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Flood Vulnerability Assessment Using GIS/AHP in Jalingo Metropolis., Taraba State, Nigeria

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Abstract

This study identifies areas that are vulnerable to flood in Jalingo Metropolis using Remote Sensing and Geographical Information System (GIS) Techniques. Remote Sensing was used to generate the landuse map of the study area and GIS was used to integrate various layers of information to produce a vulnerability map. Multicriteria Evaluation particularly Analytical Hierarchical Process was employed to determine the influence of flood causative factors (elevation, slope, soil, drainage density, rainfall and land use land cover) on flood vulnerability in the study area. Weighted overlay tool in ArcGIS 10.1 was used to generate the final vulnerability map. Findings from the study revealed that elevation has the greatest influence on flood occurrences in the study area. The results also showed that areas that are highly vulnerable to flood constitute about 45% of the study area while moderate and low vulnerable areas constitute about 37% and 18% respectively. An estimate of 127,615 people is at risk of flood as revealed by the research. The study recommends improved land use planning, resettlement of communities along the river to safer areas and raising awareness of residents of the study area as measures to mitigate flood disaster.

Keywords: Assessment, Analytical Hierarchical Process, Flood, Multi-criteria, Vulnerability

1.1 Introduction

Flood has been defined by the United Nations International Strategy for Disaster Reduction (UNISDR, 2004)as a general temporary condition of partial or complete inundation of normally dry areas from overflow of inland or tidal waters or from unusual and rapid accumulation or runoff of surface waters from any source. According to Laner, Fellner, and Brunner (2009) and Merten, Nielsen, Soetarto, and Faust (2021) floods are purely environmental hazards which result from a number of basic causes of which the most frequent are climatologically in nature, but very often induced by man's improper utilization or abuse of the environment. Flood is considered the world's worst global hazard in terms of its magnitude, occurrence and geographical spread, loss of lives and properties, and displacement of people and socio-economic activities (Mukoro, Agunbiade, & Yakubu, 2015). It is also regarded as the costliest natural hazard in the world that accounts for about 31% of the economic losses resulting from natural catastrophes (Galy & Sanders, 2002), and causes about one-third of all deaths, injuries and damages from natural disasters (Ologunorisa & Abawua, 2005).

Enormous damage both in terms of properties and lives have been recorded as a result of floods all around the world. In July 1998, the Yangtze River in Yueyang, Hunan Province in China, overflowed its banks killing more than 4,000 people and drove millions from their homes. The event has been described as one of the worst on record (O'Connor & Costa, 2004). Goodwell et al. (2014) records the damage wrecked by the Mississippi River in the United States of America at over several millions of dollars when it overflowed its bank flooding towns, farmlands and major industrial installations and ravaging the state of Iowa. Similarly, several parts of Netherlands in 1998, experienced intense rainfall which led to the destruction of 2470 houses, 1220 premises, and 350 governmental agencies(Jak & Kok, 2000).

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On February 20, 2013 four people were killed overnight in flash floods in the village of Novomikhailovsky Russia's Black Sea region after torrential rains caused the local river to burst its banks. About 1,500 people were displaced from their homes, and 600 houses were flooded. Electricity was cut off, leaving more than 11,000 people without power. A total of 352,434 people were affected (Neußner, 2021). Barely five days after this incidence, was the northern town of Kumanovo in Macedonia hit by floods on February 26 as a result of heavy rainfall that left one dead, bridges wiped out and homes and fields inundated. Roughly 300 homes were also flooded in the village of Josifovo, 100 kilometers south of the capital of Skopje. An estimated population of 2,001,302 persons are said to have been affected (Neußner, 2021).

In recent years, African countries have also had devastating experiences, for example between August and September 2007, an estimated 1.5 million people were affected and other 300 killed as a result of floods that swept through 22 countries, from the east to west coast of the continent, the worst hit being Uganda, Sudan, Kenya, Ethiopia, Ghana, and Democratic Republic of Congo (National Geographic News, 2007).

Nigerian has suffered same fate like the rest of the world as floods have almost become annual events most especially in urban centers (Egya, 2021). Despite the government's step up measures on compensation and rehabilitation, the situation seems to be worsening by the day. It has been specifically observed by Adedeji, Odufuwa, and Adebayo (2012) that urban flooding is a phenomenon of every rainy season in Lagos, Maiduguri, Aba, Warri, Benin, Ibadan and a constant occurrence in towns located on flat or low lying terrain especially where little or no provision has been made for surface drainage, or where existing drainage has been blocked with municipal waste and other materials. With an urbanization rate of 5.5% yearly; the highest in the world, Nigerian cities of today face numerous problems which include deteriorating environment, urban decay, un-cleared refuse, flooding, erosion and pollution (Adedeji et al., 2012).

Flood events have destroyed lives and properties, polluted water resources and increased the risk of diseases (Adedeji et al., 2012; Birmah, Kigun, Alfred, Majidadi, & Surajo, 2021). While flood hazard is natural, human influence in the modification and alteration of urban space exacerbates the problem. The disastrous consequences are dependent on the degree of human activities and occupancy in vulnerable areas (Iyalomhe & Cirella, 2018; Mashi, Inkani, Obaro, & Asanarimam, 2020; Wahab & Falola, 2022). Worthy of note however is the fact that although flooding generally is a source of distress to most people, it can be quite beneficial. For example ancient civilizations like Egypt blossomed as a result of silt deposited by flood waters of the Nile, excess flood waters may be held in reservoirs and used to provide water for homes, industries and generate electricity (Ologunorisa, Obioma, & Eludoyin, 2022), and fishermen need not to paddle their canoes to the far end of the river before catching fishes (Etuonovbe, 2011)

Several studies(Adedeji et al., 2012; Cirella & Iyalomhe, 2018; Echendu, 2020; Etuonovbe, 2011; Ologunorisa et al., 2022; Olorunfemi, Komolafe, Fasinmirin, Olufayo, & Akande, 2020)have shown that societies vulnerability to flood have increased due to land use practices employed. With increasing human alteration and development of the catchment area these studies revealed that runoff generation process is changed, especially through decreasing the infiltration capacity of the soil and the change of soil cover. Environmental degradation coupled with uncontrolled urban development in high-risk zones, leads to an increased vulnerability of those communities on the floodplains to catastrophic events (World Meteorological Organization /Global Water Partnership-WMO/GWP, 2007). Ramiaramanana and Teller (2021) also pointed out that population explosion witnessed in urban centers of developing nations as a result of rural-urban migration in search of better living conditions has led to occupation of flood vulnerable areas. Climate change as a result of global warming is expected to bring about the increase in the frequency of flood events as temperatures rise, ice melts, sea levels rise with attendant consequences (Salimi & Al-Ghamdi, 2020). These changes pose a serious threat to human lives, economic development and the natural world on which much of our prosperity depends. Society therefore needs to take measures to adapt to these unavoidable impacts while taking action to cut the greenhouse gas emissions that are almost certainly causing climate change.

Obi, Nwachukwu, Okeke, and Jiburum (2021) have observed that one way to mitigate the effects of flooding is to ensure that all vulnerable areas are identified and adequate precautionary measures taken to ensure either or all of adequate preparedness, effective response, quick recovery and effective prevention. In order to facilitate the mitigation process, the authors emphasized the need for information 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.

Ozim, Olufemi, Ekpo, Alamaeze, and Mbanaso (2021) and Ishaya, Ifatimehin, and Abaje (2009)are of the view that flood vulnerability mapping can offer a hundred percent security against floods as it creates easilyread, rapidly-accessible charts and maps that can facilitate administrators and planners to identify areas at risk and prioritize their mitigation/ response efforts(John-Nwagwu, Edith, & Hassan, 2014). Jalingo, in recent years (2005, 2011, and 2012) has experienced catastrophic flood events resulting to loss of lives and destruction of properties worth millions of naira. These flood events have been attributed to heavy rainstorm worsened by the physical setting of the area which is characterized by undulating plains interrupted in places by low rising hills (Oruonye, 2012) as well as the presence or rivers Mayo-gwoi and Lamurde which traverse the low lying areas. In the event of heavy rainfall, these rivers overflow their banks thereby endangering human lives and properties which have encroached unto the floodplains due to population explosion experienced in the area since it became a state capital in 1991. The knowledge of the vulnerability status of this area cannot be overemphasized as it will serve as a tool for decision makers and consequently facilitate flood mitigation strategies.

Multicriteria Evaluation (MCE) is a Geographical Information System (GIS) based decision making tool that is used to analyzea series of factors or criteria with a view to ranking them from the most preferable to the least preferable using a structured approach (Carver, 1991; Ezekiel, Mustafa, Adelalu, & Yusuf, 2022; Villacreses, Martínez-Gómez, Jijón, & Cordovez, 2022). MCE has been developed to improve spatial decision making when a set of alternatives need to be evaluated on the basis of conflicting and incommensurate criteria (Malczewski, 2006). While GIS techniques and procedures support decision system by the integration of spatially referenced data in a problem solving environment (Malczewski & Rinner, 2015), MCE provides a rich collection of techniques and procedures for structuring decision problems, designing, evaluating and prioritizing alternative decisions (Boroushaki & Malczewski, 2010). GIS-MCE thus can be thought of as a process that transforms and combines geographical data and value judgments to obtain information for decision making (Carver, 1991). The end results of this synergy are usually composite maps that serve as a basis for decision making in many fields, for example locating groundwater potential zones (Hachem, Ali, El Ouali Abdelhadi, & Said, 2015), site suitability studies (Bwadi & Mustafa, 2019) and flood vulnerability assessments(Gashaw & Legesse, 2011; Legesse & Gashaw, 2008; Yahaya, Ahmad, & Abdalla, 2010). It is the foundation on which this study is built.

Since a relationship exists between urbanization and hydrological characteristics; decreased infiltration, increased runoff, increase in frequency and flood height (Alaghmand, Abdullah, Abustan, & Vosoogh, 2010), successful flood disaster mitigation requires detailed knowledge about the expected frequency, character, and magnitude of hazardous events in an area as well as the vulnerability of the people, buildings, infrastructures and economic activities in a potential dangerous area(van Westen & Hofstee, 2000). Ishaya et al. (2009) however note that this detailed knowledge is always lacking in most urban centers of the developing world especially Nigeria.

2.0 Materials and Methods

2.1 Study Area

Jalingo, the Capital city of Taraba State lies between latitude 8° 47′N to 9° 01′N of the equator and longitudes 11° 09′E to 11° 30′E of the Greenwich Meridian. The area is bounded by Lau local government area to the North, Yorro to the East, and Ardo-kola local government area to the South with a total land mass of 195km^2 (Oruonye & Abbas, 2011),as shown in Fig.1.

According to Nasidi and Bello (2020) the study area was a native authority district during the colonial era and remained so until 1976 when it was transformed into a local government area. The present day Jalingo has served as the State headquarters upon the creation of Taraba State in 1991 by the Babangida administration and the seat of the Muri Emirate Council (Oruonye & Abbas, 2011). From the southern part of the country, Jalingo can be accessed through Benue and Plateau States at Wukari and Ibi Local Government Areas respectively and through Gassol and Ardo-Kola Local Government Areas, while from the northern axis, Jalingo can be accessed through Adamawa State at Mayo-Belwa, Zing, Lau and Yorro Local Government Areas on one hand and through Demsa and Numan Local Government Areas on the other hand (Oruonye and Bashir, 2011).

The climate of Jalingo is of the tropical continental type, characterized by well-marked wet and dry seasons (Oruonye and Bashir, 2011). The wet season which lasts for a period of six (6) months usually begins around April and ends in October with a break coming up sometime in July (Udo, 1970). The rains are at their peaks usually between August and September. However, the break is not fixed as it sometimes extends into August (Nasidi & Bello, 2020) About 60% of the rain in the study area falls between the months of July and September. The dry season is characterized by the prevalence of the northeast trade winds popularly known as harmattan wind which begins in November and ends in March. Jalingo has a mean rainfall of about 1,200mm and an annual temperature of 29^{0}C with the highest temperature experienced in the month of March.

Relative humidity ranges between 60-70% during the wet season to about 35-45% in the dry season (Oruonye and Bashir, 2011). The study area is drained by River Lamurde, which is fed by smaller stream; Mayo-gwoi. Their content is emptied into the Benue river system at Tau village, dotted with ox-bow lakes that have been formed as a result of the depositional activities of the two afore mentioned rivers (Oruonye and Bashir, 2011).

The study area consists of sandstones of the Yolde formations which mark the transition from marine to continental sedimentation. In some areas, there is the alternating sequence of shale, mudstones with minor sandstones. The town is situated on the undifferentiated basement complex rock system. The outcrop of this rock is seen in the heart of the town popularly referred to as Jalingo hill. Quartz, mica and feldspar in fairly equal proportions are some of the constituent minerals that make up this rock. The rock is overlain by sandy-loam soil characterized by hydromorphic and ferruginous soils derived from the parent materials (Oruonye and Bashir, 2011).

Oruonye and Bashir (2011) revealed that the relief of Jalingo local government area consists of undulating plain intersected with hill ranges. The compact massifs of rocks run from Kona area through the border between Jalingo and Lau to Yorro and Ardo-kola local government areas in a circular form to Gongon area, giving a periscopic semi-circle shape that is almost like a shield to the town. From any vantage point in Jalingo, one can have a glimpse of these beautiful ranges in the background.

The soil of the study area is sandy clay in some parts and sandy loam in others. According to Federal Department of Agricultural Land Resource-FDALR of Nigeria (1990), the sandy clay is moderately poorly drained while the sandy loam on the other hand is well drained. The soil favors the cultivation of groundnut, while the sandy loam supports the cultivation of yam, maize, and guinea corn (Nasidi & Bello, 2020).

The study area is dominated by grassland (Guinea savannah) being in the northern part of the State, with sparsely scattered trees, though urbanization has taken its toll on the original vegetation. Local tree species include locust bean, sheabutter, baobab and silk cotton (Adagba, 2000; Oruonye and Bashir, 2011). The Eucalyptus (*Eucalyptus tereticornis*), Neem (*Azadirachtaindica*), and Gmelina (*Arborea*) trees have been domesticated (Nasidi & Bello, 2020)

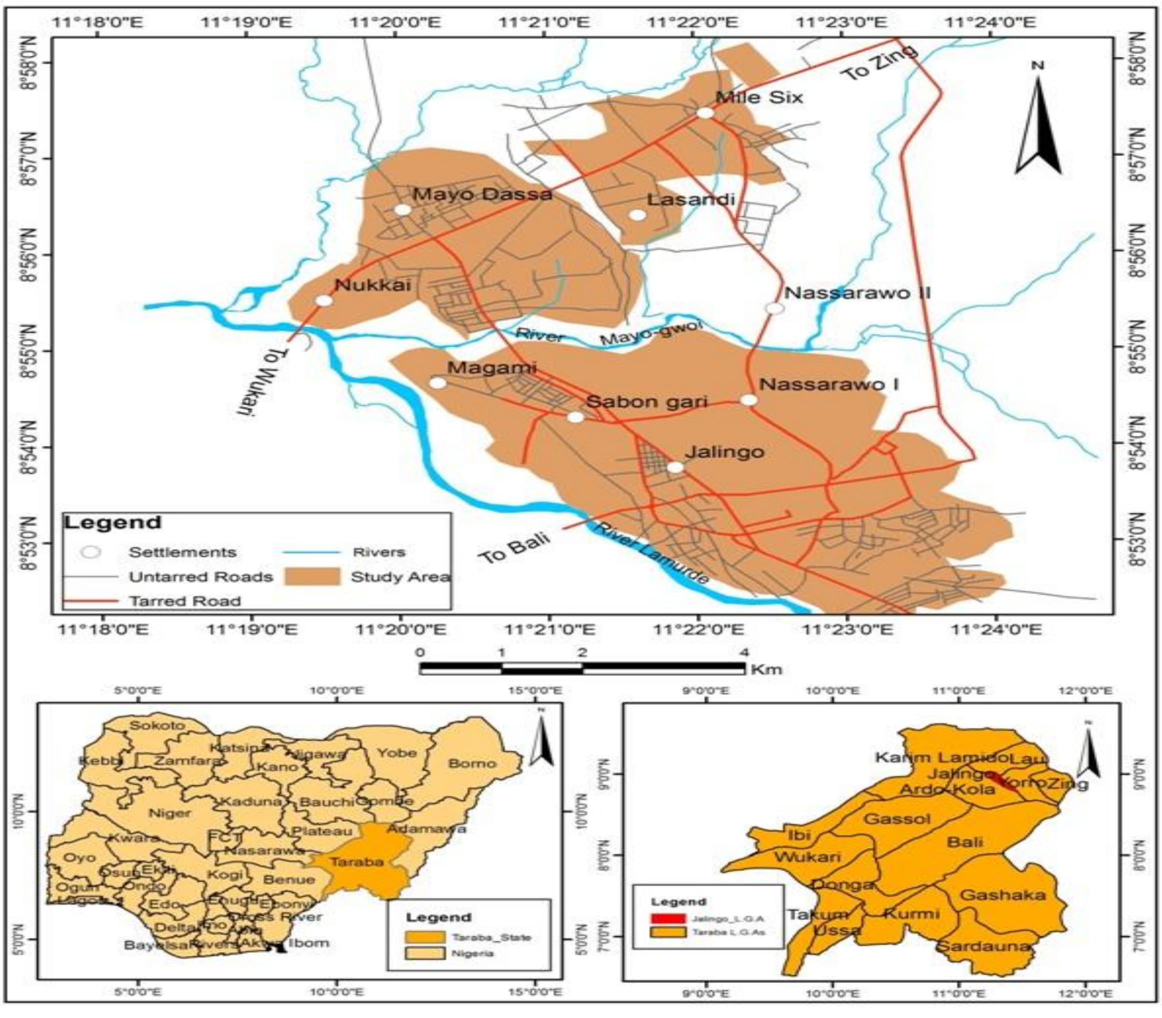

Figure. 1.1: Map of the Study Area

2.2 Methodology

2.2.1 Types and Sources of Data

Both Primary and Secondary data were used in this study.

(i) SPOT 7 Imagery with 1m spatial resolution, acquired in 2014was used to extract land use land cover (LULC) of the study area where Object-based classification method was employed to carry out the task.
(ii) Global Positioning System (GPS) was used to acquire coordinates of residential educational, commercial, and health facilities to determine their vulnerability status.
(i) Topographic map on scale 1:100,000 acquired from the State Ministry of Lands and Survey and Soil map at a scale 1:650,000 obtained from the Department of Soil Science, Ahmadu Bello University, Zaria covering the study area were used to extract the drainage and different soil types respectively.
(ii) Rainfall data of three (3) stations Yola, Gassol, and Gembu lying around the study area was obtained from Upper Benue River Basin Development Authority (UBRBDA), Yola, Adamawa State and also used to generate a thematic layer.
(iii) Advance Space borne Thermal Emission and Reflection (ASTER) imagery of 30m resolution covering the study area was downloaded from United States Geological Survey (USGS) website, www.glovis.usgs.gov., and employed in the research to extract slope and elevation data.
(iv) The Point data of localities within the study area and their Population data of NPC (1991) was obtained from the State office of the NPC and used to determine vulnerability status of localities and population at risk respectively.
(v) Existing literature from journals, thesis and reports, conferences and web references were also used.

2.2.2 Hardware and Software

Hardware

i. High speed memory digital electronic computer hardware Dell laptop was used.

Software

i. ENVI 4.5 was used for land use land cover classification.
ii. ArcGIS 10.1 was used to generate and integrate the thematic maps for the analysis.
iii. AHP software (Klaus D. Goepelversion 19.02.2013) was used in pair-wise comparison of the factors.

2.3. Methods of Data Collection

Reconnaissance survey

Reconnaissance survey was carried out in order to have a general knowledge of the study area. Information collected at this stage aided the visual image interpretation process and image classification.

Image Pre-processing

The SPOT 7 Imagery of (1m) resolution was registered using the UTM Zone 32 North and datum WGS 1984. There was no need for geometric and radiometric corrections because the image is orthorectified. This was followed by subsetting, which is the process of clipping out the Area of Interest (AOI) otherwise known as the study area from the image. The Spot Imagery (1m) resolution and ASTER data of 30m resolution were both sub-mapped to Jalingo.

Image Classification

Image classification is a procedure for categorizing all pixels in an image of a terrain into land use land cover classes. Image classification was carried out using the Object based classification method in ENVI 4.5 to determine the land use land cover type in the image. Unsupervised classification was performed in order to have a general idea of the area which was followed by supervised classification for the final land use land cover classes mapping. Information obtained from ground truthing was used to reaffirm land use land cover classes class before subjecting the imagery to supervised classification using the Object based classification. The land use land cover classes of the study area was classified based on Anderson, Hardy, Roach, and Witner (2001) classification of Agriculture, built-up land, bare surfaces, forest, wetland and water body. It was however modified to suit the study area after ground truthing.

Image Transformation

Image transformation was employed to differentiate the various brightness values which may cause conflicting appearances as a result of identical surfaces appearing on the image due to slope, aspect, topography, shadows as well as sunlight illumination angle and intensity.

2.4 GIS Analysis

Thematic maps were produced for all six factors that affect flood in the study area and inputted into a GIS environment for proper analysis by creating a geo-database for proper data management of all dataset involved in the study. The dataset included land use land cover classes, drainage density, soil, rainfall, elevation and slope. All data layers derived were converted to raster data sets having the same pixel size. Each data set in a single map was given weight by pair-wise comparison; in addition the six (6) factor maps were compared with each other in pair-wise comparison. Reclassification of each map was done based on the weights produced.

Land use/cover

The land use land cover classes of Jalingo metropolis was obtained from Spot Imagery by subjecting it to unsupervised classification using ENVI 4.5 which gave a general idea of the land use land cover classes of the area. Information obtained from ground truthing was used to reaffirm classes before subjecting the imagery to supervised classification using the object based classification. The land use land cover class of the study area was classified based on ground truthing.

Drainage

The topographic map of Jalingo obtained from Sheet 215 (Jalingo) of scale 1:100,000, First edition was scanned and imported into ArcGIS 10.1 environment where it was geo-referenced based on the map projection UTM Zone 32 North and datum WGS 1984. The study area was clipped form the map and its drainages digitized. Verification was also done using the Spot imagery, ASTER as well as ground truthing.

Soil

The soil map of Nigeria obtained from sheet 6 of 8 of scale 1:650,000, was scanned and imported into ArcGIS 10.1 environment where it was geo-referenced based on the map projection UTM Zone 32 North and datum WGS 1984. The study area was clipped from the map and the different soil types of the study were digitized.

Rainfall

Daily rainfall data of 3 rain gauge stations that lie in the study area or near the study area has been acquired from UBRBDA, Yola. The mean annual rainfalls for 30 years were used to

Digital Terrain Model

The ASTER data was used to generate the Digital Elevation Model (DEM) of the study area with the help of the Spatial Analyst tool in ArcGIS 10.1.

Slope

The slope amount was obtained in degrees from the contours that were generated from the sub-mapped ASTER data of Jalingo. In the GIS environment, the contours were subjected to spatial analysis using the spatial analyst module in ArcGIS to generate the slope. The slope amount derived was further classified into appropriate classes.

2.5 Deriving the Criterion weights using AHP

The relationship between these six thematic layers and the relationship between their various attributes were derived using AHP. The methodology for deriving the weights of the thematic layers and their corresponding attributes using AHP involved the following steps:

Step 1: Defining the problem clearly and decomposing it into various thematic layers containing the different feature/classes of the individual themes so that they form a network of the model.

Step 2: Generation of Pair-wise Comparison Matrices: The relative important values are determined with Saaty's 1-9 scale (Table .1) where a score of 1 represents equal importance between the two attributes, and a score of 9 indicates the extreme importance of one attribute compared to the other one (Saaty, 1980).

Table 1: Fundamental Scale for Pair wise Comparison

Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective

3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very Strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
	2,4,6, and 8 are intermediate values	

Source:Saaty (1980)

Based on thematic layers used for delineating flood vulnerable zones, pair wise comparison matrix is derived using Saaty's nine point importance scale.

The AHP captures the idea of uncertainty in judgments' through the consistency index (Saaty, 2008). Saaty gave a measure of consistency, which are as follows

- Consistency Ratio (CR) is a measure of consistency of judgment amongst the criteria.
- The rule of thumb states that the CR should be less than or equal to 0.1
- Thus a value of 0-0.1 is accepted in practice.
- Any higher value indicate that the judgment warrant re-visitation
- CR thus is evaluated as follows: CR=CI/RI where
  CI- represents Consistency Index which reflects the consistency of one's judgment
  CI=λmax-n/1-n
  λ is calculated by averaging the value of the consistency vector (calculated factor weight)
  RI- denotes Random Inconsistency index that is dependent on the sample size (Table 2).

Table 2: Random Inconsistency Indices (RI) for N-10

	3	4	5	6	7	8	9	10
	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty (1980)

2.6 GIS Modelling

In order to delineate flood vulnerable zones in the study area, all the weighted data sets were integrated in ArcGIS 10.1. The final map was produced by weighted overlay where each class individual's weight was multiplied by the map scores and the results added. This procedure is facilitated by the equation:

S = ∑ Wi Xi, where;
S = Vulnerability
Wi = Weight for each map
Xi = Individual map

2.6.1 Identification of Elements at Risk

All houses roads and farmlands were digitized as points, lines and polygons respectively and overlaid on the vulnerability zones to determine their status. Furthermore, point data locations of health, educational, religious and commercial facilities were overlaid on the vulnerability map to also determine their status.

2.6.2Generation of buffers along rivers and overlay of location point data on buffered zones

Buffers of 30 and 1500meters respectively were generated along the rivers using the spatial analyst, and point data location of localities overlaid on the buffered zones to determine the vulnerability of localities and consequently estimate population at risk in the study area with the help of the Exponential method given as:

$Po=Pte^{rn}$, where
Po= Expected population
Pt=Population of previous year
e= Exponential
r=Growth rate (in this case 0.003)
n= Number of years interval (in this case 19 years)

3.0 Results and Discussion

3.1 Flood Vulnerable Areas

This section consists of two parts. The first presents the result of the pair-wise comparison carried out for each dataset and the weights generated based on Saaty's Fundamental scale of pair-wise comparison (Table 1). The second part presents the result of the pair-wise comparison carried out for the six flood causative factors under consideration in this research and the generated flood vulnerability map (Figure 4.16). The AHP software (Klaus D. Goepel version 19.02.2013) was used in the pair-wise comparison of the factors.

3.2 Land use/ land cover

The pair-wise comparison carried out and weights calculated for land-use (Table 3) was based on the fact that built-up areas and cemented surfaces generate more surface runoff since they do not allow infiltration, while others like vegetation comprising of forests and farmlands on the other hand permit interception of precipitation which can either evaporate and return to the hydrological cycle or flow down the stem of the plants and trees (stem flow) and then flow along the ground or infiltrate and percolate into the ground, thereby reducing the surface runoff and consequently the flood magnitude (Lindsay-Walters, 2015). A look at the first row/first column of Table 3 shows the comparison between built-up and built-up being rated 1 because based on Saaty's (1980) fundamental scale for pair-wise comparison (Table 1) they are of equal importance in flood occurrence. However, when comparing built-up with bare-land (first row/ second column), built-up has been rated 9 indicating that it contributes more to flood occurrence than bare-land which has been rated 5. This procedure was carried out for all the land use land cover classes with the help of the AHP software. The last two (2) columns of the table display the weights in ratio and percentage respectively of each land use land cover class indicating its position in influencing flood occurrence.

From the table built-up contributes more with a weight of 27, tarred road 20, bare-land and un-tarred road 16, vegetation 13 and water-body 7. With a CR of 0.035, the judgment was seen to be consistent and the result accepted.

Table 3: Weight for land use/land cover

	Built-up	Bareland	Tarred Road	Untarred Road	Vegetation	Waterbody	Weight	Weight *100
Built-up	1	9/5	9/7	9/5	9	3	0.27	27
Bareland	5/9	1	7/5	1	5	5/3	0.16	16
Tarred Road	7/9	5/7	1	7/5	7	7/3	0.20	20
Untarred Road	5/9	1	5/7	1	5	5/3	0.16	16
Vegetation	1/9	1/5	1/7	1/5	1	1/3	0.13	13
Waterbody	1/3	3/5	3/7	3/5	3	1	0.07	7

Consistency Ratio = 0.035

Based on the weights generated, the land use land cover classes were reclassified (see Table 4), and the reclassified map (Fig. 2) produced.

Table 4: Reclassified Landuse/cover

Land Use/Cover	Weight	Class
Built-up	27	Very high
Tarred road	20	High
Bare-land	16	Moderate
Vegetation	13	Low
Waterbody	7	Very low

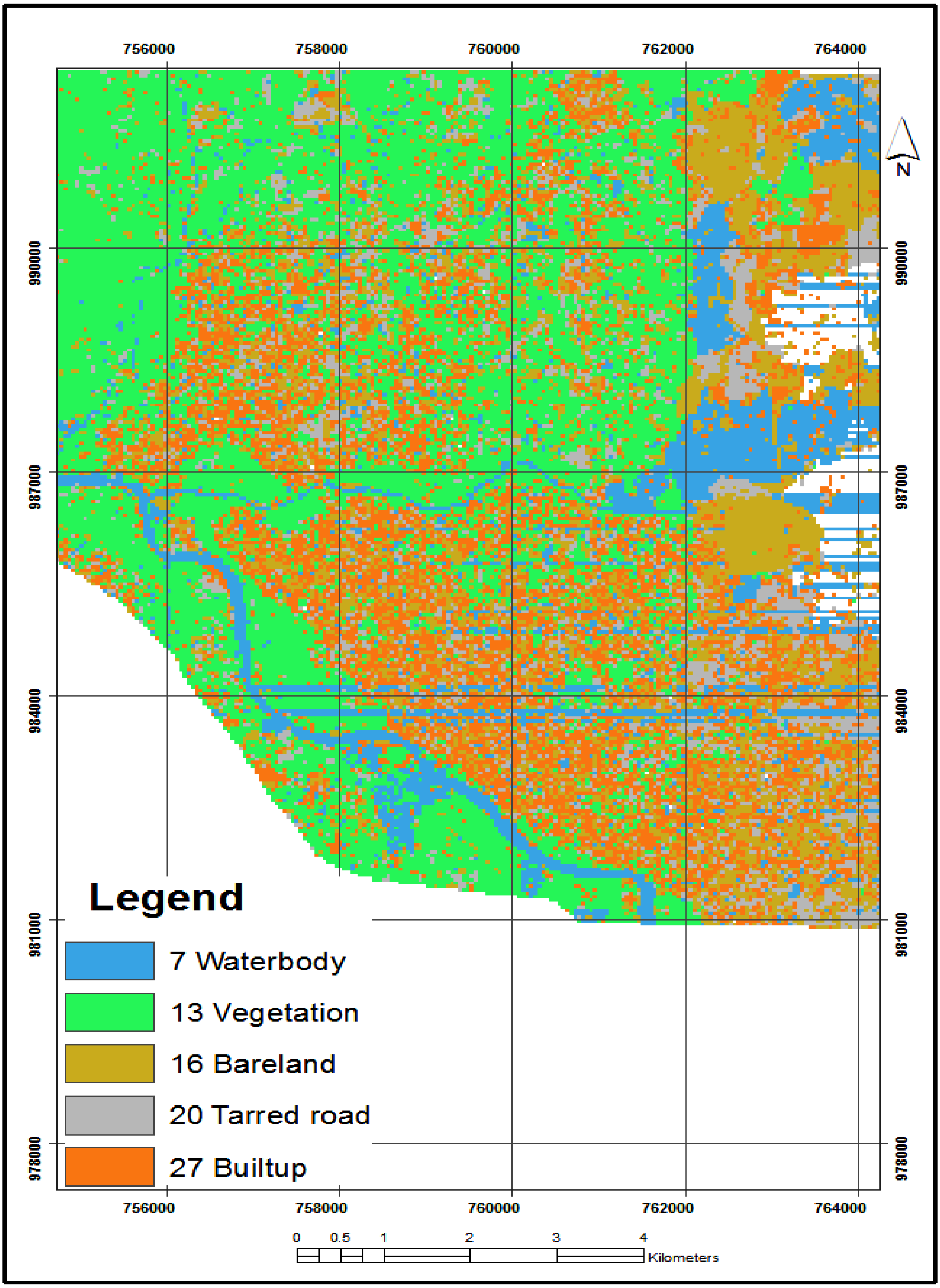

Figure 2: Reclassified land-use/ landcover of the study area

3.3 Drainage Density

Drainage density has been recognized by authors such as Gardiner and Gregory (1982) and Pallard, Castellarin, and Montanari (2009) to be significantly effective on the formation of flood flows. According to the authors, high densities can indicate a greater flood risk, while a decreasing density generally implies decreasing flood volumes.

Thus, the 5 classes of drainage density generated were compared against each other (Table 5). The pair-wise comparison done for areas with very high drainage densities against those with high has the ratio 9/7 indicating that areas with very high drainage densities rated 9, have extreme importance or influence on flood occurrence over high which has been rated 7. The ratio of 9/5 on the first column shows that very high drainage (9) is still extremely important over areas with moderate drainage (5) as far as flood incidences are concerned. The digit 3 on the fourth column/ first row is actually the result of the ratio 9/3 of the comparison between very high drainage rated 9 and low drainage rated 3. The basis for these ratings is contained in Table 1. This procedure is repeated for all the classes against each other and weights generated automatically by the AHP software.

The pair-wise comparison done for drainage density thus revealed that for areas with very low and low drainage densities, weights of 4 and 12 were calculated respectively while areas with very high and high drainage densities had high weights of 29 and 36 respectively. The CR generated stood at 0.06, thus the judgment was accepted.

Table 5: Weight for drainage density

	Very High	High	Moderate	Low	Very Low	Weight	Weight*100
Very High	1	9/7	9/5	3	9	0.36	36
High	7/9	1	7/5	7/3	7	0.29	29
Moderate	5/9	5/7	1	5/3	5	0.20	20
Low	1/3	3/7	3/5	1	3	0.116	12
Very Low	1/9	1/7	1/5	1/3	1	0.038	4

Consistency Ratio=0.06

Table 6 shows the 5 classes of drainage density, their weights and reclassification.

Table 6: Reclassified drainage density

Drainage (km^2)	Weight	Class
0-2.9	4	Very Low
2.9-9.0	12	Low
9.0-17.7	20	Moderate
17.7-29.4	29	High
29.4-60.0	36	Very High

The reclassified map of drainage density (Fig.3) was produced based on these weights. Areas with very high drainage densities are depicted in purple and those with low in green.

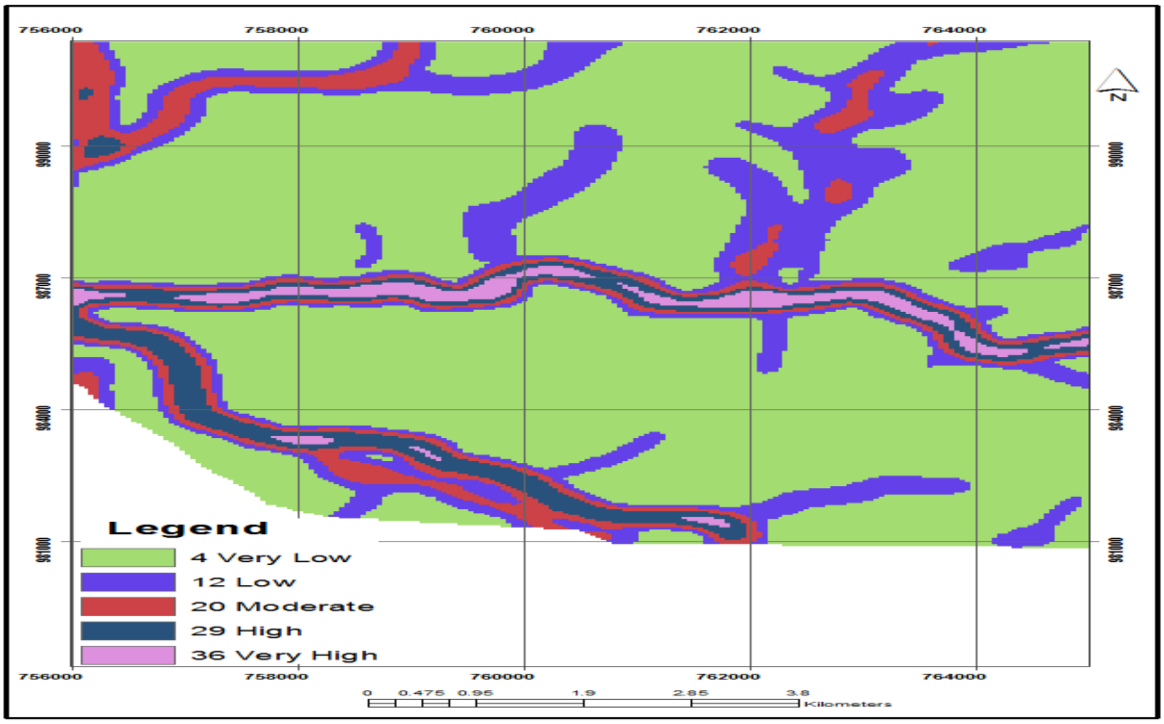

Figure 3: Reclassified drainage density of the study area

3.4 Soils

Classification of soil types for analysis was done based on their ability to allow water to infiltrate into the ground and to hold water in the ground thereby reducing run-off or vice versa as recognized by FDALR, (1990). FDALR designated sandy clay as being moderately poorly drained and loamy sand as well drained. This therefore implies that areas dominated by sandy clay soils are more prone to flood than areas covered by loamy sand soils since its infiltration rate is poor.

To facilitate the comparison, sand clay has been designated as poorly drained while loamy sand has been designated as well drained. The pair-wise comparison done for poorly drained and well drained shows a ratio of 9/5, indicating that poorly drained soil rated 9, has extreme importance in flood occurrence over well drained rated 5. The reciprocal (5/9) is the case when comparing well drained and poorly drained. Table 7 shows the weights generated after pair-wise comparison. Sandy clay has the highest weight of 64 while loamy sand has 36. The CR of 0.1 was accepted and the reclassified map (Fig.4) subsequently produced.

Table 7: Weight for Soil

	Poorly drained	Well drained	Weight	Weight*100
Poorly drained	1	9/5	0.64	64
Well drained	5/9	1	0.357	36

Consistency Ratio = 0.1

Table 8 presents the reclassified values of the soil types.

Table 8: Reclassified Soil

Soil type	Weight	Class
Sandy clay	64	Poorly drained
Loamy sand	36	Well drained

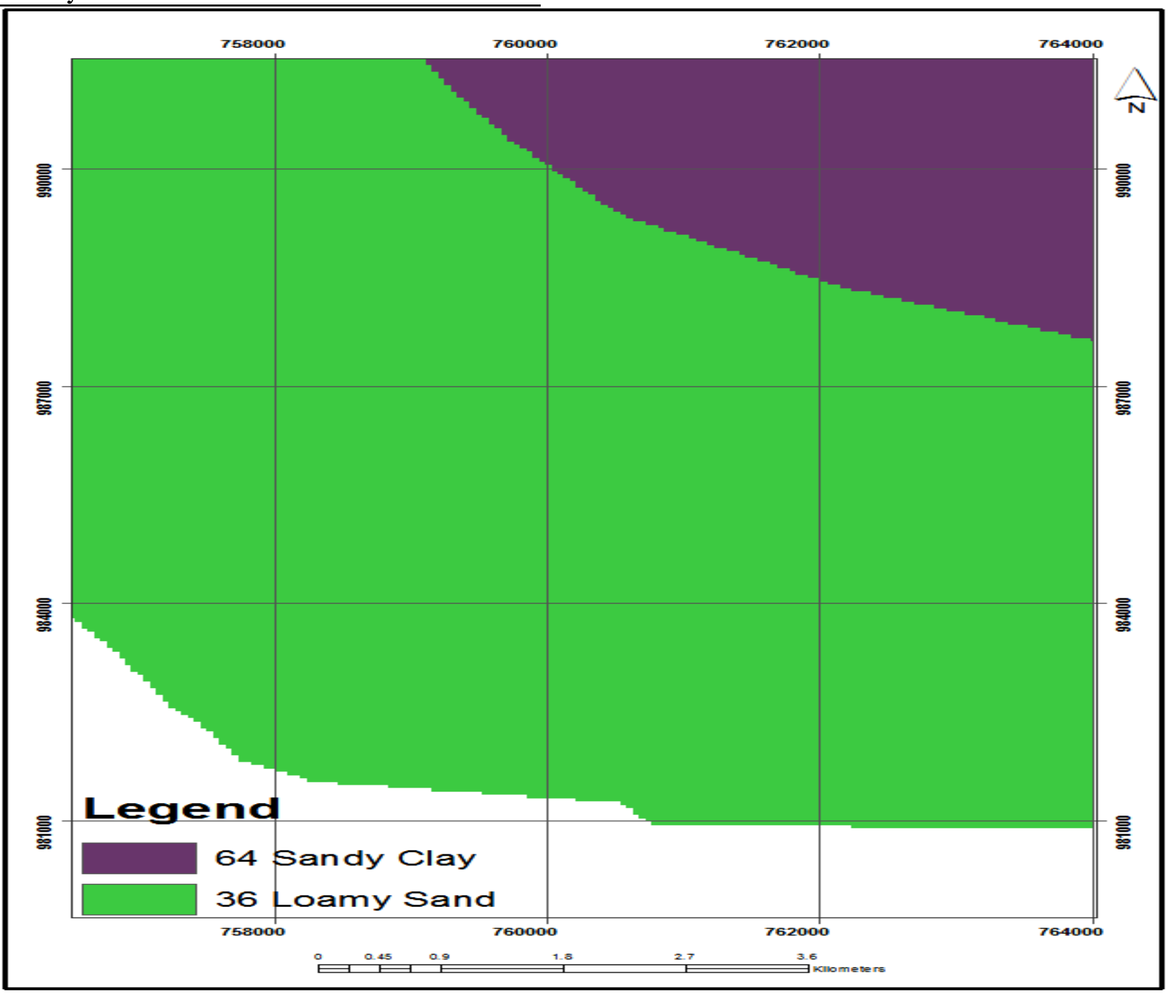

Figure 4: Reclassified soil of the study area

3.5 Rainfall

Based on the rainfall pattern observed in the study area, areas with amounts less than 923mm per annum were designated moderate, those with amounts ranging between 923mm to 970mm were designated high and areas with amounts ranging between 970mm to 2641mm per annum were designated very high. The pair-wise comparison done was based on the fact that higher rainfall amounts will mean greater flood risk and vice versa. The weights derived for moderate, high and very high stood at 24, 35 and 38 respectively (Table 9) .

Table 9: Weights for Rainfall

	Moderate	High	Very High	Weight	Weight*100
Moderate	1	5/7	5/9	0.24	24
High	7/5	1	7/9	0.35	35
Very High	9/5	9/7	1	0.38	38

Consistency Ratio= 0.058

The reclassified values are presented in Table 10 and the reclassified rainfall map (Fig. 5) was produced based on the weight calculated.

Table 10: Reclassified Rainfall

Rainfall (mm)	Weight	Class
‹923	24	Moderate
923-970	35	High
970-2641	38	Very high

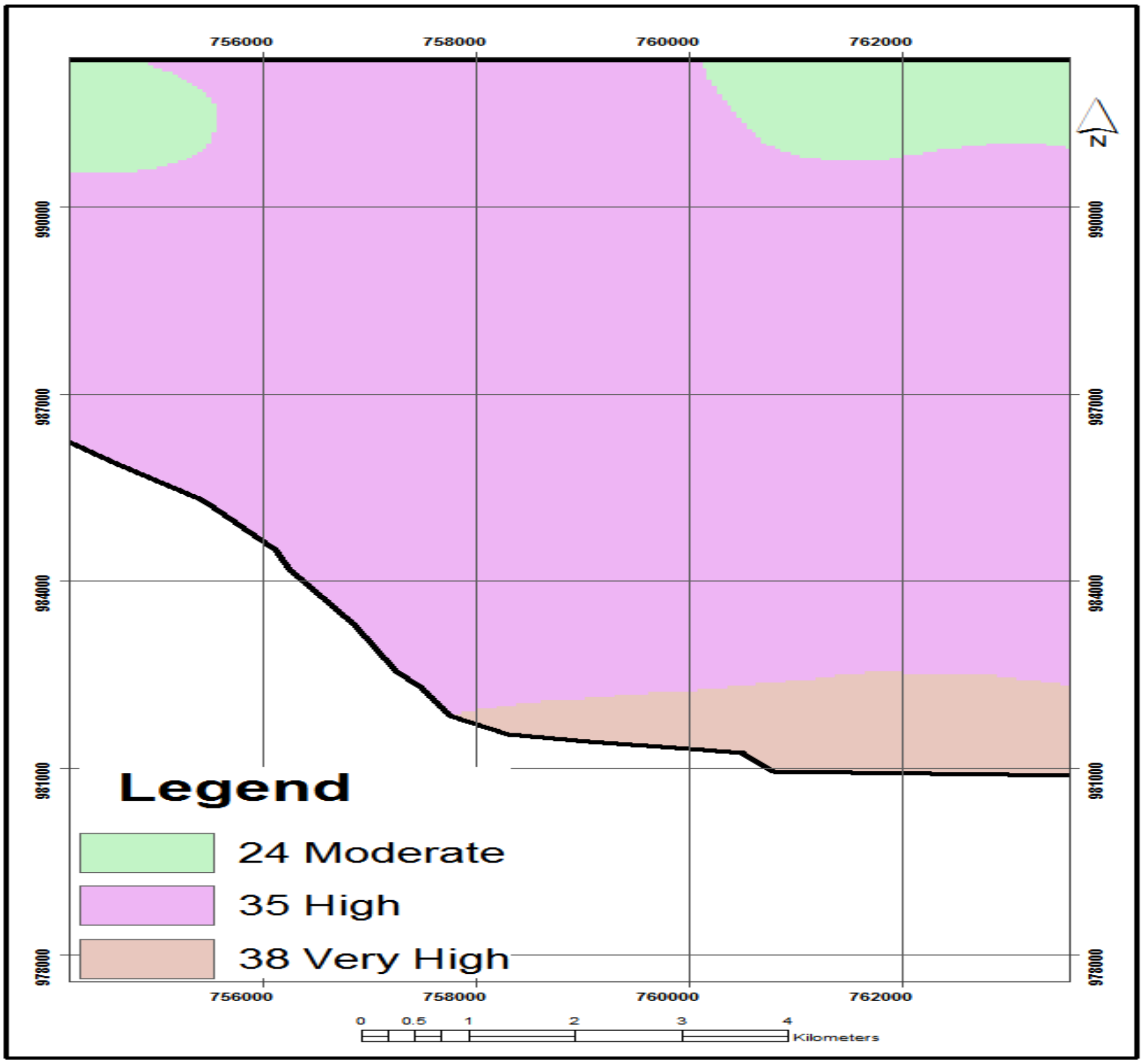

Figure 5: Reclassified Rainfallof the Study Area

3.6 Elevation

The pair-wise comparison for elevation (Table 11) was done based on the fact that areas on low elevations, lying adjacent the rivers are prone to flood while those on high elevations are less prone. A look at the first row/first column with elevation ranging between 148.9-180.8meters shows rating of 1 indicating that they are of equal importance while the first row/ second column shows a ratio that depicts that areas with elevations ranging between 148.9-180.8meters rated 9, has extreme importance over areas with heights of 180.8-197.5 meters rated 7 in contributing to flood in the area (Table.1). In order words, areas found on the former elevation can easily get flooded than those found on the latter even though all of them can be categorized as been on low elevations. Pair-wise comparison is carried out for all the classes and weights generated. A CR of 0.071 was arrived at and the result was thus accepted.

Table 11: Weight for Elevation

	148.9-180.8	**180.8-197.5**	**197.5-214.2**	**214.2-238.6**	**238.6-325.5**	**325.5-525.0**	**Weight**	**Weight *100**
148.9-180.8	1	9/7	9/5	3	9	9	0.35	35
180.8-197.5	7/9	1	7/5	7/3	7	7	0.271	27
197.5-214.2	5/9	5/7	1	5/3	5	5	0.193	19
214.2-238.6	1/3	3/7	3/5	1	3	3	0.115	12
238.6-325.5	1/9	1/7	1/5	1/3	1	1	0.035	4
325.5-525.0	1/9	1/7	1/5	1/3	1	1	0.035	3

Consistency Ratio= 0.071

The weights and reclassified values for elevation are presented in Table 12., while Figure 6 shows the reclassified elevation map of the study area that was generated from the weights derived.

Table 12: Reclassified Elevation Values

Elevation (m)	**Weight**	**Class**
148.9-180.8	35	Very flat
180.8-197.5	27	Flat
197.5-214.2	19	Moderate
214.2-238.6	12	High
238.6-325.5	4	Very high
325.5-525.0	3	Hilly

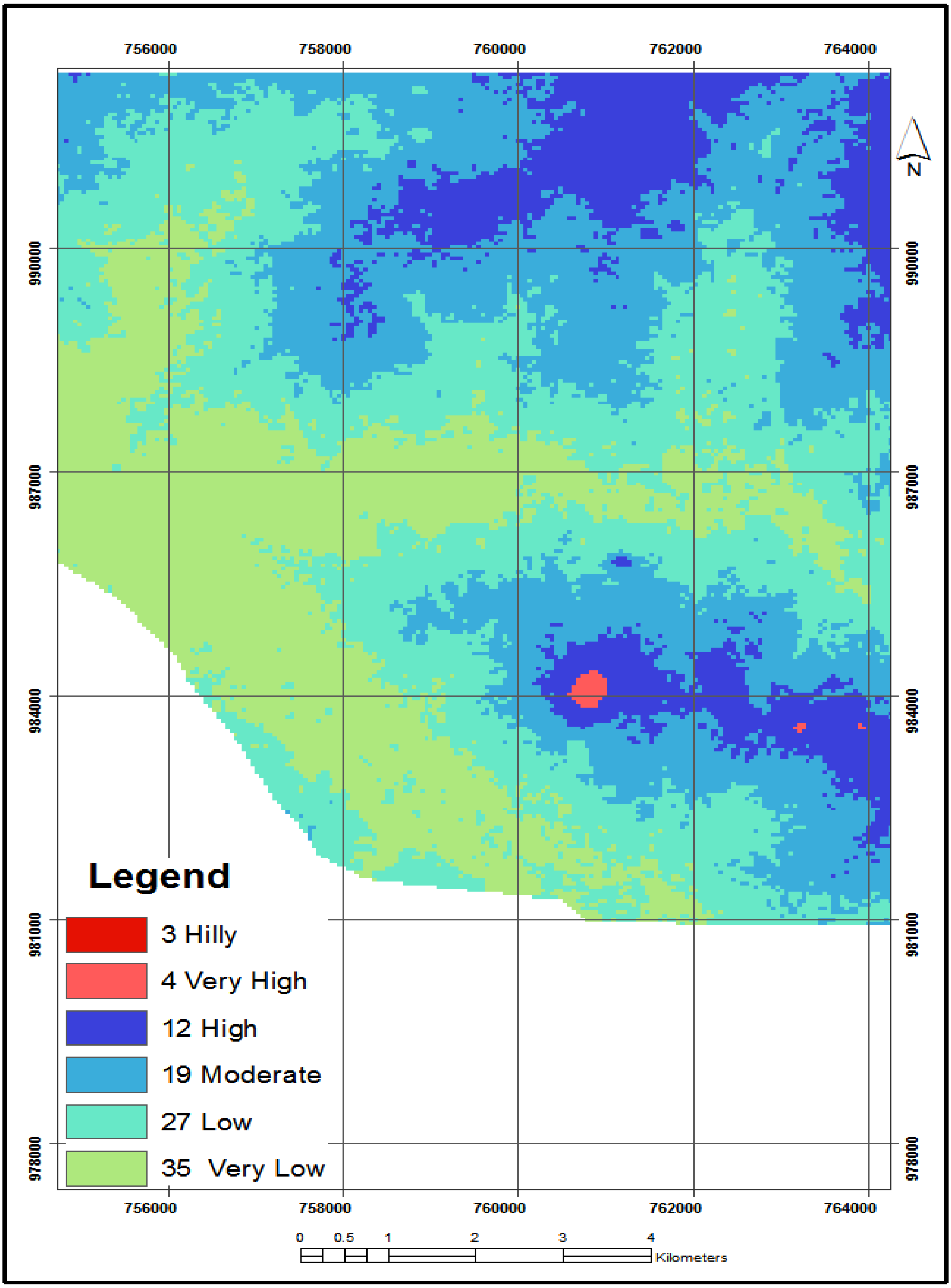

Figure 6: Reclassified Elevation of the Study Area

3.7 Slope

Lindsay-Walters (2015) observed that the topography of the drainage basin can affect the speed with which the precipitation flows: with great angle, it will be faster, and with more obtuse angle, it will be slower due to the effects of gravity, in other words the steeper the basin, the more quickly it drains and vice versa. The pair-wise comparison carried out and weights calculated (Table 13) for slope angle was based on the fact that the flatter the topography (low slope angle), the greater the chances for water to accumulate on the surface and vice versa.

Table 13: Weight for Slope

	Flat	Gentle	Moderate	Steep	Very Steep	Weight	Weight*100
Flat	1	9/7	9/5	3	9	0.362	36
Gentle	7/9	1	7/5	7/3	7	0.284	28
Moderate	5/9	5/7	1	5/3	5	0.202	20
Steep	1/3	3/7	3/5	1	3	0.116	12
Very Steep	1/9	1/7	1/5	1/3	1	0.038	4

Consistency Ratio=0.06

With a CR of 0.06, the judgment was seen to be consistent. The slope class and weights generated are presented in Table 14, and the reclassified slope map in Figure 7.

Table 14: Reclassified Slope Values

Slope class	Weight	Value (%)
Flat	36	0-3.1
Gentle	28	3.1-5.5
Moderate	20	5.5-8.8
Steep	12	8.8-19.1
Very Steep	4	19.1-42.1

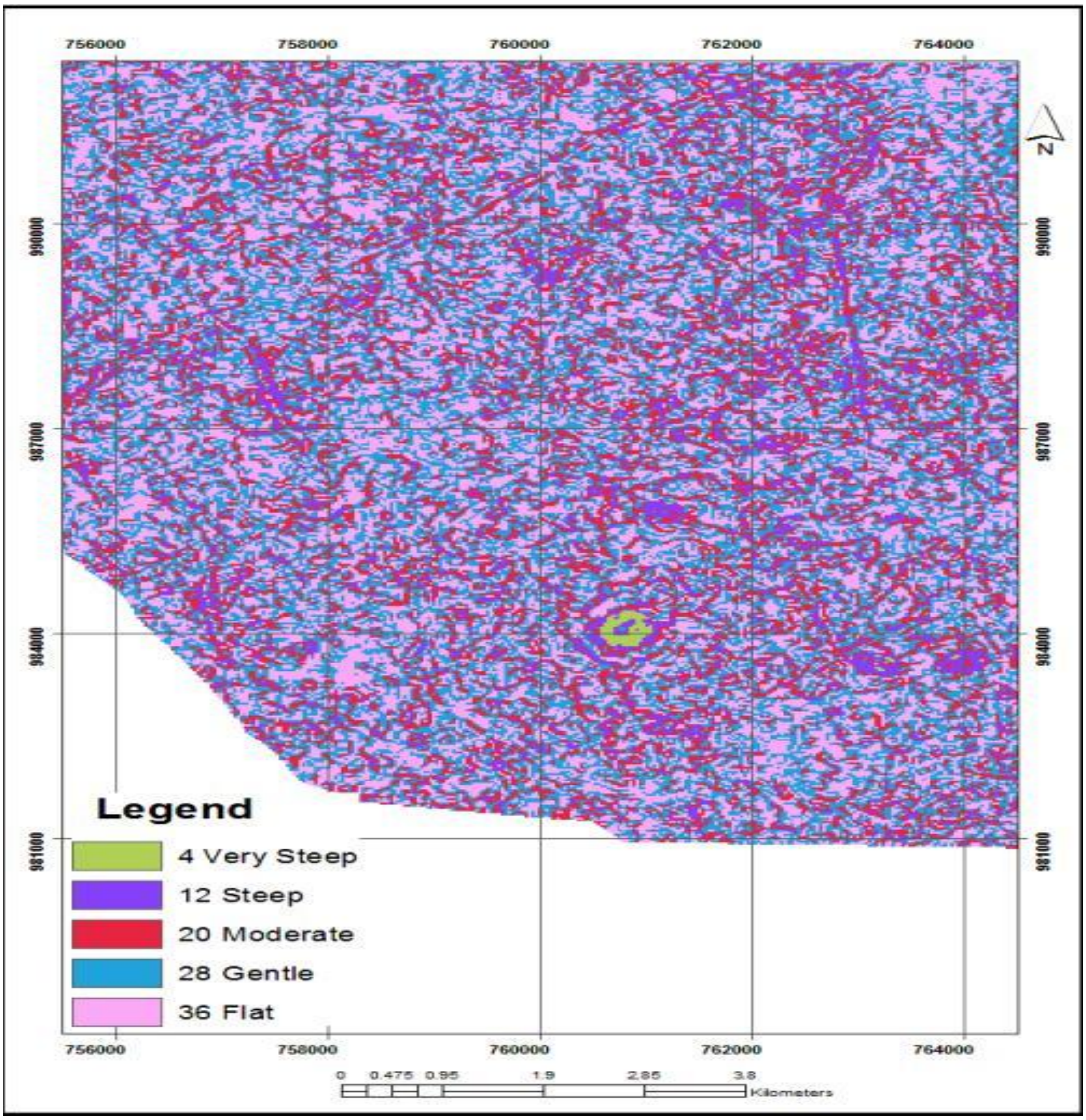

Figure 7: Reclassified Slope Map of the Study Area

3.8 Flood Vulnerability Map

This section presents the result of the pair-wise comparison carried out for the six flood causative factors (Table 15) based on Saaty's Fundamental scale of pair-wise comparison (Table.1), and the generated flood vulnerability map (Figure 8).

Table 15: Weight for all Factor Maps

	Elevation	Slope	LULC	Drainage Density	Rainfall	Soil	Weight	Weight*100
Elevation	1	9/7	9/5	9/5	9/3	9/7	0.25	25
Slope	7/9	1	7/5	7/5	7/3	1	0.20	20
LULC	5/9	3/7	1	1	5/3	5/7	0.13	13
Drainage density	5/9	5/7	1	1	5/3	5/7	0.13	13
Rainfall	3/9	3/7	3/5	3/5	1	3/7	0.08	8
Soil	7/9	1	7/5	7/5	7/3	1	0.20	20

Consistency Ratio= 0.078

The weights generated reveal that elevation with 25 as its weight has the greatest influence on flood occurrences in the study area. Slope and soil accounted for weights of 20 each, landuse and drainage density 13 each, and rainfall 8.

A field study carried out showed that areas below 197.5 meters were submerged in the 2005 and 2011 flood events. These areas include lands around Majindadi which is about 400meters from the river on a height of 191masl, Green beach about 300meters away from the river on a height of 195 m.a.s.l and Dadinkowa hotel in Sabongari area which is about 1000meters from the river on a height of 196meters. On the other hand areas like Angwan sarkindawa in Sabongari on a height of 217meters has never been submerged even though it is just about 50 meters away from the river. This affirms (Oruonye, 2012) assertion that the topography of the area consisting of undulating plain interrupted in places by low rising hills play a great role in flood occurrence. Ismail and Sanyol (2013) in a study conducted in Kaduna further buttress this fact as they observed that areas that lie beside a river may not be liable to flood if it is at a great height while areas that lie far away may experience floods if the intervening land is flat, gentle sloping or if the area lies in a depression.

The output map was thereafter reclassified into three (3) vulnerability zones of Low, Moderate and High(Fig 8). The flood vulnerability map reveals that areas of high vulnerability constitute 45% of the study area while moderate and low vulnerable areas constitute 37% and 18% respectively.

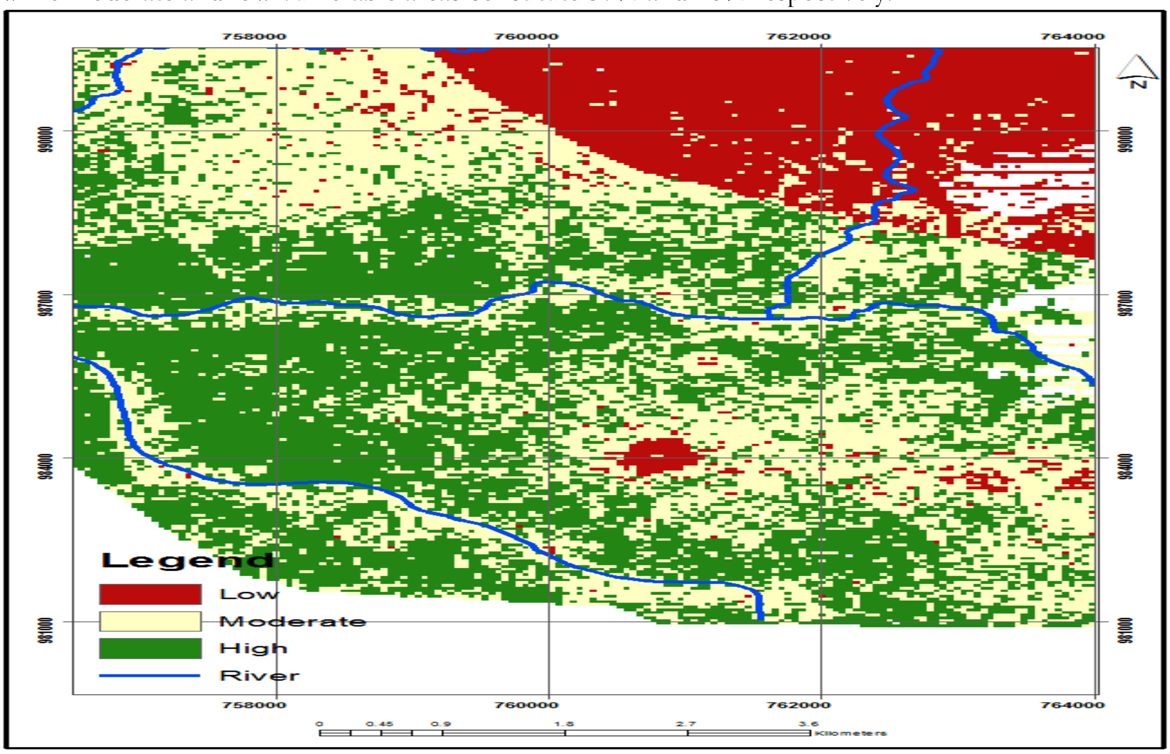

Figure 8: Flood Vulnerability Map

3.9 Elements at Risk of Flood

The transparent satellite imagery of the study area overlaid on the vulnerability zones (Figure 9a) depicts in light green color, elements that are at high risk while those at moderate and low risks are depicted in white and brownish-red colors respectively. The findings show that the elements at high risk of flood in the study area are those found on low lying areas along the rivers or depressions as asserted by Ismail and Sanyol (2013). These include built-up areas consisting of both residential and commercial structures, roads and farmlands. Figure 9b is an extract from 9a showing in greater detail a section of the study area and the elements at risk.

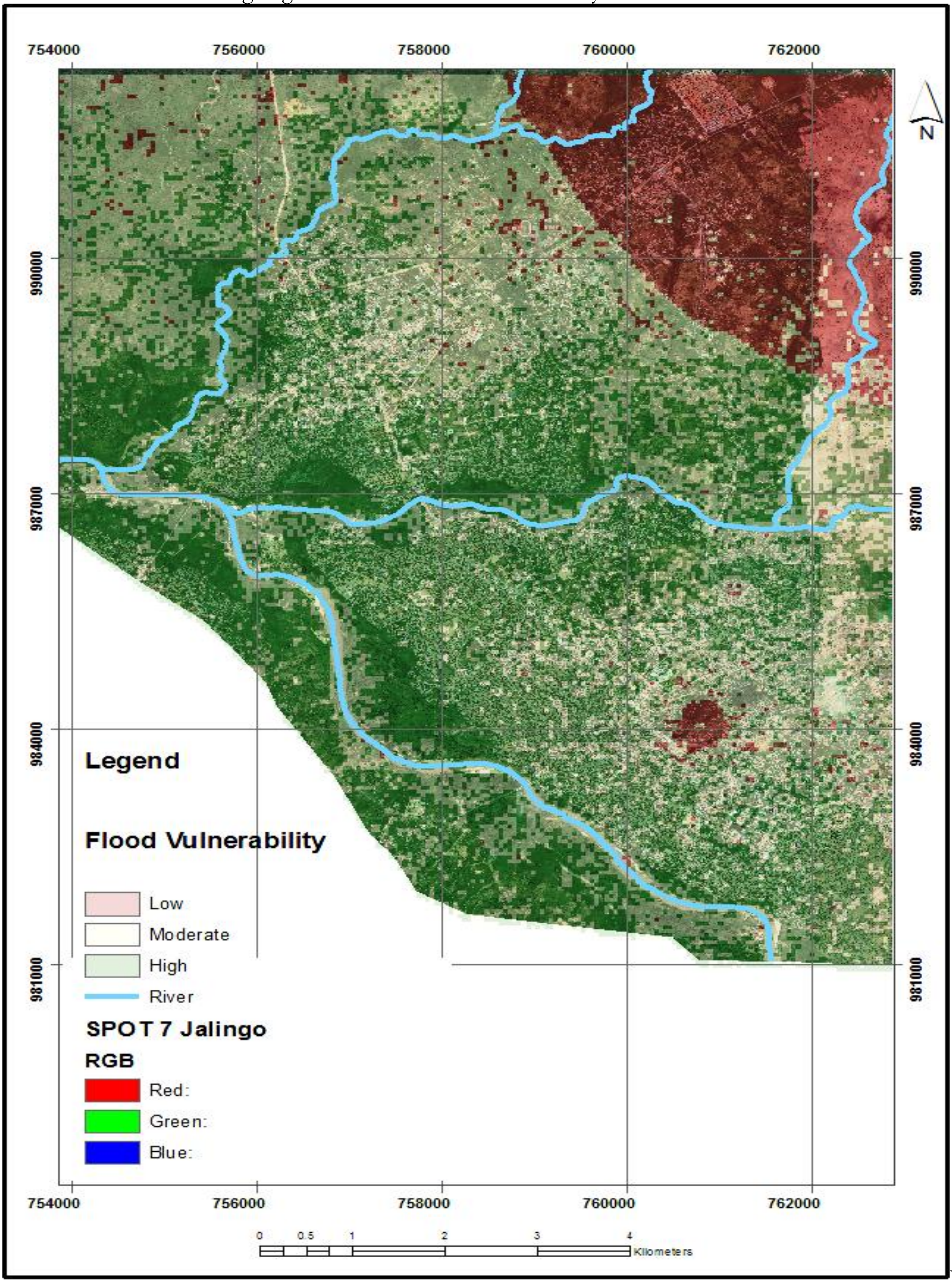

Figure 9a: Elements at risk

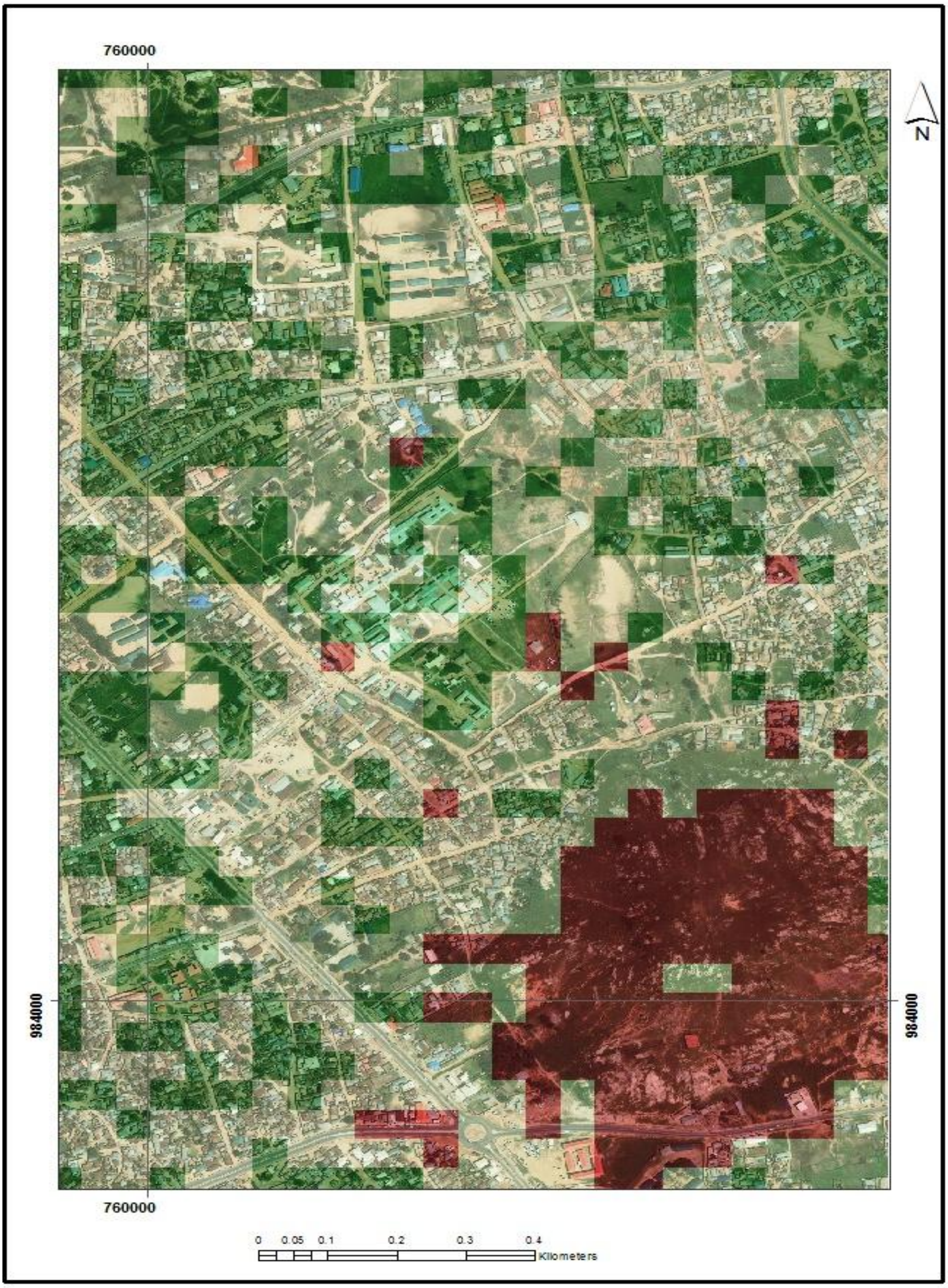

Figure 9b: Section of Elements at Risk

The vulnerability status of houses, roads, and farmlands were determined by using the query tool in ArcGIS 10.1. With reference to houses, the analysis revealed that a total of 26, 986 houses are at high risk, 17, 801 at moderate risk and 2225 at low risk to flood. Figures 10, presents in light green colour, houses that fall within the three vulnerability zones of high, moderate, and low respectively.

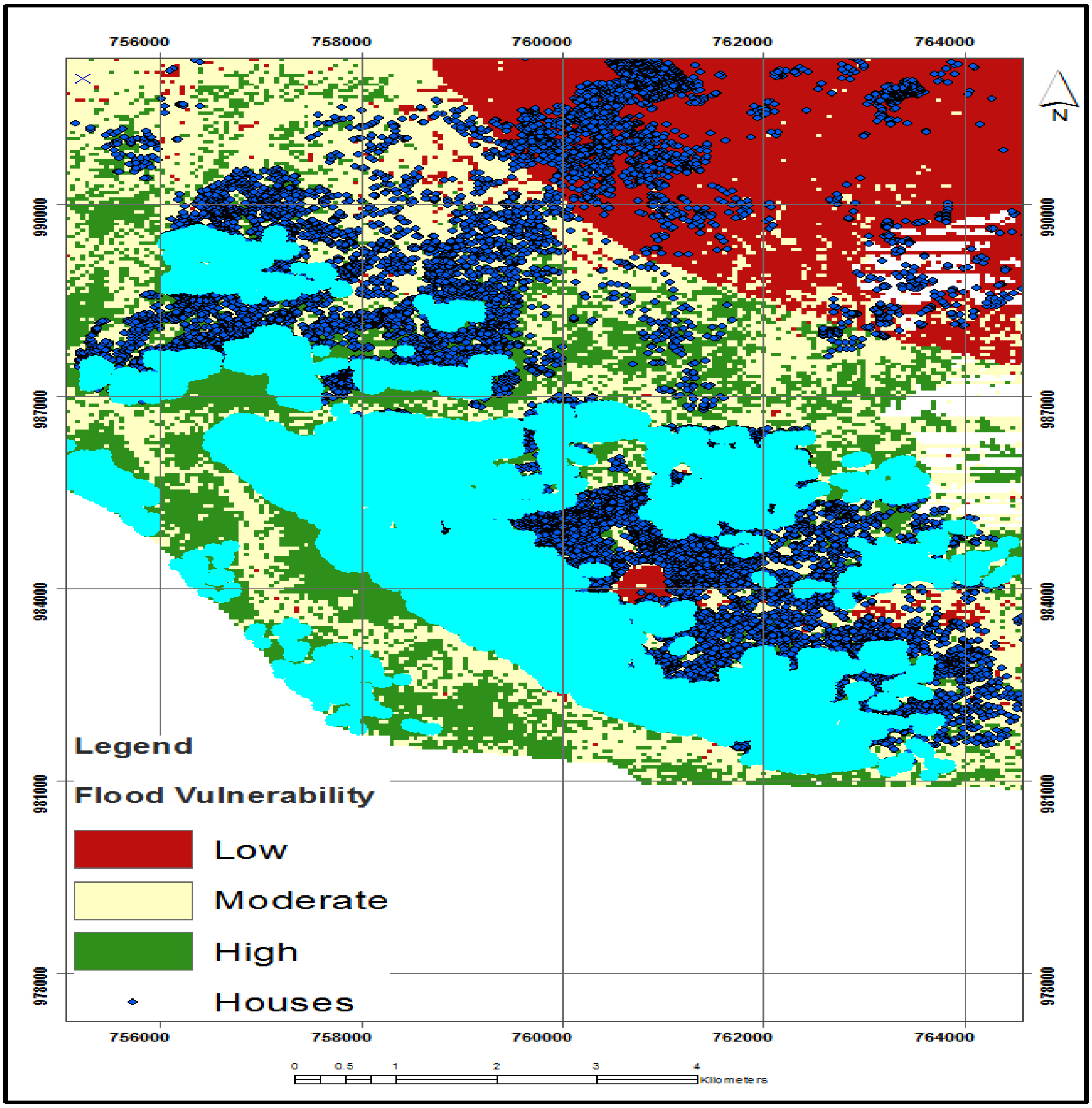

Figure 10: Houses at High risk

A critical look at the numbers of houses in each vulnerability zone shows that those in the high risk area outnumber those in the moderate and low risk zones put together. This may be attributed to the fact that the former is on lower elevation consisting of nearly leveled land to gently undulating plates (FDALR, 1990) and therefore tend to attract population due to ease of accessibility, presence of fertile soil and proximity to the river amongst others. The background check carried out however showed that only about 762 houses were actually affected by the 2011 flood event (Oruonye, 2014).

The query generated with respect to roads revealed that a total of 523 roads are at high risk of flood, 293 at moderate risk and 25 at low risk. Just as in the case of the houses, the number of roads at high risk outnumber the total of that of the moderate and low zones put together. This may be attributed to the fact that construction of roads on low and almost leveled lands are a lot easier than that on lands that are steeper. Another reason could be that since the lowlands are where population tends to concentrate, infrastructures such as roads and other facilities will be found in great number. Figures 11, captures the vulnerability status of the roads in the study area according to the three zones of high, moderate and low.

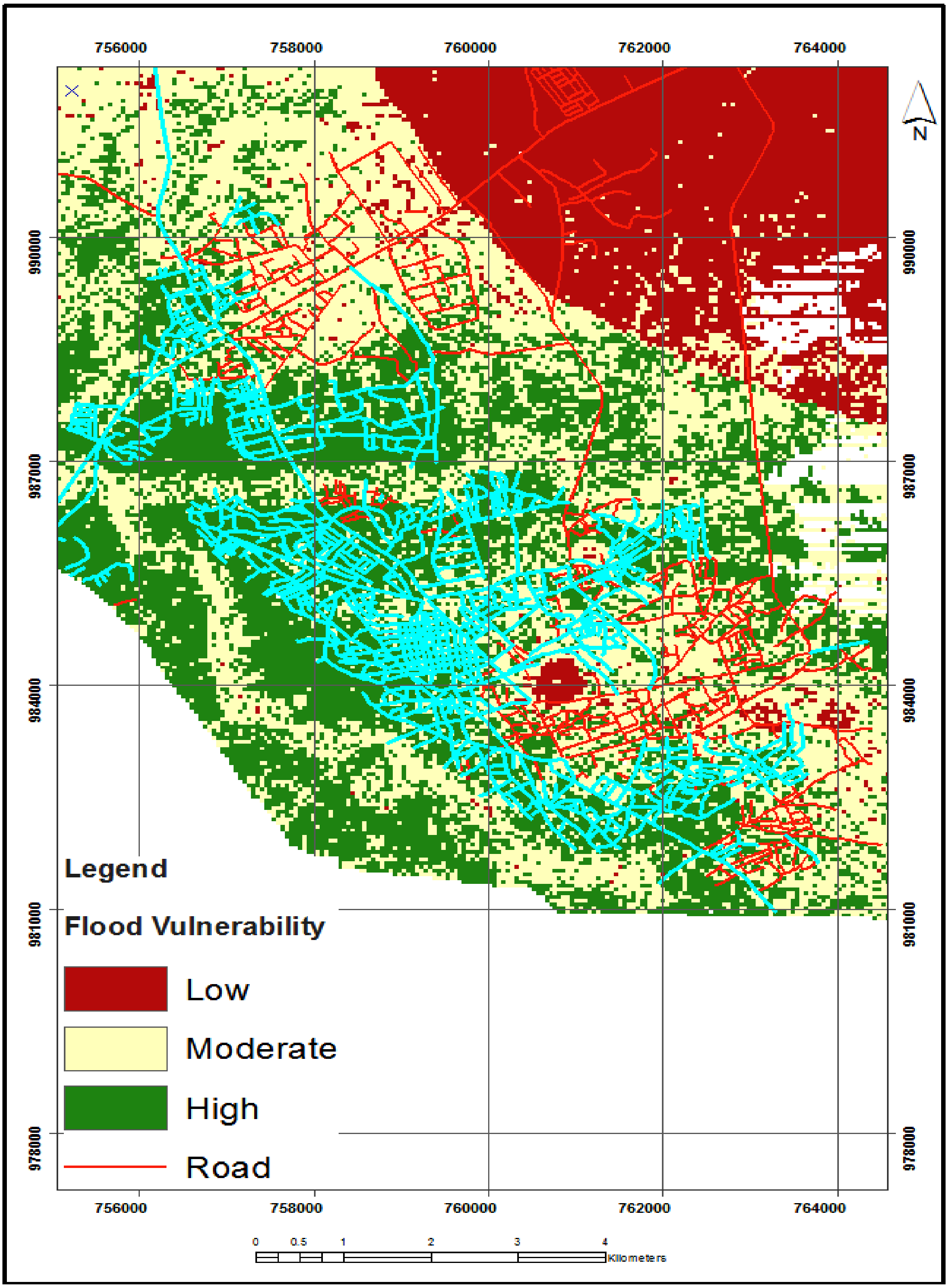

Figure 11: Roads at risk

With respect to farmlands, about 1,632.9 hectares are found to be at high risk, 1194.94 hectares at moderate risk and 1930.8 hectares are at low risk. These details are presented in Figures 12, in light green colour.

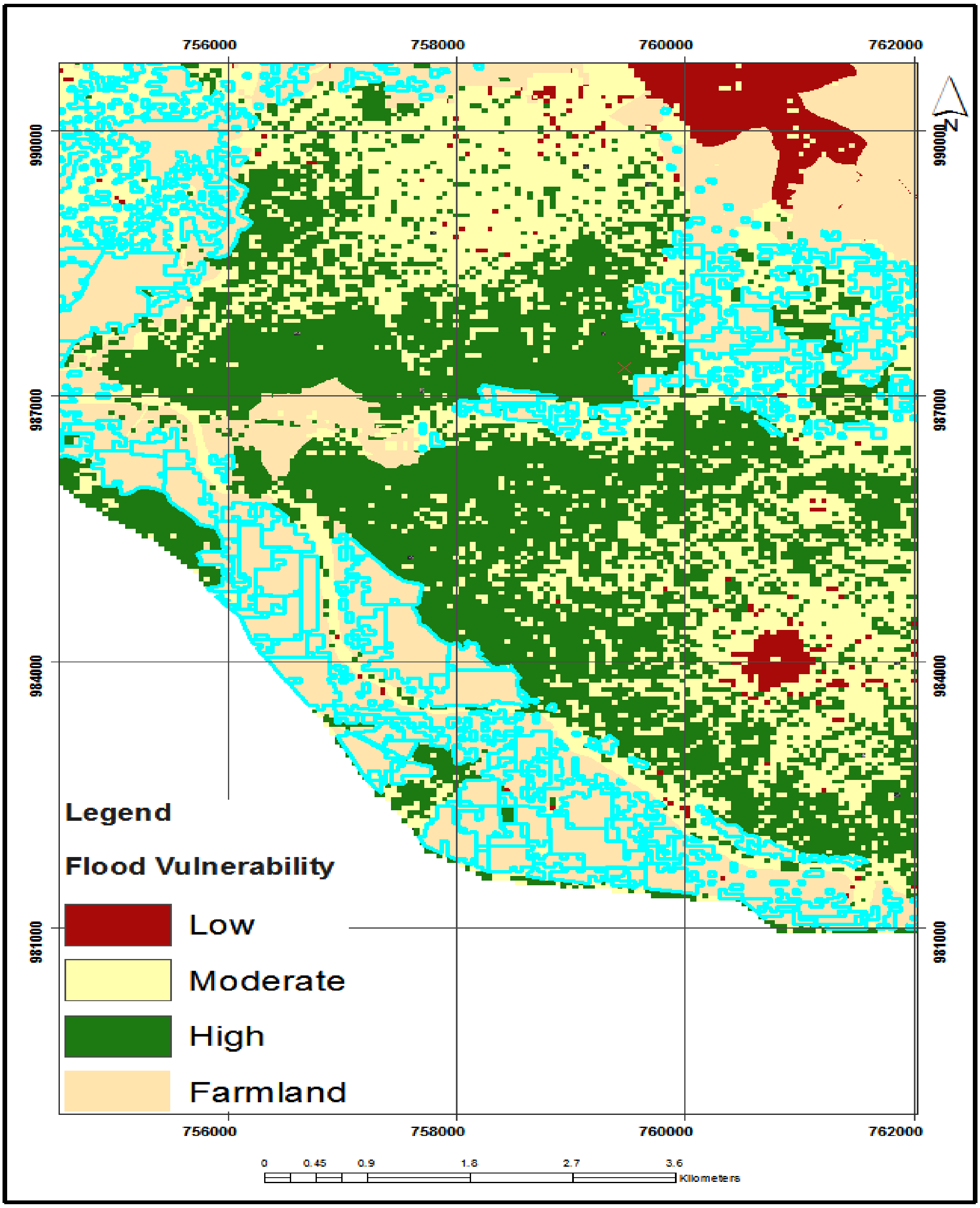

Figure 12: Farmlands at risk

Figure 13 presents the risk status of government-owned offices, educational, health, commercial, and religious facilities. The facilities at high risk are depicted in red while those at moderate and low risks are depicted in yellow and blue colours respectively.

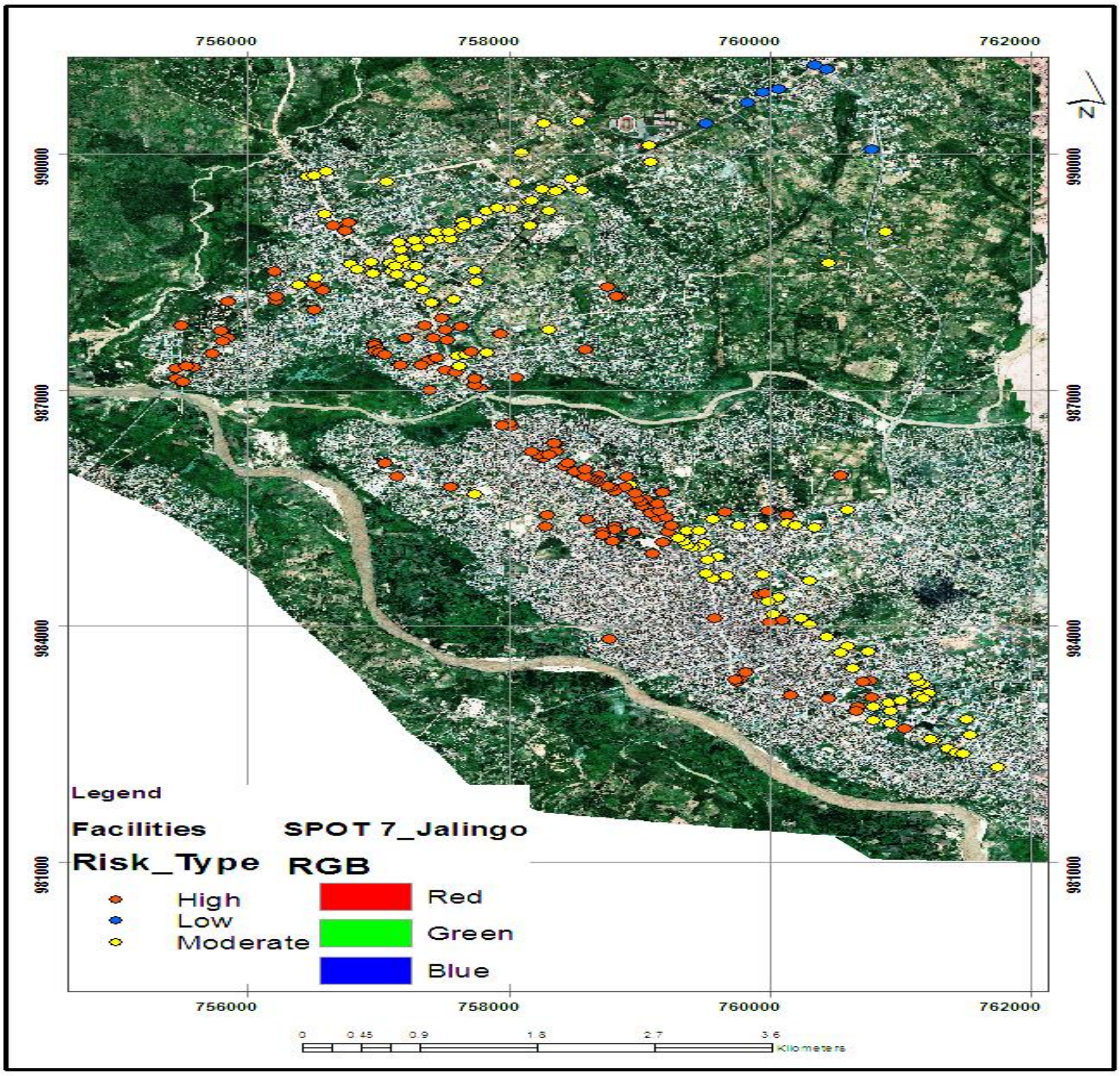

Figure 13: Risk status of Facilities

From the query generated, a total of 18 schools are at high risk of flood while the number of those at moderate and low risks stood at 11 and 4 respectively. 8 hospitals are at high risk, 13 and 5 at moderate and low risk in that order. Commercial centres made up of markets, shopping complex, motor parks, banks and fuel stations had a total of 44 being at high risk, 57 and 7 at moderate and low risk respectively. The number for worship centres, consisting of churches and mosques stood at 28 at high risk, 15 at moderate and 5 at low risks. Government offices at high risk stood at 15, moderate risk stood at 34 and the number at low risk stood at 5. A summary of the elements at risk is presented in Table 16.

Table 16: A Summary of Risk status of Elements

Elements	High risk	Moderate risk	Low risk
No. of Houses	26,986	17801	2225
No. of Roads	523	295	25
Farmlands (ha)	1632.79	1194.94	1930.95
Schools	18	11	4
Hospitals	8	13	5
Commercial centres	44	57	7
Worship centres	28	15	5
Government Offices	15	34	4

3.10 Population at Risk of Flood in the Study Area

In order to arrive at the population at risk of flood in the study area, buffers of 30meters (Government approved setback) and 1500meters (2011 flood extent) were generated along the rivers.

Point location of localities within the study area were consequently overlaid on the buffered zones as recommended by the United Nations Environment Programme (UNEP, 1998) and localities that fall within the zones noted and their respective population projected to the present year. This method was adopted because population data by wards that would have given detailed information was unavailable as at the time of this research.

3.11 30 Meters Buffer

The 30 meter buffer generated along the rivers show that almost all the localities are relatively safe as none of them falls within the zone (Fig 14). Although this suggests that there seem to be adherence to the government setback distance, it does not totally rule out the encroachment of construction works on the flood plains as seen in Plate I.

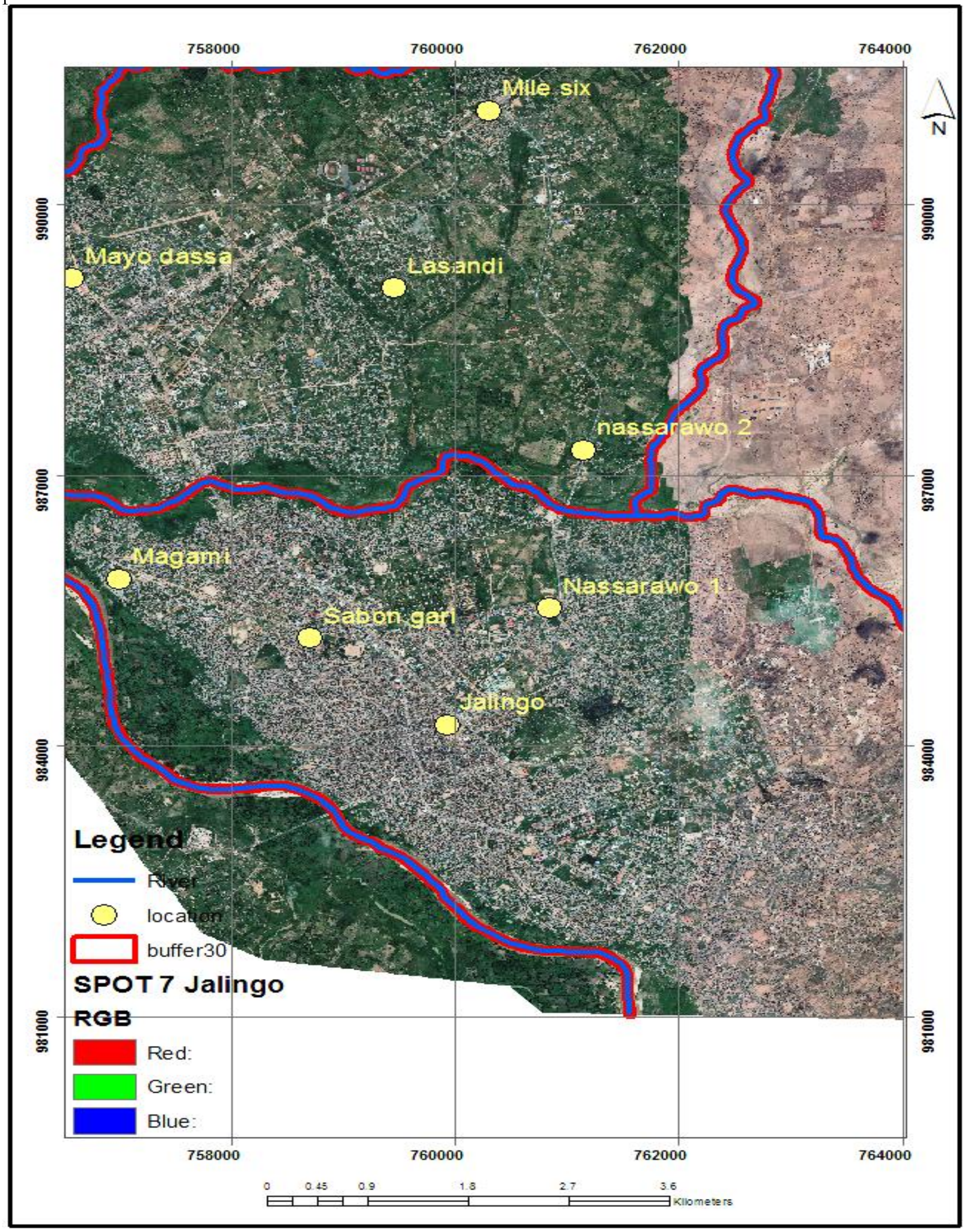

Figure 14: 30 Meters Buffer along Rivers

Plate I: On-going Construction Adjacent to the River at Nukkai

3.12 1500 Meters Buffer along Rivers

The 1500 meters buffer generated along the rivers (Figure 15) almost covered the whole metropolis except Lasandi. This implies that the whole of Jalingo metropolis will be submerged in extreme events which is unlikely because as it has been observed by authors such as Oruonye (2012) and Isma'il and Saanyol (2013), areas on high elevations may not experience flood even if they lie adjacent the river. This criterion was however included in this study because according to Oruonye (2012)the 2011 flood event extended that far in some areas. It therefore means that areas that were submerged were generally low-lying areas that extended that distance from the river into the metropolis.

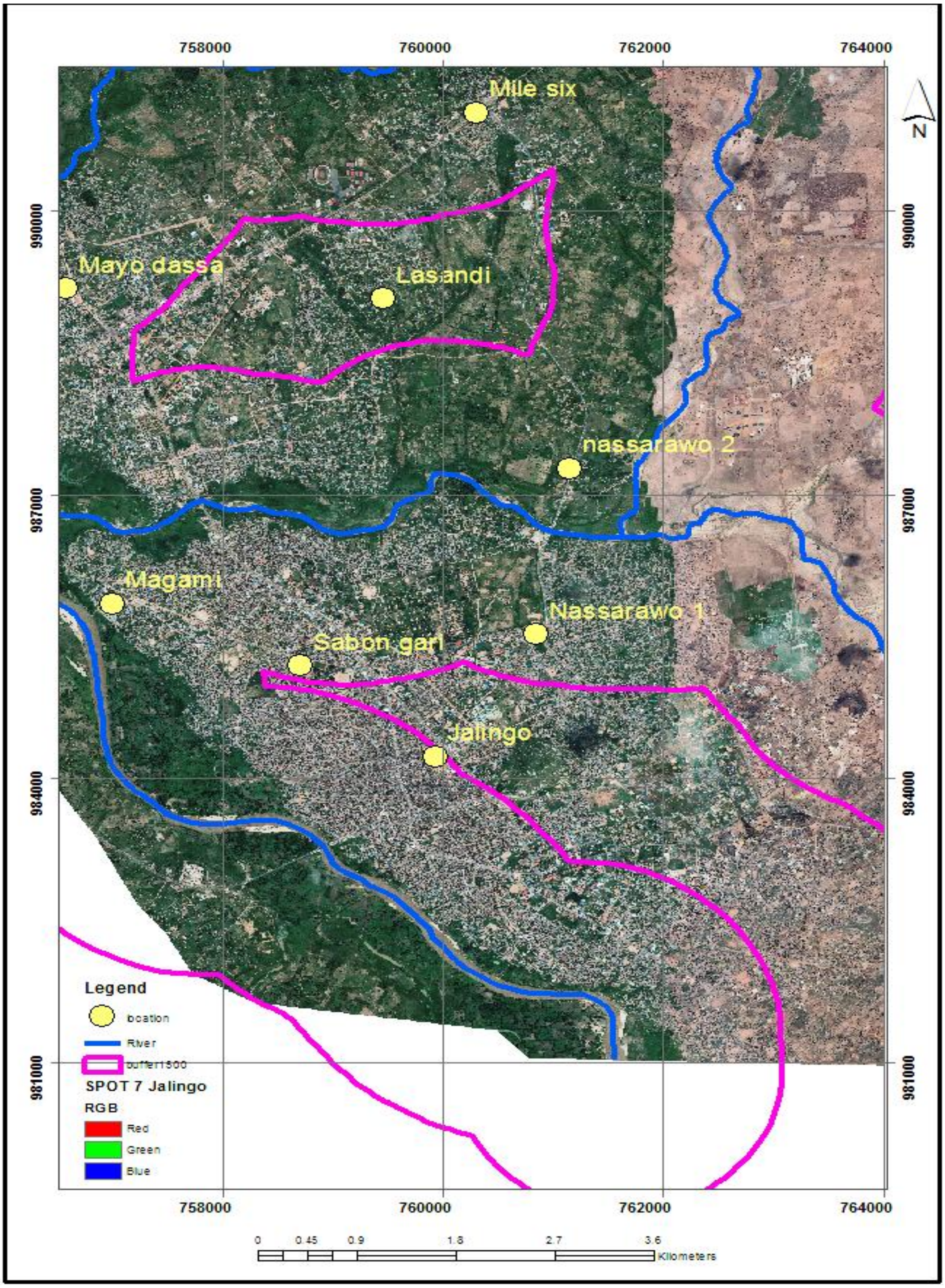

Figure 15: 1500 Meters Buffer along the Rivers

However based on the information captured by the 1500 meters buffer generated along the rivers, the projected population at risk of flood for the locality of Jalingo stands at 117, 530 people, Mayo-dassa has 1484, Mile six 1475, Magami 2237, Nassarawo 1 and 2 have 912 and 817 respectively, Nukkai 2476 and Sabon-gari 684. Cumulatively, the population at risk of flood in the study area stands at 127, 615. These figures are presented in Table 17.

Table 17: Population at Risk

Locality	Previous population (1996)	Projected Population
Jalingo	66,466	117,530
Mayo dassa	839	1484
Mile six	834	1475
Magami	1265	2237
Nassarawo 1	516	912
Nassarawo 2	462	817
Nukkai	1400	2476
Sabongari	387	684
Total	72,169	127,615

The estimated population figures generated were based on projection that assumed the population of the localities and consequently the study area was to increase at a rate of 3% per annum. However, the recent insurgency in parts of the north east especially in Adamawa, Borno, and Yobe states and the ethno-religious crises that bedeviled the southern parts of the state has led to the influx of people into Jalingo metropolis. These incidents have not only distorted the population growth rate of the study area, but have placed more lives at risk. The field study carried out revealed that some of the occupants of flood prone areas were refugees from the crisis ridden areas who were either perching with relatives or had purchased lands on floodplains at 'cheap prices', constructed houses on these lands and occupied them.

4.0 Conclusion

The study assessed flood vulnerability in the study area. The findings show that areas that lie along the rivers and on low elevations are more prone to flood than those on higher elevations. It therefore means cultural features such as residential, commercial, educational and health facilities amongst others and the populace found within this area is at great risk of flood.

Thus, it can be concluded from this study that even though flood is a natural disaster, man contributes significantly to its occurrence due to his involvement in activities that disrupt the environment like encroachment of human activities on floodplain, violation of building regulations in the areas and poor nature of materials used in building of the houses amongst others. All hands must therefore be on deck to ensure that the populace adhere to planning regulations and stop further encroachment by way of infrastructural development along the floodplains of Rivers Lamurde and Mayo-gwoi.

5.0 Recommendations

As at the time of this research, there is no concrete measure taken by the State or local authorities to reduce the menace of flood in Jalingo metropolis. However, considering the reoccurring incidences of floods in the metropolis, there is need for the State Government and other stakeholders to take precautionary measures such as:

i. Improved land use planning that prevents development from floodplains and allowing the areas to be preserved for agricultural or recreational purpose.
ii. Resettlement of communities along the river to safer areas
iii. Raising flood hazard awareness of residents of the metropolis through seminars, workshops etc.
iv. Moreover, research works should focus on prediction of future flood incidences and continuous vulnerability mapping.

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