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Abdulrahman SHUAIBU

Flood Reduction through Flood Risk and Vulnerability Assessment and Mapping in Hadejia River Basin, Nigeria

Defended on 20/09/2020 Before the Following Committee:

Chair	Thameur Chaibi	Ph.D	(INRGREF, Tunisia)
Supervisor	Aymar Y. Bossa	Ph.D	(INE/UAC/Benin)
Co-Supervisor	Jean Hounkpè	Ph.D	(INE/UAC/Benin)
External Examiner	Sameh A. Kantouch	Ph.D	(University of kyoto, Japan)
Internal Examiner	Guemou Bouabdellah	Ph.D	(University of Ain Temouchent, Algeria)

Academic year 2019-2020

DECLARATION

I, Abdulrahman SHUAIBU, the undersigned, declare that the thesis entitled *"*Flood Reduction through Flood Risk and Vulnerability Assessment and Mapping in Hadejia River Basin*",* is a result of my own work and that it has not been presented to any other learning institution for a similar award of degree, diploma or other professional. Where other sources of information have been used, they have been acknowledged. I understand that non-adherence to the principle of academic honesty and integrity, misrepresentation/fabrication of any idea/data/fact/source/ will constitute sufficient ground for disciplinary action by the university.

31 July, 2020

Signature
Abdulrahman SHUAIBU

Date

CERTIFICATION

This thesis has been submitted with my approval as the supervisor

31 July, 2020

Signature Date

Dr. Aymar Y. Bossa

(INE/UAC/Benin)

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LIST OF ABBREVIATIONS

AHP	:	Analytical Hierarchy Process
DEM	:	Digital Elevation Model
EM-DAT	:	Emergency Events Data Base
FAO	:	Food and Agricultural Organization
GDP	:	Gross Domestic Product
GIS	:	Geographical Information System
HRB	:	Hadejia River Basin
HJRBDA	:	Hadejia-Jamaare River Basin Development Authority
IPCC	:	Intergovernmental Panel on Climate Change
KRIP	:	Kano River Irrigation Project
LGA	:	Local Government Area
LULC	:	Land Use Land Cover
MCA	:	Multi-criteria Analysis
MCDM	:	Multi-Criteria Decision-Making
NiMet	:	Nigerian Meteorological Agency
NPC	:	National Population Commission
NBS	:	National Bureau Statistics
OLI	:	Operational Land Imagery
SDG	:	Sustainable Development Goal
SRTM	:	Shuttle Radar Topography Mission
UNDP	:	United Nations Development Program
UNFCCC	:	United Nations Framework Convention on Climate Change
USGS	:	United States Geological Survey
USD	:	United State Dollars
WHO	:	World Health Organization

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ABSTRACT

Floods are one of the most recurrent and devastating natural disasters that has enormous, widespread and ravaging negative impacts on lives, economy and infrastructures across the globe. Hadejia River Basin is known by its frequent flood occurrences which claims many lives and destroyed several infrastructures and vast hectares of farmlands. The purpose of this research was to develop a GIS-based flood risk and vulnerability mapping integrated with Analytical Hierarchical Process (AHP) in order to reduce the risk and vulnerabilities associated with flood in Hadejia River Basin. The research employs an efficient and reliable methodology in preparing flood risk map for the Hadejia River Basin based on the concepts of integration of flood hazard and socioeconomic vulnerability indicators. The risk map of the basin was generated by aggregating the geomorphological, hydrological, and socio-economic indicators namely; elevation, mean annual rainfall, slope, distance to rivers, soil type, drainage density, population density, female population density, literacy rate, land-use, and employment rate and road network in GIS framework using multi-criteria analysis technique called the Analytical Hierarchy Process (AHP). Accordingly, the northeastern and southeastern parts of the study area are prone to frequent floods which constitutes very high and high flood hazard zones of about 10.4% (3179.1 Km^2) and 17.2% (5257.8 Km^2) of the watershed while vulnerabilities levels are higher at the southeastern, central and extreme upstream parts of the study area which covers about 24.1% (7367Km^2) of the study area. Moreover, combination of the flood hazard (FHI) and vulnerability (FVI) indices of Hadejia River Basin reveals about 43.4% of the basin is under high and very high flood risk covering about 13266.8Km^2. The study also reveals that flood hazard and vulnerability indicators have different influence to flood risk. Furthermore, the results are validated and found to be in agreement with the historical records of flood distribution of the study area. This proves the reliability and applicability of the proposed methodology. This research has significant importance in developing strategic measures and plans through which government and relief agencies will reduce and/or prevent the negative impact of flood risk and socioeconomic vulnerability in the Hadejia River Basin.

Keywords: Flood Risk, Flood Hazard, Socioeconomic Vulnerability, Multi-criteria Analysis, Analytical Hierarchical Process (AHP), Hadejia River Basin.

CHAPTER ONE

1. INTRODUCTION

1.1. Background

In recent time, floods are considered amongst the most catastrophic, frequent and widespread natural disasters worldwide causing severe economic and environmental damages as well as destruction of livelihoods (Danumah *et al.,* 2016; Rahmati *et al.,* 2016; Ghosh & Kar, 2018; Seejata *et al.,* 2018; Alfa *et al.,* 2018; Chakraborty & Mukhopadhyay, 2019; Mishra & Sinha, 2020). About 47% of weather-related disasters are as a result of floods (Vishwanath & Tomaszewski, 2018). Weather and climate change related disasters accounted for over 10 billion USD losses in 2019. River flooding alone among these disasters has impacted adversely on 14 million people while leaving 200 million at risk worldwide (CDP, 2019)**.** It was reported by Zeleňáková *et al.,* (2018) and Petit-boix *et al.,* (2017) that 34% of worldwide natural disasters from 1960 to 2014 are floods which led to severe financial loss of over 2.5 billion USD per annum and a total deaths of 1,254 persons per year. Again, an estimate of 540,000 deaths and 2.8 billion people were affected by floods between 1980 and 2009 all over the world (Zehra *et al.,* 2019). Climate change is believed to have exacerbated and worsen the flood aftermaths (Jarraud & Steiner, 2012). It is argued that the major factors causing changes in precipitation and extreme hydrological events are the variability of climatic variables especially temperature (IPCC, 2014).

African continent was described as one of the most vulnerable continent to climate change impacts (Lamboni *et al.,* 2019). According to the report of IPCC, (2012), the West African region (including Nigeria) will experience a drastic increase in extreme hydrological events such as floods as a result of uncertainties in rainfall patterns. Studies have shown that West African has experienced heavy precipitation above normal during the months of June to September compared to the past 35 years (Adegoke *et al.,* 2019). Ntajal *et al.,* (2017) claims that factors such as over dependence on agriculture, insufficient investment in infrastructures, siting settlement in flood prone zones and poor institutions and lack of stringent policies has made most of the West African countries in extreme vulnerability to flood hazards and other related menace. One of the worst floods was experienced in September 2007 in West Africa as a result of heavy rainfall. This has recorded the worst floods the region had ever faced in many decades (Amisigo & Bossa, 2019). The flood has killed 23, 46 and 56 people in Togo, Burkina Faso and Ghana respectively (Komi *et al.,* 2016). Bénin Niger River Valley is not excluded with regards to sever flooding events. In 2013 in this Valley, floods destroyed more than 21,500 ha of crops and about 9,200 houses (Behanzin *et al.,* 2016). Furthermore, 20% of the people leaving in Mono River Basin Benin were displaced by heavy rain which caused severe floods in the downstream part of the basin in 2008 (Ntajal *et al.*, 2017).

Adegboyega *et al.,* (2018) buttresses that flood accounted for the highest losses resulting from extreme hydrological events in Nigeria. More recently in 2018, floods has affected more than 1.9 million persons across 12 states in Nigeria which caused the displacement of more than half a million of them from their households (WHO, 2018). Flood has been the highest occurring natural hazard in Nigeria, causing severe damages to lives and properties (Aderogba, 2012; Komolafe *et al.,* 2015; Alfa *et al.,* 2018). It has become an annual event in many regions of the country occurring in the form of coastal floods, river floods, flash floods and urban floods (Komolafe *et al.,* 2015). The main causes of flooding are related to the inability of river channels to accommodate floods waters beyond its carrying capacity which in most cases resulted in flooding a vast portion of lands (Alfa *et al.,* 2018). This is very similar to the case in most part Hadejia-Jamaare river system where the failure of the river to safely accommodate and discharge off it runoff during peak rainy season has resulted in flooding a vast hectares of agricultural lands and submergence of several communities along the river system over the last decades (Iliyasu, 2017).

Floods disaster risk assessment, control, and management are crucial and are a very challenging tasks because of the uncertainty of flood events which are due to many climatic and physiographic factors of the watershed such as land use, topography, rainfall intensity, lithological settings, building types and other related assets (Li *et al.,* 2019). Flooding effects are not only restricted to everyday livelihood but also the environment and the society at large in terms of economic losses and damages (Vu & Ranzi, 2016). The risk associated with flood disasters are usually assessed using a qualitative approach coupled with statistical analyses of the factors contributing to flood risk where adequate data for quantitative risk assessment is lacking or is not sufficient (Weerasinghe *et al.,* 2018). The management of flood risk can be achieved by either reduction of the hazard inflicted by floods or by reduction of the vulnerability of the exposed population (Komi *et al.,* 2016). Flood management strategies requires early identification of flood prone areas for an effective early warning system, facilitation of quick response and reduction of the impact of possible flood event (Chakraborty & Mukhopadhyay, 2019). Flood risk assessment has formed the basis of flood mitigation measures by helping engineers, decision and policy makers in implementing flood prevention and mitigation options in order to safeguard lives of the exposed population and avert economic losses (Rincón *et al.*, 2018).

Although many studies (Isma & Saanyol, 2013; Vu & Ranzi, 2016; Li *et al.*, 2019; Youssef & Hegab, 2019) have demonstrated the Geographic Information System (GIS) as a vital tool for flood risk mapping. Behanzin *et al.,* (2016) argues that the integration of Remote Sensing and GIS techniques coupled with Analytical Hierarchical Process (AHP) are the best techniques for flood risk and vulnerability assessment studies especially in areas with less or outdated data. This technique could be adopted for flood risk mapping and vulnerability assessment in Hadejia River watershed due to limited data. The risk of flash floods is a combination of the natural hazard and vulnerability (Zeleňáková *et al.*, 2018). Multi-criteria analysis (MCA) methods are decision support tools through which technological, ecological and socio-economic aspects are covered in dealing with collections of complex decisions (Shale *et al.*, 2020). The methods have been proven to be effective when integrated with Geographical Information Systems (GIS) (Danumah *et al.*, 2016; Sharma *et al.*, 2017; Rincón *et al.*, 2018).

1.2. Problem Statement

Heavy precipitation was recently predicted in major river basins in Nigeria which was highly anticipated to result in severe flooding events (Adegboyega *et al.*, 2018). About 15million people resides currently in Hadejia River Basin (HRB) (Umar *et al.*, 2019). Population density and land cover-related parameter are often the most influential factors causing floods (Zeleňáková *et al.*, 2018; Gogate *et al.*, 2016). Gogate *et al.*, (2016) has estimated that urban population will double by 2050. There were a drastic increase in problems related to flooding and it is therefore imperative to map flood prone areas efficiently in order to mitigate the negative impacts of flood disasters or flood aftermaths (Chakraborty & Mukhopadhyay, 2019). Other factors different from human-induced climate change may have exacerbated the dire situation and high population growth have contributed immensely to the Africa's high vulnerability to disasters (Komi *et al.*, 2016). The factors are the high poverty levels, inappropriate use of natural resources, corruption and failed policies and institutional frameworks (Costache & Tien, 2020).

In Hadejia River basin, Flooding has been of frequent occurrence claiming several lives and properties annually. It was anticipated that the main causes of this menace are the impastation of aquatic grasses (known as Kacala in Hausa language), Siltation of river Hadejia which consequently led to the changes of water courses. This siltation of water courses coupled with sand mining along the river coast makes the adjacent communities more vulnerable to flooding events. Over the last 20 years, there was no river dredging along the river. Some of the communities affected by flood disasters along Hadejia River are the Dabi Town, Ringim (Kyarama and Ringim town), Auyo town, Hantsin in Jahun LGA, Miga LGA and Guri LGA. There were some attempts to prevent floods damages in most of these communities such as at Auyo LGA where they constructed some levee like structures at both the riverbanks to prevent the flowing water from ravaging their houses and farm lands. Despite these preventive measures, water overflew the levees and destroyed their houses and washed away many hectares of their farmlands in 2019. Several attempts were made by different researchers to analyses floods in some part of Hadejia River Basin such as (Yahaya, 2008) who simulated flood using SRTM DEM in HEC-RAS and HEC-GeoRAS along some section of the River in 2013 and suggested the construction of levees at the overflown section. However, He considered only part of the river system without simulating for the whole river basin. Another research done in the study area was the flood risk assessment in some parts of Hadejia-Jamaare River basin by (Iliyasu, 2017) who used questionnaires to assess the flood impact in some selected communities in the basin. Therefore, this research takes a holistic approach in analyzing flood risk, and vulnerabilities in the whole basin using the famous Multi-criteria Evaluation Techniques coupled with Geographic Information System.

Moreover, in Guri LGA and Dabi and Kyarama towns of Ringim LGA floods are not new phenomenon to the people of these communities and the nearby communities. Water always submerges their farmlands and surrounds the towns and more often enters their houses after a heavy down pour leaving a large pool of water at the outskirt of the towns. The minister of water resources of Nigeria has recently ordered the implementation of irrigation scheme in Kyarama town by constructing a reservoir at the upstream so as to pump the water by gravity to the downstream farms for irrigation (HJRBDA, 2019). Hence, this may not due away with the flooding problems bedeviling the community. It is therefore imperative to undertake a detail study on flood hazards, Vulnerability of the communities and the risks associated with the flood menace in

Hadejia river basin. Floods protection and management options are basically not accurate. Therefore, this necessitated the use of complex and integrated approach of flood protection and mitigation (Vojtek & Vojteková, 2016).

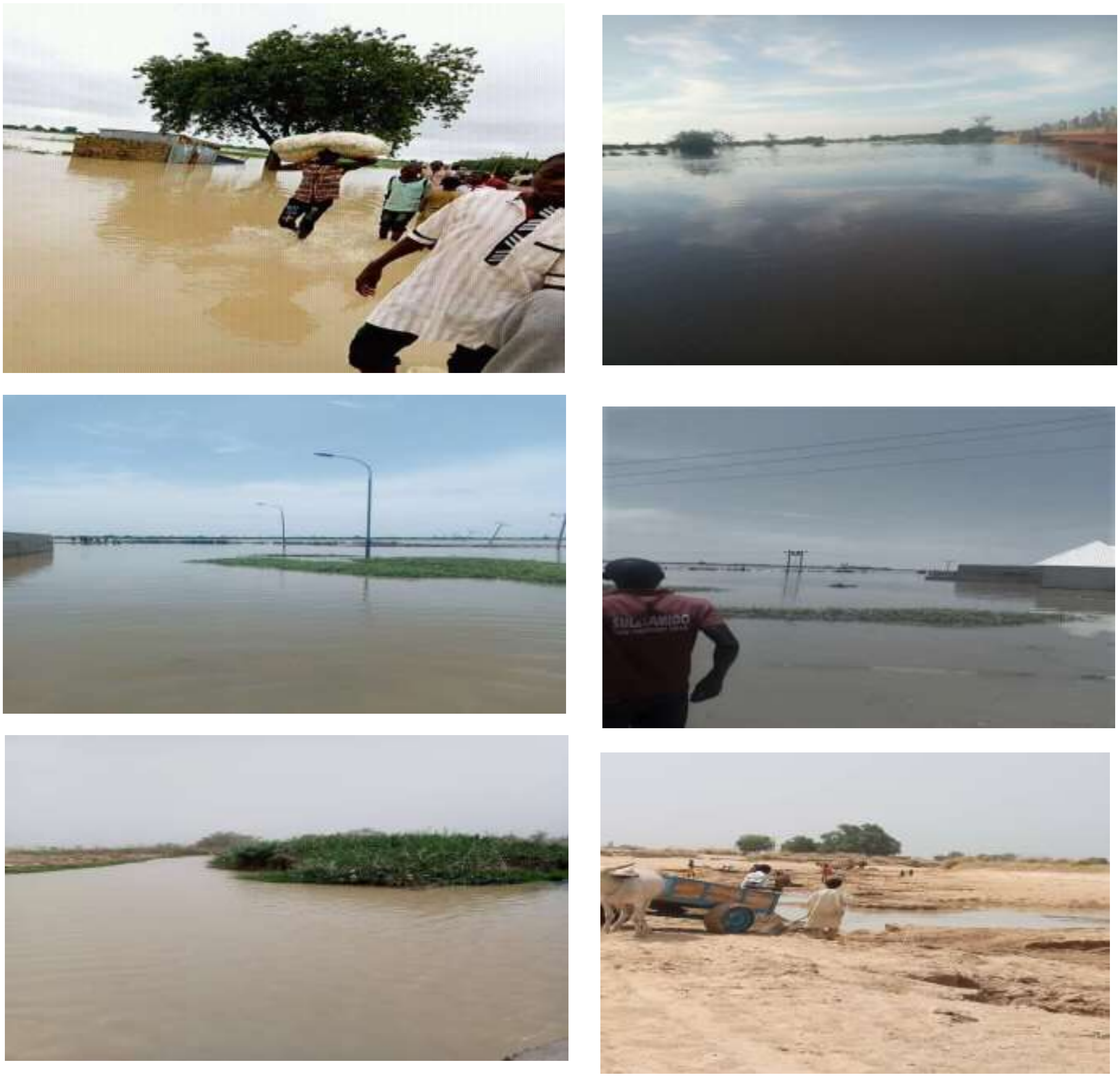

Figure 1: Pictures of some flood event and mining of sand in Hadejia River Basin

Source: (HJRBDA, (2019); Field, (2020))

1.3. Research Objective

1.3.1. Main Objective

The objective of this work is to develop a GIS-based flood risk and vulnerability mapping integrated with Analytical Hierarchical Process (AHP) in order to reduce the risk and vulnerabilities associated with flood in Hadejia River Basin.

1.3.2. Specific Objectives

The specific objectives of this work are:

1. To identify and quantify flood causative factors as well as the associated weights and ranking using Analytical Hierarchy Process (AHP).
2. To determine the total vulnerability (social and economic vulnerability) of flood susceptible zones of the study area and the associated flood risk map.
3. To explore flood mitigation and adaptation measures required to reduce flood risk and vulnerability in the study area.

1.4. Research Questions

1. What are the flood causative factors in the study area and how can they be quantified?
2. To which extent is the study area vulnerable to flood and what are the most vulnerable areas in Hadejia River Basin?
3. What kind of flood mitigation and adaptation measures are required to reduce flood risk and vulnerability in the study area?

1.5. Relevance of the Study

Undoubtedly, cities and human settlements nowadays are progressively becoming places of risks for their inhabitants. Future scenarios of urban growth present a disturbing picture if this issue is left unaddressed. In line with the proposal of sustainable development goals (SDGs), Goal 11 calls for focus on making ‘‘… cities and human settlements inclusive, safe, resilient and sustainable’’ (Rana & Routray, 2017). It is therefore imperative to identify, quantify and minimize the cities and settlements risks. According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2014), an increase of 20% of flooding in West Africa are expected over the next decades relative to the previous decades due to climate change impact which may worsen and become severe by 2050. Flash flood leads to various damages ranging from moral to material damages. Other aftermaths of flash flood includes; destruction of infrastructures, soil deterioration, socioeconomic problems, submergence of cities and towns and loss of human and animal life (Radwan *et al.,* 2018). It has therefore becomes pertinent to carry out flood risk mapping and assessment in Hadejia River Basin so as to provide warning for those who stand the risk of being affected in the event of flood and to reduce the risk of flooding and vulnerability of the people living in the basin.

1.6. Thesis Outline

The outline of the research work consists of six chapters. The first chapter mainly talked about the introduction in which a detailed background of the study was presented, the problem statement was explicitly presented, the study objectives and research questions were also present in the first chapter and relevance of the study. The second chapter provides a literature review which illustrates the state of the art as far as studies flood risk and vulnerability assessment is concerned. The chapter started my giving a brief review on flooding events in Nigeria. The chapter also present an elaborative description of ArcGIS software with respect to flood risk analysis using Multi-Criteria Evaluation techniques. Several studies of flood risk, flood hazard and flood vulnerability were presented in this chapter as well. A conceptual framework of the research activities were well documented such as Multi-criteria analysis using Analytical Hierarchical Process (AHP) were well documented in this chapter.

The third chapter presents the description of the study area. The study area location, its physical and hydro-geomorphological characteristics were presented in this chapter. This chapter mainly described the methodology that the researcher used in the research work. The methodology the researcher used in this study is GIS-based multi-criteria decision-making approach for flood risk assessment based on the spatial integration of the three flood risk component which are; flood hazard, social vulnerability and economic vulnerability. The analytical Hierarchical process AHP method is selected in weighting criteria, the researcher was able to generate some of the thematic layers necessary for the creation of flood hazard layer such as Elevation layer, Soil layer, slope layer, Drainage density layer, population density layer, land use layer and so on are described in this chapter. Finally the procedure for the development of flood risk map and the validation of the hazard, vulnerability and the risk map was also presented. The fifth chapter presents the results and discussion while the sixth chapter provides a conclusion and few suggestions.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Review of Flood Events in Nigeria

In Nigeria, the highest natural occurring natural hazard is flood which causes great and devastating life and properties losses (Aderogba, 2012). It has become an annual events occurring frequently across the nation in form of coastal flood, river flood, flash floods and urban flood (Alfa *et al.,* 2018; Komolafe *et al.,* 2015). During the last decades, many states and cities of the nation have experienced an unusual and overwhelming flood disasters which renders the government's capacity to prevent such disasters negated. One of the most notable devastating flood event that occurred in Nigeria was in Ibadan 1963 which claimed many lives and properties losses when Ogunpa River overflown. There was reoccurrence of flood events in 1978, 1980 and 2011 in this River which resulted in an estimated life and properties losses of 100 people and 30 billion Naira respectively (Komolafe *et al.,* 2015; Aderogba, 2012; Adegbola and Jolayemi, 2012). The wort flood events that hit Nigeria since the last 40 years was the one that occurred from July to October 2012 affecting about 35 out of the 36 states of the country (Including the Federal Capital Territory) as a result of heavy rainfalls with Jgawa, Kano, Yobe, Kogi, Plateau, Taraba, Bayelsa, Kwara, Delta and Benue as the most affected (Alfa *et al.*, 2018). Lagos state alone between 2011 and 2012 recorded 8 major floods which killed more than 30 people and many infrastructural damages (Komolafe *et al.,* 2015). According to the report of EM-DAT: International Disaster Database on Nigeria disaster, floods has affected about 7,000, 867 lives and accounted for 363 and $500,000 deaths and economic damages in 2012 alone (Komolafe *et al.,* 2015). More recently in 2018, floods has affected more than 1.9 million persons across 12 states in Nigeria (Including Jigawa and Yobe state) which caused the displacement of more than half a million of them from their households (WHO, 2018).

2.2. Concept of Flood Risk: A Systematic Approach from Hazard to Risk

The concept of flood risk assessment is not a localized concept because it has been widely used worldwide (Tsakiris, 2014; Mishra & Sinha, 2020). The various terms use in flood risk assessment studies such as floods, flood hazard flood losses, and flood risk narrows their emphasis on the negative economic losses and social consequences inflicted by floods (Mishra & Sinha, 2020). Risk is the define as the product of likelihood of an event and its negative consequences (Hazarika *et al.,* 2016; Rana & Routray, 2017). Flood risk has basically three component at conceptual level (Tsakiris, 2014) which are: Hazard, Exposure and Vulnerability. According to Mishra & Sinha, (2020) and Tsakiris, (2014) there is usually the same exposure or risk of flooding in certain flood hazard area but a wide range of vulnerability. Thus flood risk is defined as the product and function of hazard and vulnerability (Chakraborty & Mukhopadhyay, 2019; Danumah *et al.,* 2016; Tsakiris, 2014). Natural hazards usually converts into disasters only when "vulnerable" populations are affected and proper mitigation measures are not in place (Rana & Rou tray, 2017).

2.3. GIS-based Multi-criteria Analysis Approach

Multi-criteria analysis is a decision-making method used when there is inadequate qualitative ground data availability to solve complex problems with multiple variables and alternatives, high degree of uncertainty, and scientific and socioeconomic challenges (Danumah *et al.,* 2016; Youssef & Hegab, 2019). The integration of multi-criteria analysis (MCA) in decision making with geographic information systems (GIS) used in this research allows the use of the three component of risk assessment (hazard, exposure, and vulnerability) so that the social, economic and environmental vulnerabilities can be considered (Rincón *et al.,* 2018; Hoque *et al.,* 2019). In MCDM, the assessment of criterion weight is achieved using different methods such as; entropy, ranking, rating, trade-off analysis, and pairwise comparison (Rincón *et al.,* 2018). The rating method for assessing the criterion weights has an important limitation which makes the justification of the meaning of assigned criterion weights challenging as it lacks theoretical foundation (Rincón *et al.,* 2018).

Multi-criteria Decision making problems are usually solved using AHP in which the weight of each criterion is calculated using a pairwise comparison matrix (Danumah *et al.,* 2016; Alfa *et al.,* 2018). The two main methodologies employs in Multicriteria analysis are the Ranking and Rating. Ranking signifies the degree of importance each decision element imparts to the decision made, while Rating is a bit similar to raking except that the level of importance each element has in the decision making is assigned using a numerical score (Sharma *et al.,* 2017). Multidisciplinary approaches has become a first-hand method through which expertise analyses decision and manage various risks associated with floods particularly when there is limited knowledge about flood phenomena (Youssef & Hegab, 2019). Multicriteria evaluation is one of such approaches in which Analytical Hierarchy Process (AHP) method is coupled with GIS platform. Shale *et al.,* (2020) claims that multicriteria analysis method are decision support tools in which technological, ecological, and social aspects of complex decision constellations were analyzed and covered. These methods have been repeatedly found to be suitable for optimization of land use planning and risks analysis when combined with geographical information system (GIS) (Weerasinghe *et al.,* 2018). Multicriteria decision analysis (MCA) / multicriteria evaluation (MCE) has gained renewed interest because of its uniqueness in improving decision making, developing and evaluating alternative plans and it is predominantly appropriate for spatial decision making (Rahmati *et al.,* 2016; Seejata *et al.,* 2018; Shale *et al.,* 2020).

Shale *et al.,* (2020) analyses the flood hazard and risk in Ambo town and its watershed using GIS-based multi-criteria approach for the purpose of implementing strategic measures for sustainable flood disaster risk management in the watershed. The flood hazard layer was derived from various factors such as the land use / land cover, slope, drainage density, elevation, soil and rainfall while the flood risk analysis was done by using flood hazard layer and two other element at risk namely; human population and land use. Mishra & Sinha, (2020) integrated geomorphological, hydrological, and socio-economic data in GIS framework using multi-criteria evaluation to produce flood risk map in the Kosi megafan region. The study assesses the flood risk in the Kosi megafan region by combining the flood hazard and flood vulnerability maps. Such maps will serve as a guide for mitigation measures through which flood consequences and flood risk should be reduced. Danumah *et al.,* (2016) identified and mapped areas prone to flood risk in Abidjan district in South of Côte d'Ivoire using GIS-based multi-criteria evaluation approach. The flood risk zones were mapped and assessed with the aid of analytical hierarchy process AHP under the concept of hazard and vulnerability. Hazarika *et al.,* (2016) assessed flood hazard, vulnerability and flood risk using an indicator-based approach comprising of stakeholder's knowledge and multi-criteria evaluation in geographical information system GIS.

2.4. Analytical Hierarchical Process (AHP)

Many Methods of multi-criteria evaluation weighting have evolved such as the analytic hierarchy process (AHP), the gray target model, the fuzzy comprehensive evaluation model, technique for order preference by similarity to the ideal solution, principal component analysis, set pair analysis, data envelopment analysis, and the variable sets method (Hu *et al.,* 2017). but Analytical Hierarchy Process is one of the best and most frequently used approach among all the methods mentioned

(Danumah *et al.*, 2016; Mahmoud & Gan, 2018; Alfa *et al.,* 2018; Rincón *et al.,* 2018; Hoque *et al.,* 2019; Youssef & Hegab, 2019). The AHP is a multi-criteria approach that makes the best decision by coupling qualitative and quantitative factors to rank and evaluate various alternatives scenarios (Youssef & Hegab, 2019). AHP helps decision makers and engineers in deciding the best alternative that suits their goal among different options and criteria (Rincón *et al.,* 2018). In this method, a pairwise comparison matrix is used to compares two alternatives at a time by assigning values of relative importance from one alternative over another alternative (Shale *et al.*, 2020). The scale of relative importance has a range between one and nine in which one is equal importance and nine is extreme importance (Komi *et al.,* 2016; Rincón *et al.,* 2018). AHP has been applied worldwide in various fields such as education, healthcare, site selection, industry, suitability analysis, reginal planning, land slide susceptibility and transportation (Youssef & Hegab, 2019). AHP have been proven by various researches to be very robust and effective in providing accurate and reliable flood hazard, susceptibility and risk predictions (Alfa et al., 2018; Radwan *et al,* 2018). In AHP analysis, complete amalgamation of several criteria is assumed and a linear additive model is developed (Danumah *et al.,* 2016).

Chakraborty & Mukhopadhyay, (2019) employs the concept of hazard and vulnerability for preparing flood risk map in Coochbehar district. The flood hazard and vulnerability index were derived with the aid of AHP in GIS environment which collectively yielded the flood risk map. Alfa *et al.,* (2018) have applied analytical hierarchy process AHP in deciding and ranking flood causative factors for flood hazard map development. The flood vulnerability map was developed based on physical and social vulnerability. In their study the flood risk map was produce by multiplying the hazard and the vulnerability map. Radwan *et al.,* (2018) Integrated Remote Sensing Techniques (RST) and Geographic Information Systems (GIS) to assess the flood risk in Riyadh city. The analytical hierarchy process AHP of multi-criteria analysis was used as a criteria weighing technique. Several remotely sensed data were used to form the flood risk layer such as digital elevation model, spatial soil and geologic maps, historical daily rainfall records, and data on rainwater drainage systems. The result of the analysis proved the effectiveness of the integration of Remote Sensing Techniques (RST) and Geographic Information Systems (GIS) in assessing flood risk. Rincón *et al.,* (2018) developed an updated and accurate flood risk maps in the Don River Watershed within the Great Toronto Area. The weights of the various indicators of flood risk were defined and quantified using Analytical Hierarchy Process (AHP). The flood hazard and the total vulnerability (social and economic vulnerability) were generated for four and three scenarios respectively. The result reveals that using indicators such as digital elevation model, the census data, the streams, land use, and soil type layers yields a reliable and accurate flood risk map compared to the use of more complex hydraulic and hydrological models to generate flood hazard maps.

Komi *et al.,* (2016) carried out an integrated flood risk assessment in Oti River Basin in Togo. In their study the relevant factors contributing to flood risk in the rural communities of the basin were identified. The methodology employed in the study involves a field work through which primary data were collected with the aid of questionnaires by applying a community based disaster risk index model, population and housing census analysis and analytical hierarchical process (AHP). Danumah *et al.,* (2016) identified and mapped out areas prone to flood risks in Abidjan district (South of Côte d'Ivoire). Flood risk indicators such as slope, drainage density, soil type, isohyet, population density, and land use and sewer system density were considered in the analysis of flood risk in ArcGIS interface. The flood risk assessment and mapping was achieved by integrating the various indicators under two criteria of hazard and vulnerability using the Analytical Hierarchical Process (AHP) of multi-criteria analysis. The results reveals a high risk of flooding within the district which makes it imperative for decision makers to develop effective and robust strategies for future flood occurrences.

The development of analytical hierarchical process (AHP) is summarized in five main steps (Costache *et al.,* 2019; Mishra & Sinha, 2020) which are described below:

The first step for determining the criteria weight is to create a pairwise comparison matrix at each decision level using the Saaty's scale (Saaty, 1980) for the criteria selected. The scale in the upper half of the matrix uses a sequence of absolute numbers from 1-9 for each pair to represent the individual preferences (Britain & Avenue, 1987) while the pairing in the lower half of the matrix is assigned a rating equal to the reciprocal of the value of the corresponding pair in the upper matrix based on the decision makers subjectivity, experience and intuitive and natural knowledge (Saaty & Vargas, 2001). The decision in the pairwise comparison matrix for the flood hazard and socio-economic vulnerability is based on the literature review, area experts, policy makers, stakeholders from academia and local community members.

The second step involves the use of Eigen value technique for the determination of the relative weight of each decision indicators as well as sub-indicators (called the Estimated Eigen value). This is achieved by together multiplying all the elements in each row in the matrix and then taking its N^th root for each element using the Equation (2.1).

$$\text{Estimated Eigen Value (EE) of Each Element} = \sqrt[N]{a_a \times a_b \times a_c \times a_d \times .... \times a_N} \quad (2.1)$$

Where, $a_a, a_b, a_c, a_d, ...a_N$ are the values of the row elements and N is the number of the row elements.

The third step is to calculate the sum of EE values in a given column and estimate the Relative Importance Weights (RIW) for each row element of that decision factor using the Equation (2.2)

$$\text{Relative Importance Weight (RIW)} = \frac{\sqrt[N]{a_a \times a_b \times a_c \times a_d \times .... \times a_N}}{EE_1 + EE_2 + EE_3 + EE_4 + ... + EE_N} \quad (2.2)$$

Where EE_1, EE_2, EE_3, EE_4, …… EE_N are the Estimated Eigen value of each element.

The fourth step is the check for consistency. This is done by computing the Consistency Ratio (CR) which depicts the quality of the pair-wise comparisons because in practice, the decision maker's expression involves some fuzziness that may make the matrix have some inconsistencies (Mishra & Sinha, 2020). The judgment or preference is consistent only if the CR is greater than 0.10. Saaty's Consistency Ratio CR is used to check the pair-wise comparison (Saaty, 1980; Saaty, 2008)**.**

CR is calculated using the Equation (2.3)

$$CR = \frac{CI}{RI} \quad (2.3)$$

Where:

CI = Consistency Index which reflects the consistency of the judgment

RI = Random Inconsistency Index dependent on the sample size

The consistency Index, *CI* is calculated using the equation (2.4)

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (2.4)$$

Where, n is the number of criteria and λ_{max} is the average of the value of the consistency vector (calculated factor Weight)

The Random Inconsistency Indices *RI* depends on the sample size. *RI* for respective sample sizes is presented in the Table II below;

Table 2.1: Random Index Matrix (Saaty, 1980)

Number of Criteria	1	2	3	4	5	6	7	8	9	10	11
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

The acceptable judgment range is from $0 \leq CR \leq 0.1$ with a value of zero (0) being the most consistent (Saaty, 2008). Any value outside this range would require the assignment of the criterion weight again. A consistency ratio $CR < 0.10$ indicates a reasonable level of consistency in the pairwise comparison while CR value ≥ 0.10 dignifies inconsistent judgment (Mishra & Sinha, 2020).

The fifth step is to derive the flood hazard index (FHI) and flood vulnerability index (FVI) by aggregating the RIWs at each level of hierarchy using Equation (2.5).

$$FHI / FVI = \sum_{i=1}^{N_2} RIW_i^2 \times RIW_{ij}^3 \tag{2.5}$$

Where, FHI/FVI = Flood Hazard / Flood Vulnerability Index

N_2 = Number of level 2 decision factor

RIW_i^2 = Relative Importance Weight of level 2 decision factor i.

RIW_{ij}^3 = Relative Importance Weight of level 3 sub-factor j of level 2 decision factor i (Mishra & Sinha, 2020).

2.5. Flood Risk Assessment using MCA Approach

The essential components of flood risk assessment are the flood hazard and vulnerability assessment through which the damages resulting from flood events can be quantified (Ghosh &

Kar, 2018; Roxana *et al.,* 2019). Amisigo & Bossa, (2019) performed flood frequency analysis, hydrological modelling, mapping of flood hazard using flood inundation model and a community-based flood risk assessment through integration of flood hazard mapping and survey data on vulnerability, exposure and coping capacity in order to examine the various factors that contribute to incessant flood risk in the Oti River basin in Togo. The study reveals that flood risk in the area depend mainly on high vulnerability and hazard while coping capacity an exposure are less important. Zehra *et al.,* (2019) described a rapid assessment of flood risk via community and external stakeholder perceptions of challenges in the neighbourhood, coupled with the description of how floods affected basic infrastructures such as drainage and sanitation and services like pit evacuation and solid waste collection and disposal. The outcome of their study suggest the need to collaborative partnership with community members to develop sustainable flood management strategies and infrastructure solutions.

Țîncu *et al.,* (2019) have used ArcMap 10.2 software and FloodRisk tool from AGIS software to estimate the damages caused by flood of different return periods to three land classes (residential building, infrastructure and agriculture) using the damage curves developed by the European Joint Research Centre (JRC) as well as site specific maximum damage values in the section Făgetul de Sus-Ghimeş-Palanca Pass of Trotuș River, with the aim of highlighting the need of improved land use plans. The flood risk was assessed using the damage – probability curves. The methodology used in this research provides quantitative results regarding the flood damage and flood risk assessment. Weerasinghe *et al.,* (2018) presented the results of a qualitative flood risk assessment in western province of Sri Lanka. The study present flood risk as a statistical expression of hazard, exposure and vulnerability. The study considered three types of vulnerabilities namely, social, economic and physical (housing) vulnerabilities. The results reveals that the flood risk of the population is more sensitive to economic vulnerability than social vulnerability. Ghosh & Kar, (2018) used a composite flood hazard and vulnerability index to assessed flood risk in Malda district of West Bengal, India in order to formulate policies for flood risk reduction. In their study, the analytical hierarchy process AHP was used to develop flood hazard elements and vulnerability indicators in geographical information system GIS. The flood hazard map was prepared by considering some morphological and hydro-meteorological elements while the vulnerability map was produced using demographic, socio-economic and infrastructural elements.

Hu *et al.,* (2017) employed GIS-based multi-criteria approach to map flood risk zones in in the Fangshan District, China, using nine criteria in which six factors were considered in relation to hazard while three were considered for vulnerability. The study defined risk as a function and product of hazard and vulnerability. The flood risk map was developed using analytical hierarchy process (AHP) in GIS ambience. The study compares the developed risk map with an actual flood disaster and has proved the method to be effective and reliable in flood disaster risk assessment and mapping. Ntajal *et al.,* (2017) assesses and mapped the social flood risk in Lower Mono River Basin, West Africa. Their study adopted the GIS, Remote Sensing and indicator-based flood risk assessment framework of Davidson (1997) and Bolin *et al.,* (2003) that comprises Hazard, Exposure, Vulnerability and Capacity. The results suggested positive behavioral change towards early action and warning systems and implementation of appropriate building codes in order to reduce to risk associated with floods. Rana & Routray, (2017) have clearly conceptualized disaster risk and proposes a risk assessment methodology consisting of hazard, vulnerability (exposure and sensitivity) and coping/adaptive capacity. Various data relating to flood hazard, vulnerability and capacity were collected by conducting a primary survey in some selected communities to compute the risk index. The proposed methodology is found to be effective and operational in risk assessment of flood-prone areas.

Hazarika *et al.,* (2016) assesses hazard, vulnerability and risk as a result of floods using an indicator-based approach by integrating multicriteria evaluation in geographic information system (GIS) and stakeholder's knowledge to achieve community-based assessment. The result of the study shows the spatial distribution of flood hazard and vulnerability and areas at risk at both regional and sub regional level. The results reveals that vulnerability indicator are more significant than hazard indicators in their ability to contribute to flood in the river valley. Komolafe *et al.,* (2015) have reviewed the various methods and results of flood risk analysis in Nigeria by focusing on recent papers. The methodologies of flood hazard mapping and modelling, exposure and vulnerability assessment were analyzed while possible urgent needs and further development were suggested. The review concluded by suggesting the use of a state of art flood models which integrate all hydrological processes for sound and accurate prediction and mapping of flood risks. Finally the study recommended that further researches on flood risk impact on health and environment should be carried out in Nigeria.

2.6. Flood Hazard and Flood Hazard Assessment

Hazard can be defined as the measure of likelihood occurrences of a potentially harmful natural phenomena at a particular period of time and over a given area (Hazarika *et al.,* 2016; Ghosh & Kar, 2018). Youssef & Hegab, (2019) defined hazard as the probability of occurrence of potentially harmful phenomenon at a particular location over a specified period of time. The process of flood risk assessment usually gives more attention to flood hazard assessment because it is based on the likelihood occurrence of floods in a particular area and on the flood strength (Seejata *et al.*, 2018; Roxana *et al.*, 2019). Flood hazard mapping is of paramount importance in providing appropriate land use planning in flood areas and mitigation measures (Danumah *et al.,* 2016; Ghosh & Kar, 2018). Natural hazards are generally assessed using various approaches such as heuristic, statistical and deterministic methods (Youssef & Hegab, 2019). AHP is found to be one of the most widely applied heuristic method that involves multiple objective decision making method which was developed by Saaty, (1980).

Rahmati *et al.,* (2016) have assessed the efficiency of analytical hierarchical process (AHP) in identification of flood hazard zones through comparison with hydraulic model results. The comparative results renders the AHP promising in making accurate and reliable predictions of flood hazard extent. Moreover, their results suggests the integration of GIS and AHP in assessment of flood hazard potential is promising particularly in less or no data areas. Seejata *et al.*, (2018) carried out an assessment of flood hazard zones in Sukhothai province of Thailand. The study uses six different relevant flood causative factors such as rainfall amount, slope, elevation, river density, and land use and soil permeability in estimation of flood risk zones in GIS ambience. Mahmoud & Gan, (2018) integrated ten (10) flood susceptibility factors such as flow accumulation, annual rainfall, slope, runoff, land use/cover, elevation, geology, soil type, distance from the drainage network, and drainage density to identify flood susceptibility zones in the central region of Saudi Arabia using multicriteria analysis. The analytical hierarchy process was used to derive the criteria weight while sensitivity analysis was done to test how sensitive the results are to changes in the criteria weights and to evaluate the contribution of various factors in developing flood susceptibility maps. The results were validated using historical flood records and the results were found to be in good agreement with the historical flood events. The sensitivity analysis results suggest that six or more susceptibility factors should be considered when developing flood susceptibility maps particular those related to surface runoff and flow accumulation.

2.7. Flood Vulnerability and Flood Vulnerability Assessment

Adger, (2006) posit that the states of powerlessness, susceptibility to harm and marginality of both physical and social systems are best described by vulnerability. Vulnerability is used to determine how susceptible a community is to the impact of hazards by assessing its physical, socio-economic and environmental factors and processes (Amisigo & Bossa, 2019). According to Roy & Blaschke, (2015) and Mavhura *et al.,* (2017) vulnerability is defined as "the conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of an individual, a community, assets or system to the impact of hazards". Vulnerability to disaster is simply defined by Mavhura *et al.,* (2017) as the potential for loss. The determination of vulnerability depend collectively on population composition, economy, livelihood, supporting infrastructures and resilience capacity of community to cope with hazardous events (Mondal & Pal, 2015; Hazarika *et al.,* 2016; Ghosh & Kar, 2018). Vulnerability with respect to coping capacity can be viewed as the gaps and weaknesses of the adopted coping capacity of a community (Rana & Routray, 2018).

Hoque *et al.,* (2019) performed flood vulnerability mapping by developing a spatial multicriteria approach using geospatial techniques at local scale in Kalapara Upazila in Bangladesh. The study used 16 relevant vulnerability indictors under physical vulnerability, social vulnerability and coping capacity. The vulnerability maps were produced by aggregating the individual vulnerability maps created from the 16 relevant criteria. The results of the study shows that areas close to active channel and areas that has low elevation and more social components has the highest vulnerability. Rana & Routray, (2018) quantified vulnerability indicators and developed a multidimensional model for vulnerability assessment. The study has explored vulnerability through physical / infrastructural, social, economic, institutional and attitudinal dimension. The proposed methodology of the study was verified and tested and was found to be operational when applied to urban flooding in Pakistan. Mavhura *et al.,* (2017) demonstrates an accessible way of assessing the spatial variation of social vulnerability. The variables contributing social vulnerability in the community were identified by the local residents and the social vulnerability index (SoVI) was developed using the principal component analysis (PCA). The study reveals that the economic, social and institutional factors greatly influenced the social vulnerability.

Roy & Blaschke, (2015) assesses the spatial vulnerability of floods in the coastal regions of Bangladesh using a methodology comprising of 12 vulnerability domains and 44 indicators. The analytic hierarchy process (AHP) was used to rank the indicators while GIS weighted overlay operation was used to assess the spatial vulnerability. The vulnerability maps were assessed based on visualization by local expert and comparison with the past flood maps. Isma'il & Saanyol, (2013) applied remote sensing and GIS techniques to develop flood vulnerability map of the Middle Course of River Kaduna. The study uses Digital elevation model DEM and flow accumulation and form the flood map and interviews with sampled resident of certain areas and identified element at risk of flood.

2.8. Disaster Risk Management and Disaster Risk Reduction

Disaster risk management is the systematic process of using administrative decisions, organization, operational skills and capacities to implement policies, strategies and coping capacities of the society and communities to lessen the impacts of natural hazards and related environmental and technological disasters. This includes structural and non-structural measures to avoid (prevention) or to limit (mitigation and preparedness) adverse effects of hazards (Baas *et al.,* 2008). Disaster risk reduction on the other hand refers to the conceptual framework of elements considered with the possibilities to minimize vulnerabilities and disaster risks throughout a society, to avoid (prevention) or to limit (mitigation and preparedness) the adverse impacts of hazards, within the broad context of sustainable development (Baas *et al.*, 2008). The disaster risk reduction framework is composed of the following fields of actions:

i. Risk awareness and assessment including hazard analysis and vulnerability/capacity analysis;

ii. Knowledge development including education, training, research and information;

iii. Public commitment and institutional frameworks, including organizational, policy, legislation and community action;

iv. Application of measures including environmental management, land-use and urban planning, protection of critical facilities, application of science and technology, partnership and networking, and financial instruments;

v. Early warning systems including forecasting, dissemination of warnings, preparedness measures and reaction capacities.

CHAPTER THREE

3. STUDY AREA

The Hadejia-Jama'are River Basin housed the Hadejia-Jama'are River System (H-JRS) which is part of the larger basin popularly known as Komadugu Yobe River Basin. The Basin is located in the semi-arid northern part of Nigeria. The two major rivers of the H-JRS (Hadejia and Jama'are) meet in the Hadejia-Nguru Wetlands (HNWs) to form the Yobe River. The source of River Hadejia is from the Kano highlands while the Jama'are takes its source from the Jos plateau. Among the major dams situated in the basin are the Tiga Watari and Challawa gorge dams, while Kafin Zaki dam is a proposed dam (Sobowale *et al.,* 2015). Other large-scale water resources management and irrigation projects present in the basin are the Kano River Irrigation Project (KRIP), Hadejia Valley Irrigation Project (HVIP) and the Hadejia Nguru Wetlands (HNW) Conservation Project, which is the most extensive flood-plain area in the basin (Goes, 1999). The Jama'are River System has no dam structures, it is uncontrolled. The third main river in the upstream part of the Hadejia River System, is the Watari River. The Watari River has a small dam that does not influence its flow significantly. The three rivers (Kano, Challawa and Watari rivers) join upstream of Wudil and become the Hadejia River (Goes, 2002). The Hadejia River is a gaining river until the geological boundary between the basement complex and the permeable sands, gravels and clays of the fluviatile and lacustrine Chad Formation. However, it becomes an infiltrating river downstream of the geological boundary. Gaya River is a relatively small right bank tributary to the Hadejia River situated in the Chad Formation area. In addition to the ecological richness of the wetlands, the HNW also serve as groundwater recharge zones. The basin has a mean annual rainfall of about 1100 mm in the upstream basement complex area, to about 400 mm in the middle part of the basin and less than 300 mm at the extreme downstream near the Lake Chad (Sobowale *et al.,* 2010).

The area faces challenges due to its high rural populations which are basically poor, degradation of its natural resources and losses of its biodiversity. The area is water stressed mostly in the mid center because of the increase in temperature of high evaporation rate. Several adaptation strategies existed in the basin to curb the impacts high level variation and variability in the hydro-climatic variables such flood recession farming by farmers and the construction of the Tiga dam in 1992 of storage capacity 1492 $\times 10^6$ m^3 and the Chalawa Gorge Dam in 1992 of storage capacity of 972

$\times 10^6$ m^3 (Sobowale *et al.*, 2015) . These dams controls 80% of the flows into the Hadejia-Nguru Wetlands. Tiga Dam is primarily used to store water for the Kano River Irrigation Project (KRIP) scheme. However, it reduces the flow of large volume of water downstream which decreases the possibility of inundation by flood waters.

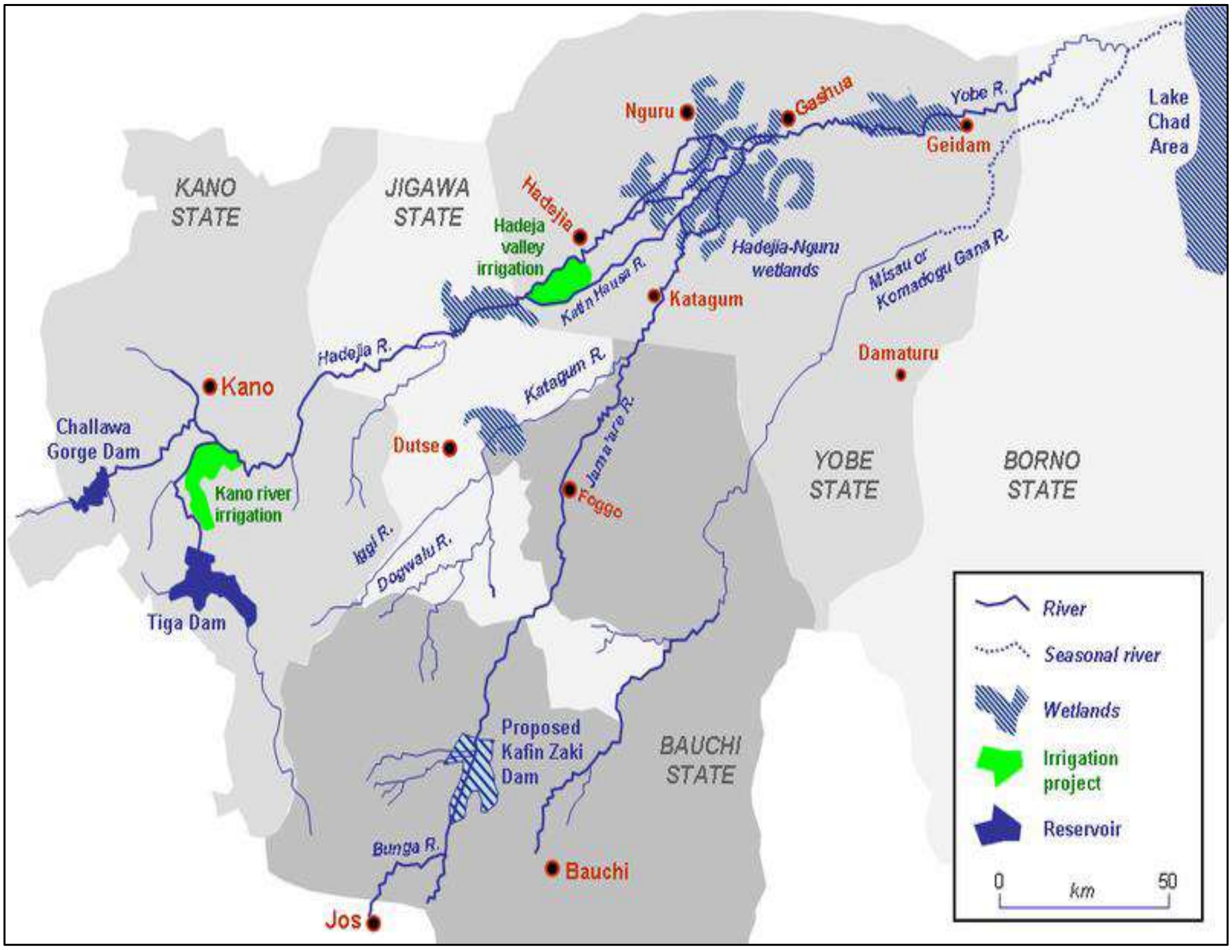

Figure 3.1 : Haejia-Jama'are River System

3.1. Location of the Study Area

The study area is Hadejia River Basin (HRB) situated in the Northwestern part of the Federal Republic of Nigeria which is a semi-arid zone (Umar *et al.*, 2019). The river basin has an area of about 30,569 Km^2 and is located between the latitudes 11°32´08.4´´N to 12°26´24.8´´N and longitudes 8°07´50.0´´E to 10°01´50.9´´E.

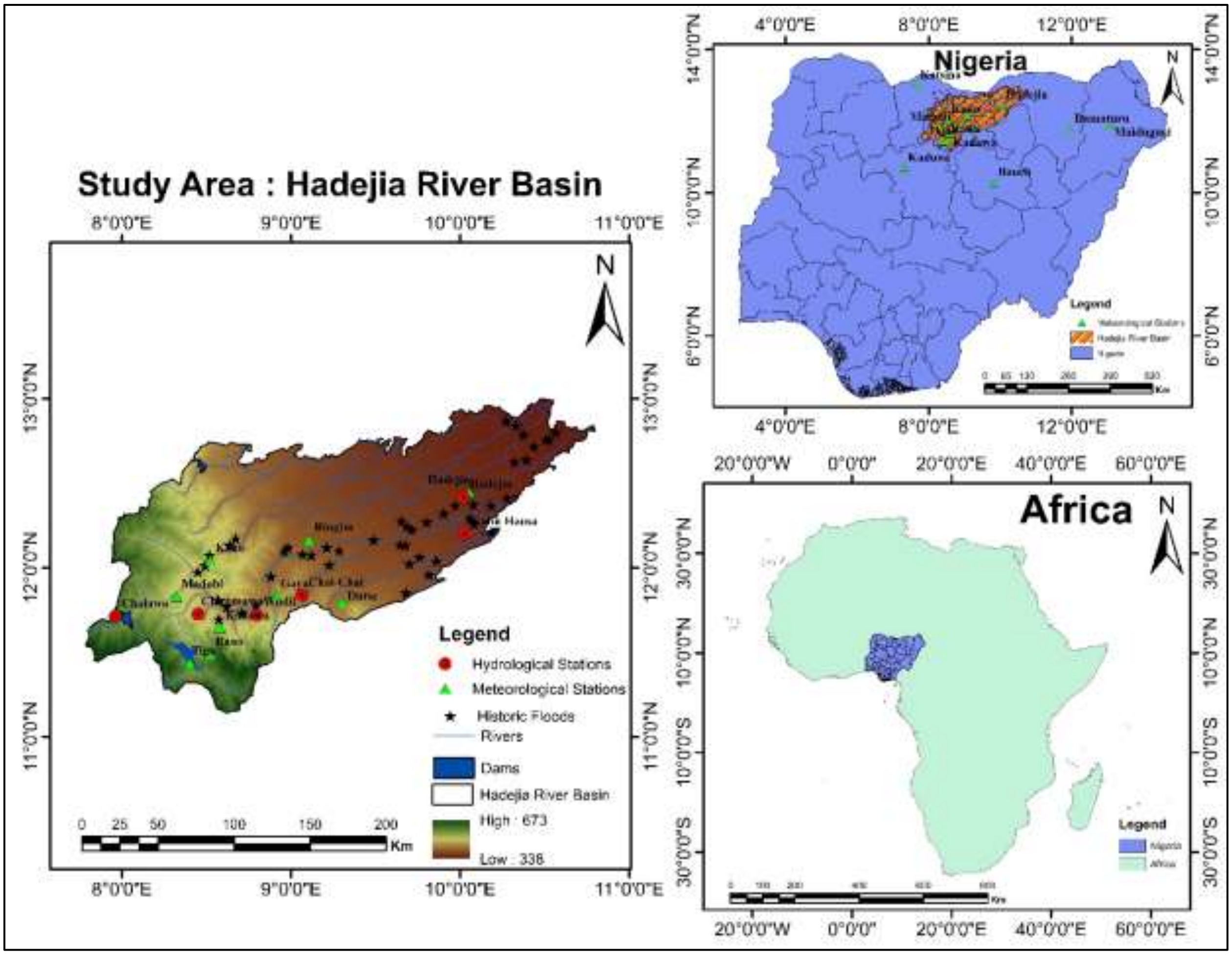

Figure 3.2: Location map of the study area

3.2. Hydrology and Drainage

The hydrology of the study area is dendritic in nature (Umar *et al.*, 2018). The observed mean annual flow and the peak flow in the basin are 1,396 m^3/s to $43m^3/s$ and $597m^3/s$ to $38m^3/s$. Peak flows are observed from 10 August to 16 September between the upstream and downstream areas of the basin (Umar *et al.*, 2019). River Hadejia takes source from the Kano highlands. The basin constituted the Tiga and Challawa gorge dams (Goes, 2002). Other notable water resource management and irrigation projects in the basin are the Kano River Irrigation Project (KRIP) and Hadejia Valley Irrigation Project (HVIP) (Odunuga *et al.*, 2011; Sobowale *et al.*, 2010; Ikusemoran *et al.*, 2011). The channels of the river in some sections is ephemeral (i.e it flows only during rainy season). The water levels in these channels rises during the wet season and usually dries up during the dry season. The channels drained through the Hadejia-Nguru wetlands and empties into the Lake Chad (Sobowale *et al.,* 2010).

3.2. Geology, Soil and Topography

The basin is underlain by two main geological configurations in the southern and northeastern portion of the watershed. The southern portion is covered by basement complex geological structure of igneous origin whereas sedimentary Chad formation dominated the northeastern portion (Sobowale *et al.,* 2010; Umar *et al.,* 2019) The basement complex structure consists of the comparatively shallow weathered mantle on top of solid igneous rocks which hinders surface water penetration. Similar to the geological variation, the soil of the study area varied from south to the north of the basin with the northern portion dominated by sandy soil fractions (Umar *et al.,* 2019). Hence this soil difference helps in the determination of the rate of infiltration and thus surface and groundwater potentials in the region. However, the Chad formation sedimentary rocks are made up of unconsolidated sediments. The elevation is higher at the southern part of the basin and northern part is dominated with lower elevation.

3.3. Climate and Vegetation of the Study Area

The climate system in the basin is regulated by two air masses which are the South West (SW) and North East (NE) trade wind (Adakayi, 2012). The SW trade winds stays in summer in the North from May to September and it comes along with moisture from the coast while the NE trade wind in winter comes along with dry cold 35°C around April and May before the onset of the rains and it drops dramatically in December/January to as low as 18°C (Umar *et al.,* 2018). The average maximum and average minimum temperatures winds from the Sahara Desert from October to April. The temperature of the basin rises to about recorded in the basin are 40°C between March to April and 12°C between December and January (Ahmed *et al.,* 2018). The rainfall of the area is known to vary spatially and temporally with the mean annual rainfall in the northeastern, midstream and the extreme south of the basin of about 600mm, 800mm and 1000mm respectively (Ahmed *et al.,* 2018). The basin experiences wet periods that last between four, five and six months in all its parts. However, dry periods are experienced in the rest of the months of the year.

The prominent vegetation found in the study area is the savannah vegetation, dominated by grasses and shrubs with scattered tree species (Nalami *et al.,* 2019). The area has two distinct types of savanna vegetation of Sudan Savanna and Sahel Savanna. The Sudan Savanna covers about 70%

of the total vegetation cover of the area. The tree species that dominates the vegetation are mainly Acacia species that are usually 10m-15m in height while the Sahel Savanna is usually found in the north-eastern parts of the study area. The trees mostly found in this region are usually not more than 1-5m in height. However, few drought resistant trees like Date Palm, Gum Arabic which may reach 20m in height are present in this region.

3.4 Population and Economic Activities of the Study Area

The population of the area is over 15 million which is sparsely distributed across different Local Government Areas of the basin. Kano state being the most populous state among the basin states has about 10 million people (Ahmad & Haie, 2018). The major economic activities taking place in the basin is Agriculture (Goes, 1999). This is evident because about 80% of the total land area of the study area is made up of arable land which renders about 85% of the total population of the state engaged in Agricultural activities. Crops like Millet, Maize, Sorghum, Cowpea, Groundnut, etc. are usually cultivated during the rainy season in the basin while crops like Rice, Maize, Sorghum, Water Melon, and Vegetables (Onion, Tomato, Spices, Pepper and Potato) are usually cultivated in the Kano Irrigation Project and Hadejia Valley Irrigation Project (Ahmad & Haie, 2018; Nalami *et al.*, 2019). The wetlands also provide Fisheries resources as well as grazing land for livestock especially cattle (Ahmad & Haie, 2018). Other economic activities in the study area include: trade, mining, small scale manufacturing etc.

CHAPTER FOUR

4. METERIALS AND METHODS

4.1. Materials

The following materials are used in this study

- **ArcGIS 10.5**: ArcGIS is the main software on which the study is based. It serves as an environment on which several analysis of the study are done such as watershed preprocessing, terrain analysis, thematic maps generation etc.
- **Arc-Hydro 10.5**: Arc-Hydro is used to delineate and characterize the watershed in raster and vector formats. It is also used to define and analyze hydro-geometric networks in the study.
- **Microsoft Excel:** This is used for, rainfall analysis and other statistical analysis.
- **A Garmin hand-held Global Positioning System (GPS)**: This is used for marking of locations during fieldwork.

4.1.2. Data Types and Data Sources

Data is the fundamental and essential element for GIS analysis. The data that is utilized in this research work for the achievement of the stated objectives includes data derived from remote sensing, raster and vector data in GIS, meteorological data from meteorological stations and other ancillary data. 36 years daily rainfall data for 7 stations, 4 outside the basin and 3 inside the study area was obtained from Nigerian Meteorological Agency (NiMet) and Hadejia-Jama'are River Basin Development Authority (HJRBDA). The data was checked for missing values and corrected, the data was then subjected to consistency check using statistical approaches. The population census data of 2006 and 2011 of the basin was obtained from National Population Commission and National Bureau Statistics. Other relevant data such as the public perception about floods disasters, factors responsible for floods, causes of floods in the study area and history of the previous flood events were gotten through focus group discussions with the stakeholders, policy makers and local residents and field surveys. The stream flow data for 50 years from 1968-2018 was gotten from Hadejia-Jama'are River Basin Development Authority (HJRBDA). The soil data of the basin was gotten from Food and Agriculture Organization (FAO) website while the Landsat 8 data and elevation data were gotten from United State Geologic Surveys (USGS). The data categories, data types and data sources are listed in the Table 4.1 below.

Table 4.1: Data Type and Sources of Data

S/N	Data Category	Data Type	Data Source
1	Satellite imagery (Landsat 8 OLI)	Land use and Land cover data	United State Geological Survey (USGS)
2	GIS data	SRTM Elevation data	United State Geological Survey (USGS)
		Slope Road Network shapefile River shapefile	
3	Hydro-meteorological data	Rainfall data (1982-2018) Stream Flow data (1968-2018)	Nigerian Meteorological Agency (NiMet) & HJRBD Authority and Hadejia Jama’are Komadugu Trust Fund, Damaturu
4	Geomorphological data	Soil data (2020)	Digital World Soil Map (FAO)
5	Demographic data	Population Census data (2006 and 2011)	National Population Commission & National Bureau Statistics
6	Ancillary data	Other relevant information (2020)	USGS Verbal interviews and field surveys

4.2. Methodology

4.2.1. Overview of the Methodology

The methodology used in this study is GIS-based multi-criteria decision-making approach for flood risk assessment based on the spatial integration of the three flood risk component which are; flood hazard, social vulnerability and economic vulnerability. The analytical Hierarchical process AHP method is selected in weighting criteria. The flood hazard layer is determined based on river floods causative factors / parameters. The social vulnerability is based on the population of the vulnerable groups, their literacy level, and female percentage while the economic vulnerability is based on income rates, employment rate and land-use layer. ArcGIS software is used in this research for creating the spatial layers required for the assessment of flood risk.

The spatial layers is later reclassified using the ‘Reclassify Tool’ in ArcGIS in a scale range of 1 to 5, in which 1 refers to very low level flood risk and 5 refers to a very high level flood risk. The reclassified layers is spatially overlaid using the Weighted Overlay Tool of ArcGIS to form the spatial overlay maps. The cell of each input raster is multiplied by its corresponding weight after which they are summed up to get the output raster. The following sections give detailed process of generating flood hazard map, socio-economic flood vulnerability maps and the final flood risk map of the study area. The methodological flow chart is presented in Figure 4.1 below.

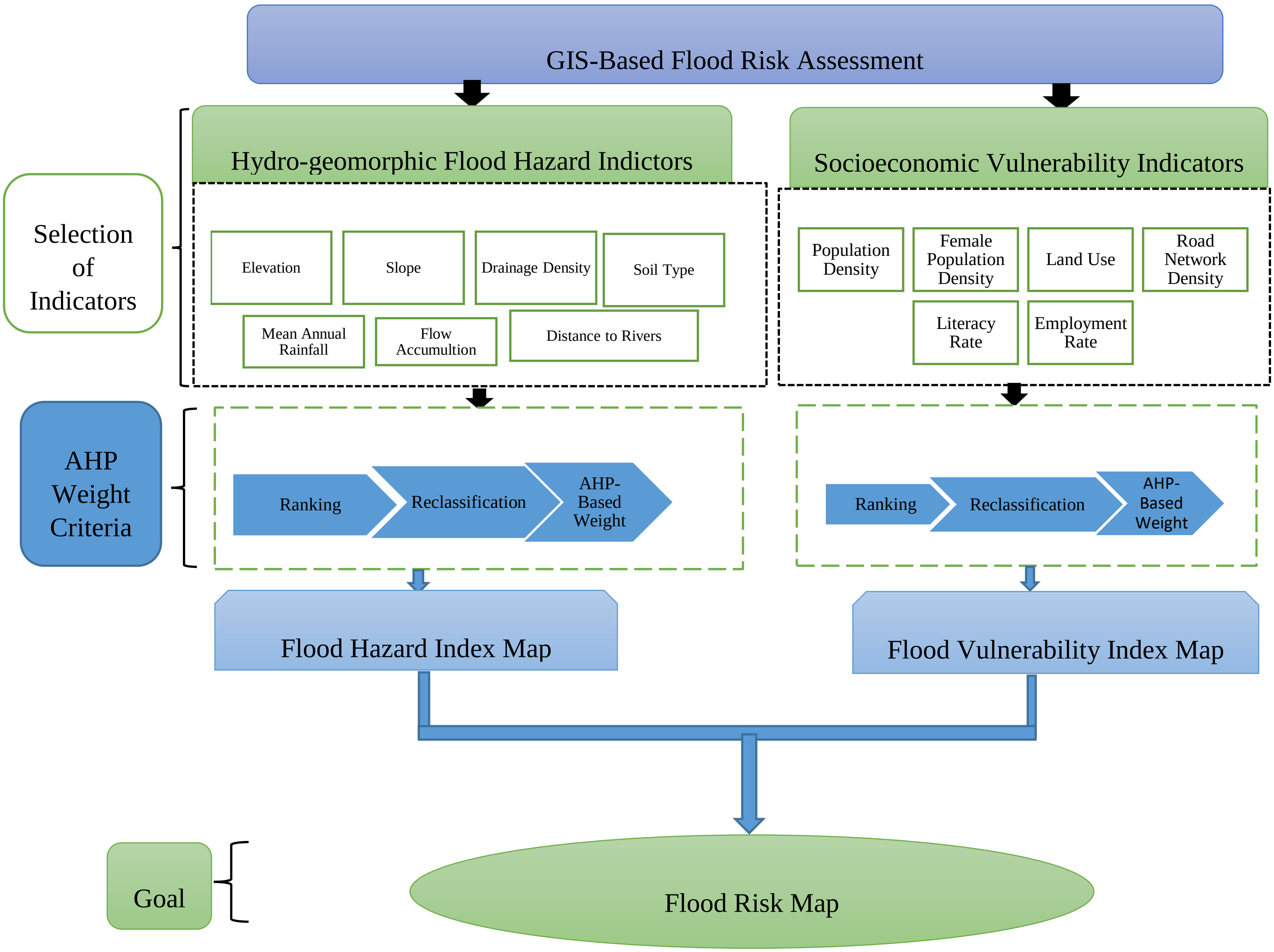

Figure 4.1: Flow Chart of the Methodology

4.2.2. Development of flood hazard indicators and associated maps using MCA

Multi-criteria analysis (MCA) of flood risk assessment have been extensively used in the field of water resources management (Zelenakova & Dobos, 2018; Ghosh & Kar, 2018; Alfa *et al.*, 2018; Youssef & Hegab, 2019; Shale *et al.*, 2020). The flood hazard layer is determined using the multi-criteria analysis and the Analytical Hierarchy Process (AHP) (Saaty, 1980) by integrating thematic layers of the flood causative factors in ArcGIS. It was argued that there is no unique way of choosing criteria that should be used in developing flood hazard layer (Rincón *et al.,* 2018). However, several studies have used various criteria that contribute to flood susceptibility such as slope, land use, distance from stream, distance from drainage line, rainfall intensities, elevation, curvature, topographic wetness index (TWI), lithological units and soil (Ghosh & Kar, 2018; Youssef & Hegab, 2019; Shale *et al.,* 2020; Mishra & Sinha, 2020). The present study will tend to includes hydro-geomorphic factors as used by Mishra & Sinha, (2020) such as elevation, mean annual rainfall, slope, distance to rivers, soil, flow accumulation, drainage density as they have high influence in determining flood hazard extent. Soil can replace the geologic layer as they have similar influence (Shale *et al.,* 2020) while flow accumulation and drainage density have been included among hydro-geomorphic factors. Rainfall and land use have been included in very few studies of mapping flood hazard using multi-criteria analysis (Rincón *et al.,* 2018). Hence, the mean annual rainfall is included among the criteria of flood susceptibility in this study.

In summary, the flood hazard map for Hadejia River System is produced by generating the thematic layers of the various flood causative factors, assignment of their criterion weight, their reclassification based on the assigned weight and their final integration. The different thematic layers that are generated for the flood hazard map are described below;

4.2.2.1. Elevation Layer

The elevation is among the most important criterion regarding flood hazard. Low lying areas can get inundated by even flood of low magnitude which renders them more prone to inundation (Ghosh & Kar, 2018; Ntajal *et al.,* 2017). The elevation layer is generated from Digital Elevation Model (30m) of the study area which is obtained from United State Geological Service Shuttle Radar Topography Mission (SRTM) data (USGS), which is in decimal degrees and datum WGS84. Elevation information is also obtained from field and is compared with the maximum elevation stage of the Hadejia River to serve as a guide in the classification of the SRTM DEM. The DEM is reclassified into groups dependent on the lowest and highest elevation. The highest elevation is assigned a scale value of 5 and the lowest elevation is assigned a value of 1.

4.2.2.2. Soil Layer

The soil type of an area determines the infiltration rate of rainfall and hence the area's potential to runoff generation and flood susceptibility (Ntajal *et al.,* 2017). The soil map of the study area is clipped from the harmonized digital soil map of the world (DSMW) by using the catchment boundary as the clip feature. The digital soil map of the world (DSMW) together with the attributes tables is obtained from the Food and Agricultural Organization (FAO)'s website. The attribute table will give the soil texture and hydrological soil groups. The clipped soil map is analyzed in ArcGIS environment and is related to the attribute table to depict the different soil textures and hydrological soil groups of the study area. The soil layer is reclassified based on their influence in causing flooding. The soil type that has the highest potential to cause flooding is assigned a value of 5 while the one with the least potential is given a scale value of 1.

4.2.2.3. Slope layer

The slope percent is one of the surface indicators that plays a vital role in the determination of velocity of surface runoff and vertical percolation which are among the key indictors in identifying flood susceptibility (Rahmati *et al.,* 2016). The velocity with which the water flows through the drainage channel and the watershed is largely affected by slope (Rincón *et al.,* 2018). Hence, the inundation of a particular area is generally affected by the slope length and steepness. For instance, areas with low slope angles would first get inundated before areas with high slope angles during flooding event (Mishra & Sinha, 2020). Moreover, the steeper the slope the higher the runoff and consequently the higher the peak discharges (Rincón *et al.,* 2018; Shale *et al.,* 2020). The slope layer is obtained in percentage from the clipped elevation of the study area using spatial analyst tools in ArcGIS 10.5. The slope is classified into five classes. The generated slope is then reclassified in a scale of 1 to 5 with a value of 5 being the lowest slope and 1 being the highest slope.

4.2.2.4. Distance to Rivers Layer

The susceptibility of an area to flooding is dependent on the measure of distance to streams (Ghosh & Kar, 2018). The closest areas to rivers are highly affected by floods than areas farther away from the rivers (Rincón *et al.,* 2018). The Euclidian Distance Tool is used in the Spatial Analyst in

ArcGIS to obtain these distances. The spatial layer is reclassified by assigning a value of 1 to the areas near to the streams and a value of 5 to areas farther from the streams.

4.2.2.5. Flow Accumulation Layer

The flow accumulation is considered among the most important factors in delineating flood hazard zones (Ntajal *et al.,* 2017). High flow accumulation signifies high susceptibility to flooding and vice-versa (Mahmoud & Gan, 2018). The flow accumulation is obtained by performing some GIS analysis with spatial analyst toolbox using the clipped DEM of the study area. The fill sinks and flow direction operation are done which are later used as an inputs for determination of flow accumulation. The flow accumulation layer is reclassified into various scale ranging from 1 to 5. The areas with lower values of flow accumulation will get the lower scale values and vice-versa.

4.2.2.6. Mean Annual Rainfall

The total surface runoff of an area is determine by its terrain characteristics coupled with the rainfall intensity / rainfall amount (Mishra & Sinha, 2020). Flooding in any river basin is usually triggered by high rainfall events. The higher the rainfall amount the higher the flood susceptibility (Rincón *et al.,* 2018; Mahmoud & Gan, 2018). Daily Rainfall data for 36 years from 1982 – 2018 is obtained from NiMet (Nigerian Meteorological Agency) and HJRBDA (Hadejia-Jamaare River Basin Development Authority) for the 3 stations in the study area namely; Kano, Tiga and Dutse and 4 stations adjacent to the study area namely Damaturu, Maiduguri, Katsina and Bauchi. The data is subjected to statistical analysis and consistency checks in order to fill the missing gaps and estimate the distribution of average annual rainfall of the whole basin. These data are used to create the precipitation-isohyet map by interpolating the annual average rainfall data using the inverse distance weighed (IDW) interpolation method in ArcGIS ambience. The generated total precipitation map is reclassified on a scale ranging from 1 for low value of mean annual rainfall and 5 for high value of mean annual rainfall.

4.2.2.7. Drainage Density

Drainage density is considered among the most important morphometric parameters of flood risk assessment (Radwan *et al.,* 2018). The impact of land use/ land cover, terrain, soil texture of a watershed is usually determined by drainage density. Drainage density is defined as the ration of the total length of stream in watershed and the area of the watershed and it is expressed in Km/Km^2

(Mahmoud & Gan, 2018; Hu *et al.,* 2017) . The factors that influence drainage density are the rock characteristics, vegetation, soil texture, climate and relief (Hu *et al.,* 2017; Danumah et al., 2016). High drainage density values signifies that there are impermeable subsurface materials, mountainous reliefs and sparse vegetation (Mahmoud & Gan, 2018; Radwan *et al.,* 2018). While Low drainage density values means very high permeable sub-soil, low to moderate relief and thick vegetation (Radwan *et al.,* 2018). In general the density of drainage increases with decrease in infiltration capacity of soil. The drainage density layer of the basin is produce in ArcGIS using line density tool in spatial analyst tool. The highest value of drainage density is assigned to a scale of 5 while a scale of 1 is assigned to the lowest drainage density value.

4.2.3. Reclassification of thematic maps and flood hazard map

The generated thematic layers is reclassified into appropriate classes based on the weights derived in relation to their influence in flood occurrence as described in details in section 4.2.2. The weighed data sets is integrated in ArcGIS to produce the flood hazard map by weighed overlay. This involves the multiplication of each class individual weight by the map scores and its addition to the results. The produced flood hazard map is reclassified into various classes of hazards: 'Very High Hazard,' 'High Hazard,' 'Moderate Hazard,' 'Low Hazard' and 'Very Low Hazard'.

4.2.4. Development of Indicators for Flood Vulnerability and Vulnerability map

Generally, flood vulnerability studies are based on the extent of potential harm that is inflicted under a certain physical and socio-economic susceptibility and capacity measures in a particular area at a particular time period (Adger, 2006; Ntajal *et al.,* 2017; Mavhura *et al.,* 2017; Ahmad *et al.,* 2018; Ghosh & Kar, 2018; Alazba & Mossad, 2018; Hoque *et al.,* 2019). In this study, the socio-economic indictors are considered based on the data availability. This study adopted and modified the socio-economic indicators selected by Mishra & Sinha, (2020) to suit the conditions of the study area. The various indicators that are selected for socio-economic flood vulnerability analysis are based on the data availability, extensive literature review and rigorous group discussion with the populace, policy makers residing in the community and their influence and relationship with flood vulnerability. Based on the literatures reviewed, field visit and focused group discussion (FGD) with key informants in the study area, the socio-economic indicators such as population density, female population density, literacy rate, land-use, and employment rate and road network are selected in this study as they so much influence the vulnerable nature of the study area.

Population census and land use data are the most paramount data for socio-economic vulnerability analysis (Mishra & Sinha, 2020; Hoque *et al.,* 2019). The population distribution of the study area are obtained from National Population commission of Nigeria and National Bureau of Statistics. The socio-economic variables are derived from the information available in the 2006 census data for Nigeria (obtained from NPC and NBS) and the land use data obtained from USGS. The population density and female population is considered as the key factors in vulnerability mapping because the population density is the superset of all the vulnerability indicator drivable from population census data whereas female population density is the next factor because high percent of the population residing in the communities were engaged in the traditional role of homemakers, they solemnly depend on their husbands. Hence, they lack independence and they do not have the skill to withstand with disasters and calamities. Total number of households, literacy rate, and age distribution and population densities are extracted from the NPC dataset. Finally, these dataset are processed in GIS to generate spatial maps which are afterward used for the flood vulnerability analysis. The flood vulnerability map is produced by integrating these maps to a single whole using GIS analysis.

4.2.4.1. Population Density (Pd)

Population density is one of the most important indicator with regard to vulnerability to floods in a given environment. According to Mishra & Sinha, (2020) population density is a central point of flood risk assessment because it reveals the extent of potential harm to which flood disasters will poses to human life and health. The higher the population density of a given area, the higher the likelihood of life and property losses (Alazba & Mossad, 2018; Mishra & Sinha, 2020). The population density layer is created using projected population census data of 2006 in ArcGIS software. The highest weightage for level 2 decision factor is given to population density for the flood vulnerability assessment because the life losses as a result of floods are dependent upon the number of individuals per unit area. The areas with high population density are more vulnerable to floods than areas with low population density (Radwan *et al.,* 2018; Hoque *et al.,* 2019).The area with the higher population density will be given the higher weight and vice-versa. The total population of each Local Government is obtained from census data of 2006 which is projected to

2020 using geometric growth rate forecasting technique. The population density of the respective areas is estimated using Equation 4.1 which is classified into various classes in ArcGIS environment to produce population density map.

$$P_d = \frac{P_e}{A} \tag{4.1}$$

Where P_d = Population density (persons/km^2), P_e = Estimated Population for the year, A = Land Area (km^2).

4.2.4.2. Female Population Density (F)

Women population have the highest perception of risk to flood among all the vulnerable population groups (Chakraborty & Mukhopadhyay, 2019; Sharma *et al.*, 2017). As a result of family care and responsibilities, female population has a slower recovery rate and are socially deprived. Many other factors such as cultural restrictions on clothing, lack of mobility to access the information and services, overdependence, lack of skills and lack of decision making ability impedes women to withstand the risk of flooding (Mishra & Sinha, 2020). The female population density map is produce by first estimating the total number of female residing per square kilometer in each of the area. These numbers is classified to various classes of densities which is used to produce the female density map.

$$F_d = \frac{N_F}{A_u} \tag{4.2}$$

Where, F_d = Female Density, N_F = Number of Females per Km^2, A_u = Land Area (Km^2).

4.2.4.3. Literacy rate (Lr)

Literacy rate is the proportion of the population that are literate (Mishra & Sinha, 2020). Literate populations have the capacity to respond to hazardous event more quickly because they can understand its nature and severity in a short time. Household with illiterate people exhibit low coping capacity to disaster risk than households with literate persons (Ghosh & Kar, 2018). Low education or lack of education brings about overpopulation, poverty and unemployment (Rincón *et al.,* 2018). Hence, illiterate population are more vulnerable to flooding because of their low knowledge that would enable them to have the capacity to cope after a flooding event. The literacy rate data is extracted from the population census data of 2006 which is used to produce a spatial layer in ArcGIS environment. The map is reclassified to various classes of literacy rate ranging from low to very high. The literacy rate is given a low weightage compared to population density and Female density because it is their subset.

4.2.4.4. Road network density (Rd)

The availability of road networks such as the main district roads, state highway roads and national highways are of paramount importance especially in rescue and relief operations during flooding. (Mishra & Sinha, 2020). Lack of efficient road systems increases community's vulnerability flood risk (Hu *et al.*, 2017). They serves as temporary shelters (Ghosh & Kar, 2018). The spatial map of the road network density is produce in ArcGIS and reclassified to various classes from the assigned weighted that ranged on a scale of 1 to 5.

4.2.4.5. Land-use

Land use land cover (LULC) map is one of the main spatial indicators necessary for the quantification of severity of flood (Shale *et al.*, 2020; Waghwala & Agnihotri, 2019; Asmat *et al.*, 2016). The runoff characteristics of river and its catchment areas is determine by the nature and the extent of land use land Cover of the catchment (Mishra & Sinha, 2020; Radwan *et al.*, 2018). The use map of the study area will be prepared under supervised classification with the employment of the method of maximum likelihood algorithm of Landsat 8 OLI satellite imagery which is obtained from USGS. The imagery is classified into various classes of land uses of the study area. The land use is validated through a rigorous field survey and assistance from experts, local people and other related personnel that has an in-depth knowledge of the study area. The highest weightage is given to industrial land use type because of its high economic value while recreational and open space is assigned the lowest weightage. The land use is reclassified in a scale ranging from 1 to 5 based on their economic value and with respect to their abilities to intercept rainfall and prevent flooding.

4.2.4.6. Employment Rate

Employment rate is a measure of the local economic health and flood loss recovery (Chakraborty & Mukhopadhyay, 2019). The employment rate layer is generated based on the state level working population information gotten National population commission (NPC) and National bureau of statistics (NBS) in ArcGIS using spatial analyst tool by joining and excel file of the employment rate of the various states with the watershed shapefile. The map layer is reclassified to various classes of employment rate ranging from low to very high.

In summary, the socio-economic vulnerability is based on 6 criteria as enlisted in the above sections. The shapefile boundary data of the study area is merged with the dBase (dBF) file format census data. The resulting map layer is converted into a raster file and divided into individual raster for each criterion. The individual raster is reclassified on a scale from 1 to 5 by assigning higher levels of vulnerability to higher percentage of the population belonging to each criterion.

4.2.5. Normalization of flood Hazard Indicators

The normalization of the indicators is done using the method of UNDP's Human Development Index (Hu *et al.,* 2017; Ntajal *et al.,* 2017). The functional relationship indicators values and flood hazard and vulnerability is identified. Equation 4.3 and 4.4 are used for positive and negative functional relationship with flood hazard and vulnerability respectively (Hu *et al.,* 2017).

$$Y = 1 + 9 \times \frac{\left(X - X_{\min}\right)}{\left(X_{\max} - X_{\min}\right)} \tag{4.3}$$

$$Y = 1 + 9 \times \frac{\left(X_{\max} - X\right)}{\left(X_{\max} - X_{\min}\right)} \tag{4.4}$$

Where, X = the raw data; $X_{\max} =$ the maximum value in the data; $X_{\min} =$ the minimum value in the data; and Y = the normalized value.

The indicators are normalized to values of 1 to 10 based on the functional relationship the variables and the flood hazard and vulnerability component.

4.2.6. Assigning Weights using Analytical hierarchical process

The Analytical Hierarchical Process (AHP) developed by Saaty, (1980) is one of the best method of criteria weighting of MCDM. The method compares two criteria at a time through a pairwise comparison matrix by assigning the values of relative importance of one criterion over another criterion (Doumpos *et al.,* 2019). It is supported by theoretical background and it provides a high measure of a level of consistent judgement (Rincón *et al.,* 2018). AHP is used to establish the relationship between the respective thematic maps as well as deriving their respective weights.

The thematic maps that are produced as well as their respective classifications forms the network for the pair-wise comparison in the AHP. The pair-wise Comparison Matrix of the relative important values will the generated based on the standardized Saaty's 1-9 scale where 1 is equal importance and 9 is extreme importance (the details are provided in Table 4.2). The thematic maps is associated with flood occurrence to serve as a guide for the derivation of relative importance matrix. The respective weights of the various criteria is estimated using the method of Eigen vector.

Table 4.3: Saaty's Critera Weight Scale

Relative Importance	**Definition**
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

The consistency check is done by computing the Consistency Ratio (CR) which depicts the quality of the pair-wise comparisons because in practice, the decision maker's expression involves some fuzziness that may make the matrix have some inconsistencies (Mishra & Sinha, 2020). The judgment or preference is consistent only if the CR is greater than 0.10. Saaty's Consistency Ratio CR is used to check the pair-wise comparison (Saaty, 1980; Saaty, 2008)**.**

CR is calculated using the Equation (4.5)

$$CR = \frac{CI}{RI} \tag{4.5}$$

where;

CI = Consistency Index which reflects the consistency of the judgment

RI = Random Inconsistency Index dependent on the sample size

The consistency Index, *CI* is calculated using the equation (4.6)

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (4.6)$$

Where, *n* is the number of criteria and λ_{max} is the average of the value of the consistency vector (calculated factor Weight)

The Random Inconsistency Indices *RI* depends on the sample size. *RI* for respective sample sizes is presented in the Table 2.1above.

The acceptable judgment range is from $0 \leq CR \leq 0.1$ with a value of zero (0) being the most consistent (Saaty, 2008). Any value outside this range would require the assignment of the criterion weight again. A consistency ratio *CR* < 0.10 indicates a reasonable level of consistency in the pairwise comparison while *CR* value ≥ 0.10 signifies inconsistent judgment (Mishra & Sinha, 2020).

4.2.7. Derivation of Flood Hazard and Flood Vulnerability Index

The flood hazard index (FHI) and flood vulnerability index (FVI) were derived by aggregating the weights and corresponding hazard and vulnerability classes at each level of hierarchy using Equation 4.7 or 4.8 and 4.9 respectively;

$$FHI / \text{FVI} = \sum_{i=1}^{n} W_i \times r_i \quad (4.7)$$

where; $FHI / FVI =$ flood hazard/ flood vulnerability index, W_i = weight of each indicator, r_i = the rating of the indicator in each point and *n* = the number of the criteria.

$$FHI = W_{El} \times El + W_{Sp} \times Sp + W_{DD} \times DD + W_{ST} \times ST + W_R \times R + W_F \times F + W_{DR} \times DR \quad (4.8)$$

where; El, Sp, DD, ST, R, F, DR and W_{El}, W_{Sp}, W_{DD}, W_{ST}, W_R, W_F, W_{DR} = Elevation, Slope, Drainage density, Soil type, Mean annual rainfall, Flow accumulation, Distance to rivers and their corresponding weights.

$$FVI = W_{Pd} \times Pd + W_{Fd} \times Fd + W_{Lu} \times Lu + W_{Rd} \times Rd + W_{Lr} \times Lr + W_{Er} \times Er \quad (4.9)$$

where; Pd , Fd , Lu , Rd , Lr , Er and W_{Pd} , W_{Fd} , W_{Lu} , W_{RD} , W_{Lr} , W_{Er} = Population density, Female population density, Land use, Road network density, Literacy rate, Employment rate and their corresponding weights.

4.2.8. Development of flood disaster risk indicators

According to Ntajal *et al.*, (2017), the most common widely used procedures for developing indicators are those that includes inductive or deductive procedures. The deductive procedure is adopted and used in this study in developing the indicators. Ntajal *et al.*, (2017) and Ghosh & Kar, (2018) claims that the main factors necessary for a community to adapt to flood disasters are the physical attributes of the place and the socio-economic attributes of its population.

4.2.8.1. Flood risk indicators and flood risk index

Flood risk is defined as the product of "hazard", and the "total vulnerability" (Danumah *et al.*, 2016; Waghwala & Agnihotri, 2019; Roxana *et al.*, 2019). The flood disaster risk indicator F_{RI} of the study area is generated by spatial layer overlay operation between the flood hazard and total vulnerability (socio-economic vulnerability) i.e. Hazard indicator F_{HI} and Total vulnerability indicator $F_{VI.}$ The flood risk map based on flood hazard and total vulnerability is derived from Equation (4.4):

$$F_{RI} = F_{HI} \times F_{VI} \qquad (4.4)$$

Where, F_{RI} = Flood risk index, F_{HI} = Flood hazard index, F_{VI} = Flood vulnerability index.

4.2.6. Validation of flood Risk maps

There is no specific quantitative method available that can be used to validate spatial flood risk map. However, a qualitative validation method used by Roy & Blaschke (2015), Mahmoud & Gan (2018) and Mishra & Sinha (2020) is adopted to verify the spatial risk maps. The method involves an extensive field survey to the study location to assess the accuracy of the spatially generated hazard, vulnerability and risk maps. The coordinates of various historic floods locations such as inundated towns, farmlands, dilapidated infrastructures that suffers floods and other prominent features such as bridges, dams, irrigation farms are collected using GPS equipment as done by Mishra & Sinha (2020). The visit includes an in-depth field observation and discussion with local people, experts and policymakers in order to get their views about the produced maps. The history of previous floods effects, their severity and extents were also explored through literature reviews and discussions with the stakeholders and local residents.

CHAPTER FIVE

5. RESULTS AND DISCUSSION

5.1. Introduction

During the last decades, flood risk assessment was based on the combination of hydrologic and hydraulic models which involves the solution of water flow balance and channel/waterways conveyance (Radwan *et al.,* 2018). However, this study adopted an unconventional method of identifying flood risk regions by combining flood hazard and vulnerability maps using multi-criteria approaches. The Analytical Hierarchical Process (AHP) is used in weighting the various flood hazard and vulnerability indicators outlined in chapter four above based on their relative influence to flood hazard and vulnerability. It is worth noting that, the study employs geospatial analysis on both remotely sensed, secondary and primary data acquired from the field, online and government agencies and all spatial operations were done in ArcGIS. The flood hazard map shows the areas susceptible to flooding while the vulnerability shows mainly areas that will severely bear the aftermaths of flooding and the flood risk map shows the regions that are at risk of flooding. Hence, the results obtained in this research work as well as their discussions are explicitly presented in this section.

5.2. Flood Hazard indicators

In the present research, flood hazard represents the probability of the occurrence of a flooding events in a particular location based on the hydrological and geomorphological variables of the region (Mishra & Sinha, 2020; Danumah *et al.,* 2016). Different hazard indicators selected in this study are based on the geomorphological and hydrological attributes namely, elevation, slope, soil type, flow accumulation, mean annual rainfall, drainage density, and distance to rivers.

5.2.1. Elevation

The elevation of a watershed is one of the factors that contributes to flood hazard in that watershed (Chakraborty & Mukhopadhyay, 2019). The highest elevation in the watershed is 673m while the lowest elevation is 338m. The lowest elevation class was rated as very high flooding hazard class whereas the highest elevation class is rated as very low flood hazard class. It is shown in Figure 5.1 that the lower elevations are dominant in the northeastern part of the basin which renders it more prone to flood. Local Government Areas of Jagawa state comprising of Jahun, Guri, Auyo, Dabi, Hadejia, Miga, Gumel, Kari Kasama, Briniwa and Nguru, Bade, and Jakusko of Yobe state have elevation ranging from 338 to 383m which made them to have the highest flood hazard. The elevation class of (338 -383m) represent a very high flood hazard area while very low flood hazard is represented by the elevation class of (539-673m).

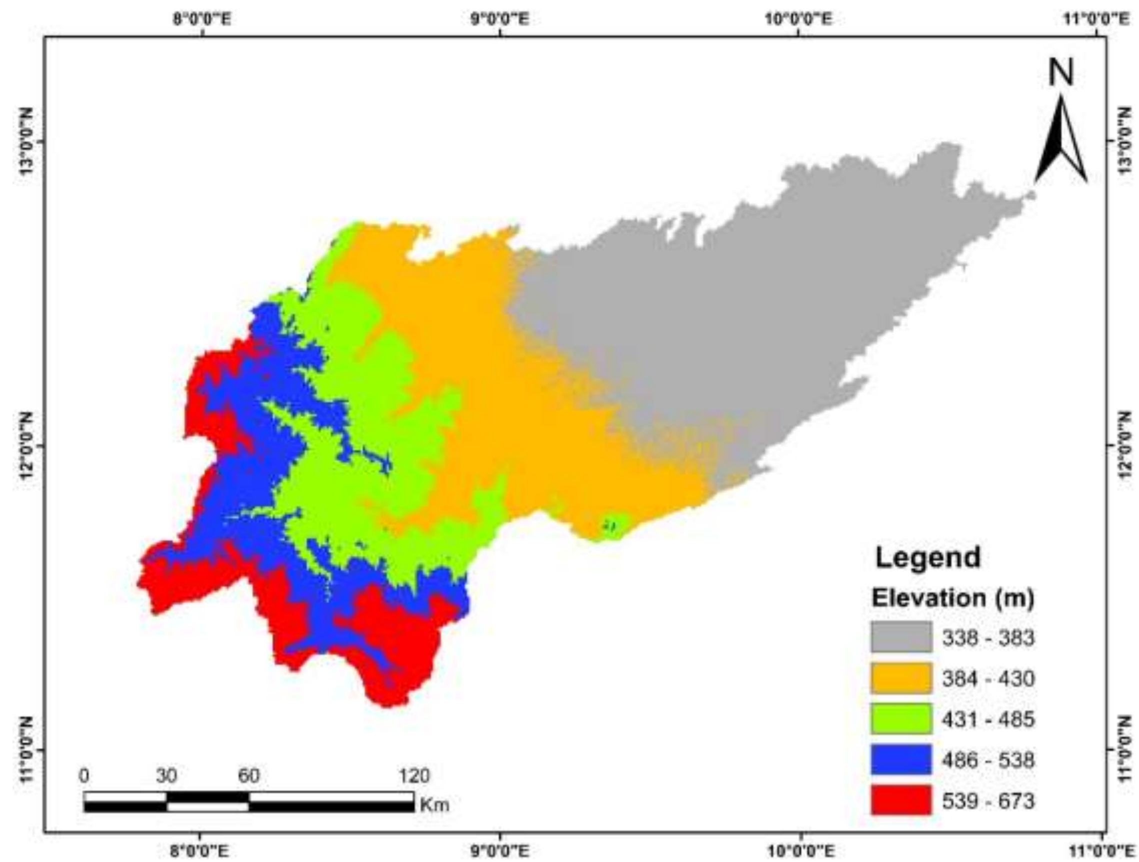

Figure 5.1: Elevation Layer of Hadejia River Basin

5.2.2. Slope

The inundation of an area depends on the length and steepness of its slope. For instance, areas with low slope length and angle will experience inundation compared to areas with high slope length and angle (Mishra & Sinha, 2020). The slope of Hadejia River Basin ranges from a minimum of 0° to maximum of 42.5°. Figure 5.2 shows the slope map of the entire basin which are classified into five slope classes of very high (0.00°-1.33°) to very high (11.6°-42.5°). It is worth noting that the northeastern part of the catchment has relatively flat slope which renders it more prone to flooding events while higher slope values are dominated at the central and northwestern part of the basin. This is evident because the central and northwestern part of the catchment has the highest elevation classes. This could be the sole reason why the northwestern part of the watershed is less prone to frequent flooding events.

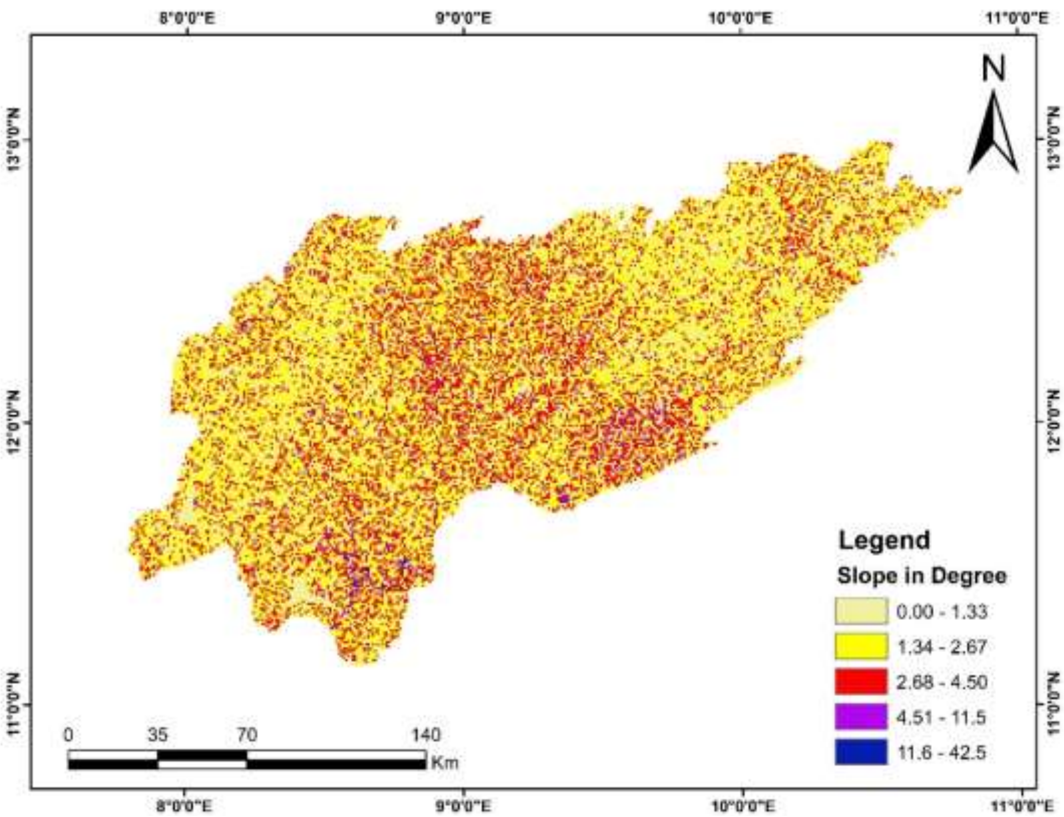

Figure 5.2: Slope Layer of Hadejia River Basin

5.2.3. Mean Annual Rainfall

The mean annual rainfall of the basin ranges from 757 to 1030mm. The rainfall falls from northwestern to northeastern portion of the watershed. Flood hazard increases with an increase in rainfall (Radwan *et al.*, 2018; Ghosh & Kar, 2018). Figure 5.4 shows the various mean annual rainfall classes, which are very low (757-833 mm), low (834-875 mm), medium (876-919 mm), high (920-967 mm), and very high (968-1030 mm). It is worth noting that, the northwestern and central part of the watershed receives the highest mean annual rainfall amount. This high amount of rainfall increases the chances of flash flood occurrence in this regions. Rainfall depth of 968-1030mm and 876-919mm concentrates at the entire part of Kano state and it adjacent LGAs of Jigawa state which increase the chance of severe flood events in this regions. However, the region is characterized with high slope angle and elevation. As such, all floods water easily flow downstream to some part of Jigawa and Yobe State making large portion of the states at high risk of severe flash floods. Despite the fact that the upstream rainfall amount is slightly higher than that of the central part of the watershed, the central and the downstream areas have relatively flat topography, extremely flat slope and poor drainage condition are more dominant in the region. As such the influence of rainfall on flood hazard is overshadowed with these geomorphic characteristics. Figure 5.3 shows the variation of annual peak flows of Hadejia River from 1968 to 2018. The highest peak flow occurred in 2002 recording about 139.44 m^3/s. This figure is capable of inundating vast hectares of land as compared to the lowest flow which occurred in 1984.

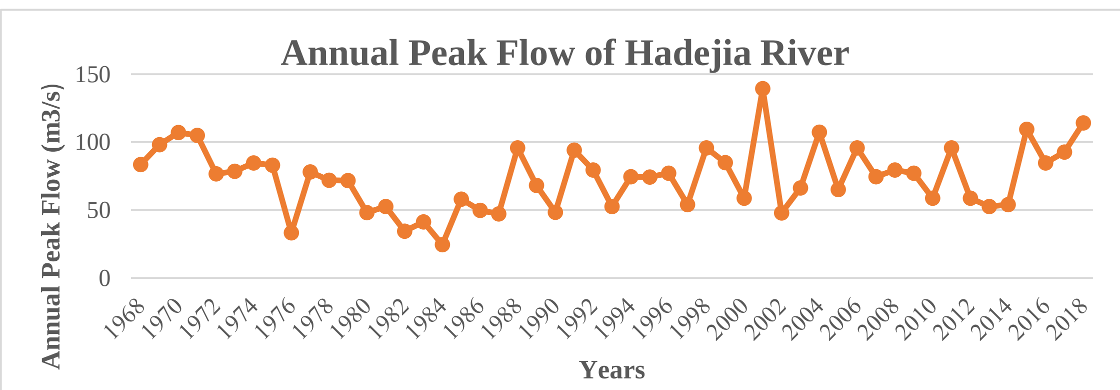

Figure 5.3: Annual Peak Flows of Hadejia River

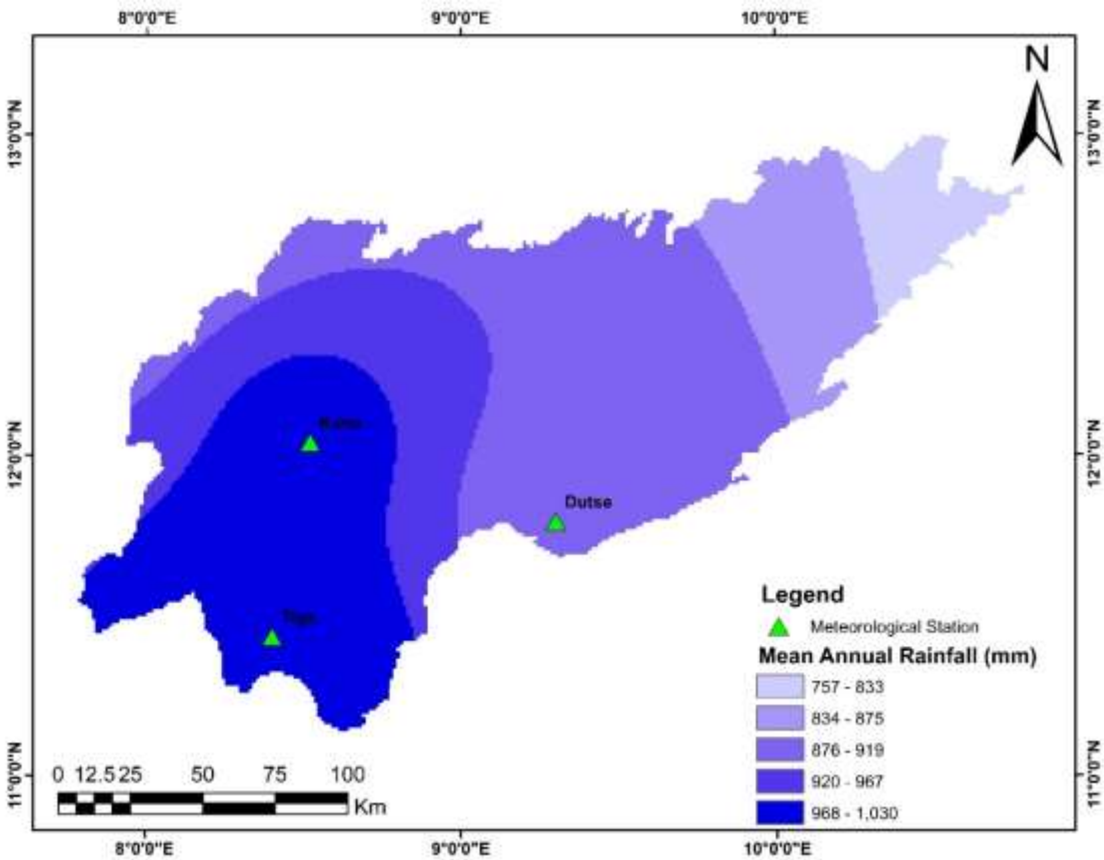

Figure 5.4: Mean Annual Rainfall Layer of Hadejia River Basin

5.2.4. Soil Type

The soil map of the study area is presented in Figure 5.5 which shows four soil types present in the basin. Arenosols soil which covers 39.7 % of the basin is a sandy loam soil characterized with low permeability and therefore rated to have high flood hazard because of its low infiltration rate. The next soil type is the Fluvisols which is constitutes 13.5 % of the basin. This soil has low infiltration rate because of its high clay content and therefore, it is rated to be very high flood hazard. Another soil type present in Hadejia River Basin is the Gleysols which covers about 35.2 % of the basin and is sandy clay loam. This soil is classified to have high flood hazard due to its low infiltration rate. Lastly, Luvisols soils are also present in the study area which covers about 11.6 % of the watershed and has high permeability. This soil have high rate of infiltration which renders it to have very low flooding hazard. The soil type map indicated that in the lower portion of the study area the dominant soils are those of clay and clay loam which have low infiltration rate. This renders the region more prone to flooding and hence have the highest hazard.

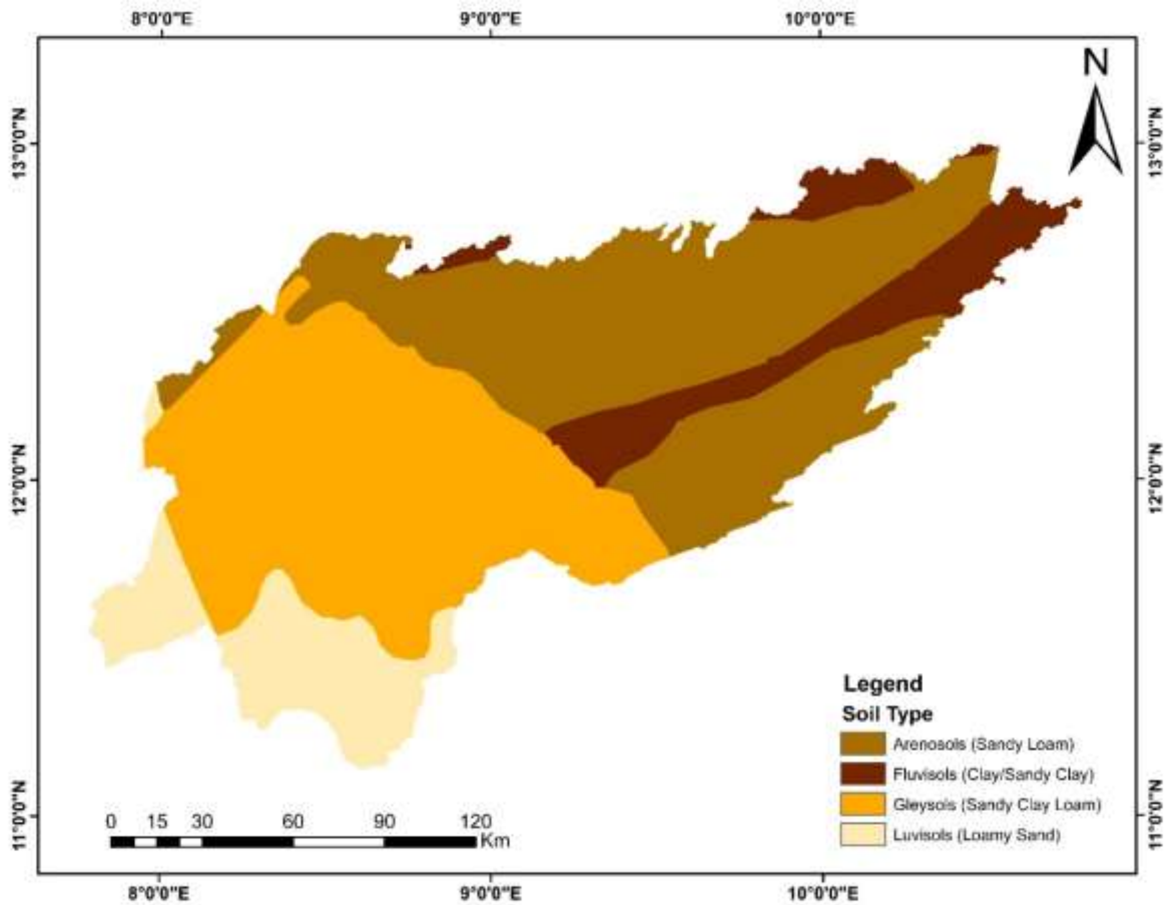

Figure 5.5: Soil Type Map of Hadejia River Basin

5.2.5. Drainage Density

High drainage density signifies high surface runoff generation and therefore higher likelihood of flooding, and vice versa (Mahmoud & Gan, 2018; Danumah *et al.*, 2016). High drainage densities means greater runoff rates and hence, high flood susceptibility (Radwan *et al.*, 2018; Danumah *et al.*, 2016). Figure 5.6 shows the drainage density map of the study area. The drainage density map is classified into five density classes namely, very high, high, medium, low, and very low. Very high drainage densities were found in urban areas, main road and agricultural lands while very low drainage densities were found in bared land and areas that lacks vegetation. Very high drainage density class ranges from (0.190 - 0.310 km/km^2), which means very high flood hazard, high (0.140 - 0.180km/km^2), moderate (0.082 - 0.130km/ km2), low (0.033 - 0.081 km/km^2), and very low (0 - 0.032km/km^2) drainage densities.

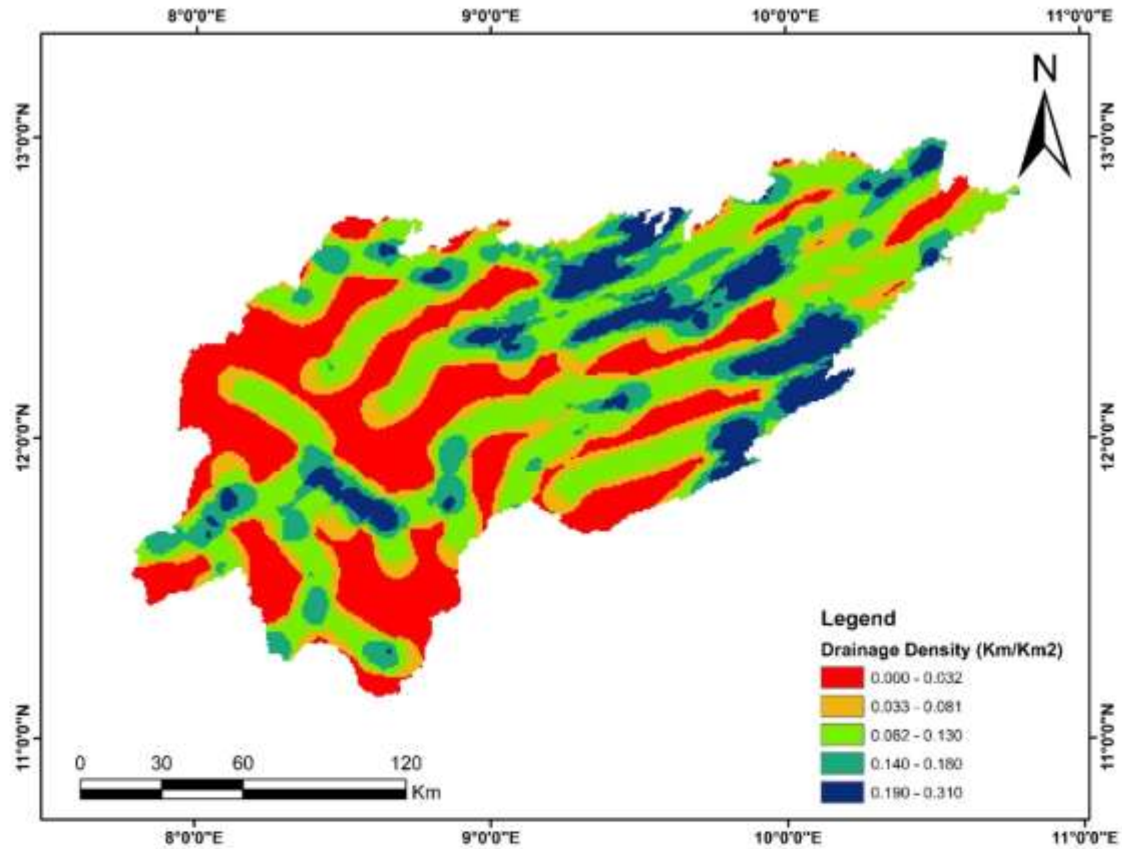

Figure 5.6: Drainage Density Map of Hadejia River Basin

5.2.6. Flow Accumulation

The flow accumulation was considered as one of the contributing indicator of flood hazard in Hadejia River Basin. High flow accumulation signifies high flood hazard (Mahmoud & Gan, 2018). The flow accumulation map is obtained by performing GIS analysis of the digital elevation model with spatial analyst tool in ArcGIS is shown in Figure 5.7. In the figure, the black and the blue pixels represent high flow accumulation while the green, light green pixels and the back-surrounding (grey pixels) represents moderate and low flow accumulation. The study area is dominated with areas of high flow accumulation mostly in the Northeastern part of the basin and some places close to Wudil and Rano L.G.A which makes them more prone to flood inundation. From the Figure, it is seen that the flow accumulation ranges from 0 to a maximum of 23800 pixels.

These pixels are classified into five classes of flow accumulation raging from a very low class (0-829 pixels) to a very high class of (13230-23800 pixels).

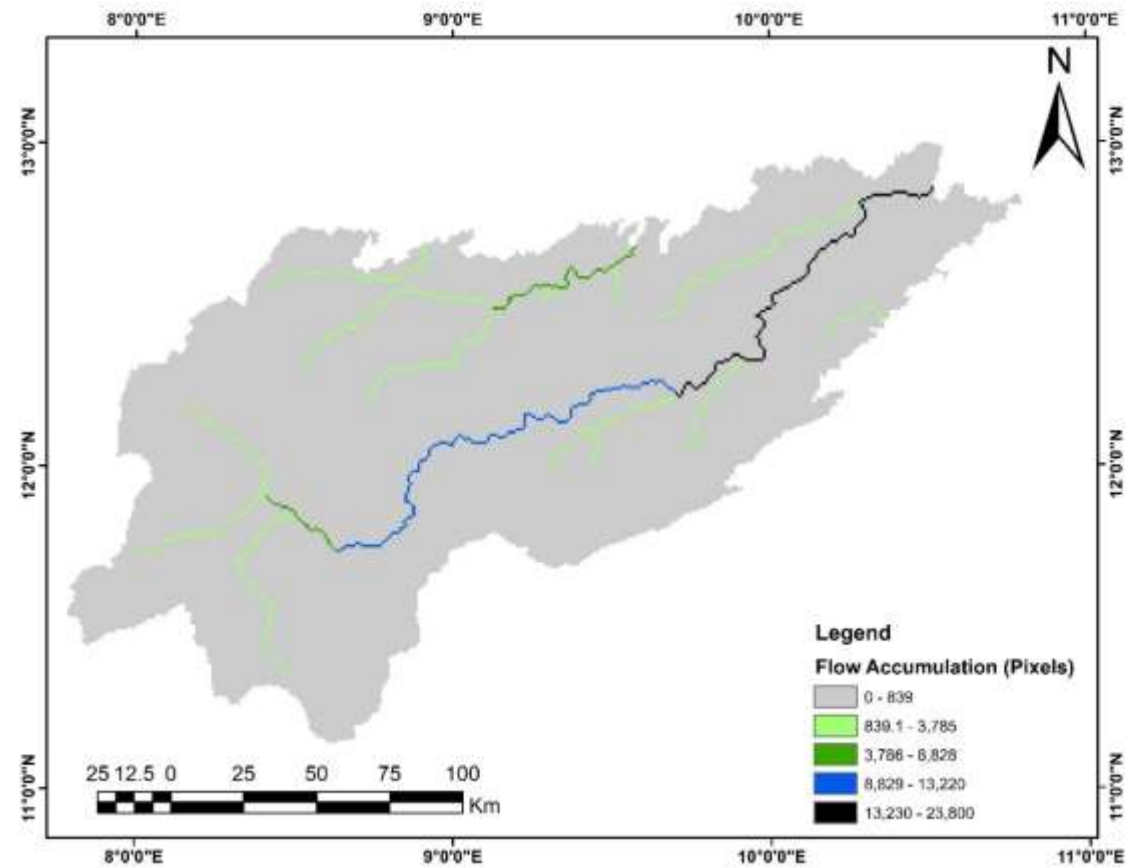

Figure 5.7: Flow Accumulation Layer Hadejia River Basin

5.2.7. Distance to Rivers

Proximity to river is an important indicator of flood hazard as areas close to river experience more frequent flood than areas further away from the river and vice versa. The relationship between flood hazard and distance from rivers can be subjective even though ideally it should be based on historic flood records (Mahmoud & Gan, 2018). Figure 5.8 shows the distance to rivers map of the study area. Based on the historic flood records and expert judgement areas that are within 1000m from rivers are rated to have very high hazard of floods, whereas areas within distances of 2000, 3000, 4000, and 5000m from rivers are considered to have high, moderate, low, and very low flood hazard respectively. From Figure 5.8 the downstream portion of the watershed have more rivers which are close to each other, as such close distances to rivers are dominant in that region which increases it susceptibility to flash floods.

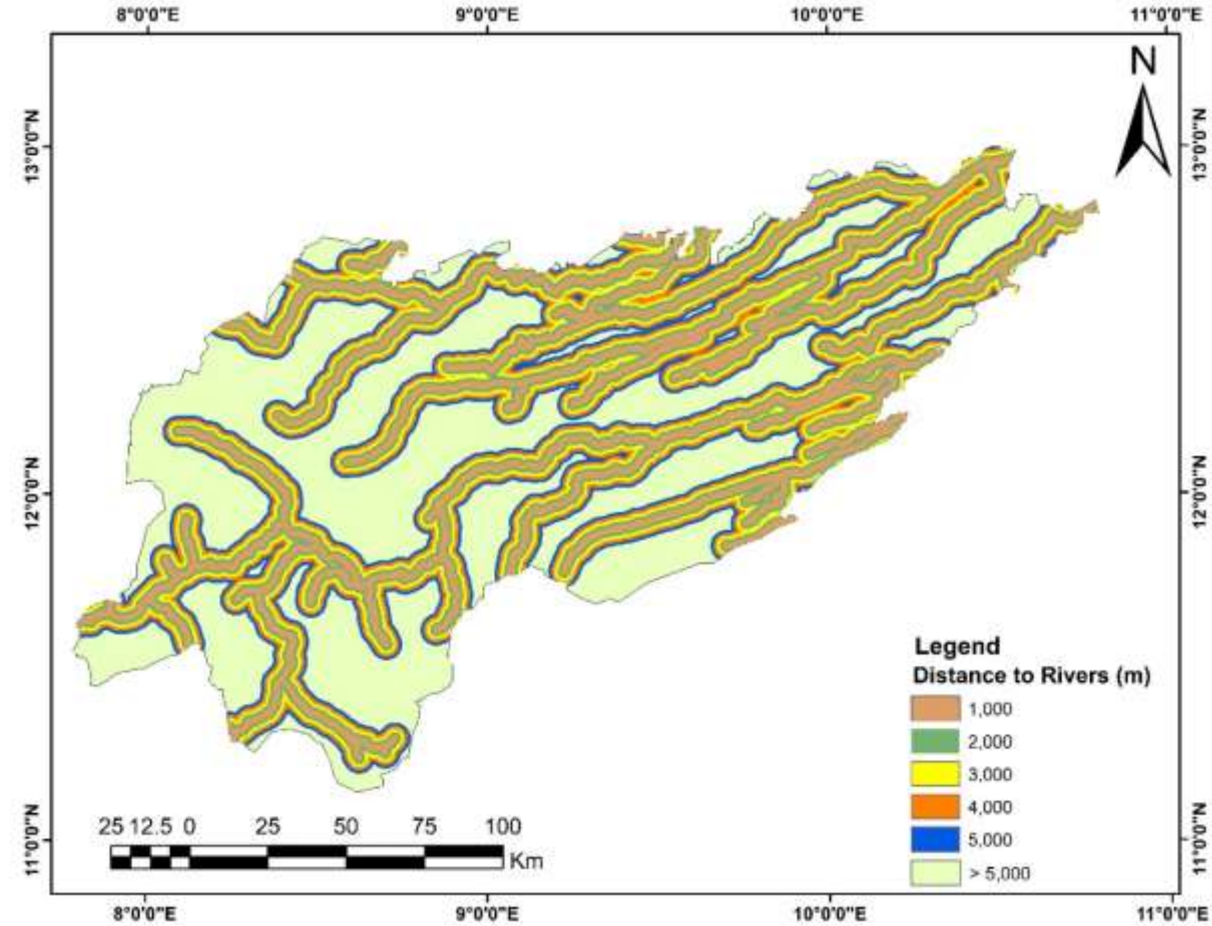

Figure 5.8: Distance to Rivers Map of Hadejia River Basin

5.3. Socioeconomic flood vulnerability indicators

In the present study, flood vulnerability is considered as the socioeconomic activities such as people with their economic interests that may be affected by any natural hazard phenomena in terms of quantity and quality (Danumah et al., 2016; Radwan *et al.*, 2018). Six different indicators of flood vulnerability have been selected for the present study based on their presence, absence and functional relation with the flood vulnerability namely, population density, female population density, literacy rate, land-use, employment rate, and road network density.

5. 3.1. Population Density

Population density distribution map is considered as one of the instrumental components of vulnerability determination of flash floods (Radwan *et al.*, 2018). Higher sensitivity is expected in population with poor living conditions such as malnutrition, overcrowding and inadequate access to health facilities. Figure 5.9 shows the population density map of Hadejia River Basin. From the figure, the population density is categorize in five density classes of very low, low, medium, high, and very high population densities. The highest densely populated area has a population range of 778 – 31504 person per Sq.Km while lowest populated zone has a population density of 78 – 210 person per Sq.Km. Areas in central part of Kano state including Kano municipal, Fage, Dala, Ungogo and Gezawa has highest population densities.

Other areas with very high population density are Hadejia town and Itas/Gadau LGA of Jigawa state. The reason behind this could be attributed to the economic activities taking place in the areas as Kano is the northern economic capital of the nation. This high value of population density of Kano state is evident that it is the highest populous state in the Nigeria. Figure 5.9 reveals that seventeen local government areas were found to have very low population density most of which are situated in Jigawa state comprising of Jahun, Miga, Gumel, Taura, Ringim, Mallam Madori among others while places like Dutse, Kiyawa and Ajingi have low population density. This very low and low population densities of these region renders them less vulnerable to flood disasters.

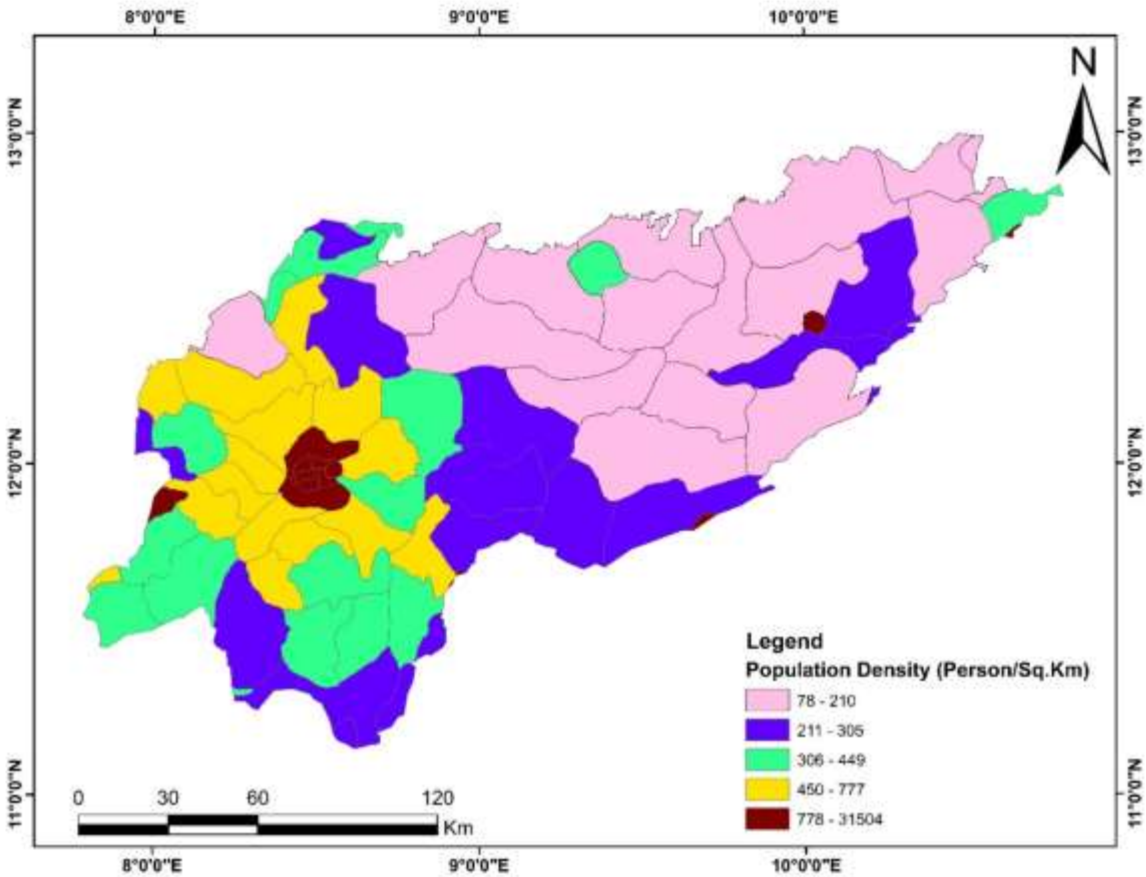

Figure 5.9: Population Density Map of Hadejia River Basin

5.3.2. Female Population Density

The female population density of an area determines the areas vulnerability to natural disasters such floods (Mishra & Sinha, 2020). Women have the highest perception of risk among all vulnerable group of population. Therefore they need to be well prepared for action during floods. As a result of their low income, low decision-making power, lack of mobility, cultural restrictions and greater family care and responsibilities women experience more difficulties during recovery from floods aftermaths. Figure 5.10 presents the female population density map of the study area which shows the various female population densities classes. The Figure shows that seventeen Local Government Areas (LGA) of the study area have very low female population density of 40 – 105 females/Sq.Km. The very high female population density was found in the central portion of Kano state comprising of Kano Municipal, Fagge, Dala, Ungogo, Tofa and Gezawa LGAs and Hadejia and Itas/Gadau LGAs of Jigawa state. The moderate female population density is found in the north western fringe of the study area. The LGAs that made this class of density includes Karaye, Bunkure, Rogo, Kiru, Kura and Madobi.

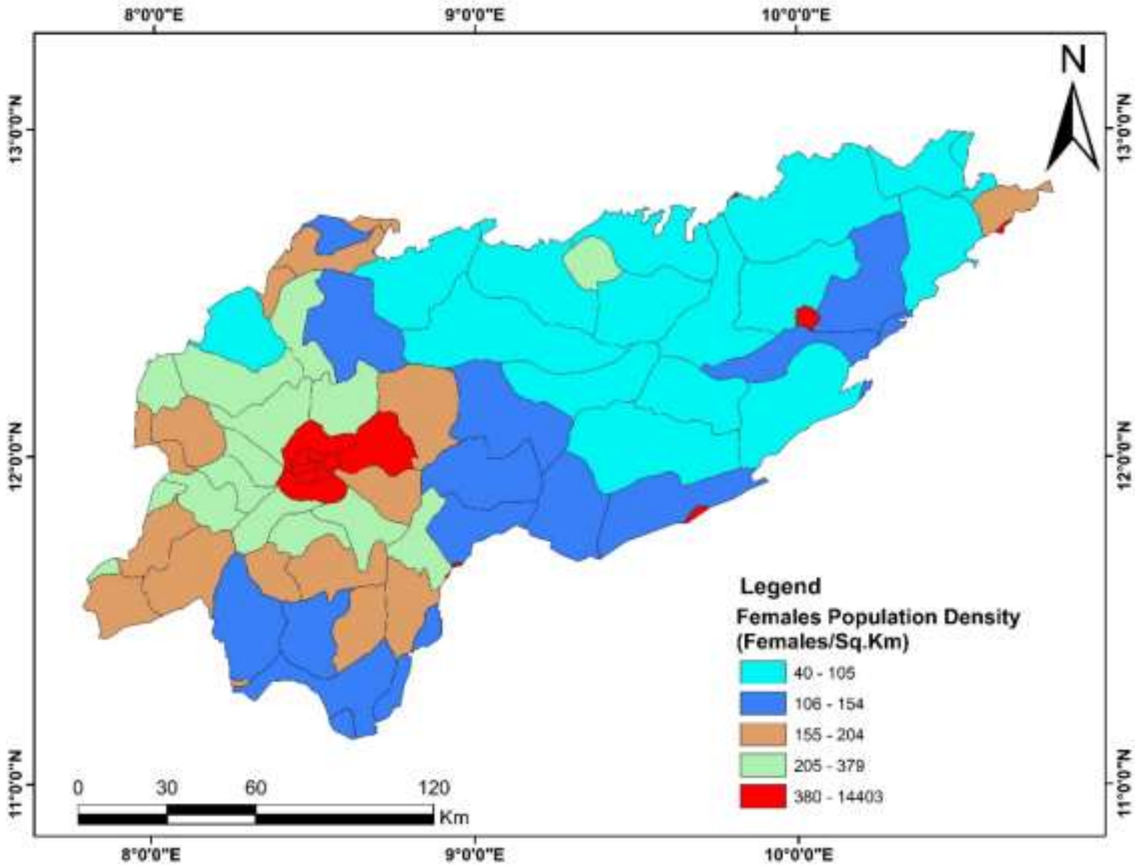

Figure 5.10: Female Population Density Map of Hadejia River Basin

5.3.3. Literacy Rate

The percentage of people that have knowledge in an area is expressed in terms of literacy rate. Literate population can easily understand the severity and nature of disaster and be able to respond quickly (Mishra & Sinha, 2020). The literacy rate map of the study area is presented in Figure 5.11 and shows that the literacy rate varies significantly from state to state. Very low and low literacy rate (0 – 39.8%) mostly all the north western part of the study area (Kano State) and Baure and Kafur portion of Katsina state. The moderate literacy rate (39.9 - 53.6%) covers the LGAs of Jigawa state. This made the population of the state to have moderate vulnerability to floods. Furthermore, the very high literacy rate (58.2 – 58.3%) is concentrated in the LGAs of Yobe state. The higher value of literacy rate in this region aids the inhabitants to be able to understand the severity and nature of natural hazard and how quickly they will adapt and recover from such menaces.

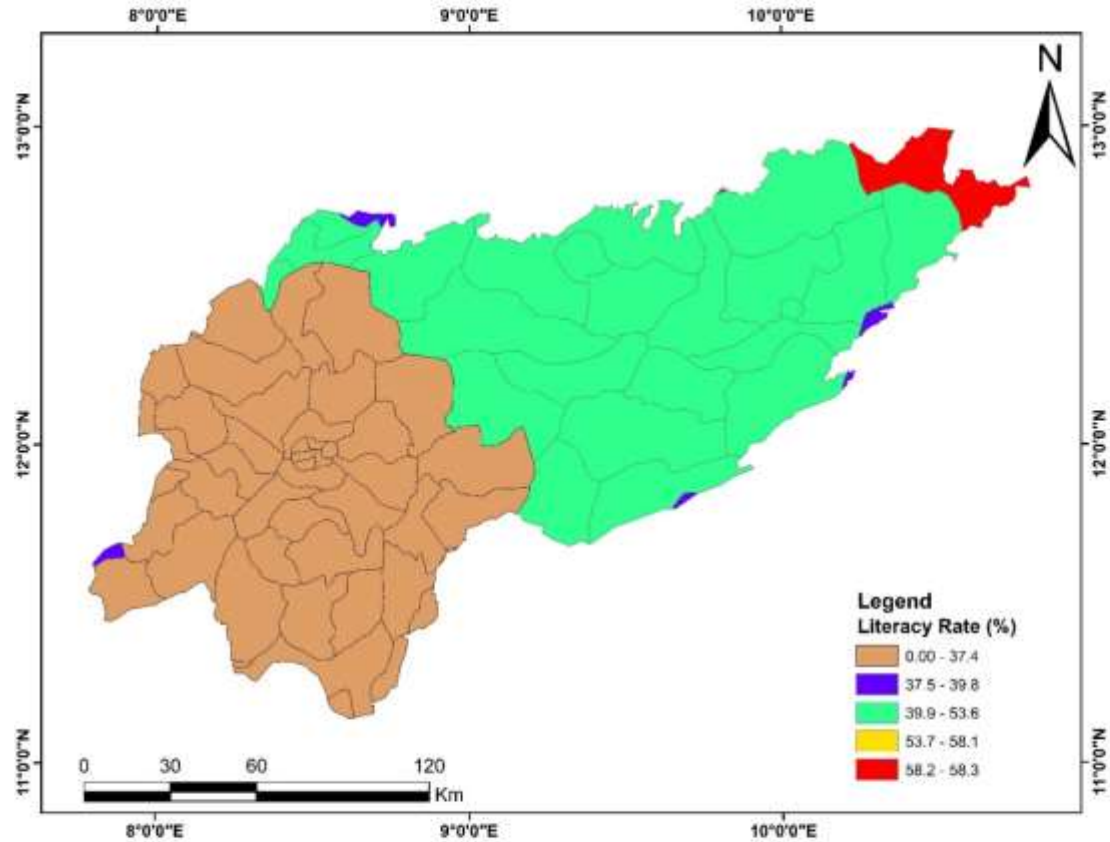

Figure 5.11: Literacy Rate Map of Hadejia River Basin

5.3.4. Land Use

Land use/land cover plays an important role in identifying zones that are vulnerable to flooding (Ghosh & Kar, 2018). Impervious surfaces such as residential areas and roads increases storm runoff generation. Bared lands tends to increase erosion of soils and high runoff flow downstream of watershed whereas areas with high vegetation density generally have low potential to flooding as vegetation negatively influence runoff generation (Mishra & Sinha, 2020). Built up and agricultural areas are more prone to flooding than bared marshy and fellow lands (Ghosh & Kar, 2018). Therefore built up areas are assign more weight than other areas. Figure 5.11 presents the land use map of the study area which is classified into eight classes namely, wood and grasses, irrigated cropland, bare land, forest, shrub-land, vegetation, built-up areas, and water bodies. Table 5.6 presents the ranking of the land uses classes based on their influence and contribution to vulnerability. The land use map shows that rainfed croplands areas takes the highest percentage of the study area covering an approximate area of 16525.62Km^2 and a percentage of 54.06%, followed by grassland which covers an approximate area of 8329.68Km^2 which is equivalent to 27.25% of the total watershed area. Wood and grass, and irrigated cropland covers an area of 4147.17 Km^2 (13.57%) and 799.24Km^2 (2.61%) respectively. Built-up and bare soil covers an area of 355.42Km^2 (1.16%) and 313.41 Km^2 (1.03%) respectively. Finally water body and shrubland covers an approximate area of 81.81 Km^2 (0.27 %) and 16.32Km^2 (0.06%) respectively

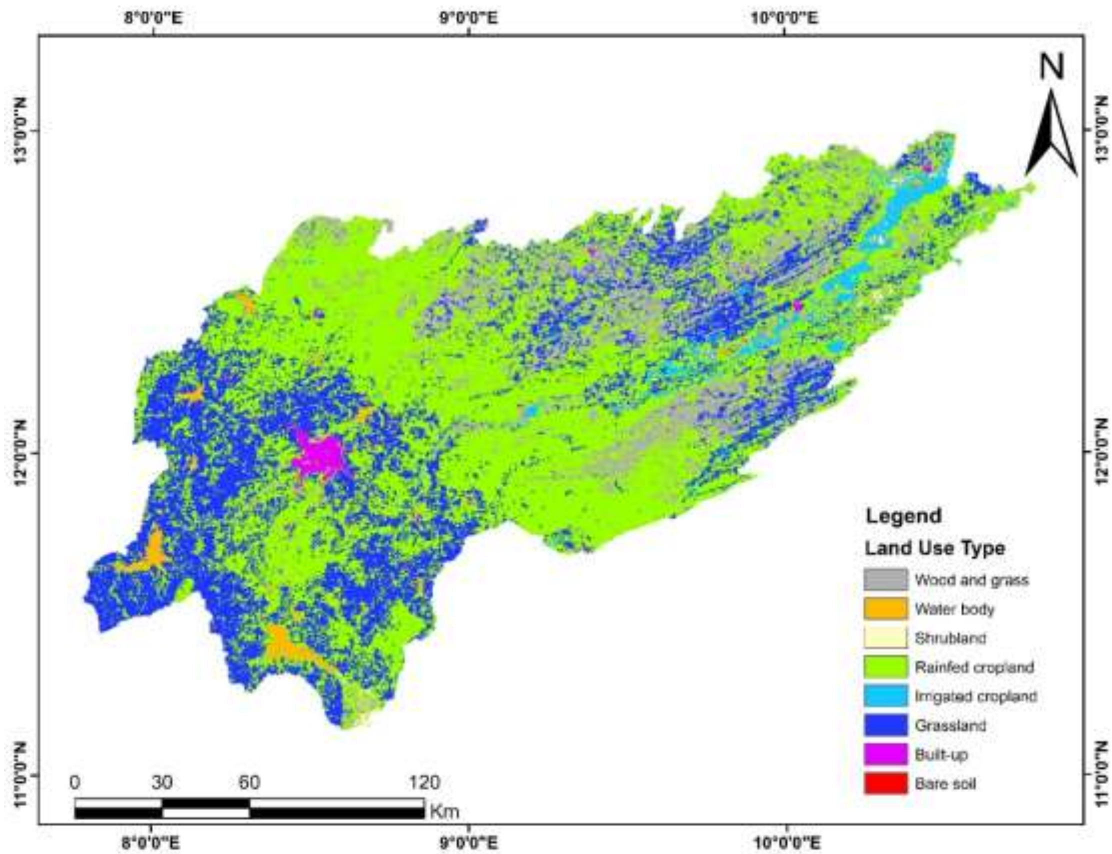

Figure 5.12: Land Use Map of Hadejia River Basin

5.3.5. Road Network Density

The road network density plays a vital role during flooding especially in relief and rescue operations. They also serves as flood shelters (Mishra & Sinha, 2020; Vishwanath & Tomaszewski, 2018). The availability of roads namely federal highway, state highways and local government roads defines how an area will quickly recover from floods impacts. The road network density of the study area is presented in Figure 5.13. Very high road density (0.240 – 0.640) is found in Kano central and Hadjia LGA of Jigawa state. High road network density class (0.150 – 0.230) covers about 50% of the study area mostly in the north eastern part. Due to the availability of different roads ranging from federal highway, state highways and local government roads in Kano central, Hadejia LGA of Jigawa state and the northeastern portion of the watershed, these location have less vulnerability to flooding events. All other portions of the study area have moderate (0.097 – 0.140), low (0.059 – 0.096), very low (0.00 – 0.058) road network densities.

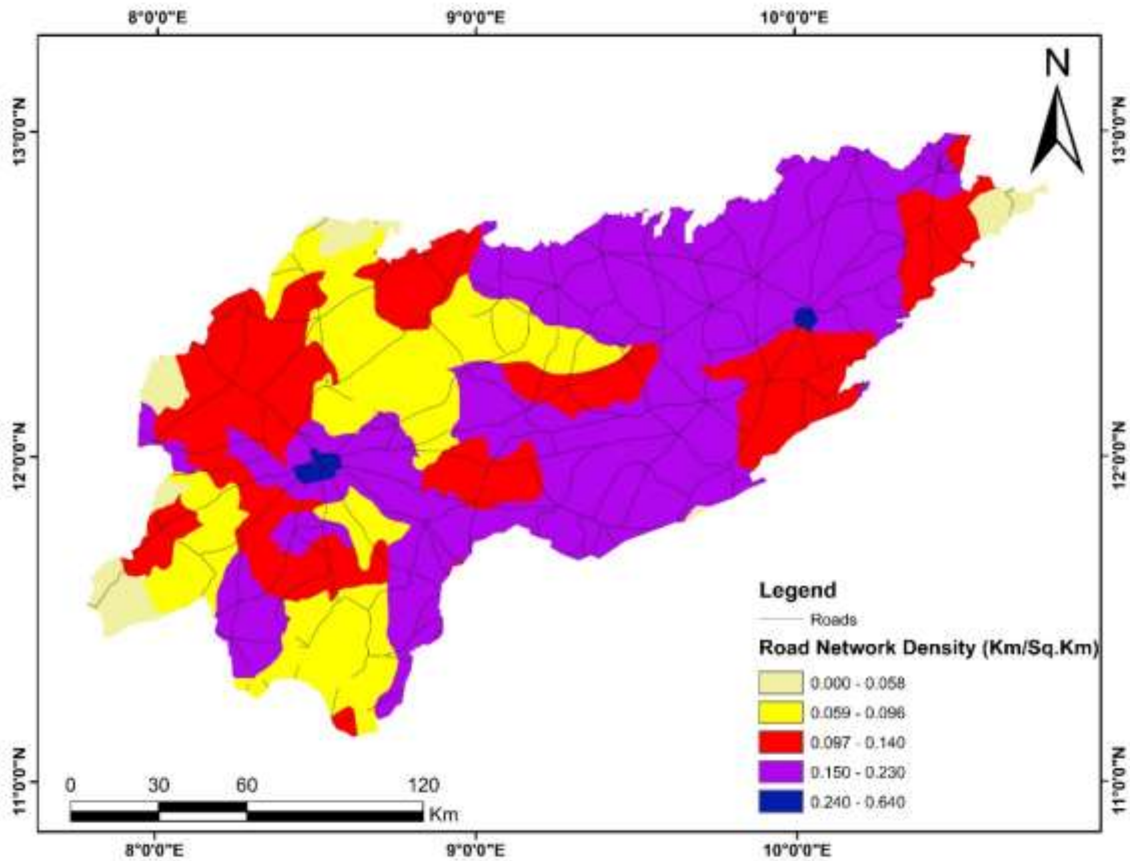

Figure 5.13: Road Network Density Map of Hadejia River Basin

5.3.6. Employment Rate

The employment rate map of the study area is presented in Figure 5.14 and shows that the rate of employment of the study area varies significantly from state to state. Very low and low employment rate (0 – 58.6%) and (58.7 – 64.1%) mostly all the northeastern part of the study area constituting Jigawa and some portion of Bauchi state while the extreme northeastern part of the study area have moderate employment rate (64.2 – 64.4%). This made the population of the state to have moderate vulnerability to floods. Furthermore, the high and very high employment rate (64.5 – 78.7%) is concentrated in the LGAs of Kano state. Higher value of employment rate of this region plays a vital role in making the region safe from economic vulnerability to flood.

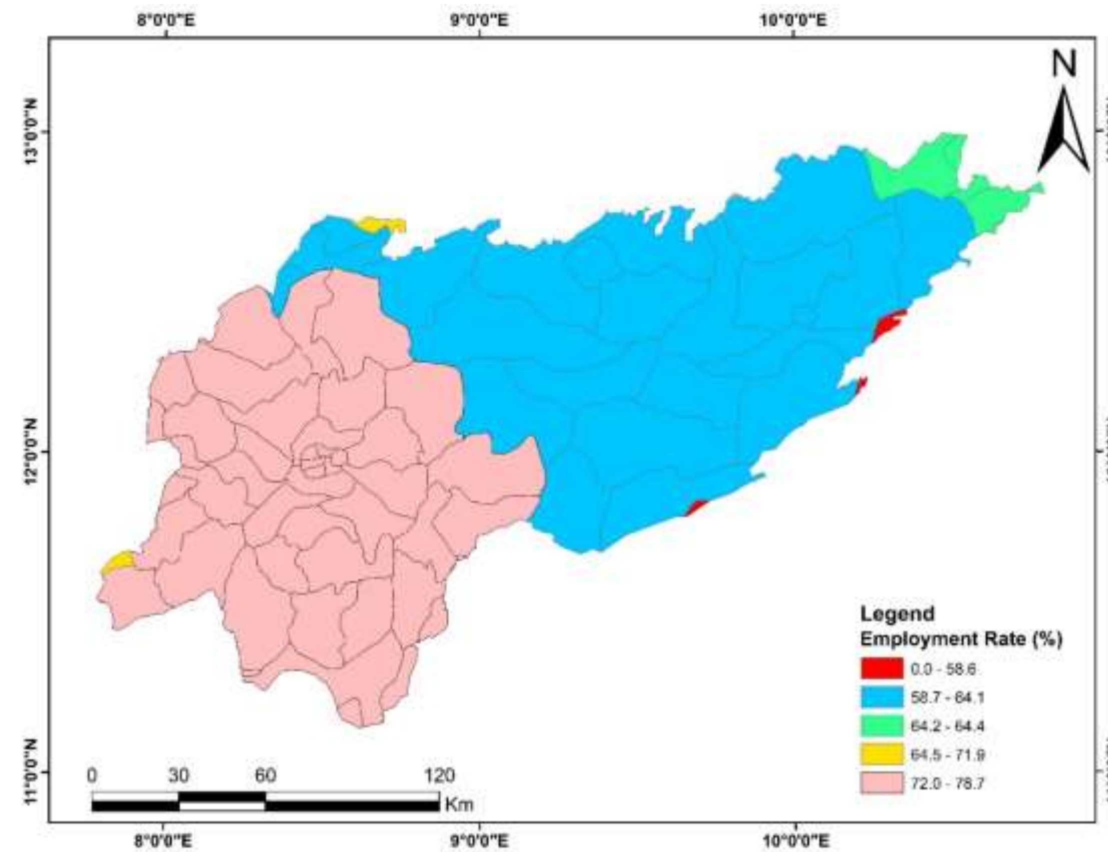

Figure 5.14: Employment Rate Map of Hadejia River Basin

5.4. Normalization of Flood Hazard and Vulnerability Indicators

To compare the indicators in order to aggregate them to form the flood hazard and vulnerability map layers, all the indicator were made dimensionless. This was done by assigning quantitative values to the qualitative data such soil type and land use sub indicators based on their influence and contribution to flood hazard and vulnerability. The assigned values for the land use and soil type are presented in Table 5.5 and 5.6. Equation 4.3 and 4.4 were used to normalize all indicators to values ranged 1 to 10, which revealed the influence of each factor on the flood hazard or vulnerability of flood disasters. The normalized indicators for all the hazard and vulnerability are presented in Appendix I and II.

5.5. Calculation of Weights and Ranking of Flood Hazard and Vulnerability Indicators Using AHP

Analytical Hierarchy Process (AHP) is a semi-quantitative decision-making value judgment approach where experts, planners and policy makers can use their expertise experience and knowledge to break down a problem into a hierarchy structure in order to solve it (Ghosh & Kar, 2018). AHP considers both objective and subjective factors to selects the best alternatives. In the present study, AHP Excel Template Version 2018-09-15 was used for the pair-wise comparisons and calculations of the weights and CRs (Youssef & Hegab, 2019). In this pairwise comparison matrix, the relative importance value of each factor is assigned by rating each factor against every other factor based on a comparative scale proposed by (Saaty, 1980) that ranges between 1 and 9. Table 5.1 and 5.2 shows an example of a pair-wise matrix for all flood hazard and vulnerability-related factors. The CR value for the flood hazard and vulnerability are 2.3% and 2.1% respectively which are less than 10% signifying an acceptable consistency level (Saaty, 1980). The overall weight and ranking of each factor for both hazard and vulnerability is presented in Table 5.2 and 5.4 and Table 5.5 and 5.6 respectively. The derived weights of the flood hazard indicators are Elevation (33%), slope (24%), drainage density (16%), soil type (12%), mean annual rainfall (8%), flow accumulation (5%), and distance to rivers (3%). From the derived weights of all the factors, one can see that elevation has the greatest weight, followed by slope and drainage density. This implies that elevation and slopes have more influence and contribution to flooding events in the study area than other indicators such as rainfall which is believed to have the highest contribution to flooding in areas that have relative the same elevation and slope evenly distributed (Mishra & Sinha, 2020; Seejata *et al.,* 2018). Furthermore, the derived weights for the socioeconomic vulnerability indicators are population density (36%), female population density (25%), and land use (15%), road network density (11%), literacy rate (8%) and employment rate (4%). The ranking for the hazard indicators shows that places that have low elevation, flat slope, high drainage density, clay/clay sandy soil type, greater mean annual rainfall, high flow accumulation and very close to rivers have higher hazard whereas the ranking for the flood vulnerability indicators reveals that areas with high population density, high female population density, built-up type of land use, lower road network density, lower literacy rate and lower employment rate have the highest vulnerability. This implies that population density have the highest contribution to flood vulnerability in the study area which is in line with various researches such as (Mishra & Sinha, 2020; Chakraborty, & Mukhopadhyay, 2019).

Table 5.4: Comparison Matrix for Flood Hazard Indicators

Flood Hazard Indicators	Elevation	Slope	Drainage Density	Soil Type	Mean Annual Rainfall	Flow Accumulation	Distance to Rivers
Elevation	1	2	3	3	4	5	7
Slope	0.5	1	2	2	3	6	7
Drainage Density	0.33	0.5	1	2	3	3	6
Soil Type	0.33	0.5	0.5	1	2	3	4
Mean Annual Rainfall	0.25	0.33	0.33	0.5	1	2	3
Flow Accumulation	0.20	0.17	0.33	0.33	0.5	1	2
Distance to Rivers	0.14	0.14	0.17	0.25	0.33	0.5	1
Total	2.76	4.64	7.33	9.08	13.83	20.5	30

Source: (Based on Experts' and local residents' interview, 2020 and literature review, 2020)

Table 5.5: Normalized Matrix of Flood Hazard Indicators

Flood Hazard Factors	Elevation	Slope	Drainage Density	Soil Type	Mean Annual Rainfall	Flow Accm.	Distance to Rivers	Sum	Ave rage
Elevation	0.36	0.43	0.41	0.33	0.29	0.24	0.23	2.30	0.33
Slope	0.18	0.22	0.27	0.22	0.22	0.29	0.23	1.63	0.23
Drainage Density	0.12	0.11	0.14	0.22	0.22	0.15	0.20	1.15	0.16
Soil Type	0.12	0.11	0.07	0.11	0.14	0.15	0.13	0.83	0.12
Mean Annual Rainfall	0.09	0.07	0.05	0.06	0.07	0.10	0.10	0.53	0.08
Flow Accm.	0.07	0.04	0.05	0.04	0.04	0.05	0.07	0.34	0.05
Distance to Rivers	0.05	0.03	0.02	0.03	0.02	0.02	0.03	0.21	0.03
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	7.00	1.00

Source: (Based on Expert's and local people's interview, 2020 and literature review, 2020)

Table 5.6: Comparison Matrix for Flood Vulnerability Indicators

Flood Vulnerability Indicators	Population Density	Female Population Density	Land Use	Road Network Density	Literacy Rate	Employment Rate
Population Density	1	2	3	3	4	6
Female Population Density	0.5	1	2	3	3	6
Land Use	0.33	0.5	1	2	2	4
Road Network Density	0.33	0.33	0.5	1	2	3
Literacy Rate	0.25	0.33	0.5	0.5	1	2
Employment Rate	0.17	0.17	0.25	0.33	0.5	1
Total	2.58	4.33	7.25	9.83	12.5	22

Source: (Based on Expert's and local people's interview, 2020 and literature review, 2020)

Table 5.7: Normalized Matrix for Flood Vulnerability Indicators

Flood Vulnerability Indicators	Population Density	Female Population Density	Land Use	Road Network Density	Literacy Rate	Employ ment Rate	Sum	Ave rage
Population Density	0.39	0.46	0.41	0.31	0.32	0.27	2.16	0.36
Female Population Density	0.19	0.23	0.28	0.31	0.24	0.27	1.52	0.25
Land Use	0.13	0.12	0.14	0.20	0.16	0.18	0.93	0.15
Road Network Density	0.13	0.08	0.07	0.10	0.16	0.14	0.67	0.11
Literacy Rate	0.10	0.08	0.07	0.05	0.08	0.09	0.46	0.08
Employment Rate	0.06	0.04	0.03	0.03	0.04	0.05	0.26	0.04
Total	1.00	1.00	1.00	1.00	1.00	1.00	6.00	1.00

Source: (Based on Expert's and local people's interview, 2020 and literature review, 2020)

Table 5.8: Classes of Flood Hazard Indicators, their Weight and Ranking

Indicators	Relative Weight	Reclassified Indicators	Ranking	Hazard
Elevation (Meters)	33%	539-673	1	Very low
		486-538	2	Low
		431-485	3	Moderate
		384-430	4	High
		338-383	5	Very high
Slope (Degrees)	23%	11.6-42.5	1	Very low
		4.51-11.5	2	Low
		2.68-4.50	3	Moderate
		1.34-2.67	4	High
		0.00-1.33	5	Very high
Drainage Density (Km/Km^2)	16%	0.00-0.032	1	Very low
		0.033-0.081	2	Low
		0.082-0.130	3	Moderate
		0.140-0.180	4	High
		0.190-0.310	5	Very High
Soil Type	12%	Luvisols (Loamy Sand)	1	Very Low
		Gleysols (Sandy Clay Loam)	4	High
		Arenosols (Sandy Loam)	4	High
		Fluvisols (Clay/Sandy Clay)	5	Very High
Mean Annual Rainfall (mm)	8%	757-833	1	Very low
		834-875	2	Low
		876-919	3	Moderate
		920-967	4	High
		968-1030	5	Very High
Flow Accumulation (Pixels)	5%	0-839	1	Very low
		839.1-3785	2	Low
		3786-8828	3	Moderate
		8829-13220	4	High
		13230-23800	5	Very High
Distance to Rivers (Meters)	3%	>5000	1	Very low
		4000-5000	2	Low
		3000-4000	3	Moderate
		2000-3000	4	High
		<1000	5	Very High

Source: (Based on Experts' and local people interview, 2020 and literature review, 2020)

Table 5.9: Classes of Flood Vulnerability Indicators, their Weight and Ranking

Indicators	Relative Weight	Reclassified Indicators	Ranking	Hazard
Population Density (Person/Km^2)	36%	78-210	1	Very low
		211-305	2	Low
		306-449	3	Moderate
		450-777	4	High
		778-31504	5	Very high
Female Population Density (Female/Km^2)	25%	40-105	1	Very low
		106-154	2	Low
		155-204	3	Moderate
		205-379	4	High
		340-14403	5	Very high
Land Use	15%	Water Bodies	1	Very low
		Wood and Grass	1	Very low
		Grassland	1	Very low
		Shrubland	2	Low
		Bare soil	3	Moderate
		Irrigated Cropland	4	High
		Rainfed Cropland	5	Very high
		Built-up	5	Very high
Road Network Density (Km/Km^2)	11%	0.240-0.640	1	Very low
		0.150-0.230	2	Low
		0.097-0.140	3	Moderate
		0.059-0.096	4	High
		0.000-0.058	5	Very high
Literacy Rate (%)	8%	58.2-58.3	1	Very low
		53.7-58.1	2	Low
		39.9-53.6	3	Moderate
		37.5-39.8	4	High
		0.00-37.4	5	Very high
Employment Rate (%)	4%	72.0-78.7	1	Very low
		64.5-71.9	2	Low
		64.2-64.4	3	Moderate
		58.7-64.1	4	High
		0.00-58.6	5	Very high

Source: (Based on Experts' and local people's interview, 2020 and literature review, 2020)

5.6. Flood Hazard Map

The flood hazard map of the study area is presented in Figure 5.15 which illustrates the potential areas liable to flooding. It highlights five hazard classes ranging from very low to very high flood hazard. The very high and high classes constitutes 10.4% (3179.1 Km^2) and 17.2% (5257.8 Km^2) of the study area distributed mostly in Jigawa state covering (Guri, Auyo, Dabi, Jahun Karika Sama, Miga, Hadejia, Maigatari, Taura, Mallam Maduri, Gagarawa and Kafin Hausa LGAs). Other areas that have high flood hazard outside Jigawa state are Babura, Garki, Dawakin Kudu of Kano state and Karasawa, Nguru and Jakusko of Yobe state. These area are essentially known to have relative flat slopes, low elevation and lower amount of rainfall compared to the upstream part of the watershed (Kano state). High and very high hazards were evident in agricultural land and urban built up areas of the watershed as seen from the flood hazard map. Other factors responsible for high hazard intensity in this region are the river bed siltation, high rise of water depth during rainy season, impastation of aquatic grasses along the river coast and mining of sand by local people of the communities. The high hazard nature of this region has subjected it to high risk of flooding. In a nutshell high flood hazard indicates high flood risk (Hu *et al.,* 2017).

Furthermore, the moderate class covers about 49.4% (15100.9 Km^2) of the basin which includes small portion of Jigawa state covering few places (Dutse, Birinuwa, Sule Tankar Tankar, and Kiyawa LGAs) and large part of Kano state (Dambatta, Gabasawa, Minjibir, Kura, Wudil, Dawakin Tofa and Kabo LGAs). In contrast with the northeastern part of the study area, the upstream extreme part (The western part of the study area) is dominated with low and very low hazard classes which is spatial distributed all over the area and covers about 18.3% (5594.1Km^2) and 4.5% (1375.6Km^2) of the study area. These places includes Rano, Kibiya, Rogo, Sumaila, Gwarzo, Karaye, Bebeji, Doguwa and Rimin Gado LGAs. These areas are characterize with high elevation, steep slopes, rocky and sandy soils, moderate rainfall and relatively low drainage density. This findings is in accordance with many studies (Chakraborty & Mukhopadhyay, 2019; Ntajal *et al.*, 2017) where areas location in high elevation, steep slopes and rocky and sandy lithologic setting are less prone to flooding events.

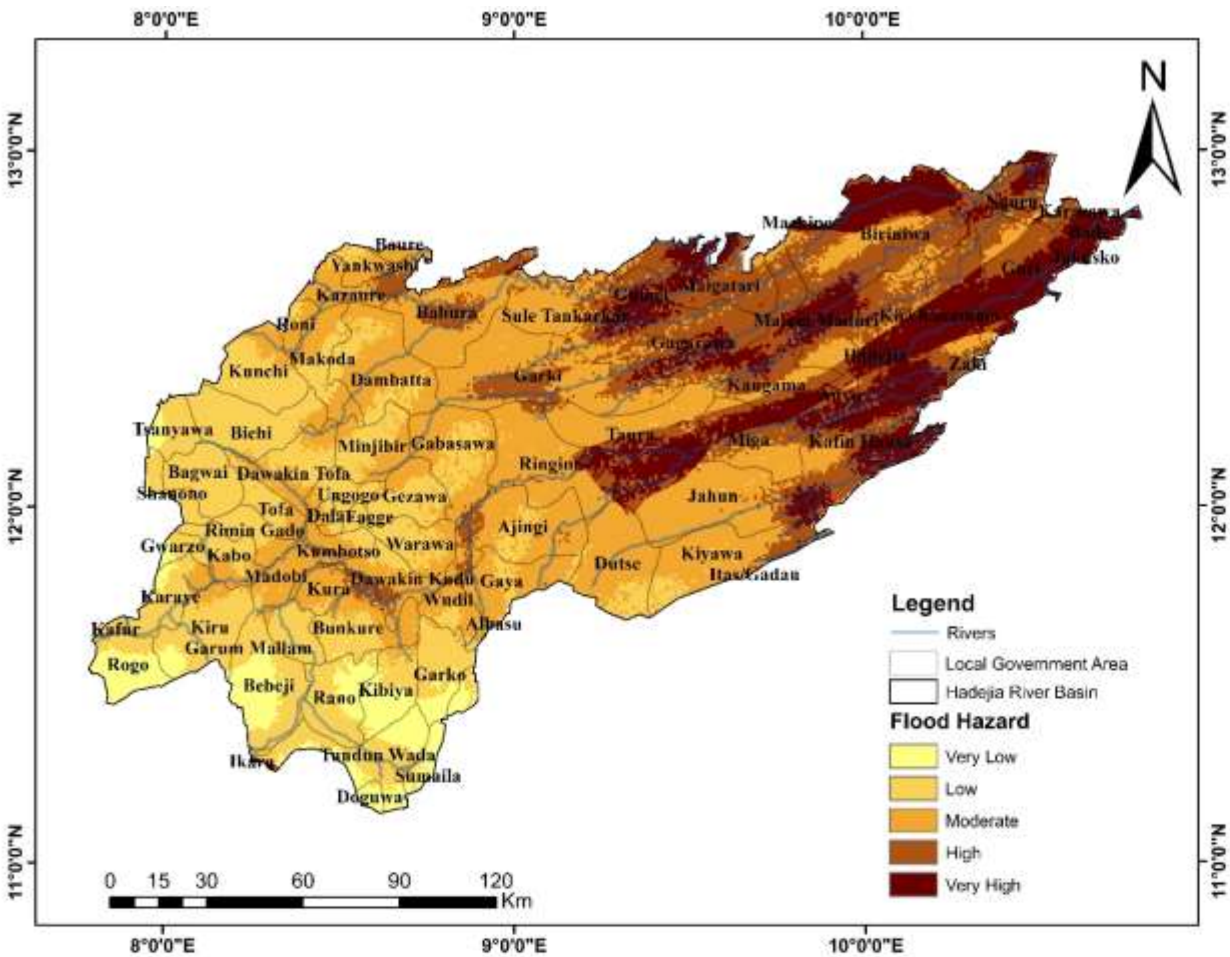

Figure 5.15: Flood Hazard Map of Hadejia River Basin

5.7. Flood Vulnerability Map

The flood vulnerability map of the study area is presented in Figure 5.16 which highlights five areas of vulnerability classes ranging from very low, low moderate, high and very high. The very high and high classes constitutes about 2.3% (703.1Km^2) and 21.8% (6663.9Km^2) of the study area respectively. It is basically areas characterize with urban built up and bared soil classes of land use, high population and female population densities, less literacy and employment rate, and very poor road network systems. Places such as Kano Municipal, Rano, Tsanyawa, Gwarzo and Fage LGA of Kano state and Dabi, Kafin Hausa, Guri, Kiyawa, Tura and Auyo LGA of Jigawa state have the very high and high flood vulnerability classes. The medium vulnerability class covers 53.6 % (16384.8Km^2) of the basin which constitutes about 24 local government areas of Kano and Jigawa States respectively. This class of vulnerability is spatially distributed across

Tarauni, Ungogo, Rano, Gumel Ringim, Jahun, Miga, Minjibir, Dutse, Kumbotso, Gagarawa, Gumel, Maigatari LGAs among others. The low and very low vulnerability classes covers 13.4 % (4096.2Km^2) and 8.9 % (2720.6Km^2) of the study area respectively. These constitutes areas of agricultural lands, vegetation, less population density, high literacy rate, high economic activities, good drainage system and high residence area. This is in agreement with the findings of (Mishra & Sinha, 2020). Places such Kura, Bebeji, Wudil, Sumaila, Garko, Gezawa, Warawa, Gaya, Shanono LGA of Kano state and Nguru and Karasawa LGAs of Yobe state constitutes the low and very low vulnerability classes. In general, high flood vulnerability may lead to high flood risk.

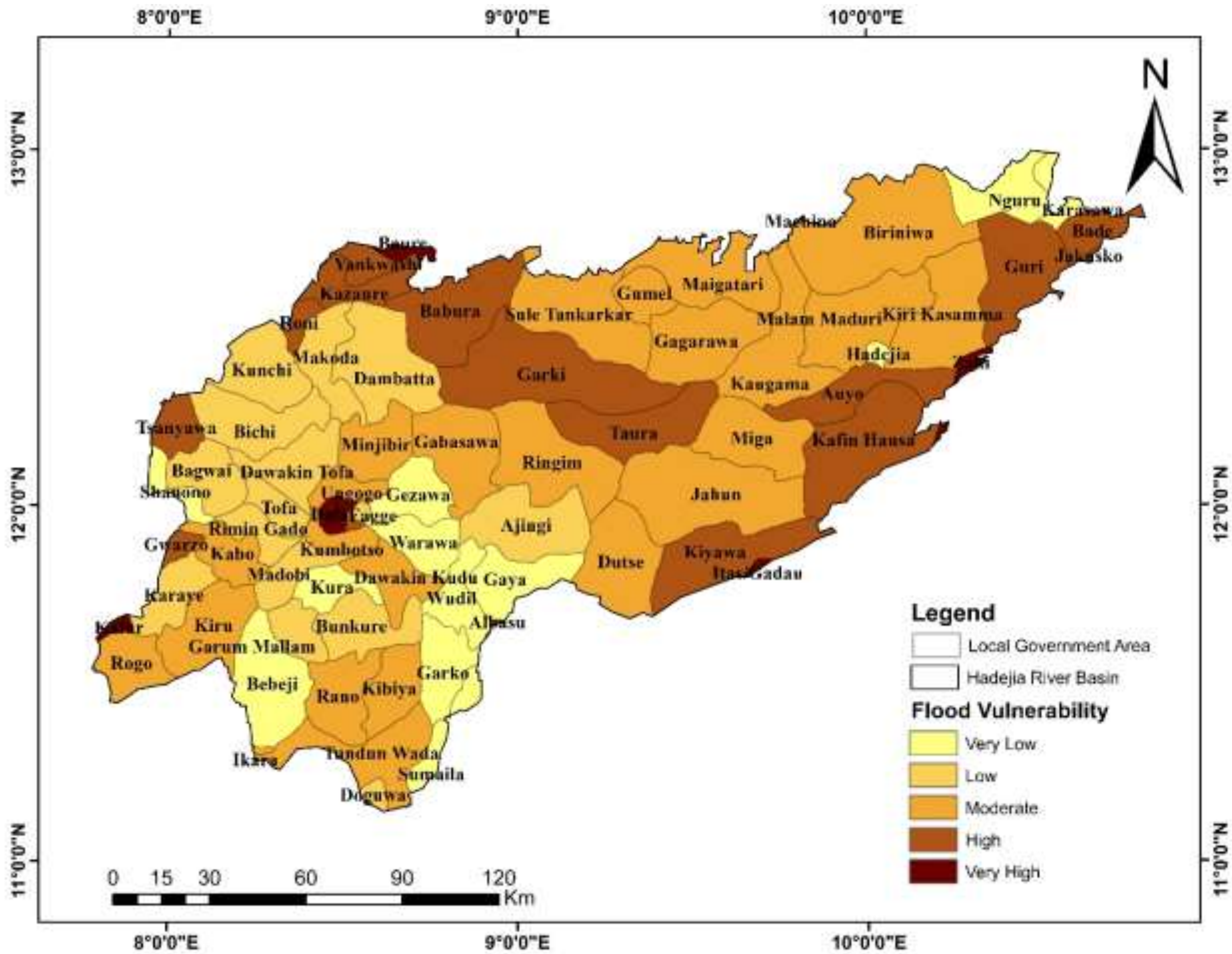

Figure 5.16: Flood Vulnerability Map of Hadejia River Basin

5.8. Flood Risk Map

The flood risk map of the study area is presented in Figure 5.17. The flood risk is divided into five levels of risk ranging from very low to very high risk. The Figure reveals that areas of very high, high, moderate, low and very low risk are respectively 1.8 %, 41.6 %, 24.8 %, 20.3 % and 11.5 % of the study area. The high and very high risk zones are characterize by low slopes and elevations, high drainage density, and low permeable soil, high population density, low literacy rate, slightly high annual rainfall, urban built up and bared land type land uses. The overall area covered with high and very high flood risk in the basin constitutes about 43.4 % (13266.7Km^2) of the entire watershed. Communities identified to have high and very high risk of flooding within the study area are Guri, Dabi, Auyo, Kano Municical, Fage, Jahun, Maigatari, Gumel, Gagarawa and Hadejia LGA. A careful analysis of the risk map reveals that the urban built up, clay soil types, low slope and elevation plays a vital role in increasing the risk of flood in these regions.

The medium risk class covers about 24.8% (7581Km^2) of the study area while the low and very low flood risk zones constitutes 31.8 % (9720.8Km^2) of the study area. These risk classes are concentrated at the upstream part of the watershed and the zones are characterize by steeper slope and high elevation, permeable soil, vegetation and forest type of land use, very low population density and very high literacy and income rate. Another reason for their low and very low risk of flooding is the presence of Tiga and Challawa Gorge dams at Tiga and Kiru LGAs of Kano states. These hydraulic structures impounds large quantity of runoff water coming from upstream locations that may cause flooding downstream which renders the area to have low flooding risks. These hydro-geomorphic and socioeconomic nature of the area plays a vital role in having low and very low flood risk.

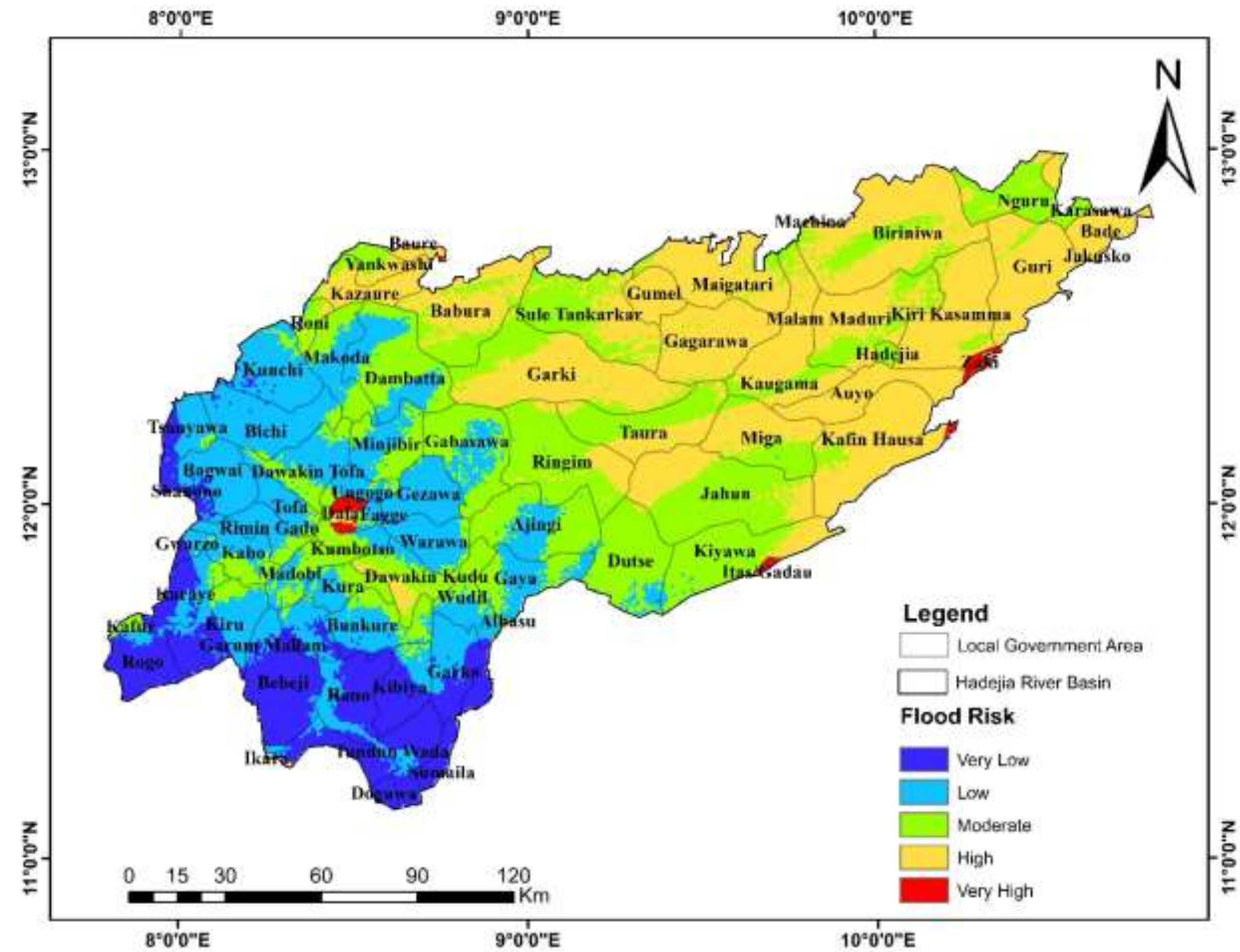

Figure 5.17: Flood Risk Map of Hadejia River Basin

5.9. Validation of Flood Risk Map

The verified flood risk map of Hadejia River Basin is presented in Figure 5.18. The results of the verification reveals good agreement between the flood risk map and the historical flood records. This proves that the proposed methodology can be applied in other study areas to developed flood risk map as it is flexible, easy to use, has high accuracy and requires less data. The Figure shows that the high and very high flood risk are located in areas that has historical flood records while low and very low flood risk concentrated at the upstream part of the basin particularly in areas near Tiga and Chalawa Gorge dams and the irrigation scheme at Kura LGA. An example is the flood event of Guri and Auyo that occurred in August 2018 which led to the destruction of vast agricultural lands, collapse of many infrastructures and more than a dozen deaths. 29 out of the 49 historical flood events occurred within the high and very high flood risk regions. Furthermore, only 16 historical flood events were recorded in moderate flood risk zones while 2 historical flood event were in low flood risk regions and 2 surveyed coordinates of Chalawa Gorge and Tiga dams were also found in low risk zones except the Watari dam of Kazaure LGA which is based in moderate to high flood risk regions. Hence, this shows that the adopted methodology can predict area that are likely to experience flood accurately.

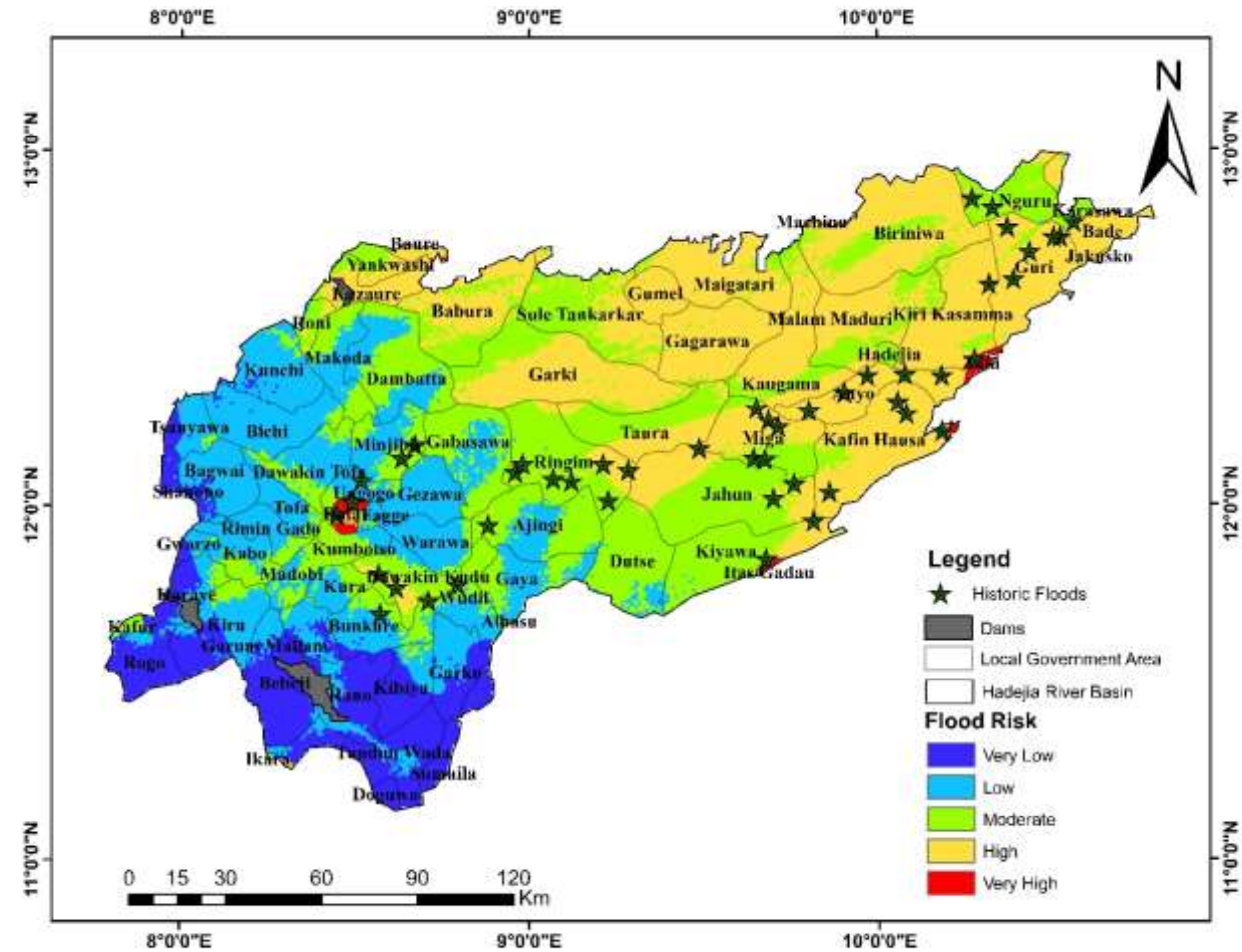

Figure 5.18: Validated Flood Risk Map of Hadejia River Basin

5.10. Flood Risk and Vulnerability Reduction through Mitigation and Management Options in Hadejia River Basin

Flood reduction and mitigation can be achieved by employing either structural or non-structural measures which largely depends on available flood information and knowledge of potentially affected areas or areas that are prone to flooding event (Nasiri *et al.,* 2016; Kang *et al.,* 2009). Based on the literature review, focus group discussion with expert, rigorous field study and analysis of result of the flood hazard, risk and vulnerability of the study area, different regions in the study area were identified to have different hazard, vulnerability and risk classes. This suggest the quest for exploring sustainable flood reduction and mitigation measures that will suit the condition of the study area. As such various structural and non-structural measures were explored for the study area and include the following;

5.10.1. Structural Measures of Flood Risk and Vulnerability Reduction and Mitigation

The structural measures of flood control employs the techniques of storing, diverting and confinement of flood water (Mishra & Sinha, 2020). This measure can be achieved through the installation of facilities that prevent disasters (Kang *et al.*, 2009). They are basically designed to keep water away from infrastructures, residential areas, agricultural lands, and flood plains by constructing permanent structures in order to reduce the damage of risk. This method involves the use of hydraulic infrastructures such as dams, levees, and floodwalls that alters the flood characteristics and reduces the probability of flood occurrence in location of interest. Other measures includes methods of riverbed dredging, river restoration, denaturalization and flood prevention (Mishra & Sinha, 2020). The outcome of this research and the in depth field observation and the interview with experts suggested the following structural measures to be undertaken in the study area.

- **Channel Modification**

Due to sand mining, embankment construction and impastation of aquatic grasses in the channel, many changes in water courses and channel morphology have occurred over the last decades leading to submergence of large portion of farm lands, villages, roads and dilapidation of electric poles and culverts in Hadejia River Basin. This was illustrated in Figure 1.1 where there is imperious need to restore the natural conditions of the channel in such affected zones through riverbed dredging and construction of backflow preventers.

- **Proper Monitoring and Evaluation of Flood Control Structures**

Flood control structures such as levees and embankments provide a sound degree of flood protection especially when combine with other alternative means of flood reduction (Mishra & Sinha, 2020). Hadejia River embankment is not monitored and evaluated properly and large population of the basin are dwelling close to rivers. This calls for frequent monitoring and evaluation of this structure by government and local residence. This activity should be combined with a comprehensive health monitoring programs particularly in the more vulnerable areas identified in this research in order to derive long lasting protection.

- **Sustainable Drainage Systems (SUDs)**

Sustainable Drainage Systems are best management practices that incorporate various drainage components such as swales, wetlands, detention basin, retention basin and green roofs, permeable pavements, infiltration trenches or infiltration areas. It is imperative to utilize such structures in cities with complex infrastructures and which are vulnerable to flooding and pollution. SUDs should be practiced in cities of Kano state (Kano municipal, Dala, Fage) in order to prevent the impact of urban development on flooding and pollution of waterways.

- **Removal of interventions for safe discharge of floodwaters**

The drainage density and road network density maps (Figure 5.6 and 5.13) of Hadejia River basin shows a high degree of congestion of drainages and roads in some areas such as Kano Municipal, Fage, Guri, Auyo, Ungogo, and Hadejia as a result of roads construction without proper waterways. It was explored during field visit that debris and other solid waste block some channels in Kano Municipal and Hadejia town. Large portion of these areas have high population density, high drainage and road network density which fall in very high to moderate flood risk zones. Therefore, it is imperative to identify these places that have interventions in order to carryout proper evacuation of debris and redesign of some of them for safe discharge of floodwaters.

- **Establishing urban rainwater storage and flood diversion**

This is achieved by constructing reservoirs at the upstream of an urban settlement to cut down the flood into downstream reach and to reduce the intensity of flood risk disasters. Flood diversion and storage areas should also be established to change the spatial distribution of flood and reduce the risk of flooding to highly populated areas.

5.10.2. Non-Structural Structural Measures of Flood Risk and Vulnerability Reduction and Mitigation

The non-structural measures are designed to keep the infrastructures, agricultural land and other structures away from waterways. This measure allows individuals or a community to cope with flood risk disaster more effectively (Khunwishit *et al.,* 2018). The environmental impact of non-structural measures of flood control is relatively less and their implementation is easy compared to the structural measures (Mishra & Sinha, 2020; Kang *et al.*, 2009). This gives it more importance in socio-economic and institutional perspectives. There should be a collective effort and cooperation between local communities and government authorities for these measures to be effective (Mishra & Sinha, 2020). Based on this study, the following non-structural measures are suggested;

- **Architectural Planning Approaches**

Floods usually results in large number of lives and economic losses due to submergence of vast area of agricultural lands and collapse of buildings and other government infrastructures especially in low lying areas. It is highly suggested that architectural approaches of flood control measures such as structure elevation (building structures above the flood level), prevention of exterior walls of building by using watertight emulsion and establishing flood resilient building codes with regards to occupancy and the use of buildings in areas with low lying elevations and high flood risk areas such as Auyo, Guri, Jahun, Miga, Nguru and Jakusko (Figure 5.16) could be implemented to reduce the flood risk of these locations.

- **Land Use Planning and Zoning**

Land use planning when coupled with land use restriction policies provide an effective measure of risk reduction in a particular area (Mishra & Sinha, 2020). Land use planning defines how land should be used in a given area. Land use planning should be implemented in the study allocating various land uses to specific areas that suit such land uses such as agricultural land, industrial areas, business spots, and residential areas. From Figure 5.17 in the result analysis places such Auyo, Guri, Jahun have high flood risk and should be designated to have low occupancy uses whereas the moderate and less risk zones should be designated for high occupancy uses with implementation of improve drainage network and reduction of less pervious surfaces. Proper land use planning and zoning signifies less flood disaster risk.

- **Flood Insurance**

Financial risk of living in floodplain for individual or societies to flood risk is reduced through flood insurance particularly in areas of high flood risk and vulnerability due to high population density and low economic status. Flood insurance is considered a mitigation technique because it doesn’t reduce damage but compensate the affected individual or societies for their losses (Mishra & Sinha, 2020; Kang *et al.,* 2009). In areas with high to very high flood risk and vulnerability such Auyo, Guri, Kano Municipal, Fage, Jahun and Miga LGAs of the study area, the government should implement flood insurance system for the inhabitants living in these regions that covers life and economic damages due to floods.

- **Capacity Building for Flood Resilience**

Capacity building for flood resilience is a measure used reduce the physical vulnerability of people to floods (Mishra & Sinha, 2020; Khunwishit *et al.,* 2018). This could be achieved through sensitization workshops and training of the residence of the local communities on flood risk reduction. The communities with high to very high vulnerability in the study area has low literacy rate and need to be educated on the techniques of flood risk reduction and mitigation.

- **Hazard forecasting, Early Warning System and Emergency Plans**

Weather forecasts of the severity and intensity of rainstorm and accurate prediction of flood levels in rivers helps government and the public in making decision of evacuating valuable properties from flood hazard zones. Early warning systems and proper dissemination of information on flood occurrence and intensity reduce life and property losses (Shale *et al.*, 2020). Furthermore, timely mitigation and preparedness measures should be implemented in high to very high risk areas of the study area in order to reduce the aftermath of the flooding.

CHAPTER SIX

6. CONCLUSION AND SUGGESTIONS

6.1. Conclusion

In this study, the spatial distribution of flood risk zones of Hadejia River Basin were mapped using the Analytic Hierarchy Process (AHP) method integrated with Geographical Information System (GIS). The study has combined the hydro-geomorphic hazard analysis which is very flexible and requires less hydrological data and socio-economic vulnerability assessment to identify flood risk zones. The flood hazard and vulnerability indicators of the study area were determined by extensive literature review, field survey, and discussion with experts, local leaders and residents. The study has identified thirteen indicators necessary for flood risk assessment in the basin, including elevation, slope, drainage network density, soil type, flow accumulation, distance to rivers, population density, female population density, land use, literacy rate, road network density and employment rate. Based on the results obtained in the study, the following major conclusions can be drawn;

- The proposed methodology showed that, very high and high flood hazard zones constituted about 10.4% (3179.1 Km^2) and 17.2% (5257.8 Km^2) of the study area and are mainly identified in the northeastern and southeastern parts of the watershed. According to the flood hazard map, about 27.6 % (8436.9Km^2) of the basin is prone to flooding. However, the north western and southeastern part constituted the very low and low classes of flood hazard.
- The study reveals that about 2.3% (703.1Km^2) and 21.8% (6663.9Km^2) of the study area belongs to high and very high vulnerability classes which are primarily located in the southeastern, central and extreme upstream parts of the study area. In contrast with southeastern and extreme part of the watershed, the northeastern and southwestern portion of the study area is characterize with moderate, low and very low vulnerability classes which covers a total of 75.9 % (23201.6Km^2) of the entire basin.
- Combining the flood hazard (FHI) and vulnerability (FVI) indices of Hadejia River Basin, approximately 43.4% of the basin is under high and very high flood risk covering about 13266.8Km^2. This implies that close to the half of the basin is high and very high flood risk area. The moderate, low and very low risk classes are concentrated mainly in the

upstream and central portion of the study area. This covers a total of 56.6% (17301.9Km^2) of the basin.

- The study also reveals that flood hazard and vulnerability indicators have different influence to flood risk. For instance high flood hazard does not necessarily lead to high flood risk giving low vulnerability. Furthermore, the results are validated to be in agreement with the historical records of flood risk distribution. This is proves the reliability and applicability of the proposed methodology.

6.2. Suggestions

The following suggestions can be drawn from the study;

- Land use planning and building zoning should be practiced in the study area and other measures such as prohibiting agricultural encroachments towards rivers, constructing easily accessible flood shelters in order to reduce the vulnerability of people should also be practiced.
- Further researches should be done for high flood risk regions to better understand the nature, timing and causative agents of floods as well as the extent of area that will experience inundation of flood waters.
- An improvement in the proposed methodology would be to incorporate coping capacity and resilience in computing flood risk.
- The principles of good governance should be practiced in the study area for an effective flood management.
- Reliable communication channels and data acquisition networks should be developed for effective information dissemination and data mining.
- Watershed management plans such as afforestation, reforestation, soil and water conservation should be practiced to regulate the downstream discharge.
- Non-structural options of flood defense system should be giving more priorities than simply constructing flood protection embankment.
- Public participation in flood risk management should be encouraged as it contribute to public acceptance and serves as an avenue for eluding potential conflicts.
- An integrated flood risk reduction / management approach should be practiced in the basin as it is essential in addressing multiple water related conflicts at all levels.

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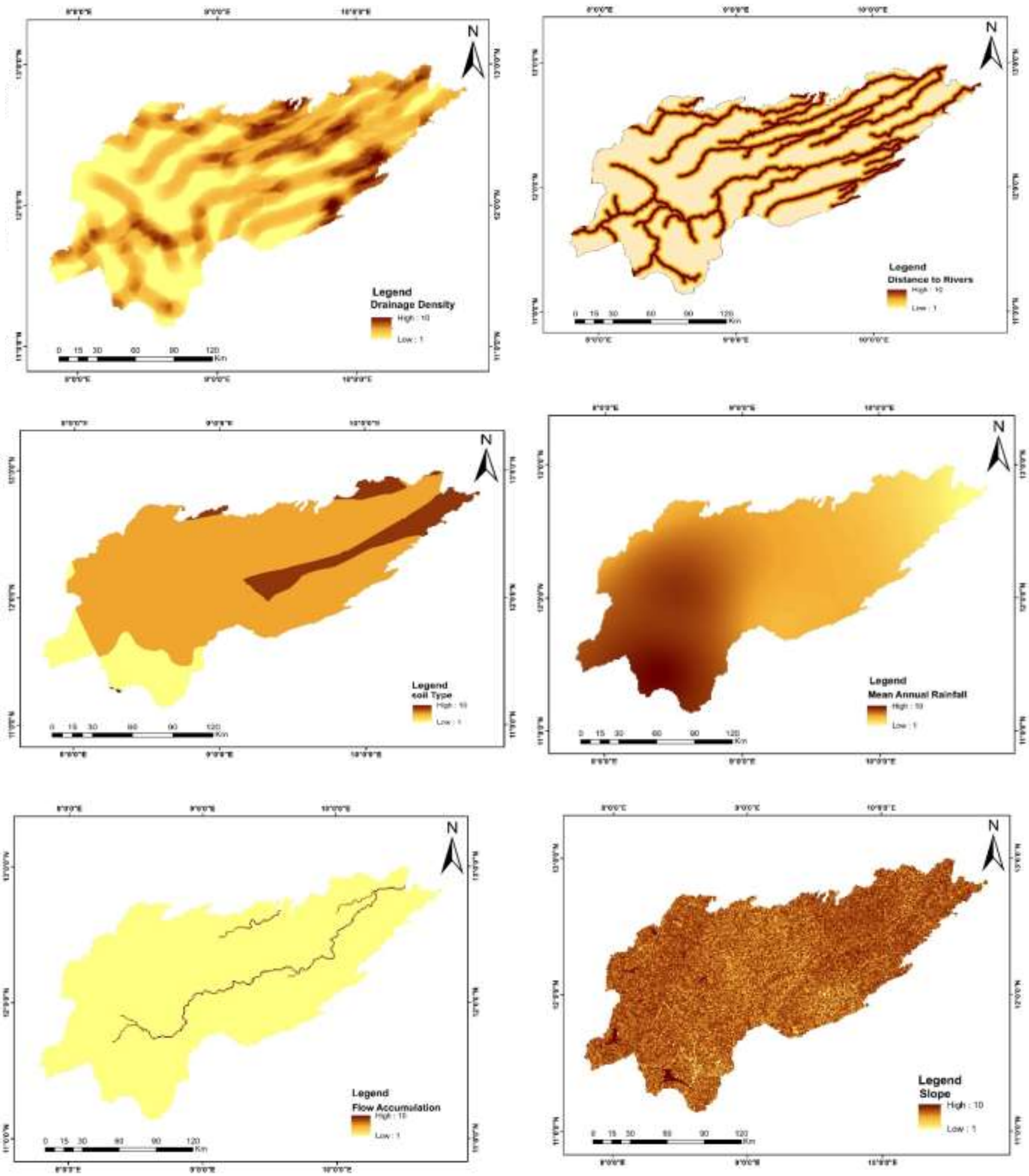
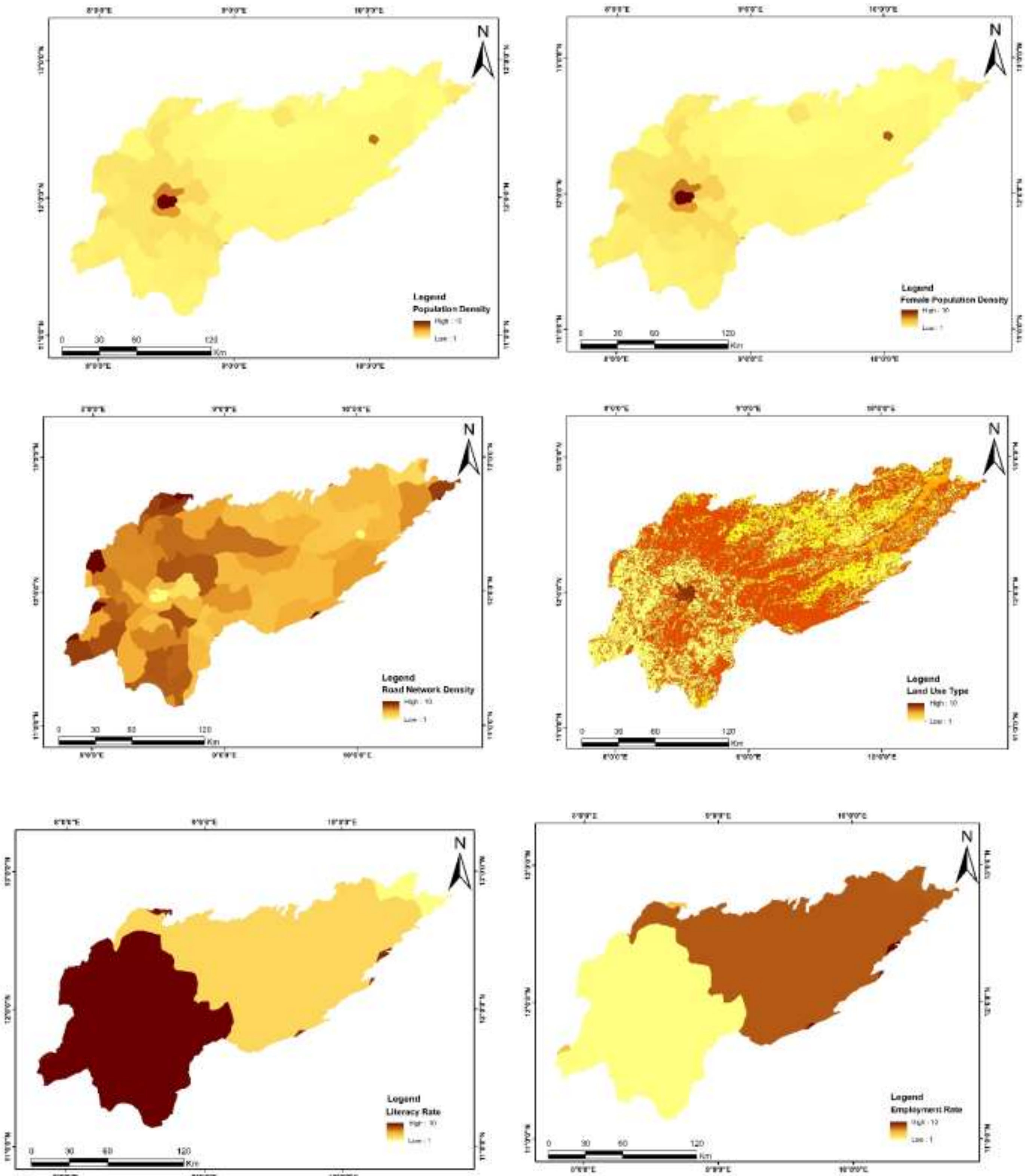
APPENDICES

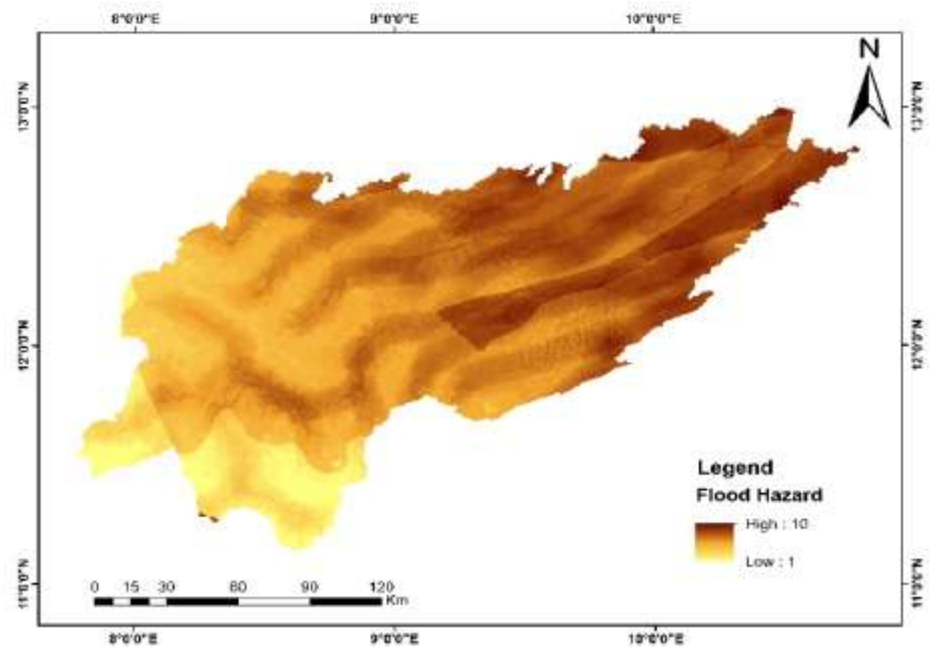
Appendix I: Normalized Flood Hazard Indicators

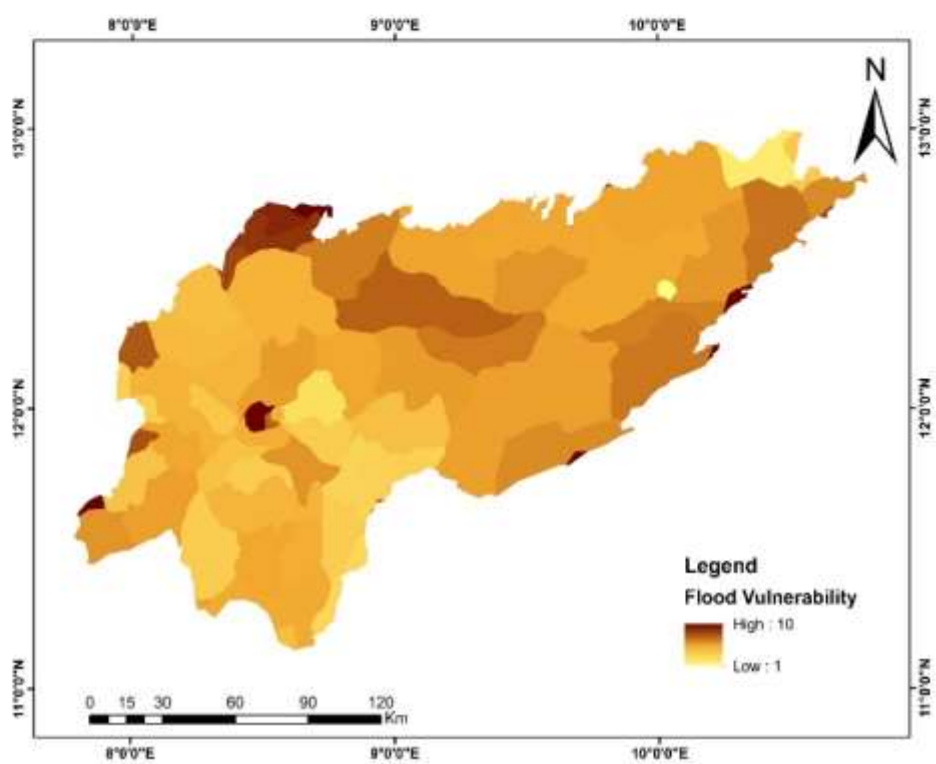


Appendix II: Normalized Vulnerability Indicators



Appendix II: Normalized Flood Hazard and vulnerability Maps





Appendix IV : Field Surveys and Focus Group Discussions

Submerged Farmland in Harbo Jahun LGA (Iliyasu, 2017).