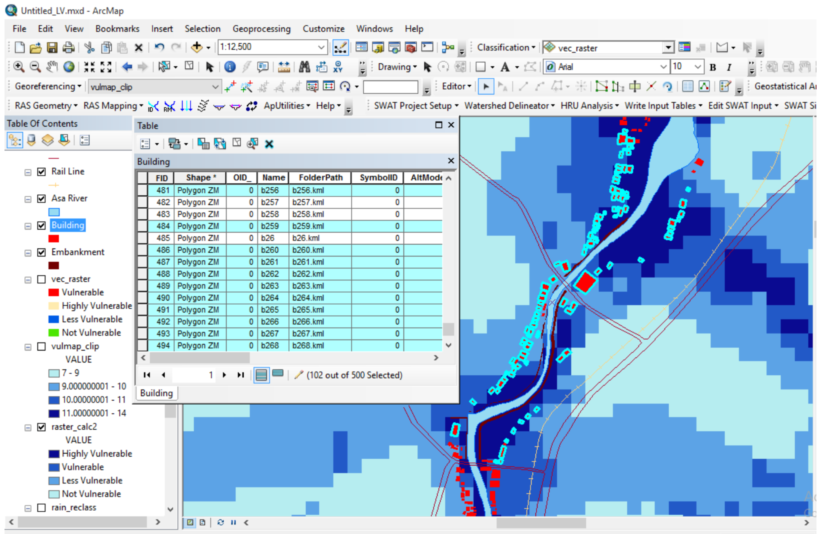

Figure 10: Infrastructure and Table of Attribute

The attribute table shows part of the buildings that fall within the different flood vulnerable zones, the highly vulnerable and vulnerable zones. The buildings, rail network, road network, embankment are mapped along Unity/Coca-Cola road, lower Taiwo road, Amilegbe/Emir's road, Aduralere axis towards Harmony Estate as shown in figure 10. The aforementioned areas are the majorly affected, in order to validate the result (accuracy assessment), ground truthing was carried out and it was discovered these areas are highly prone to flooding, hence the construction of embankments for flood mitigation in the axis.

4.6 Estimation of Population Vulnerable to Flooding

The flood risk map as shown estimated the total numbers of building that are highly prone to flooding because of their proximity to water channel. A total sum of 425 buildings was estimated to be at risk. From historical perspectives, most affected buildings are within Adualere, Amilegbe, Duma and Harmony Estate axis which is along the downstream of the study area. Total number of household was used to estimate the population at risk. National Population Commission from the 2006 census analysis concluded that average household figure in Nigeria is five (5). We can therefore estimate population as:

Table 6: Estimated Population Vulnerable to Flooding

	Area in square km	Average Household Size	Buildings at risk	Estimated Population at risk
Highly Vulnerable Zone	14.526	5	425	2,125

5.0 CONCLUSIONS

Geospatial techniques and GIScience (Spatial Analyst Tool) are valuable tools for mapping, modeling and variety of analysis in disaster management at various scales. Floods are natural phenomena which cannot be prevented. However, anthropogenic activity is contributing to an increase in the likelihood and adverse impacts of extreme flood events. The possibility to identify and predict flood prone areas on ungauged rivers is the major advantage of this method. The present study shows a simple way of using geographical information science and remote sensing for generating flood vulnerability factors (FVF), flood vulnerability zones (FVZ) and flood risk map (FRM) from the available remotely sensed data sets and the outcomes of this study can contribute towards an efficient flood risk management decisions towards sustainable development. For instance, flood inundation maps can help in mitigating flood damages and establishing early flood warning systems.

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