

# **Flood Vulnerability Assessment and Adaptive Capacity of Smallholder Farmers: A Case Study of the Orashi Basin in the Niger Delta**

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## **Declaration**

I hereby declare that this thesis has not been previously published or written by another person; neither has it been submitted nor accepted for any other academic award. It is the result of my original work carried out at Brandenburg University of Technology Cottbus, Germany, within the framework of the Ph.D. Programme “Environmental and Resource Management”. All materials from other sources have been duly and adequately acknowledged.

Mbachu Ikechukwu Christian

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## **Dedication**

This thesis is dedicated to Gabriel Oko, Jesse Ojobor and to the memory of my late father, Sir D.L Mbachu and my twins, Nnenna Chloe and Ikenna Bryan Mbachu



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## List of Abbreviations and Acronyms

ADB:	Asia Development Bank
CanSIS:	Canadian Soil Information Service
CASC2D:	CASCade of planes in 2-Dimensions
DEM:	Digital Elevation Model
DER:	Department of Environmental Resources
EEA:	European Environment Agency
ESRI:	Environmental Systems Research Institute
ETM:	Enhanced Thematic Mapper
FAO:	Food and Agriculture Organization
GIZ:	Deutsche Gesellschaft für Internationale Zusammenarbeit
IARAN:	The Inter-Agency Regional Analysts Network
ICRAF:	International Council for Research in Agroforestry
IFAD:	International Fund for Agricultural Development
IPCC:	Intergovernmental Panel on Climate Change
iSWM:	Integrated Storm water Management
IWMI:	International Water Management Institute
LOWESS:	Locally Weighted Scatterplot Smoothing
LULC:	Land use and Land Cover
NASA:	National Aeronautics and Space Administration
NBS:	Nigeria Bureau of Statistics
MDG:	Millennium Development Goal
NDDC:	Niger Delta Development Commission
NDES:	Niger Delta Environmental Survey

NIMET:.....Nigerian Meteorological Agency

NRCS:.....Natural Resource Conservation Service

Min Ch El:.....Minimum main channel elevation

OLI:.....Operational Land Imager

PCI: .....Problem Confrontation Index

RGB: .....Red, Blue, Green

SCS: .....Soil Conservation Service

SPI:.....Stream Power Index

SRTM:.....Shuttle Radar Topography Mission

TIN:.....Triangular Irregular Network

TM: .....Thematic Mapper

TWI:.....Topographic Wetness Index

UNEP:.....United Nations Environmental Program

UNISDR:.....United Nations International Strategy for Disaster Reduction

UNDESA: .....United Nations, Department of Economic and Social Affairs

USACE: .....US Army Corps of Engineers

USDA:.....United States Agricultural Department

USGS:.....United States Geological Survey

WBGU: .....the German Advisory Council on Global Change

WMO: .....World Meteorological Organization

## **Abstract**

Although flooding is a fairly constant occurrence in the Niger Delta, however, flood events have increased both in frequency and intensity. However, climate change may not be the only factor responsible for flooding in the Niger Delta. There are other causative factors such as the morphometric characteristics of the area and the rapid rate of land use change in the area.

In most studies on flood risk in Nigeria, priority is given to urban flood risk than rural flood risk. Smallholder farmers who mostly inhabit rural areas and flood plains are known to be at great risk of flooding, but to date, there have been no studies on the impacts they experience and how they cope with these impacts.

To establish the existence of significant change in precipitation in the study area, statistical analysis of precipitation data was conducted using linear regression and non-parametric Mann Kendall test. Landsat satellite images for 1986, 2003 and 2016 were obtained from the United States Geological Survey's (USGS) website and used to collect and analyze data related to land use.

To carry out topographical and hydrological analysis in the region, Digital Elevation Models (DEM) derived parameters were employed. The morphometric analysis methodology involved delineating the catchment using ArcGIS Hydrology tools. Based on the DEM, morphological derivatives were derived and used in determining flood prone areas. To create the flood risk map; DEM, Slope, SPI, TWI and Drainage Density maps were employed. The thematic layers were integrated using the weighted overlay tool. Based on the integration and overlay process, different flood zones were identified.

To determine flood risk in the context of land use change, the HEC-HMS model version 3.5 was used. Land use maps corresponding to 1986, 2003, and 2016 LULC conditions were analysed and prepared for the calculation of CN values using Soil Conservation Service (SCS-CN) method. CN map was prepared by integrating the maps of hydrologic soil groups and land use in ArcGIS software.

The result reveals a Mann Kendall Z value of 0.91 which is less than the critical value of 1.96, hence the results of the analyses indicate that although there is an increasing trend in annual

rainfall, however, at a 95% confidence level, the increase is not significant, hence the increased case of flood events in the region cannot be wholly attributed to a change in rainfall regime.

Land cover change analysis showed that there has been marked land use and land cover change during the study period of 30 years. During the 1986–2016 period forest cover area experienced the highest change (49.81% decrease). Further, the major type of land conversion type was found to be the conversion of forest area to agricultural land.

Based on selected morphological parameters, a flood risk map was developed for the study area. The morphologic flood risk showed that most parts of the basin face moderate flood risk. Higher runoff values were observed under 2016 LULC conditions mainly due to intense deforestation relative to those of 1986 and 2003. The results indicated that runoff and peak discharge are significantly affected by deforestation instead of changes in the rainfall pattern. Flood inundation maps of the study area were prepared for the flood events of 2012 and 2015. Maximum depth for the 2012 and 2015 flood events was calculated as 10.58m and 7.39m, respectively.

The socioeconomic aspects of the research were conducted using household survey method. Using snowball sampling techniques, 400 flood-affected households were selected. The results show that the adaptive capacity of smallholder farmers in the study area remains very low and hampered by several factors such as poverty and weakened social networks. The synopsis of the examined variables leads to the following conclusion: Instead of climatic factors – as one indicator of vulnerability – it is social inequality and poverty in the region as well as the structural economic differences between various groups that mainly drives vulnerability in the study area.

**Keywords: Vulnerability, flood, smallholder farmers, adaptive capacity**

## Zusammenfassung

Obwohl Überschwemmungen ein ziemlich konstante Begebenheit im Nigerdelta sind, haben Hochwasserereignisse sowohl in ihrer Häufigkeit als auch in ihrer Intensität zugenommen. Allerdings ist der Klimawandel möglicherweise nicht der einzige Faktor, der für Überschwemmungen im Nigerdelta verantwortlich ist. Es gibt noch andere Ursachen wie die morphometrischen Eigenschaften des Gebiets und die schnelle Veränderung der Landnutzung in dieser Region.

In den meisten Studien zum Hochwasserrisiko in Nigeria erhält das städtische gegenüber dem ländlichen Hochwasserrisiko Priorität. Es ist bekannt, dass Kleinbauern, die meist in ländlichen Gebieten und Überschwemmungsgebieten leben, einem großen Hochwasserrisiko ausgesetzt sind. Bis heute gibt es jedoch keine Studien über die Auswirkungen und wie die Kleinbauern hiermit umgehen.

Um das Vorhandensein signifikanter Änderungen des Niederschlags im Untersuchungsgebiet festzustellen, wurde eine statistische Analyse der Niederschlagsdaten mithilfe einer linearen Regression und eines nichtparametrischen Mann-Kendall-Tests durchgeführt. Landsat-Satellitenbilder für die Jahre 1986, 2003 und 2016 wurden von der Website der United States Geological Survey (USGS) bezogen und zum Sammeln sowie Analysieren von Daten bezüglich der Landnutzung verwendet.

Zur Durchführung der topografischen und hydrologischen Analyse in der Region wurden die aus dem Digital Elevation Model (DEM) abgeleiteten Parameter verwendet. Die morphometrische Analyseverfahren beinhaltete die Abgrenzung des Einzugsgebiets mit Hilfe von ArcGIS Hydrology Tools. Basierend auf dem DEM wurden morphologische Ableitungen vorgenommen und zur Bestimmung hochwassergefährdeter Gebiete genutzt. Zur Erstellung der Hochwasserrisikokarte wurden die Karten DEM, Slope, SPI, TWI und Drainage Density verwendet. Die thematischen Schichten wurden mit Hilfe des gewichteten Überlagerungswerkzeugs integriert. Basierend auf dem Integrations- und Überlagerungsprozess wurden verschiedene Überschwemmungsgebiete identifiziert.

Zur Ermittlung des Hochwasserrisikos im Kontext der Landnutzungsänderung wurde das Modell HEC-HMS Version 3.5 verwendet. Landnutzungskarten, die den LULC-Bedingungen von 1986, 2003 und 2016 entsprechen, wurden analysiert und für die Berechnung der CN-

Werte mit der Methode des Soil Conservation Service (SCS-CN) vorbereitet. Die CN-Karte wurde durch Integration der Karten der hydrologischen Bodengruppen und der Landnutzung in der ArcGIS-Software erstellt.

Das Ergebnis zeigt einen Mann Kendall Z-Wert von 0,91, der unter dem kritischen Wert von 1,96 liegt. Daher zeigen die Ergebnisse der Analysen, dass trotz eines zunehmenden Trends der jährlichen Niederschläge, der Anstieg bei einem Konfidenzniveau von 95 % nicht signifikant ist, sodass der erhöhte Fall von Hochwasserereignissen in der Region nicht vollständig auf eine Änderung des Niederschlagsregimes zurückzuführen ist.

Die Analyse der veränderten Landbedeckung zeigte, dass es während des Untersuchungszeitraums von 30 Jahren eine deutliche Änderung der Landnutzung und Landbedeckung gab. Während des Zeitraums 1986 bis 2016 erfuhr die Waldfläche die größte Veränderung (49,81 % Rückgang). Außerdem wurde festgestellt, dass die Hauptart der Landumwandlung die Umwandlung von Waldflächen in landwirtschaftliche Flächen ist.

Basierend auf ausgewählten morphologischen Parametern wurde eine Karte mit dem Hochwasserrisiko für das Untersuchungsgebiet entwickelt. Das morphologische Hochwasserrisiko zeigte, dass die meisten Teile des Einzugsgebietes einem moderaten Hochwasserrisiko ausgesetzt sind. Unter den LULC-Bedingungen von 2016 wurden höhere Abflusswerte beobachtet, die hauptsächlich auf die intensive Abholzung im Vergleich zu denen von 1986 und 2003 zurückzuführen sind. Die Ergebnisse deuten darauf hin, dass Abflussmenge sowie höchster Abfluss signifikant von der Abholzung beeinflusst werden und nicht von Veränderungen im Niederschlagsmuster. Überschwemmungskarten des Untersuchungsgebiets wurden für die Hochwasserereignisse von 2012 und 2015 erstellt. Die maximale Tiefe für die Hochwasserereignisse 2012 und 2015 wurde mit 10,58m bzw. 7,39m berechnet.

Die sozioökonomischen Aspekte der Untersuchung wurden mit der Methode der Haushaltsbefragung durchgeführt. Mittels Schneeballverfahren wurden 400 von der Flut betroffene Haushalte ausgewählt. Die Ergebnisse zeigen, dass die Anpassungsfähigkeit der Kleinbauern im Untersuchungsgebiet nach wie vor sehr gering ist und durch verschiedene Faktoren wie Armut und geschwächte soziale Netzwerke erschwert wird. Die Zusammenfassung der untersuchten Variablen führt zu folgender Schlussfolgerung: Statt klimatischer Faktoren - als ein Indikator für Vulnerabilität - sind es die soziale Ungleichheit

und Armut in der Region sowie die strukturellen wirtschaftlichen Unterschiede zwischen verschiedenen Gruppen, welche die Vulnerabilität im Untersuchungsgebiet hauptsächlich antreiben.

Abstract translated from English to German

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## **Chapter 1: Introduction and Conceptual Basis**

### **1.1: Background: Flood in Global Context**

Floods are part of the hydrological cycle and a natural hydrological feature of most river systems (Campion and Venzke, 2013). In recent years, however, flood events have drastically increased both in terms of frequency and severity due to a variety of reasons such as climate change (Liu, et al., 2018) and urbanization (Hollis, 1975; Zhang et al. 2008), hence, flood events are regarded mostly in negative terms. Floods have not just become the most frequent natural hazard worldwide (Jongman, et al., 2012), it appears to be one of the deadliest natural disasters and often kills the most people, for instance, in 2016, flood killed the most people (4731), (Guha-Sapir, et al., 2016).

According to Loster (1999), a ten-year comparative study of the world's great flood disasters from 1950 to 1998 showed a three-fold increase in the number of flood events, while the economic losses from flood events from the 1990's were ten times as high as in the 1950's, amounting to \$250 billion globally. Further, UNISDR (2015) notes that since 1995, floods have accounted for 47% of all weather-related disaster and that flood affects Asia and Africa more than other continents, for example, 560,000 people were affected by floods on average each year between 1995 and 2004.

Di Baldassarre et al. (2010) notes that in the last decades, there has been an increased incidence of severe flooding due to a variety of reasons, however, the capacity of most of the affected parties to anticipate and mitigate flood damages is very poor. While flood affects every part of the society, the most vulnerable groups are usually the indigent (Chan and Parker, 1996) and marginalized who enjoy little protective mechanisms against disasters, especially in the developing nations where the main source of income is agriculture. People can experience the same type of hazards and yet have different degrees of vulnerability as a result of variations in exposure, sensitivity and adaptive capacity. According to Harvey et al. (2014), exposure to floods, for instance, may differ depending on the location of households in relation to floodplains, steep slopes, low-lying areas or ravines and in most cases; poorer households are those that inhabit these high-risk locations.

Disasters do not just disrupt the livelihood of the poor, it leads to the poor incurring severe losses and such losses may take time to recoup. Majority of Sub-Saharan Africa farmers are

mostly dependent on rain-fed agriculture and have limited capacity to mitigate, adapt or cope with the effects of extreme climatic events such as flood which greatly impedes production. Studies such as Adhikari et al. (2014), Elum et al. (2016), Thorlakson and Neufeld (2012) and Hertel and Rosch (2010) have indicated that smallholder farmers are highly vulnerable to climatic extremes such as floods because they generally are the least able to cope with disaster, live in the most at-risk areas and have little resources to help reduce their level of risk.

## **1.2: Problem Statement and Analysis**

For millennia, there have been attempts to understand, assess and predict flood events and impacts, hence, the development and application of flood models and relevant researches have become very popular and indispensable. Since the 1970s, consistent efforts in several flood related disciplines have greatly improved the capacity and capability of flood models.

Globally, there has been a lot of research on different aspects of flood. For instance, in the past three decades, there has been a plethora of research on flood risk, hazard and vulnerability; this includes studies by Kron (2005), Cançado et al. (2008) and Zeleňáková et al. (2015). Other scholars such as Marfai et al. (2015), Lasage et al. (2014) and Jongman, (2018) have focused on adaptation strategies, while others like Mashi et al. (2020), Vinh Hung et al. (2007.) carried out studies on community perception of flood and flood mitigation. In the area of flood hydrology and hydraulics, there have also been a lot of studies on the interrelationship between flooding and other hydrologic parameters such as changes in total runoff (He, et al., 2013), infiltration (Russo, et al., 2012). Further, in the last three decades, many studies such as Tollan (2002) and Apollonio et al. (2016) have paid to attention to gaining deeper insights on the links between increasing changing land use patterns and increased flood events.

Additionally, technological and scientific advancement in recent years have led to improved understanding of contributing factors to flood risks, and as a result, physical and economic measures taken to reduce flood risk and vulnerability. For instance, high-resolution topographic data collected through the Light Detection and Ranging (LiDAR) technology, are now increasingly available and high-resolution LiDAR DEMs are now increasing been used in flood modelling globally.

Despite the global advancement in flood studies and modelling, it is observed that the overall flood situation in the Niger Delta is deteriorating gradually. To date, there have been few studies investigating major contributing factors of current and future flood risks in the country.

Besides, there has been no specific study on the vulnerability of smallholder farmers to flood in the different basins in the Niger Delta. Globally, studies such as Consuegra et al. (1995) on the impacts of flooding on agriculture using GIS techniques are receiving increasing attention in the scientific world, but there has been limited attempt to assess the impacts of extreme flooding on smallholder farmers in the Niger Delta. Based on the above postulations, this section identifies the following gaps in flood risk assessment in the Niger Delta and discusses them as problem statements.

### **1.2.1: Problem Statement: Local Basin Approach**

The river basin has become increasingly accepted as the most appropriate hydro-geomorphic and climatic unit of analyses by many researchers such as Desale (2015), ICRAF (2006), ADB (2016) and Hardy (2005). The rationale stems from the concept of a river as an organic system, where interference with or modification of any part of it will be felt elsewhere in the system (Gordon, et al., 2004). Gregory and Walling (1973) defines a drainage basin as an area that contributes water to a particular channel or sets of channels. Peckham (2003) goes further to describe a river basin as a physical, ecological, biological and climatic entity, where a hydrological balance can be struck when one considers inflow and outflow of moisture and energy. In other words, it provides an essential geomorphic unit for analyzing hydrological input and output.

According to Hardy (2005), hydrological changes, mainly, increasing runoff and flooding in many river basins, have led to the increased investigation of the morphometric characteristics of the drainage basin as a unit of landscape analysis. There is an increasingly significant change in the hydrology (i.e. Channel profile and average annual flow) and climate (i.e. the distribution, characteristics and amount of rainfall) of many river basins. This change is responsible for the seasonal floods that affect the population living within such river basins. This provides a rationale for using the basin area as a case study. Further, Bloschl et al. (2007) argues that scale of analysis is a critical variable in governing watershed hydrological response, while Pattison et al. (2014) notes that land use changes are likely to be more local in impact,

with the magnitude of this impact decreasing with increasing scale. Studies by Viglione et al. (2016) confirm that as catchment scale increases, it becomes more difficult to identify any land use change effects on flood risk from observed discharge data due to multiple controlling factors and process interactions (Figure 1).

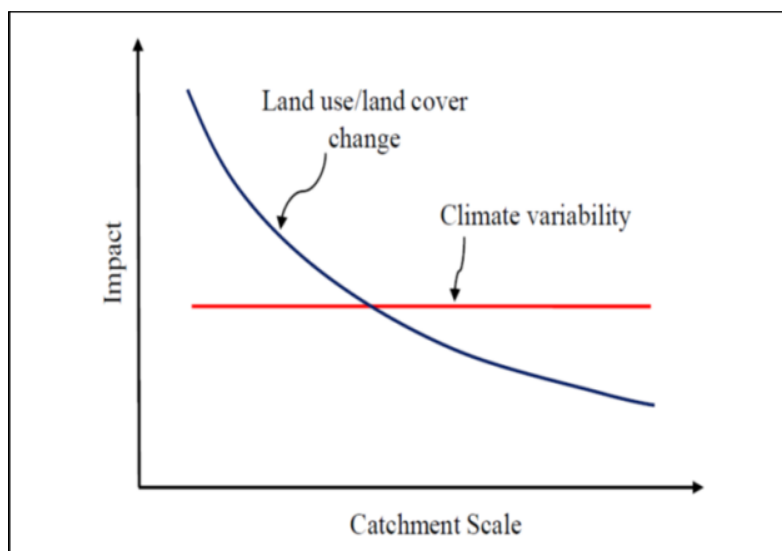


Figure 1: Land use and climate change impact on hydrological response (Shrestha, 2019)

Although some flood studies such as that of Amarnath et al (2015) which used the LISFLOOD-FP model, coupled with a hydrological modelling system, to map flood inundation extent and depth at the Mundeni Aru River Basin in Sri Lanka have been carried out, most developing countries lack baseline data for flood risk assessment at the basin level, as most of the studies are carried out using political boundaries without considering the problem at the river basin scale. Like most developing countries, flood risk mapping and assessment in Nigeria is still rudimentary. Apart from piecemeal approaches on a limited scale, no pragmatic efforts at comprehensive flood risk assessment and hazard mapping have been done at the local basin level. There is, therefore an urgent need to assess the watershed characteristics holistically in order to analyze the hydrological response of watersheds and to develop an understanding of the processes involved in the occurrence of floods in specific locations in the Niger Delta.

### 1.2.2: Problem Statement: Dearth of Studies on Flood in Rural Areas

Although flood event does not discriminate, however, there are spatial dichotomies in terms of the type of risk, economic loss, flood duration, etc. According to Consoer and Milman (2017), the rural-urban distinction is important because rural and urban areas experience climatic

hazards differently, it is, therefore, vital to point out these differences or at least recognize the difference between both classes of settlement. Flood damage evaluation in rural areas, particularly flood damage assessments of agricultural production, are either frequently neglected or measured using simple approaches and rough estimates because the expected losses are typically much lower than those in urban areas (Forster, et al., 2008).

Rural flooding is neglected because the urban areas have higher population densities and a higher assemblage of expensive infrastructure. The WMO (2008) also notes that damages in the rural areas due to floods are mostly direct and mostly involve the loss of agricultural production but in an urban area the damage is very complex. So, in general, priority is given to the urban risk rather than rural risk. However, as Adger et al. (2003) opines, climate change poses the greatest risks to rural populations in the developing world. Flooding is particularly ruinous to agriculture in the rural areas as indigent farmers often incur direct losses in form crop loss or yield reduction due to flooding and associated waterlogging of fields. Although total costs to agriculture were small compared with urban flood costs, they were typically large at the individual farm scale. Such impacts should be properly acknowledged in future strategies for flood risk management (Posthumus, et al., 2009).

In the context of the Niger Delta, rural settlements (less than 5,000 inhabitants) constitute about 94% of the total number of settlements in the Niger Delta; however, because rural settlements are not considered as economic hub or development centres, most of the researches in flood risk assessment in the country have so far been carried out in the urban areas. And although some of these rural areas are prone to flood hazards and are highly influenced by flood events, there is hardly any research on assessing flood risk and vulnerability of the rural areas in the Niger Delta. It is pertinent to note that there is often a greater risk of loss of lives and properties (especially for agricultural crops) in rural areas and most settlements remain cut off from the rest of the country during heavy flood event due to a variety of factors. As established earlier, rural dwellers who have their livelihood grounded in rain-fed agriculture often suffer severe impacts of flood as a result of lack of proper warning system to the rural dwellers, thereby incurring greater damage and cost. This thesis, therefore, focuses on the assessment of the impact of flooding on the rural smallholder farmers.

Despite extensive global research on adaptive capacity and coping strategies of smallholder farmers to flooding, little work has been done so far in the Niger Delta area. Similarly, the

scope of research linking flooding to agriculture is very restricted. To date, studies on flooding and agriculture in the Niger Delta have been mostly limited to the impacts of climate change on particular crops or sectors. Few of the studies considered the farmers' perspectives of the flood and how these farmers cope with floods. Hence, the thesis was designed to fill the existing research gap in the Niger Delta with respect to the perception of farmers to increased flooding events.

This thesis looks at how farmers perceive changes in local climate and also focuses on how farmers adapt their farming in response to perceived changes in climate. Further, this study also considers the factors affecting farm-level coping strategy adopted by farm households in the study area. Most of the factors affecting the farm household's choice of adaptation/coping measures to flooding are already known, but the actual impact of these factors varies across regions, this thesis attempts to unpack and examine the factors that determine the farmer's adaptation/coping strategies.

### **1.3: The Significance of the Research**

The Orashi basin is one of the most vulnerable flood-prone areas in Nigeria. For the local and national government, the management and control of flood hazards in the region have considerable importance. However, due to lack of data, there has not been any detailed study on flooding hazard and risk in the basin. In more developed parts of the world, where data availability and coordination is not a limiting issue, many flood warning systems based on the hydrologic modelling approach have been developed. An example is the European Flood Alert System (EFAS), which runs with the LISFLOOD hydrological rainfall-runoff model (Van Der Knijff, et al., 2008). However, few studies have assessed hydrological impacts due to land use and climate changes in tropical regions; this is mainly due to the paucity of hydrological data in most developing countries for model calibration and validation purposes.

Lately, researchers have used a suite of satellite-based rainfall and geospatial datasets with cost-effective detection methods to assess flood hazards in ungauged regions, but to date, the estimation of current and predicted flood effects is poor in the Orashi basin area. For instance, there is presently no estimate of future catchment responses or effects on lag time, peak discharge or runoff volume found in the literature for this basin. In this regard, for the first time

in the Orashi Basin, a comprehensive approach will investigate the LCLU impacts on the flood occurrence in the basin.

Further, there is generally a low level of knowledge and understanding of how hydrological responses in the basin affect flood events, characteristics and behaviour in the basin. Spatial information on the most probable area of flooding, depth and extent of flood inundation is currently lacking in the area. Studies showing the link between hydrological response and exposure small holder farmers to flood events have also not been carried out in the study area. This calls for an integrated assessment of both hydrological and socio-economic aspects of flood studies in order to provide a sound background for the development of long-term flood adaptation strategies. Globally, integrated assessment of flood risk and hazard are becoming very common, for example, Jha and Gundimeda (2019) assessed vulnerability of flood affected districts in Bihar, India by integrating various indicators for exposure, sensitivity and adaptive capacity into a composite index using principal component analysis; in addition, Tanir et al., 2021 used an integrated vulnerability assessment framework, combining a flood hazard and a comprehensive social vulnerability assessment tool to assess vulnerability and agricultural damages for agricultural populations in the Potomac River Watershed, United States.

This study offers a veritable opportunity for using geospatial technology to demonstrate the interplay and combination of flood causative factors, including dynamics in LULC, drainage, rainfall and morphologic factors to flood risk in Niger Delta using the Orashi as a case study. The result of this research, besides its academic value, will generate essential information for policymakers to deal with flood menace. In addition, the study serves as a guidepost for future research.

There is a growing impression that the flood situation is worsening in the Niger Delta and most parties have attributed and explained this trend by the natural variability of climatic factors. However, an in-depth probe into the literature shows that these positions are not backed up by statistics. In line with the global debate on the causative factors of flooding, there is currently a debate on climate change and its link with the increasing flood frequency in the Niger Delta. Although there are observational evidences showing that the rainfall trend is changing, it is of critical importance to investigate whether the study area has experienced a significant change in precipitation. Hydro-meteorological data will be investigated to detect temporal trends.

Investigating hydro-climatological data will discover or dispute change in trends of climate conditions (rainfall) from past to present.

This study will help establish and deconstruct the interplay between flood causative factors in the Niger Delta using the Orashi Basin as a case study. In addition, the findings of this thesis will have a direct impact on identifying land-use management practices that have contributed to higher peak discharge storm events. The novel aspect of this study lies in the establishment of a direct link between sub-basin scale land-use changes and their contribution to the flood peak at the Orashi basin through semi-distributed rainfall-runoff modelling.

#### **1.4: Research Aim, Objectives and Questions**

##### **Research Aim**

The main aim of this thesis is to investigate the degree of smallholder farmers' vulnerability to floods in the Orashi region of the Niger Delta.

##### **Research Objectives**

- I. To analyze and situate the causative forces of increased flood events in the Orashi Basin
- II. To model the impact of land use and land cover changes on the hydrology of the Orashi Basin
- III. To analyze morphologic and hydrologic properties and evaluate their effects on the hydrologic processes in the catchment
- IV. To identify flood prone areas in the basin
- V. Investigate the adaptive capacity of smallholder farmers and analyze the impact of flooding on smallholder farmers
- VI. Identify and evaluate key historical and contemporary household flood coping strategies
- VII. Examine the major socioeconomic factors that relate to flood vulnerability in the study area

##### **Research Questions**

- I. What are the conditions which influence or precipitate flooding in the study area?
- II. Are there significant changes in precipitation in the Orashi basin?
- III. How has the land cover pattern in the Orashi Basin changed over time?
- IV. What are the driving forces of these land cover changes?
- V. What are the hydrological and morphometric characteristics of the Orashi Basin?
- VI. Which areas are most susceptible to flood conditions?
- VII. What is the level of farmer's capacity to adapt to flooding in the area?



- VIII. How do the smallholder farmers cope with flooding and how sustainable are these coping strategies?
- IX. Is migration trend and propensity in the area related to flooding?
- X. Are there links between poverty and flooding in the context of vulnerability?
- XI. How is poor land use and land right administration related to flood vulnerability in the study area?

### **1.5: Thesis Structure**

The thesis consists of nine chapters. The first chapter provides a background of the research. It also states the significance of the research, the problem statement and study rationale is discussed. Lastly, the study aim, objectives and research questions are stated in this chapter. The second chapter examines the theoretical and conceptual approaches to flood vulnerability. Additionally, the chapter contains the literature review (state of the art). A brief overview of the Niger Delta and a background of the study are given in this chapter. It also briefly discusses the state of smallholder farmers in context of flood in the study area.

Chapter three broadly discusses the major causative factors of increased flooding. The fourth chapter gives an in-depth account of the methodological approach used in the analysis of causal factors, namely, rainfall, land cover and morphometry. It also focuses on the methodology employed in the analysis of socioeconomic parameters such as adaptive capacity, coping strategies, migration forces, poverty, and land rights, among others.

The fifth chapter focuses on the results and discussion of rainfall characteristics and trend. Chapter six deals with analyzing the spatial and temporal change of land cover in the study area. The seventh chapter analyses and discusses morphometric flood risk of the study area. The Eighth chapter examines the socioeconomic characteristics of the smallholder farmer and discusses their adaptive capacity in the context of flooding. The chapter also focuses on discussing the nexus between poverty and flood in the study area. It briefly touches on how the respondents perceive the flood burden and examine the migration propensity of the farmers in the study area in relation to flood events in the area. The final chapter provides the conclusion and a synopsis of the research. Final recommendations are made in this chapter.



## **Chapter 2: Conceptual Overview**

### **2.1: Contextual Clarification**

#### **2.1.1: Vulnerability and Adaptive Capacity Concept**

The vulnerability concept has become a keystone of hazard studies and human environmental research. According to Smit and Ford (2004), the concept evolved from various research fields, including risk assessment and natural hazards, food security, national security and environmental change. Birkmann (2013) advises that assessing vulnerability in the context of natural hazards and climate change requires first and foremost a clear understanding of the concept(s) of vulnerability. Vulnerability has been conceptualized and interpreted in many different ways depending on the purpose and direction of the researcher. The concept has extensively been discussed and used in hazard research and other disciplines, and there is a plethora of definitions by different authors (see Table 1).

Generally, the vulnerability concept emphasizes how certain elements or groups of people are exposed to hazards, to what degree they are affected by the hazards, and how they can cope with and recover from the hazardous impacts (Dewan, 2013). Pelling (1997) states that “Vulnerability is determined by a household’s resource characteristics (economic, political, social, demographic, psychological and environmental) and, in this case, their appropriateness in reducing the likelihood of living space being flooded and the scale and distribution of impacts should flooding occur”. According to Few (2003), vulnerability should not only be seen just as a product of physical location but also as a social product. Cannon (2000) argues the vulnerability concept should be treated as a condition of people that derives from their political-economic position. He notes further that it is ‘misleading’ to use the term loosely or limit it as a characteristic of exposure to hazards alone, since this allows the key components of power and income distribution to be played down and prominence given to technical fixes.

As can be denoted from the definitions, vulnerability is a function of three variables: namely, exposure, sensitivity and adaptive capacity. The concept of vulnerability cannot adequately be characterized without simultaneously considering its associated component “adaptive capacity”. Vulnerability is largely determined by adaptive capacity. The concept of adaptive capacity has been used differently in varying contexts. For instance, IPCC (2001) defined

adaptive capacity “as the ability of a certain system, region, or community to adapt to the impacts of climate change”.

Table 1: Definitions of Vulnerability

Author(s)	Definitions
<b>(Cannon, 1994)</b>	People’s condition and their social, political economic behaviors in the face of risks provides different degrees of vulnerability
<b>(Turner, et al., 2003)</b>	Vulnerability is the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress/stressors.
<b>(Wisner, et al., 2004)</b>	The characteristics of an individual or a group of people and their conditions that affect their ability to predict, tackling, struggle and recover from the effects of environmental threats
<b>(UNISDR, 2009)</b>	The characteristics and circumstances of a community system or asset that make it susceptible to the damaging effects of a hazard
<b>(Adger, 2006)</b>	Susceptibility to harm from exposures to pressures related with environmental and social changes and in lack of adaptation ability
<b>(Naess, 2006)</b>	A function of exposure, sensitivity, and adaptive capacity, generated by multiple factors and processes

IPCC (2012) also defines adaptive capacity as “the combination of available personal, community and societal strengths, attributes and resources harnessed to adjust to the surrounding’s changing circumstances, reduce adverse impacts, and take advantage of opportunities” On their part, Brooks and Adger (2005) describe adaptive capacity as “the property of a system to adjust its characteristics or behaviours, in order to expand its coping range under existing climate variability, or future climate conditions”. Engle (2011) argues that a system’s adaptive capacity influences the ultimate potential for implementing sustainable adaptations. Adaptive capacity varies between different contexts and systems, and it is not equally distributed (Smith and Wandel, 2006; Adger et al., 2007), therefore, it is important to identify what builds adaptive capacity or, similarly, what functions as barriers or limits to adaptations (Adger, et al., 2009). According to CARE (2009), the most important factors shaping the adaptive capacity of individuals, households and communities is their access to and control over natural, human, social, physical, and financial resources. The postulations

above clearly show that adaptive capacity of a society is influenced by the nature of its institutions and the natural systems on which it relies (Berkes, et al., 2003).

### **2.1.2: Coping strategies**

This thesis distinguishes between two types of household responses to flood events: “coping” and “adaptation.” Many studies use these terms synonymously. However, van der Geest and Dietz (2004) argue that this is problematic because both concepts involve different types of responses to different types of stresses. According to IPCC (2012), “Coping capacity refers to the ability of people, organizations, and systems to face, mitigate, and overcome adverse conditions, using available resources, abilities, and opportunities to achieve basic functions in the short to medium term”. Coping strategies are short-term responses to the impacts of sudden or unusual events. By contrast, adaptation refers to longer-term adjustments to more permanent changes in the climate (Smit and Wandel, 2006; Berman et al. 2012; van der Geest and Warner, 2015)

Vulnerability cannot be assessed without considering the capacity of a community to cope with the impacts of a hazardous event. Coping is as important as adaptation strategies to reduce the intensity of shocks following any sudden natural disaster especially, in the short run. Over time, smallholder farmers have developed various coping mechanisms that offer a buffer against climatic extremes such as flood events.

Farmers’ response to flood or their choice of coping strategies is dictated by a host of socioeconomic and environmental factors, such as education, income, perception, etc. It is important to analyze and document such strategies, to comprehend the determinants of farmers’ choices and to identify policies that can promote coping strategies as an initial step in the adoption of more robust adaptation strategies against flood events. In the Niger Delta, only a small amount of empirical research has been done towards the understanding of farmers’ coping strategies and their adaptive capacity or their motive and willingness to act or not to act in response to increased flood events.

This thesis explores smallholder farmers’ adaptive capacity and driving factors that determines their response to flood events. In addition, this thesis enriches the literature by highlighting the role of coping measures used by the households to lessen flood burden. Understanding existing farm-level coping strategies and farmers’ perceptions of possible future adaptation strategies

provide vital input for the formulation of additional coping initiatives and fortifies farmers' social learning to handle future climate risks (Mengistu, 2011).

### **2.1.3: Flood Risk**

There is a multiplicity of definition for risk in the literature. The UNISDR (2015) defines risk as “the combination of the probability of an event and its negative consequences. Shabman and Scodari (2014) defines flood risk as “The likelihood and adverse consequences of flooding” They note further that flood risk for assets and people at any location in a floodplain is a function of flood hazard at that location and their exposure and vulnerability to the flood hazard. Merz et al. (2007) defines flood risk as “The probability that floods of a given intensity and a given loss will occur in a certain area within a specified time period” suggesting that risk results from the interaction of hazard and vulnerability. Despite the multiplicity of definitions in the literature, the concept of risk as a function or a combination of “hazard” and “vulnerability” seems to be the most accepted (WBGU, 1999; Birkmann, 2007; Ouma and Tateishi, 2014).

## **2.2: Smallholder Farmers in Local and Global Context**

Smallholder agriculture is used generally to describe rural producers (Netting, 1995), who farm using mainly family labour and for whom the farm provides the principal source of income (Cornish, 1998). Farming systems in most of these low-income countries are characterized by smallholder farmers who farm plots of 3 hectares or less (IFAD, 2009). Caxton et al. (2013) notes that such farms are generally small and are often held under traditional or informal tenure, and are mostly located in marginal or risk-prone environments. Further, Niles and Brown (2017) notes that small holder farming is often typified by limited resource endowments, minimal education, training, and finance to enable the adoption of new technology. Smallholder farmers depend on family labour, including the extended family for their agricultural activities. In light of the challenges enunciated above, Africa's smallholder farmers are often described as ‘resource-poor’ (Mignouna, et al., 2008).

Worldwide, the population of smallholder farmers is estimated to be about 450 to 500 million, which accounts for 85% of the world's farms (Harvey et al., 2014). In Asia and sub-Saharan African smallholder farmers produce up to 80% of the food consumed and support up to two billion people (IFAD, 2009). Smallholder farmers also represent about half of the hungry in

the world and close to three-quarters of the hungry in Africa. Further, out of the 2.5 billion people in poor countries living directly from the food and agriculture sector, 1.5 billion people live in smallholder households (IFAD, 2013).

It is evident that smallholders' farmers have vital roles to play in achieving food security in developing countries and are essential players in the quest toward food sufficiency in sub-Saharan Africa and meeting the global MDG of hunger-reduction. However, as Harvey et.al (2014) notes, smallholder farmers in Sub-Saharan Africa are already facing numerous risks to their agricultural production, including pest and disease outbreaks and market shocks, among others, which often undermine their household food and income security. Additional shocks in the form of extreme weather events will worsen an already perilous situation. Increases in the frequency and severity of floods often lead to poor yields and crop failure. Since most of the smallholder farmers depend on rain-fed agriculture and are sensitive to climatic vagaries (Parry, et al., 1998), flood event directly affects agricultural output and low agricultural yields invariably threaten not just food security, but the wellbeing of smallholder farmers as well (Morton, 2007).

The agricultural sector is the most important non-oil economic activity in the country. According to NBS (2009), about 70% of the labour force is engaged in some form of agriculture, making it the highest employer of labour. Agriculture also contributes a significant proportion of the Gross Domestic Product (GDP) (about 40.07 in 2010). More than 90% of the Agriculture output is accounted for by small-scale farmers with less than two (2) hectares typically in fragmented plots. An estimated 65% of the population resides in rural areas where agriculture is the predominant occupation. It is estimated that about 85% of the rural population are engaged in agriculture. The traditional system of agricultural production still predominates, with its characteristically low technological base, high reliance on manual labor, and hence low resource productivity. The market systems are usually traditionally based. There is a heavy dependence on natural weather patterns and climate cycles for productivity, as a result, seasonal and annual fluctuations in agricultural outputs are common (Amaza, et al., 2010).

The major factors responsible for low productivity include reliance on traditional farming techniques; soil degradation caused by overgrazing and deforestation; poor complementary services such as extension, credit, marketing and infrastructure; and climatic factors such as droughts and floods. These factors reduce the adaptive capacity or increase the vulnerability of

farmers to future changes in climate and negatively affect the performance of the already weak agricultural production.

### **2:3: The Niger Delta Area and the Risk of Flooding - an Overview**

The Niger Delta faces some notable environmental challenges such as pollution from oil and gas production activities, the deforestation and the ever-growing risk of chemical and pesticides use in agriculture and fish farming, river and coastal erosion, flooding, saline intrusion, buoyant pollutant transport (e.g. oil spill or water hyacinth). However, the major challenge common in the area is severe flooding. According to Abam (2009), the major precipitants of ecological problems in the Niger Delta derive from the surface water dynamics. Flooding has always been part of the natural development of the Niger Delta because of the relatively low, flat, and poorly drained terrain whose elevations does not exceed 30m inland and 8m at the coast above sea level (Okagbue, 1989; Abam, 1999).

In the Niger Delta, flood hampers agricultural development and severely affects the livelihoods of residents of this region. Recent studies have pointed out the severity of increased flood frequency and intensity in the Niger Delta. Flooding in the Niger Delta is mainly seasonal and is mainly induced by rainfall during the rainy season. The study area is typically rural catchment that is characterized by different land use types, the majority of which is agricultural land use. The lowland areas of the basin (delta area) are one of the most fertile areas in the country, partially due to humus soil as a result of flooding during the wet season. However, major flood events such as those of 2012 and 2015 still negatively affect those areas through inundation extents that adversely affect agricultural lands.



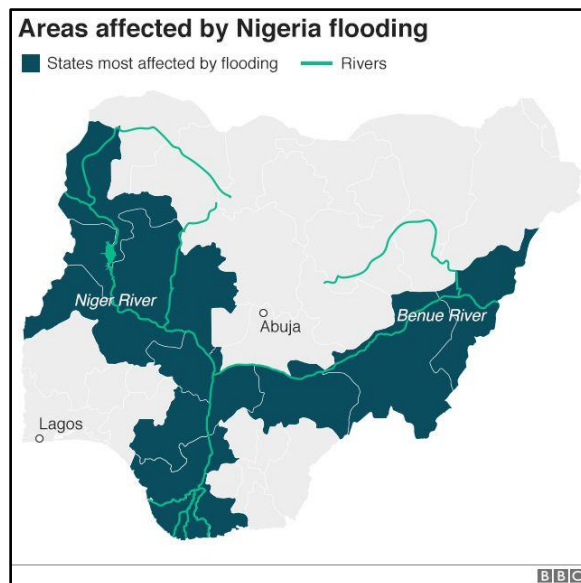


Figure 2: Flood mapping within Nigeria Left (British Broadcasting Corporation, 2018)

Niger Delta region of Nigeria lies between latitudes  $4^{\circ}$  and  $6^{\circ}$  north of the Equator and  $4^{\circ}$  and  $8^{\circ}$  east of the Greenwich meridian (Okonkwo and Etemire, 2017). According to Abam (2001), the Niger Delta is situated in the coastal sedimentary basin area of Southern Nigeria (Figure 4). It covers an area of  $36,270 \text{ km}^2$  (Abam, 1999), constituting roughly 3.9% of the land area of Nigeria. The Niger Delta occupies half of the country's shoreline (Sexton and Murday, 1994). It has a convex shoreline stretching for about  $350 \text{ km}^2$  from the coastal boundary of Ondo State to the boundary of Cross River State. The Niger Delta region is a low-lying area consisting of several tributaries of the Niger River and ending at the edge of the Atlantic Ocean (Musa, et al., 2014). It is a large area of a floodplain which is built up as a result of deposition and accumulation of sediments washed down for over about 100 million years from the Benue and Niger Rivers (Lindén and Pålsson, 2013). Being one of the most dynamic deltas in the world, it is known for its sandy coastal ridge barriers, brackish or saline mangroves, freshwater, permanent and seasonal swamp forests as well as lowland rainforest (Olowu, 2010). The Niger delta supports one of the world's most extensive wetlands. It is the largest wetland in Africa and the third-largest in the world (Akpan, 2005), after the Netherlands and Mississippi Delta. It is a classic arcuate delta, typically below the 15-metre contour across its entire extent and it is characterized by extensive interconnectivity of creeks, deltaic tributaries, flood plains, mangrove swamps and other coastal features (Moffat and Linden, 1995; Olawoyin, 2013; Abam, 2016).

The hydrology of the Niger Delta is dependent primarily on the River Niger (Inger, et al., 2005) which rises from Guinea highlands (Fouta Djallon) (Figure 3) and flows over a distance of 4,200 km (Gleick, 2000) draining parts of Guinea, Mali, Niger and Nigeria and discharging its waters and sediments into the Gulf of Guinea of the Atlantic Ocean. Kravtsova et al. (2008) notes that the Niger River is mainly rain-fed and rains carried with the southeast monsoons make the greatest contribution to water replenishment of the River Niger.

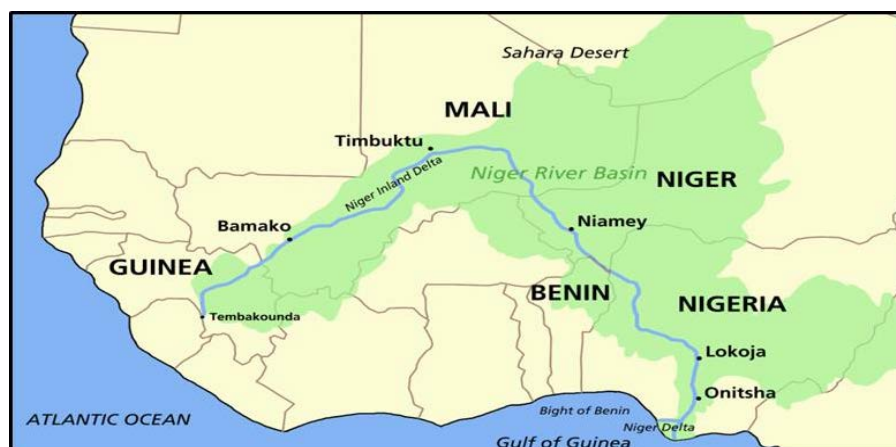


Figure 3: Map of the River Niger (Geography, 2018)<sup>1</sup>

The region has recorded severe perennial floods that affected people and livelihood with the 2012 and 2015 flood being the most destructive in recent times. The region is also characterized by poverty and underdevelopment which generally limits their adaptive capacity to floods. The Niger Delta is also the main centre of oil production activity and therefore the center of Nigeria's economy, accounting for more than eighty per cent of government revenue.

#### 2.4: Background on Case Study Area (Orashi Basin)

The region lies in the southern fringe of the tropical rainforest belt. The Orashi area lies between latitudes 50° 45" and 60° 35" N and longitudes 40° 50" and 50° 15" E (Figure 5). The Orashi basin is generally ungauged (Aisuebeogun, et al., 2014). It is made up of about 7 basins (Figure 6). The Orashi region is estimated to be about 2500 km<sup>2</sup> in size. In terms of population, in 1991, its population was 225,613 with a population density of 411.03 persons per square km. The population rose to 531,642 in 2006 with a population density of 1,044 persons per square km; and a total of 112,208 regular households. The region's population was projected

<sup>1</sup> Unless otherwise stated, uncited images in this thesis are original works of the author.

to be 609,093 persons in 2010 (Arokoyu and Ukpere, 2014). Majority of the inhabitants of the basins are engaged in primary activities such as farming, fishing, quarrying (fine sand, gravels), timber lumbering, oil palm milling and local gin production. The following section provides a brief background of the study area.

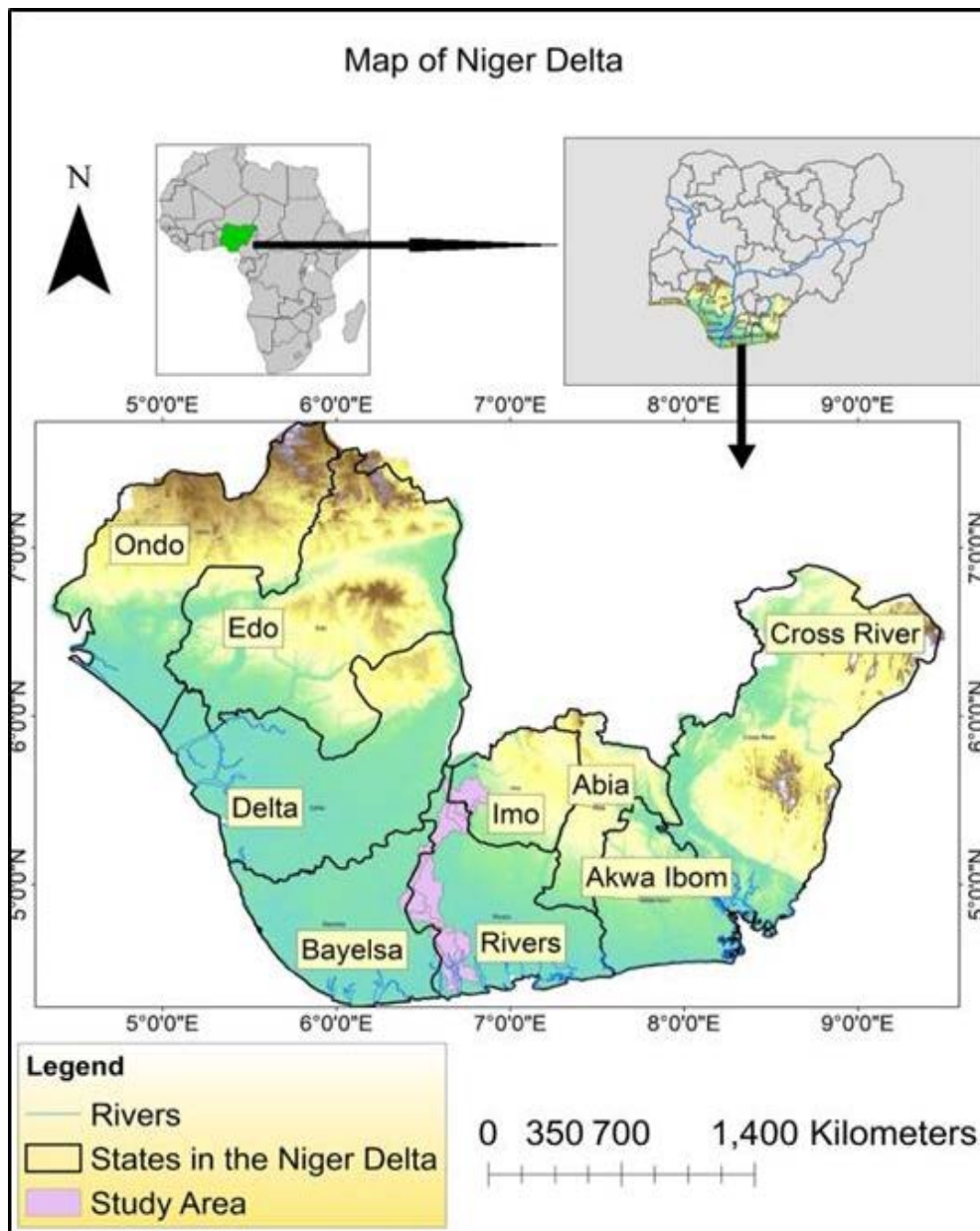


Figure 4: Map showing the Niger Delta Area

**Hydrology:** The larger Orashi River Basin System stretches from Ndoni-Onelga (where the Orashi River starts) to the sea via Abonnema- Asalga (Arokoyu and Ukpere, 2014). The

catchment area comprises the drainage area of the River Orashi upstream of the Reserve. The Orashi province is not a very coastline, but a deltaic region, crisscrossed by several small rivers known as creeks which make the area susceptible to flood hazards (Mmom and Aifesehi, 2013). The Basin is primarily a rural area; however, there are major urban settlements in the Orashi Basin which, includes, Mbiama, Agbo, Akiogbologbo, Okaki and Okparaki. Orashi River has acted as age long trade and cultural passageway providing transportation and transportation route for indigenous population moving from one town to another by canoe, for money making ventures carrying farm produce for markets along its course (Igwe and Wordu, 2016).

**Climate:** The climate lies within the Koppen's Af zone (i.e. humid tropical rain forest). The area is characterized by high rainfall amount almost throughout the year; however, between December and February, there is a dry spell when the northeast trade wind blowing over the Sahara Desert extends its dehydrating influence progressively towards the equator, reaching the southern coast of Nigeria in late December or early January. The period is known as the "Harmattan", which is more noticeable in some years than others (NDDC, 2006). Mean annual rainfall is 2435.7 mm with a bimodal distribution (Figure 8).

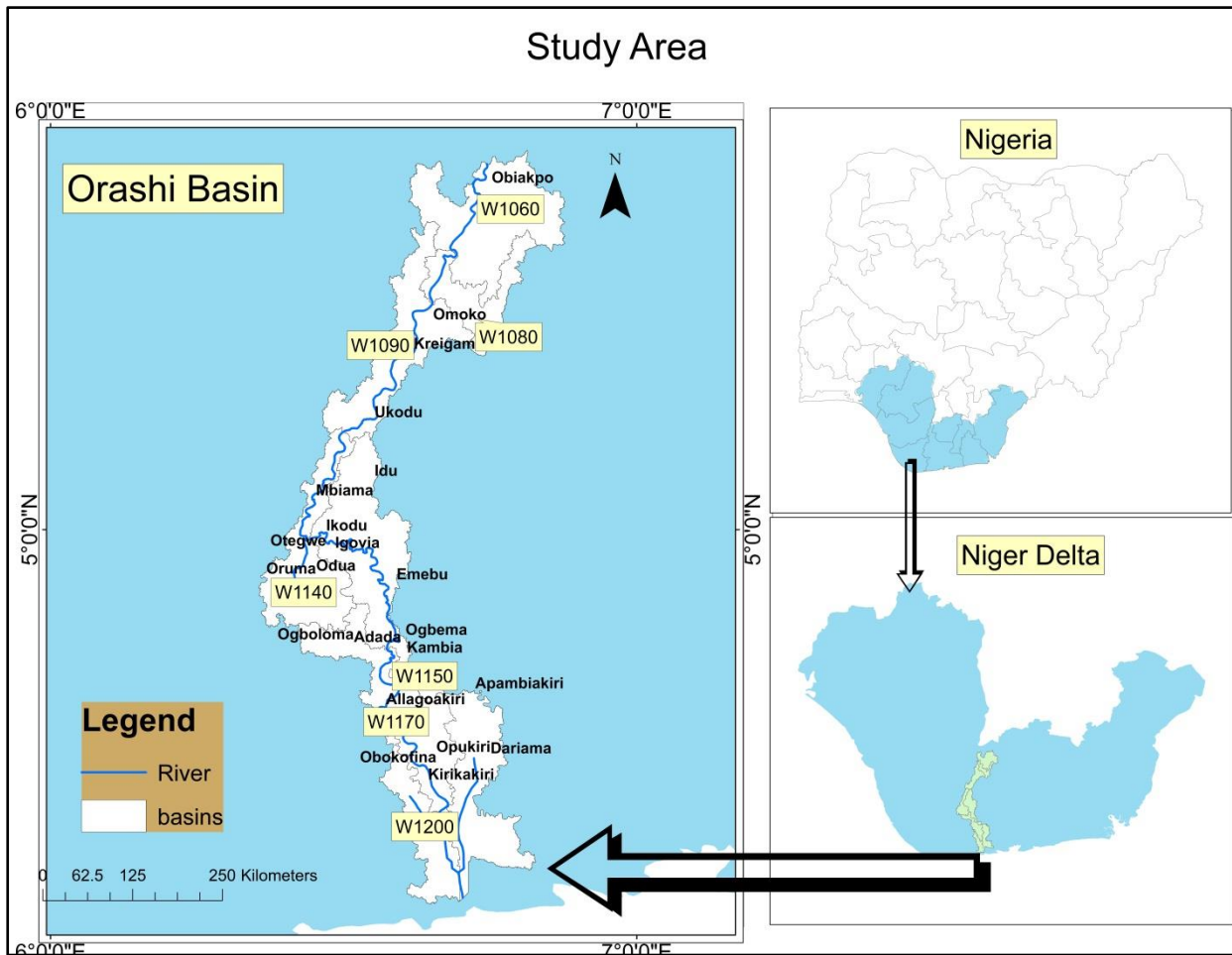


Figure 5: Map of the Orashi study area

The peaks are in July (346.8mm) and September (353mm) separated by a short break around August, otherwise termed the "August break with an average precipitation of 300.1 mm. The Orashi basin like most areas in the Niger Delta is a place of uniform high temperature throughout the year, mean temperatures range from 24°C in August to 27°C in April. Relative humidity is high (85%) (Afa, 2013), throughout the year.

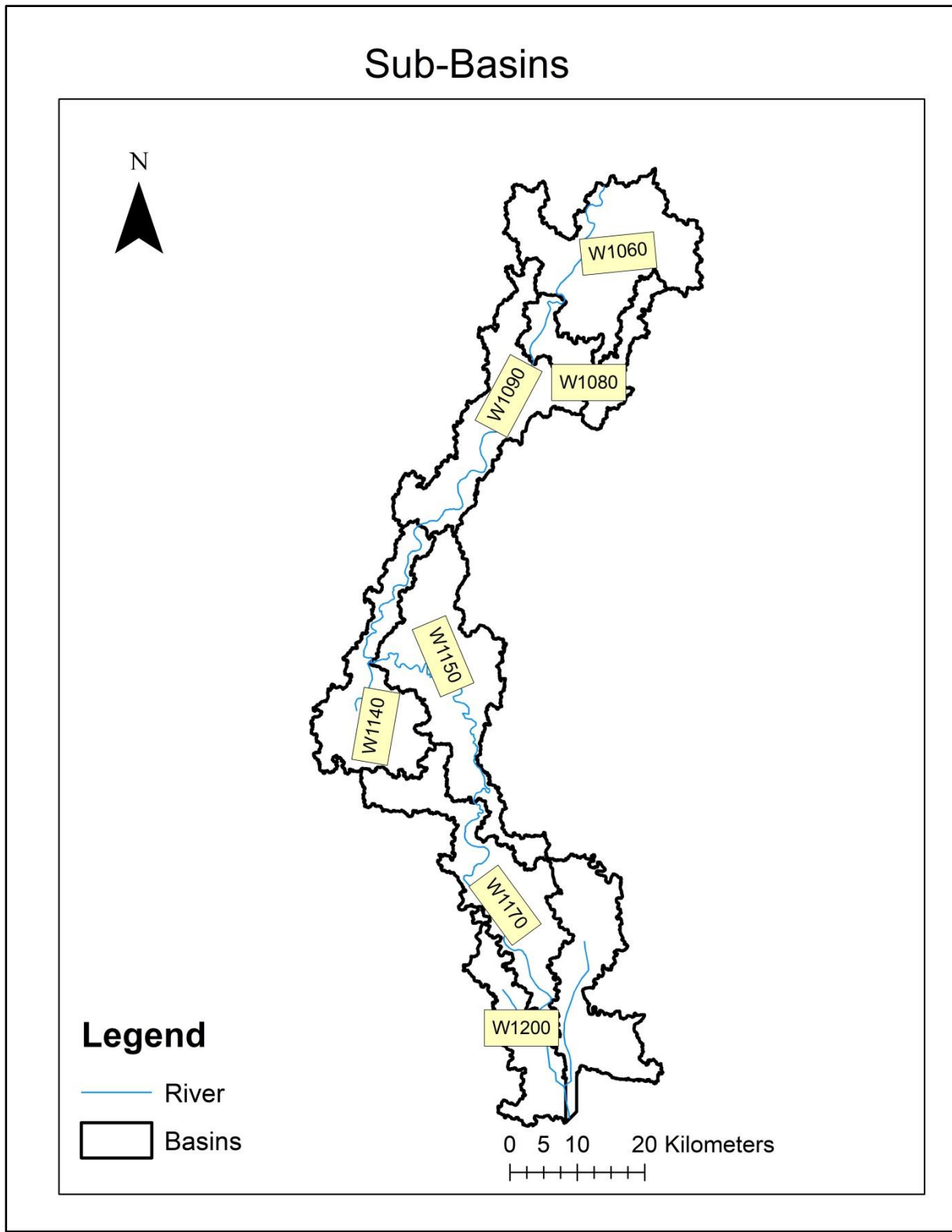


Figure 6: Sub-basins in the study area



Figure 7: One of the numerous streams in the study area

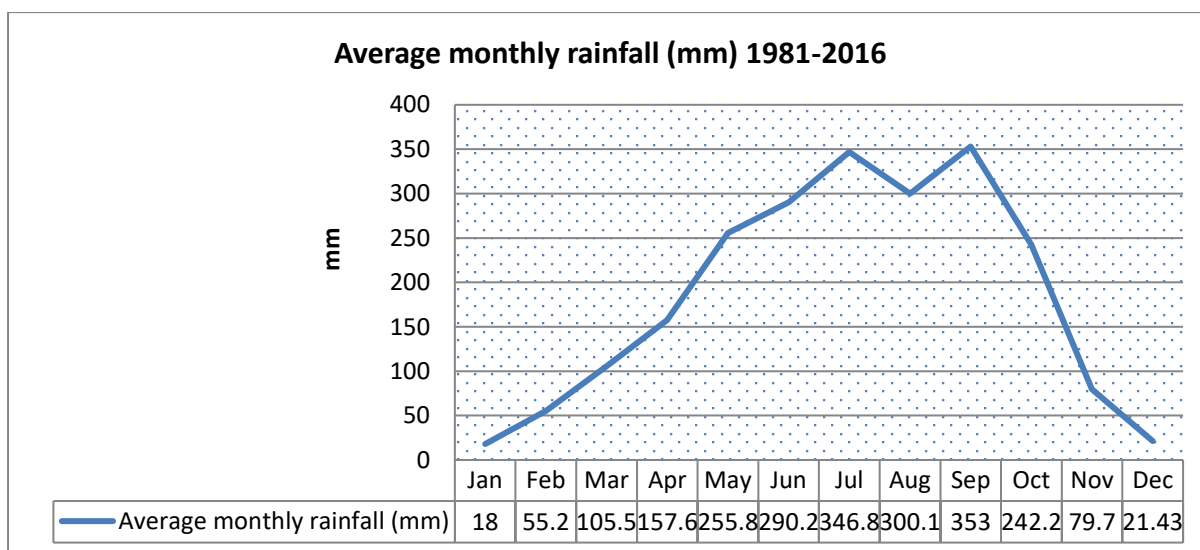


Figure 8: Average monthly rainfall in the Niger Delta 1972-2016 (NIMET, 2016)

**Vegetation:** The vegetation is freshwater swamp forest associated with the Niger Delta wetland ecosystem where waterlogging and annual periodic flooding during the rainy season help maintain the fertility of the soil that supports the vegetation (NDES, 1998). Typical plant species are *Raphia hookeri*, *Mitragyna ciliate*, *Elaeis guineensis*, *Khaya ivorensis*, *Lophira alata*, and *Sterculia oblonga*.



**Settlement pattern:** According to Amangabara and Obenade (2015), “the settlement pattern in the Niger Delta Region is largely influenced by the availability of dry land and the nature of the terrain. Low relief and poor ground drainage are the primary factors responsible for the low number of large settlements in the region”. The larger settlements are found in the interior parts of the Delta, with better drainage conditions and accessibility. Given the fact that the mangrove swamp zone is a massive swamp with scattered islands, the population is sparsely distributed.



Figure 9: Images depicting examples of flora in the study area

**Economic activities:** The traditional economic activities of the communities fall into two main categories (NNDC 2006). Land-based type on the drier parts, which includes farming, fishing, collecting, processing palm fruits, as well as hunting and water-based type of economy mainly fishing and trading. Over 70% of the people of the area are engaged in primary activities such as farming, fishing, quarrying (fine sand, gravels), timber lumbering, oil palm milling and local gin production. Agriculture is the main sustainer of the rural economics of the area. The area possesses over 35% of the oil wells in the Niger Delta, so oil exploration is a major economic activity.

**Geology and soil type:** It is a low lying region and has an almost flat monotonous low relief interspersed by several wetlands (Ellah, 1995). Its hydro-geologic profile is characterized by



alluvial sedimentary strata composed chiefly by poorly leached loosed porous sandy to fertile loamy soils. These soils are mostly made up of clayey to sandy-clay (Arokoyu and Ukpere 2014).

## **2.5: State of the Art**

Although there is a paucity of studies on flood and its impacts in the Niger Delta, but there have been some significant studies such as that by Ologunorisa (2004), who carried out an assessment of flood vulnerability zones in the Niger Delta region by using a hydrological technique based on some measurable physical characteristics of flooding and vulnerability factors. Based on these factors, 18 settlements randomly selected across the three ecological zones in the region were assessed. The flood vulnerability assessment was achieved in two stages. The first step involves the identification of the most important environmental parameters (that is hazard and vulnerability indices) influencing flood risk. The second stage involves the quantitative rating and assessment of the environmental parameters (hazard and vulnerability factors) in the selected settlements for flood risk mapping based on the rating scales devised in this study. The study concluded by noting that that the coastal areas of the Niger Delta do not experience severe flooding because they are under tidal influence. Tidal floods have a short duration, and are less severe and therefore of low risk. Ologunorisa and Adeyemo (2005) using simple statistics undertook a study to understand how floodplain dwellers regard the risk of flooding in the Niger Delta in General. The results of their study revealed that the population regards heavy and prolonged rainfall and river overflow as the most important causes of floods. Prekeyi et al (2015), in their study selected settlements affected by flood events and evaluated the effects of the floodwaters. A study by Bariweni et al. (2012) emphasized on providing the desired knowledge needed for the effective management of flooding in the Niger Delta region of Nigeria.

## **Chapter 3: Background: Causative Factors of Increased Flood Events**

Flooding is a natural phenomenon which cannot be entirely prevented and has an important role in the natural environment. However, in recent decades, the frequency, magnitude and associated deleterious impacts of flood events are showing an increasing trend. The increasing trend in flood frequency and severity has been attributed to several natural and anthropogenic factors (Kundzewicz, 2003; Bates et al. 2008), often acting in combination rather than individually. Different authors have cited different causative factor, depending on different factors. Balica (2007) notes that flood disasters are precipitated by either natural factors, such as climate change and climate variability or anthropogenic factors, such as socioeconomic and land-use developments. According to the EEA (2001), the main driving forces behind flood are “climate change, land-sealing, changes in catchment and floodplain land-use, population growth, urbanization and increasing settlement, roads and railways and hydraulic engineering measures”. Further, according to Youssef et al. (2009), topography, geomorphology, drainage, rainfall intensity and duration, evaporation and infiltration, and environmental and human processes are the main factors in determining flash flood hazards.

Clearly, the causes of flooding are highly variable and a complex set of factors influences whether or not flooding occurs in a catchment. Each of these factors also impacts the other significantly, and their complex relationship determines the probability and degree of flood events. To comprehend flood risk in an area, a good grasp of the interaction between these factors is mandatory (Kia et al, 2012). However, we are limited by the data we can use to assess flood risk. As noted above, these data may not always be available, may not be ready to use, or the quality of the data may vary significantly. As a result of dearth of data, analysis of the causative factors in this thesis is limited to precipitation, land use and terrain characteristics.

### **3.1: Causative Factor: Precipitation**

Precipitation is one of the most influential and critical variables of climate and hydrological studies (Charlton et al., 2006; Ramesh and Teegavarapu, 2013; Ren et al. 2017) and changes in precipitation levels are often considered as one of the primary signals of climate change (McVicar, et al., 2007). Although floods have a variety of causes, however, as Middelmann et al. (2000) suggest, they are mostly triggered and influenced by precipitation factors such as the total amount of rainfall falling over the catchment; the geographical spread and concentration of rainfall over the catchment, i.e. the spatial variation; rainfall intensity and duration. Several

studies such as those of Biniyam and Kemal (2017), Wan et al. (2017), Charlton et al. (2006) and Nied et al. (2013) have established the causal relationship between precipitation and flooding. De Risi (2013) notes that the triggering of a flooding event is determined by the amount of prior rainfall and Adnan and Atkinson (2011) also states that more intense precipitation may lead to increases in flood peaks and may subsequently cause increases in the extent of flood inundation. Rainfall and runoff have a complex relationship as indicated by the hydrological or water cycle. Normally, rainfall infiltrates into the upper layers of soil and rock and only tiny amounts of water runs off in the catchment, however, continuing rain may lead to saturation of the surface soil layers; and as a result, the volume of water will eventually exceed the amount that can be absorbed, this leads to overland flow (Simonović, 2012), (Figure 10).

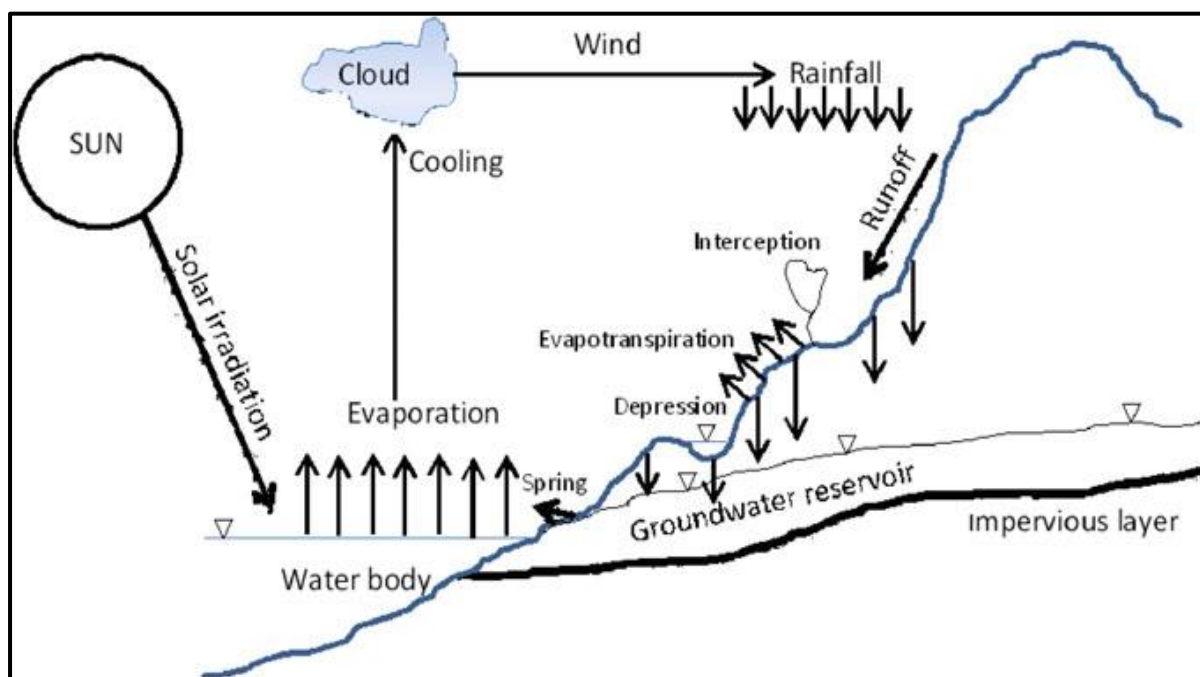


Figure 10: Hydrological cycle components (Source: Sen, 2015)

### 3.2: Causative factor: Land-use Change

Land use is characterized by “the total of arrangements, activities, and inputs undertaken in a certain land cover type (a set of human actions) to produce, change or maintain it” (FAO, 1999). Studies such as Foresman et al. (1997) and Naqvi et al. (2014) have recognized Anthropogenic factors as the driving forces behind the degree and direction of change upon the earth’s surface (Although anthropogenic-induced land cover change and modifications have been going on for

millennia, however, current rates, extents and intensities of land use/land cover change are far greater than ever in human history, causing unprecedented perturbation in environmental processes at different spatial scales (Zhu, et al., 2012). Globally, the influence of land-use changes on flood risk is now a central feature of flood-management discussions (APFM, 2016). According to Taofik et al. (2017) the hydrological response of a drainage basin (described as the conversion capability of rainfall to runoff) is mainly governed by the basin morphometric properties, soil characteristics and land use pattern, while Ajibade et al.(2010) notes that land use pattern has effects on interception whereas morphometry decides the distribution of runoff excess

Several studies have been carried out to understand the relationship between land-use changes, hydrological responses and flood events (Ramesh, 2013). Various studies such as Alexakis et al. (2014), Wang et al. (2014) and Thanapakpawin et al. (2007) have established that land cover plays a key role in controlling the hydrologic response of watersheds in a number of important ways, such as, leaf area index and evapotranspiration (Mao and Cherkauer, 2009), soil moisture content and infiltration capacity (Fu, et al., 2000), surface and subsurface flow regimes including base-flow contributions to streams and recharge (Tu, 2009), surface roughness, (Feddema, et al., 2005) runoff (Selby, 1972, Burch, et al., 1987) as well as soil erosion through complex interactions among vegetation, soils, geology, terrain and climate processes (Nejadhashemi, et al., 2011). According to Dwarakish and Ganasri (2015), water and energy balances are significantly influenced by land cover pattern via its effect on transpiration, interception, evaporation and infiltration. There are several other studies that show that changes in land use have influenced the hydrological regime of various river basins (Van et al. 2012; Getahun and Van Lanen, 2015; Pervez and Henebry, 2015; Chithra et al. 2015).

In addition, Pati (2014) argues that vegetation plays an important role in infiltration and slows the movement of runoff, allowing more time for water to seep into the ground. The surface soil layer in a forest or a pasture generally has greater infiltration capacity than a compacted soil surface and changes in land cover from woodland to agricultural land also lower the infiltration rate of the soil. Conversion of forest, to agricultural areas usually comes with a vast increase in impervious surface, which can alter the natural hydrologic condition within a watershed. Agricultural expansion has been confirmed to increase the rate of runoff (Kwaad and Mulligan, 1991; Martyn et al. 2000; Clements and Donaldson, 2002) due to soil compaction and

associated reductions in soil infiltration capacity. Figure 11 depicts infiltration process of compacted and non-compacted soils.

Urbanization leads to significant changes in surface cover, which influence the hydrological properties of an area. According to Zabret and Šraj (2015) urbanization reduces the infiltration of precipitation into the soil, so that both surface water runoff and the velocity at which water travels increases drastically which eventually lead to larger and more frequent incidents of local flooding.

Furthermore, flood hydrology of watershed shows an intimate relationship with land-use. Land use change potentially has a very strong effect on floods as humans have heavily modified natural landscapes (Rogger, et al., 2017), therefore, any changes in the land use, such as urbanization across a catchment area, may trigger a sequence of flood occurrences. As the watershed becomes more developed, it also becomes hydrologically more active, changing the flood volume, runoff components as well as the origin of streamflow. In turn, floods that once occurred infrequently during pre-development periods have now become more frequent and more severe due to the transformation of watershed from one land use to another (Coutu and Vega, 2007). O'Connell et al. (2007) notes that, in the context of land-use changes, “flooding is generated when landscape runoff delivered to the channel network exceeds its capacity to convey runoff to the catchment outfall, leading to the inundation of rural and/or urban riparian/floodplain areas”. Additionally, Bruijnzeel (1993) notes that it is the shift from subsurface flow to overland flow dominated storm-flows, which often accompanies land clearing due to effects of soil compaction and burning that produces strongly increased peak flows.

According to DER (1999), urban development changes hydrological regime, resulting in a new annual and seasonal hydrologic balance, causing frequency distribution changes of peak flows, magnitude and duration of high flows, and magnitude and duration of low flows. Further, development, depending on its size and location in a watershed, alters the existing hydrologic balance by increasing surface flow volumes up to 43%, reducing subsurface flows to 32%, and reducing evapotranspiration rates to 25% (DER, 1999). This results in major changes to the local hydrology. An increased stream flows due to changes in surface topography result in more rapid drainage and increases in the amount of hydrologically active areas within a watershed. (DER, 1999).

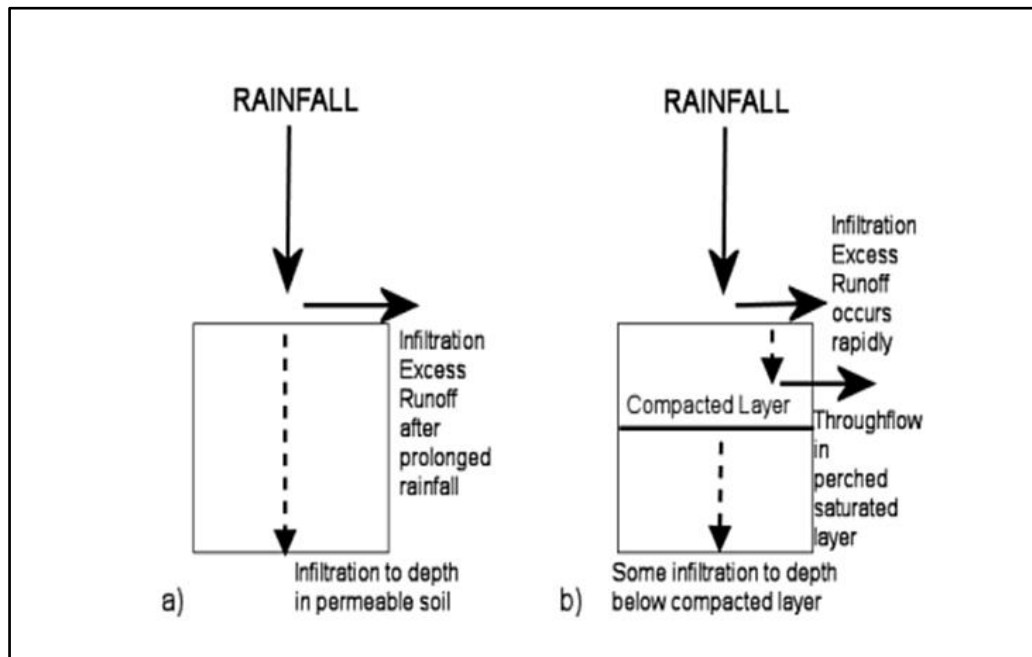


Figure 11: Schematic showing the effects of compaction on soil infiltration a) shows infiltration process in non-compacted soil while b) shows infiltration process in compacted soils (Pattison and Lane, 2011).

These areas also increase in size, in comparison to their predevelopment size, due to reductions in depression storage capacity and in the retention capacity of the site's existing natural vegetation. Also, increases in impervious ground covers contribute to increasing volumes of runoff. These changes coupled with shorter times of concentration result in sharp modifications to the shape of the resulting hydrograph (Figure 12) (DER, 1999).

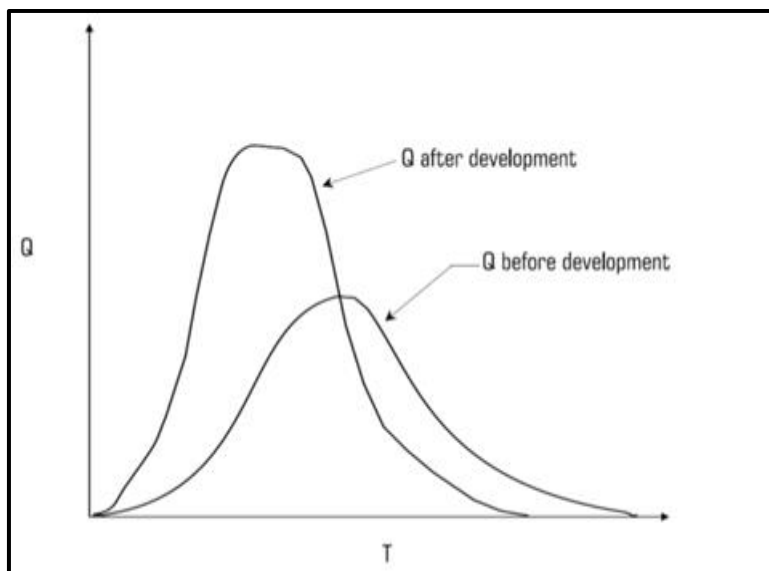


Figure 12: Hydrologic Alterations due to site development (DER, 1999)

The Niger Delta is densely populated, and its landscape cannot be assumed to be pristine. Most parts of the basins in the Niger Delta have undergone widespread land use changes. Therefore, it is necessary to document land cover and land use changes, and to understand their drivers and consequences, especially in the context of global environmental changes, rapid population growth. Land cover/land use in the Niger Delta changed drastically in the last 60 years due to a variety of biophysical and societal factors such as oil exploitation, population rise and urbanization. A number of studies have attempted to detect and describe the land cover/land use changes in different areas of the Niger Delta Basin (Twumasi and Merem, 2006; Kuenzer, et al., 2014; Eyoh and Okwuashi, 2016) however; none of these studies addressed these issues in details in the Orashi Basin.

Despite the aforementioned studies, the effects of the land use change on the runoff and flood remain unclear and have not been fully studied in the context of increased flood events in the area. Further, none of these studies have investigated the spatial-temporal dynamics of these changes using a multi-temporal time series. The Orashi Basin is an important case study because it is characterized by a mixture of diverse land cover/land use types, including mangrove forest referred to as “the physical barrier against the tides and ocean” and a high density of settlements along the river and canal network. In addition, the area has been the subject of rapid and large-scale changes in land cover/land use types. Therefore, understanding the trend and nature of land use changes in the Orashi Basin is vital.

To support effective watershed management, a thorough understanding of the relationship between LULC change in the Orashi Basin and associated hydrological response is required. Unfortunately, there have been limited studies investigating LULC change in the area. Currently, no published literature looks at how land use within watersheds have changed during the last few decades, and what are the potential direct and non-direct drivers for such change. Further, there has been a gap of information about how land use affects hydrological responses in most basins in the Niger Delta.

### **3.3: Causative Factor: Terrain and Hydrologic Characteristics**

Meteorological conditions and land use pattern are necessary, but not sufficient conditions for flood occurrence in an area. Flood intensity and frequency does not only depend on land cover system and precipitation (Şen, 2018), but also physical characteristics such as topography, geology, soil, geomorphology and morphometric characteristics such as stream order, drainage density, stream frequency, and elongation ratio of a watershed, which influences the hydrological response of a watershed and have a significant influence on the incidence and magnitude of floods (Chow, 1964; Strahler, 1964).

Topography plays a key role in flood behaviour through a fundamental interaction that involves the elevation of the landscape across multiple spatial and temporal scales (Tucker and Whipple, 2002). According to Şen (2018), “topographic conditions such as high-exposure (steeply sloping) high land terrains, narrow valleys, or ravines hasten the runoff and increase the likelihood of flash flood occurrence. Saturated soil or shallow watertight geological layers increase surface runoff. Urbanization processes and affiliated construction with watertight materials are thought to make runoff 2–6 times greater in comparison to terrains with natural such as coverage, fields, meadows, forests”. Topography is considered by several authors such as Bajabaa, et al. (2014), Sande et al. (2012), Brasington and Richards (1998) and Bates and Roo (2000) to be one of the most important controlling factors concerning the hydrological response to flood.

From the hydrological standpoint, floods occur when the land surface is inundated and the soil no longer has the capacity to absorb water. Therefore, the excess water flows over the land surface. The overflow is due to either of two reasons. The first is explained by Horton’s overland flow (Knighton, 1998) where the infiltration capacity of the soil is exceeded while the



second is the result of saturated overland flow. In the second case, the water table rises as more water is received and then the excess water is discharged as overland flow. Evidently, surface hydrological behaviour is one of the main drivers behind floods; it is rapid or delayed hydrological response, which often makes a watershed vulnerable to flooding (Meraj, et al., 2014).

Morphological characteristics such as stream order, drainage density, channel slope, relief, stream frequency etc., are important in understanding the hydrology of the watershed since the hydrologic behaviour of a catchment depends on these characteristics (Gupta, et al., 1980). Morphological characteristics of a basin can help show the extent of inundated areas, the direction of flood flows, and changes in river channel which promotes understanding of the nature, characteristics and probability of flood occurring in the future. Diakakis (2010), mentions that the importance of morphological characteristics becomes even more significant when studying runoff reaction to intense rainfall, especially in the case of ungauged, flash flood prone basins. The application of geomorphic principles to understand and quantify environmental hazards such as flooding has led to a significant amount of research focused on identifying the relationships between basin morphometry and stream flooding (Patton, 1988).

Building on earlier studies, this thesis addresses the fundamental scientific question of assessing the morphometric and topographical factors that makes the Orashi basin more prone to flooding. In this research, an integrated analysis of the hydrological, morphological and morphometric properties of the Orashi basin is attempted in order to facilitate a better understanding of the flooding problem and its associated processes.

### **3.4: Causative Factor: Intrusion into marginal land**

Environments that are prone to floods include alluvial fans, low-lying inland shorelines, low-lying deltas, coasts and low-lying parts of major floodplains. Flood plains are nearly flat plain along the course of a stream or river that is naturally subject to flooding. They are one of the most productive and valuable environments on the surface of the earth that provide abundant ecosystems and human services (Harun, 2009). Human beings have been attracted to settle on floodplain and river banks since time immemorial (Reddy, 1991), Before the advent of human settlement and development of the floodplains of rivers, rivers were unregulated, free of dams and levees among others (River Partners, 2014), the natural rivers acted as natural sculptors of

the landscape, however, with time, people have settled next to waterways and in flood plains because of the advantages that they offer such as freshwater supply (Kummu et al. 2011, Oruonye 2015), fertile land and transportation accessibility (Mukolwe, 2016). Ramesh (2012) states that “due to their strategic location and/or suitability for agriculture activities, there is often a tremendous pressure to develop these areas for various type of land use beneficial purpose, therefore, rapid population growth, significant increase in agricultural exploitation, urbanization, and industrialization may be observed in these lowland and flood-prone areas”.

Over time, natural floodplains have been heavily transformed by human activities, especially since the industrial revolution in the 19th century (Turner, et al., 1990); consequently, hitherto pristine floodplains have been encroached upon, vegetal covers removed and the landscape drastically modified. The spatial morphology, morphometry and hydrology of the rivers and floodplains continue to be altered in many places (Patil, et al., 2008). Amoateng (2016) opines that rapid urban population growth, uncontrolled urbanization and urban expansion, poor urban planning and management, changing communal/local interests and climate change are among the factors accounting for the spatial changes in rivers and floodplains. Where these changes are not met with complementary planning and management measures, challenges such as water pollution, high risk disaster (e.g. flood) becomes unavoidable, particularly along the river banks (Adewumi, 2013). Although living on floodplains has great advantages, their occupants are exposed to many disturbances, such as floods. With a growing population, this generates greater risk and cost for society in terms of flood loss and damage potential. Flood plain encroachment has seriously increased flood risk and damage potentials, especially of settlement (Kundzewicz, et al., 2010), due to heavy socio-economic infrastructural development on these floodplains.

## **Chapter 4: Methodological Approaches**

A detailed description of the methods used in this research is enunciated in this chapter. It commences with a discussion of the research approaches and rationale behind the methods adopted in this research. This is followed by a discussion of the required data types, as well as the data collection instruments and analysis methods. Flood study is often a complex problem that requires multi-disciplinary understanding and marriage of socioeconomic factors, hydrology, geomorphology and geology.

In light of the multifaceted nature of the research, a suite of mixed methods was employed in this thesis. Mixed-methods research advocates for the collection of multiple data sources using different strategies and methods, in a way that the resulting mixture leads to complementary strengths and non-overlapping weaknesses (Brewer and Hunter, 1989). The use of several sources of evidence ensures generation of quality and superior results, expansive understanding of the subject matter and the derivation of singular conclusions that can be held in greater confidence (Johnson and Onwuegbuzie, 2004). Figure 13 shows the methodological framework that was employed to achieve the set objectives of the research.

### **4.1: Methodology: Justification of Choice of Study Area**

A single basin case study was chosen to enable the in-depth examination of the context-specific nature of vulnerability and adaptation. The study area is Orashi Basin, which is one of the worst flood-affected regions of the Niger delta. The area was selected as a case study because of the recurrent flood events and crop failures that are common in this part of the Niger Delta, making it one of the hotspots of flooding in the Niger Delta. In addition, the region is one of the major food production areas of the nation and the major economic activity in the area for millennia has been agriculture, as such; farmers in this area have a great deal of knowledge about floods and its effect on agriculture. Hence, their experience and perceptions about flood are very valuable.

Another reason for choosing the Orashi basin as a case study is the high level of poverty of farmers in the area. Data from the field study revealed that the average monthly income was \$43.4; with an income level that is far below the national average of \$204 (World Data, 2016), most of the smallholders can be described as poor. Because of their high poverty level and low resource base, smallholder farmers usually bear the brunt of disasters such as floods.

It is therefore essential to investigate possible relationships between poverty and flood vulnerability in the basin.

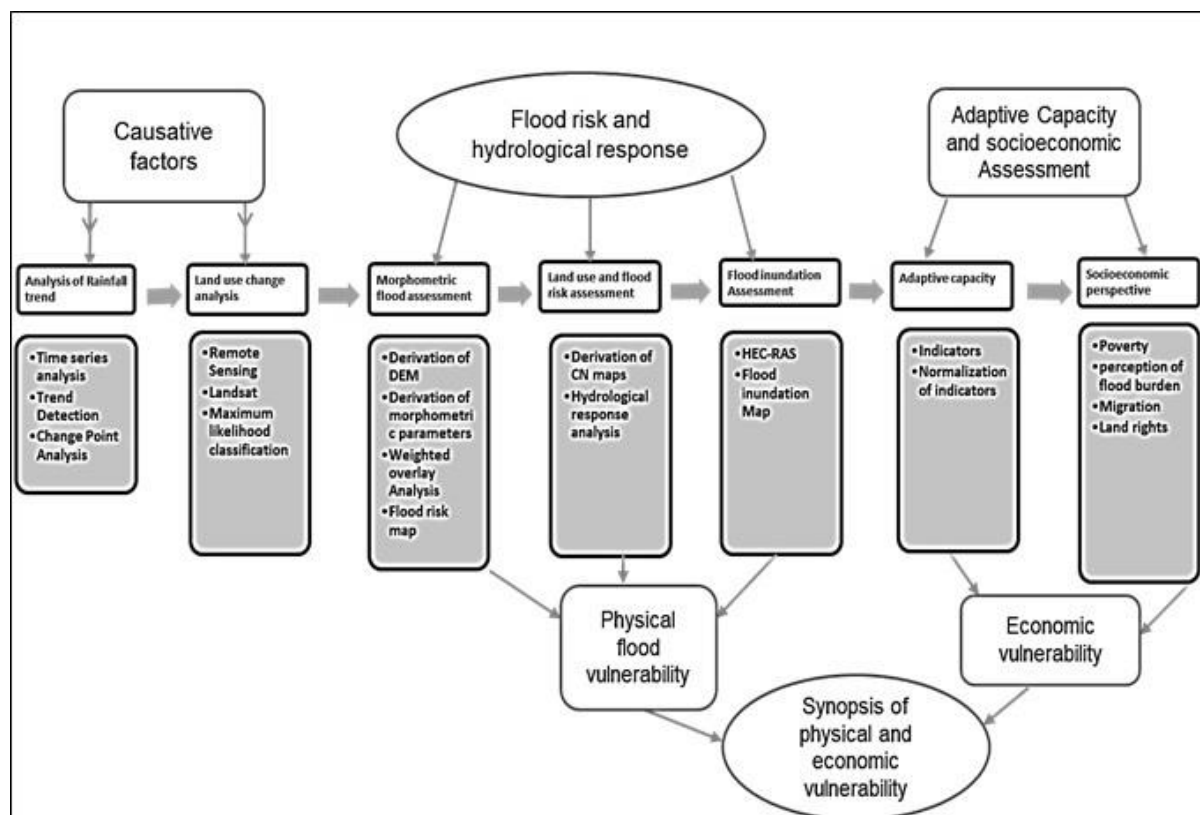


Figure 13: Methodological flowchart

## 4.2. Analysis of Data Availability and Acquisition

This section briefly outlines specific key data needed for flood vulnerability assessment and modelling, it briefly describes the sources and availability or lack of data to be used during the research. Before the in-depth description of the methodology of this research, the data requirements and availability for different parameters for the vulnerability assessment and flood modelling of the Orashi Basin are listed below (Table 2).

Table 2: Brief background on data requirement and available data for the study

Task	Required Data	Data source	Status	Comment
Meteorological analysis	Annual rainfall	Meteorological station	Available	<ul style="list-style-type: none"> <li>Annual rainfall data was only available from 1972. A longer duration would have produced more meaningful and concrete results</li> </ul>
	Monthly rainfall	Meteorological station	Available	<ul style="list-style-type: none"> <li>Monthly rainfall was available only from 1981-2016. For climate change analysis, this might be acceptable, but a long-term record would have provided the chance for a deeper analysis of climate change trend</li> </ul>
Morphometric	DEM Derived morphometric parameters	SRTM DEM	Available	
Land use map	Satellite Map	Landsat 8	Available and free	<ul style="list-style-type: none"> <li>Although, land use map from the state ministry would have enabled an in-depth analysis or enriched the analysis of land use change in the basin, it was not available. However, the Landsat derived land use maps proved sufficient for the thesis.</li> </ul>
	Land use map, Town planning plans	State urban planning development board	Not available Only outdated and unusable maps were available	
Hydrological Modelling	Daily rainfall	Meteorological station and river basin development authority	Not available	<ul style="list-style-type: none"> <li>Long-term, daily rainfall data for the basin was not readily available. The solution was usage of TRMM data</li> </ul>
	Sub daily rainfall	Meteorological station and river basin development authority	Not available	<ul style="list-style-type: none"> <li>It is important to note that the TRMM data are only an estimation of rainfall based on cloud density and atmospheric moisture measured by a satellite; these data are not the actual measured rainfall</li> </ul>
	Channel parameters such as width, depth, and slope,	River Basin Authority	Not available.	<ul style="list-style-type: none"> <li>These parameters were computed by the HEC-HMS model. Although, data from the river basin authority would have been more accurate and precise</li> </ul>

Digital Terrain Model	High resolution DEM or LIDAR	United States Geological Survey (USGS)	Not available	
	Flood Event Flow Hydrograph	River Basin Authority	Not available	<ul style="list-style-type: none"> <li>The Orashi River Basin Authority is responsible for providing hydrological and flow data in the area. But they mentioned that there was no gauge station in the basin, so discharge and flow data could not be provided</li> </ul>
	River discharge data	River Basin Authority	Not available	
	Bathymetric data	River Basin Authority	Available (Restricted use)	<ul style="list-style-type: none"> <li>Attempts was made to obtain bathymetric data for the river Basin. But only one oil producing company was said to have such data. Several attempts were made to acquire the data from the company, but such attempt proved fruitless.</li> </ul>
	Cross Section	River Basin Authority	Not available	<ul style="list-style-type: none"> <li>Cross sections data was needed for comparative purposes with the cross sections that was obtained from the HEC RAS modelling process</li> </ul>
Calibration	Long duration time series of rainfall and discharge data	River Basin Authority Hydrological Agency of Nigeria	Not available	<ul style="list-style-type: none"> <li>There was no gauge station in the basin</li> </ul>
Validation	<p>Details of historical floods such as flood flow, flood level, flood maps,</p> <p>High resolution cloud free satellite images</p>	Various sources and methods		An attempt was made to obtain satellite images/data such as MODIS for validation of the flood risk map generated, but due to the high amount of cloud cover, it was not possible to use such satellite maps

Flood vulnerability Assessment	flood statistics (damage and loss information)	From various sources	Not available	
Socioeconomic Analysis	Population Settlement	<ul style="list-style-type: none"> <li>• National statistical bureau:</li> <li>• State ministry of agriculture</li> </ul>	Only partially available	Socioeconomic data was obtained mostly from questionnaire administration

### 4.3: Methodology: Analysis of Rainfall Trend

Since evidence of climate change is uncovered basically through the occurrence of extreme change climatic variables, the presence of a significant trend in a long-term record obviously provides evidence of a significant shift in climate change. Thus, an analysis of the time-series behaviour of rainfall pattern is important for understanding the climate dynamics. This is useful for the prediction of future climate change scenarios in the study area. One of the objectives of this study aimed at examining precipitation characteristics in the Orashi basin. Different methods have been used to test and analyze precipitation characteristics (Abdulkareem and Sulaiman, 2016). In this thesis, two rainfall characteristics are examined, namely, time series and rainfall trend. To investigate the rainfall pattern and trend, annual data (from 1972-2016) and monthly data (1981-2016) were collected from the Nigerian Meteorological Agency (NIMET).

#### 4.3.1: Time series analysis

Time series plots are designed to illustrate trends with respect to time, together with any seasonality effects. A change in a time series may occur abruptly (step change) or gradually (trend) or may take a cyclic form (cycle) or a combination of trend and cycle with intermittent step jump (Shahin et al., 1993). Simple linear regression is a commonly used method for identifying trends in a time series. It is used to describe the relationship between one variable with another or other variables, further, it gives results which are simple to interpret; both graphically and analytically on the basis of the shape and parameters of the trend equation. It is often performed to obtain the slope of hydrological and meteorological variables on time.

Simple linear regression provides a measure of significance based on the hypothesis test on the slope and also gives the magnitude of the rate of change. A positive slope shows an increasing trend while a negative slope indicates a decreasing trend. The total change during the period under observation is obtained by multiplying the slope with the number of years. Such change may affect the overall long-term statistical properties of the time series such as the mean, median, variance or any other aspects of the time series. This study used 45 years (1972 to 2016) of annual rainfall data to investigate rainfall variations.

Interpretation of the time series plot is often aided by adding a smoothing curve to follow the general trend in the data. Data smoothing methods include methods such as splines, kernel and polynomial regression. In this thesis, Locally Weighted Scatterplot Smooth (LOWESS) is employed due to a variety of reasons. LOWESS is one of the most widely used methods for data smoothing and trend estimation and derives its acronym from the fact that a locally weighted regression is employed in this type of smoothing. Its graphical representation helps to visualize the overall trends in a time series and identify times of changes (Sharma, et al., 2015). LOWESS is a powerful non-parametric technique for fitting a smoothed line for a given data set either through univariate or multivariate smoothing (Cleveland and Devlin, 1988).

The LOWESS regression provides some attractive features; the robust weight function can be used to compensate for undue influence of extreme points. According to Cleveland (1979), the LOWESS fit is extremely informative when the data set is very large; in addition, it is used to solve the problems of precision, noise filtering, and outliers and is known to adapt well to bias problems, compared to other methods. A LOWESS smooth line was used to determine the trend and pattern in the long-term time-series data, and also to remove noise from data series so that a smooth trend is exhibited in order to easily understand the trend of rainfall in the study area.

#### **4.3.2: Trend Detection**

In the last decades, there has been increased interest in the use of trend detection techniques to detect changes in the magnitude of temporal and spatial distribution of hydro-climatic variables like temperature and precipitation (Adnan, et al. 2016). The purpose of trend testing is to determine if the values of a random variable generally increases (or decreases) over a period



of time in statistical terms (Helsel and Hirsch, 1992). Also, an estimate of the trend's magnitude can help to determine whether a statistically significant trend is of practical concern.

There are different types of test for detection trends in meteorological time series which can be classified broadly into parametric and non-parametric (Gocic and Trajkovic, 2013; Kumar et al. 2016). A test is said to be parametric if the change evaluated by the test can be specified in terms of one or more parameters. In parametric testing, it is necessary to assume an underlying distribution for the data (often the normal distribution) and to make assumptions that data observations are independent of one another. On the other hand, in non-parametric and distribution-free methods, fewer assumptions about the data need to be made (Kundzewicz and Robson, 2004). With such methods, it is not necessary to assume a distribution.

Hydro-meteorological time series are often characterized by data that exhibit departures from normality, and, therefore, non-parametric tests are considered more robust compared to their parametric counterparts (Hess et al. 2001). Non-parametric methods have for long been applied for trend detection of the statistical significance of various hydrological and climatological phenomena. There are several statistical tests available for trend detection, such as Mann-Kendall test (MK), Spearman's rho test (SR) and Linear regression test (LR). Of all these, the Mann-Kendall test has become the most common one used by researchers in studying hydrologic time series trends (Longobardi and Villani, 2010). The method was initially developed by Mann (1945) with Kendall (1975) deriving the distribution of the test statistic. The ability of the Mann Kendall test for detecting linear trends in time series has been established by numerous hydro-meteorological studies such as Yue and Hashino (2003) and Guhathakurta and Rajeevan (2008). Further, the Mann Kendall test was selected for trend detection in this study based on the following factors:

- The Mann-Kendall test is a rank-based non-parametric test. The test compares the relative magnitudes of sample data rather than the data values themselves; hence, the method does not require any assumption about the form of the distribution the data is derived from. The test has a higher power for non-normally distributed data which are frequently encountered in hydrological records (Onoz and Bayazit, 2003).
- The Mann Kendall test has been extensively used to determine trends in similar hydrologic studies done in the past. In addition, because the Mann Kendall test is based on sign differences

rather than values, it is amenable to the effect of extreme values and outliers, and performs well even with missing values

The null hypothesis ( $H_0$ ) of the trend test suggests that there is no trend and that the data are random and independent;

Alternate hypotheses ( $H_1$ ) suggest that a trend is present in the time series.

The Mann-Kendall S Statistic is computed as follows.

Let  $x_1, x_2, \dots, x_n$  denote  $n$  data points where  $x_j$  represents the data point at time  $j$ . Each data value is compared to all other data values in an ordered time series. The data values are evaluated as ordered time series. Each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic  $S$  is assumed to be 0. If a data value from a time period is higher than a data value from an earlier time,  $S$  is increased by 1. On the other hand, if the data value from the later time period is lower than a data value sampled earlier, is decreased by 1. The net result of increments and decrements yields the final value of  $S$ . The sign (Sign) is used to denote the difference between the two values ( $x_j$  and  $x_i$ ) from the time series.

An expression of  $S$  is given by:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^N \text{sign}(x_j - x_i)$$

A positive value of  $S$  indicates an increasing trend, a negative value indicates a decreasing trend, while  $S = 0$  means that no trend is detected.

$$\begin{aligned} \text{sign}(x_j - x_i) &= 1 \text{ if } x_j - x_i > 0 \\ &= 0 \text{ if } x_j - x_i = 0 \\ &= -1 \text{ if } x_j - x_i < 0 \end{aligned}$$

If the time series has less than 8 data points the  $S$  test is used, and if the time series has 8 or more data points the normal approximation ( $Z$  statistics) is used. Mann (1945) and Kendall

(1975) have determined that when  $n \geq 8$ , the statistic  $S$  is approximately normally distributed with the mean and variance as follows:

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^g t_p(t_p-1)(2t_p+5)}{18}$$

Where  $n$  is the number of data points,  $g$  is the number of tied groups (a tied group is a set of data having the same value), and  $t_p$  is the number of data points in the  $P^{\text{th}}$  group. The normalized test statistic  $Z$  can then be computed by using the following formular

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}}, & S < 0 \end{cases}$$

A positive value of  $Z$  indicates an upward trend, while a negative value of  $Z$  indicates a downward trend. The decision to either reject or accept the null hypothesis is made by comparing the calculated  $Z$  value with the critical value at a chosen level of significance. For this thesis, a 95 per cent level of significance was selected to indicate the presence of statistically significant trends. The XLSTAT and Mankensen software were used to perform the Mann-Kendall's test. The steps involved in using the critical value for trend detection are shown in Figure 14.

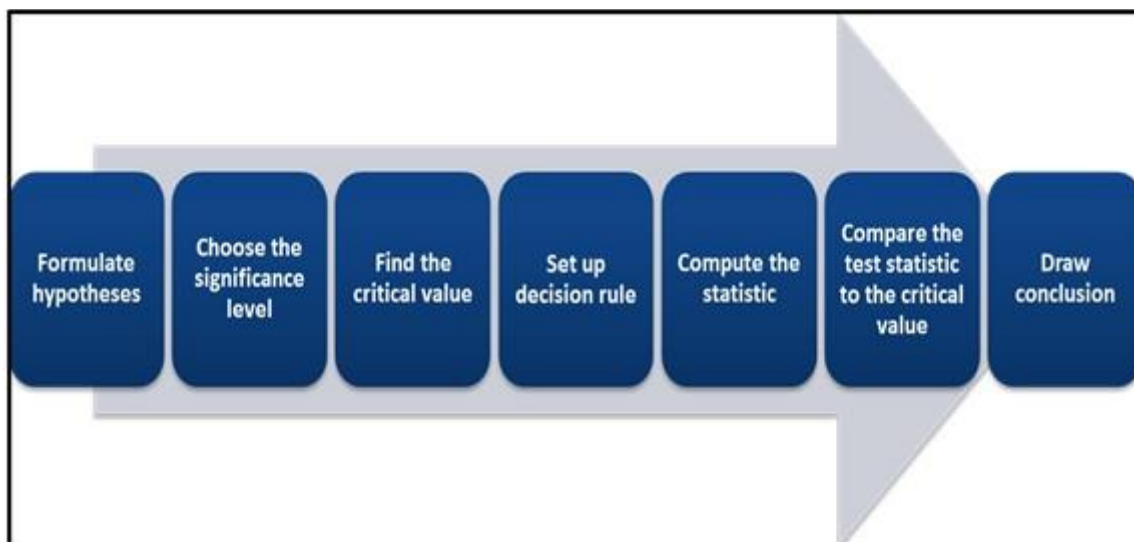


Figure 14: Steps involved in trend detection using the critical value approach

**Determination of Critical Value:** Hypothesis testing can be conducted either by P-value approach or critical value approach. The critical value approach is used in this thesis. A critical value refers to a point on the scale of the test statistic outside which the null hypothesis is not accepted and it is based on the significance level, i.e alpha ( $\alpha$ ) of the test.  $H_0$  is rejected if the absolute value of  $Z$  is greater than the critical value at different levels of significance, where, the critical value is obtained from the  $Z$  standard normal distribution table (Louangrath, 2015, Hughes and Grawoig, 1971).

In other words, the critical values for a test of hypothesis depend upon a test statistic, which is specific to the type of test, and the significance level ( $\alpha$ ) which defines the sensitivity of the test. The critical value divides the area under the probability distribution curve into rejection region(s) and in non-rejection region. Figure 15 shows a bell-shaped normal probability curve and their region of acceptance and rejection.

The selection of a significance level for an interval determines the probability that the interval produced will contain the true parameter value. Common choices for the significance level are 0.10, 0.50, and 0.01. These levels correspond to percentages of the area of the normal density curve. For example, a 0.50 significance level covers 95% of the normal curve, the probability of observing a value outside of this area is less than 0.05. Because the normal curve is symmetric, half of the area is in the left tail of the curve, and the other half of the area is in the right tail of the curve.

As shown in Figure 14, for a confidence interval with level  $\alpha$ , the area in each tail of the curve is equal to  $(1 - \alpha)/2$ . Therefore, for a 95% confidence interval, the area in each tail is equal to  $0.05 / 2 = 0.025$ . This means that all the area to the left must be  $1 - 0.025$  or 0.975. This value is used to determine the critical value. Using Z Table of normal distribution, a value of Z matching 0.975 is located. The critical value for the test is hence determined to be equal to 1.96.

Step 1=  $1 - \text{confidence level} = 1 - .95 = .05$

Step 2= divide  $\alpha$  by 2 =  $0.05/2 = 0.025$

Step 3=  $1 - 0.025 = 0.975$

Step 4= Look up .975 on the Z-score chart, Z was determined to be 1.96. Therefore, the critical value of the test at 95% Confidence Level is 1.96.

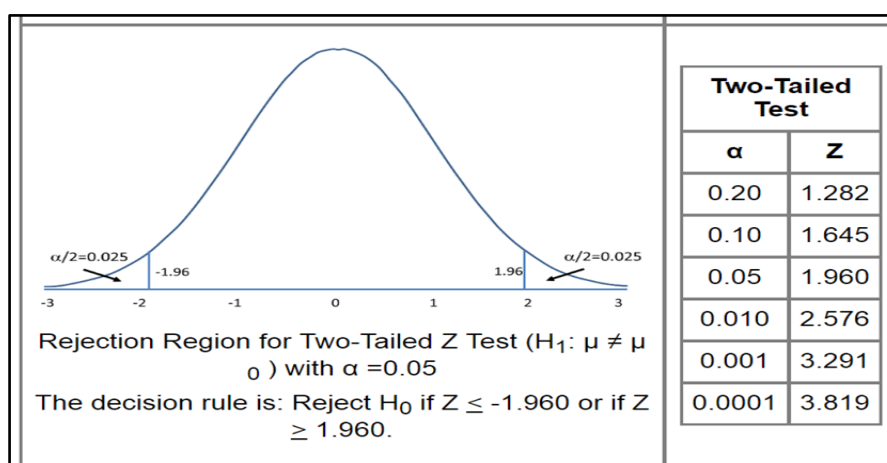


Figure 15: Image showing critical value and zone of rejection at 0.05 significance level<sup>2</sup>

Table 3 below was developed using the procedure outlined above.

Table 3: Significance level and critical value

Significance level	Critical Value (Z-score)
0.90	1.645
0.91	1.70
0.92	1.75
0.93	1.81
0.94	1.88

<sup>2</sup> Inset in the image is the significance level and the corresponding Z score

Significance level	Critical Value (Z-score)
0.95	1.96
0.96	2.05
0.97	2.17
0.98	2.33
0.99	2.575

### 4.3.3: Change Point Analysis

In this study, the non-parametric Pettitt change point test was also used to detect occurrence of the abrupt change (Pettitt, 1979). It is a rank-based and distribution-free test for detecting a significant change in the mean of a time series and it is particularly useful when no hypothesis required to be made about the location of the change point. The Pettitt test has been widely applied to detect changes in the observed climatic as well as observed hydrological time series. The Pettitt test is also applicable for testing an unknown change point by considering a sequence of random variables  $X_1, X_2, \dots, X_T$ , which have a change point at  $K$  (Zarenistanak, et al., 2014).

The first step is to compute  $U_k$  statistic using the following formula

$$U_k = 2 \sum_{i=0}^n m_i - k(n + 1)$$

where  $m_i$  is the rank of the  $i$ th observation when the values  $x_1, x_2, \dots, x_n$  in the series are arranged in ascending order and  $k$  takes values from  $1, 2, \dots, n$ . The next step is to define the statistical change point test (SCP) as follows:

$$\text{SCP} = \max_{1 \leq k \leq n} |U_k|$$

When  $U_k$  attains maximum value of  $K$  in a series, then a change point will occur in the series. The critical value is obtained by:

$$K_{\alpha} = [-\ln \alpha (n^3 + n^2)/6]^{1/2},$$

where  $n$  is number of observations and  $\alpha$  is level of significance which determines the critical value (Zarenistanak, et al., 2014).

## **4.4: Methodology: Land-use Change Analysis**

### **4.4.1: Remote Sensing and Land Use Mapping**

The use of remote sensing technique in the mapping of land use and Land cover is gaining global acceptance (Melesse, et al. 2007, Hassan, et al. 2016, Grupa, 2016). “Remotely sensed” satellite images offer an important opportunity to extract information on spatial and temporal trends of LULC (Fonji and Taff 2014, Naqvi, et al. 2014). According to Zoungrana et al. (2015), remote sensing plays an important role in the management of the earth’s surface by providing spatial-temporal information on land use/cover (e.g., water, forest, bare area, and cropland). Satellite remote sensing is a vital source of data for studies of the Earth’s surface, because of its ability to capture information of a large part of the Earth’s surface and to acquire repeated measurements of the same area regularly. Historical datasets such as images and photographs are used in identifying the spatial extent and type of LULC to assess the impacts of the changes on floods (Jeb and Aggarwal, 2008). Jensen (2004) points out that they are also vital for the detection of changes and prediction of land cover changes. The rationale of using remote sensing data for change detection is that changes in land cover result in changes in measurement values which can be remotely sensed.

In recent years, techniques to perform change detection with satellite imagery has not just improved, but have become numerous as a result of increased flexibility in handling and manipulating digital data and increasing computer power. There is now a multiplicity of satellite remote sensing tools in land-use analysis and change detection studies, varying from the very high-resolution datasets produced irregularly over extents no larger than a single state or province by high-resolution satellite sensors such as *IKONOS* and *Quickbird*, to regional datasets produced at regular intervals from satellites (e.g., *Landsat*, *SPOT*), to the lower-resolution (> 250 m) datasets now produced across the entire Earth on a daily basis (e.g., *MODIS*).

### **4.4.2: Landsat Characteristics**

Multi-temporal Landsat datasets between 1986 and 2016 were used in this research. The Landsat dataset was selected for a variety of reasons, not only because of its suitability for regional studies but due to their free availability as well. Although in comparison to other paid-for software, Landsat datasets are lower in resolution, however, their spatial resolution is



sufficient to reveal most of the floodplain channels that are observable from above, Landsat TM, ETM and OLI images have already had their utility demonstrated in several studies (Abd El-Kawy, et al., 2011). Their wide spatial coverage also makes them suitable for land use and land cover change detection. Further, the duration of the Landsat dataset (NASA and the Geological survey have maintained the satellite since 1972) means that long term land use change analysis can easily be carried out. The Landsat 5 Thematic Mapper (TM) sensor which was launched in 1984 created images consisting of six spectral bands with a spatial resolution of 30 meters for Bands 1-5 and 7, and one thermal band (Band 6). The approximate scene size is 170 km north-south and 183 km east-west (106 mi by 114 mi). Landsat 7 was launched in 1999 with an Enhanced Thematic Mapper plus (ETM+). Landsat 7 ETM+ images consist of eight spectral bands with a spatial resolution of 30 metres for bands 1 to 7. The panchromatic band 8 has a resolution of 15 meters. Approximate scene size is 170 km north-south by 183 km east-west (106 mi by 114 mi). The OLI was launched in 2013, it collects images using nine spectral bands in different wavelengths of visible, near-infrared, and shortwave light to observe a 185 kilometres (115 miles) wide swath of the Earth in 15-30 meter resolution covering wide areas of the Earth's landscape while providing sufficient resolution to distinguish features like urban centres, farms, forests and other land uses.

Figure 17 shows the methodological framework for the analysis of landcover. All the required satellite data were downloaded via the USGS Earth Explorer platform. An initial obstacle for obtaining satellite images in the Niger Delta is the frequent cloud coverage in the area. Investigating the free Landsat archives for cloud-free data (0% cloud coverage) covering this complete area in the dry season (November March) meant that only a few possible dates for an analysis covering the late 1980s, the early 2000s, as well as the year 2016. Satellite images used in the study were from the dry period, i.e., December to January, based on the availability of images devoid of clouds and clarity of the images. Due to the unique location of the study area, it fell astride four Landsat scenes (Figure 16). Hence this required mosaicking of the images and subsequent clipping of the mosaicked images. Mosaicking refers to the seamless joining and stitching of adjacent imagery, while clipping refers to the subsetting of mosaicked images. A set of Landsat 5 TM, Landsat 7 ETM and Landsat 8 OLI images was used to generate spatial information for 1986, 2002/3 and 2015/6 land use respectively.

Table 4 presents detailed information about the Landsat images used in the research.

Table 4: Landsat scenes used in the research (Dates in yyyy/mm/dd format)

	Path 188	Path 189
Row 056	1986/12/19	1987/12/27
	2003/01/08	2002/12/30
	2016/01/04	2016/12/28
Row 057	1986/12/19	1987/12/27
	2003/01/08	2002/12/30
	2015/12/19	2015/12/26

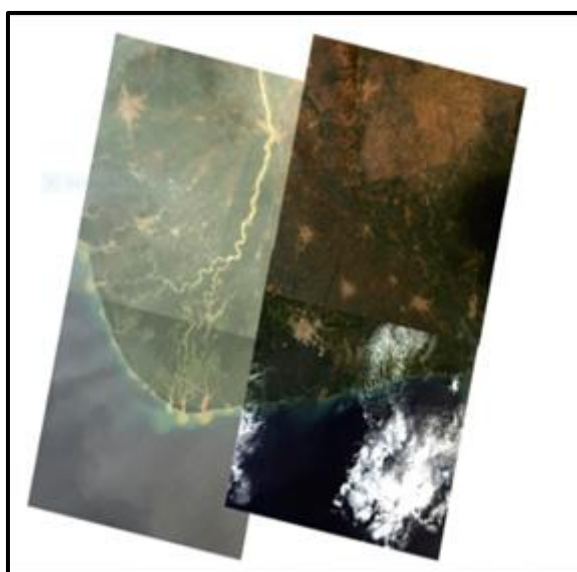


Figure 16: True colour combination of the four Landsat scenes used in the research

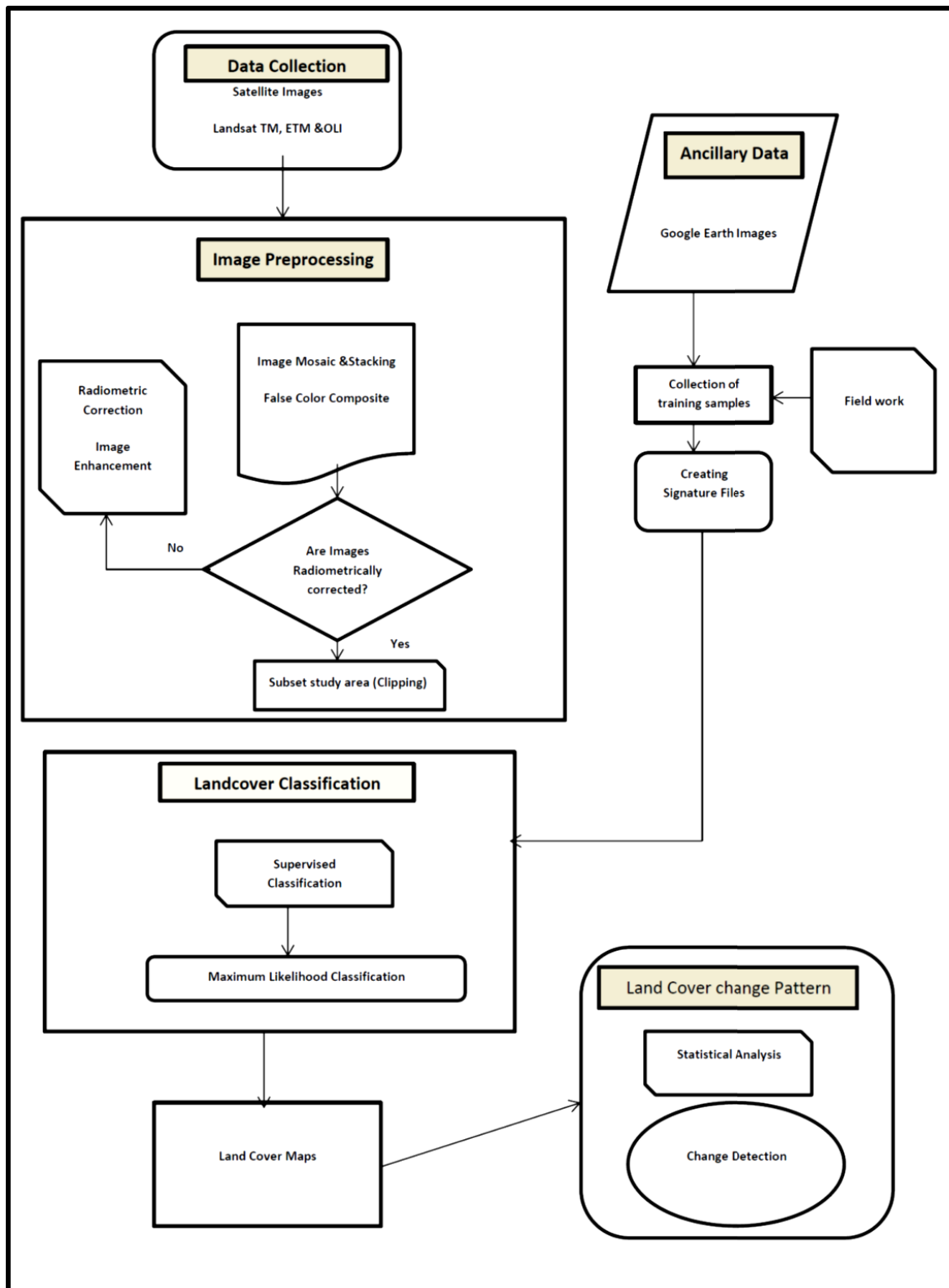


Figure 17: Landcover change analysis methodological framework

Most earth observation satellites record various spectral bands. These bands can be combined to ensure greater visibility for particular features. These combinations require an understanding

of the wavelength of each band and the colour they reflect when they meet each specific feature. This is because different features display different colours in the visible part of the spectrum. The images were loaded and layer-stacked in the ArcGIS Software for display in various RGB bands. Two composite types are mostly used in the classification of land use features, true image composite (where the features appear in the true colour) and the "false colour" composite of band 2, 3 and 4 where vegetation appears in shades of red, urban areas are cyan blue, and soils vary from dark to light browns.

Preprocessing of satellite images before image classification and change detection is essential. Preprocessing commonly comprises a series of iterative operations such as atmospheric correction, geometric correction, and masking (e.g., for clouds). The volatility of the atmosphere can introduce variation between the reflectance values or digital numbers (DN's) of satellite images acquired at different times, making corrections of such images essential.

Geometric rectification of the imagery re-samples or changes the pixel grid to fit that of a map projection or another reference image. This becomes especially important when scene to scene comparisons of individual pixels in applications such as change detection are being sought (ERDAS, 1999). The preprocessing of satellite imagery considers the combined, measurable reflectance of the atmosphere, aerosol scattering and absorption, and the earth's surface. The images were atmospherically corrected using the Semi-Automatic Classification (SCP) tool in the QGIS software (Congedo, 2017). Upon atmospheric and geometric correction, the image data underwent pixel-based image classification using an extensive set of training samples. Based on the field experience and familiarity of the study area as well as the spectral characteristics of the images, the land use and cover classes identified were; Built up area, Agricultural area, Forest, Swamp forest and Water (Table 5).

Table 5: Land cover and categories

Land Cover Class	Categories
Built up Area	Residential areas, city centers, commercial and industrial areas
Agricultural Area	Diminished forest, farms
Forest	Evergreen forested areas, forest reserves
Swamp	Swamp, wetland, mangrove
Water	All the water bodies, e.g. streams, rivers, creeks etc.

The spatial analysis was done to determine the land cover pattern in the Orashi Basin. The spatial analysis established the trend and nature of the changes in the land use/cover changes in the study area over a thirty-year period.

Remotely sensed Landsat images can be classified through two major methods, either supervised or unsupervised. In this thesis, the supervised classification was used. Training samples were created and selected and then used to recognize certain specific characteristics from the land cover types. The training samples are recognized through particular types of pixels and using ground truth data from field survey or through personal knowledge of the area under study. Using reference data, such as the ground truth information obtained through the GPS assisted spatial survey, 30 training samples for each of the land use/cover classes were selected and assessed to determine classes that could be merged. The supervised Maximum Likelihood Classification (MLC) algorithms were applied to the images to produce five land use/cover classes of the images. Further, a post-classification refinement was done with ground truth data, visual analysis and interpretation, reference data, as well as local knowledge to correct misclassified land use/cover categories to improve the accuracy of the classification. Based on the results of image analysis, a land use/cover change trend was produced to determine the different land use types of different periods. The land use change trend showed the extent of the land use/cover classes for the three periods, as well as the change in the extent of the land uses/covers for 1986/, 2002/3 and 2015/6.

## **4.5: Methodology: Morphometric Flood Risk Analysis**

### **4.5.1: Remote Sensing and Morphometric Analysis**

Earlier studies such as Horton (1932) and Strahler (1952) successfully applied conventional methods of morphometric characterization based on map measurements or field surveys. However, the generation of morphometric parameters through traditional methods such as field observations and topographic maps is a tedious activity (Fenta, et al., 2017) and in recent years, the analysis of morphometric parameters has gained increasing attention after the advent of tools such as remote sensing and geographical information system (GIS) (Kusre, 2016).

The increasing availability of remote sensing datasets with improved spatial accuracy, advances in computational power and geographical information system (GIS) enables evaluation of morphometric parameters with ease and better accuracy (Grohmann, 2004). Remote sensing can contribute to mapping topography such as DEM generation and defining surface roughness and land use/cover.

Remotely sensed images have a synoptic view of large areas with distinct land form features. These features can be extracted as thematic layers using digital image classification techniques in image processing software (Kaliraj, et al., 2012). Integrating remote sensing data and GIS tools which allow for automated computation, different researchers such as Vincy, et al. (2012), Sreedevi et al. (2013), Singh et al. (2014) and Sujatha et al. (2015) have carried out morphometric studies characterizing watershed physiographic attributes.

To describe the geomorphic and hydrologic characteristics of the Orashi Basin, Digital Elevation Model (DEM) is employed. DEM is a regular grid of elevation of the earth's surface in a raster form. DEMs can be derived from contour surveys, cartography, photogrammetry, interferometry and radar imaging. DEM data has a wide range of application in morphometric studies. DEMs are used to identify drainage features such as ridges, valley bottoms, channel networks, surface drainage patterns, and to quantify sub-catchment and channel properties such as size, length, and slope. Further, characteristics such as slope, drainage watershed (basin) and topographic wetness index are extracted from DEM. The increasing availability of DEM has given a strong impetus to the development of the so-called DEM-based hydro-geomorphic models.

The first step in doing any kind of hydrologic modelling involves delineating streams and watersheds, and getting some basic watershed properties such as area, slope, flow length, and stream network density. In this thesis, ArcGIS and a variety of open source and free geospatial tools such as the QGIS, SAGA GIS and GRASS GIS are used in the delineation of watershed and morphometric analysis (Table 6).

Table 6: Tools used in Morphometric analysis

Tools	Function
QGIS	Merge tiles
GRASS	Basin delineation
SAGA	Derivation of TWI and SPI
ARCGIS	Reclassification of grid values

DEM which was used for this study was downloaded from Shuttle Radar Topography Mission (SRTM). Several studies (Romshoo et al. 2012; Thomas et al. 2012 and Gajbhiye et al. 2014) have used SRTM (90 m resolution) DEMs in GIS environment to derive morphometric characteristics of watersheds with different geological and hydrological settings. The SRTM provides hydrographical information for regional and global-scale applications. It provides a suite of georeferenced data sets (vector and raster) at various scales. Commonly, SRTM data with global coverage are readily available at 3 arc-seconds (90 m) and 30 arc-seconds (1 km) resolutions via <http://earthexplorer.usgs.gov/>. Several studies such as Rabus et al. (2003) and Yang et al. (2011) provides more elaborate details of SRTM datasets including issues such as data processing, accuracy, errors, and applications.

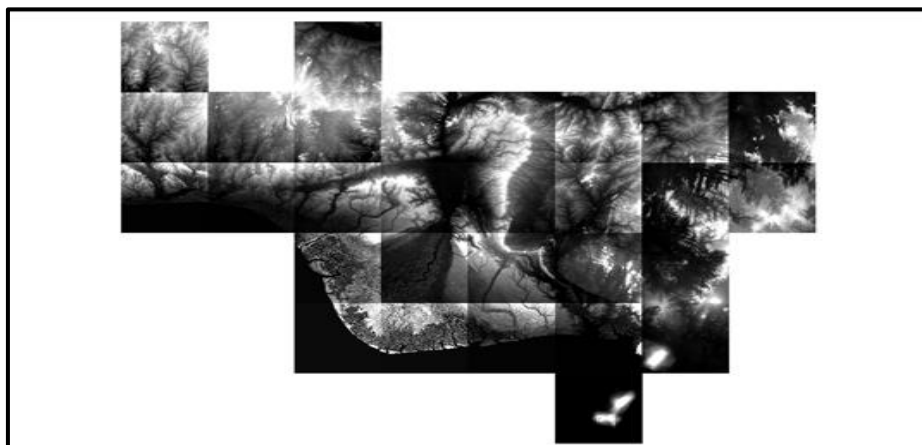


Figure 18: Image showing the merged SRTM tiles

To construct the Niger Delta DEM, 29 adjacent tiles covering the Niger Delta area were downloaded from SRTM and imported to QGIS platform and merged into a single DEM (Figure 18). The DEM was then clipped to the provincial Niger Delta boundary to produce the DEM of Niger Delta). Subsequently, it was re-projected in WGS UTM 32N. To extract the Orashi Basin area from the Niger Delta DEM, hydrological and basin analysis was done with the GRASS software using the basin delineation tool.

### **Morphometric Analysis: Preprocessing**

**Fill Sink:** Spurious sinks or local depressions in DEMs are frequently encountered and are a significant source of problems in hydrological applications. Sinks may be caused by incorrect or insufficient data, or by interpolation techniques that do not enforce surface drainage. For instance, if cells with higher elevation surround a cell, the water is trapped in that cell and cannot flow. The fill sink function modifies the elevation value to eliminate this problem. They are easily detected by comparing elevations with surrounding neighbours (Ramesh, 2012). The depressions or pits in the raw raster data of Digital Elevation Model (DEM) are filled to the level of the surrounding terrain by making use of the Wang and Liu (2006) fill tool of the SAGA GIS package. This is important to determine the direction of descent steps for each terrain cell and the flow direction. The detection of spurious sinks features or local depressions in DEMs lead to improvements in DEM generation techniques as well as detection of errors in source data

**Determine flow direction:** The main purpose of this step is to ensure that the water always flows to lower elevations. There are numerous algorithms employed to determine flow direction from DEMs, but, probably, the most common algorithm is the “D8” algorithm, where the flow direction for every cell within the watershed is determined by considering the surrounding eight neighboring cells. The local slope in each of the eight directions of these neighbouring cells is calculated by taking the difference in elevation indicated by the DEM value at each of these eight neighbouring locations and the value at the cell being examined. This difference in elevation is then divided by the center-to-center distance between these cells. The direction that yields the steepest downhill slope is the inferred direction of water flow. The determination of flow direction is very important because it allows for the inference of drainage areas, flow lengths, and the automated delineation of watersheds.



**Determine flow accumulation:** It is an indicator of the water quantity of the area. The accumulation of flow is the quantity of water, which will move to each pixel from its neighbours and eventually accumulated to it. Flow accumulation is determined on the base of the DEM and presents the accumulated flow in each cell of the raster. The value of the cell shows the number of the cells from which the flow is accumulated. If the flow accumulation is 0 then there is no runoff. The runoff is increased at greater values of flow accumulation (Nikolova and Zlateva, 2017). Figure 19 shows the morphometric analysis procedure.

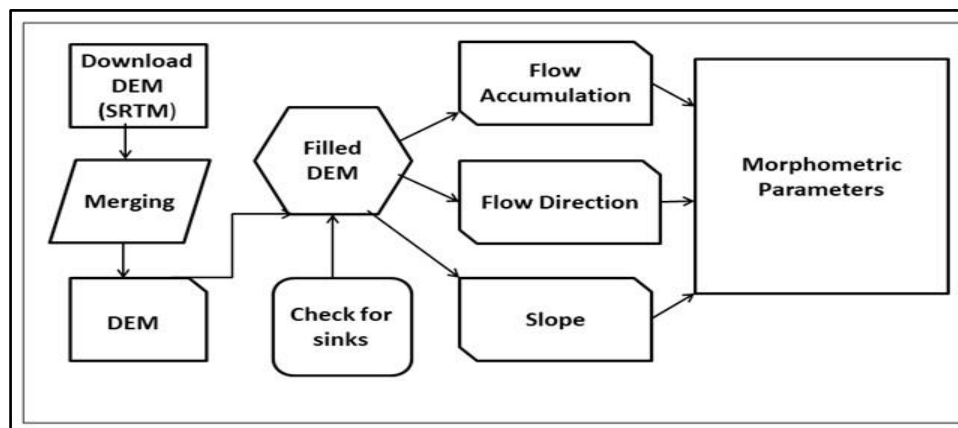


Figure 19: Procedure of Morphometric Analysis

#### 4.5.2: Weighted Overlay Analysis

One of the essences of flood studies is the evaluation of flood risk of places and people at the local level so that preventive and remedial measures are taken to minimize the loss. There is a variety of qualitative and quantitative approaches for flood risk studies, which involves the use of different data, such as hydraulic information, topographic base map, terrain models, land use/cover map, inundation map, population density, etc. Procedures such as Multi-Criteria Analysis (MCA), Objected Oriented Analysis, surveys, questionnaires and Geographical Information System (GIS) have also been successfully used for determining flood risk.

Several studies such as Samson et al. (2016); Mahmood and Rahman (2019) and Diakakis (2011) have used morphometric indexes to predict or determine flood risk. To produce the morphometric hazard map, a type of Multi Criteria Analysis called the Weighted Overlay Analysis is employed. The Weighted Overlay method is an efficient method to delineate flood hazard risk zones and can be used for planning and forecasting of flood risk zones, for example, Gaňová et al. (2013) used this method to compute the index of flood risk based on multi-criteria

analysis in Eastern Slovakia. Elkhachy (2015) also used the weighted overlay method to generate flash flood risk map for Najran city in Saudi Arabia.

The Weighted Overlay Analysis is a technique often used for solving multi-criteria problems such as flood risk assessment. Weighted overlay is employed when a number of factors of varying importance need to be considered to arrive at a final decision. Geographic problems such as flood risk analysis require the analysis of many different factors. This information exists in different rasters with different value scales, distances, degrees etc. and so, to obtain a meaningful result, different layers or raster cannot be simply combined. Additionally, the factors in the analysis may not be of equal importance, for instance in determining the flood risk of a particular area, it may be that the elevation is more important than the stream power index factor, vice versa, hence different weight of importance may need to be attached to different layers according to the degree of their influence, hence the need for the use of the weighted overlay analysis. Additionally, the Weighted Overlay Analysis offers some advantages, such as its ability to successfully model facts and human judgements based on field experience, and incorporate these into the final analysis (Aladejana, et al., 2019). Further, it is simple to apply since it only requires the spatial layers of the factors that contribute to the flood hazard. The Weighted Overlay Analysis is carried out by overlaying classified layers (rasters), assigning a weight to each layer, summing the values of each vertical cell stack, and then evaluating the resulting composite map. The thematic layers were integrated in ArcGIS 10.1 platform to create a flood risk map depicting different flood risk zones. Although the concept of the weighted overlay method is simple, there are required steps. The following is a summary of these steps (Figure 20).

- Determine and chose significant criteria (morphometric parameters)
- Reclassification of raster values
- Ranking of classes
- Assigning Weight to each layer
- Weighted Overlay Analysis

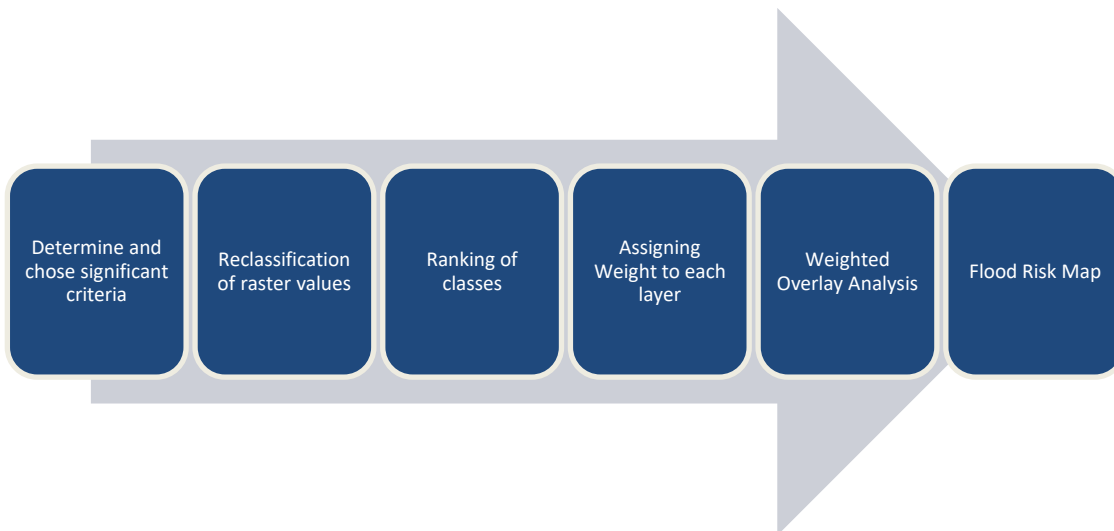


Figure 20: Weighted Overlay Analysis Procedures

In order to generate a map for evaluating the flood vulnerability, a series of conditioning parameters were defined. Determination of proper flood-conditioning factors is essential for flood susceptibility mapping (Kia, et al., 2012), therefore; flood-conditioning factors should be carefully selected to enhance results. The chosen parameters should be representative, reliable, and readily obtained for the study area. A composite flood risk map based on five causal factors/indices layers that were derived from the morphometric analysis is used during this thesis. These factors have been selected based on other case studies with similar characteristics. Information about the different factors used and the rationale behind their use in flood risk is discussed below.

- Digital Elevation Model (DEM)
- Slope
- Drainage density (Dd)
- Stream power index (SPI)
- Topographic wetness index (TWI)
- 

Elevation: Water flows from higher to lower elevations, and low elevation areas may flood quicker than areas at higher elevation. Elevation affects flood severity, flow size and direction. Areas of lower elevation are affected by flood more than areas of higher elevation. Besides, water tends to remain in areas of lower elevation for a long period of time than areas of high elevation.

Slope: The DEM-derived slope layer was generated in percentage. Slope is considered as an important factor in identifying flood risk areas (Gitika and Ranjan, 2016). The slope of any landscape refers to the amount of inclination of topographic landforms to the horizontal surface. Slope is the means by which gravity induces the flow of water and other materials, so it is of great significance in hydrology and geomorphology. Slope angles affect the velocity and frequency of runoff and the rate of infiltration in an area. On gentle slopes, surface runoff is usually slow, whereas on steep slopes, the rate of runoff is usually very high. On gentle slope, runoff doesn't drain fast, as there is low velocity and thus accumulation of much water after precipitation events is likely to develop into a flood. Further, the low-lying area with a low slope angle will be inundated first as compared to the high slope area during flooding.

Drainage Density: The concept of drainage density (Dd) model was developed by Horton (1945) and it has been used by several studies to determine the flood risk level such as that of Makhamreh et al. (2020). Drainage density is the stream length per unit area in region of watershed. It indicates the closeness of channel spacing and provides a numerical measurement of land form dissection and runoff potential. Regions with high drainage densities will have limited infiltration, promote considerable runoff, and have at least moderately erodible surface material. If the drainage network is dense at any area, it will be a good indicator of high flow accumulation path and more likely to get flooded (Islam and Sado, 2000). Drainage density is an inverse function of infiltration. The core idea of the Drainage density is that a basin with high drainage density is more vulnerable to flooding (Biswas et al., 2018).

Stream Power Index (SPI): The SPI has been employed in several flood risk studies (Cao et al. 2016; Khosravi et al. 2016). The SPI is considered a “measure of the erosive power of flowing water based on the assumption that discharge is proportional to specific catchment area (As)” (Wilson and Gallant, 2000). As specific catchment area and slope steepness increase, the amount of water contributed by upslope areas and the velocity of water flow increase, hence stream power and potential erosion increase (Gruber and Peckham, 2009). The SPI is calculated as

$$As * \tan b.$$

Where As is the specific catchment area (m<sup>2</sup>/m), and b (radian) is the slope gradient (in degrees).

Topographic Wetness Index (TWI): There are several methods used to identify areas exposed to flooding, however, this thesis aims to determine flood-prone areas in the Orashi Basin by using the Topographic Wetness Index (TWI) which was first introduced by Beven and Kirkby, (1979). The TWI is derived from Digital Elevation Models (DEMs) and is defined as

$$TWI = \ln\left(\frac{A_s}{\tan \beta}\right)$$

Where  $A_s$  is the (upslope) flow accumulation area (or drainage area) per unit contour length and  $\beta$  is the angle of the surface slope (Ruhoff, et al., 2011). The TWI estimates the relative propensity of a point in the landscape to become saturated and hence generate runoff based on the assumption that topography controls the near-surface position of the groundwater table (Thomas et al. 2012, Naghibi, et al. 2014, and Jothibasu and Anbazhagan, 2016). Topographical indexes such as the TWI yields a first rough estimate of areas endangered by flood events. As topography is a dominant factor controlling surface runoff generation, flood-prone areas can be modelled within a topographic index such as the TWI. The TWI has been shown to be strongly correlated to the area exposed to flood inundation (De Risi et al. 2014; Aksoy et al. 2016) hence it can be used as a viable flood risk prediction tool.

The TWI is created using the open-source software Quantum GIS (QGIS). Although TWI assumes that the soil in the watershed is homogeneous and isotropic as a constraint, it was found that topographical changes become much more important, therefore, the difficulty in this assumption becomes negligible compared to the change in the topography of the watershed. This allows the use of the TWI in the hydrological analysis in this study. According to Aksoy et.al (2016), a value of zero indicates a location where saturation is low, and a value of 20 or more indicates locations where saturation will be high. Generally, high saturation values occur in areas where the specific catchment area ( $A_s$ ) is large (typically convergent areas in the landscape) and slope angle ( $\beta$ ) is relatively small. Conversely, low saturation values are found in areas where specific catchment area is small and slope gradient is relatively elevated.

### **Reclassification and Ranking**

There are different numbering levels, namely, ratio, interval, ordinal and nominal. Rasters in different number systems cannot be directly combined effectively. For example, in determining

morphometric flood risk, simply adding slope layer to drainage density layer would produce meaningless results due to the fact that both layers are not in the same number scale. Due to the different ranges of values and the different types of numbering systems each input layer may have, before the multiple factors can be combined for analysis, each must be reclassified or transformed to a common ratio scale and such common scales can be predetermined, such as a 1 to 5. Additionally, the values of continuous rasters such as for slope, elevation are grouped into ranges, however, each range must then be assigned a single value (rank) before it can be used in the Weighted Overlay tool (Table 7). The ArcGIS Reclassify tool allows for such rasters to be reclassified. The layers were reclassified into four sub classes using Equal Interval classification scheme. This classification scheme divides the range of attribute values into equal-sized sub-ranges. The number of intervals is specified while ArcMap determines where the breaks should be and new values re-assigned in order of flood susceptibility rating.

### Weighted overlay

Each of the criteria in the weighted overlay analysis may not have equal importance as certain parameters may be more important to the overall goal than others. Therefore, each of the parameter may be assigned different weights. The weights assigned represent the relative significance of a factor as against the modelled overall objective.

The weight of each factor determines its importance in the final flood risk map. The weight assigned for each layer can be based on expert judgement/perception of the relevance of each layer or sometimes backed by analytical processes such as the Analytical Hierarchy Process. The total weight of the layers must sum up to 100. To avoid subjective weighing and bias, all the layers were assigned equal weights. Finally, the obtained flood risk map was classified into four zones, namely, low, moderate, high and very high flood risk classes.

Table 7: Weight and reclassified values for different parameters

Parameters	Weight of Each Parameter in relation to the final score	Reclassified values (Classes)	Ranking	Hazard
Elevation	20	74.01 - 99	1	Low
		49.01 - 74	2	Moderate
		24.01 - 49	3	High
		-1 - 24	4	Very high
Slope	20	32.69 - 43.58	1	Low
		21.79 - 32.68	2	Moderate

Parameters	Weight of Each Parameter in relation to the final score	Reclassified values (Classes)	Ranking	Hazard
		10.90 - 21.78	3	High
		0 - 10.89	4	Very high
Drainage Density	20	0.03 - 1.37	1	Low
		1.38 - 2.72	2	Moderate
		2.73 - 4.07	3	High
		4.08 - 5.42	4	Very high
SPI	20	-13.86 - -4.22	1	Low
		-4.23 - 5.37	2	Moderate
		5.38 - 14.96	3	High
		14.97 - 24.56	4	Very high
TWI	20	4.03 - 9.18	1	Low
		9.19 - 14.32	2	Moderate
		14.33 - 19.47	3	High
		19.48 - 24.61	4	Very high

## **4.6: Methodology: Hydrologic Modeling and Flood Risk Mapping**

### **4.6.1: Computation of Runoff Curve Number (CN)**

According to Szwagrzyk et al. (2018), land use and land cover (LULC) affect both the probability of flood and its consequences in several ways. LULC changes have implications for the consequence component of flood risk through increased development of settlements on flood-prone areas (Kundzewicz et al. 2010). The Natural Resources Conservation Service's (NRCS) Runoff Curve Number (CN) is an empirical parameter that describes the response of the land surface to rainfall and the flood potential for the area. It is a representation of the watershed soil and cover conditions which include hydrologic soil group, cover type, treatment, and hydrologic). It is an index that represents the runoff potential of a sub-basin (Feldman, 2000). It is reflective of the fraction of the total precipitation that becomes runoff; consequently, the higher the CN, the greater the runoff fraction. It considers the characteristics of land use and soil type. The values of CN range from 100 for impermeable surfaces to 30 for very permeable soils with low runoff potential. SCS-CN method has proven to be a reliable method and has been used by a myriad of researchers. The precipitation excess, or runoff, will remain zero until the accumulated rainfall exceeds the initial abstraction. The inputs for constructing a CN map are soil and land-use maps.

Soil map is one of the major input parameters for generating CN. Hydrologic Soil Groups (HSG) of soils represents soils having similar runoff potential under similar storm and land-cover conditions. Generally, there are four types of HSG soil groups (A, B, C and D), and runoff potential increases from A to D (USDA, 1986; Feldman, 2000). HSG A soils have an infiltration rate greater than 0.3 in/hr and are predominantly sand or gravel soils with low runoff potential. HSG B are soils typified by infiltration rates ranging from between 0.15 to 0.30 in/hr and are moderately coarse soils. The infiltration rate of HSG group C soils ranges from 0.05 to 0.15 in/hr and are moderately fine to fine soils that can impede water flow. For HSG D, the infiltration rate is less than 0.05 in/hr and are typically very fine soils (clays) with high runoff potential (Mockus, 1972).

Since there was no available soil map for determining Hydrologic soil group (HSG) in the study area, a self-prepared soil map (Figure 21) was developed for the study area. To generate data for the soil map, the following procedure was followed:



- First, a digital soil map in TIFF format was obtained from the United Nation's Food and Agricultural Organization (FAO)
- Then the map was clipped and re-classified based on soil texture, of which four types of soil were identified (Table 8). Two types of HSG were categorized in the area.

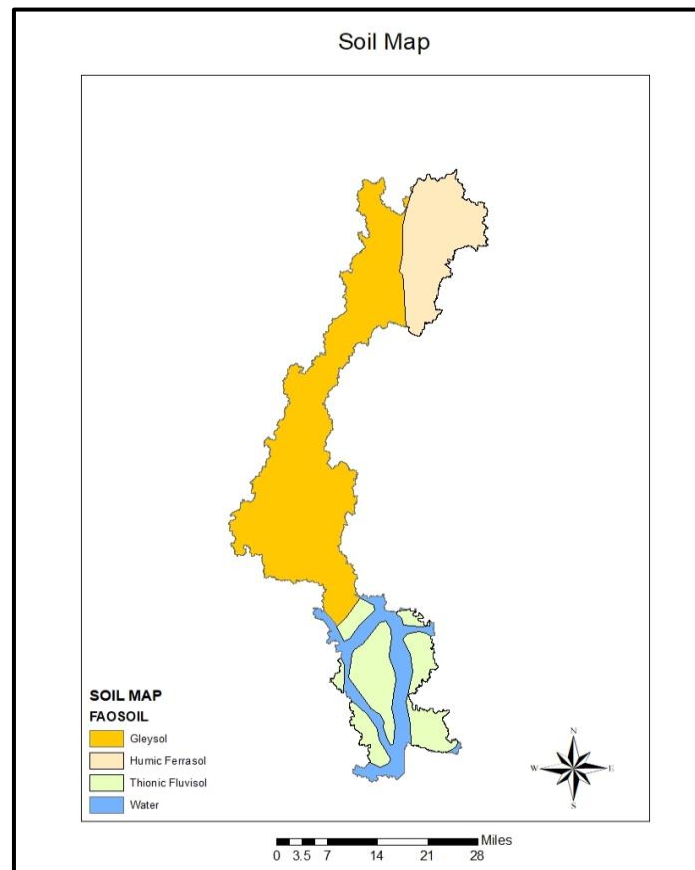


Figure 21: Soil Map of the Orashi Basin<sup>3</sup>

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<sup>3</sup> The area marked water is made up of water bodies and so classification could not be carried out in such areas.

Table 8: Hydrologic Soil Group Classification for Study Area

FAO soil type	Texture	HSG code	Infiltration rate
Gleysol	Clay	D	Very low
Fluvisol	Clay	D	Very low
Ferrosol	Sandy clay	C	Low
Nitisols	Sandy clay	C	Low

Table 9: CN look-up table used for developing the curve number

LU value	Description	A	B	C	D
5	Water	100	100	100	100
4	Swamp	100	100	100	100
1	Built-up	77	85	90	92
2	Agricultural area	43	65	76	82
3	Forest area	30	55	70	77

- All LULC raster maps were converted to polygon maps and assigned land-use codes based on the LULC type. <sup>4</sup>
- Next, depending on the HSG and LULC type, CN values were assigned. The CN values were assigned using NRCS runoff CN values in Table 8 (USDA, 1986). That is for built up areas, forest, agricultural area and water body. The higher the CN value, the greater the runoff potential.
- Finally, after merging the land-use and soil group layer, a Look-up table (Table 9) was further generated. The Look-up table was then used to create a CN-grid map in HECGeoHMS.

#### 4.6.2: Hydrologic Modelling

The use of hydrological models has become popular and vital in studying the hydrological response of catchments to land use and climate change. Hydrological modelling has become a veritable technique for investigating hydrological system by researchers involved in water resources management. Additionally, hydrologic model forms the basic tools in traditional flood warning systems for predicting flows based on the hydro-morphological and meteorological data in a river catchment (Adnan, 2015).

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<sup>4</sup> Note in hydrology: water and mangrove classes are assigned very high runoff potential, therefore, both land-cover types were re-classified to as waterbody due to similarity in their hydrologic properties

In this thesis, the hydrologic modelling method was used to understand the watershed's response to rainfall and land-use changes. According to Obiora-Okeke (2019), rainfall-runoff simulation is vital in generating peak discharges required for the design of hydraulic structures and flood investigation. Tassew et al. (2019) further notes that rainfall-runoff models are employed as a tool for a broad range of objectives, such as the modelling of flood events, the monitoring of water levels during different water conditions or the prediction of flow. It is also used as a tool for assessing the impacts of climate change and land use changes on hydrological cycles.

While the modelling of climate change generally relies on conceptual rainfall-runoff models, models with spatially-distributed parameters are needed to simulate the effects of land-use changes on runoff in river basins (Kohnová et al., 2019). Most hydrologic modelling systems are designed to simulate the precipitation-runoff process of a dendritic watershed system. These models estimate peak discharges and runoff hydrographs for various return periods at different location of the watershed.

In recent years there has been plenty of studies by different researchers to understand and model the processes involved in the hydrological cycle, this has resulted in a wide variety of models been developed to address a wide spectrum of environmental and water resources problems (Singh and Woolhise, 2002). Several models have used to analyze and forecast the effects of climate and land use change on hydrological process. Recently, hydrological simulation models such as SWAT, MIKE-SHE, HSPF, WASIM-ETH, DHSVM, and HEC-HMS etc. have been developed to quantify the influence of change in land use, land cover and management practices on the hydrologic cycle (Abebe, 2014).

#### **4.6.3: Classification of Hydrological Models**

The purpose of a model is to represent a complex system in a simplified way. There is a wide variety of models to represent the complex hydrologic dynamics of the earth system. Hydrological models may vary in terms of how processes are represented, in time and in space scale that are used and in methods of solution to equations are used. Different researchers have developed different classification systems where they grouped the hydrological models to facilitate the modelling approach (Figure 22). For instance, Singh (1995) classified hydrologic models based on the following criteria

- Process description;
- Timescale;
- Space scale;
- Techniques of solution;
- Land use; and
- Model use.

In terms of the hydrological processes, hydrological models can be also classified as deterministic, stochastic, or mixed (Olsson and Pilesjo, 2002). In a deterministic model, outcomes are precisely determined through known relationships among states and events, without any room for random variation. In such models, two equal sets of input always yield the same output if run through the model under identical conditions. Conversely, if a model has at least one component of random character which is not explicit in the model input, but only implicit or hidden it is referred to as a stochastic model. If the model components are described by a mix of deterministic and stochastic components, the model is called stochastic-deterministic or hybrid model.

Based on spatial description, hydrological models are classified as lumped models, semi-distributed and distributed models (Lastoria, 2008; Xu, 2009). Lumped models do not consider the spatially varying character of drainage basin rather it considers the whole basin as one entity. It averages the output results at the outlet of the basin (Lastoria, 2008). Lumped conceptual models are characterized by a simple structure, minimum data requirements, fast setup and calibration and ease of use (Cunderlik, 2003). In a lumped model, the model uses average values for the entire catchment. The averages can be derived either physically or empirically which can give the model a semi-empirical appearance. These lumped models are mainly used in rainfall-runoff modelling. Lumped conceptual models need moderately accurate rainfall and runoff data and average physical characteristics of the area concerned. Parameters of these models can be calibrated and verified with historical data available. Most of the hydrological models available currently come under this category.

In semi-distributed models, spatial variation is partially allowed by dividing the basin into several smaller entities or sub-basins (Abebe, 2014). They are more physically-based than lumped models and demands less input data than fully distributed models (Xu and Singh, 2004). Semi-distributed hydrologic models calculate flow contribution from separate sub-

basins, considering that the sub-basins are homogenous (Xu, 2002). Examples of semi-distributed hydrologic models are the TOPMODEL (Beven and Kirkby, 1979) and Soil and Water Assessment Tool (SWAT) (Douglas-Mankin, et al., 2010).

In distributed models, the whole basin is divided into elementary units (i.e. areas are divided as a grid net where water flows from one grid point to another when water drains through the basin) (Xu, 2002). Distributed models allow parameters to vary in space at a resolution usually chosen by the user. These models generally require large amounts of (often unavailable) data for parameterization in each grid cell (Pechlivanidis, et al., 2011), however, the governing physical processes are modelled in detail, and if properly applied, they can provide the highest degree of accuracy (Cunderlik, 2003). Typical examples of these models include CASC2D (Ogden, 1998) and MIKE SHE (Refsgaard and Storm, 1995). Distributed hydrological models are advantageous in terms of studying effects of land-use changes because its distributed nature enables the simulation and estimation of spatial variations, characteristics and changes inside a catchment. It not only provides a single outlet discharge but multiple outputs on a temporally and spatially distributed basis (Mango, 2010). However, in practice, the paucity of data militates against the formulation of distributed models.

Hydrological models also can be differentiated based on the time scale into event-based or continuous. Event-based calculations need initial conditions while continuous models need data of soil type to calculate soil moisture content and atmospheric data as well to calculate evaporation losses (Singh, 1995). Event-based models are designed to simulate individual precipitation-runoff events; they are capable of simulating short-term events. Their emphasis is placed on infiltration and surface runoff; they are mostly applied where direct runoff is the dominating runoff component (Lastoria, 2008). Typically, event models have no provision for moisture recovery between storm events and, therefore, are not suited for the simulation of dry weather flows. Conversely, a continuous model simulates a longer period, predicting watershed response both during and between precipitation events. These models take explicit account of all runoff components, including direct and indirect runoff. They focus on long-term hydrologic abstractions responsible for the rate of moisture recovery during the periods of no precipitation. They are suited for simulation of daily, monthly or seasonal streamflow, usually for long-term runoff-volume forecasting and for estimates of water yield (Singh, 1995; Cunderlik, 2003).

The choice of the particular model to be employed in hydrological analysis is a key issue. Currently, there are numerous hydrological models simulating the hydrological process at different spatial and temporal scales. Although there are no clear rules for making a choice between models, some simple guidelines can be stated. To facilitate the selection process of the hydrological model, Table 10 has been prepared. It presents a summarised review of different hydrological models, describing their input requirements, strengths and limitations. Subsequently, based on the review of different models, the simplest models that can provide reliable answers to the research problems were chosen. From the preceding sections and considering the criteria developed, HEC-HMS model have been selected for this research.

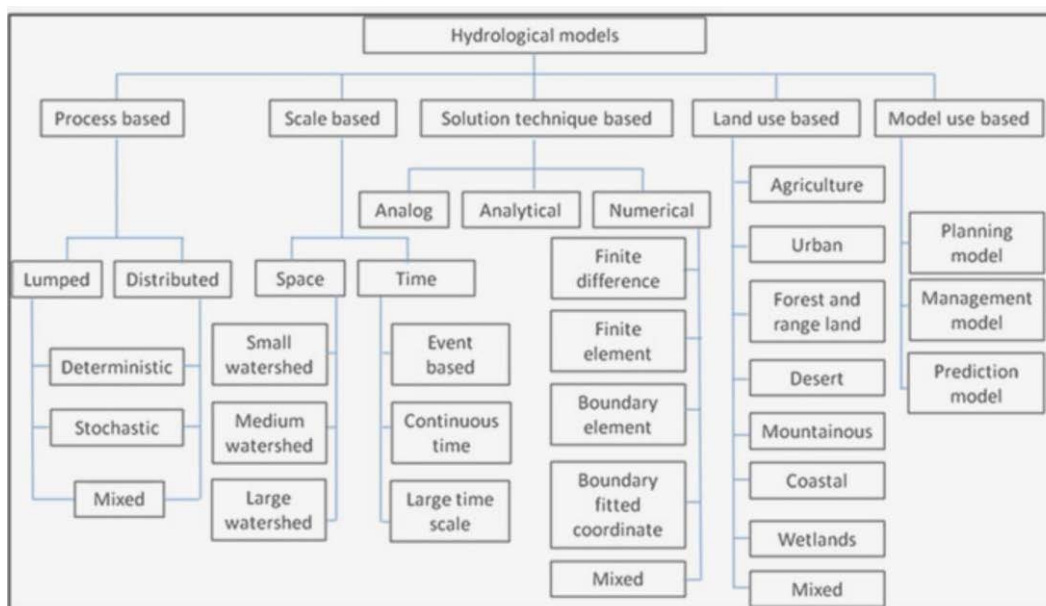


Figure 22: Classification of Hydrological Models (Saha and Zeleke, 2015)

Table 10: Description of six examined semi-distributed hydrological models (Source Mengistu, 2009)

Description	SWAT	HSPF	HEC-HMS	WaSiM-ETH	DWSM	HBV
Model Type	Semi-distributed Physically-	Semi-Distributed conceptual model	Semi-distributed Physically-based	Semi-distributed Physically-	Semi-distributed Physically-based	Semi-distributed conceptual model

Description	SWAT	HSPF	HEC-HMS	WaSiM-ETH	DWSM	HBV
	based long-term			based modular		
Model objective	Predict the impact of land management practices on water and sediment	Simulates watershed hydrology, and sediment-chemical interactions	Simulate the rainfall-runoff process of dendritic watersheds	Simulate watershed water balance	Simulations of surface and subsurface storm water runoff, flood, sediment transport,	Simulate rainfall-runoff process and floods
Temporal scale	Day+	Flexible	Day-	Day+	Day+	Day-
Watershed representation	Sub-watersheds grouped based on climate, HRU, ponds, groundwater, and main Channel	Uses sub-basins as primary hydrological units	Uses sub-basins as primary hydrological units	Grid based	Sub-watersheds (1-D overland elements, channel, and reservoir units.	Uses sub-basins as primary hydrological units
Process modelled	Continuous	Continuous and event	Continuous and event	Continuous	Single event	Continuous and event
Runoff on overland	Runoff volume using CN and flow peak using Rational formula.	Chezy-Manning equation.	Clark's, Snyder's, SCS UHs, ModClark Kinematic wave	using saturation time after Peschke (1977)	Kinematic wave equations	Uses response function to transform excess rainfall to runoff
Evapo-transpiration	Hargreaves, Priestley-Taylor and Penman	Hamon, Jensen methods	Monthly average	Penman-Monteith, Wending, Hamon	No information	Monthly average

Description	SWAT	HSPF	HEC-HMS	WaSiM-ETH	DWSM	HBV
Subsurface flow	Lateral s flow using kinematic storage model and groundwater flow using empirical relations.	Interflow outflow, and groundwater flow using empirical relations	Constant monthly, Exponential recession or Linear reservoir	Empirical equation	Combined interflow, and baseflow using kinematic storage equation	Simple functions of actual water storage in a soil box
Water Routing	Variable storage coefficient method Or Muskingum method	Inflows enter upstream point, and outflow is a function of reach volume	Kinematic wave, Lag, Muskingum, Cunge	Translation-retention approach using hydraulic parameters	Same as overland flow	Muskingum method or simple time lag
Management practices	Agricultural management, tillage, irrigation, etc	Agricultural management, irrigation,	Account human impact runoff	Irrigation, Water management options	Detention basins, alternative ground covers,	Different management practices

### The rationale for using HEC-HMS Software

A flood warning system based on precipitation data alone cannot function without a component relating precipitation to river flow, which is what the exact function of the hydrologic model. In order to quantify the impact of land use changes in the Orashi basin, land use map and other data was inputted in the hydrologic model of the basin. The hydrology of the basin was simulated using a model built with the Hydrologic Engineering Center Hydrologic Model Simulation (HEC-HMS) software developed by the United States Army Corps of Engineers (USACE). The selection of the HEC-HMS software was mainly based on the objectives of this study and available data. The rationale for selection includes:



- The capacity to estimate peak discharge in ungauged basins: Catchments in the study area are ungauged, which is a challenge for hydrologic studies. The HMS model is able to simulate the rainfall-runoff process in ungauged basins where input and calibration data are unavailable.
- Less data-intensive: In terms of input complexity, HEC-HMS has a medium input complexity while other software such as SWMM, SWAT and Mike URBAN has high input complexity. This means the latter are more data intensive. HEC-HMS is able to perform hydrologic analysis of basins with a few parameter inputs; an important fact, considering the lack of reliable data for this region.
- Wide application: HEC-HMS model have been widely used in a wide range of geographical areas and contexts. Importantly, it has been used for modelling rainfall-runoff in many areas, for example Muller and Reinstorf (2011) used it in the exploration of land-use scenarios for flood hazard modelling in Santiago, Chile.
- Ability to model a wide range of hydrologic processes: The model considers every hydrologic process from losses (such as evaporation, evapotranspiration, surface storage, interception and infiltration) to surface runoff to base flow (Feldman, 2000).

#### **4.5.4: Description of HEC-HMS Model**

Hydrologic Engineering Centers Hydrologic Modeling System (HEC-HMS) is public domain software developed by the US Army Corps of Engineers (USACE) (USACE, 2009b), which is designed to simulate the rainfall-runoff processes, particularly for dendritic watershed. It is a semi-distributed physically-based hydrologic model which is designed to simulate event-driven and continuous runoff over a long period of time, and to compute runoff using grid-cell depiction of the watershed (Scharffenberg and Fleming, 2006). The model has the capacity to estimate peak discharge, peak volume, and time to peak, given the precipitation, soil and land-use inputs (Feldman, 2000; Scharffenberg and Fleming, 2006). It has an integrated graphical user interface (Scharffenberg, 2001). Its operation is seamless with a fast-computational engine as well as data storing and reporting capability (Feldman, 2000). The model can be used both for small and large river basins to simulate water supply and flood hydrographs (Fleming and Neary, 2004).

Over 30 years of continuous research and improvement has made the model widely applicable for rainfall-runoff modelling (Scharffenberg, 2001)). The current version of the HEC-HMS model is a highly flexible package both in time and space and it is capable to model the effect

of land use and climate change (Cunderlik, 2003). The model can be integrated with other software (e.g. HEC-RAS) for several applications such as, floodplain delineations, urbanization studies, reservoir design, and water availability analysis. According to Halwatura and Najim (2013), many researchers have used HEC-HMS to simulate runoff in different parts of the world. Tulu (2010) used an event-based HEC-HMS approach to develop rainfall-runoff relations in Northern Ethiopia to regionalize runoff coefficients. Emam et al. (2016) simulated the effects of land-use and climate change on flooding (e.g., peak flow and river discharge) in the upper Ciliwung River basin in Greater Jakarta, Indonesia using the Hydrologic Modeling System to simulate peak river discharge values for current and future conditions. Mahmood et al. (2016) used HEC-HMS to analyze the impact of climate change on water resources in Pakistan. The HEC-HMS has also been applied in other areas such as water balance studies (Tefera, 2017).

Figure 23 shows the general interrelation between HEC-HMS, Geographical information system (GIS) and HEC-GeoHMS. Input data to HEC-HMS is pre-processed using HEC-GeoHMS under GIS environment. In this thesis, HEC-GeoHMS is used to delineate sub basins and other watershed characteristics that collectively describe the drainage patterns from the digital elevation model (DEM) of the basin.

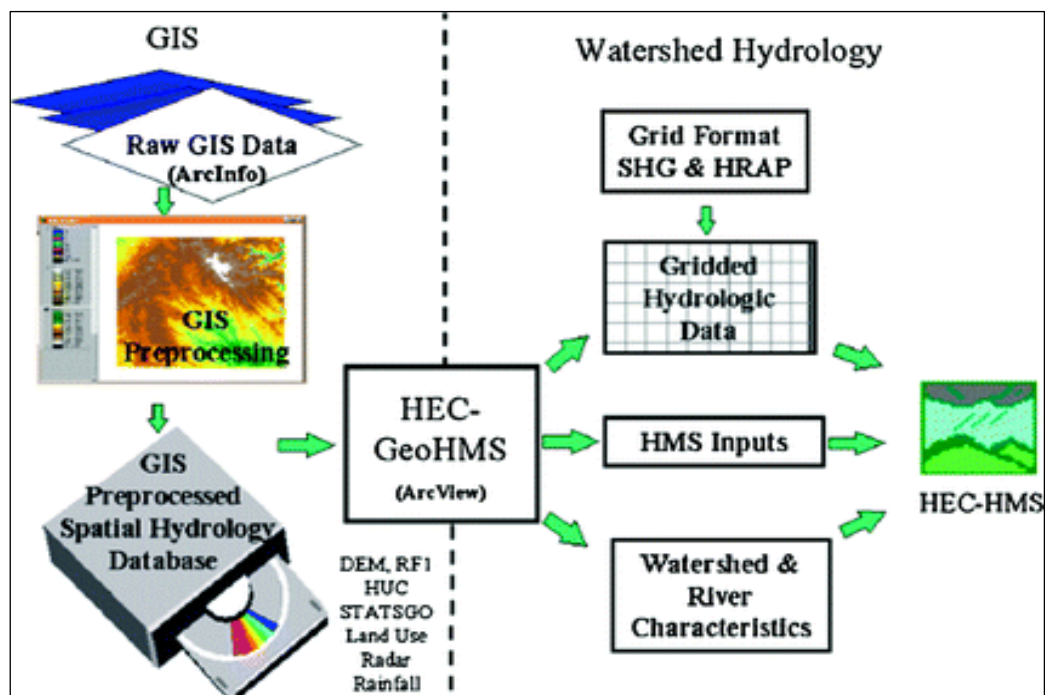


Figure 23: Relationship between HEC-HMS, (GIS) and HEC-GeoHMS (USACE, 2013).

## Components of the HEC-HMS Model

HEC-HMS combines separate models to represent the components of the rainfall-runoff process. It estimates loss (runoff volume), transformation (discharge runoff), base flow and channel routing respectively (Feldman, 2000). The HEC-HMS (Version 4.0) model is grouped into four major input components,

- The basin model,
- The meteorological model,
- The data manager and
- The control manager.

**The Basin model:** is used to represent the physical process of the watershed, comprising of the basin and channel routing parameters as well as connectivity data (Dan-Jumbo and Metzger, 2019). It is a description of the different elements of the hydrologic system (sub-basins, channels, junctions, sources, sinks, reservoirs and diversions) including their hydrologic parameters and topology. The basin model component is capable of representing a variety of watersheds by subdividing the hydrological system into smaller and manageable pieces with seven types of hydrologic elements sub-basins, reach, junction, source, sink, reservoir and diversion.

**The meteorological model:** Precipitation is the driving force for the watershed responses in the case of HEC-HMS model; so an effort was made to compute the meteorological model to receive spatially and temporally distributed precipitation input data. A meteorological component, which is a description in space and time, of the precipitation event to be modeled, and consists of time series of precipitation at specific points or areas and their relation to the hydrologic elements. The meteorological model in HEC-HMS includes precipitation and evapotranspiration for continuous runoff modeling (Feldman, 2000). In this thesis, evaporation and transpiration (evapotranspiration) were neglected in the modeling since the focus is to simulate short duration, large rain events when evapotranspiration is a minimal component of the water balance.

**Control specifications component:** Defines the time window for the precipitation event and for the calculated flow hydrograph (Olivera and Maidment, 1999). The component contains

information about the start and end times, and the time-step interval for the simulation (USACE 2013).

### Model Pre-processing

In order to set-up the HEC-HMS for the Orashi basin, a hydrologically-corrected DEM was created from SRTM data. Land cover and soil properties were also processed and re-classed using ArcHydro tool. A series of pre-processing tasks were performed with the input data using HEC-GeoHMS and Arc-Hydro in the ArcGIS environment. Terrain pre-processing steps, such as filling sink, flow direction, flow accumulation, stream/drainage line processing and watershed delineation, were performed using ArcHydro Tools and ArcGIS HEC-GeoHMS. Figure 24 shows the preprocessing steps of the HEC-HMS modelling process. Figure 25 shows the HEC-HMS modelling process.

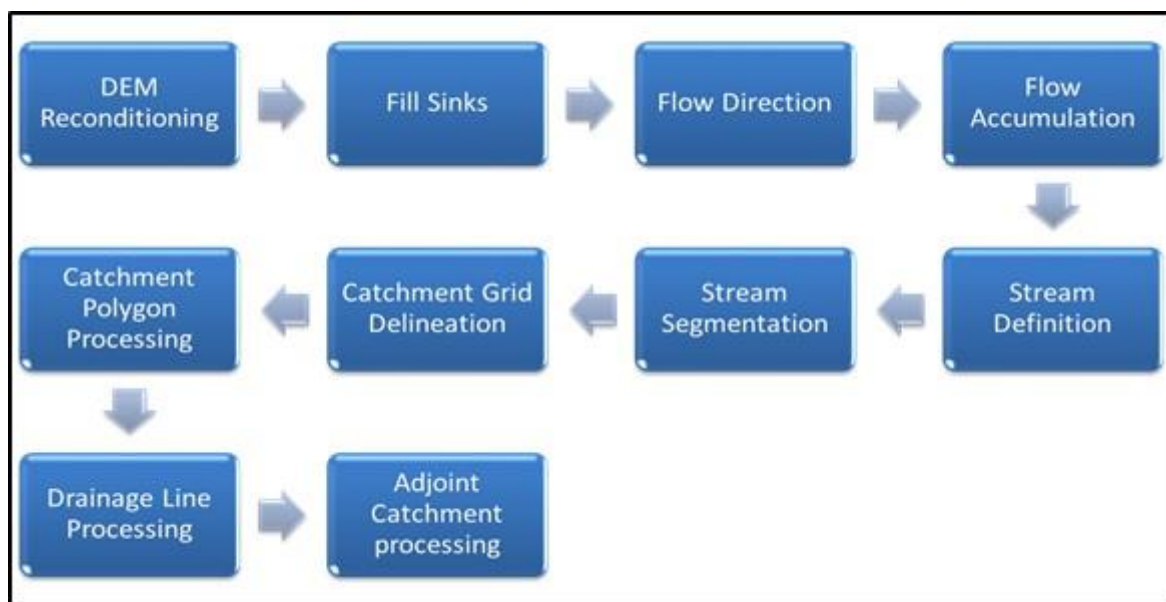


Figure 24: pre-processing steps of the HEC-HMS

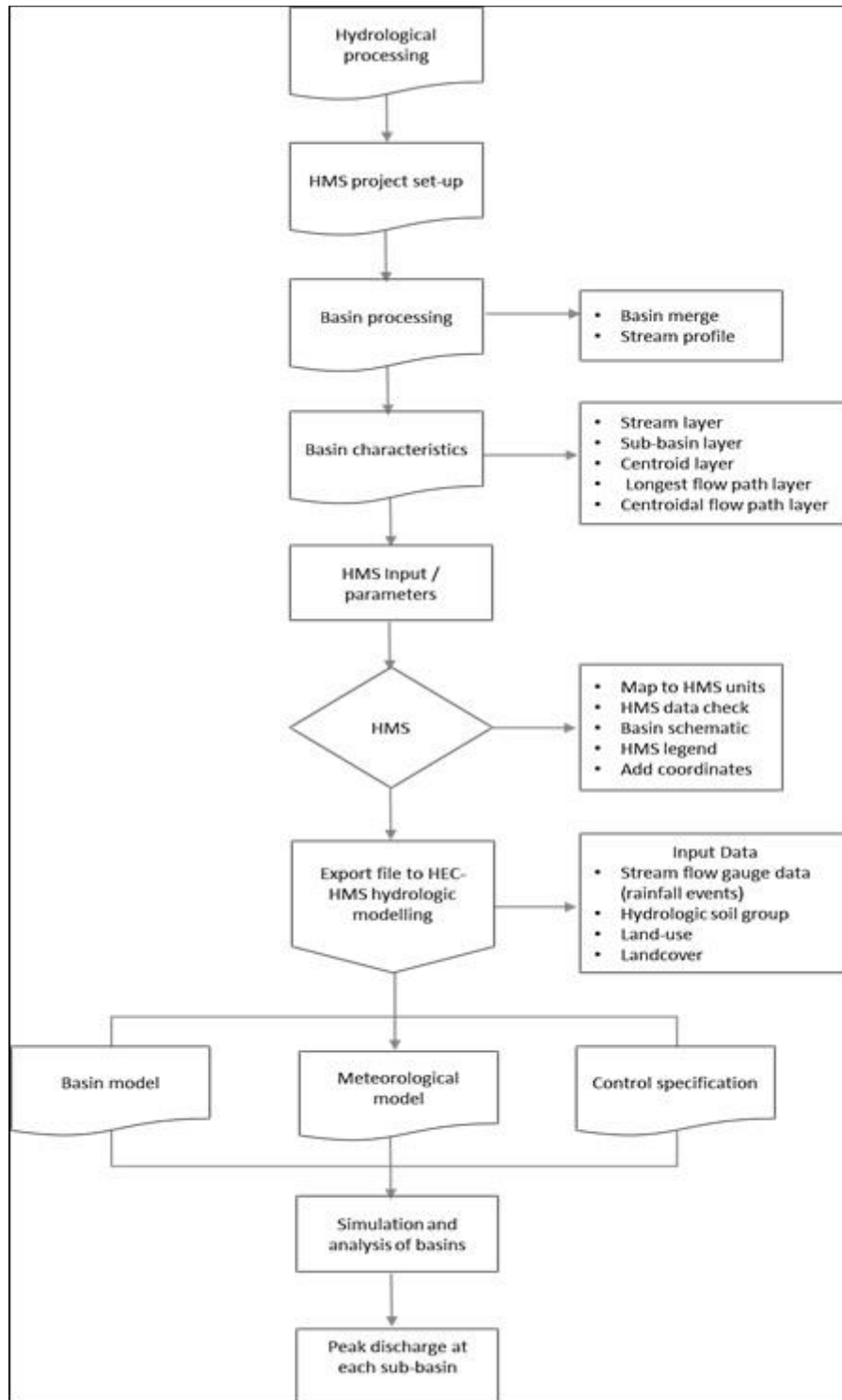


Figure 25: HEC-HMS modelling process

In the basin model, the watershed is represented by combinations of hydrologic elements such as subbasin, reach, reservoir, junction, diversion, sources, and sink. The development of a basin model requires the specifications of these elements and the data that controls the flow of water

through these elements in the watershed. The basin model requires setting up the parameters for calculating the basin loss, runoff transform, runoff routing, and base flow.

### **Loss Model**

The loss model in HEC-HMS calculates the runoff volume by computing the volume of water that is intercepted, infiltrated, stored, evaporated, or transpired and subtracting it from the precipitation. For infiltration loss computations, the following methods are available: initial and constant, SCS curve number, gridded SCS curve number, Green and Ampt method, deficit and constant, soil moisture accounting and gridded soil moisture accounting. The SCS method was used to compute precipitation loss in this thesis. The SCS method has several advantages over other methods in that: It is a simple conceptual method for the estimation of the direct runoff amount from a storm rainfall event, and is well supported by empirical data; it relies only on the curve number, which is a function of the soil type and land use/cover that are the major runoff-producing watershed characteristics.

The SCS curve number method only requires the following input.

- Curve Number - CN<sup>5</sup>
- Basin Area<sup>6</sup>
- Initial Abstraction (Ia)
- Impervious percentage layer<sup>7</sup>

The initial abstraction comprises all the losses that occur before surface runoff begins. It includes water retained in surface depressions as well as water intercepted by vegetation, evaporation and infiltration. An empirical relationship (Equation) used in the SCS method for estimating Ia is:

$Ia = 0.2S$  (iSWM, 2014) Where S = Potential maximum retention (in) after runoff.

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<sup>5</sup> Refer to chapter 4 for the methodology

<sup>6</sup> It is automatically calculated by the HEC-HMS

<sup>7</sup> The baseline Impervious layer is assumed to be zero since all parts of the basin is assumed to be pervious to some extent

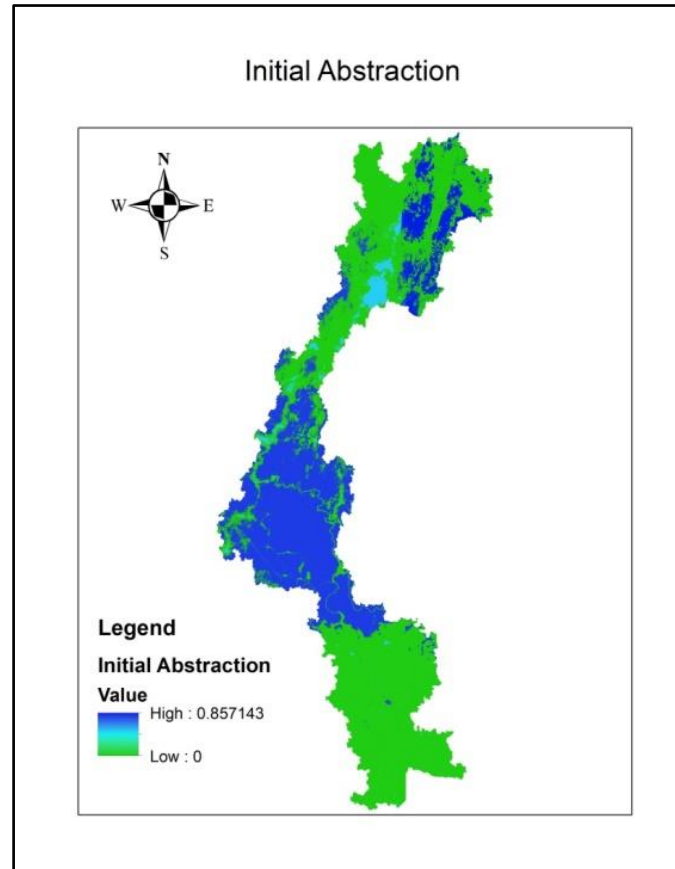


Figure 26: Initial abstraction

Additionally, impervious surface variations were not considered in the scenarios because the impervious surface in the basin is negligible.

### **Transformation of excess precipitation to runoff**

In HEC-HMS hydrologic model, precipitation excess is transformed into surface runoff and HEC HMS has several transform methods available, namely, Clark, Snyder, and SCS unit hydrograph methods; user-specified unit hydrograph or s-graph ordinates; ModClark (with gridded meteorologic data), kinematic wave method (with multiple planes and channels).

The SCS Unit Hydrograph method which is based on average unit hydrographs from geographic rainfall distributions is used in this thesis. The SCS method determines direct runoff from rainfall based on the physiographic characteristics of land use, antecedent moisture conditions and soil type (Nicandrou, 2010). The SCS hydrologic models are among the most widely used models in water resources planning and design. They have great utility because they can be applied to ungauged watersheds. They were originally developed for agricultural

areas; however, they have been extended for use in urban areas (Rallison and Miller, 1982). Figure 27 illustrate the SCS methodologies as applied for runoff volume estimation and conversion of the excess precipitation into a runoff hydrograph.

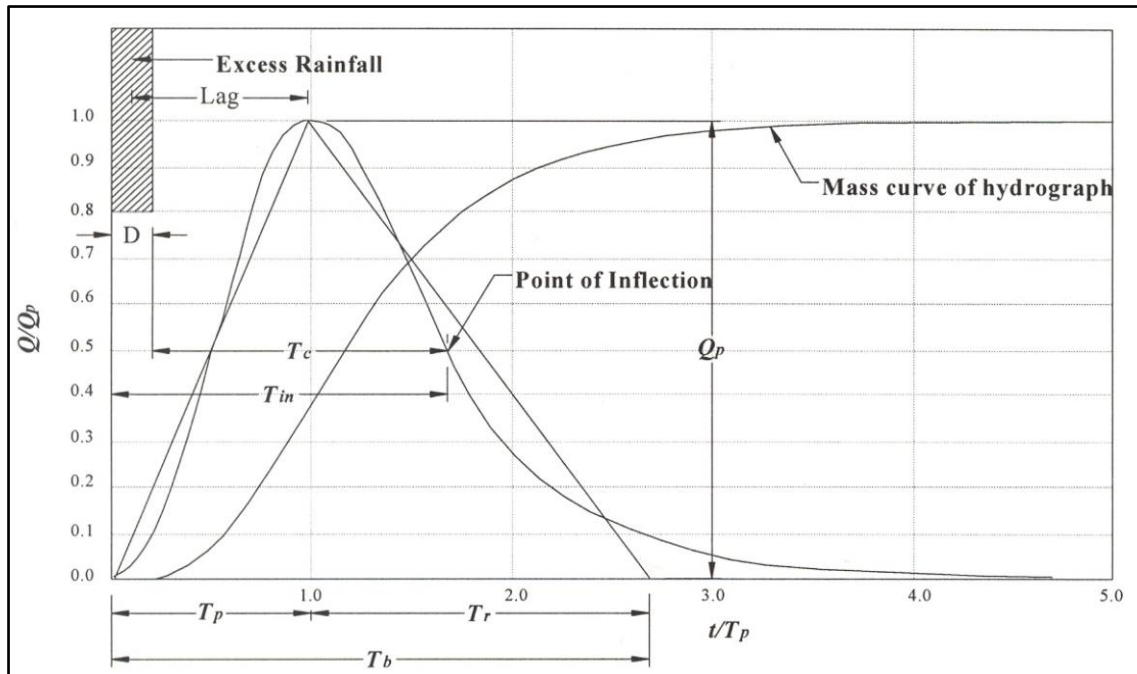


Figure 27: Illustration of the SCS methodology (Patel, 2019)<sup>8</sup>

The SCS proposes that UH peak ( $q_p$ ) and time of UH ( $T_p$ ) peak are related by:

$$q_p = 2.08 \left( \frac{A+Q}{T_p} \right)$$

Where,

A = the drainage area

Q = the runoff volume (excess rainfall)

$T_p$  = the time to peak in hours, and  $q_p$  = the peak flow

Time to peak or time of rise equals to the duration of the unit excess precipitation  $\Delta t$  given by the following equation.

<sup>8</sup> Online: <http://www.professorpatel.com/introduction.html>



$$T_p = \frac{\Delta t}{2} + t_{lag}$$

Where  $\Delta t$  = excess precipitation duration (which is the computational interval in HMS)

$t_{lag}$  = the basin lag

The SCS method requires a lag parameter, which is calculated using the Time of Concentration method. For ungauged watersheds, the SCS suggests that the lag time of UH may be related to time of concentration,  $t_c$ , as:

$$t_{lag} = 0.6 t_c$$

The basin lag: The standard lag is known as the length of time between the centroid of precipitation mass and the peak discharges of the resulting hydrograph (USGS 2012). The basin lag time parameter values are computed during data processing using of the HECGeoHMS application and stored in the attributes' table of the sub-basin data layer. In the transform method, the lag time is given as input, and the SCS developed is given as a link between the time of concentration ( $T_c$ ) and the lag time ( $T_{lag}$ ), as given by equation below.

The SCS formula is

$$T_{lag} = 0.0057 \cdot \left( \frac{100}{CN} - 9 \right)^{0.7} \cdot \frac{L^{0.8}}{\sqrt{S}}$$

Where  $T_{lag}$  is watershed lag time in hours,  $L$  is the length of the longest flow path in kilometres,  $S$  is the average watershed slope in m/m, and  $CN$  is the SCS runoff curve number.

**Base flow:** Base flow was neglected in this study in the absence of available records. Although this may reduce the accuracy of the result, however Feldman (2000) supports that the contribution of base flow in urban watersheds is negligible and can be neglected. Furthermore, the rivers and the watersheds are ungauged and due to their location in a remote and impoverished area, complex field surveys are not possible.

**Channel routing model:** Channel routing is the movement of a flood wave through a river reach. A routing model is used to calculate the conversion of rainfall flow to channel flow for a river. Channel flow computes a downstream hydrograph based on upstream hydrograph as a boundary condition. Different routing models are available in HEC-HMS, such as Lag, Muskingum, Modified, Modified Puls, Kinematic-wave and Muskingum-Cunge methods. In this thesis, the Muskingum-Cunge method was chosen to calculate channel runoff. For this method, the following parameters must be specified: the width of the channel bottom and side slope, the Manning Roughness Coefficient and the shape of the channel (Vanova and Langhammer, 2011). The method involves the use of a finite difference scheme to solve the Muskingum equation. The Muskingum equation relates the relationship between the reach storage and discharge as the flood propagates through the reach (Rahman, et al., 2017). The basic parameters in the Muskingum-Cunge equation that are incorporated by National Resources Conservation System (NRCS) are X and K and are given as:

$$X = \frac{1}{2} \left( 1 - \frac{Q}{BS_0c\Delta x} \right)$$

where, X = weighting factor, non-dimensional, Q = reference flow from the inflow hydrograph (m<sup>3</sup>/s), B = bottom width of flow area or average width (m), c = flood wave celerity (m/sec), Δx = length of routing (m), S<sub>0</sub> = bed slope of the channel (dimensionless) and

$$K = \Delta x / c$$

$$c = \beta V$$

where, β = exponent, V = Average velocity (m/s).

**The Meteorological model:** Is a major component of HEC-HMS. Its purpose is to prepare meteorologic boundary conditions for sub-basins. It uses the atmospheric conditions over the watershed to classify the rain gauge station precipitation values along the watershed. The meteorologic model stores the precipitation and evaporation data required to simulate watershed processes. In this thesis, it is assumed that evapotranspiration is negligible for the

event model due to the intensity of the storm being modelled, therefore, no information of evapotranspiration included in the model. A variety of methods are available within HEC-HMS for distributing measured precipitation data over the study area. But the gauge weight method was adopted for the meteorological data analysis. The weight to be given to each gauge was defined using Thiessen polygons. The Thiessen polygon was created using the ‘Create Thiessen Polygon’ analysis tool in Arc Toolbox within ArcCatalog (a component of ArcGIS Desktop). Based on the location of gage points, Thiessen polygons are created and clipped to the boundary of the basin. Figure 28 shows the Thiessen polygons of the gages and the sub basins. Details of percentage depth weight for different basins are shown in the appendix.

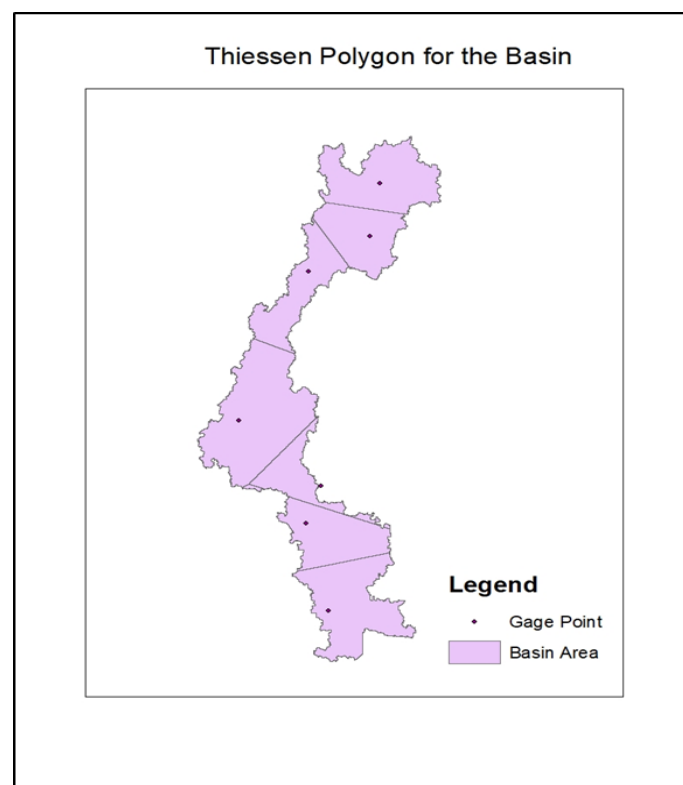


Figure 28: Thiesson Polygon

### Source of Precipitation Data

Estimated precipitation values from satellite products provide a solution for areas where rain gauge density is either sparse or poor. Several methods have been developed and used for estimating precipitation values from satellite images using several bands of the electromagnetic spectrum (Dingman, 2002). However, the Geostationary Operational Environmental System (GOES, METEOSAT) and the Tropical Rainfall Measuring Mission (TRMM) are the most

popular satellites to measure precipitation over the oceans and tropics. TRMM was launched by the H-II rocket from Tanegashima Space Center of NASDA, November 28, 1997. This satellite was developed as a joint project between Japan and US, which is the first space mission dedicated to measuring rainfall. TRMM mainly observes rain structure, rate and distribution in tropical and subtropical region. Right from 1997, TRMM has provided vital precipitation measurements in the tropical and subtropical regions of the earth. At first step, satellite rainfall data from the TRMM database (TMPA 3B42 product) was evaluated by comparison with actual rain gauge data from the study area.

Based on other studies such as Chen et al. (2019) and Cruz et al. (2018), it was concluded that TRMM data are quite reliable for their direct and real time use for conducting any rainfall-based studies. A set of 3 hourly data covering the storm period was downloaded and stacked. Using the multi-point tool in ArcGIS, the value of the pixel data was extracted. In the next step, seven artificial rain gauges were created in HEC-HMS for the different sub-basins in the basin and the gauges were populated with the extracted pixel values of the corresponding TRMM grid (Figure 29). In this manner, quasi-distributed rainfall data was input into HEC-HMS for simulating the different storm events.

Due to incomplete data to run a continuous-based runoff model, an event-based model was used. An event-based model was deemed suitable since the goal of the analysis was not to forecast changes in stream flow, but rather to evaluate the impact of land use changes on peak flow and runoff volume and other hydrological parameters. Rainfall data of the 2015 and 2012 flood events are selected for use in the HEC-HMS model.

The basin model showed in Figure 30 represents the physical characteristics of the watershed.

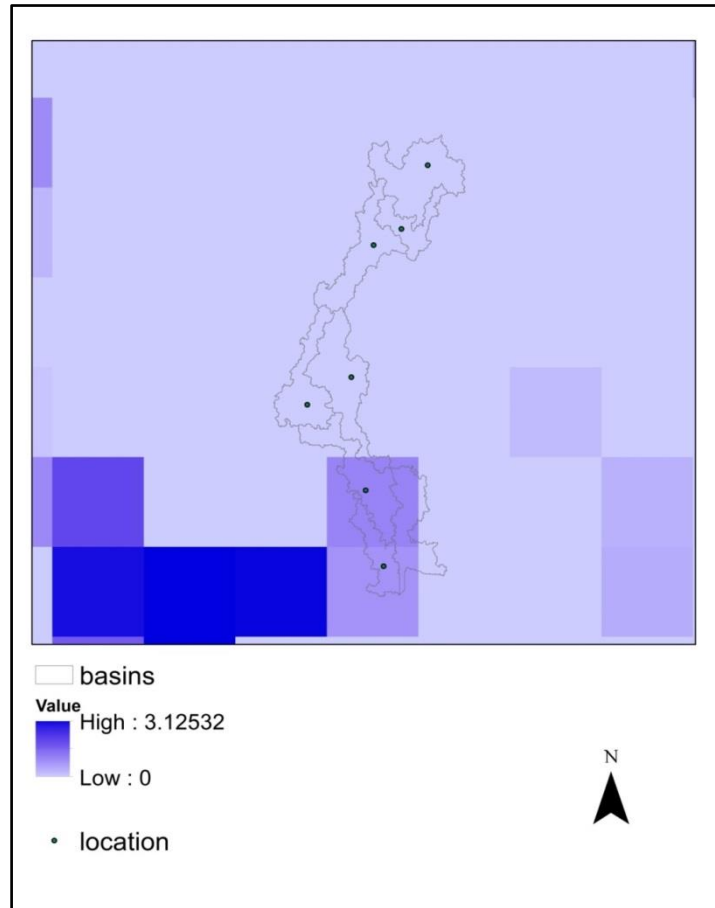


Figure 29: Samples of TRMM data tiles

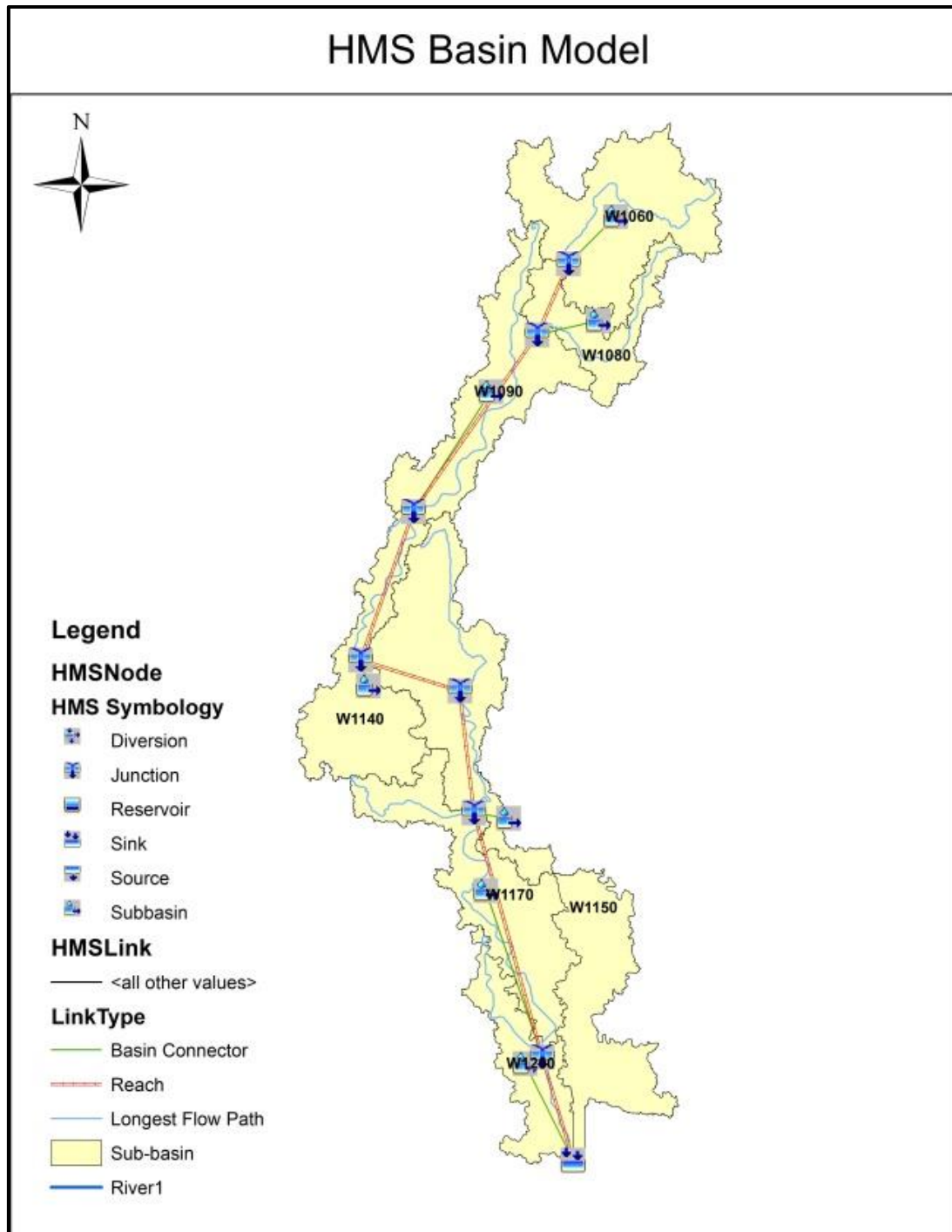


Figure 30: HEC-HMS Basin model

## **4.7: Methodology: Hydraulic Flood Risk Modelling**

### **4.7.1: Flood Risk Modelling**

Hydraulic flood modelling is important for the assessment of flood vulnerability studies to show the magnitude of and inundation extent of flood events. Hydraulic modelling and flood inundation mapping are done in order to provide vital information from a flood event such as the level of inundation and flood depth in the study area. One of the methods used in inundation mapping is using hydraulic models to generate a water surface elevation at a given location, which is then extrapolated across a digital terrain model to find out which areas would be inundated during a flood event. Various software packages are available for modelling flood hazards. These software packages are differentiated based on the modelling type, dimension (i.e. one, two or three dimensions), data requirements and the applications for which it was originally developed. Two- and three-dimensional models require very high-resolution data as well as data pertaining to flood wave characteristics, to determine the duration and peaks. One-dimensional software is normally used to perform basic hydraulic analysis of, for example, water level and flood extent. The water level is then combined with the TIN to determine the water depth or inundation zones. Mike 11 and HEC-RAS are examples of software packages that carry out one-dimensional modelling.

### **4.7.2: HEC-RAS Flood Simulation Model**

The hydraulic analysis for flood inundation was performed using the Hydraulic Engineering Center's River Analysis System (HEC-RAS) computer program developed by the United States Army Corps of Engineers (USACE). The HEC-RAS model is one of the most commonly utilized floods modelling software in hydrodynamic simulation (Waghchaure, et al., 2020). It has numerous applications in flood modelling especially when combined with other hydrologic model such as HEC-HMS; these applications include floodplain delineation, channel modification studies, and dam breach analysis. The HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking environment. It is comprised of a graphical user interface (GUI), separate analysis components, data storage and management capabilities, graphics and reporting facilities (Brunner, 2016).

Before the release of the updated version (Version 5.0) the model was one-dimensional, that is, there was no direct modelling of the hydraulic effect of cross section shape changes, bends,

and other two- and three-dimensional aspects of flow. Currently, the model can perform 1D steady flow as well as 2D unsteady flow simulations for river flow analysis, and sediment transport and water temperature/quality modelling.

The HEC-RAS model includes four one-dimensional river analysis components: steady flow water surface profile computations, unsteady flow simulation, movable boundary sediment transport computations, and water quality analysis. These components allow the user to perform numerous hydraulic calculations on geometric data (Brunner, 2016). The model uses geometric data representation as well as geometric and hydraulic computation routines for a network of natural and constructed channels of river.

The HEC-RAS model has the capacity of modelling subcritical, supercritical, and mixed-flow regimes for streams consisting of a full network of channels, a dendrite system, or a single river reach. The key data used in model are DEM and the peak flow resulting from simulation of the HEC-HMS model.

### **HEC-GeoRAS**

To facilitate the creation of geometric files for use and viewing the output from HEC-RAS the software package HEC-GeoRAS was created to ease the passage of geographic information between the GIS environment and HEC-RAS. HEC-GeoRAS is a software program extension for use with ArcGIS that provides the user with a set of procedures, tools, and utilities for the preparation of GIS data for import into HEC-RAS and the generation of GIS data from HEC-RAS output. It comprises of a set of procedures, tools, and utilities for geospatial data processing in ArcGIS through a graphical user interface (GUI). HEC-GeoRAS supports the creation of several types of geometric data for input into HEC-RAS including: stream networks, bank lines, flow path centerlines, cross sections, bridges, culverts, ineffective flow areas, blocked obstructions, land use areas, levees, inline structures, lateral structures and storage areas.

The software also gives the user the ability to assign river and reach names to stream networks, assign station values to stream endpoints, and assign line type values (left, channel, and right) to flow paths. The basic data the HEC-GeoRAS utilizes in developing geometry files include a digital terrain model (DTM), in the form of a GRID or Triangulated Irregular Network (TIN), and geographic features located in GIS layers. HEC-GeoRAS handles these layers and by



utilizing the Digital Terrain Model creates an input file, which HEC-RAS accepts as an input for the creation of a geometry file. Upon completion of hydraulic computations HEC-RAS allows for the export of water surface profile data into an output file. With the output file HEC-GeoRAS creates new GIS layers representing water surface extents, velocity grids, and depth grids which can be viewed and analyzed within GIS environment.

### Rationale for Selecting HEC-RAS

The advantage of using HEC-RAS for flood modelling is that it draws on more than 30 years of experience in hydrologic simulation. Moreover, it has been successfully applied in many previous studies which indicate that the model can provide reliable estimates of Water Surface Elevation etc. It is freely available for download from the HEC website and is supported by the US Army Corps of Engineers. It provides a graphical user interface making it easier to use the software. Further, the software was selected because of its ability to perform 1D steady and unsteady flow calculations for full network of natural open channels. HECRAS was also selected due the fact that HECRAS 1D model is considered computationally more efficient than 2D and 3D inundation models, hence it is valuable for use in data scarce environment such as the study area. Its relative ease of use makes HEC-RAS an appropriate choice for flood risk assessment. The system is able to quickly compute water surface profiles for different characterizations of the system under study. Modifications can be made to channel geometry and flow data, and ‘plans’ formulated by selecting a particular geometry and/or flowfile enabling comparisons between existing and future channel and flow conditions to be made (Aggett and Wilson, 2009).

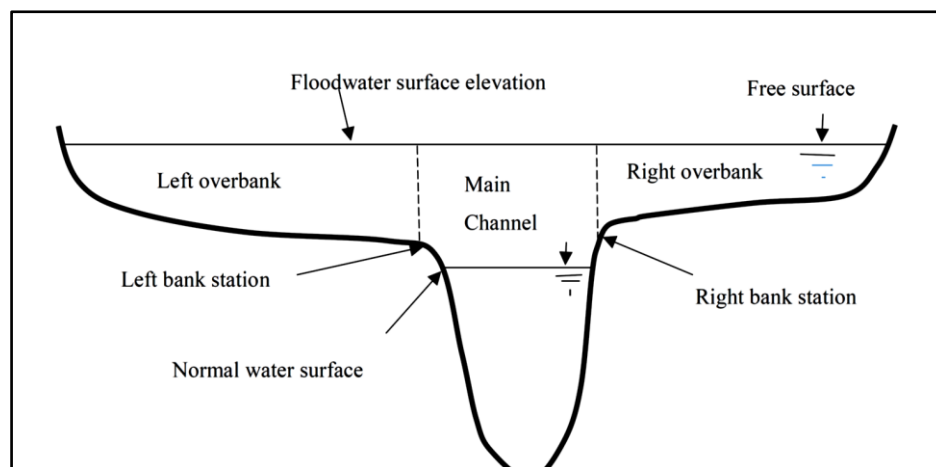


Figure 31: Schematic diagram of the stream cross-section of an open flow channel

In theory, open channel flow (Figure 31) is used to explain the movement and depth of water through natural river channels. Open channel flow is defined as the flow of a free surface fluid within a defined channel. Typical examples are flow in natural streams, constructed drainage canals and storm sewers. The development of effective floodplain management plans requires understanding the hydraulics of open channel flow, which in turn depends upon the flow classification, flow and conveyance, and the energy equation.

### **HEC-RAS Parameters**

HEC-RAS uses different input parameters for hydraulic analysis of the stream channel geometry and water flow. These parameters are employed to formulate a series of cross-sections along the stream. In each cross-section, the locations of the stream banks are identified and used to segregate the channel into segments of left floodway, main channel, and right floodway. According to El-Naqa and Jaber (2018), “HEC-RAS subdivides the cross sections in this manner, because of the differences in hydraulic parameters. For instance, the wetted perimeter in the floodway is much higher than in the main channel. Thus, friction forces between the water and channel bed have a greater influence in flow resistance in the floodway, leading to lower values of the Manning coefficient, consequently, the flow velocity and conveyance are substantially higher in the main channel than in the floodplains”.

In hydraulics studies, three basic principles consisting of conservation of mass, energy, and momentum are applied to solve problems of open-channel flow (Andrei, et al., 2017). Based on these principles, three fundamental equations derived known as St Venant’s equations are solved by models. They include the continuity equation, energy equation and the momentum equation (Kane, et al., 2017). The energy equation parameters are illustrated in Figure 32.

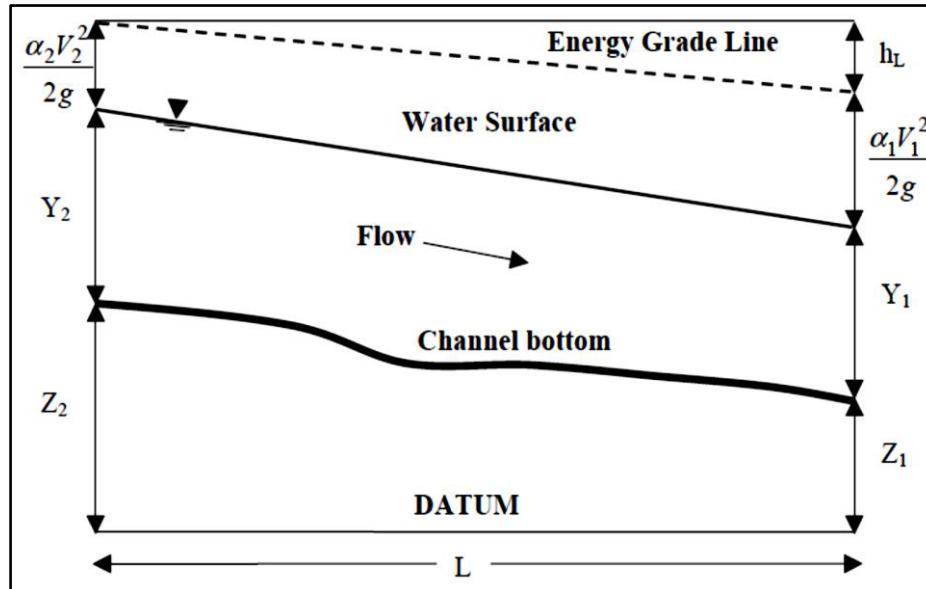


Figure 32: The energy equation parameters

Figure 32 is a short length of channel used to represent terms in energy equation (Tate and Maidment, 1999). From the diagram, three main components make up the total energy head per unit area, namely, elevation head, pressure head and velocity. Generally, gradually varied flow requires the application of energy and frictional resistance equations.

The energy equation is expressed as

$$Z_2 + Y_2 + \frac{\alpha_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e$$

Where:  $Z_1, Z_2$  = elevation of the main channel inverts

$Y_1, Y_2$  = water depth at cross sections or pressure head

$V_1, V_2$  = average velocities (total discharge / total flow)

$\alpha_1, \alpha_2$  = Velocity weighting coefficient

$h_e$  = energy head loss

Moreover, the energy head loss between two cross sections in a reach also consist of frictional losses and contraction or expansion losses expressed as:

$$h_e = LS_f + C \left| \frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g} \right|$$

Where L= discharge weighted reach length

$S_f$ = representative friction slope between two section

C = expansion or contraction loss coefficient

Alongside Manning's n values, the contraction and expansion values were used to determine friction losses and transition losses respectively.

A contraction coefficient of 0.1 and an expansion coefficient of 0.3 are used for a typical river and it is the default value (Brunner, 2016). The default contraction and expansion coefficients of 0.1 and 0.3 were used in this thesis.

Conveyance explains the movement of water downhill from points of higher energy to points of lower energy until it reaches a point of equilibrium, such as an ocean. This is enabled by the presence of natural conveyance channels e.g., streams, and rivers (Akan, 2006). Conveyance for a cross section in HEC RAS is calculated from the Manning's equation given as:

$$K = \frac{1.486}{n} AR^{2/3}$$

Where: K= conveyance for subdivision

N=Manning's roughness coefficient for subdivision

A=flow area for subdivision

R=hydraulic radius for subdivision (area/wetted perimeter)

### **Data requirement**

To carry out computations of water surface elevation using HEC-RAS, some basic data were required. These data inputs can be grouped into 4 categories namely terrain data, geometric data, land use data and steady flow data. The basic geometric data used in this study include: cross-section outline, reach length, channel and bank lines, stream junction data, flow paths, stream centerlines and energy loss coefficients (i.e. frictional losses, contraction and expansion

losses). The methodology consists of the steps shown in Figure 33 representing the HEC-RAS modelling process

Terrain data are important for flood inundation modelling and the use of accurate topographic data is a prerequisite for proper modelling, however, this is not always possible due to time and financial constraints. Although high resolution DEMs provides greater and more precise information about the terrain, high resolution Digital Elevation Models such as LiDAR data are not readily available for use in the study area, so the readily available 90x90m SRTM was employed. Although, the readily available 90x90m DEM is coarse and produces less accurate vertical and horizontal representation of the channels than other high resolution DEMs, it is a little auspicious that for the sake of flood modelling, in comparison with high relief area, SRTM vertical accuracy is better on relatively flat terrain, such as flood plains (Sanders, 2007). As the Orashi study area is made up of generally flat topography with typical elevation ranges between 0.5 m to 12 m, the readily available 90x90m DEM was used in line with similar studies such as Dan-Jumbo (2017). Like most other basins in the Niger Delta, the Orashi Basin is made up of a very dense network of rivers and only major rivers within the delineated watershed area were modelled. Hence, many very small river channels were not properly represented after TIN conversion and could not be used for modelling.

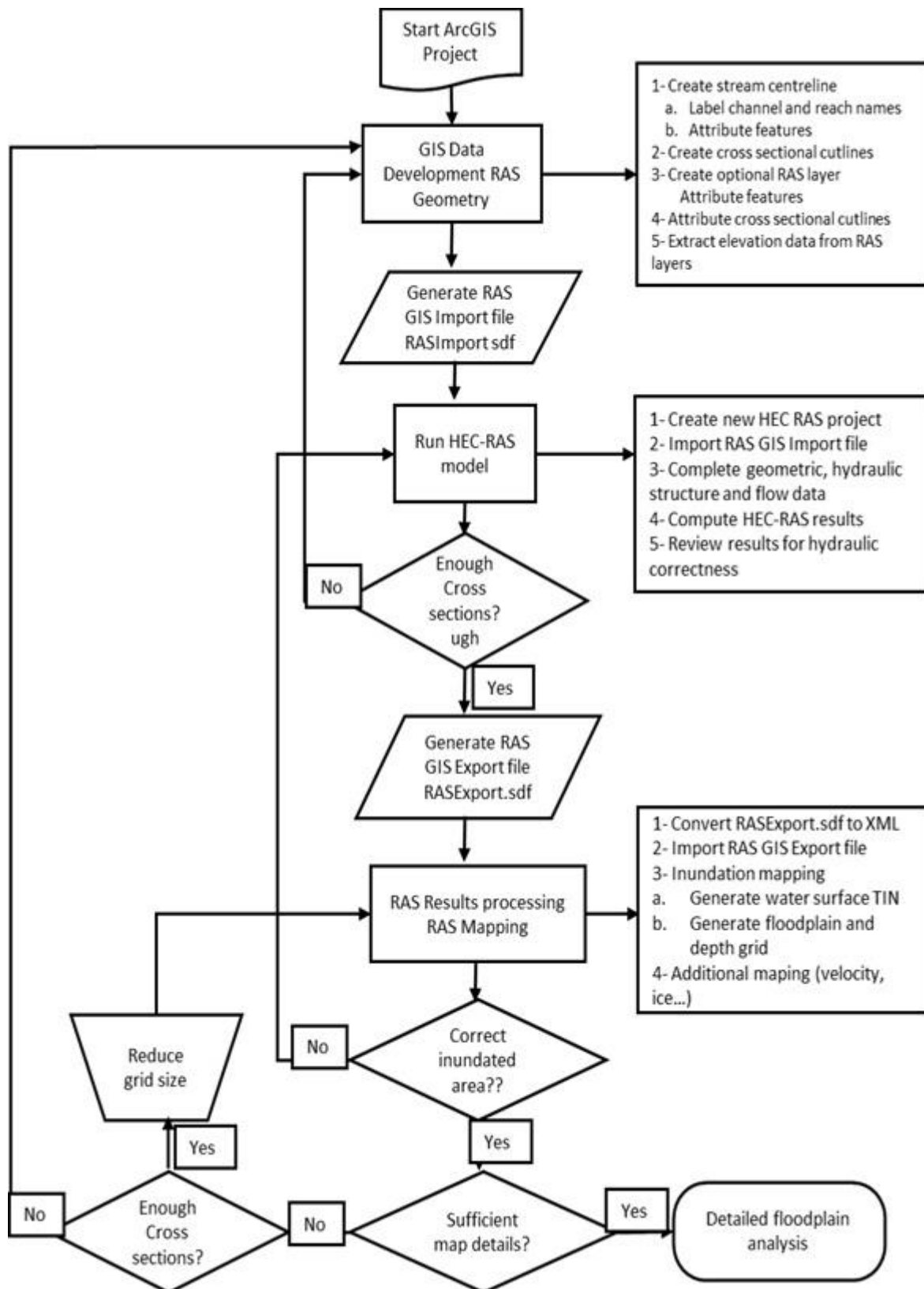


Figure 33: Schematic representation of HEC-RAS modelling process

Generally, A DEM surface is generally not suitable for large-scale terrain representation required for the hydraulic analysis of river channels. Because they cannot vary in spatial resolution, DEMs may poorly define the land surface in areas of complex relief (Carter, 1998). For hydraulic modelling of river channels, the triangular irregular network (TIN) model is preferred (Salajegheh, et al., 2009).

TIN is a triangulated mesh constructed on the (x,y,z) locations of a set of data points. The TIN model allows for a dense network of points where the land surface is complex and detailed, such as river channels, and for a lower point density in flat or gently sloping areas (Carter, 1998). The TIN surface was found to be effective for the determination of parameters for design flow calculations. The DEM file was converted to the TIN format using the 3D Analyst toolbox in ArcGIS. Figure 34 shows the TIN derived from the SRTM 90x90DEM.

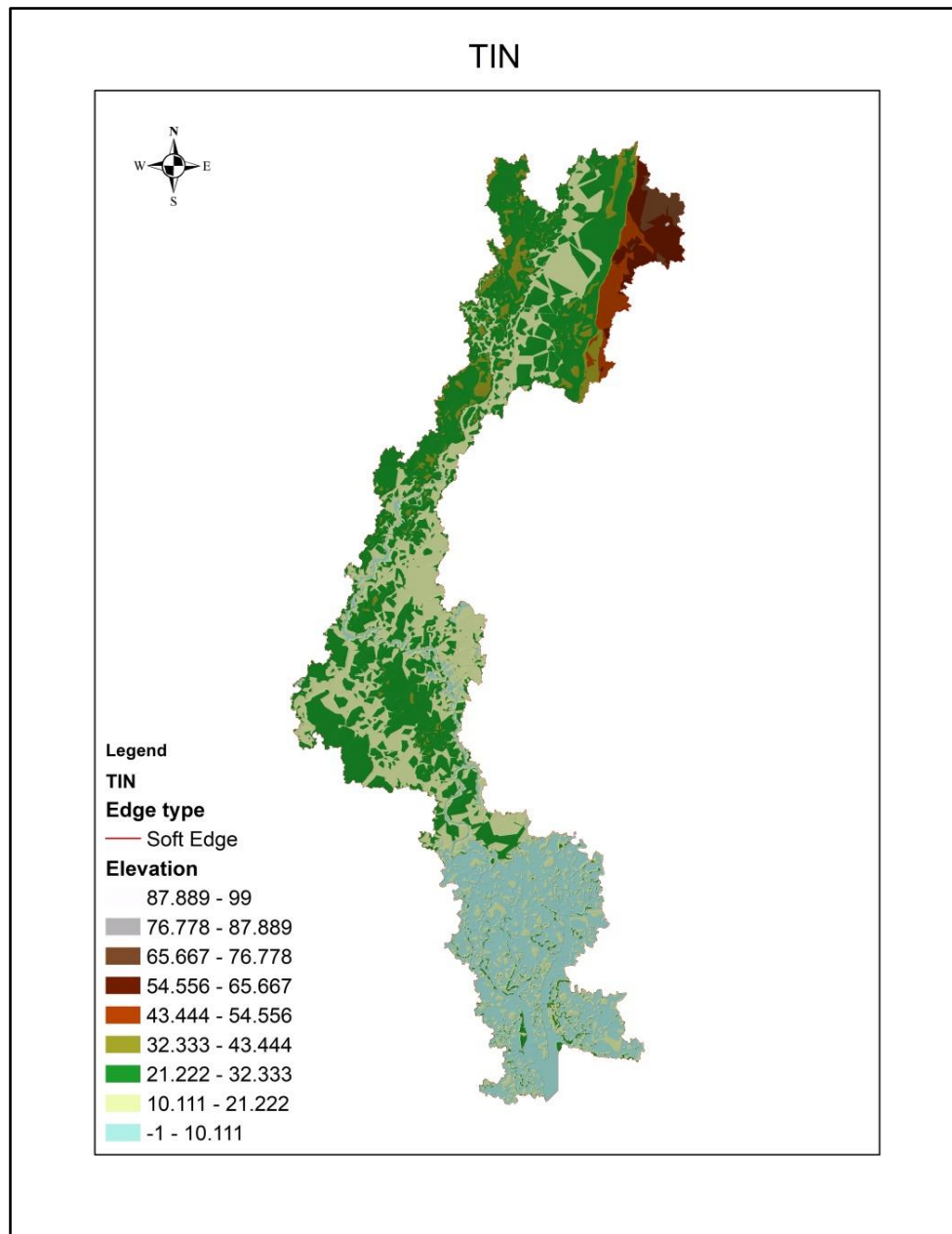


Figure 34: Triangular Irregular Network (TIN) converted from DEM

### Preprocessing and creation of geometric data layers

The first process in hydraulic model construction was to create RAS layers. These layers were used for geometric data development and extraction (USACE 2012). The HEC-RAS layers include stream centreline, main channel banks, flow path centrelines, and cross-section cut lines. The following section provides an overview of creating the RAS layers.

The main task of the pre-processing is to create the geometry data file for the use with HEC-RAS. The geometry data file contains important information about cross-sections, river bank



points and other physical attributes of river channels (USACE, 2005). The pre-processing is done using the HECGeoRAS for creating physical attributes in GIS, and then exporting them to the HEC-RAS geometry file. In HEC-GeoRAS, each attribute is stored in a separate feature class referred to as a RAS Layer (USACE, 2005). Before creating river attributes in GIS, it was necessary to create empty GIS layers using the RAS Geometry menu on the HEC-GeoRAS toolbar. The RAS layers were created in one step and stored collectively in a GeoDatabase, which HEC-GeoRAS creates automatically. By default, this GeoDatabase is saved under the same name and at the same location as the ArcMap project.

**Stream Lines:** To define the path of the various streams, stream lines were drawn into the HEC-GeoRAS environment. The stream centerline is used to establish the river reach network. The river centerline layer is very important, because it represents the river network for HEC-RAS. Digitizing of the stream centerline starts with selecting the sketch tool from the Editor Toolbar, and digitization proceeds in the direction of river flow. Hence, the process begins at the uppermost end of the stream (defined by the project extent), and ends at the confluence. Another rule for creating the river center line is that the stream centerline must follow the path of lowest elevation.

In the event that a river has tributaries, it is necessary to modify some of the editing options. The Snapping tool was used from the Editor tool box to provide connectivity between reaches within the main stream, as well as the main stream and tributaries. After digitizing all of the reaches, the next task is to name them. Each river in HEC-RAS, as well as each reach within a river, is assigned a unique name. This was accomplished by the selection of Assign RiverCode/ReachCode menu item and assigning appropriate names.

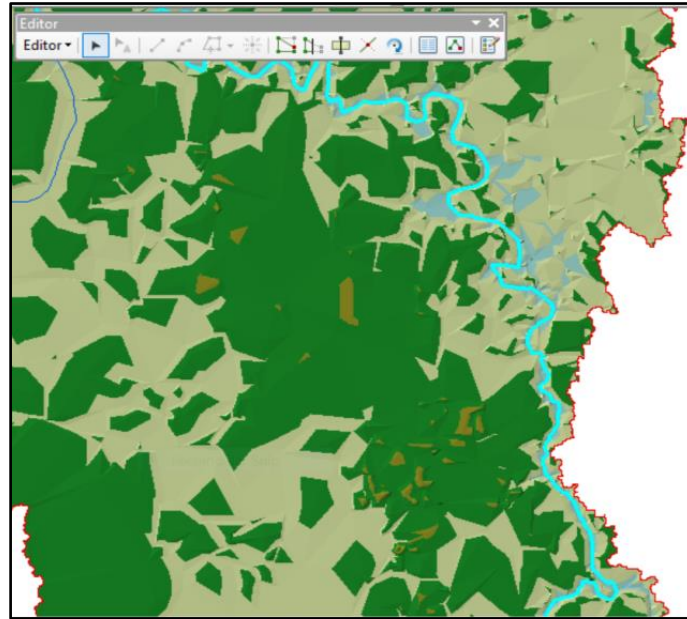


Figure 35: Image showing digitization of a section of the stream

**Bank Lines:** The bank lines layer was utilised to identify the main channel conveyance area from that of the overbank floodplain areas. Identification of the main channel will also provide greater insight into the terrain, movement of water in the floodplain, and in identifying non-conveyance areas. Information related to bank locations was utilized to assign various properties for cross-sections. For example, overbank areas are assigned higher values of Manning's  $n$  than the main channel to account for more roughness caused by vegetation.

Creating bank lines is similar to creating the channel centreline, but there are no specific guide lines with regard to line orientation and connectivity. They can be digitized either along the flow direction or against the flow direction, and may be continuous or broken. Figure 36 shows the digitization of the bank lines layer. The digitizing of bank lines starts from the upstream end, with the left bank (looking in downstream direction) being digitized first.

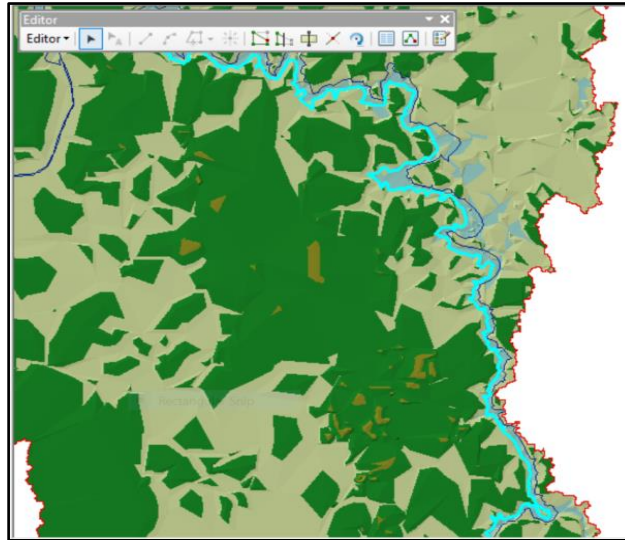


Figure 36: Image showing digitization of a section of the bankline

**Flowpaths:** The flowpath layer is a set of lines that follows the center of mass of the water flowing down the river. The flowpath layer contains three types of lines: centerline, left overbank, and right overbank. For the main channel, the flowpath centerline is defined to be the same as the stream centerline. For floodplains, the flowpath centerlines are digitized to represent assumed water flow within the floodplain. The flowpath layer is used to determine the length between two neighbouring crosssections (required by HEC-RAS). Flowpath centerlines are also created in the upstream to downstream direction. By using the Assign Line Type button, the Flowpath is labelled Right, Channel, Right looking in downstream direction

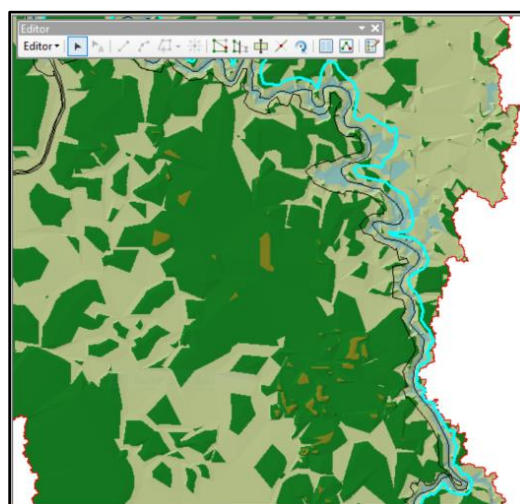


Figure 37: Image showing digitization of a section of the river flowpath

**Cross Sections Cut Lines:** Cross-sections are one of the main inputs to the HEC-RAS model. Cross sections are used to define the shape of the stream and its characteristics, such as roughness, expansion and contraction losses, and ineffective flow areas. The intersection of cutlines with other RAS layers such as centerline and flow path lines are used to compute HEC-RAS attributes such as bank stations (locations that separate main channel from the floodplain), and downstream reach lengths (distance between cross-sections). Cross-sections were drawn on the TIN to define the terrain in the basin. Cross-section cut lines must always be oriented from the left to right bank. Cross-sections extend across the entire width of the floodplain perpendicular to flow so that they can contain the maximum amount of flow during a flooding event. Each of the cross-sections can incorporate up to 500 changes in elevation.

**Manning's Roughness Values:** Manning's n values were utilized in the model to define roughness for each cross section. The Manning's n-values is supposed to be assigned in two steps: The first step involved defining land-use characteristics throughout the watershed. Each land-use characteristic is given an n-value based on published values for similar conditions (Chow, 1959). Once the land-use was defined for the entire watershed, the representative n-values were assigned to the portion of each cross section that intersects the respective land-use area. The n-values were then exported to the HEC-RAS model using HEC-GeoRAS. Table 11 shows the Manning's n coefficient used in this study<sup>9</sup>.

Table 11: Manning inputs values

Landuse type	Manning's coefficient
Forest	0.36
Floodplain/pasture/farmland	0.035
Channel	0.05
Urban area	0.04

---

<sup>9</sup> The model displayed some degree of instability using the Manning produced from the landuse map developed by the author. So, the Manning's n value of 0.035 on LOB & ROB and 0.05 for the channel was provided for the river at all cross sections because the banks are generally floodplains comprised mostly of agricultural land.

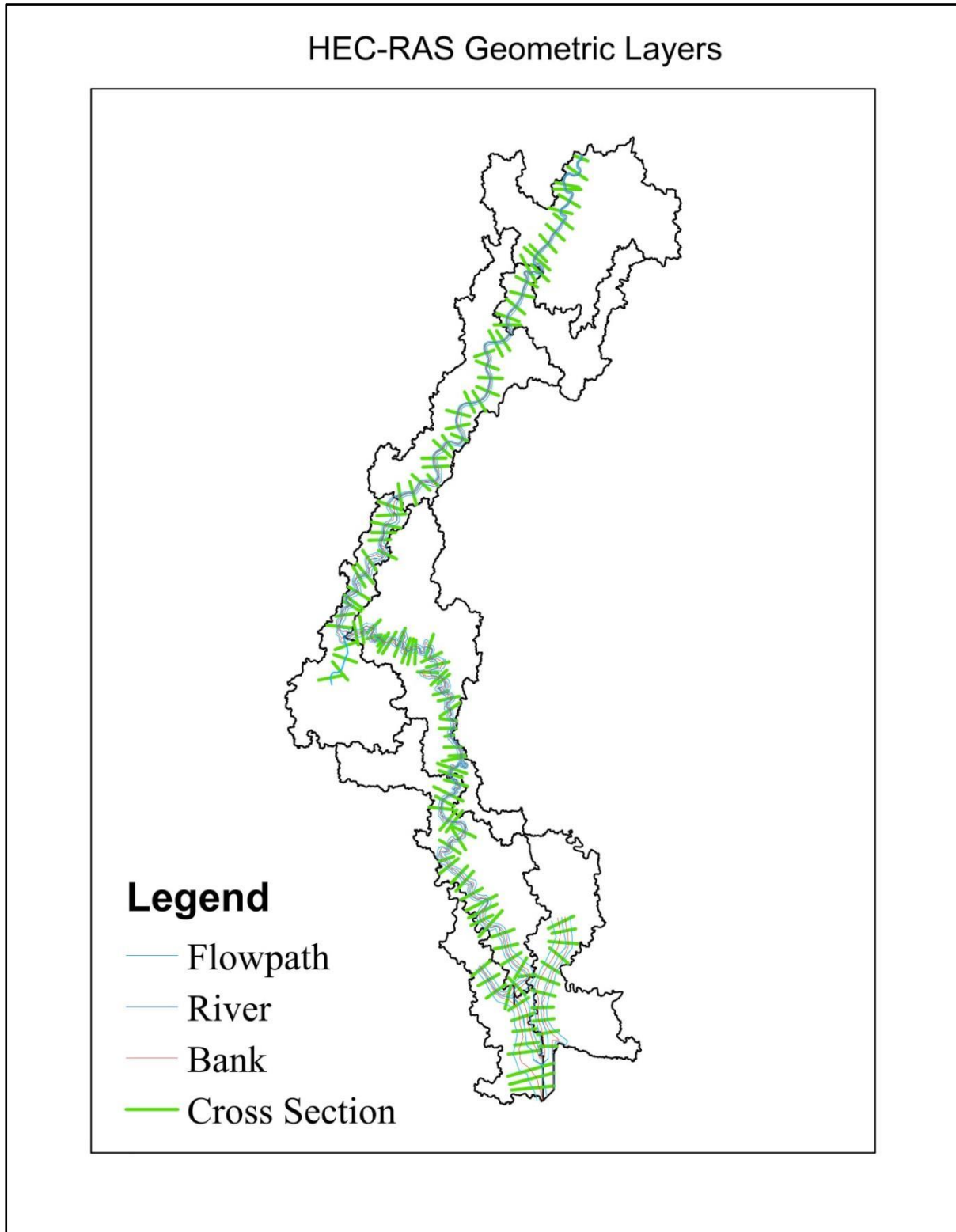


Figure 38: Flow path, bank line and cross-section cutline

According Zainalfikry et al. (2020), hydraulic model requires a good geometry and flow data input and the efficiency of the simulations are also affected by model type. There are different

models currently available for simulating flows, namely, one-dimensional (1D), two-dimensional (2D) and one/two dimensional coupled (1D/2D) hydrodynamic calculations. The choice of 1D, 2D or 1D/2D modelling depends largely on the needed outcome and availability of data.

In 1D modelling, it is assumed that all water flows in the longitudinal direction (Dasallas, et al., 2019). According to Anees et al. (2017), one-dimensional model represents the landscape as a sequence of cross sections and simulate flow to estimate the average velocity and water depth at each cross section. 1D model are advantageous because they are comparatively easy to develop and are much faster to run. 1D models are also computationally efficient but are subject to modelling limitations, such as the inability to simulate flood wave lateral diffusion, the subjectivity of cross-section location and orientation, and the discretization of topography as cross-sections rather than as a continuous surface (Teng, et al., 2017).

The recent HEC- RAS's unsteady flow analysis from version 5.0 onwards has the capability to perform 2D flood modelling (Brunner, 2016). Two-dimensional flood models allow water to move in both longitudinal and lateral directions, while velocity is assumed to be negligible in the z-direction (Dasallas, et al., 2019), however, unlike 1D model, these models represent the terrain as a continuous surface through a mesh or grid (Teng et al., 2017). The 2D model either uses the full Saint-Venant equation or uses the diffusion wave equation. Requisite model parameters for 2D model include topographic data in the form of a continuous surface represented by computational cells (mesh cells), a resistance parameter for each cell in the form of a Manning's value, flow data, a turbulent parameter and boundary conditions. The major drawbacks of 2D modelling include the fact that they require comparatively greater effort to develop, require more computation time to perform simulations, and also tend to have more challenges with numerical instability, especially in areas of wetting and drying.

### **1D/2D Model**

In recent times, flood modelling has evolved into using the combined 1D/2D model where according to Vozinaki et al (2017), a 1D treatment is applied to the main channel and a 2D treatment of the floodplain. Integrating 1D/2D model in flood modelling was found to be efficient but the application depends largely on high-resolution data availability. The 1D/2D model allows users to work in large river system involving 1D modelling for river system with

dominant unidirectional flow and 2D model for wider flood plain, which requires higher level of hydrodynamic precision. The 2D areas can be connected to 1D model directly as upstream end or downstream end or using lateral structure (Brunner, 2016).

Appropriate modelling system is usually determined by considering the characteristics of the area to be modelled, available resources and data. Hence, the 1D model was employed to simulate flood inundation extent in this thesis. The limitations of using the HEC-RAS 1D model for flood inundation study, when flow is essentially two dimensional, is recognized and acknowledged. However, 1D HEC-RAS modelling was used instead of 2D HEC-RAS modelling mainly because of limited data availability in the study area and computational efficiency of 1D model. In addition, the performance of 1D modelling in flood inundation has been tested and confirmed by a plethora of studies such as Huțanu et al. (2020), Zainalfikry et al. (2020) and Horritt and Bates (2002). Furthermore, Tate et al. (2002) notes that with one-dimensional stable model such as HEC-RAS, water surface profile and water velocities can be well predicted along the River.

### **Flow Data and Boundary Conditions**

An important factor in choosing models is whether a steady flow or unsteady flow is appropriate for the analysis. The HEC-RAS model has the ability to simulate two types of flow: steady flow and unsteady flow. The steady flow represents constant flow of water in a river without any changes and is applicable in open channel because the changes in depth and velocity at a point are generally gradual. In a steady flow simulation, the water surface profiles are computed from one section to the next by solving the energy equation. The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation may be used in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (i.e., hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluences (stream junctions). The steady flow simulation is capable of modelling subcritical, supercritical or mixed flow regime water surfaces (Salimi, et al., 2008).

Unsteady flow is the opposite of steady flow, it describes conditions in which depth and velocity at a given channel location changes with time (Sankhua, et al., 2012). Unsteady flow routing solves the 1D Saint-Venant equation which is comprised of a continuity and a momentum Equation respectively, as listed as below:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0$$

$$\frac{\partial Q}{\partial t} + \frac{\partial \left( \frac{Q^2}{A} \right)}{\partial x} + gA \frac{\partial H}{\partial x} + gA(S_0 - S_f) = 0$$

where A represents cross-section area; t is time, Q is waterflow; x is the measured distance in the direction of the channel; g is the gravitational acceleration; H is the height of water level above the datum;  $S_0$  is the slope of the river bed and  $S_f$  is the energy slope (Ghimire, et al., 2020). A 4-point implicit finite difference technique is used to solve the 1D unsteady flow equation under which space derivatives and function values are evaluated at interior points (Brunner 2016).

The 2D unsteady flow equation is also solved using an implicit finite volume algorithm, which allows larger time intervals compared to the explicit method, making the model more stable and robust regarding traditional finite element techniques (Brunner 2016). The 2D unsteady flow routing solves the continuity and momentum equation in space and time, which are presented in the following equations

$$\frac{\partial H}{\partial t} + \frac{\partial(hu)}{\partial x} + \frac{\partial(hv)}{\partial y} + q = 0$$

$$\frac{\partial u}{\partial t} + \frac{u\partial u}{\partial x} + \frac{v\partial u}{\partial y} = -g \frac{\partial H}{\partial x} + v_t \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) - c_f \cdot u + fv$$

$$\frac{\partial v}{\partial t} + \frac{u\partial v}{\partial x} + \frac{v\partial v}{\partial y} = -g \frac{\partial H}{\partial y} + v_t \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) - c_f \cdot v + fu$$

where t is time, u is velocity component in the x-direction, v is velocity component in y directions,  $h(x,y,t)$  is the height of the water, H is the total head, and q is the flux term height ofg is gravitational acceleration,  $v_t$  is horizontal eddy velocity,  $c_f$  is the bottom friction coefficient, R is the hydraulic radius, and f represents the Coriolis coefficient. The left side of the equations represents acceleration, whereas the right side of the equations represents forces



(internal and/or external) affecting the fluid. More detailed and extensive discussion on the HEC-RAS unsteady flow model is provided in the HEC-RAS documentation manual (Brunner 2016).

Only the steady flow model is used in this thesis. The steady flow condition was selected because of the primary interest of this study, which is determination of flood extent and depth in the study area. Also, the steady flow model was selected for use because several studies such as Huţanu et al. (2020), Khattak et al. (2015) and Sarhadi et al. (2012) have successfully used the steady flow to analyse and predict flood extent. Furthermore, a study by Brandimarte and Baldassarre (2012) in a study on the uncertainty in hydraulic modelling showed that the computation of flood profiles via steady-state simulations provide results that are nearly as accurate as the ones obtained via unsteady simulation because of the broad and flat hydrographs of alluvial river, which leads to relatively little transient behaviour. They concluded that the use of dynamic (unsteady) model is not compulsory if the modelling purpose is to derive the maximum water stage levels, i.e. flood profiles.

In order to begin computations, boundary conditions must be specified. The boundary condition is then used as part of the iterative standard step method as previously discussed. The four types of boundary conditions in the steady flow are:

- Known water surface elevations: based on observed data
- Critical depth: the program will calculate critical depth
- Normal depth: the program will calculate normal depth
- Rating curve: elevation determined from an existing stage-discharge relationship curve

It is difficult to accurately estimate a boundary water surface elevation for a given discharge without gauge data. As the Orashi basin is ungauged and there was no measured water surface data; it was decided to use critical depth boundary condition.

The user must also specify which type of flow regime is expected: sub-critical, supercritical, or mixed. This indicates whether RAS should begin computations at the most upstream or downstream cross-section. Specifying a mixed flow regime causes the program to calculate both sub-critical and super-critical portions of the profile. In a subcritical flow regime, boundary conditions are only required at the downstream ends of the river system. If a

supercritical flow regime is going to be calculated, boundary conditions are only necessary at the upstream ends of the river system. If a mixed flow regime calculation is going to be made, then boundary conditions must be entered at all open ends of the river system. In this thesis, it is assumed that the flow is subcritical throughout the river system; therefore, it was only necessary to enter a boundary condition at the downstream end of the river.

### Post Processing

After the completion of the running of HEC-RAS model, output data was exported back to the ArcGIS environment. HEC-GeoRAS was then applied to develop the data into useful graphical output such as floodplain polygon shape files. To generate floodplain shape files, the GeoRAS extension is used to create a water surface TIN for each of the flood events. The water surface TIN is then automatically clipped to fall within the bounds of the cross sections (i.e. it does not extend beyond the end points of any cross section), and is completely independent of the terrain TIN. After the water surface TIN is created, the rasterization of the water surface TIN and the terrain TIN takes place and the floodplain is delineated where the water surface exceeds the terrain elevations.

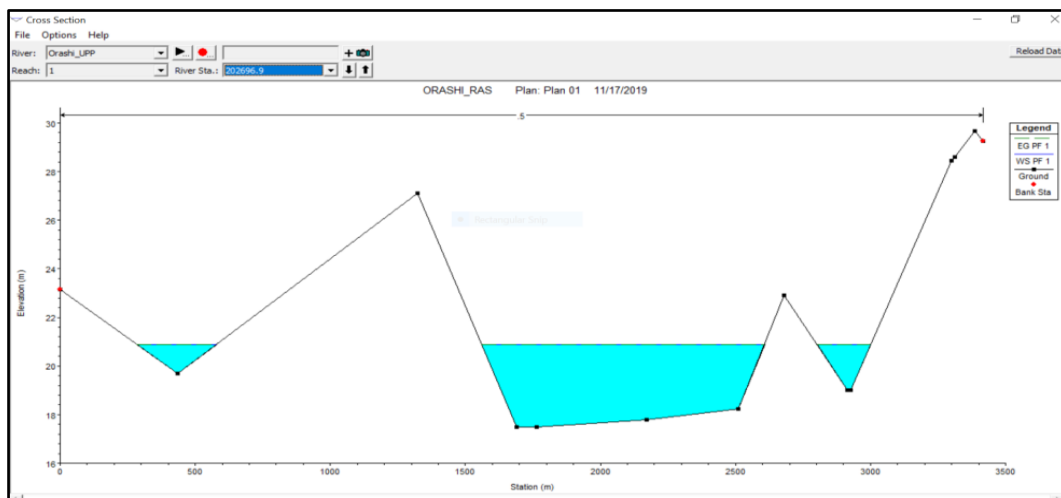


Figure 39: One of the cross sections of the Orashi River

### Sensitivity Analysis

High degree of uncertainty sometimes exists in floodplain-mapping models due to complexity of the surface water level modelling processes including the structure of the model, topography, parameters and data. As a result, calibration and validation hydraulic is a essential stage in flood modelling.

According to Bates, et al. (2006), the use of gauged data for calibration and validation of the hydraulic-models, is the most popular approach in floodplain modelling and mapping process. The choice of appropriate historical flood events for calibration and validation depends mostly on the availability of relevant historical flood information. However, in most developing areas such as the Orashi Basin, calibration and validation efforts are hampered by a lack of situ data. Details of historical flood events in the area were extensively sought from relevant authorities and sources, but there were no data, measured information, direct, historical, photographic or other evidence on the extent or depth of flood events or flood water levels in the area or even basins in the immediate vicinity of the area.

Although strenuous and time-consuming attempts were made to obtain data (both primary and secondary), these attempts were met with failures due to bureaucratic delays (The researcher attempted to obtain data to be used in calibration and validation from concerned agencies for two months). Obtaining field data was also difficult in view of security challenges in the area. It must be mentioned that the Orashi region is a volatile region and high-risk zone in terms of security; hence the researcher could not find a way to physically discern flood areas and determine the flood inundation depth in the study area.

The complete lack of data for ungauged rivers in the study area seriously deprived the researcher an opportunity to carry out calibration and validation exercises. The conventional solution/compromise to a lack of such data is to conduct a sensitivity analysis on selected parameters. Montanari (2007) argues that in ungauged or scarcely gauged catchments, sensitivity analysis provides good uncertainty estimations.

McCuen (1973) defined sensitivity analysis as a measure of the influence of input variables on the final result. The main purpose of the sensitivity analysis is to determine the effects that the varying values of different parameters can have hydrological components like water surface elevation, peak stage, time to peak, and general hydrograph shape.

Studies have shown that the calibration of an HEC-RAS model is particularly sensitive to Manning's roughness; hence, sensitivity analysis was performed in this thesis to test the sensitivity of the one-dimensional model to Manning's  $n$  roughness coefficient. The procedure involves holding all input parameter constant except the one being analysed and then varying that value. The Manning's roughness coefficient ( $n$ ) was varied in incremental steps from -30%

of the base value to +30% of the base value. Table 12 shows the values of the manning's coefficient used for sensitivity analysis.

Table 12: n values

	Base value (n)	n+30%	n+20%	n+10%	n - 10%	n - 20%	n - 30%
River channel	0.05	0.065	0.06	0.055	0.045	0.04	0.035
ROB	0.035	0.045	0.042	0.039	0.032	0.028	0.0245
LOB	0.035	0.045	0.042	0.039	0.032	0.028	0.0245

## 4.8: Methodology: Socioeconomic and Adaptive Capacity Analysis

### 4.8.1: Data Sources

Figure 40 shows the methodological flowchart for socioeconomic analysis. Socioeconomic data from both primary and secondary sources were collected and employed in this research. Primary socioeconomic data were collected using questionnaire administration and covered a multiplicity of topics. In-depth interviews during the field research enabled the researcher to probe deeper research findings and explore the main relationships among determinants influencing flood vulnerability. Secondary socioeconomic data in the form of annual reports, project reports, development policies and plans were collected from a variety of public institutions such as the meteorological bodies, the National Population Census Commission (NPC) and Ministries of agriculture and environment etc.

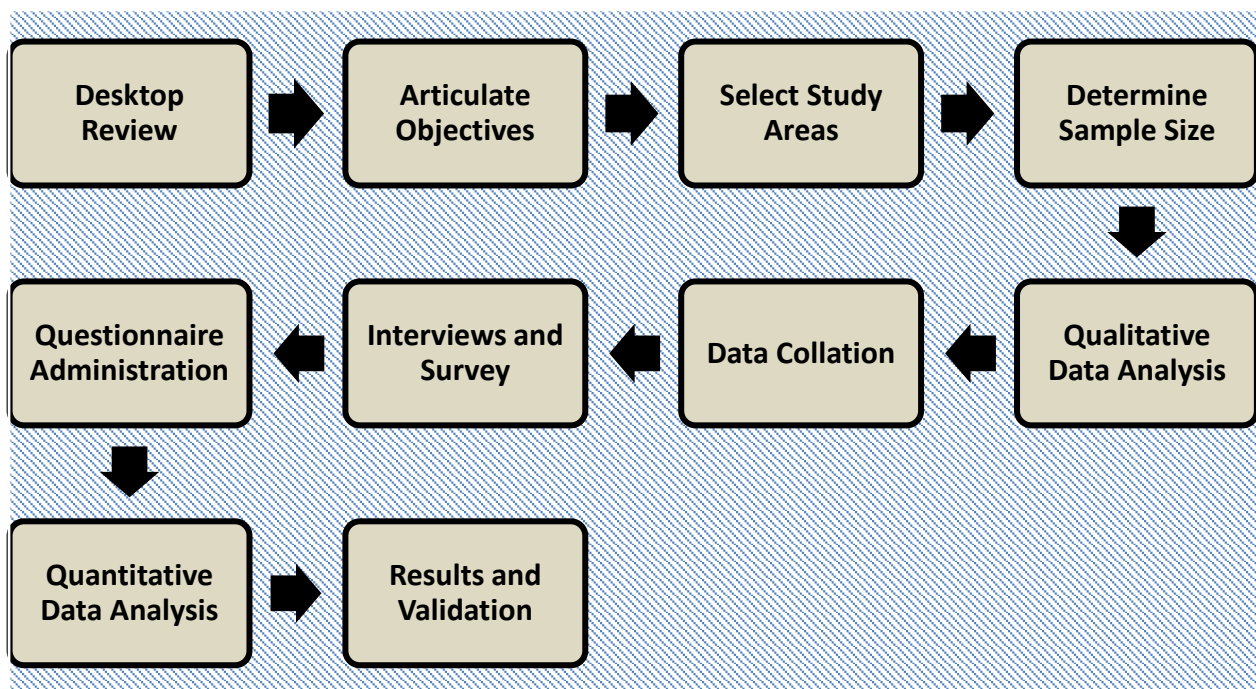


Figure 40: Socioeconomic analysis methodological flowchart

Table 13: Socioeconomic analysis methodological approaches

Adaptive capacity	Adaptive Capacity Index
Perception of environmental problems	Problem Confrontation Index
Socioeconomic characteristics	Descriptive statistics
Poverty	Anecdotal questions
	Pearson correlation and Regression

#### 4.8.2: Sample Size and Procedure

To conduct the socioeconomic survey, due to the peculiar nature of the research, the multi-stage sampling method was employed. To select the study sites, purposive sampling, a type of non-probability sampling, which involves the selection of sampling units with the characteristics of interest and relevance to the phenomenon being studied from within the study population (Guarte and Barrios, 2006) was used. The study sites are purposefully selected because they are information-rich, and as such can provide important, reliable and valid information that cannot be obtained from other sources. In this study, to ensure maximum representativeness one hundred flood affected communities were selected based on information from the flood location inventory.

In view of the fact that it is practically impossible to administer the questionnaire to every smallholder farmer in the study area since their population was unknown, it was necessary to calculate and use a sample size. Sample size is the number of observations used for calculating estimates of a given population. The use of sample size reduces expenses and time by allowing researchers to estimate information about a whole population without having to survey each member of the population. It is necessary to do sample size calculations in order to ensure that analyses have adequate statistical power and that the results obtained are accurate and useful. If samples are too large in size, researchers could waste time, money and resources. On the other hand, if samples are too small, the results obtained may not be accurate or reliable. However, the larger the sample the more accurate the result will be. Sample size can be calculated by hand, but the calculations can be complicated. Most researchers choose instead to use a sample size calculator. Sample size software represents an easy, reliable and fast means of getting the correct sample size.

To compute the sample size for this research, the Raosoft statistical software was used. The Raosoft software was used in this research because of its simplicity, flexibility and amenability.

It allows the researcher to input the total population size of the study area, the confidence level and the margin of error he can tolerate. The software computes and tells the researcher the right sample size to use. The sample size calculator returned a figure of 377 samples. However, to ensure a more equitable distribution of the questionnaire, the sample size was increased to 400. To ensure equal spread, the questionnaire was administered to four respondents in each of the 100-flood affected location. To select individual respondents, the snowball sampling method was employed.

Snowball sampling (also known as chain-referral sampling) is a non-probability (non-random) sampling method used when characteristics to be possessed by samples are rare and difficult to find. This sampling method involves primary data sources nominating other potential primary data sources to be used in the research. In other words, the snowball sampling method is based on referrals from initial subjects to generate additional subjects. Therefore, when applying this sampling method, members of the sample group are recruited via chain referral. According to Atkinson and Flint (2001), snowball sampling is defined as: “a technique for finding research subjects. One subject gives the researcher the name of another subject, who in turn provides the name of a third, and so on”. This strategy can be viewed as a response to overcoming the problems associated with sampling concealed hard to reach populations such as the criminal and the isolated. More recently, the term “snowball sampling” has been taken to refer to a convenience sampling mechanism by collecting information and for the purpose of studying the characteristics of individuals in the hard to reach population characterized by the lack of a serviceable sampling frame (Handcock and Gile, 2011).

#### **4.8.3: Questionnaire Distribution**

In this thesis, the “household” is adopted as the main unit of analysis. A “household” is defined as a farm family unit consisting of a group of interrelated people living together, sharing the same dwelling house, working on the family farm, making farm-level decisions (including adaptation) and pooling their labour to manage their farm under the prime leadership of the household head (Davies and Bennett, 2007). The household is the major social unit of the smallholder farm. It is a social group engaged in a combination of production, distribution, transmission (e.g., transfer of property), biological and social reproduction, and co-residence (Netting, 1993). Further, the household is the basic unit of production and consumption as well as the unit that owns assets and determines adaptation strategies against extreme weather

conditions (Stanturf, et al., 2011). Smallholder farmers manage resources and organize consumption at the household level (Netting 1993; Ruben et al. 1998).

In all the sampled communities, the head of household was the focal person. The choice of the household head as a primary source of information is justified because the household head plays a primary role in the majority of household and farming decisions related to production, marketing, resource allocation and adaptation decisions in traditional farming (Polson and Spencer, 1991). A standardized survey questionnaire of both closed and open-ended questions were administered to the respondents. The use of questionnaires provided a direct way of eliciting, verifying and backing up information. The primary focus of the questionnaire was to obtain a profile of the socioeconomic characteristics of the farmers, their response to the impact of flood events, flood risk perception, coping strategy, etc.

Respondent confidentiality was assured with the inclusion of the "informed consent clause" in the questionnaire, the nature of the interview clearly explained and permission requested. Steps were taken to make the questionnaire administration as brief as possible so as to avoid respondent apathy. Hence the questionnaire was designed to elicit more responses and deeper meanings using few questions as possible.

#### **4.8.4: Interviews**

In-depth interviews during the field research enabled the researcher to probe deeper research findings and explore the relationships between determinants influencing flood vulnerability. Key informants interviewed included the traditional rulers, the oldest farmers and the highly educated farmers. The interviewees were purposely targeted. For instance, traditional leaders were purposefully selected to provide information on land allocation and development in their area. The traditional leaders are the overseers of lands, and are regarded as important stakeholders in socioeconomic issue and served as key informants. The involvement of the traditional leaders provided an in-depth understanding of the pattern of land ownership, the snags in land ownership and control, flood intensity and damage in the communities. The key informant interviews were primarily qualitative in nature.



#### **4.8.8: Field Survey and Ground-truth**

During the research period, an extensive field visit was undertaken in the whole region in order to understand the overall flood situation. Groundtruthing is important to properly identify objects, provide precise image registration and verify results. Therefore, field work and observations are essential. A total of 100 Ground Control Points (GCPs) (determined by flood inventory list) was checked. Physical information on the types, characteristics and nature of land use activities along the rivers and floodplains, as well as width of some of the important rivers and their buffers were obtained through a spatial survey using handheld GPS and digital camera (photographs). These physically observed data helped to verify and confirm information on the satellite images, as well as providing additional information that could not be obtained from the satellite images.

#### **4.8.9: Data collection and Analysis**

Data collection was conducted in two phases; the first phase took during one month fieldwork program between November and December 2015, while the second phase took place between March and April 2016. The data collection was preceded by a pilot pre-test exercise to assess the consistency of the research instruments. Pre-testing is the use of a small proportion of research participants to ascertain the suitability of a research instrument to accurately measure variables and address research questions. Pre-test of questions was done by distributing questionnaires to ten farmers in each site who were not involved in the actual survey to assess whether the instruments and questions were appropriate and suited to the study. Necessary amendments were made through deleting and modifying questions having confusing and sensitive ideas based on the comments from experts and observations of households' responses. Pre-testing of the questions also helped to determine the mean interview length needed for covering the samples and to plan the time, days and data collectors required for the field survey. The researcher trained data collectors with respect to the survey techniques and confidentiality protocol to establish internal quality control procedures. Quantitative data from the questionnaire were coded, processed, and analyzed descriptively using Statistical Package for Social Science (SPSS) and Excel.

To establish if there was a significant statistical relationship between income level and the time of recovery, the Correlation test was employed. The level of statistical significance is expressed

as a p value between 0 and 1. The smaller the p value, the stronger the evidence that the null hypothesis should be rejected.

The correlation test is based on the following on the hypothesis

- Null Hypothesis: There is no correlation between level of income and time of recovery from flood
- Alternative Hypothesis: There is a correlation between the level of income and the time of recovery from flood

The alternative Hypothesis is accepted if P value is less than 0.05

The alternative Hypothesis is Rejected if P value is greater than 0.05

The excel software was used to carry out the correlation analysis.

#### **4.9: Computation of Adaptive Capacity**

Smit and Wandel (2005) describe adaptive capacity as the capacity of a system to cope with or recover from a potentially damaging change in climate conditions. Posey (2009), notes that the adaptive capacity of a place is determined by a combination of social and economic components. Although flooding happens globally, however, adaptive capacity is site-specific. Many scholars such as Oo et al. (2018) have therefore recommended localized assessment of adaptive capacity. Considering this, the adaptive capacity index (ACI) presented in this thesis is made up of components that characterize the social capacity, economic capacity, technological eco-efficiency, natural capital and climate capital of the region, which in combination determine the system's ability to adapt to floods.

According to Downing et al. (2001) many variables or components of vulnerability and adaptive capacity are multidimensional, complex and no directly observed phenomena and this makes evaluation of such concepts difficult. However, studies have addressed this problem using different approaches. Several approaches have been developed for the computation of adaptive capacity, for instance, Asrat and Simane (2017) mentioned the two most commonly used approaches to compute adaptive capacity, namely, econometric and indicator-based method. Deresa et al. (2008) notes that econometric method, which has its roots in the poverty and development literature, makes use of household-level socioeconomic survey data to analyze the level of vulnerability of different social groups, while, Weldegebriel and Amphune

(2017) argues that the disadvantage of the econometric technique is the challenge associated with testing various econometric assumptions concerning the standard errors, hypotheses, confidence intervals and imputing causality without making stringent assumptions. On the other hand, the indicator method of measuring adaptive capacity is predicated on choosing indicators from a set of potential indicators and then systematically combining the selected indicators to show the levels of adaptive capacity (Hinkel, 2011).

Although, the Indicator method is the most common method adopted for quantifying vulnerability and adaptive capacity, researchers such Etwire et al. (2013) and Asrat and Simane (2017) has identified the subjectivity of the indicators selection process as a limitation. Although this is a major limitation of the indicator-based approach, recently different scholars like Žurovec et al. 2017, Asrat and Simane (2017) have used this approach to construct adaptive capacity indexes in different contexts. In line with these studies, this thesis employed the indicator-based approach to determine the adaptive capacity of smallholder farm households in the study area. The selection of indicators was done based on an extensive review of the literature such as those of ABARE–BRS (2010) and Adger et al.(2004). Further, in line with Sietchiping (2006), in cases where the key variables could not be fully accounted for due to paucity of data, or difficulty in measurement etc., surrogates and proxies are used. According Baptista (2014), there are certain conditions that must be met before settling on the choice of indicators to be used and during the course of the field work, these conditions were mostly fulfilled. The conditions include the following...

- I. Data availability from public or private sources,
- II. Cost, frequency, timeliness, consistency, and accessibility of available data
- III. Data quality (Whether the data quality is high enough to be used)
- IV. The degree of salience (How relevant is the indicator to the intended users of the index?)
- V. The degree of audience resonance (How meaningful is the indicator to the intended audience?).
- VI. Representativeness (i.e., whether or not the indicator represents underlying vulnerability or resilience).

According to Žurovec et al. (2017), a commonly used approach to assess vulnerability is the construction of a vulnerability index based on specific sets or combinations of indicators, which serve as proxies. Due to the simplicity of aggregating indicators to form a composite index, different composite indexes have been developed (Vincent, 2004). Additionally, Baptista,

(2014) states that increasingly, researchers and practitioners are developing composite indices to provide multidimensional, integrated assessments and synthetic measures of climate change vulnerability and resilience.

Nguyen et al. (2016) states that a composite index generally aims to simplify a number of complex and interacting parameters, represented by diverse data types, to a form that is more easily understood and has much greater utility as a management tool. Leichenko and O'Brien (2002) add that composite indices capture the multi-dimensionality of vulnerability (In this case adaptive capacity) in a comprehensible form. Further, composite indexes can provide a potentially useful overview of aggregate socio-ecological vulnerability (Fussel, 2009), therefore, a potential advantage of designing a composite index to analyze multidimensional complex systems is its understandability when results are presented as scores or rankings that key stakeholders, decision makers, and the general public can easily comprehend (Kenney, et al., 2012). However, Baptista (2014) argues in using the index method, complex concepts are reduced to a single index that to some extent masks local contextual differences.

### **Procedure for computation of Adaptive Capacity**

Generally, adaptive capacity index development involves sequential stages, including the selection of indicators, normalization of indicators to a common scale, and aggregation to a final value (Figure 41).

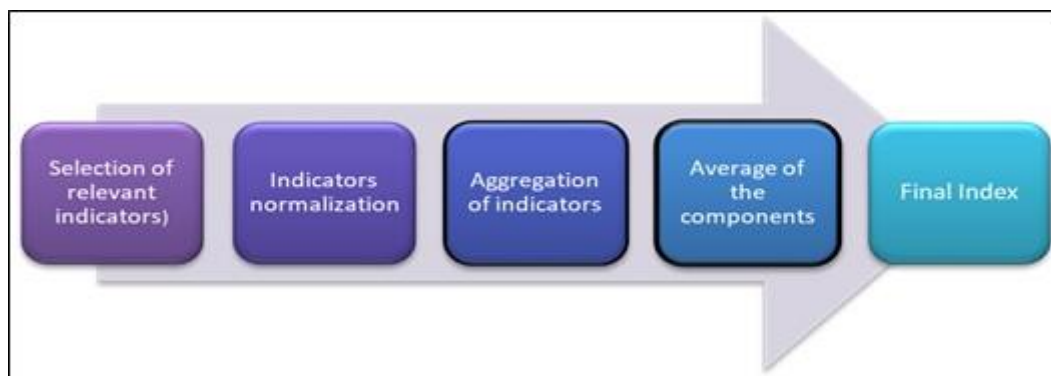


Figure 41: Flowchart for computation of adaptive capacity index

Since each indicator used is measured on different scales and units, there is the problem of incommensurability and disparity of indicators; therefore, indicators need to be normalized to unitless scales to ensure that they are comparable (GIZ, 2014, Žurovec et al. 2017, Swanson,

et al., 2007). Although there are several methods of normalization, however normalization was carried out based on the minimum-maximum methodology developed by the UNDP (2007) in the computation of the Human Development Index (HDI). All indicators were normalized to values between 0 and 1. Due to differences in direction of impact, before the values are normalized, it was vital to identify the two possible types of functional relationship between the indicators and adaptive capacity; this was to ensure that index values are always in positive correlation with adaptive capacity. If vulnerability increases with an increase in the value of the indicator (positive correlation), and therefore has a positive functional relationship with vulnerability, normalization was carried out by using the following equation.

$$\text{Normalized value}_{(\text{Where higher is better})} = \frac{\text{Value of the indicator to be normalized} - \text{Minimum value of all indicators}}{\text{Maximum value of all indicators} - \text{Minimum value of all indicators}}$$

$$\text{Normalized value}_{(\text{Where lower is better})} = 1 - \frac{\text{Value of the indicator to be normalized} - \text{Minimum value of all indicators}}{\text{Maximum value of all indicators} - \text{Minimum value of all indicators}}$$

There are two options for calculating adaptive capacity. The first option is based on the assumption that all the indicators of adaptive capacity have equal importance and hence are given equal weight during the computation. Conversely, the second method is based on the notion that some indicators are more important than others and thus assign different weights to avoid the uncertainty of equal weighting given the diversity of the indicators used. However, Ajibola (2014) mentions that the method of assigning different weights to indicators is still dubious since there is no standard weighting method against which each method is tested for precision. Based on the subjective nature and allied weakness of the weighted system, it was decided to assign equal weight to indicators to be used in this thesis. Hence, each indicator was considered to be of equal importance in calculating the overall adaptive capacity index for the households. Table 14 summarizes indicators of adaptive capacity proposed in reviewed literature from several authors under different contexts, approaches.

Table 14: Indicators of Adaptive Capacity

Attributes	Indicators	Measurement	Survey Questions
Literacy level	Proportion of literate Respondents	Percentage of literate respondents  Yes/No (Binary)	Are you literate in any language?
Income	Average monthly income	Likert scale	Please give an estimate of your household monthly income
Income generating asset	Number of assets owned	Likert scale	Please mention assets that produce income
Access to credit	Percentage of respondents with access to credit	Yes/No (Binary)	Do you have access to credit?
Alternative source of income	Percentage of respondents with alternative income source	Yes/No (Binary)	Does any member of your family have another occupation?
Access to technology	Number of mechanized instruments owned	Likert scale	List the mechanical instruments you own
Social capital	Membership of society	Yes/No binary	Do you belong to any society?
Access to information	No of sources of information	Likert scale	What are the sources of information?
Infrastructure	No of infrastructure present in the area	Likert scale	List the infrastructure present in your area
Dependence ratio	Proportion of economically active members of household	Percentage	How many members of your household are economically active?

### Adaptive Capacity Indicators and Rationale

**Income level:** Higher income increases households' adaptive capacity and reduces their vulnerability. Households with low income are less able to save or accumulate assets which ultimately limit their ability to cope with environmental shocks such as flood events.

**Literacy level:** Literacy level is one of the most important indicators of adaptive capacity, the higher the level of literacy, the higher the adaptive capacity. Intuitively, people who lack

education will lack knowledge about adaptation strategies and will be thus highly vulnerable to flooding and other environmental shocks, while educated people have more knowledge about coping measures which makes them more resilient and less vulnerable to environmental shocks.

**Income generating asset:** The structure and value of assets indicate the economic status of a household. The greater the assets households possess, the greater is their capacities to sustain and resist vulnerabilities or threats. Hence, income generating is considered a vital component of adaptive capacity. Households possessing income generating assets are self-reliant and can smooth out the effects of climatic vagaries like flood using such assets. There is a positive relationship between adaptive capacity and the level of income generating asset, the more assets people have, the greater their adaptive capacity.

**Access to credit:** It is supposed that the greater the level of access to credit, a farmer, the greater his chance to overcome the burden associated with environmental shocks. During periods of disasters, farmers with access to credit can collect loans which will help him cope with the burden of the disaster. To compute the access to credit of the household, the farmers were categorized farmers into those had access to credit (=1) and those without access to credit (=0).

**Alternative source of income:** Farm households with a greater diversity and streams of income are likely to have greater adaptive capacity because of a greater capacity to substitute between alternative livelihood strategies in times of stress (Nelson, et al., 2010). Further, households having some non-farm source of income in addition to farming will improve the adaptive capacity of the households against the climatic stresses through distribution of risks across various livelihood sources (Piya, et al., 2012).

**Access to Technology:** Access and use of appropriate technology is central to maintaining and increasing productivity. Farmers with access to modern technology and agricultural tools are more likely to be more productive and resilient to the impacts of environmental shocks such as floods. The modern technologies may be mechanical, biological, chemical or managerial in nature and they are productivity-enhancing in that they improve crop yields or livestock numbers and make access to markets easier.

**Social network:** According to Rufat et al. (2015), individuals can boost their coping capacity by using social networks to connect to the emotional, social, and economic resources of others. It is surmised that farmers belonging to social groups and associations are better networked to cope with the impacts floods on their livelihoods activities (Adger 2003), As such groups represent social safety nets and a type of informal buffer available to the household during environmental shocks.

**Access to information:** Communication and access to information have always been significant in agriculture, with farmers continually seeking information, communicating with each other and sharing knowledge on new agricultural technologies (Jones, et al., 2010). Farmers are more likely to cope with shocks such as floods if they access to information about potential shocks. A better informed farmer will intuitively be able to cope with shocks than an uninformed farmer. Further, Frankhauser and Tol (1997), points out that successful adaptation will require an understanding of likely future change and its complexity, knowledge about adaptation options, the ability to assess options, and the capacity to implement suitable interventions. Access to information can help in empowering local farmers and raising awareness and understanding of specific groups in a community. In their report, Jones et.al (2010) concludes that the manner in which a system generates, collects, analyses and disseminates knowledge is an important determinant of adaptive capacity

**Ratio of economically active:** The ratio of economically active member of the household reveals the proportion of the household not in the workforce who are 'dependent' on those of working-age. To determine the ratio of the economically active portion of the household, the generic dependency ratio was slightly modified. Normally the dependence ratio is a calculation which classifies those aged under 15 with those over 65 years as the 'dependents' and classifying those aged 15-64 years as the working-age population. It's a simplistic calculation which is used across the world to understand societies and get a sense of potential pressures the economy may face in supporting an economically dependent population. However, in the case of this thesis, because it was not possible to get the age of all the members of the household, the ratio of the economically active portion of the household was compared with the size of the household, the rationale is that the higher the ratio of economically active portion of the household, the higher the adaptive capacity.



## Pearson correlation and Regression

The correlation test is based on the following on the hypothesis

Null Hypothesis: There is no correlation between level of income and time of recovery from flood

Alternative Hypothesis: There is a correlation between the level of income and the time of recovery from flood

Accept Alternative Hypothesis if P value is less than 0.05

Reject Alternative Hypothesis if P value is greater than 0.05

The P value shows the strength of the correlation

### **4.9: Study Challenges and Limitations**

In the course of this study, some teething challenges were encountered which militated against fully achieving the objectives of this thesis. One of the major challenges was the non-availability of data. Several attempts were made to obtain data about flood heights or frequency of floods in order to classify the basins in terms of flood severity or frequency, however, officials of the national emergency organization (who is supposed to have the information) could not provide any data that could help in classifying the flood area. In addition, one of the major challenges in most developing countries like Nigeria is that very little has been done on hydrologic modeling, making a comparison of results quite difficult. Besides, the calculations presented in the model could not be validated because of the lack of any discharge/stage measurements in the basin.

## **Chapter 5: Results and Discussion: Meteorological Analysis**

Climate change may have had considerable effect on rainfall patterns over the years in the Niger Delta. There have been debates on how climate change has affected rainfall pattern in Nigeria and there are numerous studies on rainfall trend in Nigeria and climate change, however, many of these studies have conflicting results and different conclusions have been reached. It is therefore exigent to analyze rainfall data in the study area and reach a concrete conclusion about rainfall trend. Hence, the main objective of this section is to perform trend analysis of rainfall spanning the period 1972-2016 in the study area.

### **5.1: Simple Descriptive statistics**

Descriptive statistics were used to determine the precipitation characteristics in this study. Figures 42, 43 and 44 present the minimum/maximum, standard deviation and mean of rainfall in the study area. The highest amount was recorded in August (578.1 mm) followed by September (574.5mm) and the lowest amount was recorded in January, December and November. While the main rainy season last from March to October, rainfall is usually at its peak between July and October which is usually the period of heavy flood events. Hence, it can be surmised that the flood events that have been recorded in the study area between September and October may have been due to the high rainfall intensity which usually occurs from July to September.

The standard deviation shows how much variation or dispersion there is from the mean. A low standard deviation means that the data points tend to be very close to the mean, whereas high standard deviation means that the data points deviate greatly from the mean (i.e. spread out over a large range of values). In other words, rainfall with a high standard deviation is considered more volatile than rainfall with a low standard deviation. The standard deviation in this study varies from 20.3 (January) to 103.4 (August). Result shows that August had the highest standard deviation. This implies that values in this month are not close to the mean and there are arbitrary values or outliers. For example, the month of August has the highest value of rainfall, but in terms of the mean value it is evidently not, so in reality, rainfall pattern in this month can be described as erratic. Such temporal variability may invariably affect the agricultural crop production in the study area.

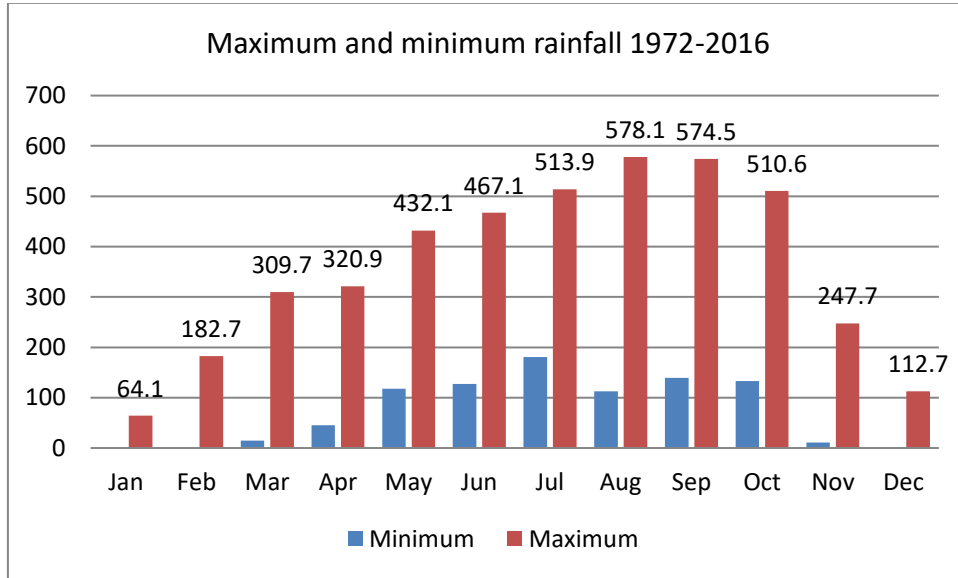


Figure 42: Maximum and minimum rainfall

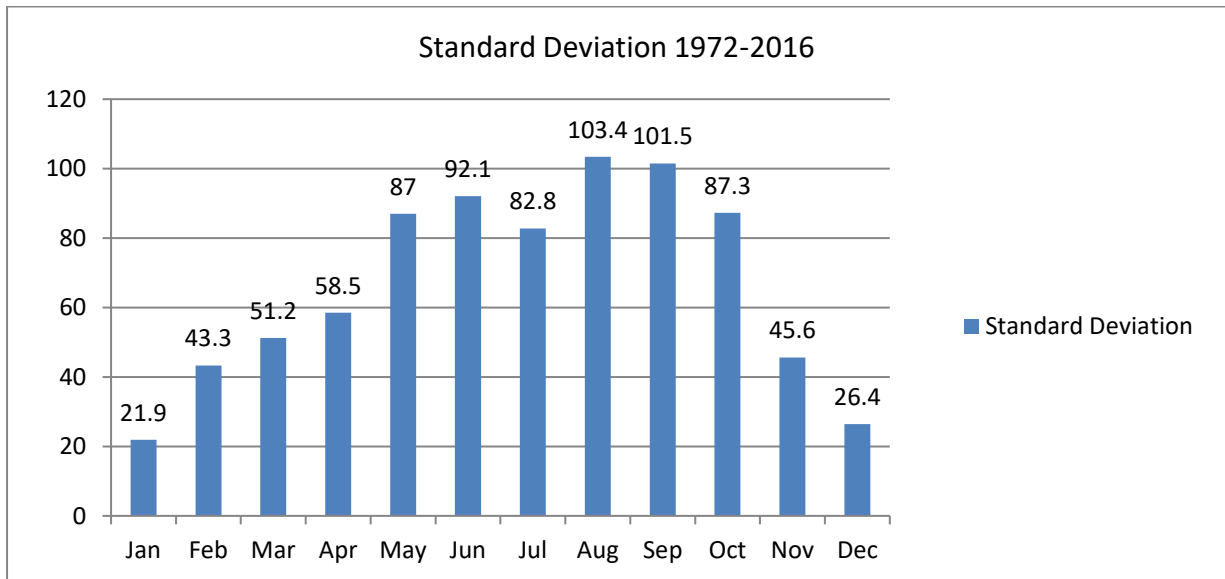


Figure 43: Standard deviation

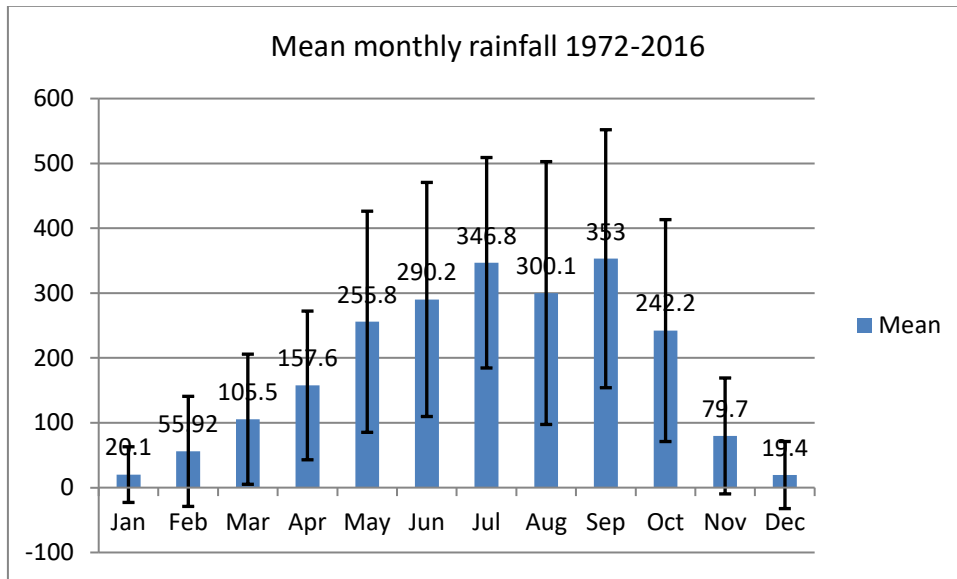


Figure 44: Mean monthly rainfall with error bars

## 5.2: Annual Trend Series Analysis

Descriptive statistics shows that the mean annual rainfall was 2435.7mm. The highest annual rainfall was recorded in 1979 (3338.8mm), other years with high annual mean rainfall include 1980 (3328mm) while 1983 on the other hand, recorded the least annual total rainfall of 1632mm. The linear regression was used to analyse rainfall trend in the Orashi Basin. This approach has been long utilized in many meteorological studies because it gives results which are simple to interpret; both graphically and analytically on the basis of the shape and parameters of the trend equation. The equation of the linear regression line is given by

$$Y = a + bX,$$

Where  $X$  is the independent variable and  $Y$  is the dependent variable.

In this thesis, the dependent variable  $Y$  is rainfall and independent variable  $X$  is the year. Using annual rainfall data from 1972 to 2016 (45 years). Microsoft Excel and Xlstat software were used to calculate the lines and statistical values of linear regression analysis. The value of  $R$ -square ( $R^2$ ) or the square of the correlation from the regression analysis was used to show how strong the correlation between the variables  $X$  (year) and  $Y$  (rainfall amount) are. The value is a fraction between 0.0 and 1.0. A  $R^2$  value of 1.0 means that the correlation is strong and all

points lie on a straight line. On the other hand, a  $R^2$  value of 0.0 means that there is no correlation and no linear relationship between  $X$  and  $Y$ .

The annual variation in rainfall over the study area is displayed in Figure 45. The trend suggests fluctuations, either increasing or decreasing. There are also outliers' years like 1979 and 1980 which recorded high rainfall amounts while the least amount was recorded in 1983 with 1816.4mm of rainfall. From the results of the linear regression analysis ( $-2.4212x + 7102.9$ ), there is a statistically insignificant decreasing trend in annual rainfall data. Additionally, the  $p$  value for the regression was found to be 0.9526<sup>10</sup>. Meaning there is no statistically significant trend in annual rainfall. The low value of the  $R^2$  statistic (0.009) also indicated a very weak relationship between the rainfall and time period.

Comparatively, this is similar to results by Adedeji et al. (2018) whose study showed that annual rainfall in Port Harcourt is decreasing at the rate of 0.44mm/year with  $R^2$  value of 0.03 which is statistically insignificant at 5% level of significance. In another study, Chinago (2020) notes that rainfall in Port Harcourt is slowly but steadily decreasing over the years and confirms that rainfall variability has not changed significantly in Port Harcourt. Study of rainfall pattern in Delta State within the Niger Delta between 1971 and 2009 by Emaziye et al. (2012) similarly showed a decreasing trend. The trend line had a negative slope of -0.38 indicating that over the time period 1971 to 2009, annual mean rainfall in Delta state fell by -38mm per unit change in time. In another study in Warri in the Niger Delta, Olarenwaju et al. (2017), found a negative correlation coefficient (-0.156), i.e. negative relationship between rainfall and time (years). The study reveals that rainfall in Warri Metropolis is decreasing at the rate of -0.45mm per year.

It is evident from the results that there is no significant detectable effect of climate change in annual rainfall trend in the Niger Delta area. Additionally, Bello et al. (2012) showed that generally there was a decline in rainfall pattern in Nigeria by 81mm within 1901-2005. However, these findings do not agree with Odjugo and Ikhuria (2003) who argues that rainfall will increase around the coastal areas such as the Niger Delta due to climate change.

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<sup>10</sup> Since the probability value ( $p$  value) from the regression analysis for the annual trend lines was greater than the significant level  $\alpha = 0.05$ , the null hypothesis ( $H_0$ : there is no trend in the data, could not be rejected).

The linear trend line is not resistant (robust) to local fluctuations and outliers, therefore, to reduce the local fluctuations; the data series were fitted with the Locally Weighted Scatterplot Smoothing (LOWESS) regression curves to identify patterns over time (Figure 45). The LOWESS curve of annual rainfall displayed a gradual rise in precipitation up to the early 1980s. From the early 1980s onwards, it showed a downward trend up to the mid 1980s and reached the lowest value in the late 1980s. Since then, it has remained largely stable with a slight increase in 2012.

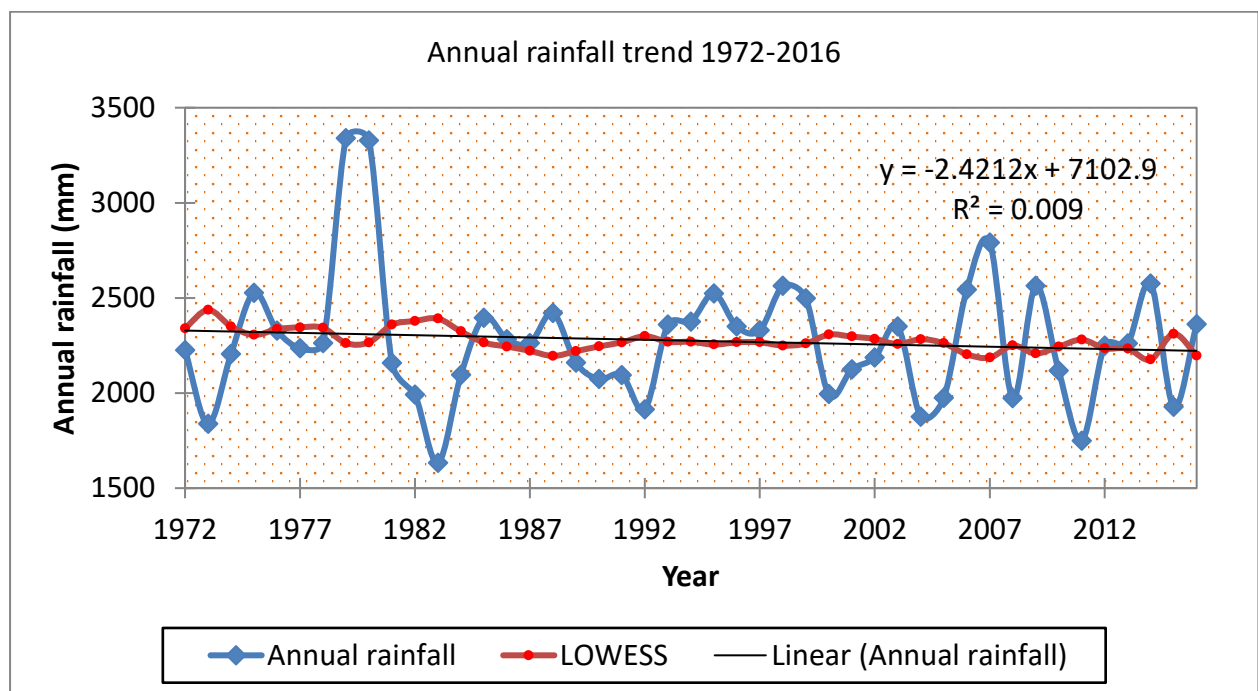


Figure 45: Annual rainfall Trend 1972 - 2016

### 5.3: Trend Analysis

Test for trend in annual series was made so as to get an overall view of possible changes in rainfall trend. The Mann Kendall test was performed to test for the presence of trends in total annual rainfall using data from 1972 to 2016. The Mann Kendall test is guided by the following conditions

Confidence level = 95%

Critical value = 1.96

**Null Hypothesis ( $H_0$ )** = There is no significant change in rainfall trend. The null hypothesis ( $H_0$ ) is rejected when  $Z > 1.96$  and the result is held to be statistically significant.

**Alternative Hypothesis (H<sub>1</sub>)** = There is a significant change in rainfall trend. The alternative (H<sub>1</sub>) is rejected when  $Z < 1.96$  and the result is held to be statistically insignificant.

The test statistic  $Z$  was used as a measure of significance in annual rainfall trend. A positive value of  $Z$  specifies an increasing trend, while decreasing trends are denoted by negative values.

Table 15: Result of Mann Kendall test on annual basis

Significance level ( $\alpha$ )	Critical values	Mann Kendall Test statistic ( $Z$ )	Trend	Significance
0.05	1.96	0.91	Increasing	Not significant

\*n= 45 (1972-2016)

Mann Kendall  $Z$  value of 0.91 is less than critical value of 1.96; (Table 15) hence the results of the analyses indicate that although there is an increasing trend in annual rainfall, however at a 95% confidence level, the increase is not significant. In line with the present result, Salami et al. (2014) analysed trends in hydro-meteorological variables covering about six stations in Nigeria and found a significant decrease in rainfall in five stations. Another study by Owolabi (2016) reveals that there was no particular trend in rainfall over the period of study in Ado-Ekiti within 2001 to 2011. Based on these results, it can be inferred that annual rainfall in most parts of the country is not significantly increasing.

Restrain should be exercised in reaching conclusion about the results from annual rainfall trend. In analyzing flood relationship, the annual rainfall total is not necessarily the sole determinant of increased flood frequency, more representative, is the fraction of it that falls as extremes especially in months of heavy rainfall when the ground is saturated.

### Monthly Trend

For agricultural activity, seasonal reliability is more important than annual reliability, hence, focusing on the annual trend alone might be misleading to the smallholder farmers. In this thesis, the application of the Mann-Kendall test to the time series of annual precipitation detects an increasing trend. However, this is not sufficient to conclude that there are no statistically significant trends because, given the seasonality of the precipitation pattern, trends may not be detectable at the annual scale. To examine possible changes in smaller time scale, it is essential

to investigate the monthly precipitation trend. Therefore, the Mann-Kendall test was repeated using monthly precipitation from 1981 to 2016 and results are presented in Figure 46.

The height of the bar shows the trend direction for each month. The monthly trends differ in direction and size from month to month: Most of the month showed increasing (upward) trend and some showed decreasing trends. Only March, July and September showed a decreasing trend. All the other months showed an increasing trend. However, of all the months, only October could be said to have increased significantly, using the 90% significance value.

This result is in line with other studies such as Umar et al. (2018) who conducted a Mann-Kendall trend test to detect monthly temporal behaviour of rainfall in several locations in Northern Nigeria. The monthly rainfall trend test results in all the stations shows an increasing trend for most of the months, however, the only month showing statistically significant increasing trends in most of the locations was October. Another study of rainfall trends across southern Nigeria by Emmanuel (2019) showed revealed similar results, in Ibadan, a statistically significant increasing trend was noticed in September, October, while in Calabar, there was a statistically significant positive increase trend in November.

A linear regression model was used to compare and validate the results of the Mann Kendall test and to determine the magnitude of the trend. The results are given in Table 16 and Figure 47. The results indicated a downward trend for the months of July, August and September and increasing trend the rest of the months. All of these trends are statistically insignificant as indicated by the P-values (Table 16). The R-squared statistic for most of the months also showed a weak relationship between the variables of rainfall and year.

Comparatively, the linear regression analysis by OLS, and Mann-Kendall's nonparametric test statistics gave the same conclusion of non-existence of a significant statistical variation in the trend of monthly rainfall. According to the results, it is clear that both methods provide the same results as they indicate that rainfall reduced in the months of July, August and September.

The statistically non-significant increasing trend in the statistical tests carried out shows that there were no statistical variations that would have significantly influenced rainfall regime in the study area during the period under review.



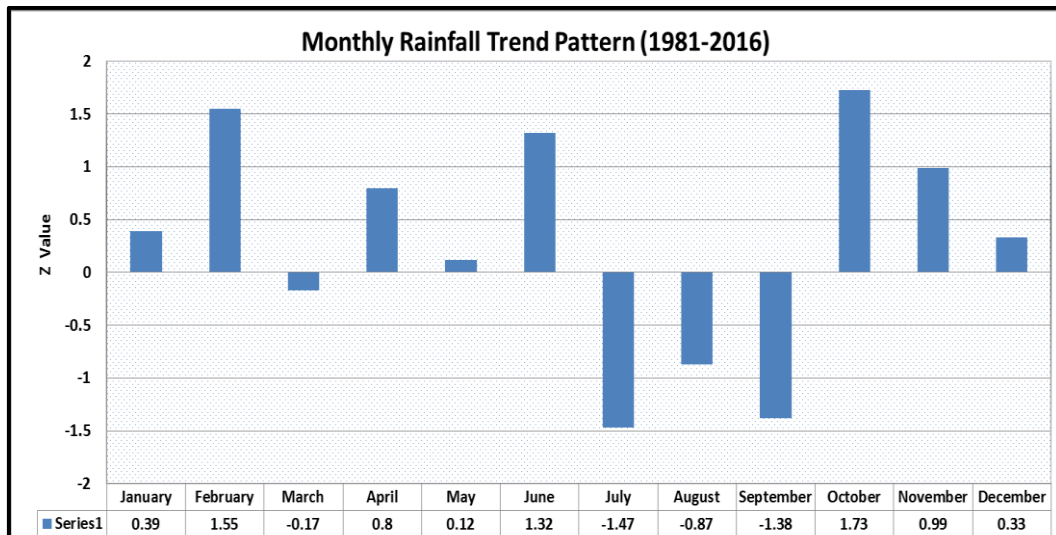


Figure 46: Results of the Mann Kendall test on monthly basis

Table 16: Monthly linear regression equation,  $R^2$  and p value

Months	Equation Y	$R^2$	p Value
January	$0.0355x - 50.935$	0.0003	0.4994
February	$1.208x - 2359$	0.084	0.4634
March	$0.4971x - 887.98$	0.0102	0.4997
April	$0.4774x - 796.44$	0.0072	0.4997
May	$0.15x - 45.078$	0.0003	0.4703
June	$2.5005x - 4707$	0.0796	0.4996
July	$-1.6557x + 3655.7$	0.0432	0.4999
August	$-0.9675x + 2233.6$	0.0094	0.4994
September	$-1.8233x + 3996.6$	0.0349	0.4999
October	$1.9964x - 3747$	0.0565	0.4992
November	$0.7106x - 1340.5$	0.0262	0.4987
December	$0.3854x - 750.71$	0.0229	0.4572

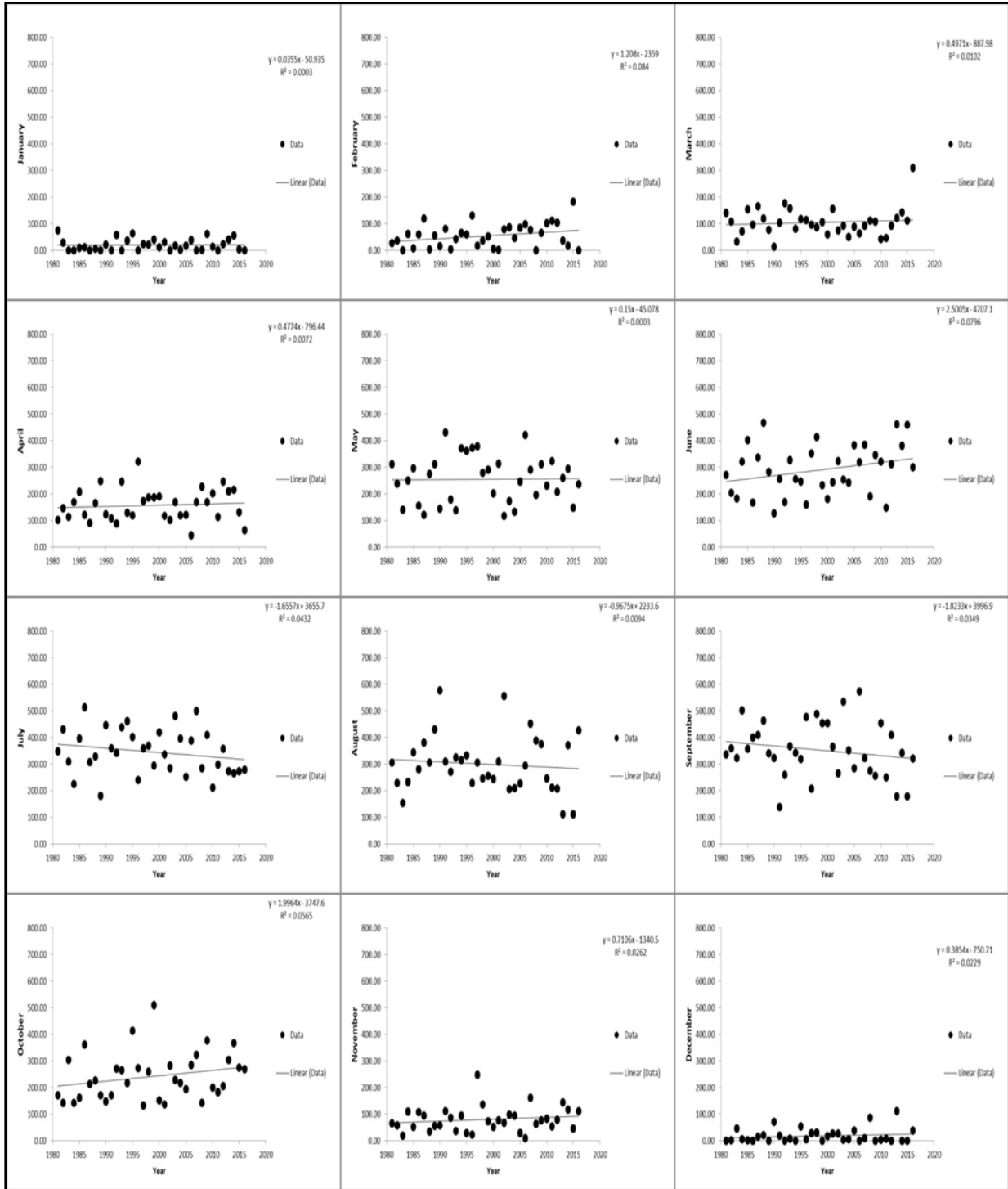


Figure 47: Scatterplot of monthly rainfall (1981- 2016)

## Change Detection

The homogeneity of the annual precipitation data was tested by using the Pettitt test (Figure 49). The results of homogeneity tests were checked at a 5% significance level. Data series were considered to be homogeneous when the p-values were lower than 5% significance level. The result of the homogeneity test shows the there is no abrupt change in rainfall trend in the study area.

## Test interpretation:

$H_0$ : Data are homogeneous

$H_a$ : There is a date at which there is a change in the data

The annual precipitation data showed that p value for the Pettitt tests was 0.431. As the computed p-value is greater than the significance level  $\alpha=0.05$ , the null hypothesis  $H_0$  is accepted.

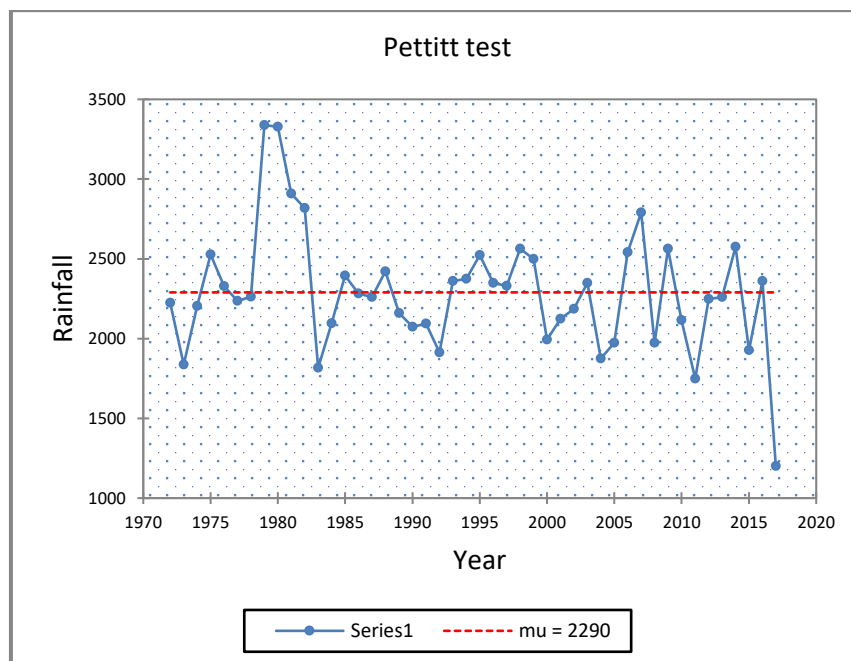


Figure 48: Pettitt test

The statistically non-significant increasing trend in most of the statistical analysis carried out signifies that there were no statistical variations that would have significantly influenced rainfall regime in the study area during the period under review. The flood events of 2012 and 2015 are apparently linked to large amount of precipitation; however, two events are not enough to draw valid conclusions about the occurrence of climate change in the area. In

conclusion, the present and near term effects of climate change do not appear to present great challenges for agricultural production in the study area, but that does not mean that the effects of these changes might not worsen in the future.

While increased intensity of precipitation over short periods in the study area might also lead to an increase in streamflow, however, the increase in flood events in the study area cannot be fully attributed to climate change. Evidence suggests the presence of other significant factors influencing the increase in flooding. It is vital to investigate the possibility of changes in land use and morphologic conditions within the basin as these factors have been acknowledged to have significant impact on the changes in increased flooding in the area.

## Chapter 6: Result and Discussion of Land use Change

### 6.1: Land use Change Trend

This section presents the results of the land cover change data analysis and also discusses the findings along with brief highlights of the factors associated with change in land cover in the study area. The land-use/land-cover changes between 1986 and 2016 were analyzed using Landsat images and GIS image processing tools. The 1986, 2003 and 2016 land use maps are presented in Figures 50, 51, and 52 respectively. The results show that built-up area increased from 15.7km<sup>2</sup> in 1986 to 175.6km<sup>2</sup> in 2016 representing 1018.47% increase (using 1986 as the base year). Agricultural areas increased from 195.6km<sup>2</sup> in 1986 to 820.3km<sup>2</sup> in 2016, representing an increase of 319.37%, while Forest areas declined from 1643.6km<sup>2</sup> in 1986 to 824.9km<sup>2</sup> in 2016, representing a 49.81% decrease (Figure 49). This is similar to findings in a study by Ochege and Okpala-Okaka (2017), in which forest area in Southeastern Nigeria declined by 44% between 1984 and 2014, while built-up area increased by 10.98% within the same period. The pattern also generally accords with that of Enaruvbe and Atafo (2016) which shows a decline in forest area, from 9522 km<sup>2</sup> to 5076 km<sup>2</sup> representing a decrease of 46.69% and 34.13% increase in agricultural area i.e. from 9796 km<sup>2</sup> to 13,140 km<sup>2</sup> within 26 years (1987 to 2013).

As Figure 52 shows, there is hardly any natural forest remaining in the upper part of the basin and this can be traced to drastic agricultural expansion going on in the area. Agricultural expansion started slowly after the mid-1990s, but in the 2000s agriculture started increasing tremendously, leading to a remarkable decline in forest areas. Result shows that more than 47.35% of the forested areas have been cleared between 2003 and 2016. This proves that forest area is not just vanishing; there is also acceleration in the rate of deforestation. In terms of the spatial distribution of changes, results show that most of the deforested areas/agricultural areas are located in close proximity with built up areas. This goes to show that the expansion of built up area and agricultural lands is taking place simultaneously and in close proximity.

For more in-depth analysis of land use change, changes in individual sub-basins were analyzed. The sub-basins show different patterns in terms of land use change. Agricultural area increased in all the sub-basins, however, the greatest increase in agricultural area were in sub-basins W1060, W1090 and W1080 respectively. The increase in built-up area was concentrated in

sub-basins W1060, W1080 and W1090. Forest area witnessed the greatest decrease. Although forest area decreased moderately in sub-basins W1140 and W1170 from 62.49% to 48.48 %, from 48.41 to 40.54%, it drastically reduced from 70.77% to 3.35% in basin W1060 and from 67.47% to 18.90% in sub-basin W1080. There was very little change in water bodies in all the sub-basins. Swamp areas, decreased in sub-basins W1060, W1080, W1090, but increased moderately in sub-basins W1150 and W1170 from 26.85 to 36.43 and from 45.04 to 51.50. However, there was a significant increase in swamp area in basin W1200 from 57.63% to 82.29%. The reason behind the increase is not clear.

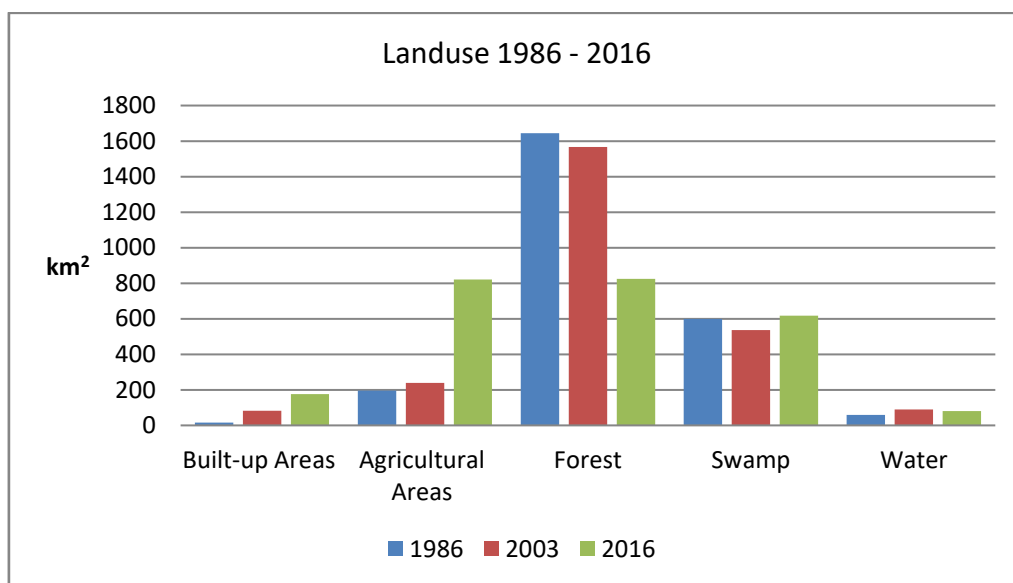


Figure 49: Types of land cover and spatial extent (km<sup>2</sup>)

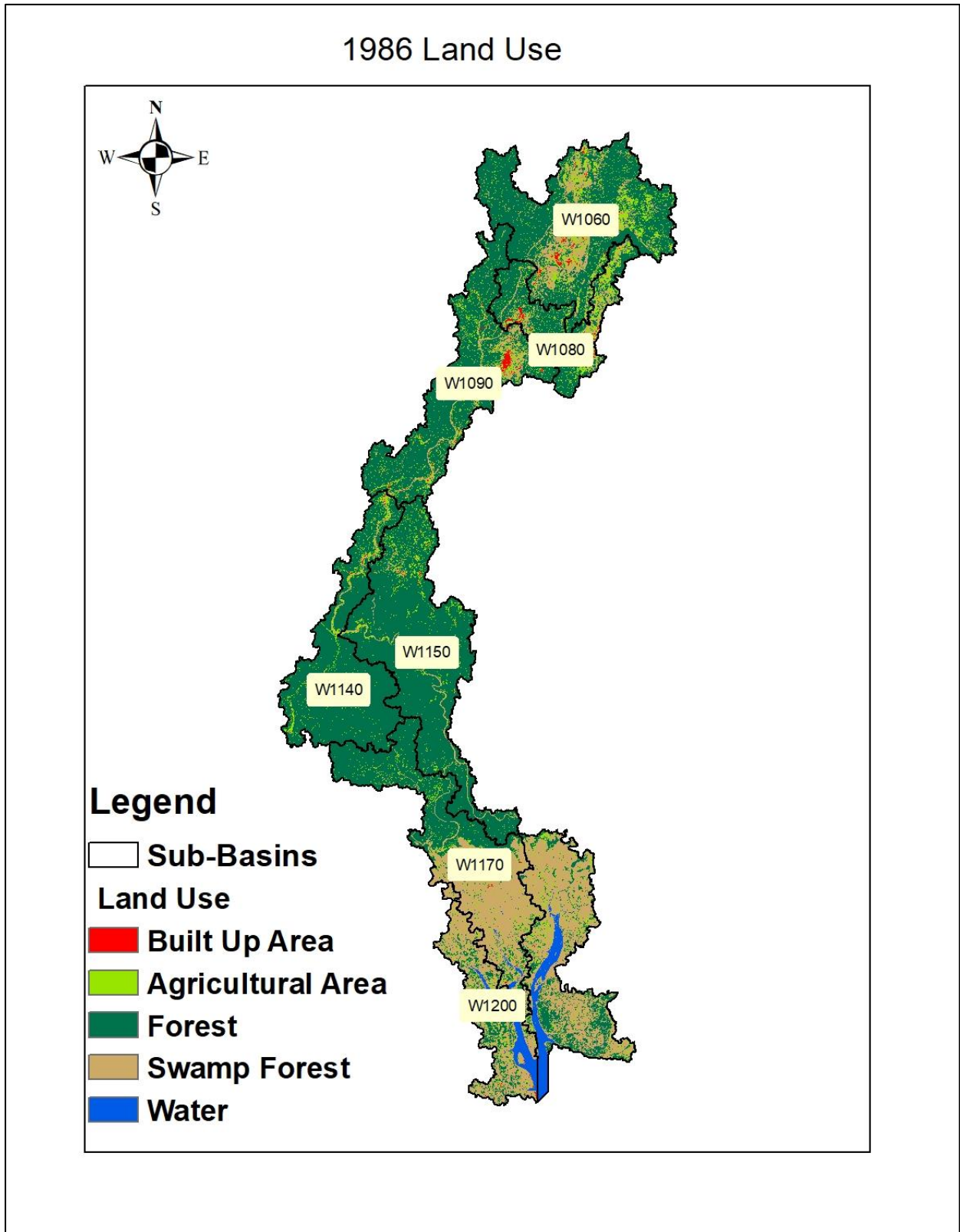


Figure 50: 1986 land use Map

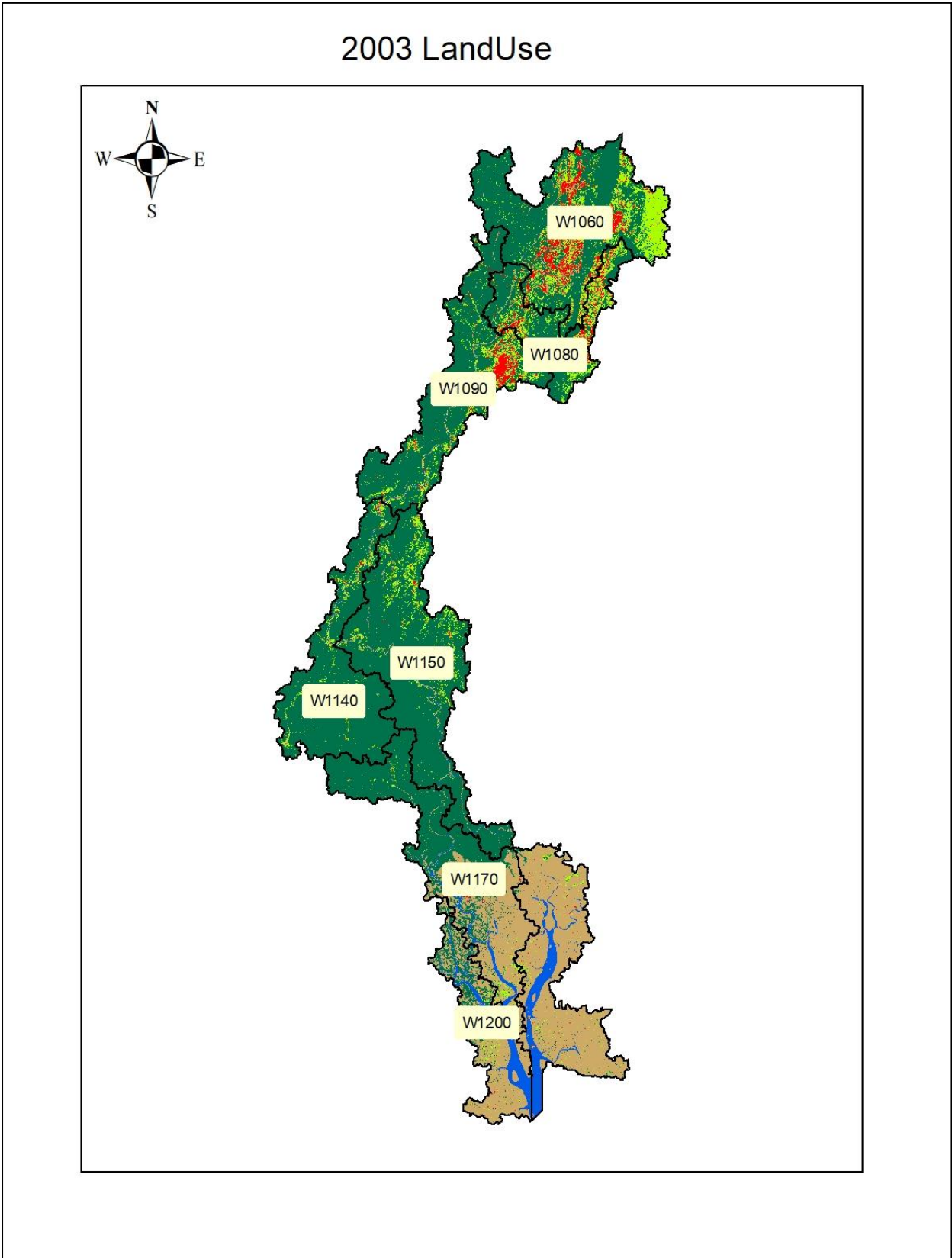


Figure 51: 2003 land use Map



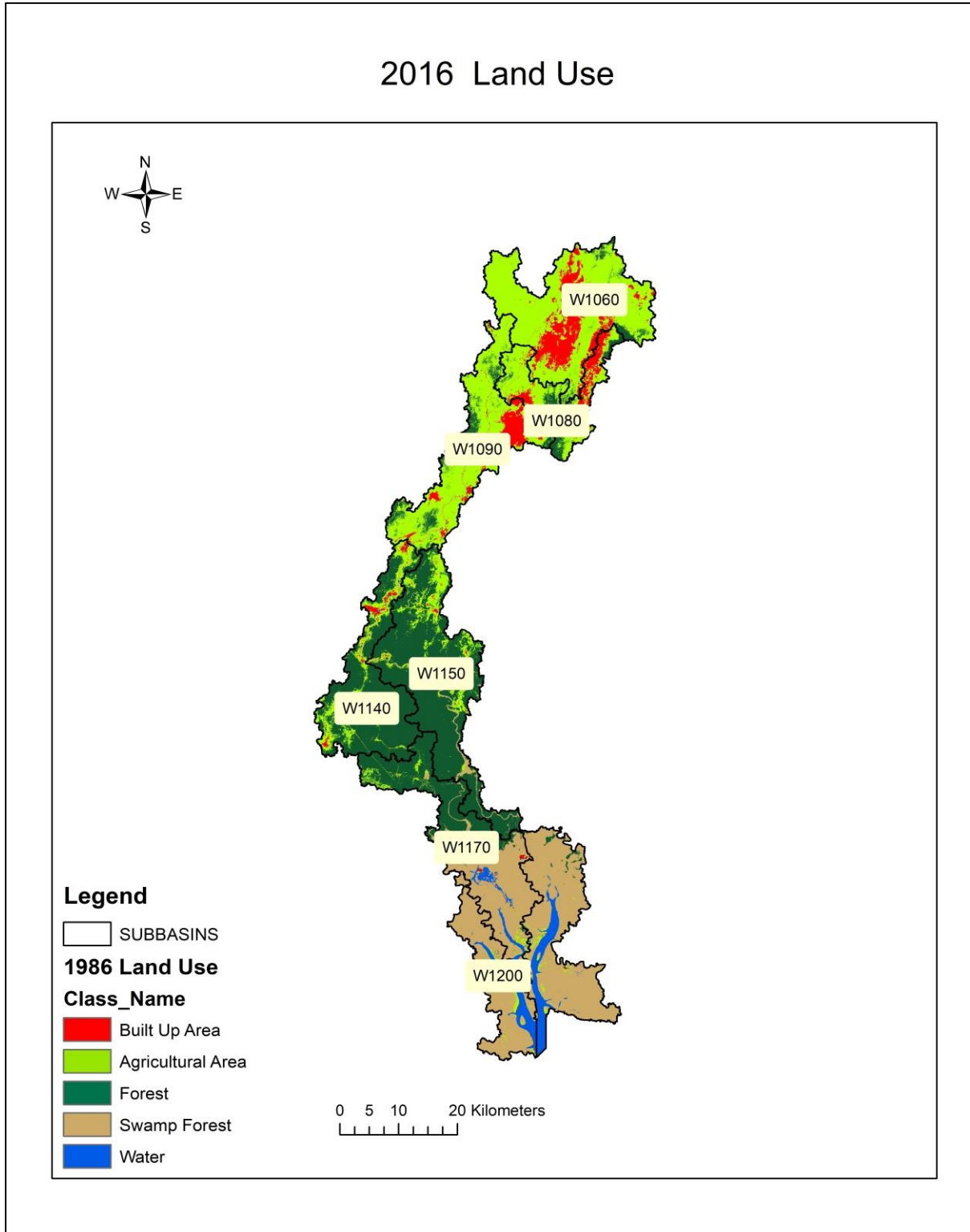


Figure 52: 2016 land use Map

## 6.2: Analysis of Land use Conversion

It is clear that the main LULC change in the study area was the conversion of forest to agricultural areas. Different studies show that the situation in the study area is not a peculiarity. Several studies in Africa have shown similar pattern, for example, according to Mengistu (2009), studies that have been carried out in different parts of Ethiopia indicated that agricultural lands have expanded at the expense of natural forests and shrub lands.

In a study of land use change in Ghana, Adjei et al. (2014) shows that between 1986 and 2008, the basin lost 18.0% of the total forest cover. Koneti et al. (2018) also observed a similar pattern in a study in India, the results of their study revealed that the overall LULC in the basin showed a reverse trend for the forest cover and cropland classes, i.e., decreasing forests and increasing agricultural areas. Another study by Twisa and Manfred (2019) of land cover change in the Wami River Basin, Tanzania, shows that 11% of the forest converted into cultivated land within 16 years. There are, however, studies that have shown the opposite pattern, e.g., studies by Andualem et al. (2018) indicated that there was a dramatic land use land cover change over a 11 year period of time in Upper Rib watershed and there was an increase of forest from 3.8% to 5.35% within a decade. Another study by Emenyonu et al. (2015) in the Western Niger Delta of Nigeria revealed that agricultural lands in the area reduced from 24.6% to 17.24% within 22 years, (1986 to 2008).

The swamp area did not undergo major drastic change; this aligns with results from a study by Dan-Jumbo (2017) in which result showed that the size of swamp area only changed slightly. Another study by Koneti et al. (2018) suggests that swamp area in India did not undergo major changes from 1985 to 2014 and this trend was attributed to the various protection legislations/ordinances formulated by the Government of India. However, the reality in the study area is different, in that the low-level change in swamp area is mainly due to the difficulty involved in converting swamp to other types of land use and not due to official regulations.

In the basin as whole, between 1986 and 2003, there was little land conversion, as most of the forest area remained the same; there was little variation in other land types. However, between 2003 and 2016, result shows there was increased land use conversion, especially from forest to agricultural land. In addition, the rate of conversion increased drastically. For instance, while only 5.5 % (138.6 km<sup>2</sup>) of the basin was converted from forest to agricultural land during 1986 and 2003, it rapidly increased within 2003 to 2016 to 24.97% (627.1 km<sup>2</sup>) (Figures 53, 54 and 55).

At the sub basin level (Figures 56 and 57) forest to agriculture conversion was also the major kind of conversion, the change from forest to agricultural was highest in sub-basins W1090, W1060 and W1080 where 65%, 57% and 41% of the basin area was converted from forest to agricultural area between 2003 and 2016. However, there are still parts of the basin that did not witness drastic conversion. For instance, significant part of sub-basins W1170 and W1150 remained as forest area. Similarly, a greater part of sub-basin W1140 did not witness major change as about 70% of the sub-basins remained forest areas. The land use change analysis suggested that the upstream area experienced the highest changes. Most land use conversion occurred from forest to agriculture in the upstream area, but some conversion to built-up area was also evident especially in the northern part of the area. In addition, observed agricultural land expansion showed a clear spatial pattern as the newly cropped areas are concentrated mainly in the upper parts of the basin. In these circumstances, land use change could be a significant factor in explaining the observed changes in streamflow in the area.

The changing proportions of these land-use types within the basin can have drastic effects on discharge and response to storms in the basins. The large amount of the conversion of forest to agricultural areas in the Orashi Basin revealed by the land use change analysis provides an important factor that may have contributed to the increased flood frequency in the study area. In particular, the expansion of agricultural land and built-up areas in the northern part of the basin provides plausible contributory factors that may adversely impact hydrological processes and subsequently increase streamflow and hence increase the risk of flooding in the basin

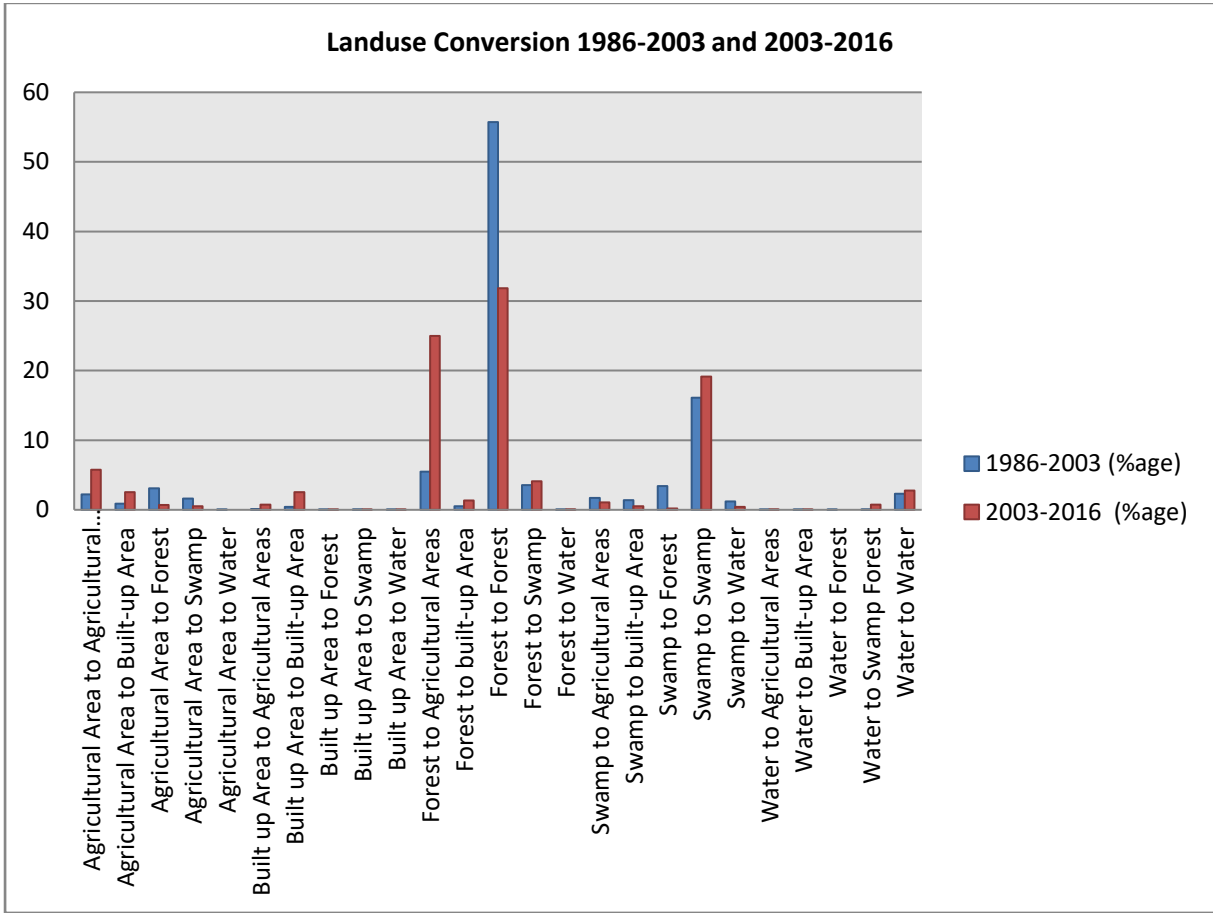


Figure 53: Land conversion 1986 - 2003 and 2003 - 2016

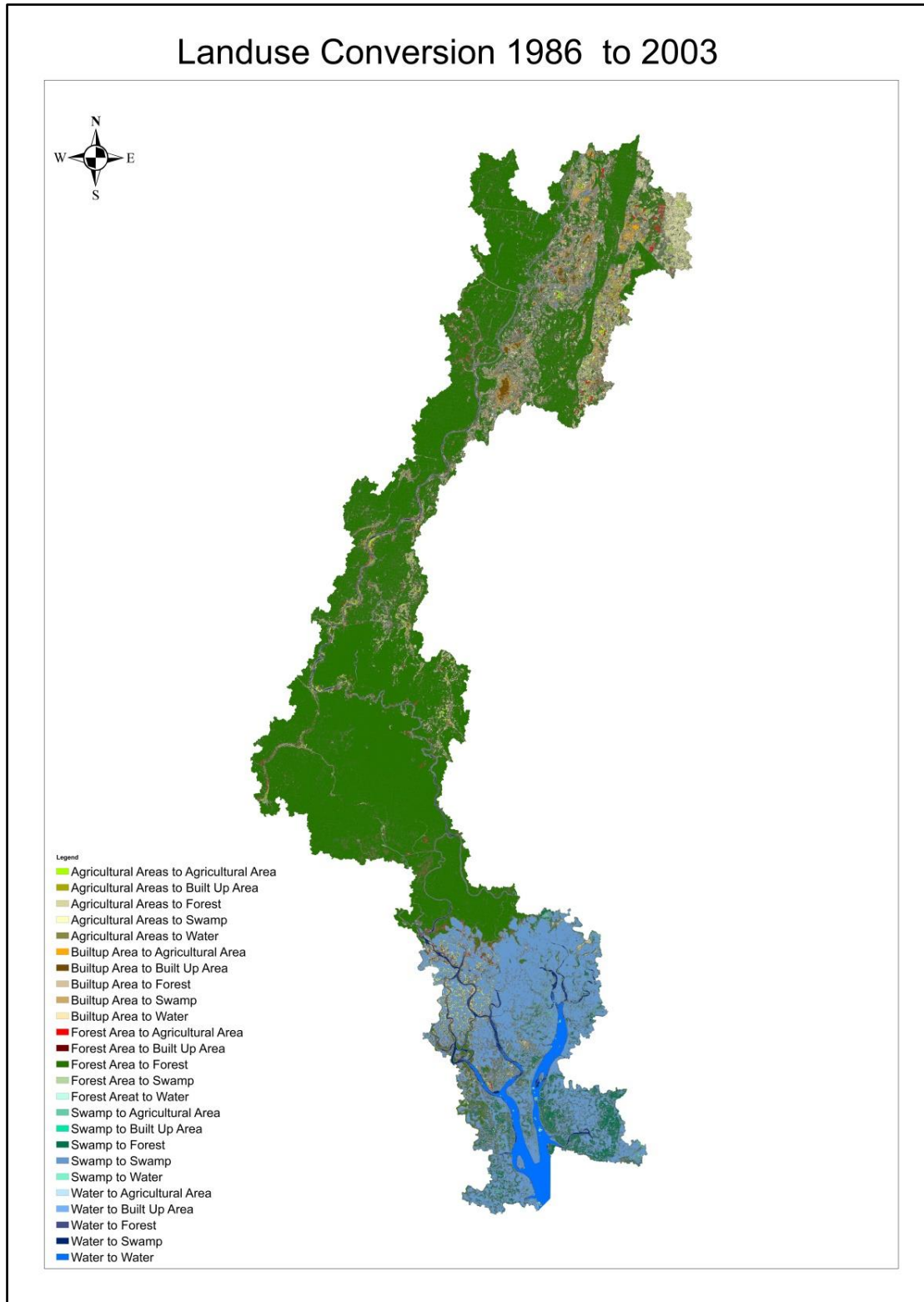


Figure 54: Land use conversion 1986 to 2003

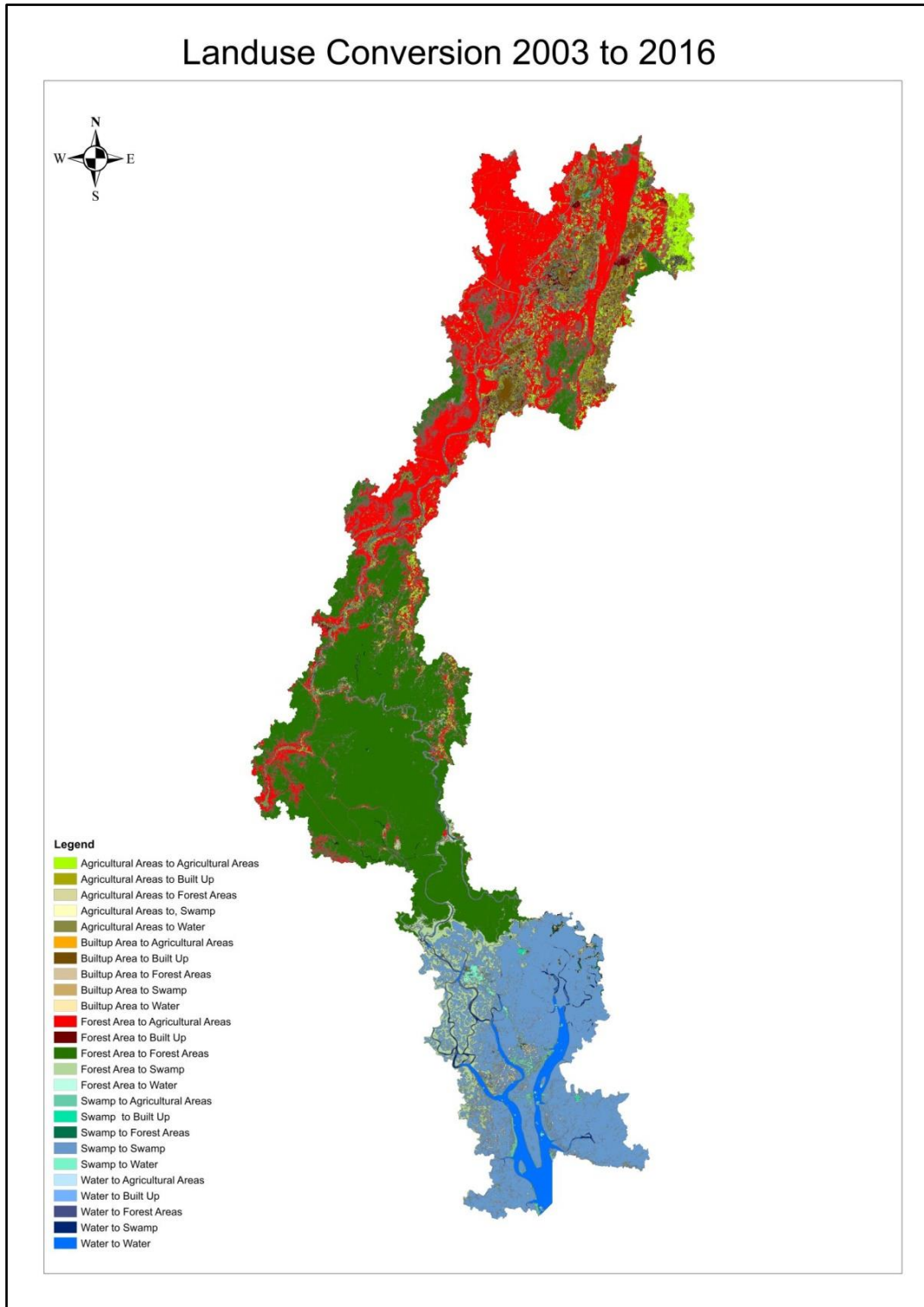


Figure 55: Land use conversion 2003 to 2016<sup>11</sup>

<sup>11</sup> Land use classes that were repeated. For example (forest areas to forest areas) denotes landuse classes that did not change. i.e it remained the same.

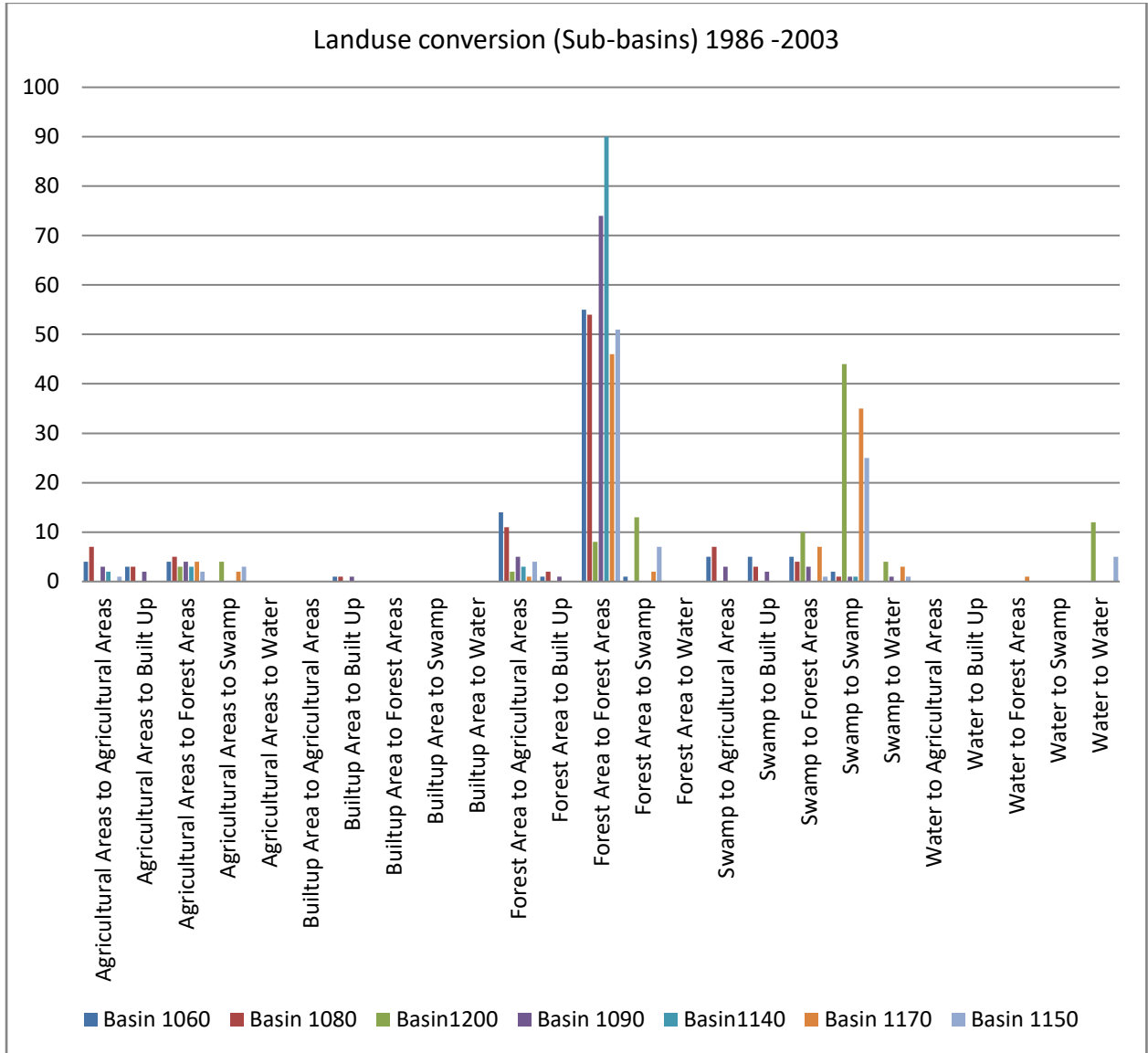


Figure 56: Land use conversion in sub-basins 1986 to 2003

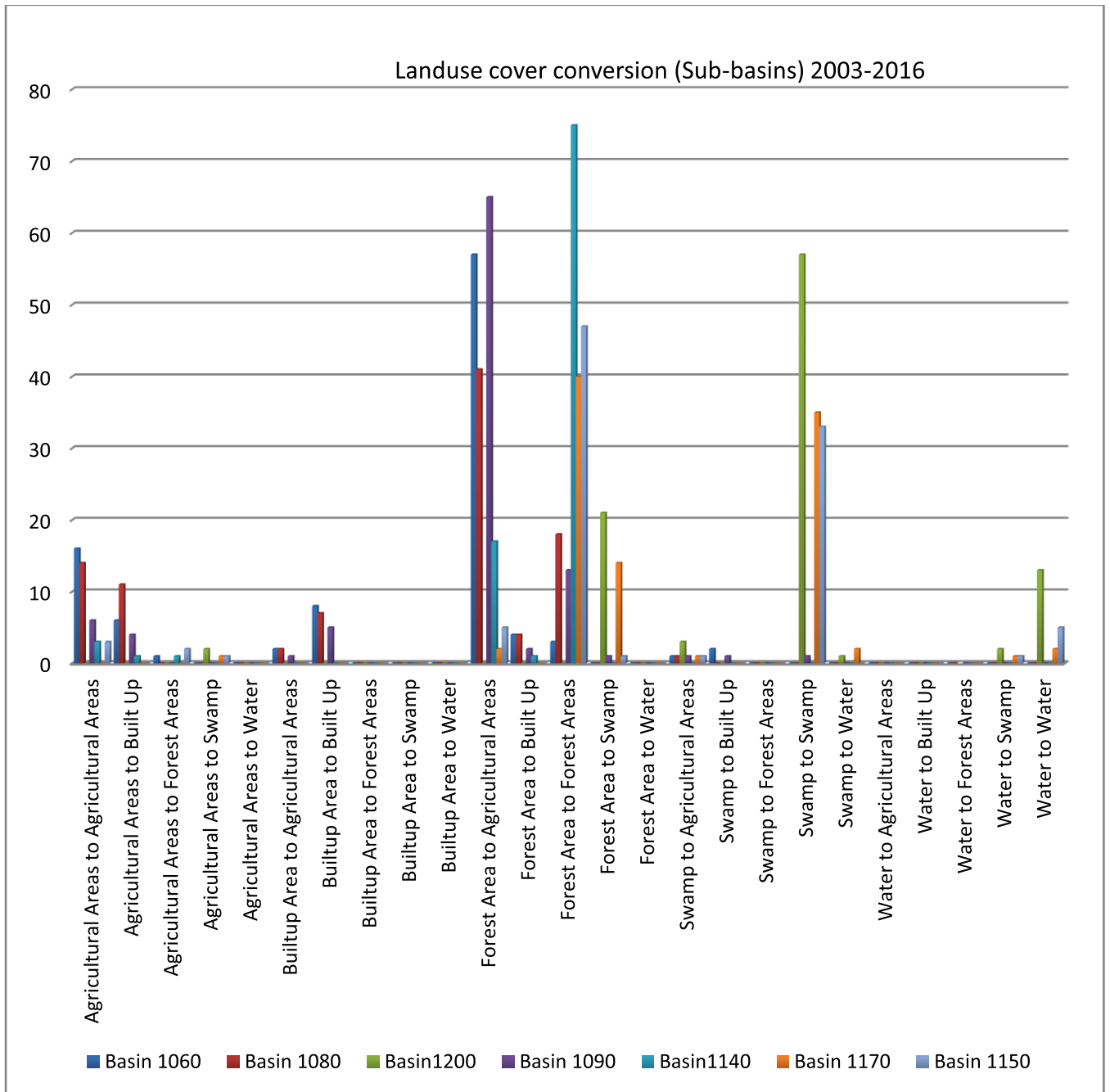


Figure 57: Land use conversion in sub-basins 2003 to 2016



### **6.3: Discussion of Land use Change Factors**

The methodological approaches used in the study of land use pattern and changes in the Niger Delta are limited and this has resulted in vague explanations of the factors that drive the land use change process. The pattern of land use is usually the end of a long and mixed chain of events; however, most studies on land use are often isolated and suffer from “narrow focus”. Consequently, previous studies have neither explicitly identified these secondary factors, nor ascertained their relative influence on flood magnitude and interactions with the hydrological system. For instance, it is not enough to depict the level of land use change, it is essential to also fully analyze the factors that are behind such trend. Assessing the driving forces behind land use and land cover change is important if past patterns are to be explained and used in forecasting future patterns.

Broadly speaking, two major concepts explain the drivers of land use change in the literature, proximate and underlying. Proximate drivers of land use can be interpreted as the direct factors which drive environmental change, and subsequently have direct impacts on the rate of land use change in a region (Lambin et al., 2001). Examples of proximate factors are agricultural activities, wood extraction and infrastructural expansion. On the other hand, underlying drivers are fundamental forces that strengthen more obvious proximate causes. Such underlying factors include such drivers as demographic, cultural, technological and political influences. The following sections will examine the proximate and underlying factors behind the trend in land cover change in the study area.

#### **6.3.1: Agricultural Expansion**

Using poor and rudimentary agricultural technologies, farmers in most parts of sub-Saharan Africa have for a long time practised shifting cultivation. Hitherto, farmlands were cultivated for a period of  $2 \pm 4$  years, and a fallow period of  $8 \pm 15$  years was allowed. However, due to several factors, the fallow period has been reduced as more land is required for production, leading to a reduction in soil fertility and agricultural yield. In recent years, low agricultural productivity and the scarcity of productive land in the Orashi Basin has led to the increased movement of farmers to uncultivated forested areas.

The conversion of prime forest into agricultural or built-up area has significant impact on streamflow and runoff. When lands are intensively cultivated over time, it results in soil

compaction, which further results in poor infiltration. According to Kathumo (2011), when agricultural land is tilled, compaction of lower soil horizons occurs and this lowers infiltration rates and increases bulk density.

Several studies have established the relationship between agricultural expansion and changes in streamflow. For instance, Dos Santos et al. (2018) in their study of hydrologic response to land use change in a large basin in Eastern Amazon found that an increase of over 57% in pasture areas increased a simulated annual streamflow by ~6.5%.

Evidence from the land cover change analysis shows that agriculture has been exerting pressure on the natural landscapes, replacing and fragmenting natural forest and wetland areas. Most of the lands were hitherto forest areas, however, with the increase in population and resultant agricultural expansion; large swaths of forest have been cleared to be used for agricultural purposes (Ayanlade and Drake 2016).

According to CILSS (2016) agricultural area accounted for 20 per cent of the Nigerian national landmass in 1975, but in 2013, the total agricultural area had doubled in size to about 40 per cent of the national land mass. Agricultural expansion in the study area can be traced to land degradation and low productivity. Although extensive studies on agricultural productivity in the Niger Delta have not been conducted, studies show that the Nigerian agricultural sector suffers from extremely low productivity, reflecting reliance on antiquated methods (Ogbebor, 2013). Such low level of productivity means that more forest land is encroached upon to feed the rising population. As Onokerhoraye (2013) states, a substantial proportion of agricultural growth in the Niger Delta comes from area expansion instead of increased productivity. Rapid and drastic agricultural expansion in the study area has evidently led to changes in hydrological responses in the area.



Figure 58: Forest that is being cleared for agricultural purpose in the Niger Delta (Source: <https://www.flickr.com/photos/jbdodane/10707729553/sizes/l/>)

### 6.3.2: Secondary Pressure Factors: Population Increase

Müller (2004) suggests that population growth induces agricultural intensification by increasing the scarcity of land relative to labour by shortening of fallow cycles and an increase in labour input per unit of land, while, Boserup (1965) argued that growing pressure on land induces a shift to higher value crops on existing fields and an expansion of agriculture into more fragile, marginal areas. Furthermore, according to Meyerson (2004), as agriculturally based population density increases in and near forested areas, the strongest relationship between population growth and deforestation occurs, as local people and young migrant families arrive at the forest frontier and clear land to provide more area for subsistence farming. In fact, Igu (2017) notes that the extent to which agricultural expansion continues to contribute to forest loss are a function of the population dynamics of the location. Numerous studies have established the line between agricultural expansion and rapid population growth in sub-Saharan Africa (Hadgu, 2008; Hurni, 1990). Further, Ngigi, et al. (2007) found that population growth had induced agricultural intensification at an unprecedented rate in parts of Ewaso Ngi'ro river basin in Kenya.

The population of the Orashi Basin has increased from about 200,000 in 1991 to 760,000 in 2016 (Figure 59). This represents an increase of 237% in just about 25 years (1991-2016), which means the population might well balloon in the next few decades. As a result of the population increase in Orashi basin, more people enter the agricultural labour force; consequently, pressure on farmland and forests has increased. Additionally, as the population

increases, there is the tendency of movements to marginal land areas. Poor migrants from rural areas to cities end up living in unplanned and informal shanty towns and slums, often in the low-lying and most flood-prone areas. This is line with the position of Watts (2010) who argues that increasing population in the Niger Delta leads to more forest lands being converted to agricultural lands, so as to meet the needs of the teeming population. On the other hand, in a study in the Ghana, Boahene (1996) posited that although, the high three per cent annual population growth exerts pressure on the forest resource, however, it is not the root cause of deforestation.

However, in most areas of the Niger Delta, in spite of the rural-urban migration, the rural population keeps increasing mostly through natural means. The increases are reflected in the growing number and size of settlements, deforestation and environmental degradation rampant in the area.

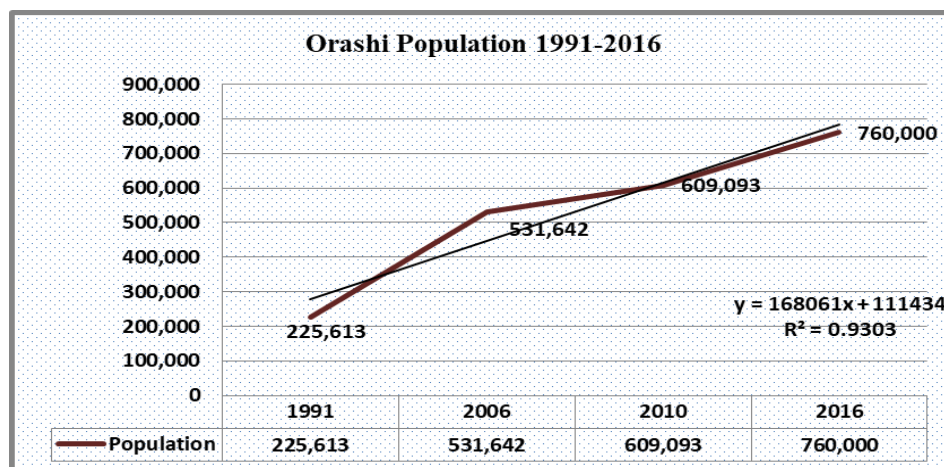


Figure 59: Orashi population trend 1991-2016

### 6.3.3: Deforestation

Tropical forests are regarded as important for preventing flooding and several studies have demonstrated that large reduction in forest cover increases runoff, annual streamflow and storm flow volumes in temperate, humid and dry tropical areas, though the extent of the increase varies (Zang et al., 2000). Maeda et al. (2009) estimated that deforestation in Suiá-Miçu River basin, Brazil, resulted in a 6% increase in surface runoff.

As previously established, agricultural land has expanded at the expense of natural vegetation in the study area. Data from the land use change analysis of the Orashi Basin showed that forest cover have decreased from 1643.6km<sup>2</sup> in 1986 to 824.9km<sup>2</sup> in 2016. This represents a drastic shrink in forest coverage in the area. Other studies show that deforestation in Nigeria is widespread phenomenon. For instance, according to Obayelu (2014) deforestation is a serious problem in Nigeria, with forest loss occurring at an average rate of 3.3% per annum. He further states since 1990, the country has lost over 6 million ha or 36%, of its forest cover and since 2000, Nigeria has been losing an average 11% of its primary forests each year. Enaruvbe and Atafo (2016) notes that the pattern of deforestation in the Niger Delta region is largely driven by urban development and agricultural activities, they further suggested that the increasing rate of deforestation in the Niger Delta can be attributed to increasing demand for arable land for food production occasioned by increase in population. However, in terms of population being a precipitating factor of deforestation in the Niger Delta, Ayanlade and Drake (2016) differs and found a poor correlation between both variables and they concluded that growth in population has no direct role to play in deforestation, at least in the short term.

However, it is evident that the demand for food resulting from population increase and the lack of alternative sources of income, coupled with an increase in the poverty level in the Niger Delta region, is likely to exert more pressure on the forest and forest resources in the region. Similarly, another study by Eregba and Irughe (2009) noted that as population increases in the Niger Delta, urban areas also expand; consuming farmland and this has resulted in deforestation in the area.

Studies in other areas further confirm the link between rapid land use change and high population growth. For instance, in a study of the Citarum watershed in Indonesia, Karsidi (2005) showed that the combination of a large population base, a relatively rapid rate of population growth has an effect of increasing the rate of land use change. Additionally, Guzha et al. (2018) notes that between 1990 and 2015, East Africa forest cover decreased annually by about 1% while human population increased at an average annual rate of 2%.

Demand for land resources by a fast-growing population, together with the pressure from rapid urbanization, agricultural land expansion and oil production infrastructure (Figure 60) have had a large impact on environmental resources in the region (Mmom and Arokoyu 2010; Fasona et al. 2011). Unfortunately, these resources (including forest) are exploited without

efficient management and this consequently results in serious environmental problems in the Niger Delta such as deforestation and floods.



Figure 60: Large scale deforestation for industrial purpose in the study area

#### **6.3.4: Intrusion into Marginal Lands**

According to Kowalski (2016), a trend that is increasingly becoming a problem for agriculture in sub-Saharan countries is that nowadays, more and more ecologically fragile marginal land is being put into production to sustain the rising rural population. According to Gessesse and Bewket (2014), as a result of the increase in food and fuel wood demands resulting from population pressure, local farmers are forced to push farm lands at the expense of vegetation cover (forest, shrub lands and grasslands) in the more marginal and fragile landscapes.

In the Niger Delta, agricultural expansion into marginal lands and wetlands have continued, largely boosted by several factors such as indigent smallholder farmers moving into cheaper marginal lands, oil exploitation activities, urbanization etc. The flood plains of the major rivers in Nigeria have become permanent abodes for several fishing and farming communities who depend on the areas for their economic livelihoods (Figure 61).



Due to a variety of factors, such as social and cultural attachment, economic reasons, most of the people living flood plains prone areas have abjectly refused to relocate, even when some relocate, such relocation is still within the floodplains thereby worsening the flood problem. Most of these areas that were newly built have become densely settled with buildings of different type and quality. These areas are highly vulnerable to seasonal flood hazard, including inundation and erosion, as new development continues. According to Douglas, et al. (2008), one of the most serious manifestations of the rapid urbanization process is the development of squatter settlements also known as the informal settlements, shanty towns, and slums. They note that as people move into cities, human impacts on urban land surfaces and drainage intensify. The proportions of small streams and river catchment areas that are urbanized will increase. As a result, even quite moderate flows produce quite high flows in rivers because much more of the catchment area supplies direct surface runoff from its hard surfaces and drains. Such situations frequently arise where poor people build their shelters on low-lying areas.



Figure 61: A fishing village located right along the banks of a river in the Niger Delta (GeoView, 2008)

## **Chapter 7: Results and Discussion of Flood Risk and Hazard**

This chapter focused on assessing flood hazard and risk. For more robust understanding, flood risk and hazard were analysed from different perspective, namely, morphometric, land use and hydraulic perspectives.

### **7.1: Morphometric Flood Risk**

To perform morphometric analysis, the Digital Elevation Model was used to extract the drainage characteristics and morphological parameters and the Weighted Overlay Analysis was used for identifying the potentially flood-prone areas by creating a map of four classes of flood vulnerability (from low to very high). This study considered elevation, slope, drainage density, TWI and SPI as important flooding conditioning factors in the basin. These factors were qualitatively combined using the weighted overlay tool in ArcGIS. The calculated morphometric parameters will be discussed accordingly.

#### **Elevation**

Low lying zones and flat topography are some of the possible biophysical triggers for LULC change mainly in Africa, Latin America and Asia. (Lambin, et al., 2003). Landscape restrictions such as steep slopes and inaccessible high elevation zones play a key role in protecting and preserving forests, shrub and grass vegetation covers (Gessesse and Bewket, 2014). The DEM shows that a substantial part of the Orashi basin is moderately low and therefore potentially flood-prone. The elevation of Orashi basin ranges between 99m in the eastern part of the study area to -1 in the southern part (Figure 62). The lowest relief is observed in the southern plains, while the highest relief is observed in the North-eastern part of the basin. The Orashi basin area was historically covered by forest, but due to its flat topography and low elevation, a significant part of basin has been converted into agricultural land. From a topographic point of view, most parts of the watershed are easily accessible by local land-users. This situation has contributed to the expansion of various forms of agricultural activities at the expense of forest cover. It can be concluded that the remnants of natural and plantation vegetation covers found in the flat and gently sloping areas are highly vulnerable to deforestation and conversion into other land use types.



## **Slope**

The slope map (Figure 63) was generated with the SRTM 90x90m DEM. The slope percentage of the Orashi basin varies between 0 and about 43.57 degrees. The study area is mostly dominated by flat topography with slope varying from 0 to 3 degrees, whereas the few high slopes (> 10 degree) are located near river channels. The map shows that the majority (62.67%) of the study area lies under a flat or little slope and these are widely distributed throughout the study area. The widespread distributions of low slope areas in the basin have implications on flooding potential in the area. According to Elmoustafa (2012), runoff volume is affected by slope and if the slope is very flat, water will not be removed rapidly. Evidence from the study area corroborates this view as most of the areas with slope less than 0.2 degree show water logging condition and moist area with lots of patches of water bodies.

## **Drainage Density**

Drainage density (Dd) indicates the landscape dissection, infiltration capacity of the land and runoff potential of the basin. Drainage densities can range from less than 5 km/km<sup>2</sup> when slopes are gentle, rainfall low and bedrock permeable (e.g. sandstones), to much larger values of more than 500 km/km<sup>2</sup> in mountainous areas where rocks are impermeable, slopes are steep and rainfall totals are high (Oruonye, 2016). High drainage density area indicates that the basin has high density of streams, less impermeable sub-surface materials, sparse vegetation, high relief, and, therefore, a quick storm response (Srivastava et al. 2008; Bhatt and Ahmed, 2014). In addition, a high drainage density is an indication of a drainage basin that is highly divided which respond quickly to rainfall events, i.e., large proportion of the precipitation runs off. Figure 64 presents the map of the drainage density of the study area which ranges from 0.028 to 5.4. The image shows that the study area is comprised mostly of areas with low drainage density. The preponderance of low drainage density areas observed in the basin is an indication of highly permeable sub-surface earth conditions, where land is covered with dense vegetation and relief is low, which lead to increase in permeability and can favour ground recharge zones. In the study area, high drainage density was found mostly close to river channels of the basin because of impermeable (hard rocks) sub-surface material in such areas (Okoyeh, 2014) and the dense network of tributaries around the river channels.

## **Stream Power Index**

The Stream Power Index (SPI) describes the potential to transfer sediment in a channel's stream. It shows negative values for areas with topographic potential for deposition and positive values for potential erosive areas. The SPI map (Figure 65) shows that the SPI value ranges from -13.82 to 24.56. Using the statistical tool in ArcGIS, the mean SPI for the basin was calculated to be 9.87. The high positive SPI mean value indicates that there is a high possibility for erosive actions in the basin. The preponderance of areas with high SPI values contributes significantly to basin's erosion process and land degradation risk process

### **Topographic Wetness Index**

The generated TWI map which is presented in Figure 66 clearly indicate that many areas have high TWI values, which is informative for deducing how and why the Orashi basin area is flood prone. Evidently, the lowest and flattest areas will be affected most by the floods because water tends to flow and accumulate in response to gradients in gravitational potential energy. Incidentally, large scale development has taken place on areas with high TWI and this greatly aggravates the flood risk within the area. Basically, the SPI and the TWI reflect the tendency of water accumulation in the landscape and highlight areas prone to both fast moving and pooling water. In general, these indices show that topographic attributes are major contributing factors to flooding in the area.

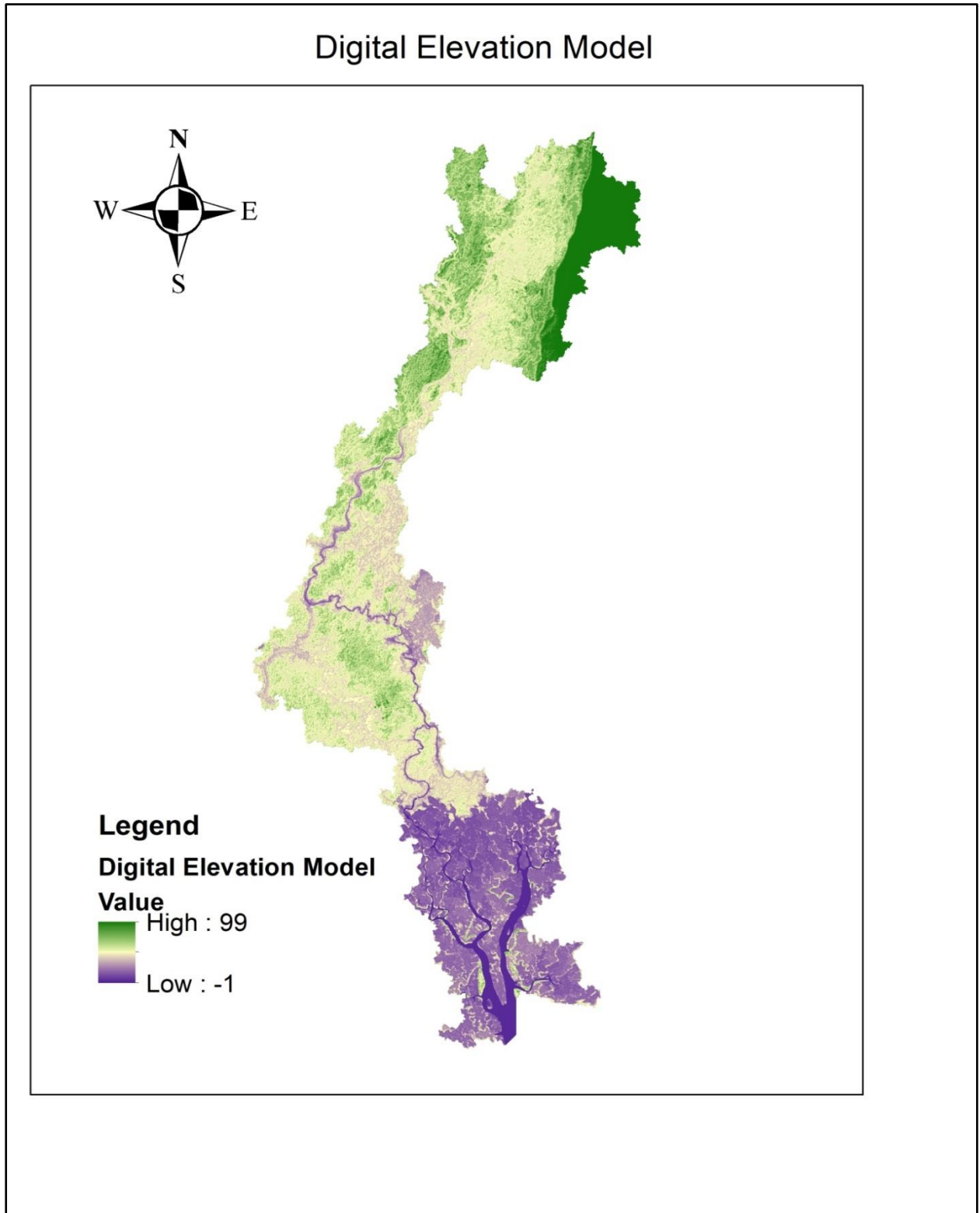


Figure 62: Digital Elevation Model

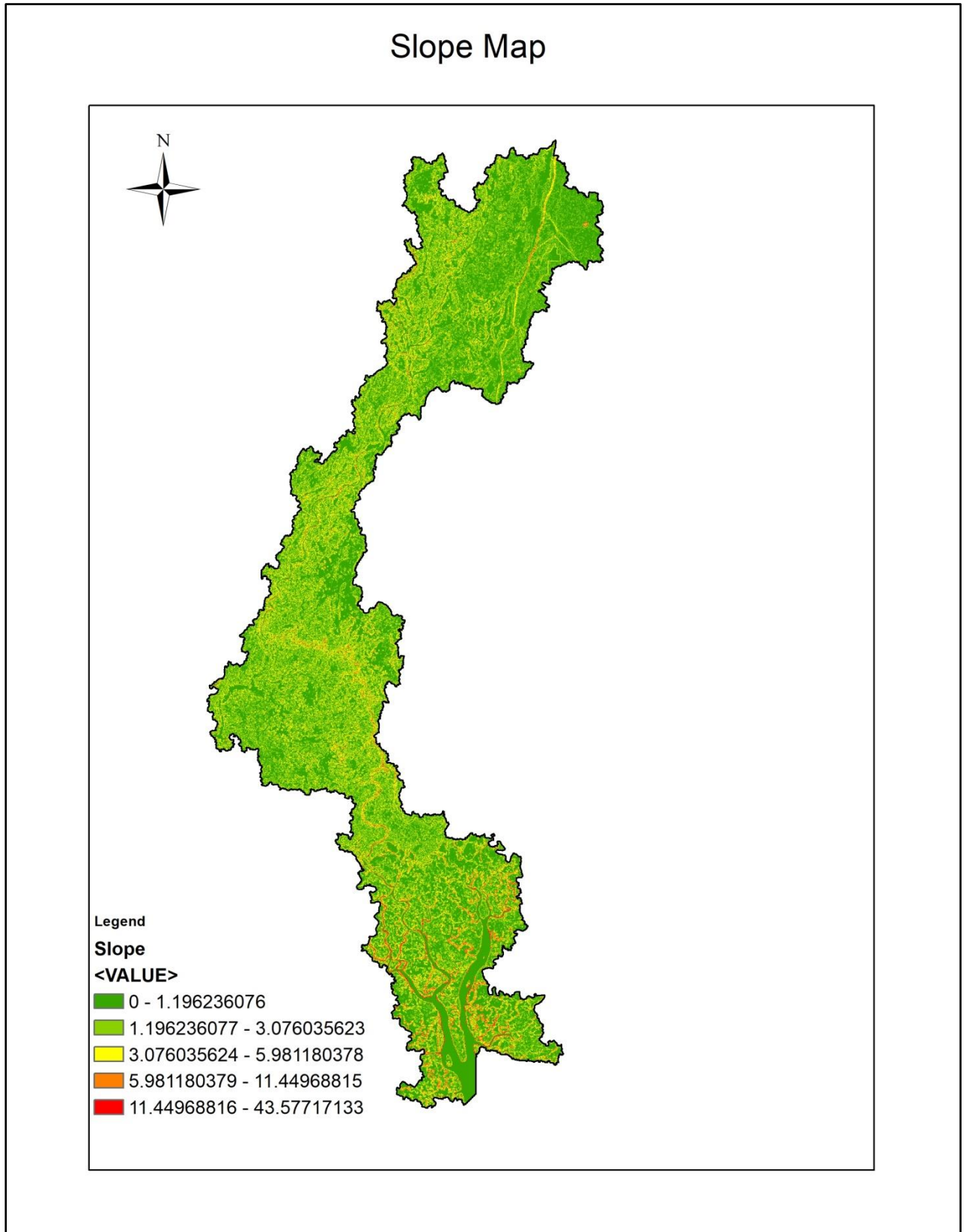


Figure 63: Slope Map

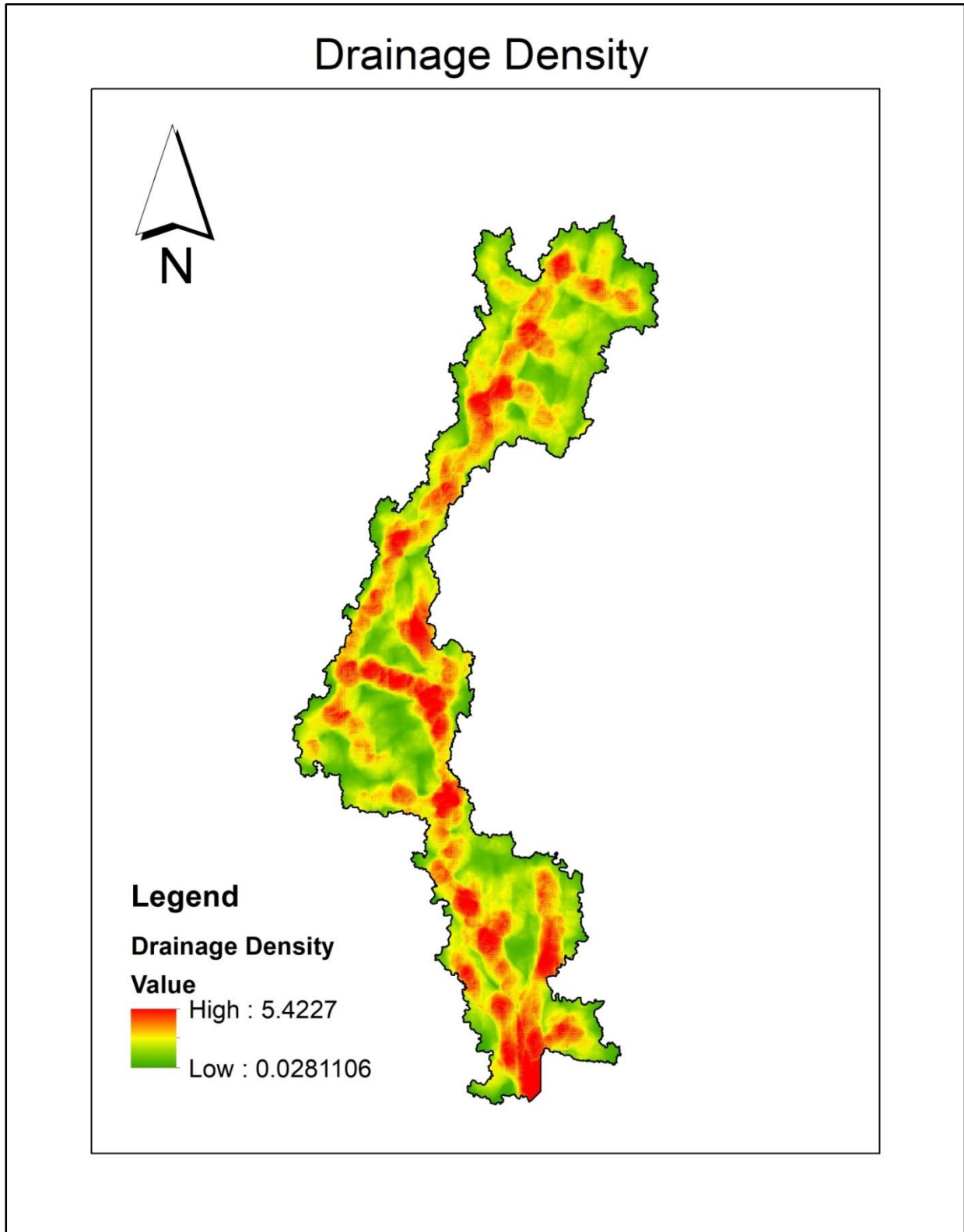


Figure 64: Drainage Density Map

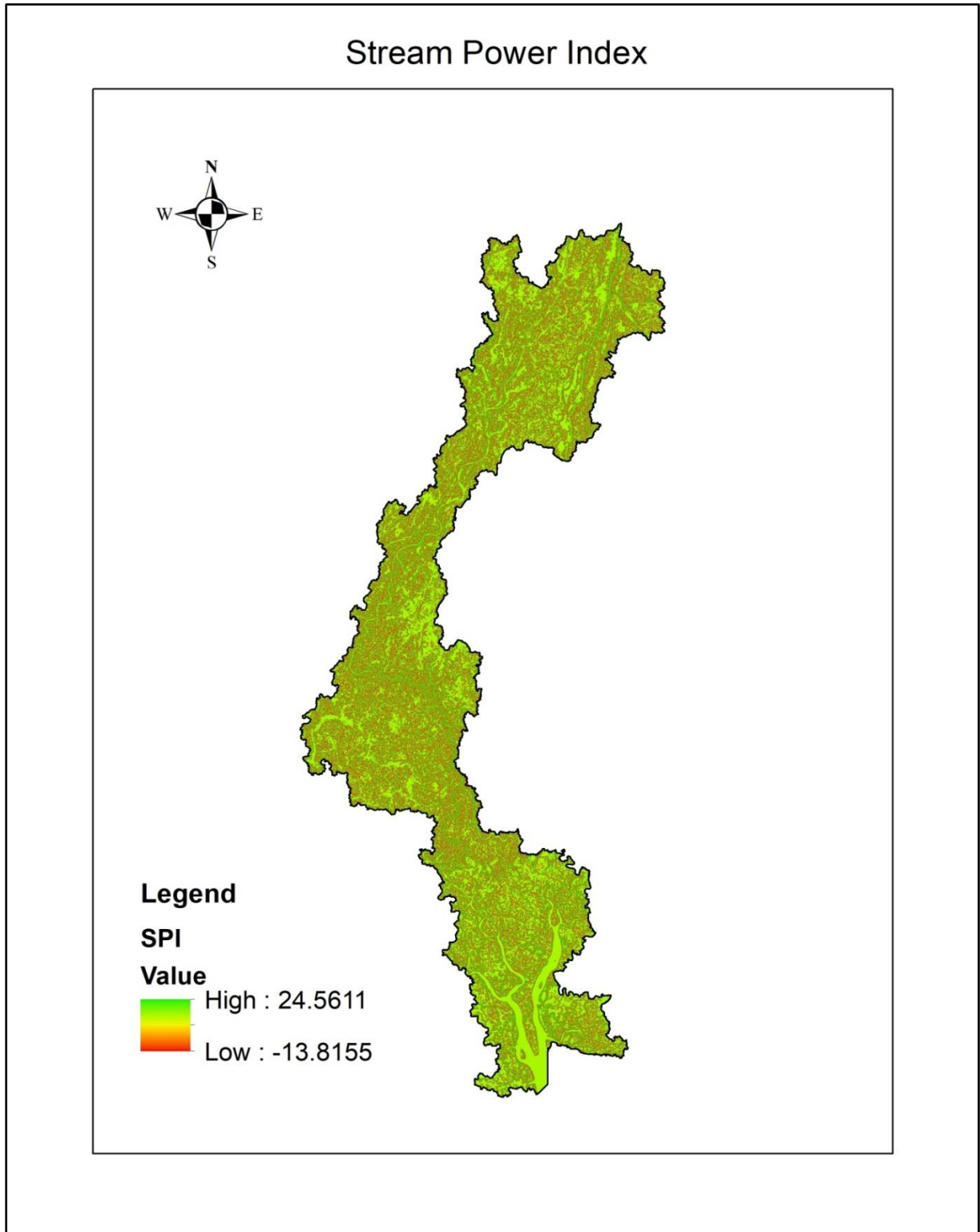


Figure 65: Stream Power Index

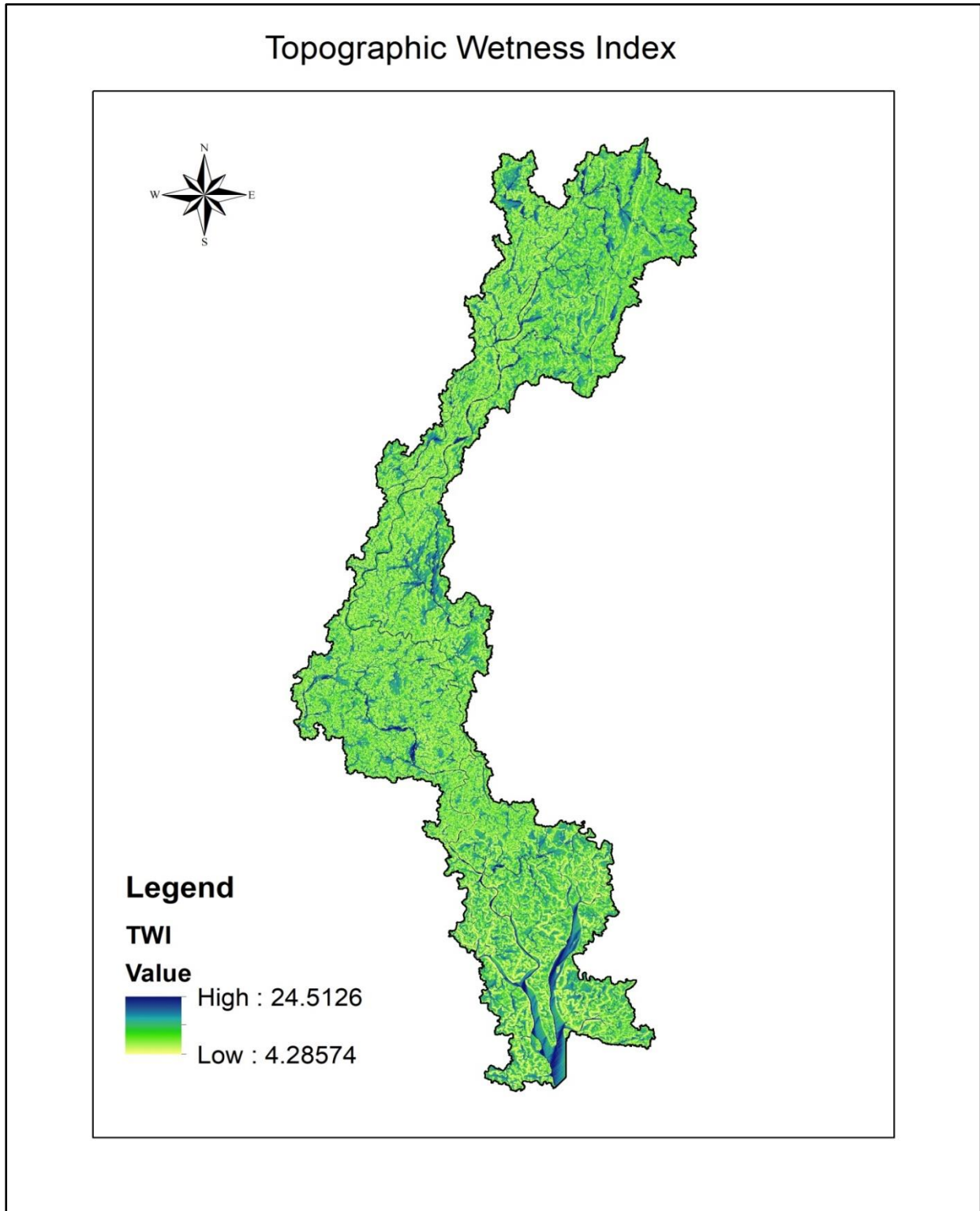


Figure 66: Topographic Wetness Index

The degree of flood susceptibility was determined by using the weighted overlay method. Flood risk in the Orashi basin was characterized into low, moderate, high and very high. Further, spatial analysis was performed to determine the proportion of the study area that fell

without specific flood risk zones. Figure 68 shows the morphometric flood risk map of the area. Morphometrically, the very high susceptible sub-basins are most concentrated in the lower reach of the study area, whereas low and moderate susceptible sub-basins are located in the upper reach of the study area. Low flood risk zone risk was mainly identified in the areas of high-altitude zones such as ridges and structural and denudational hills on the North-Eastern part of the Basin. Out of the total area of the Orashi basin, only 3% are under low risk zone of flood, 61% of the basin was identified as having moderate risk. 36% of the basin was found to be under high risk flood zone. Lastly, only 0.2% of the basin was found to be under very high flood risk. These outcomes demonstrate that not all the areas are prone to flooding, since the high elevation area of the watershed mostly corresponds with low risk. However, these upstream areas may have high potential for surface runoff, which makes it often susceptible to flash-flood occurrence.

This result mirrors that of Getahun and Gebre (2015) which found that moderate flood hazard covers the largest area in the Afar region of Ethiopia (52%), they also state that there is a low flood hazard probability in the highlands, that is, the upper part of the Afar river basin and that the very high flood hazard threats are in the downstream part of the basin, which are low-lying flat areas of the Awash River basin.

Flood risk was also analyzed within the sub-basins (Figure 67). Results show that there are minor variations in flood risk in the different sub-basins. Most of the sub-basins fall under high or moderate flood risk areas. Very high flood risk was seen in only sub-basins W1200 and W1150. The reason may not be unconnected to the position of both basins; they are adjacent basins and are located in the downstream sector of the catchment. Examination of flood risk in the sub basins reveals that flood risk increases downwards, in other words, sub basins located at the downstream segment were more susceptible to high and very high flood risk.

To assess the vulnerability of different land use types to flood risk, an overlay analysis was performed using the ArcGIS. The union geoprocessing tool was used to join different land use layers and the developed flood risk map. The zonal statistics tool was then used to compute the proportion of each land use type that falls within different flood risk zone. The relationship between the different risk areas and different types of land use was classified as in shown in Figure 69 and Table 17 shows that 6.15%, 71.33%, 22.51% of agricultural areas fall within low, moderate and high flood risk zones respectively. 6.62% 50.01%, 43.35% and 0.02% of



built up areas falls within low, moderate, high and very high flood risk zones. The result implies that although agricultural areas are affected by flood, however the level of susceptibility is not as high as have been cited in some literature like Ologunorisa and Adeyemo (2005) and ACAPS (2018). Based on the foregoing results, it can be concluded that in terms of morphometric flood risk, smallholder farmers do not face the risk of extensive damage to their crops.

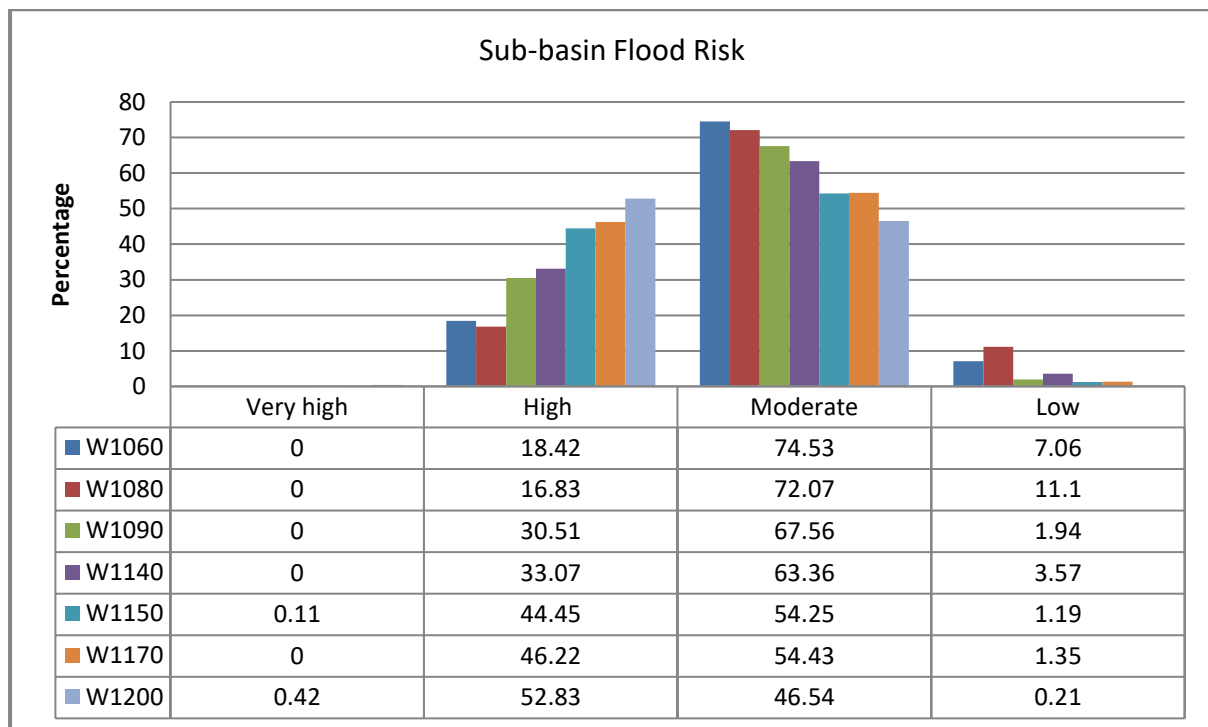


Figure 67: Sub-basin flood risk

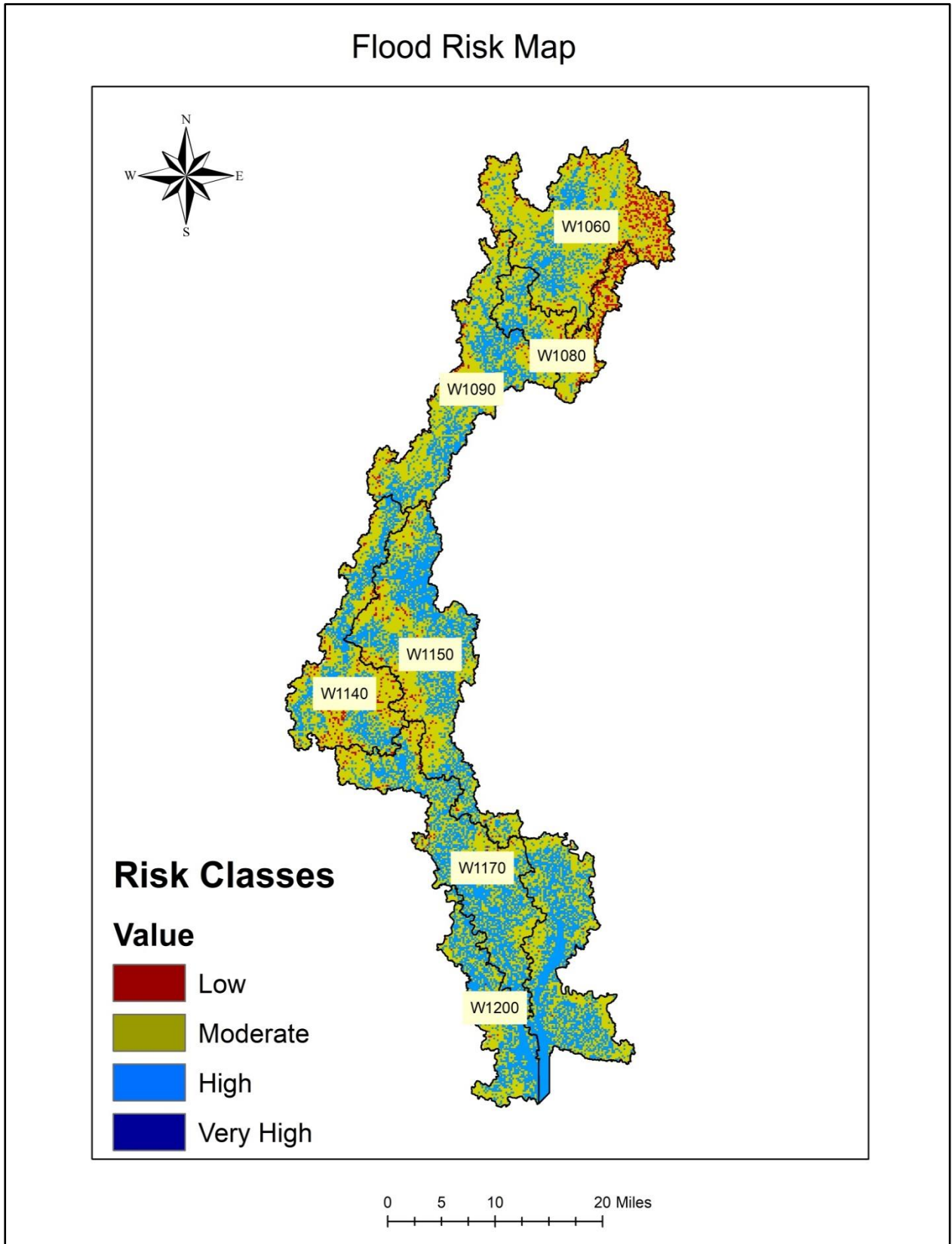
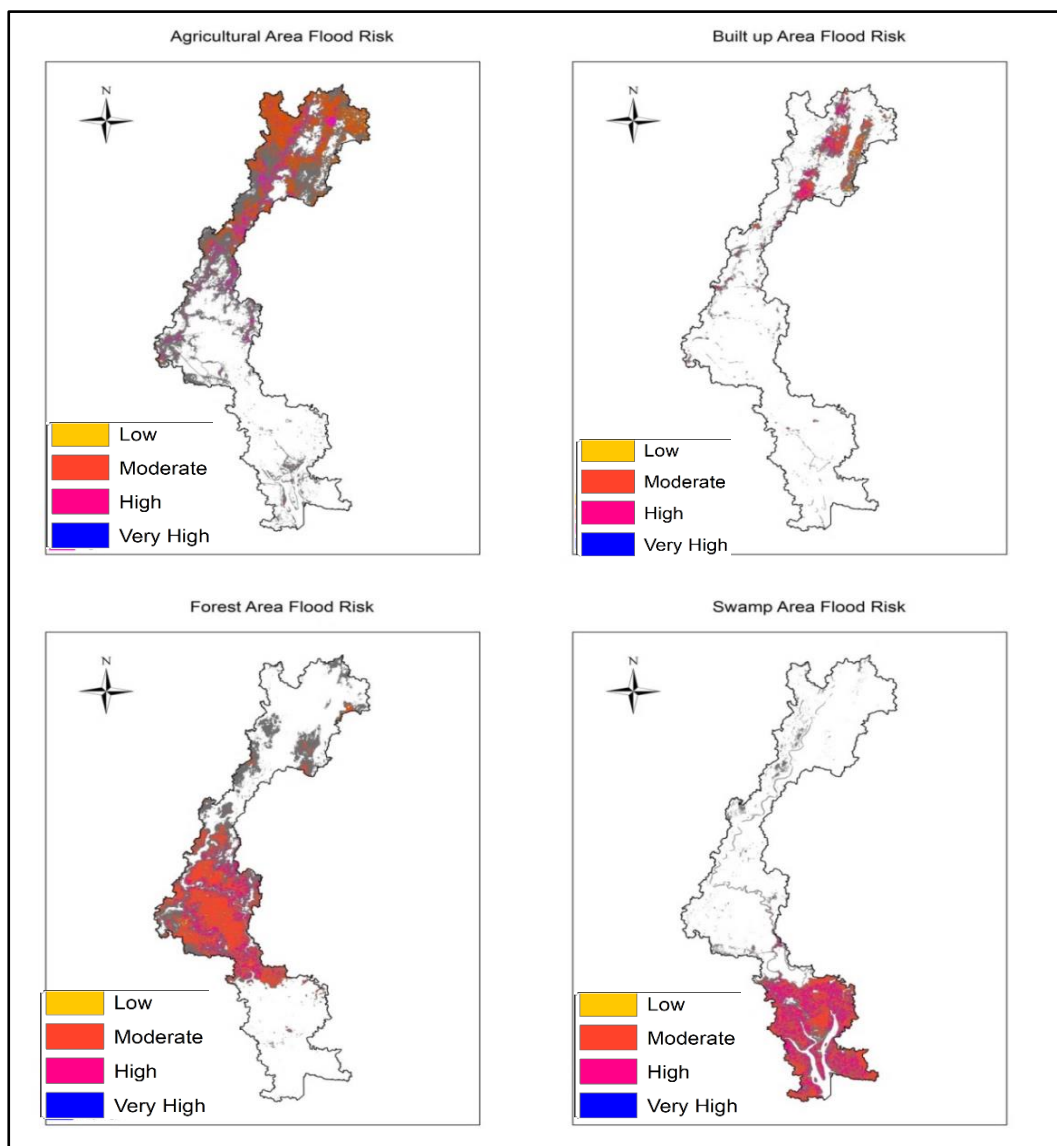


Figure 68: Morphometric flood risk map for the Orashi Basin

Table 17: Vulnerability of different land use types to flood risk in percentage<sup>12</sup>

Land Cover	Low	Moderate	High	Very high
Built-up	6.62	50.01	43.35	0.02
Agricultural Areas	6.15	71.33	22.51	0.00
Forest	5.41	66.37	28.22	0.00
Swamp	2.11	63.71	34.15	0.03
River	0.19	41.11	58.65	0.05

Figure 69: Vulnerability of different land use types to flood



<sup>12</sup> The table lists the proportion [percentage] of each land use type that falls within different flood risk zone.

## 7.2: Land Use Based Flood Risk Assessment

One of the goals of this thesis is to determine and substantiate the impact of land use changes on flood events in the Orashi river basin by using the curve number to study how land use changes affect Orashi river flow and by extension flood risk. The curve number carries the combined effect of the soil characteristics and land use/cover of the surface (Rohman, et al., 2019). The curve number, as previously mentioned, is reflective of the proportion of rainfall that becomes runoff; the greater the curve number, the greater the runoff, hence the greater the flood risk. As a result of the direct relationship between runoff and flood risk, in this thesis, the CN is employed as a proxy for land use-based flood risk assessment. Moreover, studies such as Vojtek and Vojteková (2019) have successfully used runoff maps as input variables for assessing flood potential in the Radisa basin in Western Slovakia.

As will be demonstrated subsequently, increase in the value of CN has a tremendous impact on flood risk in the study area. In the developed hydrologic model, the Orashi river catchment has been divided into seven sub basins using the HEC-HMS model (Figure 30). Map of the curve number of the Orashi basin for 1986, 2003 and 2016 is shown in Figures 70, 71 and 72. Changes between the curve number from 1986 to 2003 and 2003 and 2016 are also shown in Figures 74 and 75.

The results (Figure 73) indicate that between 1986 and 2003, CN values increased in only sub-basins W1150 and W1200. A slight decrease in CN values was noted in sub-basins W1060, W1080, W1090 and W1140 between 1986 and 2003. Between 2003 and 2016, the CN value of the sub-basins significantly changed; there was significant or drastic increase in sub-basins W1060, W1080 and W1090 which increased by 24%, 17.5% and 19.93% respectively. On the other hand, the CN values in sub-basins W1200, W1150 and W1170 decreased slightly by -1.5%, 1.2% and 0.2% respectively. From the results it is evident that the largest increases in CN values were in the upstream sub-basins, namely W1060, W1090 and W1080. On the other hand, CN value of sub-basins W1200 and W1200 downstream decreased (Table 18).

Using the raster calculator tool in the ArcGIS, the change in CN map (Figures 74 and 75) was developed. Statistical analysis showed that the mean change in CN from 1986 to 2003 was 0.973; it however increased to 6.171 between 2003 and 2016. The mean value shows that not

only are CN value changing in the basin, it is increasing drastically and this portends severe impact on runoff in the area.

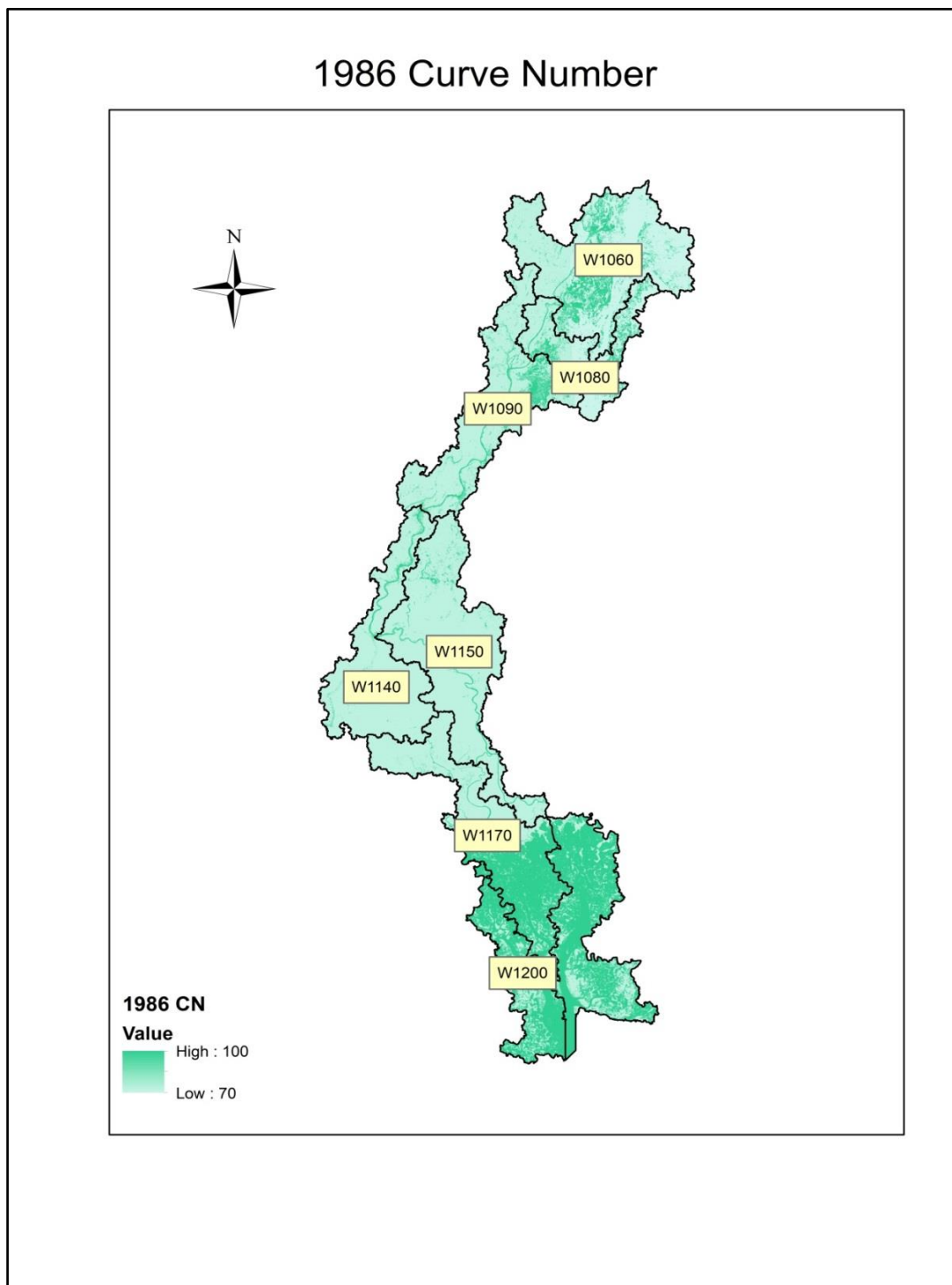


Figure 70: Curve number 1986

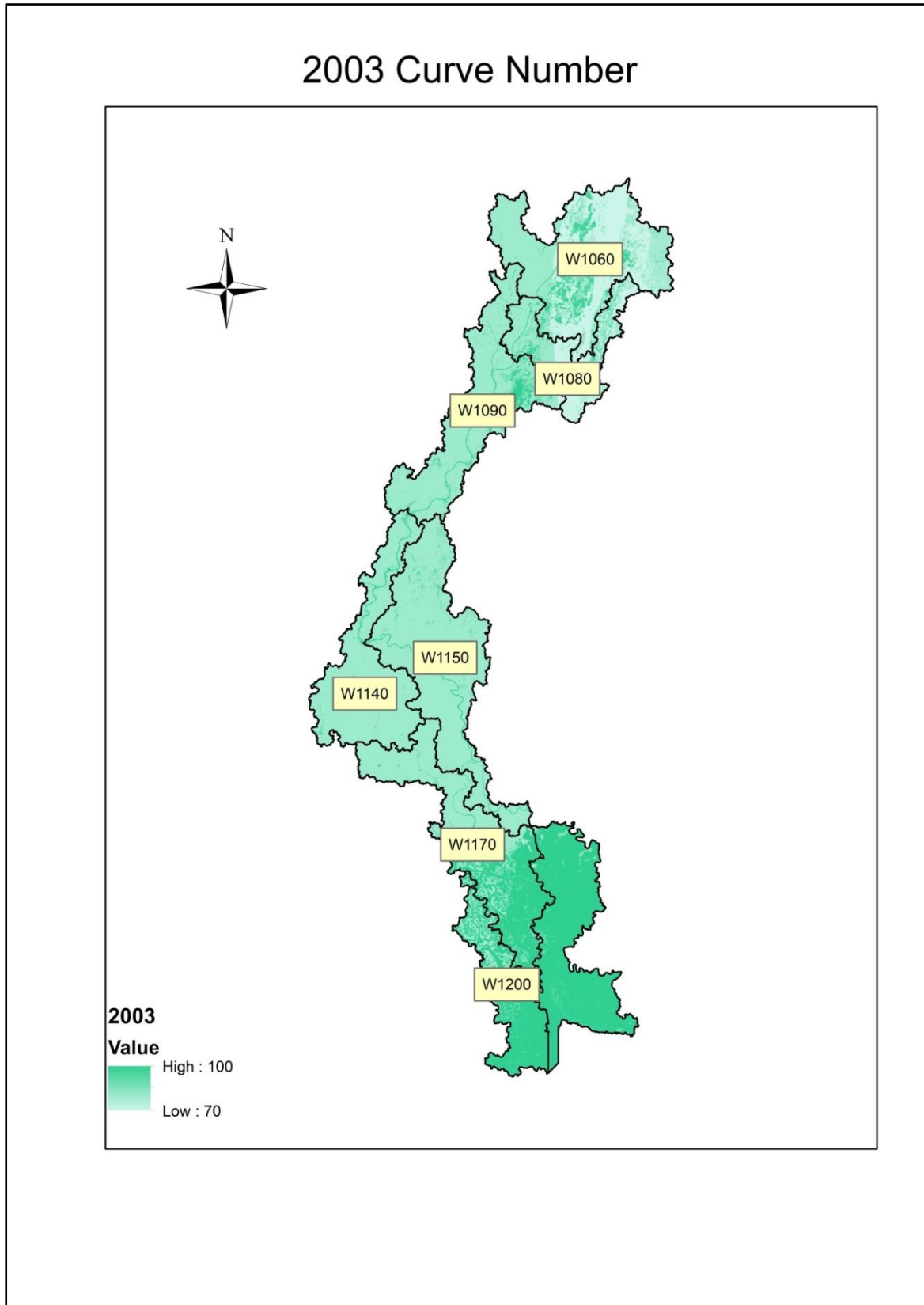


Figure 71: Curve number 2003

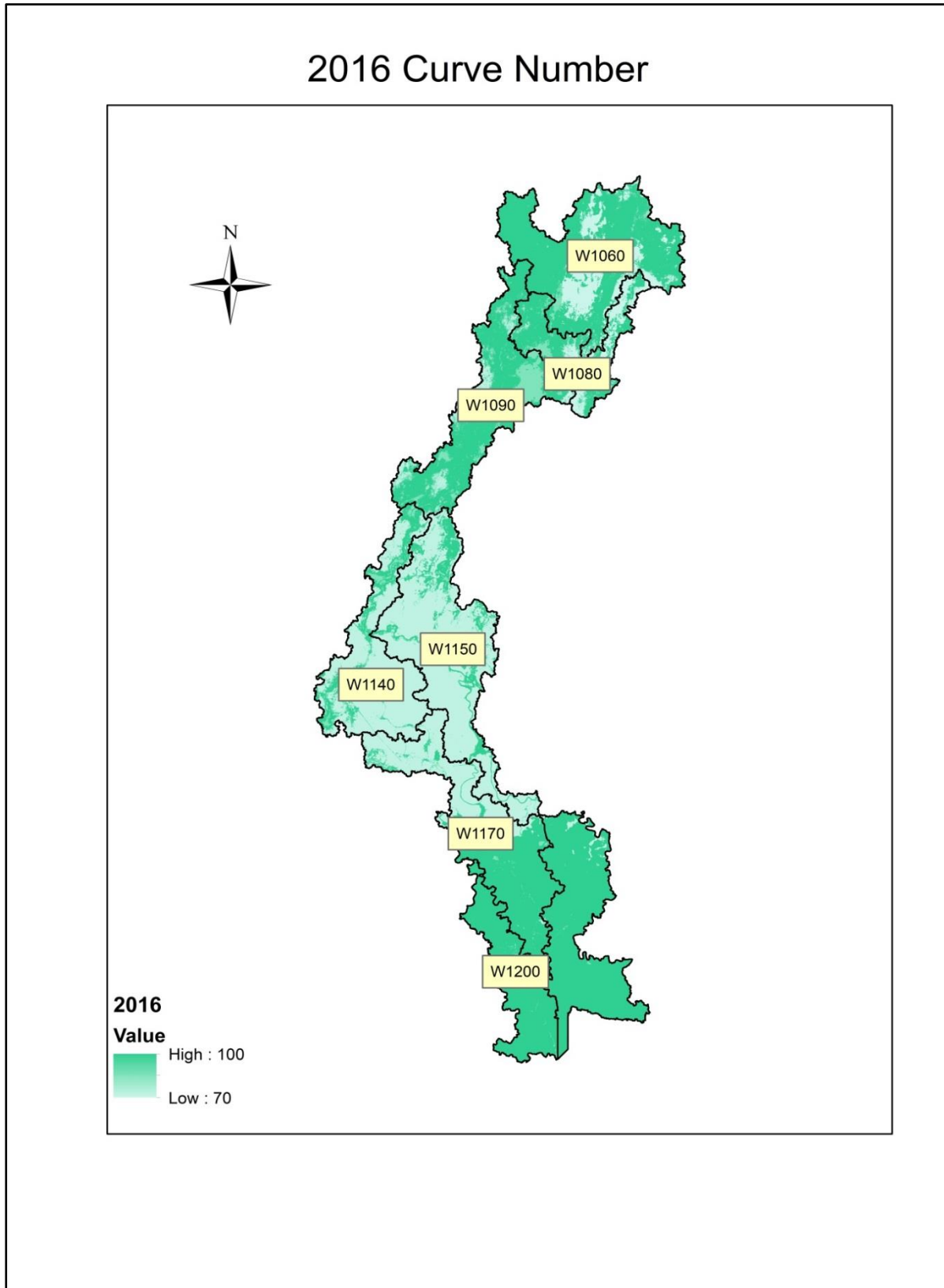


Figure 72: Curve number 2016

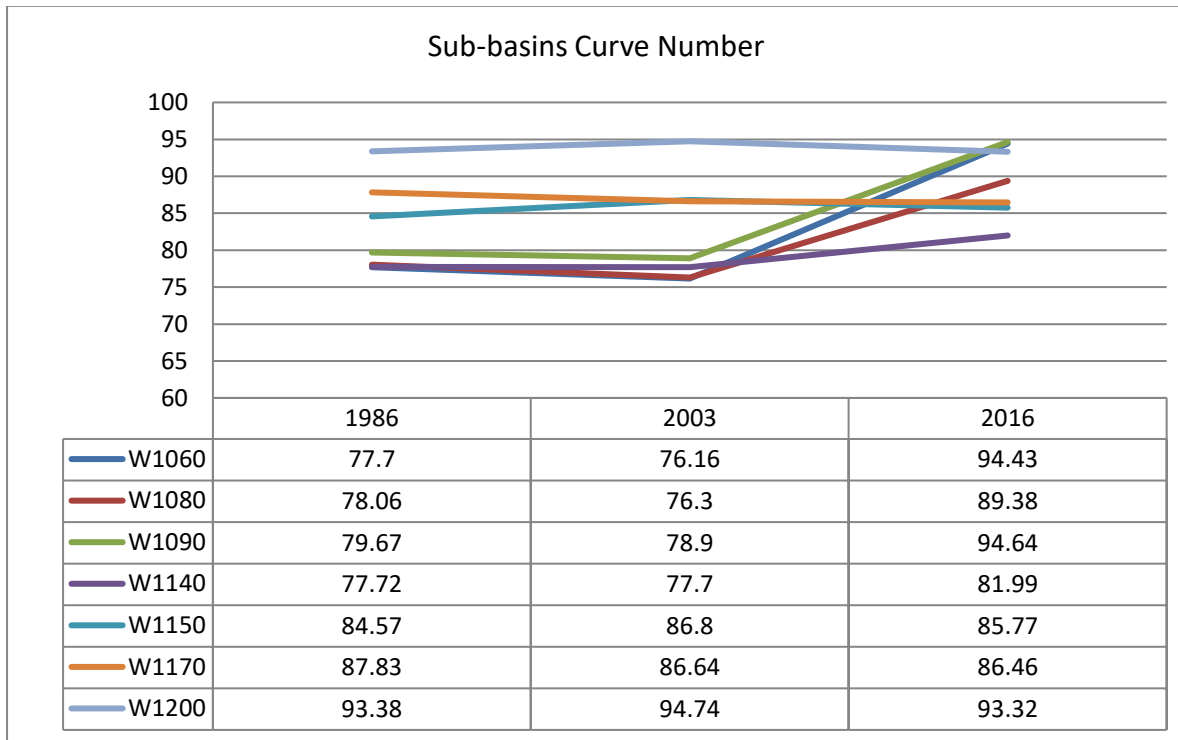


Figure 73: Sub basin CN 1986 – 2016

Table 18: Percentage change in CN

Basins	1986 – 2003 Percentage Change	2003–2016 Percentage Change
W1060	-1.98	24.0
W1080	-2.25	17.15
W1090	-0.97	19.93
W1140	-0.03	5.55
W1150	2.64	-1.2
W1170	-1.36	-0.2
W1200	1.46	-1.5

Table 19: Mean of change in CN value 1986 - 2016

Period	Mean	Standard deviation
1986 – 2003	0.973	7.836
2003 – 2016	6.171	13.33



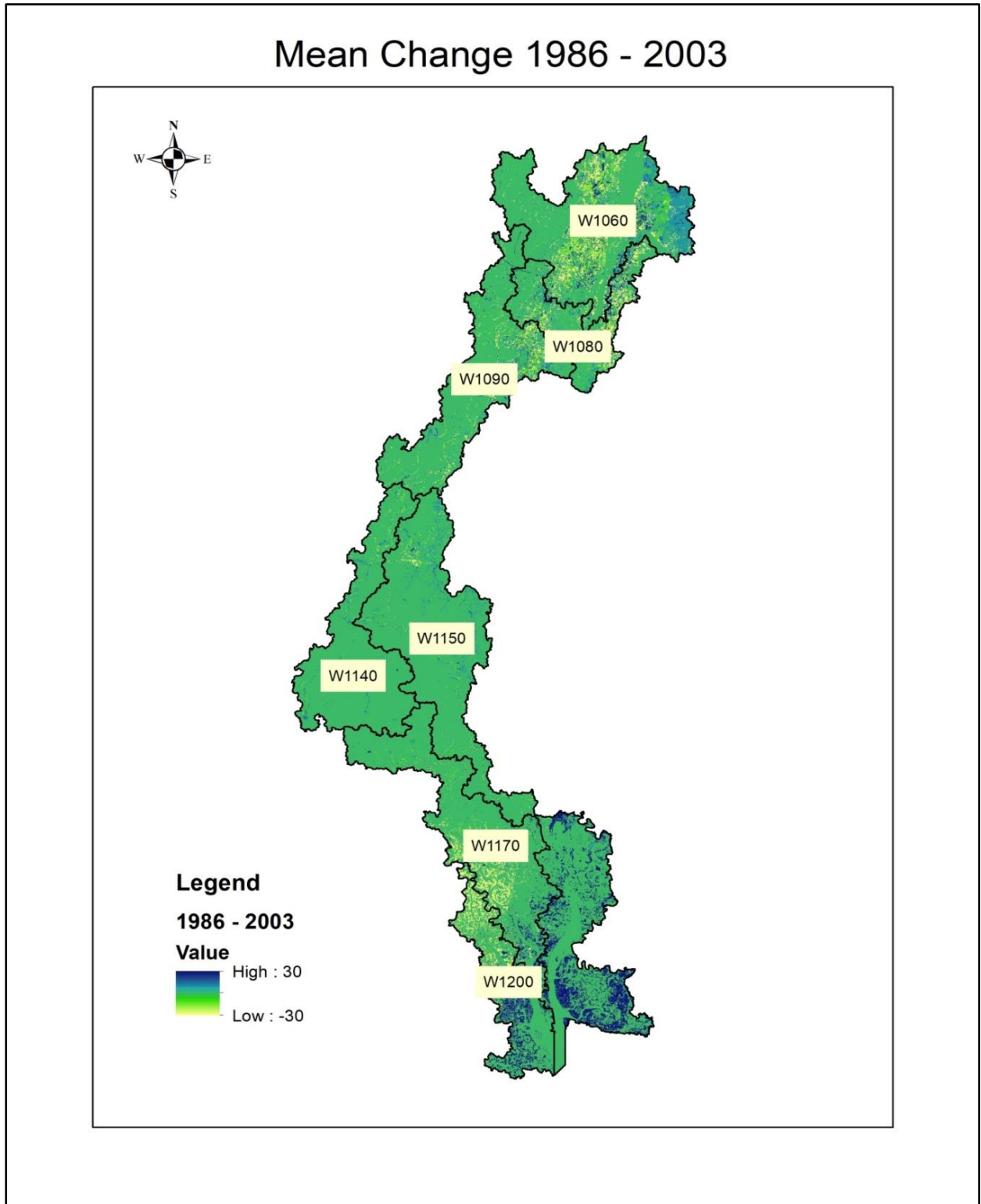


Figure 74: Change in CN 1986 – 2003

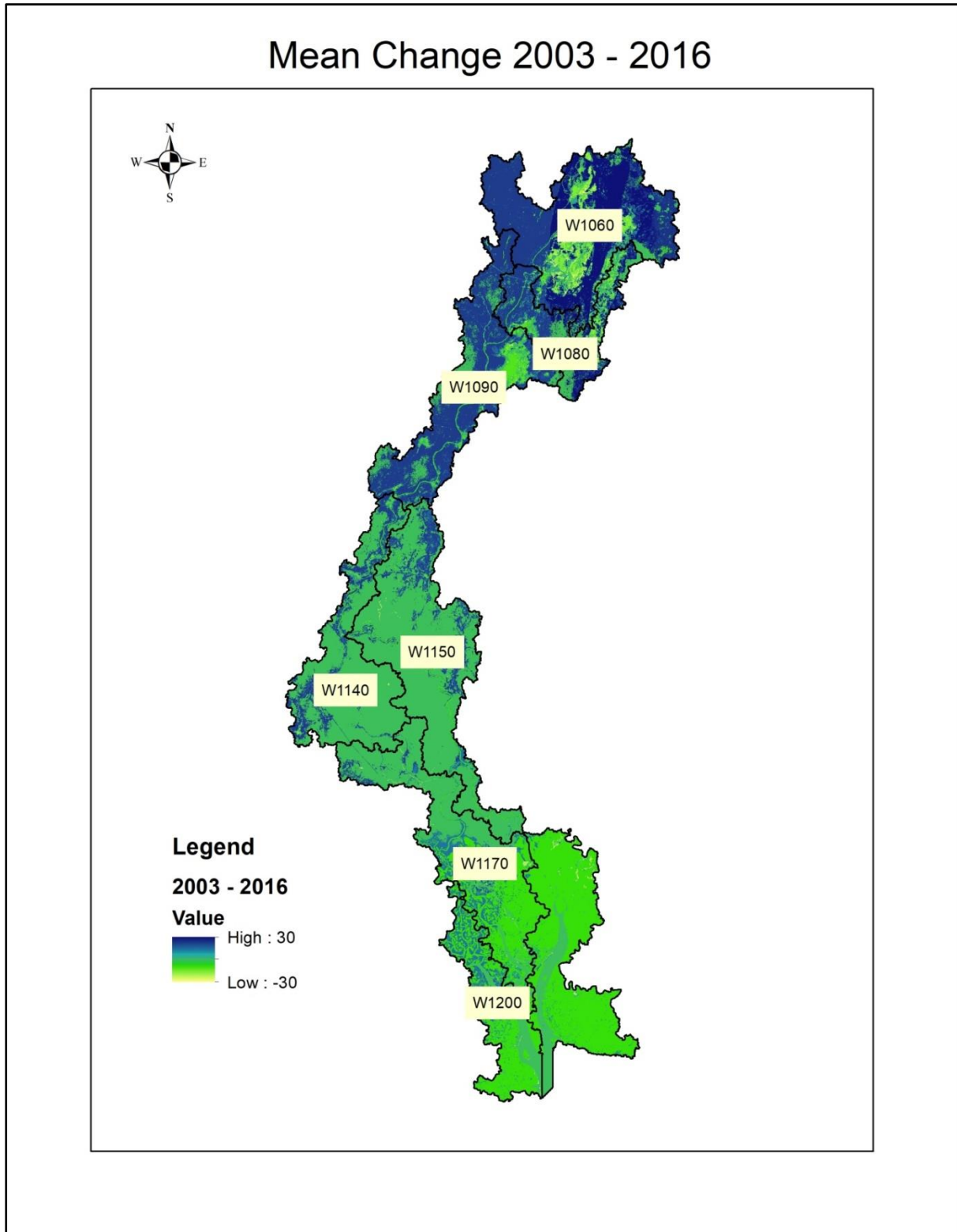


Figure 75: Change in CN 2003 - 2016

HEC-HMS model was used to assess the effect of land use change on hydrological response in the basin. The study focused on the use of high temporal resolution (3-hourly) TRMM grid data estimating pixel-based average rainfall for each sub-basin and forcing it in HEC-HMS to predict hydrologic parameters without dependency on any ground data. Thus, HEC-HMS model for the study area was formulated and simulated to reproduce rainfall event of 2015 over different land use conditions. The Control specifications which define the time window in which the model has to run the simulation was decided based on the recommendation of the State Ministry of Environment which is in charge of handling flood disasters in the state. The entire storm duration as stated by the ministry (00:00 hours 25<sup>th</sup> October 2015 to 21:00 hours 30<sup>th</sup> October 2015) is given as a control specification to run the simulation.

Precipitation was kept unchanged during the simulations so that only the impacts of land use change on the hydrological response are recognized. Sumarauw and Ohgushi (2012) successfully used this method in their study of the impact of the land use change on peak flow in Joparu Basin in Japan. In the developed hydrologic model, precipitation amount for each sub-basin were input to assess hydrologic response. Precipitation data for the 2015 flood event was used as a baseline model. In terms of magnitude of runoff, Figure 76 and Table 20 show significant changes in the magnitude of runoff in the sub-basins, along with pronounced changes in runoff in many basins, between 1986 and 2003, runoff was reduced in sub-basins W1060, W1090 and W1170 from 1784.5 m<sup>3</sup>/s to 1665.6 m<sup>3</sup>/s (6.66%), 1570.1 m<sup>3</sup>/s to 1513.1 m<sup>3</sup>/s (3.63%) and 1506.4 m<sup>3</sup>/s to 1395.2 m<sup>3</sup>/s (7.38%) respectively. The reduction in runoff was occasioned by the fact that most areas in the basins within that period consisted of thick vegetation that enhanced soil infiltration and reduced the surface runoff in the area. On the other hand, runoff was increased in sub-basins W1080, W1150 and W1200 from 469.2 m<sup>3</sup>/s to 509.5 m<sup>3</sup>/s (7.9%) 2419.3 m<sup>3</sup>/s to 2774.6 m<sup>3</sup>/s (14.69%) and 1957.1 m<sup>3</sup>/s to 2182.2 m<sup>3</sup>/s (11.5%) respectively.

Between 2003 and 2016 runoff values increased significantly in sub-basins W1060, W1080 and W1090 by 1665.6 m<sup>3</sup>/s to 4766.1 m<sup>3</sup>/s (186.15%), 469.2 m<sup>3</sup>/s to 963.8 m<sup>3</sup>/s (105.41%) and 1513.1 m<sup>3</sup>/s to 3870.4 m<sup>3</sup>/s (155.79%). Conversely, runoff values in sub-basins W1200, W1150 and W1170 reduced by 2182.2 m<sup>3</sup>/s to 1948.4 m<sup>3</sup>/s (10.71%), 2774.6 m<sup>3</sup>/s to 2599.4 m<sup>3</sup>/s (6.31%) and 1395.2 m<sup>3</sup>/s to 1379.3 m<sup>3</sup>/s (1.14%) respectively (Table 21).

Table 20: Runoff value 1986 – 2016 (m<sup>3</sup>/s)

Basins	1986	2003	2016
W1060	1784.5	1665.6	4766.1
W1080	509.5	469.2	963.8
W1090	1570.1	1513.1	3870.4
W1140	475.6	475.1	596.3
W1150	2419.3	2774.6	2599.4
W1170	1506.4	1395.2	1379.3
W1200	1957.1	2182.2	1948.4

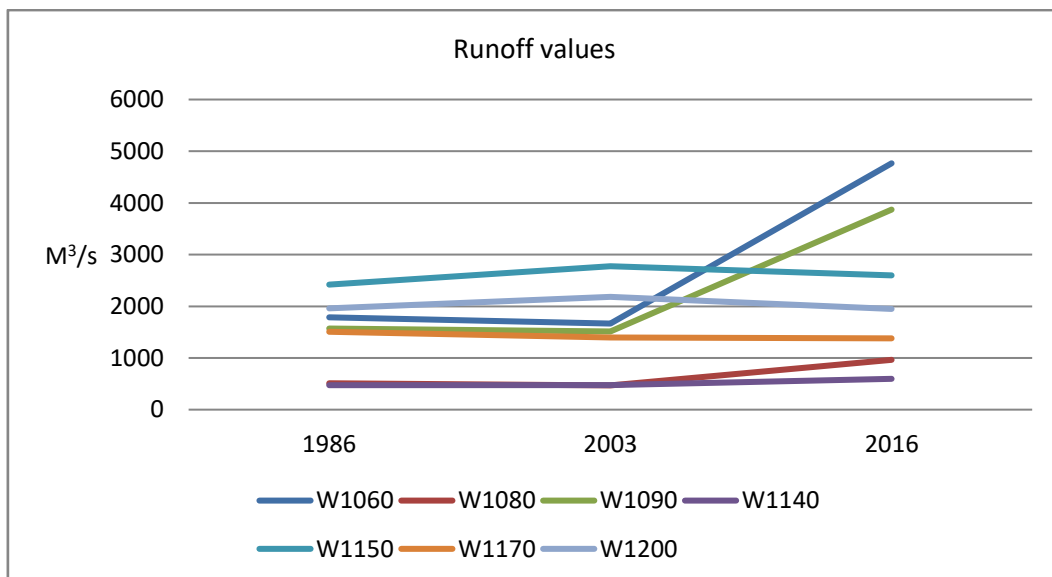


Figure 76: Runoff value 1986 – 2016

Table 21: Percentage increase and decrease in runoff values

Sub-basins	1986-2003	2003 - 2016
W1060	-6.66	186.15
W1080	7.9	105.41
W1090	-3.63	155.79
W1140	0.105	25.51
W1150	14.69	-6.31
W1170	-7.38	-1.14
W1200	11.5	-10.71

Pearson correlation coefficient was used to determine the level or significance of the relationship between runoff and land use change modelled through the CN for the years 1986, 2003, and 2016 LULC. The correlation value between the percentage changes in CN values and percentage change in runoff values showed a positive relationship. Percentage changes in CN values and percentage change in runoff between 1986 and 2016 shows a 0.7163 positive correlation. The value of the percentage change in CN and percentage change in runoff between 2003 and 2016 displayed even a higher level of correlation with a value of 0.92.

The findings from the analysis of the relationship between runoff amount and land use corroborates findings of Dawod et al. (2011) who concluded that the higher the CN values of sub-catchments were, the higher the runoff and flood hazards. Results from this study are also in line with various studies in the region that have demonstrated the relationship and effect of land use change on runoff. In a study of the Ofu River, between a 30 year time span, Alfa, et al. (2018) found that LLUC had an overall effect of 48.09% increase in the total runoff from the catchment. The result showed that land cover changes caused significant differences in hydrological response to surface water. This is line with the result of several other studies such as Koneti et al. (2018); Saadatkah et al. (2016) and Guzha et al. (2018) which confirms that increasing runoff volume is as a function of deforestation and urbanization, especially the conversion of the forest area to agricultural land. Similarly, Simulation modeling in Suiá-Miçu River basin, Brazil, estimated that deforestation in this basin resulted in a 6% increase in surface runoff (Maeda et al., 2009).

In terms of infiltration (Figure 77), sub basin W1150 had the largest amount of infiltration; this is evidently related to the size of the sub-basin. With an area of 736km<sup>2</sup>, sub-basin W1150 is the largest sub-basin. Conversely, sub-basin W1200 had the smallest change in infiltration, although it is not the smallest basin, the low infiltration value is due the fact that sub-basin W1200 comprises mostly water bodies. Infiltration in sub-basin W1090 decreased progressively from 6344.2m<sup>3</sup>/s to 3967 m<sup>3</sup>/s. Infiltration levels in sub-basin W1170 remained largely stable from 1986 to 2016.

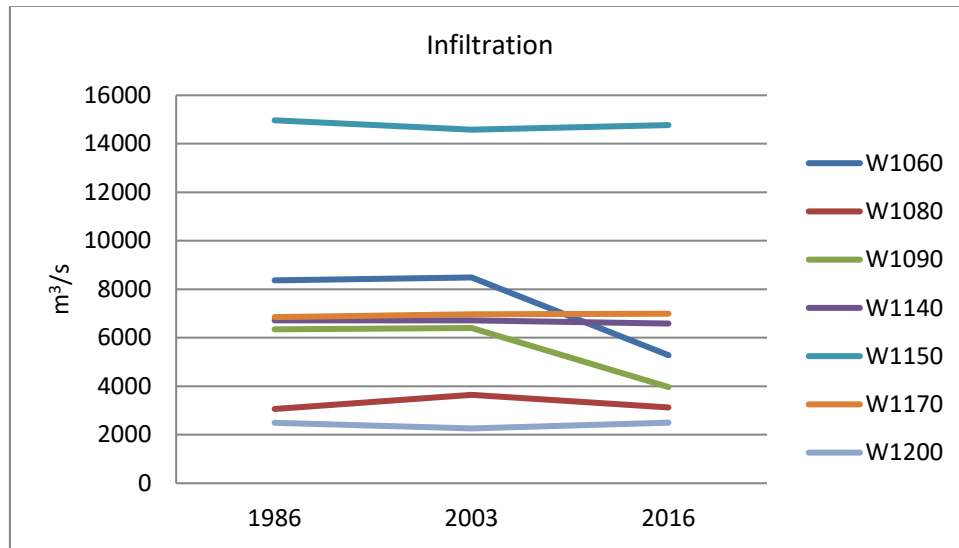


Figure 77: Infiltration in  $\text{m}^3/\text{s}$

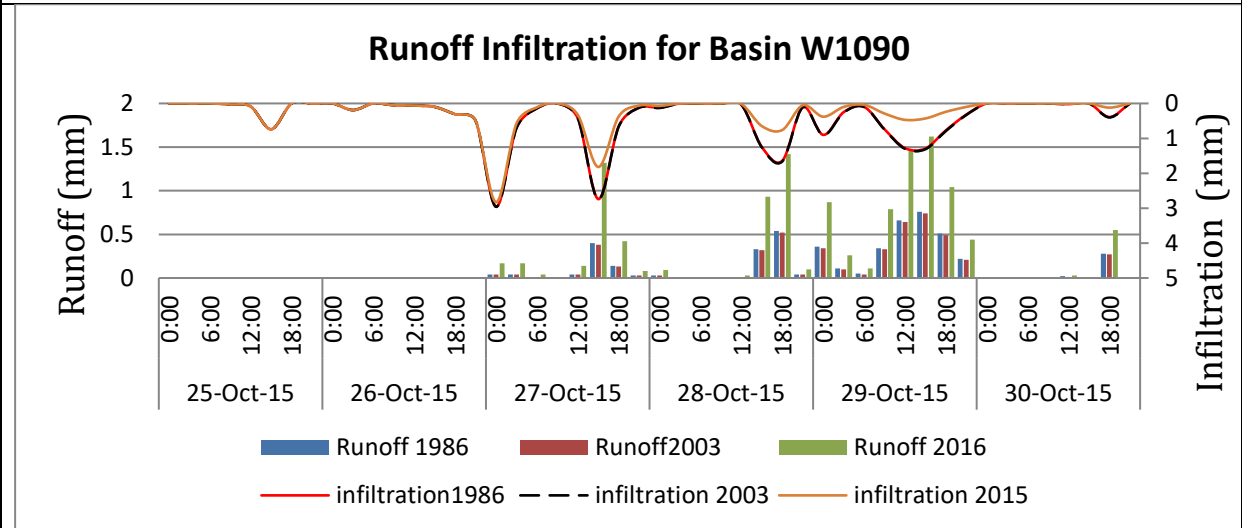
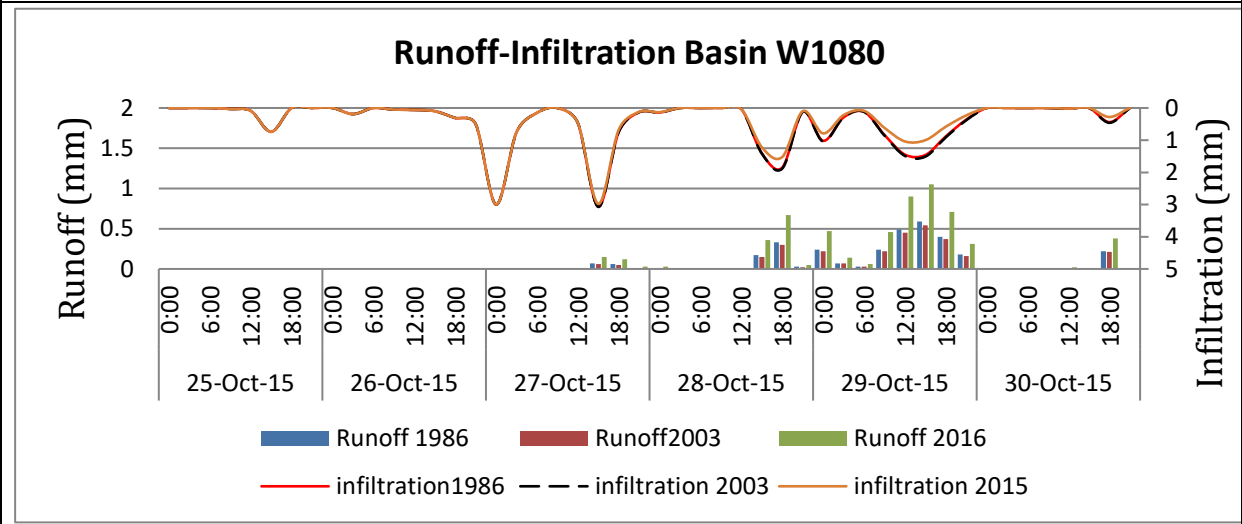
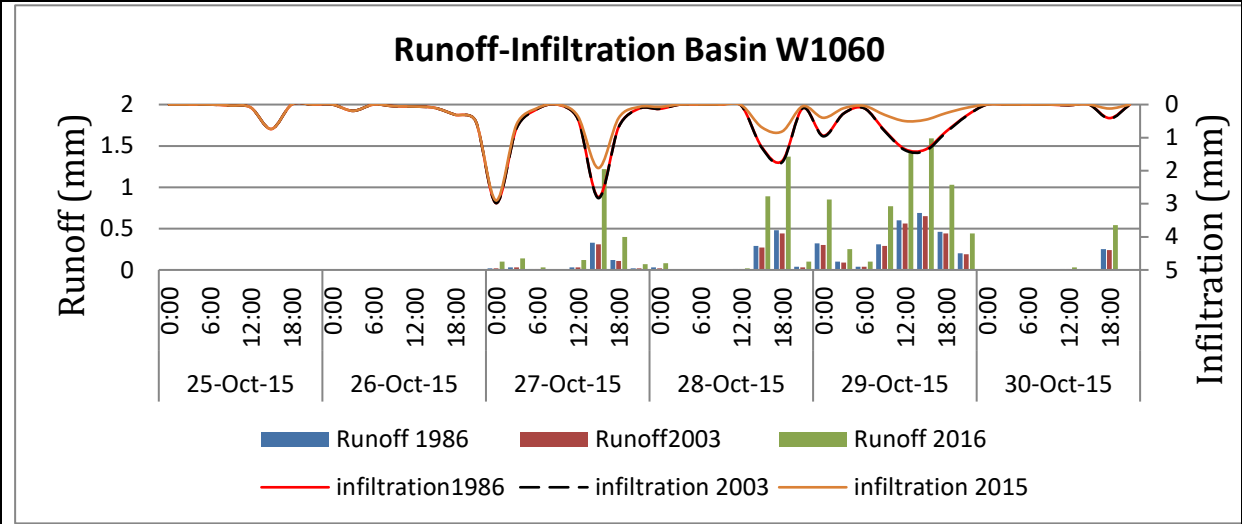
The result shows that infiltration level is much higher than runoff level in the basins. Although, the difference between infiltration and runoff levels is very high, but given the nature and terrain of the study area, the reason for such disparity may become evident. According to Nwankwoala and Ngah (2014), the high rate of infiltration in the Niger Delta is generally related to the prevailing flat nature of the Niger Delta which reduces runoff, by increasing retention time of rainwater on the land surface. They also note that, in most parts of the Niger Delta, the soil in most cases, except where surface clay and swamp prevail, is unconsolidated, porous and permeable, thus permitting quick infiltration of water underground. The level of infiltration may also be related to the high drainage density of the area. The region is well drained by several streams and rivers which promotes infiltration.

To gain better comprehension of the runoff-infiltration dynamics, time series graph relating runoff and infiltration was developed. The results are presented in Figures 78. The results highlight infiltration-runoff responses of the different sub-basins. Generally, the events were dominated by infiltration excess process. In most of the sub-basins, in the early stage of the events, all rainwater penetrated into the soil before the occurrence of runoff, and the infiltration coefficient was always nearly equal to 100%. A significant portion of rainfall in the dense forest and vegetation areas may also have been retained (infiltrated) into the soil as groundwater. With the continuous rainfall, the infiltration capacity of the soil decreased, and some of the rainwater formed runoff on the surface. Additionally, in most of the sub basins, rainfall was not significant at the beginning, so a large portion of rainfall may have been lost in initial

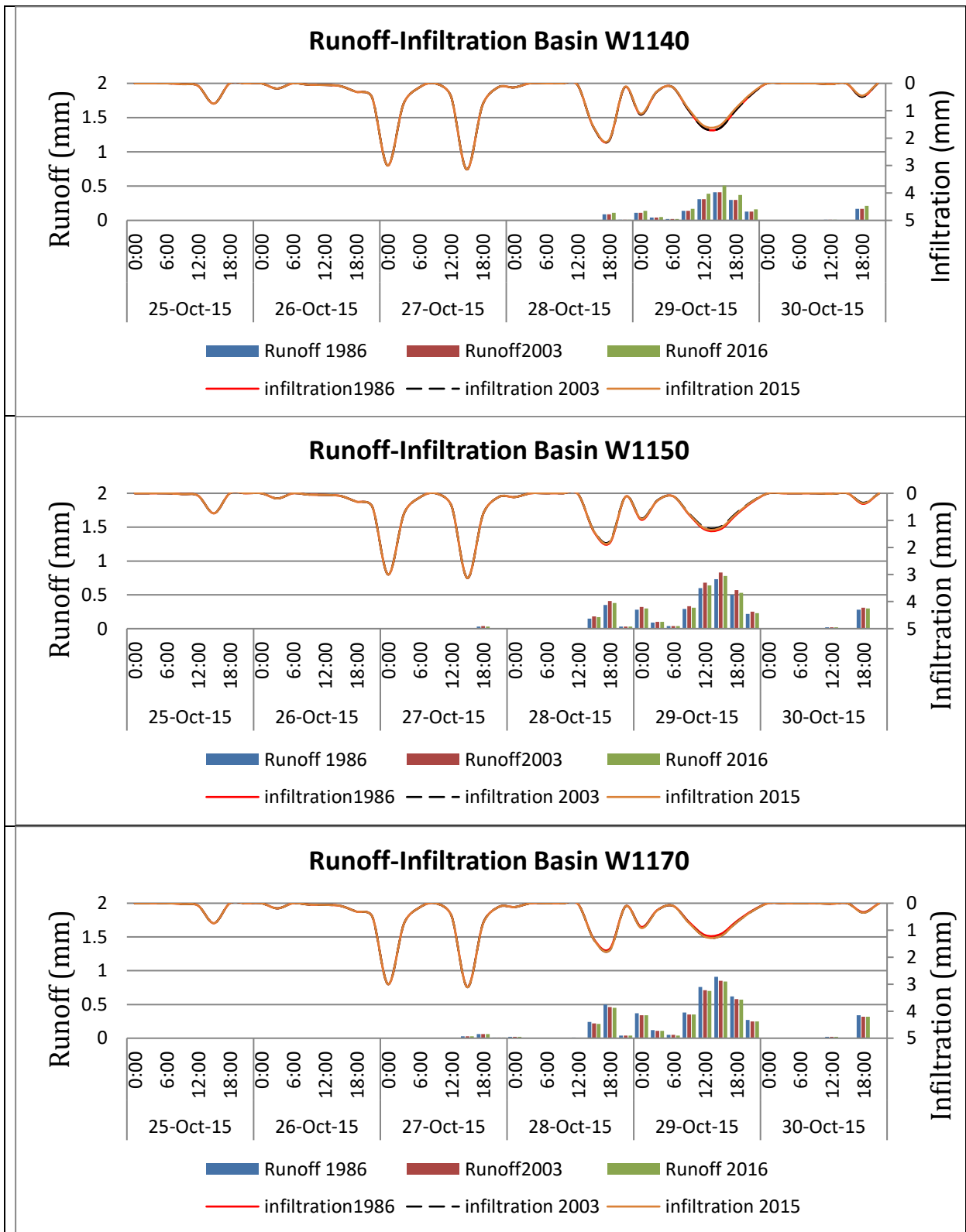
abstraction and in increasing the soil moisture condition. But after some days of the event, since the soil was already wet, more of the precipitation was changed directly into runoff.

Simulation run to compute the peak discharge in Orashi basin was created using the HEC-HMS model. Figure 80 show the temporal dynamics in peak discharge in the sub basins. Three of the sub-basins show progressive rise in peak discharge. For example, peak flow in sub-basin W1060 slightly decreased from about 18.9 m<sup>3</sup>/s in 1986 to 17.8 m<sup>3</sup>/s in 2003 but drastically increased to 44.4 m<sup>3</sup>/s in 2016. Sub-basin W1090 also showed the same pattern, peak flow slightly decreased from 16.2 m<sup>3</sup>/s in 1986 to 15.7 m<sup>3</sup>/s in 2003, but vastly increased to 34.8 m<sup>3</sup>/s in 2016. Similarly, peak discharge in sub-basin W1080 decreased from 16.2 m<sup>3</sup>/s in 1986 to 15.7 m<sup>3</sup>/s in 2003 and then increased to 34.8 m<sup>3</sup>/s in 2016.

Data in table 22 shows that amongst the individual sub-basins, sub-basin W1090 which is located in the upper stream of the study area exhibited the largest percentage increases in peak discharge compared to the other six basins (from -3.08% to 114.81%). This result is logical since these the sub-basin has the highest level of deforestation as proved in the land use analysis section. Conversely, sub-basin W1200 showed the smallest change in peak discharge with only 0.5% change in peak discharge. The low level of change in the basins may be due the nature of the terrain, the area is comprised mostly of swamp and there has been little or no change in the type of landcover. While most of the upper sub-basins showed increases in peak discharge, the downstream sub-basins W1170 and W1200 exhibited a decrease in peak discharge. This is directly similar to the conclusion reached by Adnan et al. (2014) who found that the uppermost basin exhibited the largest increases in peak discharge in the Sungai Kelantan Basin. However, this pattern is not aligned with some other studies, for instance, in their study of flood behaviors arising from varied urbanization levels in Xiang River Basin, China, Du, et al. (2018) concluded that the growth rate of peak discharge gradually increased from upstream to downstream. The result implies that the level of deforestation in the downstream sub-basins was very low. It is evident that changes in land use (modelled through the CN) have significant impact on increase in peak discharge and







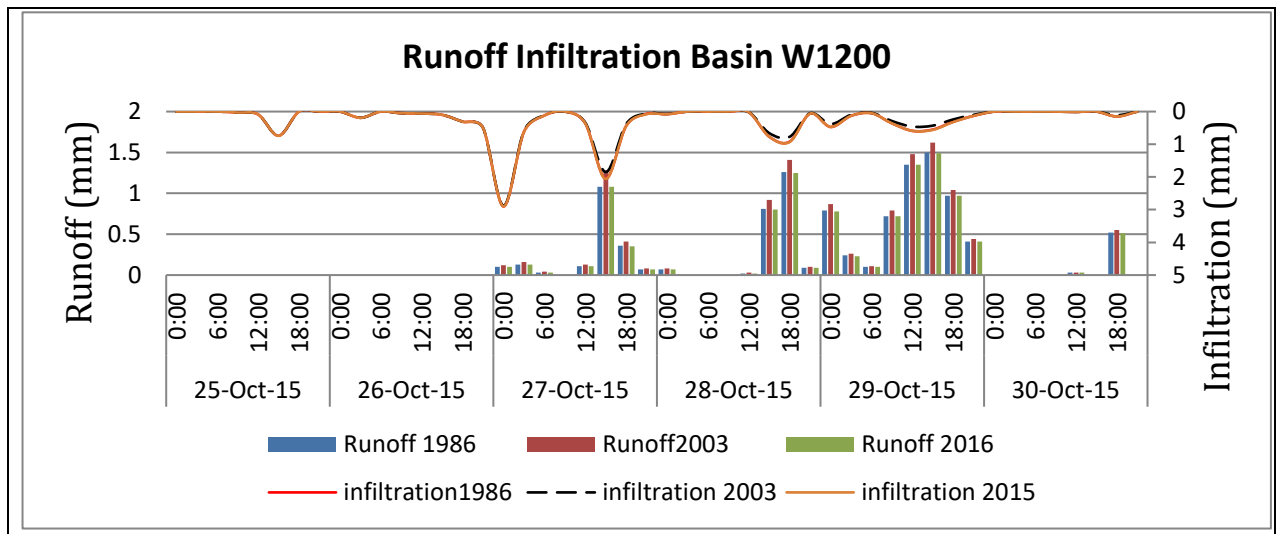


Figure 78: Runoff –Infiltration in the subbasins

flooding in the study area. This aligns with the results of a study of the impact of impervious surface location on flood peak discharge in urban areas in Longhua Basin, China by Du, et al. (2015) which indicated that land-use change in the Longhua Basin significantly increased peak discharge and flood volume. With precipitation held constant, they found out that land-use change in the area between 1980 and 2010 increased flood volume and peak discharge by 162% and 140%, respectively, and shortened the lag time from precipitation to peak discharge by 35 min. Further, results in another study by Vahabzadeh et al. (2015) showed that changes in land use between 1975 and 2008 induced an 86.8% increase in peak flow. Changes in peak flow invariably indicate variations in the magnitude and frequency of flooding.

As a result of increased peak discharge in the sub-basins, flood severity and frequency may have increased. Although, the results shows that peak flow values seem rather too small for flood events in the area. Efforts was made to obtain data on peak flow in the after the storm event for 2015, there were no data available to confirm or dispute the result. In the absence of peak flow data, an extensive search was conducted to get information about basins that were in close proximity with Orashi basin and shared similar hydrological and morphological characteristics. An application of HEC-HMS Model for Runoff Simulation in a Oguta Lake Catchment which is directly above the Orashi basin and share similar characteristics by Obiora-Okeke et al. (2019) showed that the values of peak discharge for 2015 in the catchment ranged from  $15 \text{ m}^3/\text{s}$  to  $89 \text{ m}^3/\text{s}$ . Considering the fact that the rainfall data for the 2015 precipitation event was derived from the TRMM satellite which major weakness is the underestimation of

high intensity rainfall, the peak flow and other values can be accepted with some degree of confidence.

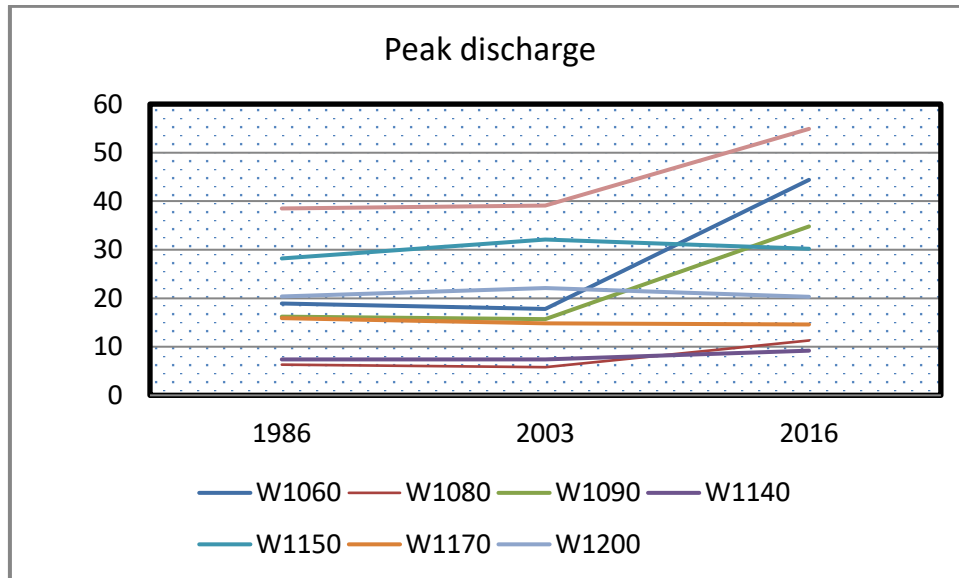


Figure 79: Peak discharge 1986 – 2016 (m<sup>3</sup>/s)

Table 22: Percentage change in peak discharge

Basins	1986 -2003	2003 - 2016
W1060	-5.82	134.9
W1080	-7.94	79.37
W1090	-3.08	114.81
W1140	0	24.32
W1150	13.83	7.09
W1170	-6.93	-8.176
W1200	8.33	-0.5

Overall, land-use changes especially at the upstream of the basin altered hydrological response in the basin and this may have resulted in flooding downstream. There is a direct relation between incorrect land use practices and increased flood risk in the basin. Most of the development and changes are taking place in areas of high flood risk, (mostly lowlands) thus exposing the population to greater flood risk. Deforestation and agricultural expansion in the upper stream sector are the main causes of rising flooding volume and peak flow in this watershed. Therefore, it is vital to protect the remnant forest in the sub-basins located in the upper stream sector of the basin.

The novel aspect of this investigation lies in the establishment of a direct link between sub-basins scale LULC changes and their contribution and relation with hydrological response in the study area using the HMS modelling tool. In addition, this study also points out the typical challenges of modelling rainfall runoff processes in data scarce environments such as the Orashi Basin and the required adaptations in methods to handle such challenge. Although this study was conducted for the Orashi basin area the results could also be generalized to other watersheds and sub basins within the Niger Delta region that have similar climatic and physiographic setting.

### **7.3: Hydraulic Flood Hazard**

Due to data limitation, there is no easily available long-term rainfall and streamflow data record in the study area and so flood risk maps with specific return period could not be easily derived or designed. However, considering that the 2015 and 2012 flood events are the two largest flood events in recent times, the HEC RAS model was applied to simulate the flood depth and inundation areas for the two flood events. Due to the fact that the basin is ungauged with nonexistent runoff data, the peak flow of 2015 and 2012 flood events obtained from the hydrological modeling analysis through the HEC-HMS model were used to simulate the flood inundation extent and depth for both flood events.

In this thesis, HEC RAS was not used for predictive purposes, rather, the model was used to simulate two past flood events (2012 and 2015) in the area and this was carried out in order to compare the level of difference between the two flood events and to highlight the effect of rainfall on flood depth and inundation in the study area.

After the processing stage, HEC-GeoRAS was used to arrange the data into more meaningful graphical outputs such as floodplain polygon shape files. To generate floodplain shape files, the GeoRAS extension was used to first extract a water surface TIN for each of the flood events. The water surface TIN was then automatically clipped to fall within the bounds of the cross sections (i.e., it does not extend beyond the end points of any cross section), and is completely independent of the terrain TIN. After the water surface TIN is created, the rasterization of the water surface TIN and the terrain TIN is done and the then floodplain is delineated where the water surface exceeds the terrain elevations. The computed water depth is the computed difference in the water surface elevation and surface elevation.

To isolate the effect of rainfall on flood inundation in the basin, every other parameter was held constant and only rainfall conditions were changed in the HEC-HMS model. Rainfall data obtained from the TRMM satellite records during the 2012 and 2015 flood events were used in the simulation. The rainfall data was inputted in the HEC HMS environment to determine the peak discharge values of the different flood events. Record from the TRMM data showed that the storm event of 2015 lasted 4 days 18 hours, while the storm event of 2012 lasted 7 days, 21 hours. The peak discharge values are shown in the appendix.

Figures 80 and 81 show the depth map for the flood events of 2012 and 2015. For clarity and comparative purpose, the same colour has been used in the maps for the 2012 and 2015 inundation extent. In terms of flood depth, although, both flood events showed the same pattern and spatial distribution of flood depth, there was a high level of disparity between both flood events. While the minimum flood depth for the 2015 event was 1.5m, the minimum flood depth for the 2012 storm event was 7.22m. Also, there was great disparity in the maximum flood depth for both storm events. The maximum flood depth for the 2015 flood event was 7.31m, while the maximum flood depth for the 2012 event was 10.59m. It is observed that in both flood depth maps, the highest flood depth is found in the middle section of the river channel of the basin; such locational differences in inundation depth have serious implications. Smallholders farmers living in high flood depth zone will invariably suffer more loss than those living in low flood depth zone. The relatively high flood depth in the study area poses a great physical and economic challenge not just to farmers in the area, but to the general population as well. According to Dan-Jumbo (2017), flood depth has direct implications for humans and their vulnerability to flood. Various studies have shown that flood depth of 1m or more; even with low-velocity is enough to cause damage depending on the duration (Schanze, 2006).

To gain more clarity on the pattern of flood depth, classified flood depth maps (Figure 82 and 83) was prepared by reclassifying the original depth map into four distinct risk flood depth zones, namely, low depth, medium depth, high depth and very high depth areas.

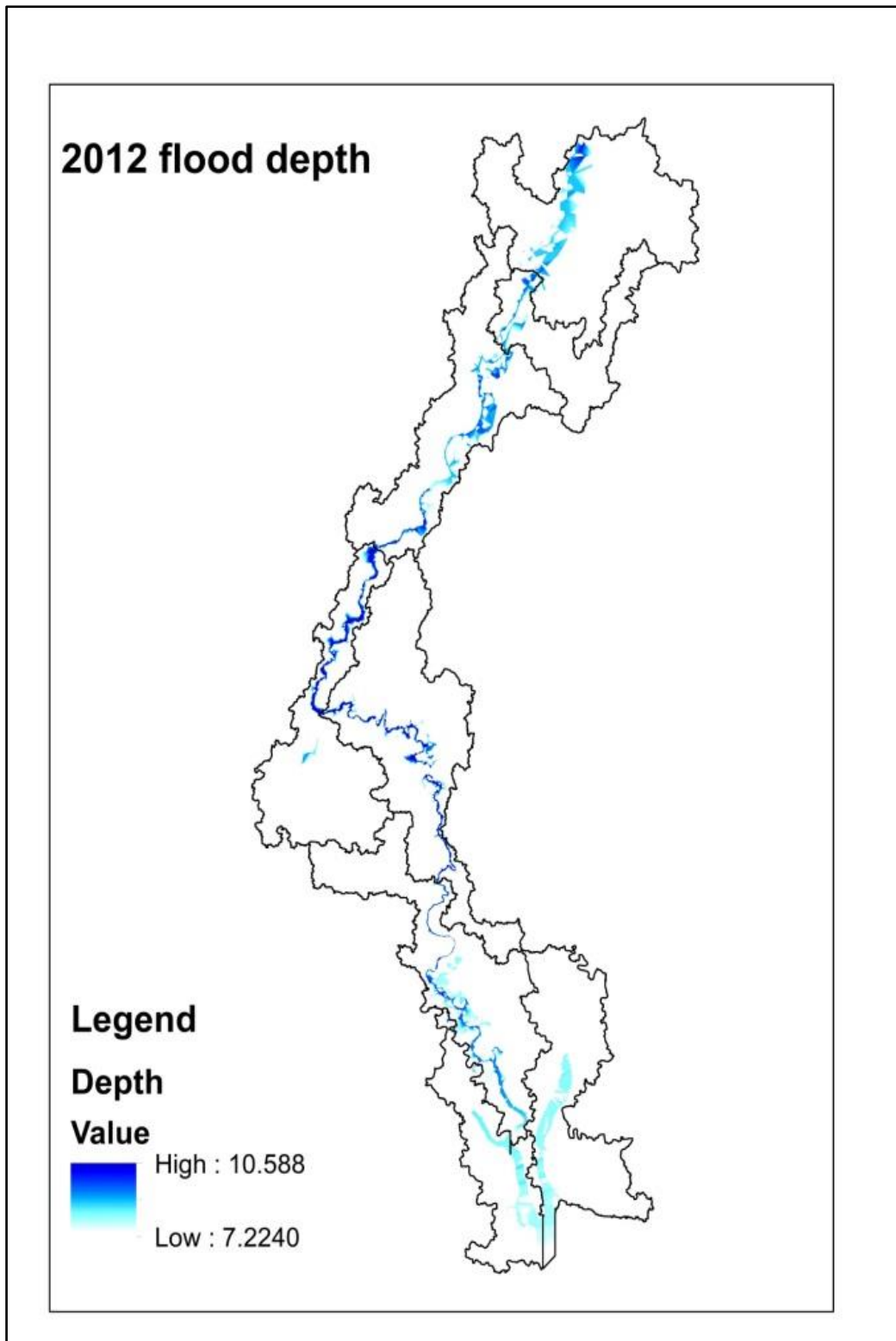


Figure 80: 2012 Flood depth map

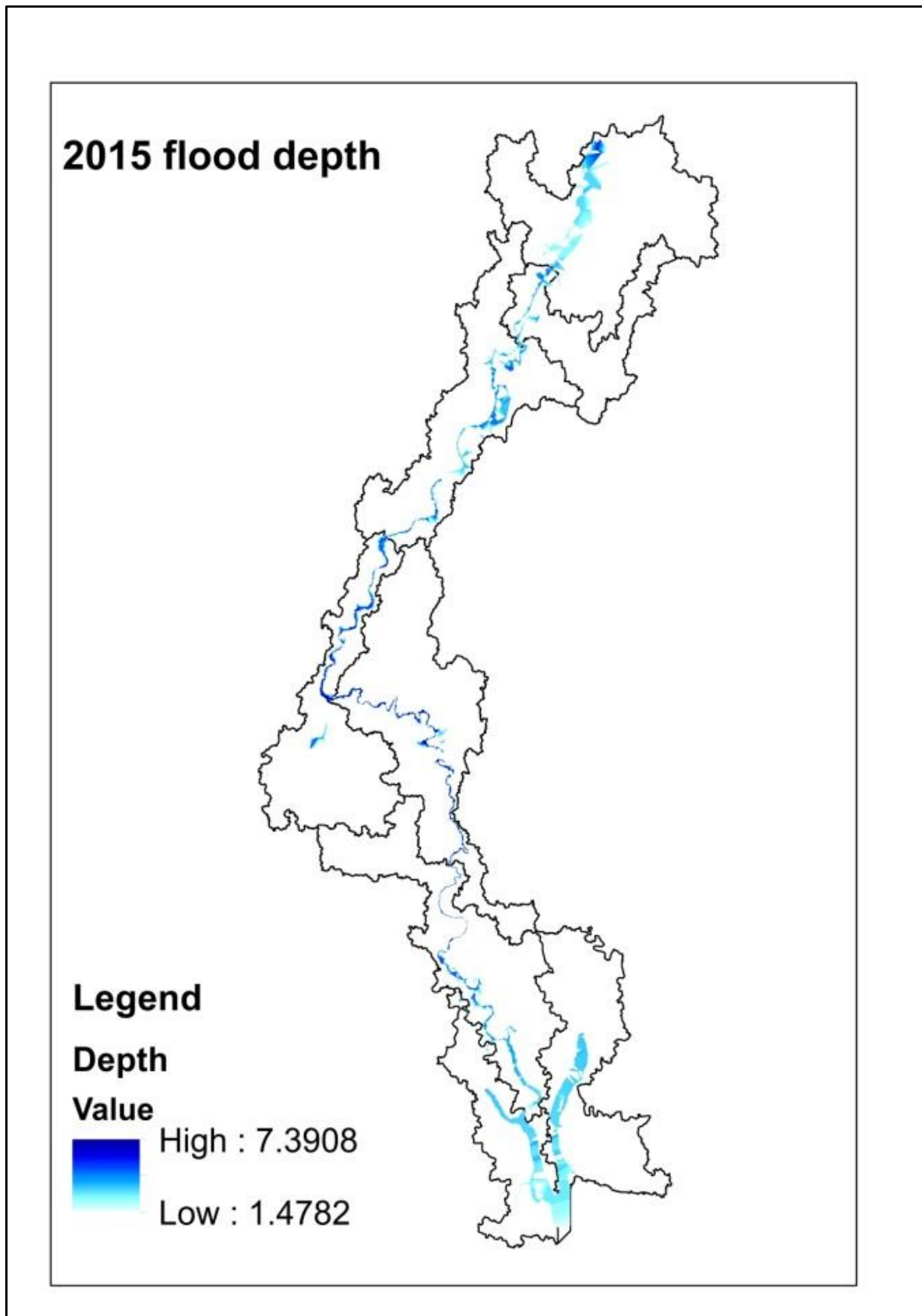


Figure 81: 2015 Flood depth

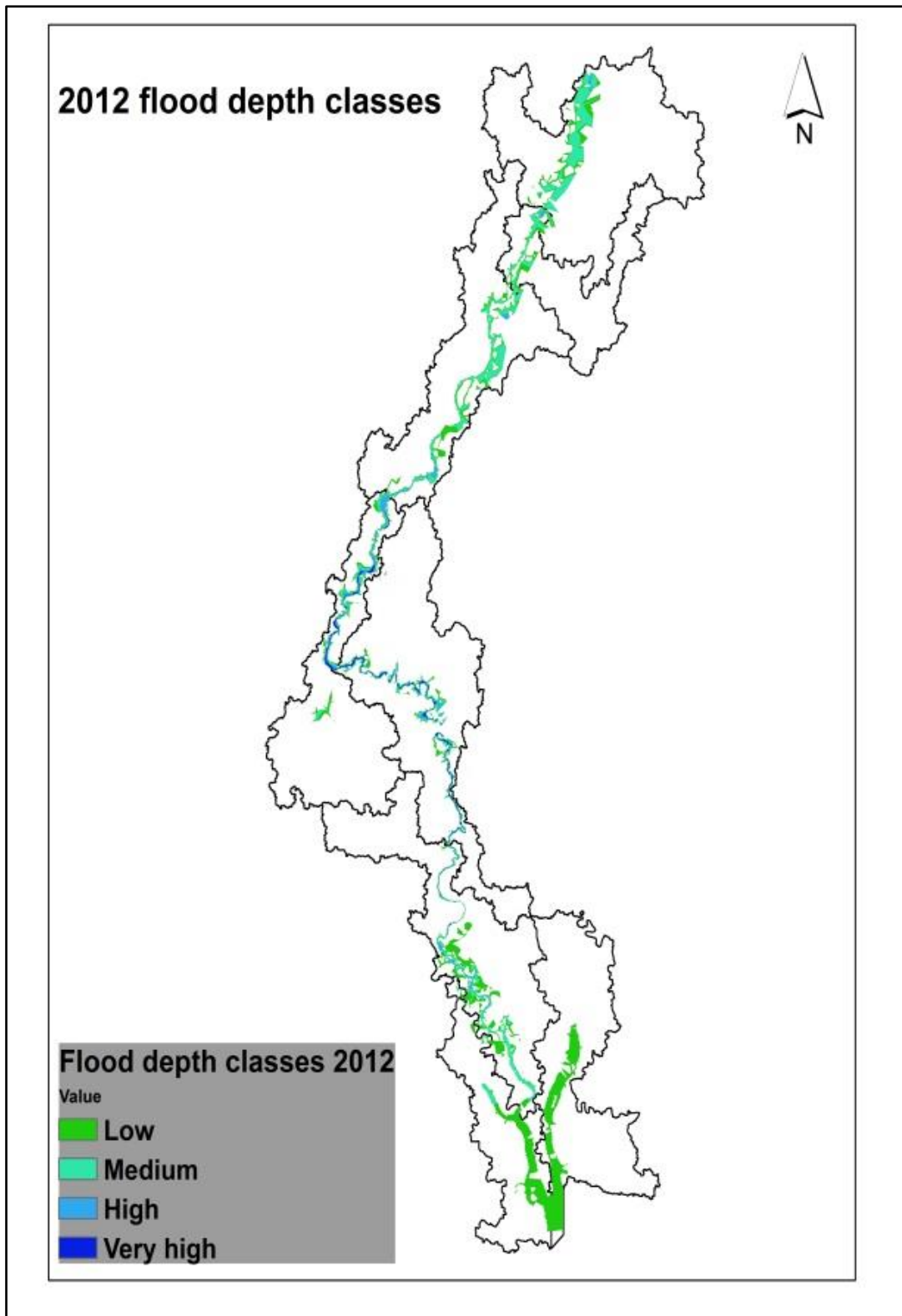


Figure 82: Flood depth classes 2012



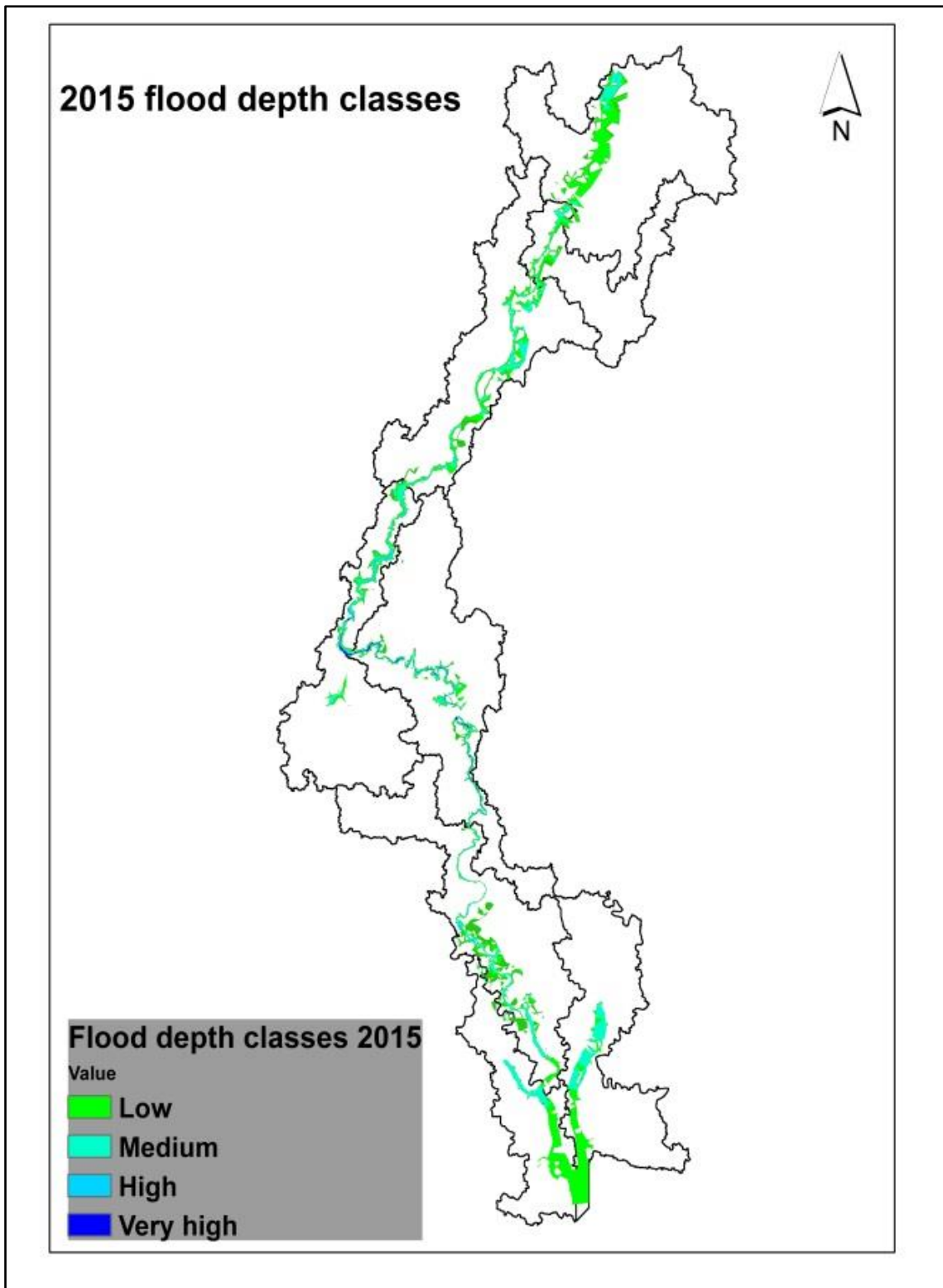


Figure 83: Flood depth classes 2015

The 2012 flood depth was also analysed and the analysis shows that about 89.2km<sup>2</sup> (58.73 %) of the total inundated area was inundated with low depth flood. About 52.2km<sup>2</sup> (34 %) of the inundated area was inundated with medium flood depth. About 8.1km<sup>2</sup> (5%) of the inundated area fell within the high flood depth area. only 2.4 km<sup>2</sup> (1.6%) of the inundated area fell into the very high flood depth group.

During the 2015 flood event, 121.1 km<sup>2</sup> (56%) of the inundated area fell within low flood depth areas. About 69.7 km<sup>2</sup> (32%) of the inundated area fell within the medium flood depth area, While, 18.2 km<sup>2</sup> (8%) of the inundated area fell within the high flood depth area, only about 7.1 km<sup>2</sup> (3%) of the inundated area fell into very high flood depth areas. The simulated potential flood areas stratified by water depth for the two flood events are shown in tables 23 and 24.

Table 23: 2012 spatial analysis of flood inundation

Depth class (m)	Inundated area (km <sup>2</sup> )	% with respect to total area
Low (0.0 - 1.702)	89.2948	58.73
Medium (1.702 - 3.487)	52.2164	34.34
High (3.487 - 6.145)	8.096	5.33
Very high (6.145 - 10.588)	2.438	1.60

Table 24: 2015 spatial analysis of flood inundation

Depth class (m)	Inundated area(km <sup>2</sup> )	% with respect to total area
Low (0 - 1.275)	121.1964	56.00
Medium (1.275 - 2.463)	69.736	32.23
High (2.463 - 4.173)	18.2868	8.5
Very high (4.173 - 7.390)	7.1756	3.32

In summary, although most parts of the Orashi basin have moderate flood depth, however, flood depth and flood extent areas may increase in the future if there is an extreme rainfall event. It is observed from first-hand experience and official responses that flood damage in the study area, does not solely occur from the depth or velocity of the floods; rather it is the long duration of the flood in the area that plays the major role in flood damage (Ojeh and Ugboma, 2012). For this reason, the thesis did not focus on flood velocity.

The long duration of flood inundation in the area is not unconnected with its low elevation which does not allow for rapid runoff of water across the basin. Typically flood inundation in the study area last around 14 days and depending on the location and flood depth can last longer, such long duration portends negative effect on crops. Officials of the ministry of environment of the state who are responsible for maintaining flood records in the study area reported that there are some areas along the River Basin that are frequently flooded after the main rainy season, such as locations around the middle of the river channel. The inundated areas indicated by HEC-RAS model are roughly similar to that of the areas mentioned by the officials of the Ministry of Environment.

The flood depth dynamics was further analysed based on the pattern of the water surface profiles (WSE) (Figure 84). The 1D hydrodynamic model was used to generate water surface profiles for steady flow conditions for the historic flood events of 2012 and 2015. The water level produced by the 2012 flood is higher than that of the 2015 event, indicating the severity of the 2012 floods. The Orashi River runs through steeper slopes in the upper reaches, thereby leading to smaller depths of flows. When the river passes through the plains the river becomes slower as compared to the upstream with the higher depth of flow. The WSE varies across the channels and the same pattern can be seen on the map for the 2012 and 2015 events. However, the 2012 and 2015 WSE shows little variations and the main difference can be observed in the upper/middle reaches of the channels. The upper/middle reaches of the channel had the highest inundation extents compared with those downstream sections of the channels. These patterns may be attributed to the low elevation and flat nature of most sections of the downstream sector of the channel.

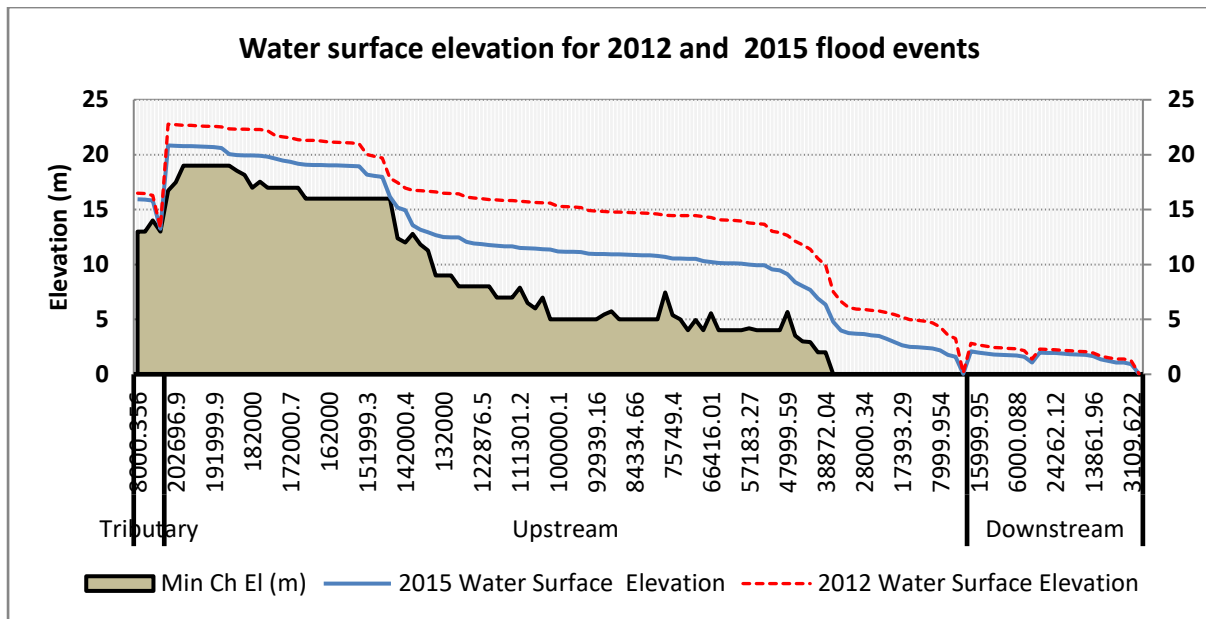


Figure 84: Water surface elevation for 2012 and 2015 flood events

The simulated inundated areas for 2012 and 2015 flood events are shown in Figure 85. Comparing the simulated inundation pattern of the 2012 and 2014 flood events showed that strong similarity existed between both events. Clearly, the two flood events have significant amount of overlapping inundated areas, of which, most are the flattened areas with low altitude. The areas colored red shows areas where the 2012 flood extent exceeded the flood extent of 2015. In addition, results from the flood inundation maps indicated that 216.41km<sup>2</sup> i.e. 8.6% of the basin was inundated in 2012, while, 152.07km<sup>2</sup> representing 6.04% of the basin was inundated during the 2015 flood event. The 2012 flood is associated with the greatest inundation extent and deepest inundation depths. The 2012 flood inundates low lying areas of the floodplain and has the greatest overbank extent in the lower study reaches. The 2012 flood inundates more extensively into the floodplain and low-lying areas throughout the upper and lower reaches.

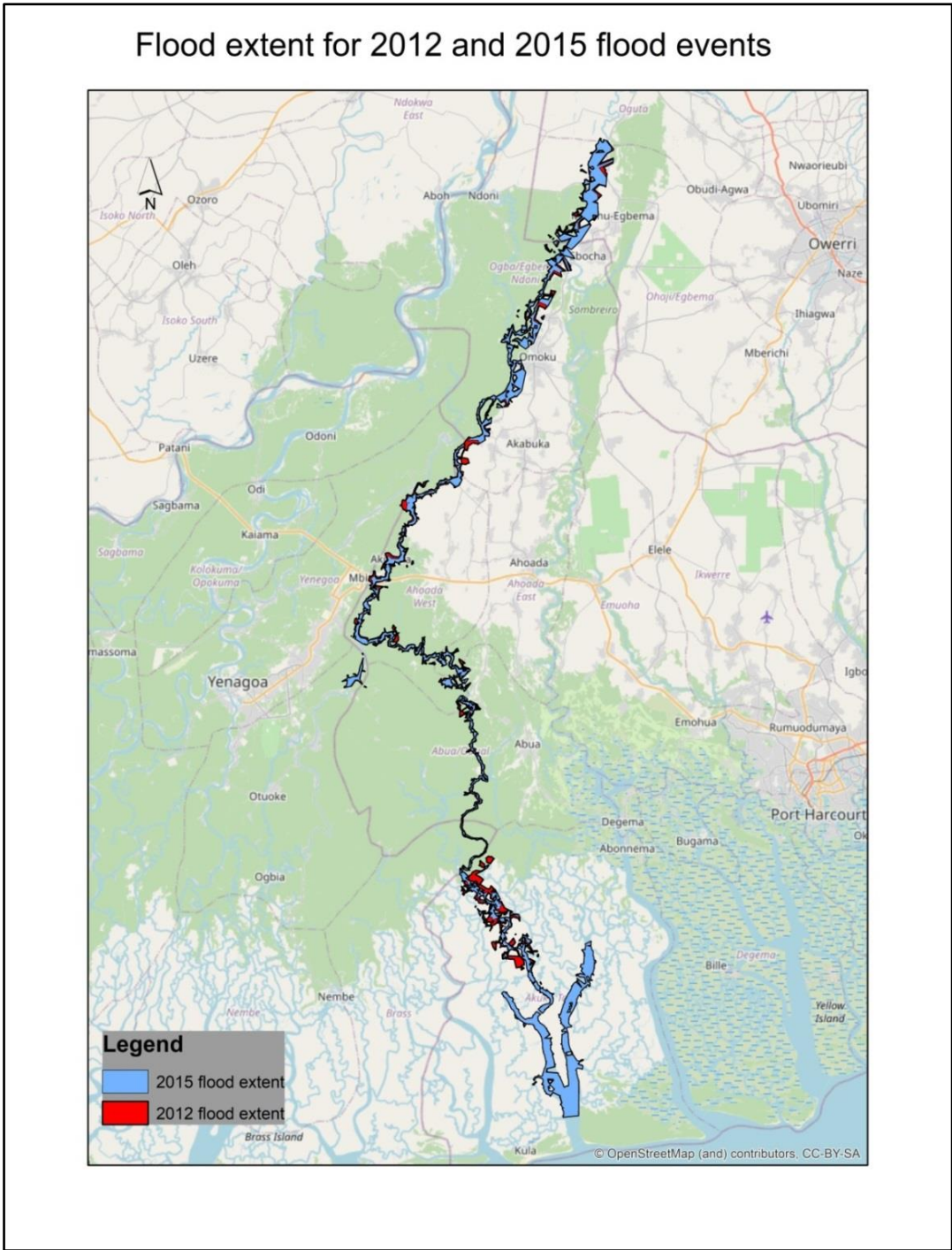


Figure 85: Flood extent for the 2012 and 2015 events

The flood hazard areas were calculated by intersecting the land use map of the study area with the polygon (shapefile) of each of the flood event being modelled. Using the intersection tool provided by ArcGIS, different landuse-inundation statistics was generated. Figures 86 87 and 88 shows the areas and extent of different land use inundated by flood. Results show that forest areas was the least inundated land cover type. Only about 16.55km<sup>2</sup> and 5.77 km<sup>2</sup> of forest areas was inundated by the 2012 and 2015 flood events respectively. Built up area did not suffer significant flood inundation. Only about 24.16 km<sup>2</sup> and 17.87 km<sup>2</sup> of built up area was inundated by the 2012 and 2015 flood respectively. This may be because of the high elevation of most built up areas, as most of the urban areas are situated in high elevation in the upper eastern part of the basin that are not usually subjected to high flood events. About 40.89 km<sup>2</sup> and 21.26 km<sup>2</sup> of swamp areas were inundated by the 2012 and 2015 flood events. Significant area of water bodies was inundated by both storm events and unlike other classes of land use classes, the difference between the areal extent of inundation of water bodies for the 2012 and 2015 inundation was minimal.

A large area of agricultural land was inundated by both flood events. 74.39 km<sup>2</sup> and 48.85 km<sup>2</sup> were inundated by the flood events of 2012 and 2015. Agricultural land was the worst hit in terms of flood inundation and it can be surmised that agriculture is the most prone land use class to flood inundation in the study area. Agricultural areas often occupies the highest percentage of land that are close to the floodplain and it is evident that most of the high flood depth zone is located around rivers banks and according to Musa and Shabu, (2019) land along the river banks is usually fertile and suitable for crop production because of the nutrient-rich silt deposited after floodwater recedes. In the study area, a significant amount of agricultural activities takes place around alluvium rich river banks and this subjects farmer living in such areas to increased vulnerability.

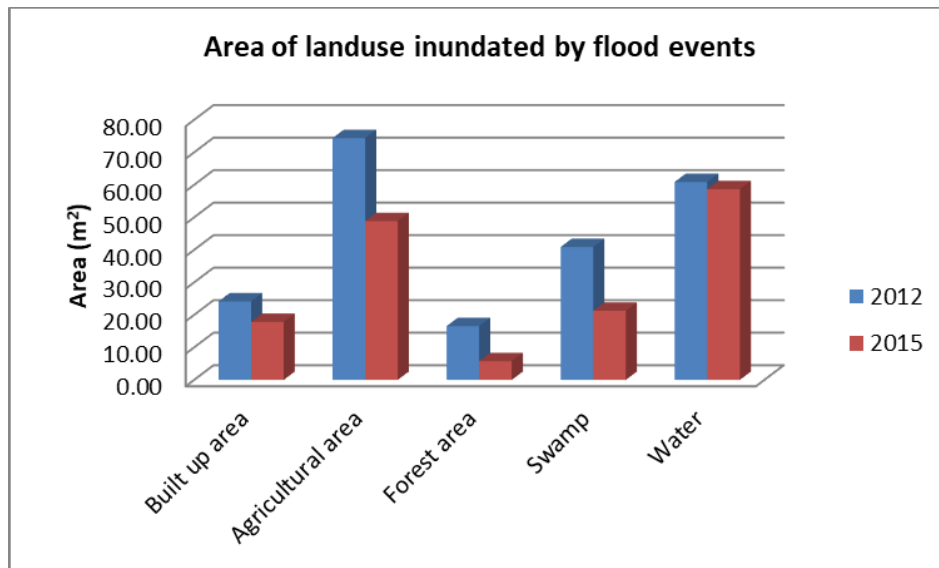


Figure 86: Area of landuse inundated by flood events of 2012 and 2015



### 2012 flood extent overlaid on the land use map

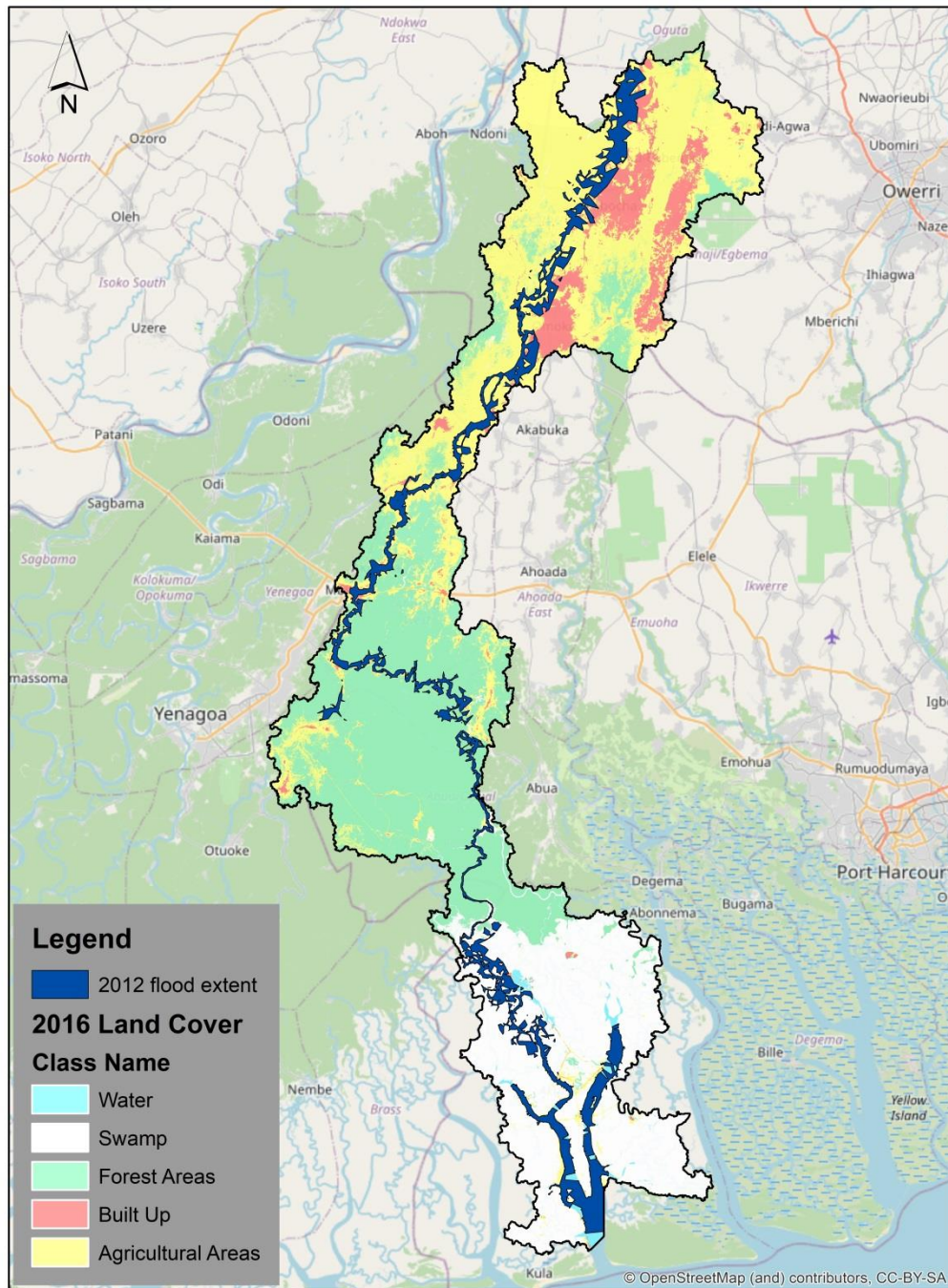


Figure 87: Intersection of 2012 inundation extent map and landuse map



### 2015 flood extent overlaid on the landuse map

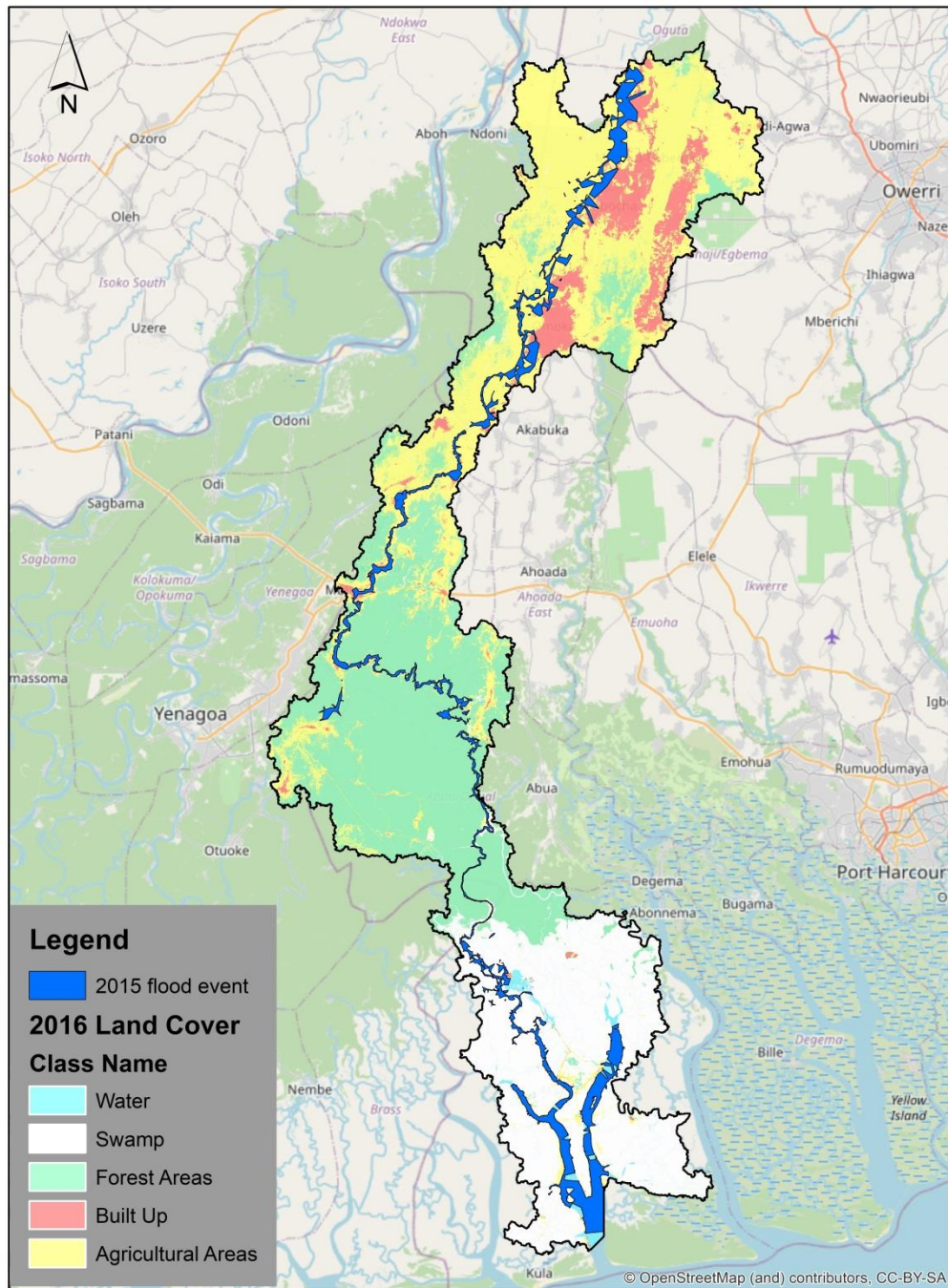


Figure 88: Intersection of 2015 inundation extent map and landuse map

### Sensitivity Analysis

In the context of this thesis, flood inundation and hazard analysis were limited by the availability of river geometry, topographical data, and hydrological data. Unfortunately, the study area is a data-scarce region and even though strenuous and time-consuming attempts were made to obtain data, such attempts were not successful, hence, calibration of the model could not be performed. Instead, a sensitivity analysis was carried out.

A sensitivity analysis was performed to test the sensitivity of the HEC-RAS one-dimensional model to Manning's  $n$  roughness coefficient by comparing the baseline values of Manning's  $n$  to different adjusted  $n$  values. The results are presented in graphical format in Figure 89. Results of the simulations are shown in tabular form in the Appendix.

The results (Table 25) show that a 10%, 20% and 30% increase bias in Manning's number results to a 1.32%, 2.57% and 3.63% increase in the average water surface elevation. Conversely, for the -10%, -20% and -30% decreases in the Manning's number, the decrease in average water surface elevation was -4.20%, -2.76% and -1.35% respectively. The results from the Manning's  $n$  sensitivity analyses demonstrated anticipated directional changes and the results from the Manning's  $n$  sensitivity analyses suggest that the model is working properly. Therefore, the model can be relied on to give a fairly good estimate of the potential flood hazard in the study area.

Table 25: Manning's  $n$  sensitivity analysis

	n-30%	n-20%	n-10%	n (Base value)	n+10%	n+20%	n+30%
Average water surface elevation (m)	9.98	10.13	10.28	10.42	10.55	10.68	10.79
%age difference from base value	-4.20	-2.76	-1.35	0.00	1.32	2.57	3.63

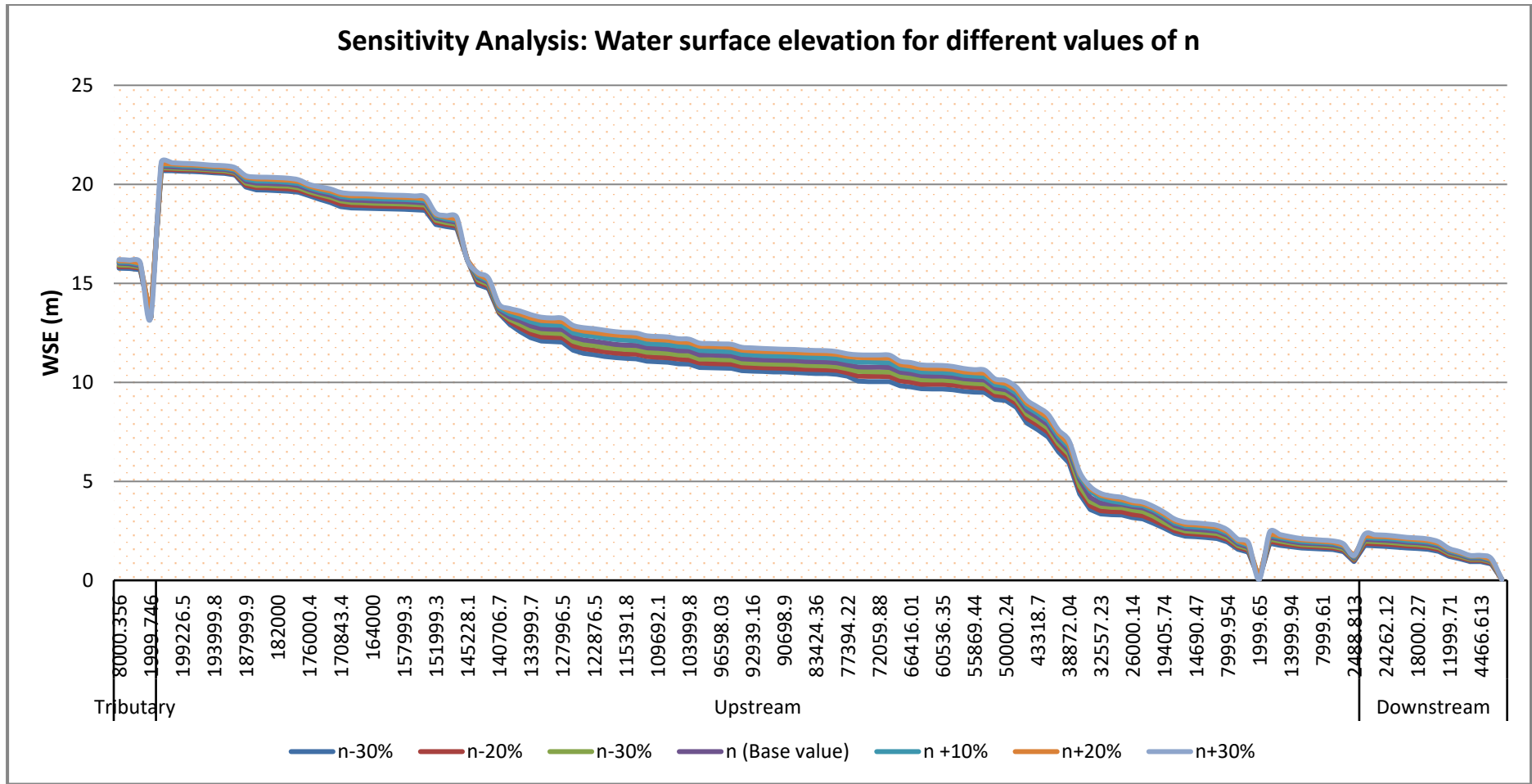


Figure 89: Manning's Sensitivity Analysis

## Chapter 8: Socioeconomic Analysis and Assessment of Adaptive Capacity

### 8.1: Description of Socioeconomic Characteristics

Socioeconomic status is among the most prominently measured characteristics in vulnerability studies. According to Rufat et al. (2015) vulnerability and by extension adaptive capacity is determined by relative distribution of income, access to resources, and diversity of economic assets, thus an understanding of the socioeconomic status of flood-affected farmers is essential in designing technological and policy interventions for effective flood mitigation and relief. This study employed snowball sampling to select 400 farmers to participate in the household survey. A semi-structured questionnaire was employed to collect information from smallholder farmers in the study area to obtain information on their socioeconomic characteristics. Personal and household characteristics were probed with a list of questions presented in different formats. Demographic indicators examined included age, household size educational status, gender, indigenous status, etc. Raw data was collated, coded and analyzed using Excel and SPSS. The results are presented in Table 26 in descriptive form.

Table 26: Respondents socioeconomic characteristics

Characteristics		Frequency	Percentage
Gender	Male	384	96%
	Female	16	4%
Marital status	Single	20	5%
	Married	355	88.75%
	Divorced	13	3.25%
	Widowed	12	3%
Age	<20-30	81	20.25%
	31-40	124	31%
	41-50	86	21.5%
	51-60	70	17.5%
	>60	39	9.75%
Educational status	None	19	4.75%
	Primary	185	46.25%
	Secondary	159	39.75%
	Tertiary	37	9.25%
Size of household	1	24	6%
	2-4	95	23.75%
	5-7	186	46.5%
	8-10	83	20.75%
	>10	12	3%

**Gender Composition:** In terms of sex composition, the data showed that 384 (96%) of the respondents were males and 16 (4%) were females. One of the main rationales explaining this phenomenon is that in most traditional homes, males still dominate the leadership of smallholder households, leaving little room for women and youth to participate in decisions regarding agricultural activities. Hence, very few women play an important role in making decisions concerning agricultural activities.

**Marital Status:** The findings of this study showed that most of the respondents, 355 (88.75%) were married and living with their spouses. 12 (3%) were widowed, 20 (5%) were single, while 13 (3.25%) were divorced.

**Age Group Composition:** In terms of age group composition, the average age of the respondents was 46 years. The range was 50 (lowest age was 21 while the highest age was 71). The modal age group is the 31- 40 years age group (31%) followed by the 41-50 age-group (21.5%), while the age group with the lowest frequency is the “above 60 years” age-group (9.75%). The figures generally roughly match with the national trend which states that the youngest age group (15–29 years old) accounts for 36% of smallholder farmer households, while, households head aged between 30 - 40 years make up 55% of agricultural household heads in Nigeria (Anderson, et al., 2017). This means that the majority of the household heads are of middle age. However, this is not in line with the pattern in most developing countries, generally, in most developing countries, older people are more likely than other age groups to be working in agriculture than in other industries. For instance, Heide-Ottosen (2014) notes that the average proportion of agricultural holders over the age of 55 is 26.8 per cent in Africa, 28.5 per cent in Asia, 44.7% in the Caribbean and 29.8% in Latin America.

According to Amaza (2016), the prevalence of middle age active and productive heads of households means increased availability of able-bodied labour for primary production and ease of adoption of innovations. These have great potential for increasing agricultural productivity and production and, hence, for improving household livelihoods and reducing poverty. Some studies, however, suggest that the more the farming experience of the household head, the more resilient the household tended to be to flood. This is intuitive since farmers that have more years of farming experience have accumulated knowledge through learning-by-doing and this

tend to have a positive effect on farm productivity leading to increased output and improved food security.

**Household Size:** The households are broadly classified into five categories, namely, household with only one member, 2-4 members, 5-7 members, 8-10 members and households with more than 10 members. In terms of frequency, the number of households with 5 to 7 members was the modal group, followed by households with 2 - 4 members. Household with more than 10 members was the group with the least frequency. Results show that in comparison to the national and regional figure, the average household size of the sampled households was 6.2, which is larger than the average size of 5 persons per household in the Niger Delta (4.9) and the national figure of 5.4 (NBS, 2017).

Traditionally, farming households are characterized by relatively large household and high rates of population growth, but since the middle of the last century, both family size and population growth have declined, with population growth rates down to 2 per cent and the extended family divided into smaller family groups. Globally, average household size has declined nearly everywhere, mirroring the fall in fertility rates. (UN DESA, 2017). Anyanwu (2013) notes that the absence of well-developed social security systems and low savings in developing countries (especially those in Africa) tends to increase fertility rates, particularly among the poor, in order for the parents to have some economic support from their children when parents reach old age, consequently, in most poor Nigerian homes, children are seen as an insurance during old age and a buffer against poverty since they form part of the family workforce. The high average size of households which does not follow the global trend has severe implications. For instance, IARAN (2016) suggest that inadequate resource constraints inhibit poor families from investing more resources in their children. For example, the incidence of national poverty with the least size (i.e. one person) was 22.60 per cent, while incidence of poverty for households with more than 7 people was estimated at 97.61 per cent in 2010. It is evident large household sizes reinforces the cycle of poverty if parents are unable to feed and educate their children; further entrenching the poverty trap.

**Education Status:** Education is one of the most important indicators of socioeconomic status and development. In view of this, an attempt is made to record the highest level of education attained by the head of the household. The distribution of data relating to levels of education

of the head of the Household reveals that 46.25 per cent of head of households had schooling up to primary education, 39.75 percent with secondary education and 9.25 per cent had tertiary education. The number of respondents with no formal education is relatively low, i.e. only 4.75 per cent.

**Land Rights Patterns:** Most smallholder farmers have limited resource endowments with respect to land and capital. In the past, in many areas of sub-Saharan Africa, land was abundant and was not a critical constraint; this allowed farmers to increase production by clearing new land and then rotating the use of fields over time to help maintain soil fertility. However, with the rapid population increase, shifting cultivation has become untenable and land became a limiting resource. Environmental shocks such as floods, in addition to inducing large scale physical and socioeconomic displacement, have also disrupted existing arrangements for agricultural livelihoods and access to agricultural and homestead land. Reale and Handmer (2011) notes that natural disasters uncover underlying social, political, economic and environmental vulnerabilities, including land tenure issues. Disasters such as flood can cause or increase tenure insecurity thus adding to other vulnerabilities households may face. In the absence of a guarantee of tenure security, access to land can be lost (Quan and Dyer, 2008). Reale and Handmer (2011) further buttresses this point by noting that “When land is lost, livelihood is threatened”. The importance of secure land tenure is even more pertinent in the case of the smallholder farmers, because land forms the major natural capital for daily living and survival. The absence of uniform title or enforcement of land claims and rights across different socio-cultural and socioeconomic classes means that floods are likely to have differential impacts across different classes. Analysis of access to land and land rights is therefore critical to understanding the overall vulnerability of farmers to floods and in instituting sustainable, equitable policies for dealing with flood. Access to land is an important livelihood asset and when land is lost, livelihood is threatened and when livelihood is destroyed by a disaster, recovery is seriously hampered by poor tenure security (Reale and Handmer, 2011). Hence, the security of rights and claims to land cannot be taken for granted in the analysis of the flood impacts. Access to agricultural land is particularly important in terms of the households’ ability to respond to floods and sustain their livelihoods, since it can be transformed into or used to access other livelihood assets. Access to agricultural land enables people to generate income and access formal loans. In addition, land and land certificates also

function as important securities when facing losses, especially flood impacts. Further, the means of acquiring land is also vital and this thesis investigated the types of land acquisition.

The most common mode of acquiring land is through inheritance. 74% of the respondents acquired their plot through this method; most of the farmers who acquired land through inheritance often do not have official documentation of ownership, which means that maintaining ownership of their property is possibly at risk. Interview with the local leaders revealed that land ownership through family inheritance is mainly patriarchal – a system in which land is owned by an extended family and is periodically shared among the households within the family. The patriarchal land ownership system ensures that every male member of the community has access to land; conversely, females play little or no role in terms of land acquisition and control. About 9% of the farmers own land under a lease agreement. About 6% of the farmers stated that they possess lands which they purchased with all official documents.

Table 27: Land acquisition methods

Land Acquisition method	Percentage
Inheritance	74
Lease	9
Official purchase with deed of ownership	6
Communal land	11

The results (Table 27) show that access to land is high, since land acquisition is mainly by inheritance, however, access to officially documented lands is still low (6%). The interview also revealed that title possession is not always a guarantee of right because in many cases, powerful and influential individuals are capable of using their influence over land administration officials through financial inducements, or even intimidated and harassed the actual landowners to the point that they ceded their rights to their ancestral land. Most of the regions seriously affected by floods happen to be areas where distribution of land ownership is also highly unequal. The proportion of rural households who own prime land is low and the concentration of land ownership in the hands of small but very powerful elite is a fact of life in nearly all the affected districts. Access to land, therefore, is closely correlated with social status and political power.



One of the greatest problems of smallholders is the insecurity of tenure. Due to the land use act of 1976, it is stipulated that the government is the de facto owner of the land and therefore may reassign ownership of land based on the best interest of the public. However, this policy has led to the appropriation of hitherto virgin land being converted to other use and sometimes farmers have been forced to relocate or evicted because of new development projects, urban sprawl etc. As a result, fertile agricultural land is being diverted for non-agricultural use, causing shrinkage of cultivable land and pushing the farmers further into marginal lands.

Additionally, compensation for dispossessed land is allegedly insufficient, according to community leaders, for families to re-establish themselves. This has a direct impact on rural land availability, productivity and the ability of the poor to sustain a livelihood. With no voice and power, residents vacate the fertile land to relocate to flood prone zones. Most of the farmers live in constant fear of being forcibly evicted. A large proportion of the farmers (20.25%) revealed that they have sold a prime portion of their lands at some point, either because they were coerced by powerful individuals to sell their lands or to meet pressing need. The sale of prime agricultural land is still ongoing. The result of the field survey is an important pointer towards increasing landlessness of smallholder farmers and landlessness is directly related to vulnerability to environmental shocks.

## 8.2: Assessing Adaptive Capacity

Smit and Pilifosova (2001) opined that adaptive capacity is influenced by different types of variables that act simultaneously in a dynamic context and reflect strategies, capacities, and assets available to households for coping with changes and disturbances. The degree of adaptive capacity is captured through indices of household assets, such as social capital, literacy rate, income and access to credit. The indicators and criteria are used to determine the adaptive capacity of the farmers. The indicator method of quantifying adaptive capacity is based on selecting some indicators from a set of potential indicators and then systematically combining them to show the level of adaptive capacity. The index is not based on thresholds nor does it represent an absolute value, it is basically a relative measure.

The first step in constructing the index comprises of the selection of indicators. However, the methodology adopted in the choice of indicators is always very crucial, since a choice of wrong

indicators may lead to a construction of an invalid index. Due to the fact that adaptive capacity is context and site-specific; the nature and characteristic of the study area were taken into consideration in drawing up the list of the indicators. To obtain the most unbiased responses and a deeper meaning, questions were mostly asked in indirect forms. It was necessary to standardize and normalize each indicator because each was assessed on a different scale (Hahn et al., 2009). The resulting index values are numbers between 0 and 1, with zero denoting no adaptive capacity, while 1 denotes very high level of adaptive capacity. It is inferred that an index of  $0 < AC < 0.33$  should be considered as low,  $0.33 < AC < 0.5$ , as moderate and  $AC > 0.5$ , as high. The result of the adaptive capacity assessment is presented in table 28.

Table 28: Adaptive capacity components and values

Indicators	Score	Level of AC
Literacy level	0.5042	High
Income generating asset	0.4556	Moderate
Level of average monthly income	0.4813	Moderate
Access to credit	0.0863	Low
Alternative source of income	0.4463	Moderate
Access to technology	0.3013	Low
Social Network	0.135	Low
Access to information	0.4725	Moderate
Access to Infrastructure	0.4219	Moderate
Economically active portion of Household	0.2645	Low

The results (Table 28) shows that in terms of literacy level index, the respondents showed a high level of adaptive capacity. Literacy level was the singular index, which the returned a high score (.5042). This indicates/corroborates the data from Table 26 which indicates that a large proportion (95%) of the respondents possess at least primary level education. In terms of the access to information index, the respondents possess a moderate level of adaptive capacity (.4725). A large part of the respondents had access to multiple sources of information. However, they noted that in terms of access to information, the cell phone played a major role and acted as the fastest means of information sharing. Further, most of the respondents note

that since the introduction of cellular phones, they have greater access to obtaining and sharing information. Another aspect where the farmers possess moderate adaptive capacity is in the area of income generating asset (.4556). Assets mentioned include cash in bank, livestock, farm implements, etc. and most of the respondents reported having more than one income-generating asset. The index access to infrastructure was moderate (.4219). However, an unequal spread of infrastructure was noticed, most of the peri-urban areas had more infrastructure than core rural areas. In terms of having alternative sources of income, the result shows that the capacity was moderate (.4463). This is not surprising, as most of the farmers reported being engaged in other occupations aside farming as a buffer.

Access to formal credit was the worst-performing index (.0863). Access to formal credit is almost non-existent among smallholder farmers in the study area. The most common source of credit was the “common community purse” where members make monthly contributions to one another on a rotational basis-locally. Limited access to credit is explained by three factors. Most of smallholder farmers hold the view that borrowing money for farming does not make economic sense as they are not sure of the successful growth and harvest of their crops. Secondly, a large proportion of the farmers is poor and often lacks the collateral to access credit. Lastly, there is a paucity of financial institution in the area. The interview revealed that there were less than five banks in the area and they were located very far from the farmers. However, the agricultural staff interviewed noted that the problem was not that of lack of access of credit as there are financial institutions and programs devoted to providing financial assistance to farmers; however most farmers are not aware of such program.

The socioeconomic networking capacity of farmers was low (.315). Very few of the respondents associated with research and training institutions and there was also low participation in farmer-based organization (FBO) or community-based organization (CBO) activities. Another area where the adaptive capacity was low (.2645) is the economically active portion of the household. The low level of economically active of the household implies that sampled households had a high level of dependents. A low level of economically active portion of the household reduces its adaptive capacity, especially in times of scarcity. A low level of economically active population translates into higher rate of dependency ratio would indicate that economically active individuals have many others to support and, hence, resources for coping with the natural disasters would be more limited.

The farmers also scored very low in the adoption and use of modern technology (.3013). Generally, farmers are risk-averse and their uptake of new technologies can be slow. Some of the respondents noted that they are used to their traditional system of farming, while some stated that the high cost of modern technologies prevented them from using such technologies.

In summary, the overall adaptive capacity of the farmers out of theoretical highest level of 1 was 0.3569. The result confirms that the level of adaptive capacity is low. The reasons for the low level of adaptive capacity may be traceable to different factors such as weak governance, behavioral traits, economic factors, beliefs, tradition and culture. The low level of adaptive capacity, especially calls for certain interventions to build up and upscale the adaptive capacity specifically in some areas. This will be addressed in the recommendation section.

### **8.3: Assessing Coping Strategies**

A substantial volume of studies has been devoted to understanding the coping strategies of farmers (Epstein et al., 2017, Diyawadana et al. 2016 and Coulibaly et al. 2015). Most of the studies show that households can still build effective ‘buffers’ against flood disasters in order to increase their capacity to cope with such disaster. Smallholder agricultural systems in Nigeria, particularly those located in areas of high risks such as coastal areas, are often characterized by livelihood strategies which have evolved to manage the impacts of hazards such as floods. In response to adverse climatic conditions, farmers, using their indigenous knowledge gained through a trial and error process and through their experiences over time have developed coping strategies to reduce the impact of such events. However, when excessive floods occur, their strategies fail to provide security and damages become severe when local knowledge is inadequate. Coping strategies are location-specific and a working strategy in one place may not be an appropriate strategy in another. Therefore, understanding the nature of specific coping strategies of local farmers to flooding is very vital. Hence this thesis sets out to investigate the coping strategies adopted by the smallholder farmers. Information on the coping strategies used by farmers was elicited by the use of open ended question. Considering the fact that farmers mostly use a combination of strategies to cope, respondents were given the opportunity to mention more than one coping strategy. The coping strategies were then assessed in the context of the level of sustainability and the implications

of each strategy. Table 28 shows the various coping strategies taken by the respondents and the frequency.

Table 29: Coping strategies

Typology of coping strategies	Strategy	Percentage
Neutral	Business as usual (Nothing done)	20.25
Non-erosive	Changing planting period	13.75
	Crop diversification	14.75
	Improved seeds	15.75
	Financial assistance from government and other institutions	10.75
	Donations from individuals and NGOs	5.75
Erosive	Borrowing	14.75
	Sales of asset	20.25
	Early harvest	28
	Occupational diversification	26.5

Most of the respondents have adopted one or more strategies to cope with adverse flooding. Only, 20.25% of the respondents reported adopting no strategy to cope with flood (i.e. Business as usual). The most common are coping strategy adopted by the farmers was early planting (28%), occupational diversification (26.5%), sales of assets (20.25%), and using improved seeds (15.75%). Conversely, the least adopted strategies were financial assistance from the government and other financial institutions (10.75%) and donations from individual and NGOs (5.75%).

### Sustainability of Coping Strategies

As noted above, smallholder farmers respond to flood and other environmental shocks by adopting a range of ‘coping strategies’, however, these coping strategies more often than not, have implication and costs. Used in the right context and combination, these strategies can

greatly help farmers cope with flooding, however, if used in the wrong context or manner these strategies can worsen the state of the farmers in the long run. Normally, the adoption of these strategies follows a logical trajectory beginning with simple and cheap strategies that are easily reversed. When such strategies prove insufficient, they are followed by strategies with higher cost and are less easily reversed. Eventually, sometimes these strategies become inefficient and families must then trade important productive assets (such as farmland) or even migrate to survive. This leads to the question of sustainability of the coping strategies used by the farmers. To examine the sustainability of the strategies, each of the strategies was examined and divided into two broad classes, namely non-erosive and erosive strategies. The following section will provide a brief description of each type of coping strategy.

**Non-erosive:** Smallholder farmers who live in risk-prone areas and who are confronted with high flood risk will usually try to avoid adverse effects through preventive or proactive measures. If the impact is not very severe, most the farmers will be able to cope by drawing on the buffers or reserves they have generated, by finding additional sources of food or money to buy food or drawing on social support networks without comprising future livelihood security. These coping strategies can be labelled ‘non-erosive’. Non-erosive coping strategies lead to little or no damage and preserve productive assets as long as possible. Hence, as soon as the period of stress has passed and normality returned these assets can be rebuilt, replenished or repaid with relative ease. Some examples of non-erosive coping may be social safety net, intra-house transfer and loan etc.

**Erosive coping:** When the disaster is more severe, for instance, when an area is hit by recurrent floods in the same year or when multiple hazards strike simultaneously. The set of non-erosive coping strategies will soon be exhausted and people will have to take more drastic actions to combat the disasters. These actions can seriously affect and compromise people’s future livelihood security. These types of ‘coping strategies’ are labelled ‘erosive’. Erosive strategies entail the exploitation of the productive assets of the concerned party. People trapped in such a situation usually destroy the natural environment and causes depletion of common property natural resources. Therefore, affected smallholder farmers suffer a loss in productivity leading to a loss in future income generating capacity in the given household (Van der Geest and Warner, 2015) hence falling into a vicious inter-generational poverty trap if the loss in productive assets is significant. This process has adverse implications for the inequality,

poverty and overall growth and development of the country. Examples of erosive coping strategies include the sale of assets and loan shark.

### **Coping Strategies in the Context of Sustainability**

**Changing Planting Dates:** In responding to increased flood events, 13.75% of the respondents mentioned that they have changed the time of planting their crops. Normally the farmers had a generally accepted planting date. Over time, however, this became untenable, the crops are now cultivated in a way that enables harvesting to be done before flood occurs.

**Crop Diversification:** 14.75 of the respondents mentioned that to cope with floods, they decided to grow more varieties of crops. Diversification of crops is common in the study communities and has been in practice for millennia. The average smallholder household grows six different crops and most of the farmers do not depend on a single crop for food or income. The common cropping configurations are combinations of maize, yam, vegetables, cassava, beans, groundnuts and plantain, mostly under different land acquisition systems. Farmers are adopting new varieties of plants as part of their response to the changing climatic conditions.

**Use Improved Seeds:** Another way the farmers responded to the problem of flood events was through the use of alternative varieties of the same crops. According to some of the respondents, extension officers often release improved and climate-smart seed at highly subsidized prices. Such seed aid programs target farmers' seed insecurity, and help them have access to healthy planting material which can withstand environmental stress. 15.75% of the farmers reported using improved seeds which, according to them performed much better in the wake of environmental disasters than the normal seeds.

**Financial Assistance from the Government and Other Institutions:** After suffering flood-induced losses farmers often find themselves in extremely difficult situations and cannot rehabilitate themselves without assistance from the government or other financial institution. In the case of large-scale flood devastation, government's role in relief and rehabilitation becomes crucial and 10.75% of the respondents mentioned depending on such assistance. However, on the whole, government organizations and NGOs provide relatively little technical and financial support to the households. In addition, the respondents reported limited access to financial institutions and extension services.

**Donation from Individuals and NGOs:** Some of the respondents (5.75%) noted that donations from individuals and NGOs during periods of environmental crisis were one of the ways they coped with the flood burden. Most of the respondents noted that such donations were far and between and sometimes there was a high level of favouritism, as some people were more favoured than the others. Although, not environmentally-threatening. However, dependence on donations as a coping strategy is not very reliable and does not allow for planning, as farmers have to depend on the goodwill of private individuals.

**Borrowing:** 14.75% of the respondents mentioned that during episodes of crop failure occasioned by environmental disasters such as flood, they resorted to borrowing or collecting loan to meet their needs. Ideally, loans are a non-erosive strategy as long as people are able to pay back and don't fall victims of loan sharks. However, credit institutions such as banks often require collaterals such as buildings and lands before giving out loans or financial assistance to the farmers and when farmers fail to return the loans within a specified period, the lending institutions often resort to confiscating and disposing of such properties. Interviews reveal that the few farmers who have access to bank loans often find it difficult to pay back such loans as they often use the cash for sustenance during disasters such as flood events. Consequently, they are forced to sell productive assets, making them more vulnerable to future environmental shocks.

**Sales of Assets:** 20.25% of the respondents stated that they sold some of their assets as a means of coping with flood events. During flood events, desperate households are forced to sell off valuable possessions such as livestock, radios, furniture, and kitchen utensils – at 'distress prices' that averaged less than half their replacement cost. Often the most important property sold was land and livestock. According to Opondo (2013) floods destroy household assets as the effects force people to dispose of assets to cope in the short term. The sale of assets diminishes the farmer's asset base and makes them more vulnerable to recurrent flood events and is particularly detrimental to long-term livelihood sustainability. When people have less land available for crop production, then they are more likely to face food shortage even in the absence of floods or droughts. Further, Bhatta and Aggarwal (2015) indicated that distressed liquidation of productive assets such as livestock and land at a lower price can provide consumption relief in a particular year but may worsen food production situation in later years.



**Early Harvest:** 28% of the respondents mentioned that they used early harvest as a strategy to cope with flood events. They stated that floodwaters compelled them to harvest their crops prematurely. However, early harvest of crops is not a sustainable option. Early harvest leads to harvesting many immature crops which translates –into less yield and quality. Most of the respondents opined that with the benefit of hindsight, they could not wait until floodwater recedes completely as this will lead to a complete loss of their crops; they therefore, preferred to harvest their crops early before they get destroyed by flood.

**Occupation Diversification:** Many households (26.5%) in the study area take advantage of the presence of abundant natural resources in their locale not only to meet their subsistence needs but also earn cash income. For instance, farmers make use of the surrounding forest to provide timber, firewood, fruits, spices, herbs as well as charcoal. These help the farmers diversify their income-generating activities. Such diversification reduces the risk of livelihood failure by spreading it across more than one income source. To cope with the burden imposed by flood, most farmers in the research area choose to diversify their income sources (both occupationally and geographically). Diversifying income-generating activities may increase flexibility and boost resilience to extreme events, but critically, it is pertinent to note that most of the activities the smallholder farmers venture into as a buffer against agricultural failure occasioned by flood events are not sustainable. For instance, most of the respondents reported that they took to selling firewood and charcoal as a coping strategy against crop loss caused by floods. But in reality, uncontrolled use of natural resources such as forest for firewood production and charcoal making is not a promising alternative due to its unsustainable nature. Unplanned extraction of wood products from the local forest is not only environmentally damaging, but invariably intensifies future hazard levels. Thus, as an immediate coping strategy, charcoal making has serious consequences, both on the environment and livelihoods of the farmers and other resource users.

In summary, each of the strategies discussed above has something to offer the big picture. However, as mentioned earlier, what is important for the uptake of coping strategies is the sustainability and impact of such strategies. The findings show that most of the households employed coping strategies that are potentially erosive. The important point about these coping strategies is that they are responses to poverty in that the adoption of erosive coping strategies is largely driven by poverty (Ahmed, et al., 2017), where people have no option but to utilize

the only savings they have to meet their immediate needs following a disaster (World Bank, 2013).

In fact, several of the coping strategies adopted by the farmers represent a failure of coping with hazards. Households that are forced to sell their assets for food are consuming their wealth. Converting future streams of income into consumption goods is impoverishing and undermines the future livelihood viability. So these responses help households to survive in the short term, but at the cost of leaving them more vulnerable to future shocks. To reiterate, many of the coping strategies followed by farmers help them to cope in an adverse situation; however, if they are unable to pull through, once the adversity is over, it will impoverish the livelihood situation. The consequence of adopting such 'erosive' coping strategies is that the household's ability to generate future livelihoods is compromised, because its productive resource base has been compromised. When the next disaster occurs, the household has fewer options and will again be forced to shed assets to survive. Over time, the 'poverty ratchet' effect that repeated shocks have on increasingly weakened livelihoods steadily undermines the ability to recover, and pushes people towards chronic poverty and destitution (Sabates-Wheeler, et al., 2008). This problem of rampant poverty leads to the next section where the nexus between poverty and flood is discussed.



Figure 90: Chopped fuel wood ready for sale in the Niger Delta area (Ajanaku, 2012)

#### **8.4: Poverty and Migration**

The burden of flood varies by social class, not just during the pre-impact and response phases of a flood event, but also during the recovery and rebuilding process (Fothergill and Peek, 2004). Rufat et.al (2015), mentions that Floods disproportionately affects lower-socioeconomic status households, while Kamel (2012) argues that that the quality and speed of recovery following an event is influenced by access to timely and sufficient external assistance. Evidently, there is a nexus between poverty and flood vulnerability. Poverty, which is characterized as the deprivation of capabilities (Sen 1987), is one of the strongest determinants of disaster risk, as well as a shaper of the capacity to recover and reconstruct (Shepherd, et al., 2013). The nexus between poverty and flood vulnerability has been widely recognized both in theory and practice (Mahanta and Das, 2017). This connection is based on the idea that the poor are the most exposed to diverse risks and they do not have enough resources to lessen these risks. According to Brouwer et al. (2007) poverty is both an important determinant of (endogenous) environmental risk and hence directly and indirectly of socioeconomic

vulnerability—and an important constraint on adaptive capacity. They mention that indigent people are more likely to be exposed to environmental risk than rich people since the wealthy often have the capacity to take protective measures or are able to avoid certain environmental risks. Various authors such as Walker, 2012; Penning-Rowsell, 1996; Chan and Parker, 1996 have pointed out that it is often the poor with limited livelihood option that live on marginal lands such as floodplains. For instance, Lal et al. (2009) states that 80 per cent of the poor in Latin America, 60 per cent of the poor in Asia, and 50 per cent of the poor in Africa live on marginal lands characterized by poor productivity. Davis and Hall (1999) suggest that poverty can drive people toward settling and working in precarious locations such as unstable riverbanks in farming areas. These indigent people are often forced to live in marginal lands based on the assumption that there is a less probability of eviction by authorities because of the low value of these areas (See Figure 92). However, the unsustainable settlement of such areas can exacerbate flooding levels, inducing a cycle of increase in hazard burden.



Figure 91: Image shows examples of substandard buildings in marginal areas in the study area

A vast majority of the flood-affected poor households living in developing countries live in rural areas and are employed in agriculture, therefore, the study and analysis of the connection

between flood vulnerability and poverty is relevant. The widespread existence of poverty in the Niger Delta is extensively acknowledged. It is estimated that 70% of the population could be classified as poor (Akani, 2013). Table 29 provides information about the income status of the smallholder farmers

Table 30: Average monthly income

Level of income*	Frequency	Percentage
Very Low ( $\leq$ \$30)	36	9
Low (\$31-\$40)	113	28.5
Medium (\$41-\$50)	137	34.25
High (\$51-\$60)	71	17.75
Very high ( $>$ \$60)	43	10.75

\*= (USA Dollars equivalent of local currency as at December 2016)

Table 29 shows the average monthly income of the respondents. Data shows that the average monthly income was \$43.4; with an income level that is far below the national average of \$204 (World Data, 2016) most of the smallholders can be described as poor. Because of their high poverty level and low resource base, smallholder farmers usually bear the brunt of disasters such as floods. It is therefore legitimate to question possible relationships between poverty and flood vulnerability.

In order to estimate or comprehend the state of poverty and the relationship to flood, an indirect (Anecdotal) question was employed. The anecdotal technique is a narrative technique used to guide participants in sharing stories in a relaxed and spontaneous manner resulting in the collection of meaningful anecdotes about an incident or situation. Anecdotal assessments have the advantage of being efficient, inexpensive, and easy to administer. The anecdotal question ensures that the respondents flow freely in providing information, besides, the fact that participants are not also conscious of the detailed objectives of the anecdotal question engenders objectivity. The deep-dive using stories allow the interviewer to tease out the objective truth about certain themes.

However, in the case of discrepancies or shortage of information, attempt was made to steer them in the right direction. Such a system of inquiry ensured the objectivity of responses, since the pre-test question showed that asking direct questions on poverty and socioeconomic led to

misleading answers. From their comments, the major issues related to poverty are isolated and examined in the context of flood. To unpack the state of poverty and its relation to vulnerability, the respondents were asked to narrate their challenges and experience during flood events, especially in relation to their livelihood<sup>13</sup>. The following impacts of flood events were gleaned from the responses of the farmers using the anecdotal question method as described above (Table 30).

Table 31: Deduced impact of flooding in the context of poverty

Deduced Impacts of flooding	Percentage
Reduction in farming activities	67
Food insecurity	52
Destruction of properties	31
Destruction of crops	76
Health risk	46
Disruption of educational progress	24
Water shortage	32
Safety issues	63

67% of the respondents disclosed that flooding caused a serious reduction in their farming activities because flood events stall any attempt to farm. 52% of respondents said that flood has threatened their household food security to a greater extent. In terms of threat to food security, the damage was double-pronged, Due to the poor and inefficient means of crop storage; (Figure 92) most of the stored crops are often destroyed by flood. In addition, they noted that flooding usually happens during the period of harvest and when planted crops get inundated by floodwaters, they end up being destroyed, leading to a significant reduction in harvest. This invariably leads to a food shortage for the household and they are often forced to sell assets to meet their dietary needs, this further exacerbates the poverty level of the farmers.

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<sup>13</sup> *The exact question asked is stated in the questionnaire section*





Figure 92: Image showing traditional systems of storing tubers of yam

The respondents particularly mentioned that apart from destroying property and infrastructure, floods pose severe health risks to them. They noted that the inundation of the area by floodwater result not just into increases in waterborne diseases, but in the increased presence of disease-bearing insects such as mosquitoes, resulting in outbreaks of dangerous diseases like malaria etc. Epidemics invariably follow large scale flood events and this result in loss of human productivity. This is worsened by the fact that most of the respondents have very low access to proper medical care and hence they either wait out the ailment or sometimes resort to traditional means of treatment. This greatly diminishes their health status both in the short run and long run.

During flood events, most people are forced to relocate to other places for safety, and as a result of the relocation, some of the respondents mention that some school-going children were seriously affected and missed lessons for weeks, as they waited for the floods to subside so that they could go to school. In the process, some of the children drop out of school for a long time, and due to the fact that it takes time for the farmers to pick up financially after flood events, children are forced to remain at home due to lack of funds to pay school fees.

Another issue mentioned by the respondent is the pollution of water sources, according to some of the respondents; one of the most severe impacts of flood is the pollution of water sources. Since most of the farmers depend on the local streams for water, in the event of flood

inundation, such water bodies become polluted, thereby limiting their access to water. In such events, they have to move long distance (often on foot) to meet up their daily needs. Some of the other issues mentioned by farmers include safety issues, lack of a safe living environment (This is due to either the invasion of reptiles or due to criminal activities prevalent during crisis periods).

In the process of coping with the flood burden, farmers are compelled to reorder their economic priorities; moving portion of their lean budget to cope with flood will lead to a situation where the farmers face difficulties in many aspects of their daily lifestyles. Further, the possibility to obtain assistance often depends on the social status and connections which often does not favour the poor and marginalized farmers. According to Rufat et al. (2015) flood disasters often reveal larger societal inequities, even if there remain some debates on the root causes of unequal post-disaster outcomes, the indigents are not just vulnerable as a result of their location; rather, their vulnerability is closely linked to their socioeconomic conditions. Even within the family, households with higher income showed better prospects of coping with flood disasters than those with lower income. To better situate the flood burden between the various income groups, the respondents were asked how long it took them to fully recover from the flood events. Correlation test was conducted to check if there was a significant statistical relationship between income level and the time of recovery and Table 31 presents the results of the correlation analysis

Figure 93 reveals that about 16% of the respondents (modal class) stated that it took them 8 weeks to recover from the flood. The least (fastest) period of recovery was 2 weeks, while the highest period was more than 16 weeks. Statistical analysis shows that the average period of recovery was 7.2 weeks. The relatively slow rate of recovery buttresses the low adaptive capacity of farmers in the study area. Besides, such long period of recovery, means that farmers are more vulnerable and have shorter period to recover before the next round of disaster.



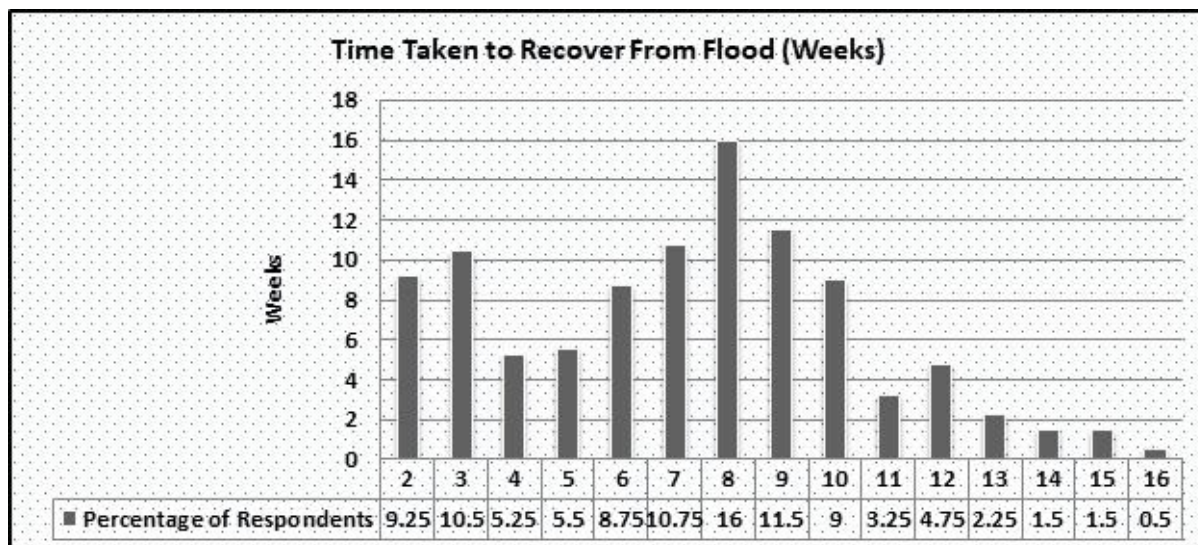


Figure 93: Time taken to recover from flood (weeks)

Table 32: Correlation of income level and time of recovery

Correlation	- 0.7
P Value	0.000003
Mean	7.2

The results show that there is a negative correlation between the level of income and the period of recovery. In other words, the higher the income, the shorter the time of recovery. The P value (0.000003) which is much lower than the 0.05 shows that there is a very strong correlation between income level and recovery period. Thus, it can be inferred that poverty in form of income inequality plays a significant role in flood vulnerability. Aldrich (2013) buttresses this point by mentioning that shocks caused by natural hazards, particularly floods, are major reasons why farmers remain poor. It can be surmised that in the case of the smallholder farmers in the Orashi basin, poverty and vulnerability reinforce each other.

### 8.5: Migration Propensity in the Context of Flood Events

The causes of migration are varied and complex, ranging from population growth, poverty, water quality, water availability to environmental threats. There is often no single factor that causes migration, but for farmers already weakened by economic reasons, migration may be the only viable adaptation strategy to changing environmental conditions. The connection between migration and disaster risk is increasingly being established (Gemenne, et al., 2006).

Based on this, there is a need to investigate the migration-flood nexus in a more context-specific manner.

Natural disasters such as floods play a part in forcing people to migrate and cope with vulnerability. Floods act in different ways to influence the desire to migrate among farmers in the Orashi basin. While smallholder farmers in flood prone area are vulnerable to environmental risks and have developed certain strategies to mitigate or cope with the consequences of events that are somewhat predictable and regular, such as annual floods, there are very limited capacity and mechanism handle to bigger shocks such as massive floods (such as the floods in 2012 and 2015) and in such cases the only remaining option for the farmer is out-migration. It is therefore important to gain an understanding into the interplay of divergent push and pull factors, the dynamics and changes in migration flows and how migration is related to flood vulnerability. This section thus focuses on establishing the link between flooding and migration characteristics of the farmers.

#### **8.5.1: Factors Affecting Migration in the Context of Flooding**

There is a need to investigate how certain factors influence migration decision to develop more informed and rounded policies. This study investigates the role of migration as an adaptation strategy to cope with floods. Further, it identifies different cognitive conditions prompting the decisions of farmer to migrate. One way to determine the extent to which migrants are forced to relocate due to environmental pressure is to differentiate between push and pull factors. The concept of push factor suggest that people are forced out of their home region while pull factors suggests that due to a variety of reasons, people opt to remain in a region or are attracted to an area.

When disasters occur, the focus is often on reporting the death toll, loss and damage figures, but researchers often have failed to ask the right question: “why were the victims living in such unsafe, vulnerable living conditions in the first place?” The most pungent question is “If people have an idea of unsafe locations that are prone to perennial flooding, why are they still living in such flood prone area?”

Pull factor in the context of this thesis, therefore, means the factors that are keeping the farmers tied to their original location, in other words, Pull factors in this thesis is a slight modification

of the general definition of pull factors used by other studies which denotes the pull of inhabitants from an original location to an alternate location. This thesis takes a slightly different approach to the concept. Here, pull factors denote forces that specifically keeps pulling the respondents to their original location or forces that prevents them from leaving their original location. This applies to those who did not move from their original locations. On the other hand, push factors entail factors that have motivated farmers to move from their original location to a new location.

### **Pull Factors**

Cultural attachment played some roles in term of migration decisions. 6% of the respondents mentioned that they had an emotional attachment and a high of sense-of-place to their tribal location and culture. Some of the respondents stated their ancestors had lived in the same area for millennia and survived and they see no reason they have to relocate despite the risk posed by the environmental conditions. The insistence of disaster victims to remain in their home sites despite the devastation and danger imposed by environmental stress is hinged on “human-land relationship” (Guo Ming, 2004; Wu et al., 2020) developed over time which has created strong bonds between the farmers and their “maternal roots” or “native soil”. A large percentage (44%) of the farmers mentioned that they did not permanently migrate simply because of concerns for their family and social ties built over time; this corresponds with findings from (Kawasaki, et al., 2020). Most of the respondents opined that migration could lead to loss of family cohesion, some noted concern for dependents such as the elderly and invalids who cannot move. Further, other households appeared unwilling to undertake long-distance migration because they wanted to retain their social networks and had rights and entitlements there. Some of the respondents expressed fears that if they moved to new areas their social networks would be destroyed and they would not be able to secure a daily income.

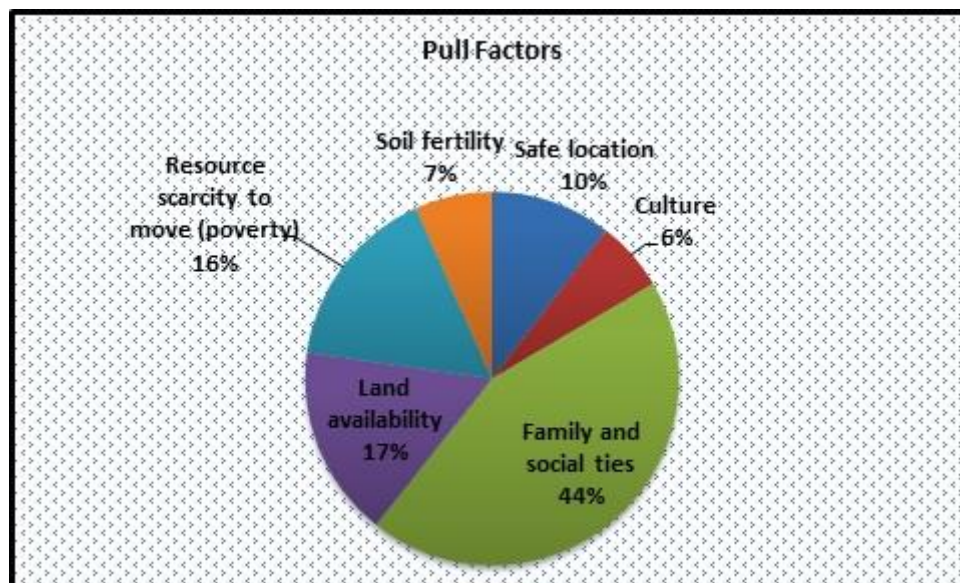


Figure 94: Pull factors

The study confirmed that resource scarcity and lack of capital constrain households from considering migration as an option. Households that lack financial and social capital are unlikely to undertake long-distance migration because of the costs involved with relocation. This implies that poor households that are most vulnerable to the effects of flood are often the least equipped to migrate. Deeper probe through interviews indicated that some of the respondents could not afford to relocate and start building new structures as they had no money or material resources for such venture. This is in line with the view of Goldberg and Frongillo (2001) who states that household poverty levels may decrease the possibility of migration to more favorable regions. Migration due to flood is not related to the burden of flood, rather it is predicated more on the socioeconomic condition of the respondents. Some of the farmers noted that their livelihood is seriously threatened by flood, but they could not permanently relocate because they lacked the resources to do so. The following quote from one of respondents highlights the role poverty plays in forcing the indigent to remain in flood prone areas against their wishes.

*“..... in recent years, floods have increased and often the harvest failed as a result of flood. I will like to move out from my present location, but I do not even have enough money to cover the living expense of my family. So I cannot afford to relocate. I have to bear recurrent destruction of my crops by flood and this has greatly affected my family”*

In the example above, it is the socioeconomic context in which the flooding occurs that eventually leads to decisions making about migration. Evidently, if some of these respondents had enough resource they would have made the decision to migrate, but due to lack of resources they have to remain in flood prone areas. It could therefore be concluded that poverty and lack of resources are a major determinant for migration decisions.

### Push Factors

The survey result revealed that there are temporal variations in terms of push factors. Some of the respondents reported that some factors pushed them to move out of a location for good, while the same factor only pushed some people away temporarily. Based on this dichotomy, the push factors were categorized into two, namely permanent and temporary push factors.

Figure 95 show that only two major factors (Flood events and conflict) played major roles in forcing respondents to relocate permanently. 51 (13%) of the respondents stated that they permanently migrated due to flood; while 31 (8%) of the respondents indicated that they moved permanently because of high level of insecurity or conflict in the area.

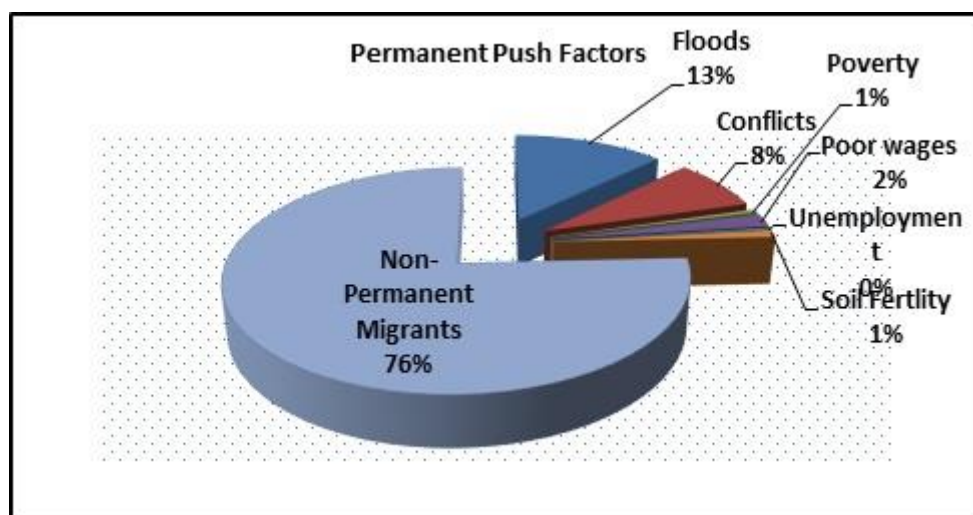


Figure 95: Permanent Push Factors

Figure 96 shows the factors that have made respondents move temporarily, i.e., temporary push factors. The major factors that have made respondents move temporarily are flooding (42%), conflict (32%) and poverty (11%). Most of the respondents mentioned that although that movement due to flood was temporary, but such repeated flooding and movement translates

into livelihood stress for the farmers. For example, when the floodwater recedes, the farmers were usually left in a worse position because their inferior structures were easily affected, resulting in the structures collapsing or being washed away.

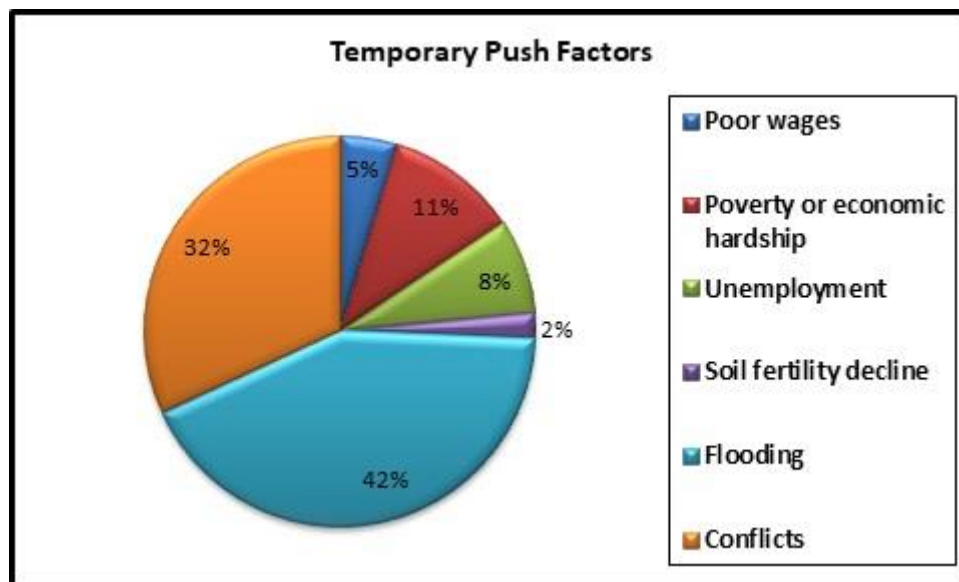


Figure 96: Temporary Push Factors

Even in terms of temporary migration, results suggest that 'poor people are most vulnerable and tend to move shorter distances and often into the fragile and marginal land because of limited resources. This often leads to conflicts between the migrant and the host, who are often faced with the same predicament as the migrant.

### **Planned and Forced Migration**

The study reveals that the degree or force of migration differs. Some of the migration movement was planned, while others were spontaneous and unplanned. For instance, sudden disasters such as flood often compel large groups of people to abrupt and often tentative flight. By contrast, migration as a consequence of gradual changes or personal choice often shows a different pattern. It is less precipitous and is based on a decision taken over time. These different forms of migrations and their resulting patterns of movement (migration, displacement and planned relocation) need to be assessed separately to determine the appropriate policy responses.

**Planned migration:** Results show that most permanent migration movement was planned migration. Many households formally and informally resettled in the other areas in order to access new livelihood opportunities. 45 (11.25%) of respondents were in this group. For these groups of farmers, the level of urgency is clearly lower. Although used as an adaptation strategy, their migration is not one of distress, but an attempt to structurally improve their livelihood by making use of better agro-ecological conditions in locations that are “environmentally safe” For these groups of respondents, migration can be said to be a coping strategy. They stated that safe sites with good farming prospects and the availability of water along the river banks made them to settle in those areas in anticipation of better harvest.

**Forced migration:** Disasters such as flood often induce large-scale displacement, often in the context of emergencies. In these situations, those who migrate may look termed refugees or internally displaced persons who fled situations above their immediate personal control. These kinds of movement often involve displacement of entire communities who will often move en-masse to new locations with little or no warning. Migration in the wake of extreme events such as the flood events of 2012 and 2015 in the study area is characterized by a lack of choice and agency in the decision-making process (as the major concern is immediate survival), and as such it can best be termed displacement. 170 of the respondents stated that their migration was mainly forced as they had no time to plan and had to abandon most of their properties in the process of escaping. Such loss of valuables further entrenches poverty of the farmers.

The findings presented above suggest that floods play a major role in causing migration and that sudden onset disaster such as floods which cause greater disruption are much more important than slow onset problems. Although responses to sudden onset disasters such as floods are temporary as most farmers return to their homes as soon as possible and become involved in the reconstruction of their destroyed homes, however such natural disasters unleash a vicious circle of increasing impoverishment and increases vulnerability to future disasters. Each round of disaster leads to more poverty, and the capacity of farmers to protect themselves from the next disaster is seriously reduced.





Figure 97: People fleeing from their homes in the wake of flood event in the Niger Delta (The Guardian, 2015)

Migration was one of the coping strategies adopted the farmers. The farmers use migration as an option of ‘last resort’ (Penning-Rowsell et al., 2013) to overcome the worst periods. While Adger et al. (2009) recognize migration as a coping strategy, it is considered undesirable due to the fact that migrants leaving their homeland induce a disruption of economic ties and social order. In the local context, migration is a coping strategy, a mechanism to cope with environmental disasters such as floods. In reality, however, migration as a temporary coping strategy cannot be termed ‘coping strategy’ for it may not improve the resilience of households to deal with future flood events. Migration in the context of extreme events such as flooding is mostly domestic and such pattern of migration comes with peculiar challenges, for instance, immediate, knee-jerk reaction to a flood event is not likely to enable households to adapt in the long term and increase their resilience to future shocks. This is especially so if migrants face resource scarcity at their receiving locations, such receiving communities will likely have few resources and potential to adequately meet the needs of the migrants, this might lead to conflict with the existing population, lowers income and/or loss of rights during the process of resettlement in a new area. Geographical proximity may also mean that the receiving location may be suffering exactly the same challenges and may have little or no help to offer and may even in be overburdened by the influx of migrants. In addition, with a large proportion of rural households already landless in the study area, flood events are particularly devastating for the






rural population, in particular for farmers who invariably have to move into their last parcels of lands which are often marginal land. There are those who have nowhere to move to and have no choice, but to move into informal and shanty towns without proper land rights. These shanty towns and settlements are often located along marginal areas and further exacerbate the flood issue. The poor land rights system can be said to increase the vulnerability of the farmers to disaster

### **8.6: Assessing Farmer's Perception of Flood events**

Hamilton-Webb et al. (2017) notes that farmers experience about flooding is not homogeneous but situational depending on location and local environment, hence they perceive flood and its impacts in different ways. Comprehending public risk perception and its determining factors are vital for improving risk communications and effective mitigation policies. Knowledge about risk perceptions of natural hazards will invariably provide critical information about people's willingness to take precautionary measures, and the public support for governments' risk reduction policies. According to Deressa et al. (2011) perceiving climate variability is the first step in the process of adapting agriculture to climate change, while Maddison, (2007) states that perception and adaptation strategies are the two key components of the adaptation process, in addition, Grothmann and Patt (2005) argues that perceptions are just as important perhaps more important than physical and economic factors in determining adaptive capacity.

Understanding public perception and opinion concerning flood in the Niger Delta remain a largely unexplored area. This section addresses how smallholder farmers perceive flood-related risks and damage, by determining how floods are ingrained in their daily lives. It draws on a qualitative assessment of farmers' attitudinal and behavioral response to flooding, considering the level of experience of flooding. The study makes an important contribution to the under-researched area of risk experience and risk response in the context of farmers and flooding in the Niger Delta. This section examines the following themes.

-  Perceived climatic variation
-  Perceived causative factors of flooding
-  Perceived severity of flood events vis a vis other problems in the area

**Perceived Climatic Variation:** Several studies have been undertaken by different scholars to understand farmers' awareness and cognizance of changing climate. There have been mixed feedback in terms of the farmers' awareness of climate change. The easiest way of assessing awareness of climate change was to inquire from respondents whether they have observed a change in the rainfall in recent times. Farmers' perceptions and comprehension of weather patterns play significant roles in their livelihoods adjustments and reactions to weather disasters. 21.5% of the respondents stated they had no idea if rainfall had increased or not in the area, 7% of the respondents stated that they did not observe any change in weather. On the other hand, 71.5% of the farmers perceived significant change in rainfall. However, statistical analysis of rainfall records in the area does not fully support this assertion. Such wrong perceptions among the people and even authorities have led to misdiagnosis or wrong identification of the causative factors of floods in the area.

**Perceived Causative Factors:** The perception of the causative factor of flood is an essential information, because, if there are wrong perceptions of the cause of flood events, people are bound to continue the adopting the wrong strategy in handling the flood issues. In terms of the causative factors of flood, results indicate fairly wide variations in the respondents' perception of the cause of increased flooding in the area; While none of the respondents linked increased flooding to the morphometry, only 8% of the respondent related increased flooding to changes in land use, 18% of the respondents perceived inadequate drainage as the major cause of flooding, followed by river overflow (24%). An overwhelming 83% of the respondents attributed increased flood events to heavy or continuous rain, while a significant proportion (47%) regarded increased flood events as divine disaster and therefore unavoidable. The results clearly imply a lack of agreement between the perceived causes of flood and the actual causes of flooding in the area. The lack of priority given to the roles played by land use and morphometry as causative factors means that individuals will continue to settle on lowland (which are mostly high risk zone) and land will continue to be used in a haphazard and unplanned manner, resulting in higher flood vulnerability for the inhabitants of the area.

**Perceived Severity of Flood in Comparison with Other Challenges:** In terms of the severity of the flood problem, it may be misleading to assume that when people are exposed to a certain hazard, that they will perceive it as an immediate risk; i.e., as something that they could be exposed to and that could result in harmful impacts to the things they value (Armaş, 2006). For

instance, Davis and Hall (1999) showed that residents of communities exposed to different natural hazards did not perceive such hazards as risky, dangerous as expected. Farmers differ in the extent to which they accept and estimate risk. Their decisions are predicated on different factors. Some farmers are willing to accept more risk than others. Farmers' behaviors concerning risk are often based on their personal feelings rather than information presented to them to help them make more rational decisions. In the study area, apart from floods, smallholder farmers experience other stressors such as exponential population growth, which drives land fragmentation, environmental degradation, pollution, erosion etc. Different households reported that they were severely affected by different shocks.

Based on the interview with the agricultural officials, five major problems were listed and the respondents were asked to rank the problem that affects their occupation the most, this was done to find out the level of importance attached to flooding and other challenges. The severity of the flood in the context of other challenges was assessed using the Problem Confrontation Index (PCI). The PCI has been used by several studies to assess the public perception of environmental challenges (Alam and Rashid 2011; Hossain and Miah 2011; K. Z. Hossain 2011). In order to determine the PCI of the challenges, a Likert scale was first developed, where the challenges were listed and then the respondents were asked to rate the severity of the problem based on their perception. Based on the ratings of the problems, the PCI was computed using the formula below.

$$PCI = P_n \times 0 + P_1 \times 1 + P_m \times 2 + P_h \times 3$$

Where:

PCI = Problem Confrontation Index;

$P_n$  = Number of respondents who graded problem as not significant

$P_1$  = Number of respondents who graded the problem of low significance

$P_m$  = Number of respondents who graded the problem as moderate significance

$P_h$  = Number of respondents who graded the constraint as high significance

Table 32 and 33 presents the results of the survey.

Table 33: Environmental issues and significance attached

	Not significant	Low significance	Moderate significance	Highly significant
Flooding	48	111	126	115
Oil Pollution	74	105	122	99
Conflict	70	87	126	117
Erosion	59	104	120	117
Soil fertility	83	92	122	103

Table 34: Problem Confrontation Index

Problems	PCI value
Erosion	695
Attacks and conflicts	690
Flood	756
Soil infertility	690
Oil pollution	646

Table 33 shows that flooding had the highest PCI, although the results also showed that the PCI difference between flooding and other challenges was not significant. This may be due to the fact that over time, farmers have developed adaptive strategies that permitted them to deal with flood and interview revealed that flood is seen as a known threat, in that the farmers can predict the period of occurrence, unlike attacks and conflicts, which are highly unpredictable and are often spontaneous. Some cultural beliefs and fatalistic attitudes contribute to the problem perception pattern. The interview revealed that is a high degree of fatalism associated with flood as most of the respondents considered natural disasters such as floods as acts of God and as such there was little or nothing they could do to counter to reduce flood occurrence. Further, interviews shows that some of the farmers perceived more immediate and palpable problems such as erosion and oil pollution almost as worrisome as floods which are mostly seasonal.

## Chapter 9: Conclusion and Recommendations

**Synthesis of Major Findings** This thesis addressed several cross-cutting themes and the findings are summarized into the following aspects.

- **Climate Change Debate:** The results of the trend analysis reveal that although rainfall shows an increasing trend in the study area, however, such changes are not significant and as such, it can be concluded that although increased flooding may be related to heavy rainfall, however, rainfall is chiefly not the main cause of increased flooding in the area.
- **Causative Factors of Flooding:** The Orashi River Basin has undergone substantial change in land use over the last 40 years. Forest to agricultural areas is the dominant land use change type. This indicates sustained deforestation and agricultural expansion in the basin. Haphazard and unrestricted land cover conversion without consideration of repercussions alters the natural hydrologic systems of the basin. The Orashi basin is characterized by a natural drainage system and developed forest systems, but significant part of the basin has been taken over by agriculture and poorly planned urban development hence rendering the natural drainage system less effective.
- Using the HEC-HMS tool, the Curve Number (CN) map for different years was developed and used to relate the detected land cover changes to runoff and flood risk in the area. The curve number maps indicated that land cover changes affected the hydrological response of the basin leading to increased peak discharge and runoff volume in the basin.
- **Morphometric Flood Risk:** One of the objectives of this research was the integration of morphometric attributes derived from DEM in a GIS environment to detect areas associated with floods. The weighted overlay analysis method showed a simple and cost effective way of using GIS for creating flood risk map from the available morphometric parameters. The GIS based flood risk maps gave a good visual impression about flood risk in the area, and these maps will be very useful in disaster planning and designing of early warning systems.
- **Flood Inundation:** Using the HEC-RAS tool, flood inundation level for two separate flood events (2012 and 2015) was simulated. The flood depth and inundation area were also noted to increase with increase in the rainfall amounts indicating that rainfall plays significant role in flood inundation during large storm events.
- **Adaptive capacity and coping strategies:** This dissertation employed the adaptive capacity index for use in the assessment of the ability of smallholder farmers in the Orashi basin to adapt

to flood. It is expected that the result will pave way for the design and execution of appropriate policy interventions, which is urgently needed to secure the currently endangered livelihoods of many households in the area. The household adaptive capacity index used in this thesis facilitates the proper targeting of the most pressing cases of households with the appropriate set of strategies aimed at raising adaptive capacity. Results show that the major factor restraining farmers' adaptive capacity includes inadequate access to credit and the huge proportion of economically inactive portion of households which greatly militates against the overall adaptive capacity of the farmers. The parlous state of infrastructure isolates and marginalizes some of the communities, since they depend on external sources for sales of their agricultural product.

- **Sustainability of coping strategies:** the research shows that households have tried to implement strategies to cope with flood events; however resource and opportunities are scarce, unstable, and only allow short-term subsistence. Indeed, as a result of limited resource, most households can hardly deal with and recover from flood impacts in a sustainable manner. Existing coping strategies are often not enough to avoid loss and damage and often have negative impacts on livelihood sustainability in the longer term (referred to as 'erosive coping'). A case in point is the uncontrolled use of and dependence on forests which invariably increases environmental degradation, thereby threatening sustainability and potentially intensifying poverty in the area. The continued dependence on charcoal and firewood accelerates forest degradation in the area, rendering soils bare and thus, leads to soil erosion, which further complicates the issue of flood. Most of the households are either not concerned or not well aware of the tradeoffs between short-run and long-run survival, as their immediate focus is on survival of immediate threats and not on the long term impact of their responses to flood disasters. As a result of the unsustainable and inefficient resource utilization, local communities are being cocooned in a "poverty trap" where they are unable to take steps to cope with the flood hazard. Essentially, coping capacity is greatly undermined by two mutually enforcing factors of ineffective resource use and poverty.
- **Poverty:** Natural disasters such as floods entrench the poverty that already exists among smallholder farmers and draw more of them into poverty as their assets disappears, together with their income generating capacity. The risk of impoverishment is linked to lack access to the markets, capital, assets and insurance mechanisms that can help people to cope and to rebuild. The lack of productive resources not only traps farmers in poverty, it also increases

their vulnerability to flood – for example, smallholders who are heavily affected by flood face more variable harvests and greater risk of hunger and destitution than farmers who not seriously affected by floods. Further, poverty can be a driver of, or an obstacle to migration. The search for greener pasture pushes people to migrate, but poor people often do not have the wherewithal to do so. Poverty is also another precipitant of land degradation as it reduces the options for improving land use, and aggravates environmental degradation. The need to increase cropland leads to movement to marginal land and by extension unsustainable agricultural practices.

- **Population Boom in the Area:** Another interesting find touch on an impending population explosion in the study area. This boom in population does not only threaten the carrying capacity of an already fragile ecosystem, but it poses enormous challenges for both environmental and natural resource managers and policy makers in the region if not confronted with the urgency it deserves.
- **Migration:** The findings from the research suggest that migration does not serve as an effective coping strategy for households. The financially well-off do not need to migrate permanently in order to adapt to the negative effects of flooding, because their livelihoods and food security status are already fairly resilient. Even when they move, they have the resources to move comfortably and often engaged in a planned migration. In stark contrast, the poorest and most insecure people lack the resource to migrate permanently and even when they migrate temporarily, they are faced with a high level of socioeconomic discrimination; hence, they are trapped in a vicious circle of poverty, both home and abroad.
- Summarily, in terms of the causative factor of flooding in the study area, it can be concluded that the source of flood risk in the study area was not just the high rainfall amount in the area. The role of agricultural expansion and setting up of settlements on river banks and flood plains and their consequence in causing floods in the study area cannot be overemphasized.
- In terms of vulnerability, this thesis proves conclusively that it's not climatic vulnerability that is increasing, but geographic vulnerability, worsened by economic vulnerability. These conclusions also correspond with that of (Mavhura, 2019) who concluded that vulnerability to flooding in Muzarabani district, Zimbabwe is not solely a function of changes in the rainfall pattern to which communities respond. Rather, it is a result of multiple interdependent physical and poor socio-economic variables involving non-linear relationships.
- Overall, the study showed that there are clear links between flood and agricultural-based livelihoods, poverty and migration. The synopsis of these variables leads us to the following

conclusion: Instead of climatic and physical factors, it is social inequality and poverty in the region as well as structural economic weakness and differences between various groups that mainly drives vulnerability in the study area.

### **Recommendations**

The management of flood risk is moving towards new ideas such as flood detention zones. A new paradigm and orientation to flood management is advocated which consists of giving more room to water by restoring floodplains or creating flood retention areas. This strategy, as it were, is not capital intensive and can be easily achieved if the political will is present.

In many parts of the rural Niger Delta, local governments are often unable to provide the services needed to handle flood disasters, because of low central government public investment in rural area. Rural authorities often fail to generate sufficient revenue at the local level. In view of this, a well-grounded integration of local people in the discussion of flood risk management strategies in national planning is strongly advocated.

It is recommended that access to credit to smallholder farmer should be enhanced by establishing small scale financial institutions dedicated solely to agriculture. It must however be mentioned that such institutions already exist, however the problem is that of penetration to the rural areas. It is recommended that such institutions should be made to be more mobile.

Land rights and use policies must reflect the fact that a large and as yet uncounted number of rural households have weak entitlements over their homestead land. There should be an adequate enforcement of land use regulations. Efficient land use planning serves as a mechanism for protection against forced evictions and can also increase tenure security for poor and vulnerable farmers. Farmers should be involved in the knowledge management process as knowledge generated in a participatory manner has a greater likelihood of being accepted and acted upon by the farmers. The participatory approach will also enable the integration of traditional knowledge of farmers.

The evidence from this study indicates that erosive coping measures require policy interventions to enable households to develop the capacity to efficiently utilize resources available locally. To make the coping strategies more sustainable there is a need of some



measures such as provision of modern storage facilities such as silos at subsidized rates to the farmers. The role of education and enlightenment in terms of sustainability should not be underrated. Most of the farmers in deciding their response to flooding often do not take sustainability into account and this often results in resource misuse.

River discharge data in the basin are limited and the accuracy of the data is poor. The installation of more river gauging stations in the basin and updating of the rating curve will improve data availability and quality. As all currently available weather stations are found only in the vicinity of the Orashi basin, it is mandatory to install additional weather and gauge station inside the basin for better estimation of areal rainfall and estimation of hydrological response in the area. This will help to improve the flood risk assessment in the future.

## Appendices

### Appendix 1

#### Questionnaire

Socioeconomic characteristics	Options	Please tick as appropriate
Gender	Male	<input type="checkbox"/>
	Female	<input type="checkbox"/>
Marital status	Single	<input type="checkbox"/>
	Married	<input type="checkbox"/>
	Divorced	<input type="checkbox"/>
	Widowed	<input type="checkbox"/>
Age	<20-30	<input type="checkbox"/>
	31-40	<input type="checkbox"/>
	41-50	<input type="checkbox"/>
	51-60	<input type="checkbox"/>
	>60	<input type="checkbox"/>
Educational status	None	<input type="checkbox"/>
	Primary	<input type="checkbox"/>
	Secondary	<input type="checkbox"/>
	Tertiary	<input type="checkbox"/>
Size of household	1	<input type="checkbox"/>
	2-4	<input type="checkbox"/>
	5-7	<input type="checkbox"/>
	8-10	<input type="checkbox"/>
	>10	<input type="checkbox"/>

Attributes		
Literacy level	Are you literate in any language?	Yes <input type="checkbox"/> No <input type="checkbox"/>
Income	Please give an estimate of average monthly income in your household	Very Low ( $\leq$ \$30) <input type="checkbox"/>
		Low (\$31-\$40) <input type="checkbox"/>
		Medium (\$41-\$50) <input type="checkbox"/>
		High (\$51-\$60) <input type="checkbox"/>
		Very high ( $>$ \$60) <input type="checkbox"/>
Income generating asset	Please mention the number of income generating asset you own	
Access to credit	Do you have access to credit	Yes <input type="checkbox"/> No <input type="checkbox"/>

Alternative source of income	Apart from agriculture, do any member of your family have alternative source of income	Yes <input type="checkbox"/>	No <input type="checkbox"/>
Access to technology	Please list the number of mechanized implements you own		
Social capital	Are you a member of any agricultural cooperative?	Yes <input type="checkbox"/>	No <input type="checkbox"/>
Access to information	Mention your sources of information		
Infrastructure	Mention infrastructures present in your area		
Dependence ratio	How many adult members of your household are economically active?		

Coping strategies	How do you cope with floods events? (You are allowed to mention more than one strategy)	
-------------------	---	--

Please narrate your challenges and experience during flood events, especially in relation to your livelihood

In your opinion, describe the areas in which flood has affected you and your community negatively

How long did it take you to fully recover from the flood events?
Have you observed any changes in average weather pattern?
What attracted you to this area?
Why are you still living in this area even though you are affected by flood?
Did you plan your movement or was it sudden?
How did you acquire your land?

## Appendix 2

### Land use conversion

Classes	1986-2003 %age)	2003-2016(%age)
Agricultural Area to Agricultural Area	2.2	5.74
Agricultural Area to Built-up Area	0.9	2.55
Agricultural Area to Forest	3.1	0.71
Agricultural Area to Swamp	1.6	0.51
Agricultural Area to Water	0.002	0.00
Built up Area to Agricultural Areas	0.1	0.72
Built up Area to Built-up Area	0.4	2.53
Built up Area to Forest	0.03	0.02
Built up Area to Swamp	0.058	0.04
Built up Area to Water	0.015	0.01
Forest to Agricultural Areas	5.5	24.97
Forest to built-up Area	0.5	1.36
Forest to Forest	55.72	31.84
Forest to Swamp	3.57	4.09
Forest to Water	0.0021	0.05
Swamp to Agricultural Areas	1.7	1.07
Swamp to built-up Area	1.4	0.52
Swamp to Forest	3.4	0.18
Swamp to Swamp	16.1	19.16
Swamp to Water	1.2	0.40
Water to Agricultural Areas	0.0005	0.05
Water to Built-up Area	0.0043	0.01
Water to Forest	0.0005	0.00
Water to Swamp Forest	0.06	0.72
Water to Water	2.31	2.77

**Appendix 3****Thiessen weight for each sub-basin**

Basin	Weight in (Percentage)
W1060	16
W1080	11
W1090	11
W1140	25
W1150	7
W1170	12
W1200	17

**Appendix 4****Basin land use Area (km<sup>2</sup>)**

Classes	1986	2003	2016
Built-up Areas	15.7	83.2	175.6
Agricultural Areas	195.6	239.1	820.3
Forest	1643.6	1566.7	824.9
Swamp	599	536.4	617.8
Water	59.8	89.1	81.5

## Appendix 5

### Sub-basin land use Area (km<sup>2</sup>)

2016	W1060	W1080	W1090	W1140	W1150	W1170	W1200
Agricultural Areas	77.14	58.28	72.97	20.32	8.87	3.34	3.41
Built Up	19.24	22.25	11.87	3.00	0.48	0.55	0.32
Forest Areas	3.35	18.90	13.21	75.71	48.84	40.54	0.14
Swamp	0.24	0.52	1.82	0.76	36.43	51.50	82.29
Water	0.02	0.04	0.13	0.21	5.39	4.07	13.84

2003	W1060	W1080	W1090	W1140	W1150	W1170	W1200
Agricultural Areas	22.52	25.22	10.74	4.79	5.29	1.62	2.40
Builtup Area	10.18	9.32	5.45	0.49	0.40	0.20	0.15
Forest Area	64.05	63.50	81.18	93.13	53.05	56.80	20.94
Swamp	3.18	1.81	2.08	1.08	35.26	38.00	61.10
Water	0.07	0.16	0.56	0.51	5.99	3.38	15.41

1986	W1060	W1080	W1090	W1140	W1150	W1170	W1200
Agricultural Area	11.34	15.61	8.61	5.11	5.76	5.67	7.31
Built Up Area	1.12	1.73	1.42	0.33	0.16	0.12	0.35
Forest	70.77	67.47	80.84	92.75	62.49	48.41	22.98
Swamp	16.77	15.17	9.11	1.74	26.85	45.04	57.63
Water	0.00	0.02	0.03	0.06	4.74	0.76	11.72

## Appendix 6

### Weighted Overlay Analysis Table

Raster	% Influence	Field	Scale value
DEM	20	Value	
		1	4
		2	3
		3	2
		4	1
Slope	20	Value	
		1	4
		2	3
		3	2
		4	1
Drainage Density	20	Value	
		1	1
		2	2
		3	3
		4	4
Stream Power index	20	Value	
		1	1
		2	2
		3	3
		4	4
Topographic wetness Index	20	Value	
		1	1
		2	2
		3	3
		4	4



## Appendix 7

### Precipitation amount 2012

Time stamp	W1060	W1080	W1090	W1140	W1150	W1170	W1200
28Sep2012, 00:00	1.88	4.74	4.74	0.00	0.00	0.00	0.00
28Sep2012, 03:00	1.19	2.86	2.86	0.80	0.66	0.00	0.00
28Sep2012, 06:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28Sep2012, 09:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28Sep2012, 12:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28Sep2012, 15:00	2.93	0.41	0.00	15.01	0.00	0.41	0.41
28Sep2012, 18:00	0.00	0.00	0.00	0.98	0.65	1.15	0.00
28Sep2012, 21:00	0.00	0.00	0.00	0.00	0.65	0.00	0.00
29Sep2012, 00:00	0.00	0.65	0.65	0.00	0.85	2.34	2.80
29Sep2012, 03:00	0.00	1.37	1.37	2.66	2.93	5.61	6.63
29Sep2012, 06:00	0.45	0.23	0.23	0.52	0.41	1.13	3.13
29Sep2012, 09:00	6.20	13.39	13.39	0.00	0.00	0.00	0.00
29Sep2012, 12:00	2.87	5.87	5.87	8.92	15.01	14.75	7.83
29Sep2012, 15:00	0.94	3.05	3.05	3.97	4.96	5.76	4.37
29Sep2012, 18:00	0.94	3.05	3.05	3.97	4.96	5.76	4.37
29Sep2012, 21:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30Sep2012, 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30Sep2012, 03:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30Sep2012, 06:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30Sep2012, 09:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30Sep2012, 12:00	0.42	1.39	1.39	0.00	0.00	0.00	0.00
30Sep2012, 15:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30Sep2012, 18:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30Sep2012, 21:00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
01Oct2012, 00:00	0.00	0.00	0.00	0.00	0.00	0.52	0.00
01Oct2012, 03:00	0.00	0.00	0.00	0.00	0.00	0.00	0.09
01Oct2012, 06:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
01Oct2012, 09:00	0.00	0.00	0.00	0.00	0.00	0.00	0.92
01Oct2012, 12:00	0.00	0.00	0.00	2.28	0.30	2.12	2.24
01Oct2012, 15:00	0.00	0.35	0.35	0.07	0.00	0.50	1.01
01Oct2012, 18:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
01Oct2012, 21:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
02Oct2012, 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
02Oct2012, 03:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
02Oct2012, 06:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
02Oct2012, 09:00	0.00	0.26	0.26	0.00	0.00	0.00	0.00
02Oct2012, 12:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
02Oct2012, 15:00	0.46	0.00	0.00	0.00	0.00	0.00	0.00



## Appendix 8

### Precipitation Amount 2015

Time stamp	W1060	W1080	W1090	W1140	W1150	W1170	W1200
24Oct2015, 21:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25Oct2015, 00:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25Oct2015, 03:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25Oct2015, 06:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25Oct2015, 09:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25Oct2015, 12:00	0.000	0.000	0.000	0.204	0.467	0.000	0.000
25Oct2015, 15:00	0.000	0.000	0.000	2.793	2.451	0.000	0.000
25Oct2015, 18:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25Oct2015, 21:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26Oct2015, 00:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26Oct2015, 03:00	0.000	0.000	0.000	0.000	0.524	0.815	0.000
26Oct2015, 06:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26Oct2015, 09:00	0.000	0.000	0.000	0.000	0.000	0.000	0.183
26Oct2015, 12:00	0.397	0.000	0.000	0.000	0.000	0.000	0.000
26Oct2015, 15:00	0.000	0.000	0.000	0.678	0.000	0.000	0.000
26Oct2015, 18:00	1.259	0.305	0.305	0.000	0.000	0.000	0.000
26Oct2015, 21:00	1.804	0.395	0.395	0.237	0.581	0.379	0.172
27Oct2015, 00:00	6.670	8.223	8.223	2.431	2.303	1.021	0.596
27Oct2015, 03:00	0.964	1.141	1.141	0.000	0.000	0.000	3.177
27Oct2015, 06:00	0.000	1.050	1.050	0.000	0.000	0.000	0.000
27Oct2015, 09:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27Oct2015, 12:00	0.000	0.203	0.203	0.000	0.000	0.631	2.466
27Oct2015, 15:00	1.894	1.378	1.378	6.321	4.765	4.648	3.188
27Oct2015, 18:00	0.613	0.418	0.418	2.171	1.653	0.746	0.000
27Oct2015, 21:00	0.998	0.000	0.000	0.000	0.000	0.000	0.000
28Oct2015, 00:00	0.000	0.000	0.000	0.204	0.308	0.367	0.206
28Oct2015, 03:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28Oct2015, 06:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28Oct2015, 09:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28Oct2015, 12:00	0.000	0.328	0.328	0.000	0.000	0.000	0.000
28Oct2015, 15:00	0.000	0.000	0.000	2.861	8.310	0.000	0.000
28Oct2015, 18:00	3.653	3.072	3.072	5.382	3.044	0.000	0.000
28Oct2015, 21:00	0.476	0.000	0.000	0.000	0.000	0.000	0.161
29Oct2015, 00:00	0.000	0.000	0.000	0.000	0.467	0.184	0.000
29Oct2015, 03:00	0.000	0.000	0.000	0.000	0.433	0.826	0.172
29Oct2015, 06:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29Oct2015, 09:00	0.000	0.463	0.463	1.538	1.072	2.594	1.995
29Oct2015, 12:00	1.509	6.043	6.043	1.504	1.721	1.423	1.353

29Oct2015, 15:00	3.176	1.502	1.502	0.882	5.061	2.525	0.000
29Oct2015, 18:00	0.976	0.678	0.678	1.402	2.816	1.618	1.181
29Oct2015, 21:00	1.883	1.017	1.017	0.317	0.376	0.218	0.000

## Appendix 9

### Basin Characteristics

Name	BasinSlope	LossMet	TransMet	InitAbst	BasinCN	LagMethod	BasinLag	Area_HMS
W1060	2.299	SCS	SCS	0.148	76.2	CNLag	11.31	164.84
W1080	2.496	SCS	SCS	0.289	76.3	CNLag	10.30	66.80
W1090	3.254	SCS	SCS	0.136	78.9	CNLag	11.51	128.74
W1140	3.077	SCS	SCS	0.467	77.7	CNLag	7.89	116.59
W1150	3.442	SCS	SCS	0.357	86.8	CNLag	10.14	284.04
W1170	3.362	SCS	SCS	0.334	86.6	CNLag	10.87	137.51
W1200	4.303	SCS	SCS	0.145	94.7	CNLag	4.66	72.66

**Appendix 10****Magnitude Of infiltration**

Sub-basins	1986	2003	2015
W1060	8363.1	8487.2	5282.1
W1080	3063.2	3645.9	3123.9
W1090	6344.2	6403.9	3967
W1140	6717.5	6718	6586.5
W1150	14969.6	14583.3	14773.7
W1170	6852.3	6974.8	6991.9
W1200	2490.1	2260.6	2499

## Annex 11

### Peak discharge in m<sup>3</sup>/s for different flood events

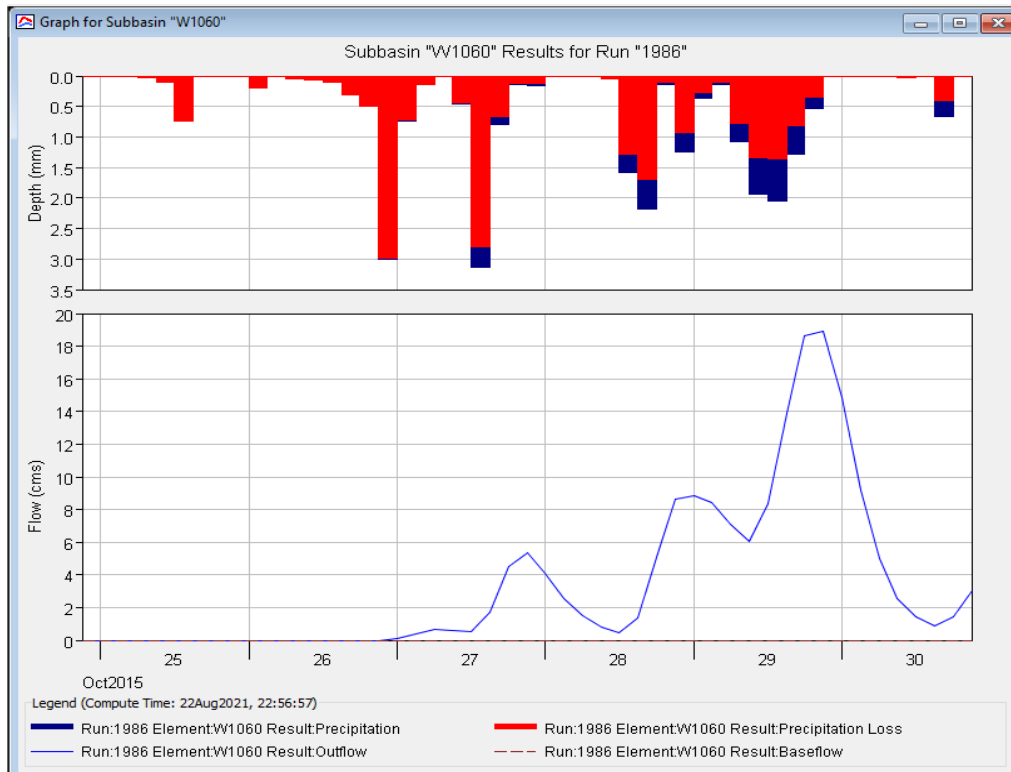
Sub-basins	1986	2003	2015
W1060	18.9	17.8	44.4
W1080	6.3	5.8	11.3
W1090	16.2	15.7	34.8
W1140	7.4	7.4	9.2
W1150	28.2	32.1	30.2
W1170	15.9	14.8	14.6
W1200	20.4	22.1	20.3

### Peak discharge for 2012 flood event (m<sup>3</sup>/s)

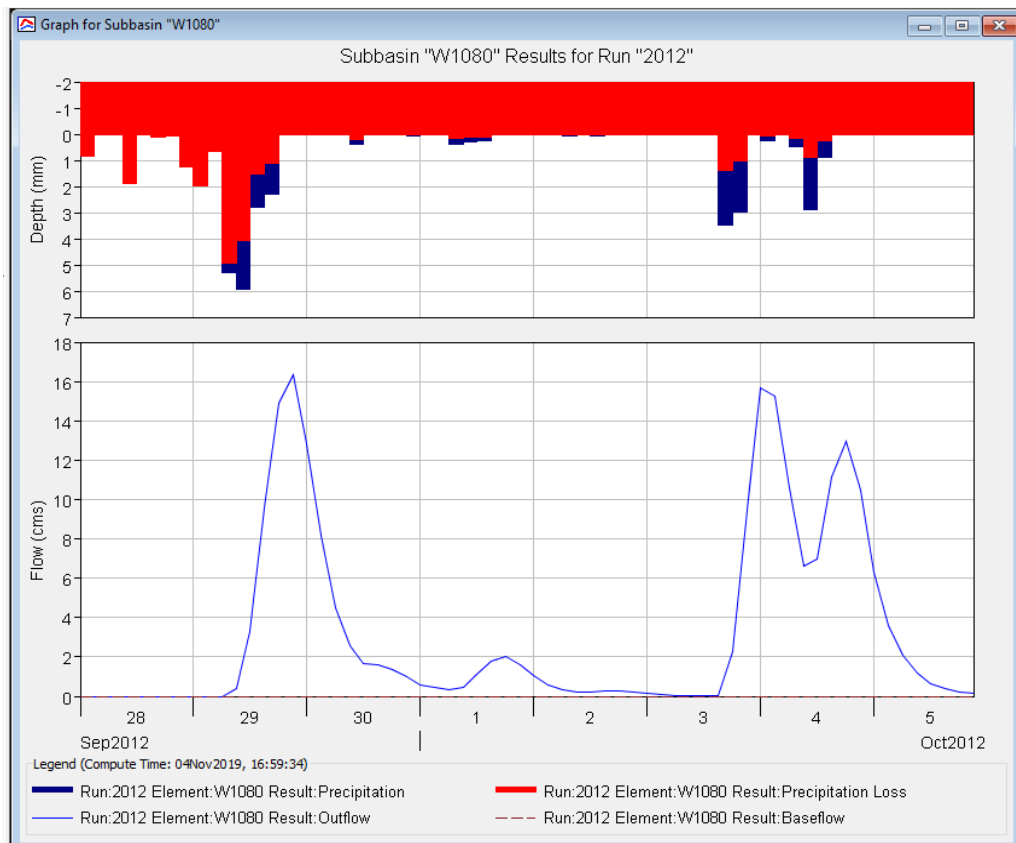
Basin	Time	Volume
W1060	29Sep2012, 18:00	85.5
W1080	29Sep2012, 21:00	16.3
W1090	29Sep2012, 18:00	67.3
W1140	04Oct2012, 00:00	16.5
W1150	04Oct2012, 03:00	42.9
W1170	04Oct2012, 06:00	19.4
W1200	29Sep2012, 18:00	36.8

## Appendix 12

### Samples of HEC-HMS derived hydrographs







## Appendix 13

### List of flood locations

Location	Latitude	Longitude
Oruma	4.917294	6.418417
Akinima	5.085357	6.466333
Mbiama	5.060586	6.453208
Joinkrama	5.133333	6.466667
Ogoda	5.115787	6.575024
Akabuka	5.233497	6.643696
Ubeta	5.16579	6.58702
Okparaki	4.9848184	6.4500207
Opuogbogolo	4.905371	6.568967
Olokuma	4.989534	6.558964
Ombor	5.19803	6.515888
Ebriba	5.144166	6.540449
Ubie	5.148195	6.579223
Ubio	5.173692	6.618362
Ubrama	5.198217	6.617267
Odireke	5.184207	6.549697
Abua Odua	4.829765	6.567391
ikodi	4.990204	6.462086
Okobe	5.06227	6.54164
Odioku	5.120748	6.598483
Ochiba	4.999085	6.587158
Oduaha	5.04056	6.628
Apiboko	4.45227	6.71225
Offorboko	4.43611	6.662314
Ababoko	4.565709	6.711243
Egbeboko	4.497405	6.656205
Roberkiri	4.546172	6.610367
Soku	4.67837	6.6819
Abelkiri	4.55623	6.60206
Apokobem	4.74745	6.65454
Abukiri	4.55623	6.60206
Akokogiri	4.74125	6.66726
Awotarighakiri	4.73891	6.54093
Benkiri	4.68424	6.56053
Ebocha	5.462096	6.687904
Abacheke	5.50372	6.72952
Mgbara	5.50181	6.77462
Mkpataku	5.59605	6.77035
Nwari	5.58003	6.77127

Obiakpu	5.50663	6.75645
Obofia	5.53373	6.77876
Obufie	5.52109	6.75074
Ubomukwu	5.57162	6.75828
Ukwugba	5.55373	6.75477
Abaezi	5.49222	6.73707
Afia-Meeting	5.50388	6.62098
Aga	5.47507	6.73485
Awara	5.3504	6.76755
Ebogoro	5.3494	6.67717
Egbada	5.33157	6.70269
Egwe-Ikai	5.53357	6.62074
Ayon	4.86027	6.45104
Akiogbologbo	5.00967	6.42855
Ikodu 2	4.98953	6.47062
Kunusha	4.97679	6.46983
Obode	5.00979	6.52626
Ogolokياما	4.97633	6.49885
Okarki	4.98334	6.42877
Udodo	4.97633	6.49885
Abessa	4.95817	6.5372
Adada	4.79951	6.51506
Ohoba	5.40857	6.87536
Ukwugba	5.55373	6.75477
Ikiri	5.27159	6.73214
Etekuru	5.47534	6.7439
Ekeugba	5.49864	6.75399
Opete	5.31707	6.82371
Ubumimi	5.27028	6.73558
Omoku	5.34388	6.65684
Abaezi	5.49222	6.73707
Ede	5.2748	6.64487
Egbada	5.33157	6.70269
Egita	5.27426	6.68129
Ekpeazizi	5.42368	6.7306
Erema	5.22051	6.7064
Kpokpopi	5.41341	6.65442
Kpigeni	5.29902	6.61921
Kreigam	5.29902	6.61921
Mbede	5.47148	6.72612
Oboh	5.38523	6.68685
Onita Creek	5.36963	6.61787
Onita-Ederi	5.36306	6.61741
Ukwugba farm	5.46028	6.79565

Akaramini	5.11557	6.48689
Betaland	5.1687	6.48035
Isua	5.16359	6.49625
Isusu	5.15803	6.4924
Abarigbo	5.15442	6.63619
Ekpena	5.08213	6.66803
Emezi	5.07173	6.52137
Ibewa	5.23472	6.6793
Abaji Okolo	4.36558	6.71475
Abissa	4.39646	6.76591
Agbakiri	4.46035	6.69289
Ekelemo	4.59913	6.75608
Old Sangama	4.640198	6.591957
Amoroto	4.72936	6.45579
Emago	4.71801	6.46714
Idoke	5.02667	6.66641
Ihuama	4.97659	6.67506

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