

**THE ROLE OF LAND USE AND LAND COVER CHANGES
AND GIS IN FLOOD RISK MAPPING IN KILIFI COUNTY,
KENYA**

MAINA PAUL MWANGI (B-EPM)

N50/CTY/PT/22693/2012

**A Thesis Submitted in Partial Fulfillment of the Requirements for
the Award of the Degree of Master of Environmental Studies
(Community Development) in the School of Environmental Studies
of Kenyatta University**

MAY, 2016

DECLARATION

This thesis is my original work and has not been submitted to any other university for any other award or degree.

Signature..... Date.....

Maina Paul Mwangi (N50/CTY/PT/22693/2012)

Department of Environmental Studies and Community Development

SUPERVISORS

We confirm that the work reported on this thesis was carried out by the candidate under our supervision:

Signature..... Date.....

Dr. Samuel Ochola

Department of Environmental Studies and Community Development

Signature..... Date.....

Prof Simon Onywere

Department of Environmental Planning and Management

DEDICATION

To my late brother Sammy who would have loved to be with me and to cheer me on but the harsh realities of life could not allow.

To my parents and siblings who were always there to encourage and support me. I couldn't have come this far without your prayers and material support.

ACKNOWLEDGEMENT

My gratitude and thanks go to the Department of Environmental Studies and Community Development of Kenyatta University and to my supervisors; Dr. Samuel Ochola and Prof. Simon Onywere for their assistance and unwavering support. Without their corrections, additions, insights and advice my work would not be complete. They guided this study and helped shape its direction.

I would like to express my gratitude to the UPGro Catalyst Program research team led by Prof. Joy Obando of the Department of Geography for funding and giving guidance to this research. I would also like to appreciate all the other UPGro team members for their input into my research.

I also acknowledge the people of Kilifi County where I did the research, who were supportive, hospitable and quite informative and responded to my questions and gave me directions during my data collection.

I would also like to thank the employees of the Regional Center for Mapping of Resources for Development (RCMRD) and in particular Miss Rose Waswa who was quite supportive with GIS resources and data.

I say thank you to my parents, brothers and sisters for material support, prayers and encouragement. You are a great people.

I would forever have gratitude to my Almighty God for His provision, strength, wisdom and protection.

TABLE OF CONTENTS

DECLARATION	ii
DEDICATION	iii
ACKNOWLEDGEMENT.....	iv
TABLE OF CONTENTS	v
LIST OF TABLES	viii
LIST OF FIGURES	ix
LIST OF PLATES	x
ACRONYMS AND ABBREVIATIONS.....	xi
ABSTRACT.....	xii
CHAPTER ONE: INTRODUCTION	1
1.1 Background to the Study.....	1
1.2 Statement of the Problem.....	5
1.3 Research Questions.....	7
1.4 Objectives of the Study	7
1.5 Research Assumptions.....	8
1.6 Justification of the Study	8
1.7 Significance of the Study	9
1.8 Scope and Limitations of the Study	10
1.9 Operational Definitions.....	11
CHAPTER TWO: LITERATURE REVIEW	12
2.1 Introduction.....	12
2.2 Land Use and Land Cover Change	12
2.2 Change Detection.....	14
2.3 Relationship between LULCC, Flooding, Runoff and Infiltration Capacities.....	17
2.4 GIS- Based Computation of Flood Risk Maps	19
2.5 Disaster Management Policy in Kenya.....	23
2.6 Conclusion	24
CHAPTER THREE: RESEARCH DESIGN AND METHODOLOGY.....	25
3.1 Introduction.....	25
3.2 Background to the Study Area.....	25
3.2.1 Physical and Topographic Features	25

3.2.2 Climate.....	28
3.2.3 Drainage.....	29
3.2.4 Geology and Soils.....	30
3.2.5 Vegetation.....	31
3.2.6 Infrastructure.....	31
3.2.7 Population Profile and Settlement Patterns.....	32
3.2.8 Social Economic Characteristics.....	34
3.3 Research Design and Methodology	35
3.4 Types and Sources of Data	36
3.4.1 Primary Data.....	36
3.4.2 Secondary Data	36
3.5 Sample Design and Sampling	36
3.5.1 Target Population.....	37
3.6 Data Description	39
3.6.1 Remote Sensing Data.....	39
3.6.2 Digital Elevation Model (DEM)	40
3.6.3 River Flow Data.....	41
3.6.4 Soil Distribution Data	41
3.6.5 Rainfall Distribution Data.....	41
3.6.6 Ground Truth Data.....	42
3.6.7 Infiltration Data.....	42
3.7 Data Analysis.....	43
3.7.1 Determination of the Extent and Nature of LULCC in Kilifi County between 1990 and 2014.....	43
3.8.2 Establish the Impact of LULCC on Surface Runoff and Infiltration Capacities	46
3.9 Stream Flow Data Analysis	48
3.10 Production of a Flood Risk Map.....	50
3.10.1 Flood Risk Zoning Based on LULC.....	50
3.10.2 Flood Risk Zoning Based on Soil Type.....	51
3.10.3 Flood Risk Zoning Based on Slope	51
3.10.4 Flood Risk Zoning Based on Spatial Rainfall Distribution	52
3.10.5 Flood Risk Zoning based on the Drainage Network.....	53
3.10.6 Flood Risk Zoning Based on Drainage Density.....	54

3.10.7 Overlay of Layers and Generation of Flood Risk Map.....	55
CHAPTER FOUR: RESULTS AND DISCUSSIONS.....	58
4.1 Introduction.....	58
4.2 Landsat Image Processing.....	58
4.2.1 Image Preprocessing	58
4.2.2 Classification of Images.....	59
4.2.4 Accuracy Analysis	67
4.3 Impact of LULCC on Surface Runoff and Infiltration Capacities	70
4.3.1 Double Ring Infiltration Experiments	70
4.3.2 Stream flow Analysis.....	74
4.4 Flood Risk Map for Kilifi County	77
4.4.1 Flood Risk Zoning Based on Land Cover Distribution	77
4.4.2 Flood Risk Zones Based on Slope Angles and Elevation.....	79
4.4.3 Flood Risk Zones Based on Soil Type.....	81
4.4.4 Flood Risk Zones Based on Spatial Rainfall Distribution	83
4.4.5 Risk Zones Based on Drainage Density.....	85
4.5 GIS Weighted Overlay Analysis.....	89
CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS	92
5.1 Summary of the Findings.....	92
5.2 Conclusions.....	94
5.3 Recommendations.....	96
5.3.1 Data needs.....	96
5.3.2 Suggestions for Further Research	97
5.3.3 Policy and Institutional recommendations.....	98
REFERENCES.....	99
APPENDIX I: OBSERVATION CHECKLIST.....	105
APPENDIX II: INFILTRATION EXPERIMENT MATRIX	106
APPENDIX III: RIVER FLOW DATA FOR SABAKI AT STATION 3HA13	107

LIST OF TABLES

Table 3.1: Population Results for Different Censuses	32
Table 3.2: List of Landsat Images.....	40
Table 3.3: Description of Land Cover Type	44
Table 3.4: Ranks and Weights for Thematic Layers.....	57
Table 4.1: Land Cover Extent for the years 1990, 2000 and 2014	59
Table 4.2: Spatial and Temporal Changes in Land cover	65
Table 4.3: Error Matrix for 1990	68
Table 4.4: Error matrix for 2000.....	68
Table 4.5: Error Matrix for 2014	69
Table 4.6: Results from Infiltration Experiments	70
Table 4.7: Area under Each Slope Angle Category	81
Table 4.9: Risk Category and Area of Coverage	91

LIST OF FIGURES

Figure 3.1: Map showing Location of Kilifi County	27
Figure 3.2: Map of Kilifi County showing the Land Forms in Kilifi	28
Figure 3.3: Market Centers and the Road Network in Kilifi County	33
Figure 3.4: Research Design and Flow Model.....	38
Figure 4.1: Land Cover Extent for 1990, 2000 and 2014	60
Figure 4.2: (a) Mosaic Image, (b) Unsupervised Classes and (c) LULC Map for 1990...	62
Figure 4.3: (a) Mosaic Image, (b) Unsupervised Classes and (c) LULC Map for 2000...	63
Figure 4.4: (a) Mosaic Image, (b) Unsupervised Classes and (c) LULC Map for 2014...	64
Figure 4.5: Flow Trend for River Sabaki at station 3HA13 between 1990 and 1994.....	75
Figure 4.6: Flow Trend for River Sabaki at station 3HA13 between 2000 and 2012.....	75
Figure 4.7: (a) LULC Map and (a) Reclassified LULC Map	79
Figure 4.8: (a) Slope Map and (b) Reclassified Slope Map of Kilifi County	80
Figure 4.9: (a) Soil Map and (b) Reclassified Soil Map	83
Figure 4.10: (a) Rainfall Distribution Map and (b) Reclassified Rainfall Map	85
Figure 4.11: (a) DEM and (b) Flow Direction Map.....	87
Figure 4.12: (a) Flow Accumulation Map, (b) Stream Network, (c) Drainage Density and (d) Reclassified Drainage Density	88
Figure 4.13: Flood Risk Map for Kilifi County	90

LIST OF PLATES

Plate 3.1: A Double Ring Infiltration Setup at various selected sites	49
---	----

ACRONYMS AND ABBREVIATIONS

DEM	Digital Elevation Model
ETM+	Enhanced Thematic Mapper Plus
GIS	Geographical Information Systems
LCC	Land Cover Change
LUC	Land Use Change
LULC	Land Use Land Cover
LULCC	Land Use Land Cover Change(s)
RCMRD	Regional Center for Mapping of Resources for Development
RS	Remote Sensing
SRTM	Shuttle Radar Topographic Mission
TRMM	Tropical Rainfall Measuring Mission

ABSTRACT

An increase in the size of population leads to changes in land use and land cover as the growing community seeks more land for agriculture, settlements and infrastructural development. Land use and land cover change (LULCC) alter natural drainage systems, impact on surface runoff and affects infiltration capacities of an area; factors which contribute to flooding. Management of floods begins by mapping flood prone areas and understanding the vulnerability factors. The main objective of this study was to identify areas in Kilifi County that are vulnerable to flooding and to assess the cause of floods using GIS - based flood risk mapping. The specific objectives were to determine the extent and nature of land use and land cover changes occurring in Kilifi County in the period between 1990 and 2014; to establish the effects of land use and land cover change on surface runoff and infiltration capacities and to generate a flood risk map for Kilifi County. Landsat images for 1990, 2000 and 2014 were used to classify the area into forestlands, grasslands, croplands, settlements, wetlands and shrublands. The mapped data from satellite images of 1990 indicated a forest cover of 1042.9km², a 26.3km² cover for settlements and a 5142.0km² cover for croplands. In 2000 there was a forest cover of 940.4km², 27.8km² for settlements and 4693.0km² for croplands. In 2014, there was 825.8km², 46.5km² and 5123.8km² cover for forestlands, settlements and croplands respectively. Between 1990 and 2014, forest cover reduced by 580.3Km², croplands increased by 1170Km² while settlements increased by 93.3Km² respectively. These changes alter surface runoff, river discharge and affect soil infiltration capacities. Infiltration experiments conducted in the different land cover classes using a Double Ring Infiltrometer established that infiltration rates were highest in the sandy soils and lowest in the clay soils. It took an average of 5.5min and 29min for water to percolate into loamy soils in the forestlands and settlements respectively; an average of 30min and 21min for infiltration under clay soils in the grasslands and shrublands respectively, while under sandy soils; it took 21.5min for infiltration in the settlement areas. Analysis of trends in stream flow data for Sabaki River available for the period between 1990 and 2012 indicated a change in the river discharge over this period albeit not significant. This data did not adequately cover the study period but covered 95% of the period between 2001 and 2012. Different thematic maps on land use and land cover, slope, rainfall, soil and drainage were generated. Different weightage values were assigned depending on their importance to flood risk and overlaid in the spatial analyst tool in ArcGIS 10.1 to generate a flood risk map. A flood risk map was developed identifying five categories of risk zones; the very high, high, moderate, low and very low risk zones. At 6735.3km², Kilifi County generally has a high risk of flooding. The low risk areas cover only 122.45km² of the total area. Zoning of flood risk areas is important for planning development in the area. The document provides base information for the national government, county governments, NGOs and the community on flood risk areas in order to intervene during flood preparedness, response, mitigation and recovery processes respectively.

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

A flood is a natural phenomenon that leads to temporary submerging of a piece of land with water (EC, 2007). Floods are caused by natural events, by human activities, or by combinations of both and have the potential to injure fatally, displace a large number of people and cause damage to the environment (Balabanova and Vassilev, 2010). There are three main types of floods namely: flash floods, river floods and coastal floods (GSL, 2001). Some of the causes of floods include anthropogenic activities through human interruptions in the natural processes occurring due to increased settlement areas, population growth and economic assets in the lowlands and coastal plains prone to flooding (Balabanova and Vassilev, 2010). This leads to changes in the drainage systems (EC, 2007). Floods are the most devastating natural hazard causing the most number of deaths and the greatest damage to property (CEOS, 2003).

Land use and land cover change (LULCC) impacts on the hydrological cycle and therefore water availability. One of the connections between land cover change and water availability in the water cycles is that land change affects not only the degree of infiltration but also runoff that follows precipitation events (Johnson, 2008). The degree of vegetation cover and albedo affects evaporation rates, alters levels of humidity and influences the formation of clouds (Calder, 1992). The nature and type of land cover influences the rate of runoff, infiltration and groundwater recharge. According to Murstard *et al.*, (2004), the land surface

performs a crucial function in the water cycle as it serves as the level or base on which precipitation is redistributed into evaporation, runoff or soil moisture storage. Increased urbanization as a result of the conversion of terrestrial environment or forest land to agricultural land or settlements are cognizable changes. The impact of increase in urban areas or deforestation on the discharge process is relatively easy to identify (Neaf *et al.*, 2002). In the built up areas, there is an increase in the impermeable areas hence causing a rise in the rates of overland flow (Mustard and Fisher, 2004). This hinders natural retention of water and alters subsurface or groundwater flow leading to increased formation of flood waves and volume or size of flood wave discharge (Calder, 1992).

Floods lead to deaths of many people, destroy many structures including homes and disrupt a wide range of ecosystem and farming related activities, flora and affect of human survival including increasing susceptibility to water borne diseases (EC, 2007). It is estimated that floods have claimed over 10000 lives since 1900 in the United States alone and caused massive environmental and economic losses (Adeoye *et al.*, 2009). In China, it is reported that the worst flood in 1998 affected 223million people with 3004 persons reported dead, 15 million people left homeless with the economic losses estimated at over US\$ 23 billion (UNDP, 2011). In 1991, 140,000 people across the world were reported dead as a result of floods and in 1998, floods affected 25 million people in different ways (UNDP, 2011). In Africa, many states have also been affected by floods (Paeth *et al.*, 2010). Mozambique has experienced floods ever since she gained independence in 1975 with the associated losses amounting to millions of dollars

(Adeoye *et al.*, 2009). In Nigeria, flooding recurs yearly especially in the Coastal areas along the Atlantic Ocean. As a result, the surrounding cities and the low lying plains as well as the ground around the area increasing in salinity (Jeb and Aggarwal, 2008). These areas attract large numbers of human settlements (Ologunorisa and Abawua, 2005). In Kenya, areas such as Budalangi in Western Kenya experience perennial floods (KRCS, 2013). Recently, due to changing patterns of land use and rainfall variability more areas in the Rift Valley, Eastern, Coast and Western parts of the country have been experiencing floods after precipitation events (Christiansen and Subbarao, 2004; GOK, 2009).

To produce flood risk maps, information regarding land use and land cover (LULC), drainage patterns, distances from the built up areas to the water bodies, elevation, presence of buffers, the cultural practices and attitudes is required (Tanavud *et al.*, 2004). Reducing risks following flooding is largely dependent on knowledge available on floods and understanding regarding the nature of the physical space with the likelihood of being affected during floods events. Modern day techniques are therefore necessary for use if appropriate measures to help the government, planning agencies and rescue institutions in establishing flood vulnerable areas and in mitigating against floods are to be put in place. GIS and Remote Sensing provide an effective tool for processing this information (Forte *et al.*, 2006). Data sets from Remote Sensing are integrated into GIS platform to generate vulnerability maps (Huggel *et al.*, 2003). Barredo and Engelen (2010) conducted a study on the flood vulnerability of Pordenone Province after a series of heavy floods. The study confirmed that the flood risk was as a result of

increased urbanization which reduced the percentage of natural vegetation. In his study, Labarda (2009) in the city of Sipalay (India), established that mining operations, logging and slash and burn method of farming resulted in the denudation of the watershed and undermined its capacity to prevent flash floods while soil erosion had also increased. According to Johnson (2008), anthropogenic activities such as increased human areas of habitation, development of economic goods in coastal plains and floodplains and reduced rates of water retention through land use changes leads to increase in the number and spatial extent covered by floods.

This research focused on Kilifi County in the Kenyan Coast. Some of the areas that experience floods whenever it rains include Ngomeni in Magarini Constituency, Kaloleni Constituency, Malindi Town and parts of Ganze Constituency (KRCS, 2013). In March 2013, some 200 families were affected by floods in Kaloleni while in April 2013, 427 households were displaced in Magarini and Malindi following a spillover of waters from Sabaki River (KRCS, 2013). Coastal ecosystems are usually delicate environments and are therefore easily disturbed and easily damaged when overexploited. The rapid growth in human population has led to coastal zones becoming areas of agriculture, habitation and industry (Kitheka, 1997). Soil erosion is a major concern in the settlement areas which results in sedimentation of the water systems downstream (Ochiewo, 2004). In coastal regions, flooding and storm protection is usually a preserve of forests, coral reefs, marshes, mangroves, sea- grass, sand dunes, and lagoons. The impacts of flooding and storm in the coastal areas is usually

regulated through mechanisms such as coastal stabilization, wave dissipation, reflection, absorption, resistance, barriers to surging floods and sediment transport regulation (Griffin *et al.*, 2001).

1.2 Statement of the Problem

An increase in the size of human population and consequent changes in settlement patterns has led to changes in LULC to address the needs of the land users in Kilifi County (Okoth, 2010). LULCC leads to alteration of natural drainage systems, impact on surface runoff and affects infiltration capacities. These are factors which contribute to flooding (Haber, 1994). The degree of available vegetation cover and the rate at which heat is absorbed or reflected alters the rates of evapotranspiration rates, humidity amounts and cloud cover (Johnson, 2008). These factors alter the mannerisms and the equilibrium occurring between water vaporization, recharge and water redistribution through rivers and streams (Calder, 1992).

Vulnerability to floods in Kilifi is aggravated by degradation of the vegetation in the area including mangroves which are important in stabilizing the coastline, collection of storm water (overland runoff) and in controlling floods. Coastal erosion and flooding leads to sea water intrusion into underground aquifers leading to water salinity (Mustard *et al.*, 2004). According to Obura (2005), more than 500 hectares of mangroves have been cleared to create more room for establishment of salt lagoons in Magarini Sub County. Deforestation has a strong link to the changing patterns of rainfall and the fluctuating sea levels in the area

and these have a bearing on coastal flooding (Obura, 2005). Other types of vegetation including shrublands and scrublands have also been exploited for charcoal burning, expansion of residential areas and clearing of land for agricultural purposes notwithstanding their importance in regulating the speed of runoff and water interception (Ochiewo, 2004).

The urban areas, which include Mazeras, Mtwapa, Kilifi, Watamu, Kaloleni and Mariakani, have grown due to increased human population, and increased beach tourism. Buildings and connection roads are established in areas previously covered with natural vegetation (Okoth 2010). The problem arising as a result of urbanization and infrastructure development is the creation of impermeable areas or surfaces. Such surfaces hinder natural water percolation (infiltration) after rain downfalls (Mustard & Fisher, 2004). This alters recharge of water into the ground and leads to rise in amounts of surface runoff often leading to flooding (Mustard & Fisher, 2004).

Much of this information is theorized or assumed. There is lack of concrete information based on scientific findings on the causes of floods. Management of floods is highly dependent on the depth of information available on causative factors that include the ever increasing dynamics in land use and land cover and the identification of areas prone to flooding. There are many areas in the County which are vulnerable to flooding but are not yet mapped. This study took advantage of the advancement in Geographic Information Science and Technology (GIST) to generate information in form of flood risk maps and to identifying all flood prone zones. This information would be of use to policy

makers and planners in the developmental planning of the area. The findings are also important in hazard zonation and in early warning systems and flood evacuation.

1.3 Research Questions

The study endeavoured to answer the following questions:

- i) What is the rate and nature of land cover and land use change in Kilifi County between 1990 and 2014?
- ii) How have the land use and land cover changes affected surface runoff and infiltration capacity?
- iii) Which areas in Kilifi County are vulnerable to flooding?

1.4 Objectives of the Study

The main objective of the study was to identify sections in Kilifi County that are susceptible to flooding and generate a flood risk map on a GIS platform. Specifically, the study aimed to:

- i) Determine the extent and nature of land cover and land use changes occurring in Kilifi County in the period between 1990 and 2014.
- ii) Establish the impact of LULCC on surface runoff and infiltration capacities
- iii) Generate a Flood Risk Map for Kilifi County

1.5 Research Assumptions

Major land use and land cover changes have occurred in Kilifi over the period between 1990 and 2014 and this affects surface runoff and infiltration capacities favouring conditions that allow flooding.

The flat terrain and low slope and elevation angles in Kilifi County favour waterlogging and consequent flooding in the area.

Some sections of Kilifi County are covered with soil types that are impermeable and/or have low infiltration capacities.

The drainage system in some sections of Kilifi County is not adequate to allow runoff to drain discharge appropriately into the available water bodies after rainfall events leading to accumulation of water that ends up as flood waters.

Floods experienced in Kilifi County are not only as a result of rainfall events but a combined response of impermeable soils, flat terrain, poor drainage systems and various land use and land cover characteristics.

1.6 Justification of the Study

Kilifi is an important tourism, agricultural and Commercial County along the Kenyan Coast and has been experiencing increased floods both in frequency and magnitude during rainy periods (KRCS, 2013). To develop a prevention and mitigation plan, assessment of floods requires information on the areas at risk of flooding. Mapping of flood risk areas is the first step towards identifying areas that are highly vulnerable (Jeb and Aggarwal, 2008). Many parts throughout the

world have benefitted from the use of GIS in the development of flood risk maps (Balabanova and Vassilev 2010). Kenya is still in the formative stages in the adoption and use of technology and in particular GIS to address problems such as those posed by floods (Ouma and Tataeshi, 2014). The study sought to fill a research vacuum and provide current information on flood risk in relation to the ground's response to rainfall events. Flood risk maps are therefore a necessity for all parts of the country and beyond.

This study offers a practical opportunity to the application of GIS to demonstrate the impacts of the combination of factors including dynamics in LULC, drainage, rainfall, slope and soil distribution to flood risk in Kilifi County. The output of this research, over and above its academic purpose will generate essential information for public consumption and advocacy. Results can be replicated to other parts with similar input parameters.

1.7 Significance of the Study

Flood risk maps are important in planning for mitigation measures against flood events. They also assist in the coordination of rescue operations and delivering aid during flooding and related hazard events. They can also be used in educating the communities on the risks associated with floods and what to do in case a flood occurs as they are easy to read and interpret. Information on LULCC and flood risk computations can serve as a reference in undertaking important development activities. Established relationship between LULCC, infiltration and Surface Runoff can provide a basis for further remedial measures and related studies.

Incorporation of GIS into the study is a good step towards adoption of technology in addressing flooding problems affecting other areas by other scholars. The findings if replicated in other parts of the world may assist in solving problems associated with land use planning and flooding. This information is important for policy makers, government agencies, donors or aid agencies and development planners.

1.8 Scope and Limitations of the Study

The study was conducted in Kilifi County with an area of 12,245.9km². The study generated multi temporal and extent land cover maps from remotely sensed satellite images which were used for identifying the nature and extent of LULCC from 1990 to 2014. A period of over 20 years is quite substantial for natural vegetation to regenerate and as such the choice of the dates. This period also coincides with the dates of the stream flow data available. Images with different spatial resolutions that were used for the computation of land cover included Landsat 5, Landsat 7 ETM and Landsat 8 ETM+.

To identify the relationship between LULC and surface runoff and infiltration capacities, infiltration experiments were conducted using a Double Ring Infiltrometer. A total of 12 experiments were conducted and distributed randomly within different land cover types. River data covering the period between 1990 and 2012 was used to assess the trends in river flow for the period under consideration. The limitations to the study included the unavailability of water on selected infiltration sites, accessibility and bulkiness of infiltration equipment,

thus greatly limiting the number of field experiments conducted, missing stream flow data for some years and time constraints.

1.9 Operational Definitions

Land cover refers to any covering that can be seen on physical space.

Land use refers to the pre-determined use and management underlying human exploitation of a land cover usually symbolized by the setup and undertakings by human beings in a particular land cover type for the purposes of production, alteration or retention in its natural form (Mustard and Fisher, 2004).

Flood is a natural phenomenon that results to the temporary submerging of a piece of land with water that does not occur under normal conditions.

Flood Risk is a summation of the likelihood to occur of a flood, the anticipated impacts on human wellbeing, the biosphere, human culture and economic impacts related to floods.

Flood Risk Management refers to an all-inclusive process that incorporates a continuous process of analysis and assessment by an individual, a community or an agency to reduce the risks associated to floods (Ouma and Tateishi, 2014).

Vulnerability is the ability of an individual or a group of individuals to anticipate, withstand or resist or rise up from the effects or consequences related to a hazard like a flood.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter reviews the existing literature on different thematic areas to fully address the objectives and identify the gaps. It includes literature on the causes and impacts of land use and land cover changes and their relationship with flood risk, the relationship between LULCC, infiltration, runoff and flooding and GIS-based flood risk assessment. Also, mentioned are some of the flood management policies by the Kenyan and the local governments.

2.2 Land Use and Land Cover Change

Land use activities affect land cover and vice versa. Changes in either land cover and/or land use do not necessarily mean that one is explicitly a consequence of the other. It is therefore improper to conclude that land cover change (LCC) occasioned by use of land explicitly degrades the land as the changes could have positive impacts depending on the use that the land is put into (Turner, 1989). Many dynamic land use patterns are driven by different social-economic aspects and result in changes that affect biodiversity, water resources, and other processes, which combine to alter the atmosphere and the environment at large (Riebsame *et al.*, 1994).

The main cause of LCC in the world today is as a result of direct human use of land resources; including urbanization, rural development, forest clearing, agriculture and livestock rearing, among others. Apart from human causes, other factors that lead to LCC are changes in climatic patterns and variability, ecosystem alterations and natural hazards such as floods and fires (Meyer, 1995). According to Turner (1989), conversion and modification of land surfaces are the main types of LCC. The former involves the complete removal of a cover type and replacing it with another. The latter can be involves a change from one type of cover to another e.g. through deforestation for the purposes of agricultural expansion (Meyer, 1995). Modification involves the altering of the structure or functioning without shifting totally from one type to another. Modifications affect land cover character without necessarily changing the overall land cover, for example increasing the housing density in a settlement (Zeleeke and Hurni, 2001).

Plant cover and litter on the ground surface plays an important role in intercepting rainfall during precipitation events thus reducing the impact associated with rainfall (Okoth, 2010). Therefore, vegetation cover helps in reducing alterations on the earth's surface as it helps reduce the ground's vulnerability to soil erosion and providing extra bond to soil, either through its roots or indirectly by altering the rates of infiltration, runoff and evapotranspiration that occur (Meyer, 1995). Total removal or alteration of vegetation therefore impacts negatively on the balance that exists between runoff, infiltration and precipitation (Okoth, 2010).

Land cover changes affect biodiversity (Okoth, 2010). In their study, Ochola *et al.*, (2012), established that the massive deforestation of mangrove forests as a result of Salt Mining activities in Magarini, Kilifi led to migration of native avian species making them unavailable to those who relied on them for livelihoods. This is because these forests acted as important sources of herbal medicine, food, pasture and herbal medicine, all of which support the people's livelihoods. In addition, the areas are excavated and flooded to form salt pans which make them inaccessible for human use.

A study conducted by Onywere *et al.*, (2011) to establish the challenges posed by growth of settlement areas in Budalangi and Yala Swamp established that the creation of more estuaries at the mouth of River Nzoia was as a result of siltation. The changes assessed with the use of multi-date Landsat images occurred due to shifts in land cover characteristics; especially due to an increase in farming activities and settlements in the area. This greatly reduced the size of the area under water bodies. Human settlement in these areas exposes them to flooding as the area is a flood plain. The area experiences floods during the long rains (April to July) period which leads to loss of lives and destruction of property (KRCS, 2013).

2.2 Change Detection

Geographical Information Systems (GIS) provide a standard method of mapping and monitoring LULCC and is an important tool in assessing the character of

landscapes and quantifying spatial changes (Jensen, 2004). Remotely sensed data in particular provides the ability to assess a wide range of landscape bio physical properties that are crucial for resources management and policy (Onywere *et al.*, 2011).

According to Jensen (2004), knowledge of the evolution in different LULC systems, analysis of LULCC at the global, continental and local levels, and having an insight on the area to be covered by changes in days to come, the available spatial records on trends and patterns in LULC plays a critical role. Satellite images offer an important opportunity to extract information on spatial and temporal trends of LULCC. They are also crucial for understanding, modeling, monitoring and predicting land changes (Jensen, 2004). GIS and satellite or space-borne remote sensing is based on studies that mainly lead to information on the amount, location, type and land cover change that has occurred over time. Recognition of the need for information on land cover, affordability of remotely sensed data and the recent advancements in computer technology are some of the motivations that have led to an increase on the interest on classifying land cover (UCAR, 2010). A combination of GIS and remotely sensed imagery forms a powerful platform for generation of spatial data which is then stored, measured, monitored and modeled as well as analysis (UCAR, 2010).

There are four major aspects that are important in land cover change detection. They form an important source of data to planners and environmentalists and can also be used for monitoring the consequences on the environment as a result of

changes in land use (UCAR, 2010). The procedure is formed by the following four processes:

- i) Establishing the land cover dynamics occurring over a period of time
- ii) Identification of the type of the changes (whether modifications or conversions).
- iii) Quantifying the spatial area of the modifications and/ or conversions and computation of statistics
- iv) Assessment of the direction and pattern followed by the changes.

The type, nature and magnitude of LULCC assists in establishing if development and resource use is sustainable or balanced (Peterson *et al.*, 2001). Landscapes are often changing and are accelerated when subjected to anthropogenic activities, often affecting ecosystem processes and functioning. The results of this are habitat fragmentation, desertification, deforestation, the loss of biodiversity, which is a response to global warming (Peterson *et al.*, 2001).

Remotely sensed Landsat images can be classified through two major methods, either supervised or unsupervised. Training samples are selected and used to recognize certain specific characteristics from land cover types in supervised classification (Forte *et al.*, 2006). The training samples are recognized through particular types of pixels and using ground truth data from field survey or through a historical knowledge of the area under study (UCAR, 2010). Unsupervised classification involves clustering of the land cover into various groups; where the clusters are used as inputs into the software- which then does the grouping

according to similar spectral characteristics depending on their brightness values (Digital Numbers- DN). The basis for the groupings is on the similarity of the pixels' spectral characteristics (UCAR, 2010). A classification combining both supervised and unsupervised classification (also known as hybrid classification) is also a common phenomenon today (UCAR, 2010).

2.3 Relationship between LULCC, Flooding, Runoff and Infiltration Capacities

Changes in LULCC have a bearing on the relationship existing between rainfall and runoff and the relationship between overland runoff and sediment yield. This alters the rate of soil erosion and water loss (Kim *et al.*, 2002). The main driving forces behind flooding are changes in land use activities in flood and coastal plains, increased population resulting in increased urbanization and settlements and increased infrastructure such as roads and railway lines (Calder, 1992). LULCC affects infiltration, evapotranspiration and erosion (Calder, 1992). Rapid development exposes the land cover to changes that compact the soil causing it to become impervious. This leads to decreased rates of soil infiltration and increased volume and speed of runoff (Kim *et al.*, 2002). An increase in runoff leads to conveyance of elevated sediment loads into water bodies downstream, contributes to stream flooding, and can also lead to increased erosion (Neaf *et al.*, 2002).

Increase in the spatial extent of built up areas and urban areas leads to the conversion of wetlands, reduction in shrublands, forests and grasslands (Ouma and Tateishi, 2014). The most common change accompanying urbanization is the

extent of a shift from previous natural surfaces to impervious ones (Calder, 1992). The associated infrastructure in settlement areas comes with increase in spatial extent of impervious surface, which alters the hydrologic characteristics within an area (Field *et al.*, 1982). Because built up areas are almost impervious or impervious, urban land surfaces such as rooftops, concrete pavements, and compacted soils yield rates and volumes of runoff that exceed those of undeveloped land (Ouma and Tateishi, 2014). According to Hall (1984), increased impervious surfaces lead to increase in the volumes and speed of runoff. Fast accumulation of runoff in flood plains and coastal plains leads to flooding. The increased rate of runoff reduces the amount of water that seeps into the ground thus recharging groundwater aquifers (Ouma and Tateishi, 2014).

Due to increase in global population, there has been an increase in the conversion of natural land to agricultural land (Mustard *et al.*, 2004). According to Mustard and Fisher, (2004), the size of cropland has more than doubled in the last half a century. Conversion of natural land to cultivated land often means reclamation of wetlands and clearance of native vegetation (Mustard *et al.*, 2004). Farley *et al.*, (2005), in a study established that the conversion from natural vegetation to croplands led to increased magnitudes in flooding in watersheds. During precipitation events, runoff in the denuded areas often flows into water channels including streams and rivers as opposed to infiltrating into the ground and recharging groundwater aquifers or going back into the hydrological cycle through evaporation causing flooding in the areas in question (Farley *et al.*, 2005).

Farming loosens the soils leading to erosion that eventually ends up in rivers as sediment which has been a major cause of flooding in flood plains.

According to Farley *et al.*, (2005) the type and amount of vegetation cover affects the amount of water that ends up in a drainage basin. Deforestation results in increased run-off and often a decrease in river channels' capacity due to increased sedimentation rates (Mustard *et al.*, 2004). Litter and leaves usually scattered under the forest canopy play an important role in holding water, and allowing evenly distributed infiltration of water into the soil. Plant canopies and litter intercept raindrops, reducing some of the intensity associated with the rainfall (Yahaya *et al.*, 2010). Through this, vegetation cover plays an important role in the increase of the ability of the surface to withstand soil erosion, thus reducing the effectiveness of runoff and providing extra cohesion to soil either by its roots or indirectly by altering the rates of infiltration, runoff, and evapotranspiration that occur (Mustard and Fisher, 2004). According to Mustard *et al.*, (2004) coastal vegetation plays an important role in coastal stabilization, filtration of land runoff and flood control. Continued exploitation of coastal vegetation therefore exposes the communities within those areas to the risks associated with coastal flooding.

2.4 GIS- Based Computation of Flood Risk Maps

All disasters occur on physical space and have a spatial extent. In disaster preparedness, there is no contention that there is need for enough information regarding floods and flood vulnerability (Ouma and Tateishi, 2014). GIS provides the necessary information important in addressing floods as it affords planners

with the opportunity to make sober and concrete judgments in applying necessary parameters during the overlay process (Ouma and Tateishi, 2014). GIS also produces a good visualization of flooding and provides an opportunity to conduct more analysis on floods and to give an estimation of the likely damage occasioned by a flood (Yahaya *et al.*, 2010).

Effective management of floods requires proper identification of areas of flood vulnerability (Ishaya *et al.*, 2009). This helps in preparedness, putting into place preventive measures and responding to flood events (Yahaya *et al.*, 2010). There are many end users of information in the flood risk maps including the government for planning purposes. Flood risk maps can be used to identify the required intervention measures and provide safety precautions meant for livelihood activities and the public safety at large (Ishaya *et al.*, 2009). To prepare an effective flood risk map, the following information is important: soil characteristics, residential density and settlement patterns, elevation, distance to the water body, steepness of slope, LULC and the inundation extent (Tanavud *et al.*, 2004).

According to Jeb and Aggarwal (2008), flood risk maps are important in many ways, they help in the enlightening on the flood risk or impacts. They help in proper visualization of the problems associated with floods in the area of interest and are also used in planning for mitigation measures. Flood risk maps also generate vital information used by planning authorities in formulating land use policies and planning for development (Forte *et al.*, 2006). In flood events, the most affected areas can be identified from flood risk maps to assist in rescue

efforts, visualization and assessment of the extent of damage to facilitate in compensation of the affected persons and in evaluation of the total cost of loss or damage (Jeb and Aggarwal, 2008).

In many parts of the world, GIS has been used in the generation of flood risk maps showing vulnerability to flooding (Ouma and Tateishi, 2014). Such maps have been used as an important criterion for carrying out major interventions especially in the developed countries (EC, 2007). Remote sensing technology is used in collating satellite data (Ouma and Tateishi, 2014). The technology is then used to identify, classify, map, monitor, plan, mitigate and guide in management of natural disasters (Jeb and Aggarwal, 2008). Remotely sensed data is integrated into Geographic Information Systems (GIS) analysis and eventual production of flood risk maps (Forte *et al.*, 2006). Historical datasets such as images and photographs are used in identifying the spatial extent and type of LULCC in order to assess impacts of the changes on floods (Jeb and Aggarwal, 2008).

To investigate flood risks and mitigation measures that require prioritization on the Kosi River Basin in India, Jeb and Aggarwal, (2008), used a GIS environment using datasets from different sources including; district level maps, topographic maps and population census data, DEM and Remotely Sensed images. The parameters applied and used in evaluation of risk and in the production of hazard prone areas in their study were drainage buffers, elevation, land cover characteristics, geomorphic characteristics and population density. Their study concluded that for a flood to occur, several factors have to act in play or combine.

In his study to determine areas prone to flood risk in Accra, Nyarko (2000) used a hydrologic model and GIS. Various datasets were used particularly from published information regarding flood generation factors such as rainfall, river discharge land use patterns, soil characteristics and analysis of long term LULCC. The findings confirmed the differences in influence between factors and parameters on flood risk and therefore were apportioned different weights while assessing their influence. The main cause of floods in the area was found out to be excessive rainfall with supporting land cover characteristics (permeability and infiltration capacities).

Ochola *et al.*, (2010), used GIS techniques to conduct flood vulnerability assessment and delineate flood risk zones for schools in the Nyando River Catchment, Kenya. The study applied a weighted ranking procedure that utilized soil type, buffer zones, rain distribution, land use type, slope/altitude, drainage density and participatory flood maps as parameters of assessment. The study found that drainage density, soil structure, slope and rain distribution were the most influential factors in the formation of floods in the area.

Onywere *et al.*, (2011), in their study assessed the challenges associated with increase in settlements in Budalangi and Yala Swamp in Western Kenya using Landsat Images- on a GIS platform and participatory data collection. The study established that one of the causes of flood vulnerability of the inhabitants of this area is the encroachment into the swamp. From 1973 to 2009, 54Km² of Yala Swamp had been encroached. The contributing factors to the flood risk were the physical setting of Budalangi in a flood plain of the River Nzoia and an increase

in the amount of runoff from degraded catchments. The study further established that floods in the area led to destruction of human settlements and crop destruction and the destruction of infrastructure, shelter and dykes.

Ouma and Tateishi (2014) in their study identified the flood prone areas and conducted a detailed risk assessment using integrated approaches and GIS in Eldoret Municipality. The study found out that to map out flood prone areas, several aspects have to be incorporated including the steepness of an area, stream density, LULC and type of soil. Susceptibility to floods in Eldoret town is occasioned by an increase in the size of urban areas coupled with poor drainage systems and alteration of natural drainage system.

2.5 Disaster Management Policy in Kenya

The National Policy for management of disasters in Kenya was formulated in 2009 by the Kenyan government (Ochola *et al*, 2010). The main emphasis of the policy is on the promotion of preparedness on the main stakeholders including the government, communities and other relevant stakeholders in reducing the risks posed by disasters. The policy also emphasizes on the need for establishment and strengthening of the disaster management institutions, partnerships, networks and the mainstreaming of reduction of floods in development processes. This would help improve the resilience of vulnerable members of the society to withstand imminent disasters (GOK, 2009).

The policy document takes into consideration the existence of other similar policy documents. It is linked to a number of flood related Acts of Parliament including,

EMCA (1999), the Kenya Red Cross Society Act (Cap 256), the Water Act (Cap 372), Local Authority Act (Cap 265) among others. There are also other relevant Acts including the Public Health Act and the Forest Act (Ochola *et al*, 2010). Areas mainly addressed by the policy include the settlement in areas that are prone to floods, conservation and protection of catchments and development of infrastructure meant for protection against floods. The policy document however doesn't address the coping mechanisms used by the stakeholders in the event of a flood disaster. There lacks specific policies or Acts that addresses flood risks in isolation (Ouma and Tateishi, 2014).

2.6 Conclusion

The study did not only probe on the impacts of land use and land cover changes on flood risk but gives an in-depth insight into the underlying processes and technologies that can be used to generate useful flood risk maps. A review of literature on the various themes provided useful information on the idea of the relationships that exist between LULCC, runoff characteristics and infiltration in the generation of floods. However, it was revealed from the National Disaster Policy that flood risk management has largely focused on flood response rather concentrating on the land use land cover processes, early warning systems and generation of information. Flood risk maps are an important component of land use planning but aren't readily available in most areas.

CHAPTER THREE: RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

This chapter forms the core of the research. It gives detailed information of the study area with regards to vegetation, geology, landforms, climatic conditions and population patterns. The chapter also gives a detailed explanation of the sources and forms of data acquired for the research, as well as the methods adopted for the zoning out of the flood prone areas in the area of study.

3.2 Background to the Study Area

Kilifi County is one of the six Counties in Coastal region of Kenya. Its headquarters are located in Kilifi town while Malindi is the largest town in the County. The County, according to the Kenya population census (2009) had a population of 1,109,735 (KNBS, 2010). The County has a spatial extent of 12,245.90 km². The County lies between 2° 20' 4" South, and between 39°05' 14" East (KNBS, 2010). Other Coastal counties bordering Kilifi are Kwale, Taita Taveta, Tana River and Mombasa Counties respectively. The Indian Ocean is situated on the eastern side of the County (Figure 3.1).

3.2.1 Physical and Topographic Features

The land generally rises gradually from the sea level to 900m on the southwestern side of the County. The topography of the area is divided into the following features: a coastal plain 30m above sea level (asl). It is only northwards towards

Malindi where the plain rises up to 60m asl in some places. The coastline is rich with beaches, of mangrove forests, sand dunes at Mtwapa, Kilifi, Mida and Ngomeni creeks respectively. A Foot Plateau is found in the western side of the coastal plain and lies between 60m and 130m above sea level (GOK, 2005). This area is generally flat except for Mwembe Chungu, Ngoni, and Mtuni Hills that rise above 120m in altitude. Coastal Range lands consist of several hills such as Wacha and Gaabo in the northwestern side, Simba, Kiwara, and Jabana in Kilifi and Mazeras and Mangea to the north of Watamu. Nyika Plateau is found to the west of the coastal range and lies on altitude between 150 and 300m except for areas where the rivers could have reduced the altitude to below 150m above sea level.

The Tana River basin and lowlands are found to the northern part of Kilifi and lie below 300m in altitude (Figure 3.2). It consists of alluvium and old sediments including sand, gravel, silt, clay, marsh and narrow elongated plateaus and lowlands (GOK, 2005).

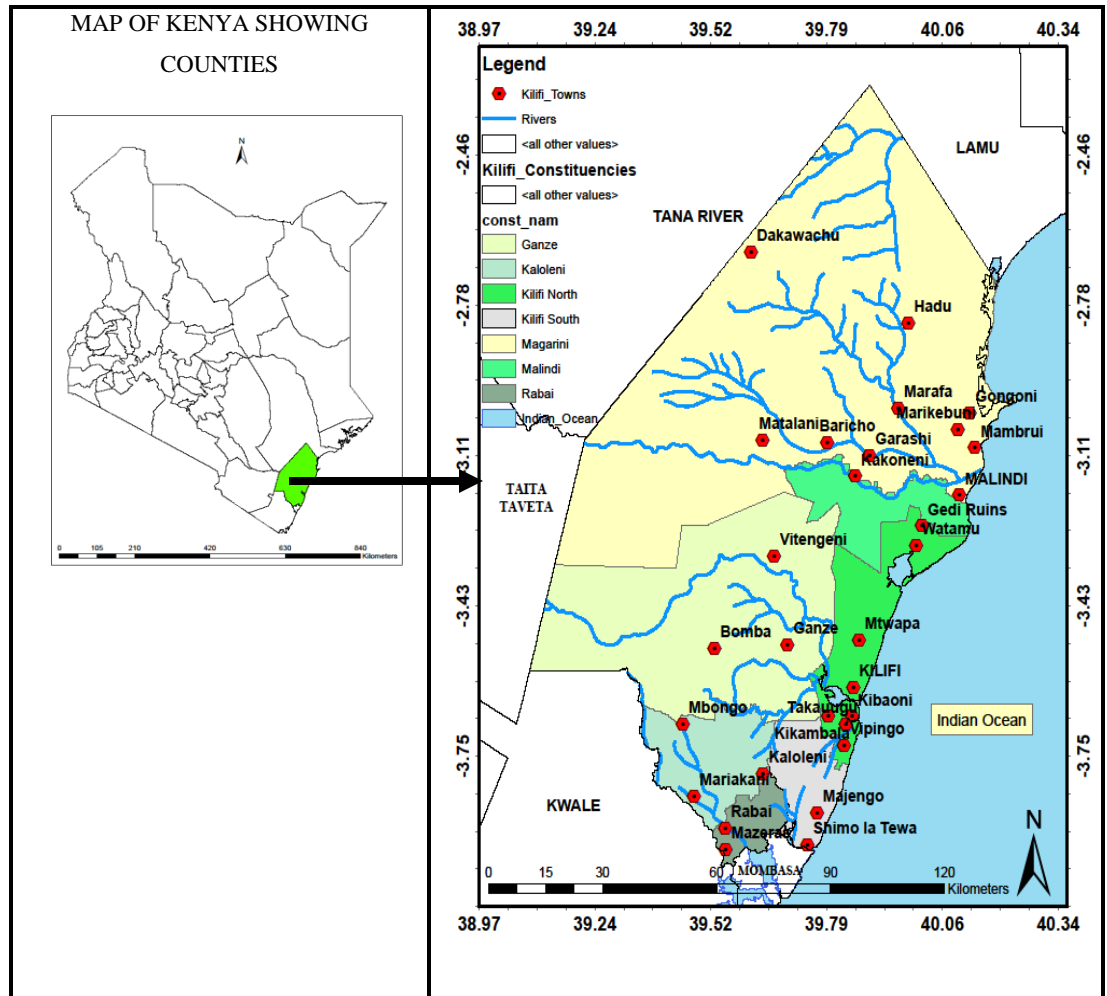


Figure 3.1: Map showing Location of Kilifi County

Source: Modified from KNBS (2010)

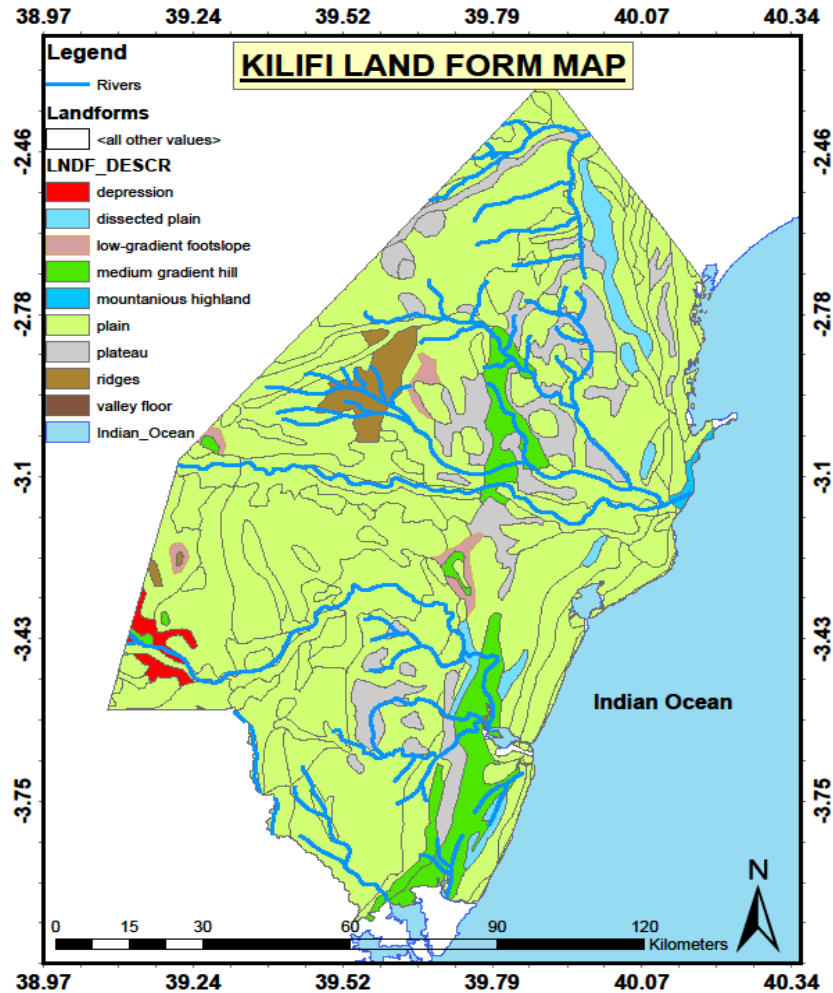


Figure 3.2: Map of Kilifi County showing the Land Forms in Kilifi

Source: Modified from Okoth (2010)

3.2.2 Climate

Along the coastal belt, the average annual rainfall ranges between 900mm and 1,100mm with decreased intensity towards the hinterland. Areas around Mtwapa to the north of the coastal strip and Arabuko Sokoke forest receive the highest amount of rainfall. Rainfall in the hinterland areas average an annual rainfall ranging from 400mm to 1,200mm around the coastal belt (Okoth, 2010).

Evaporation in the area ranges from 1800mm along the coastal strip, to 2200mm in the Nyika plateau and in the interior (GOK, 2005). The period between January and March has the highest evaporation rate in the County. The mean monthly evaporation rate ranges between 1650mm and 2300mm per annum (UNEP, 2008).

3.2.3 Drainage

The major river flowing through Kilifi area is the Sabaki (Galana) River which drains into the Indian Ocean. The drainage pattern for Kilifi County is in addition formed by seasonal rivers, which drain into the Indian Ocean through the various creeks. The rivers and streams are Nzovuni, Mleji, Kombeni, Rare, Goshi, Mtomkuu and Wimbi (GOK, 2005). The rivers and streams in the area form a dendritic drainage pattern with several seasonal and permanent rivers joining up to the main rivers. As the area slopes towards the Indian Ocean, most of the rivers in the area flow towards that direction (GOK, 2005). The area has a low drainage density. The implication of this is that there is high ground water potential in some of the area (Onyancha and Nyamai, 2014). Most of the rivers in the County are temporary due to low rainfall, low runoff rates, high evapotranspiration rates and their location in areas of sandy soils which have high infiltration rates (Onyancha and Nyamai, 2014). The area has its flood plains located along River Sabaki and along the Coastline where many creeks are situated. There are also many springs and swamps along the coastal plain with a few wet ponds in the inland (GOK, 2005).

3.2.4 Geology and Soils

The geology of Kilifi County is dominated by shallow cambisol – luvisols, vertisols, ferralic soils, fluvisols and nitisols (Onyancha and Nyamai, 2014). During rock formations, there occurred intermittent volcanic eruptions followed by periods of quiescence, where erosion of the already laid lavas would occur to form weathered interfaces between the lava layers called old land surfaces. They constitute a common ground water reservoir in the area. Kilifi County is also composed of sedimentary rocks of the Mesozoic and Cenozoic eras respectively, comprising a variety of sandstones, limestone, shales and siltstones (Onyancha and Nyamai, 2014).

In the lowlands, there are reddish, very deep, acid and clayey soils (ferrasols). These soils are distributed all over the county and are prone to soil erosion, have a low water holding capacity and are low in soil fertility. Soils within the County differ in depths, texture, chemical properties and physical conditions mainly influenced by the geology (GOK, 2005). The soils can be grouped into those falling in the coastal plains, coastal uplands and erosional plains respectively. The soils in the coastal plains have developed on coral limestone and Kilindini sands and are well drained, loamy and sandy. Sand dunes and mangrove forests are found in this region. The coastal uplands consists of sandstones, red shale, grey gravel or sand while the erosional plains consist of sandy and clayey soils developed on Pleistocene bay sediments (GOK, 2005). Different soil types have different rates of permeability and porosity and thus affect infiltration differently; aspect which are important in evaluating flood risk (Okoth, 2010).

3.2.5 Vegetation

The vegetation in Kilifi County is highly heterogeneous (Grigalunas and Congar, 1995). The original fauna and flora in the County has greatly been modified through human interface and in particular urbanization and settlements. Natural forests in the area are rich in biodiversity and are gazetted or non-gazetted. There are 14 small forests which are gazetted and are spread across the Hinterland and along the coastal area covering a total area of 220km². The non- gazetted forests cover an area of 25km² (Grigalunas and Congar, 1995). The area also has planted forests and woodlots. The main forest in the area is the Arabuko Sokoke forest and the Kayas. Others are the Dakacha Woodlands and the Mangrove. Vegetation types in the area include woodlands, bush lands, savanna, acacia and coastal dunes and they spread from the coastal line inland. The tree species in the area include; *C. Tangal*, *R. Mucronata*, *A. Marina* X. *Moluccensis*, and *L. Racemosa* (Grigalunas and Congar, 1995). Eucalyptus is the most predominant tree species in the planted forests and woodlots (Grigalunas and Congar, 1995).

3.2.6 Infrastructure

Major transport or communication lines in Kilifi County are found along the coastal strip mainly to allow access to the beaches and the rich cultural sites in the County (GOK, 2005). This helps in stimulating commerce and easing commutation with neighboring Counties. There is an international airport in Malindi which is important in transportation of tourists from overseas. Most commercial centers and service facilities such as hospitals are situated along the

transport lines. Kilifi Town which serves as the Headquarters for Kilifi County is situated along the Mombasa- Malindi road. The good transport linkage offers a mutual exchange for goods and services between Kilifi and other areas (GOK, 2005). The impervious surfaces created through road construction and development of settlements hinders water infiltration thus promoting flooding. Development of physical infrastructure also alters natural drainage thus affecting flow direction and accumulation (Mustard and Fisher, 2004).

3.2.7 Population Profile and Settlement Patterns

According to the 2009 Kenya population census report, the population of Kilifi County (then Kilifi District) was 1,109,735. The population growth projection by 2025 on the basis of the inter-census population growth rate at 3.0% is as shown in Table 3.1.

Table 3.1: Population Results for Different Censuses

Year	1979	1989	1999	2009	2025
Population	430,986	591,903	825,855	1,109,735	1,642,408
Density (p/km²)	34.2	46.9	65.5	88	134
% growth rate	3.22	3.39	3.0	3.0	

Source: KNBS (2010)

Settlement patterns are linear, especially along the major road from Mombasa to Malindi including Mtwapa and Bahari due to good communication facilities along the roads. The areas also receive plenty of rainfall that supports agricultural activities and provides business opportunities. The high density areas are found around Kilifi and Mtwapa towns that provide employment opportunities and

facilities including schools, hospitals, electricity and piped water and have high agricultural potentials. Areas in the hinterland, including Ganze, Vitengeni and Bamba are arid and less productive agriculturally. They are suitable for livestock rearing because the tracks of land are large. Areas around Kikambala and Bahari have high populations due to the existence of manufacturing industries that provide employment to the locals and fishing activities along the coastline (KNBS, 2010). Figure 3.3 is a map showing the road network, market centers and towns in Kilifi County.

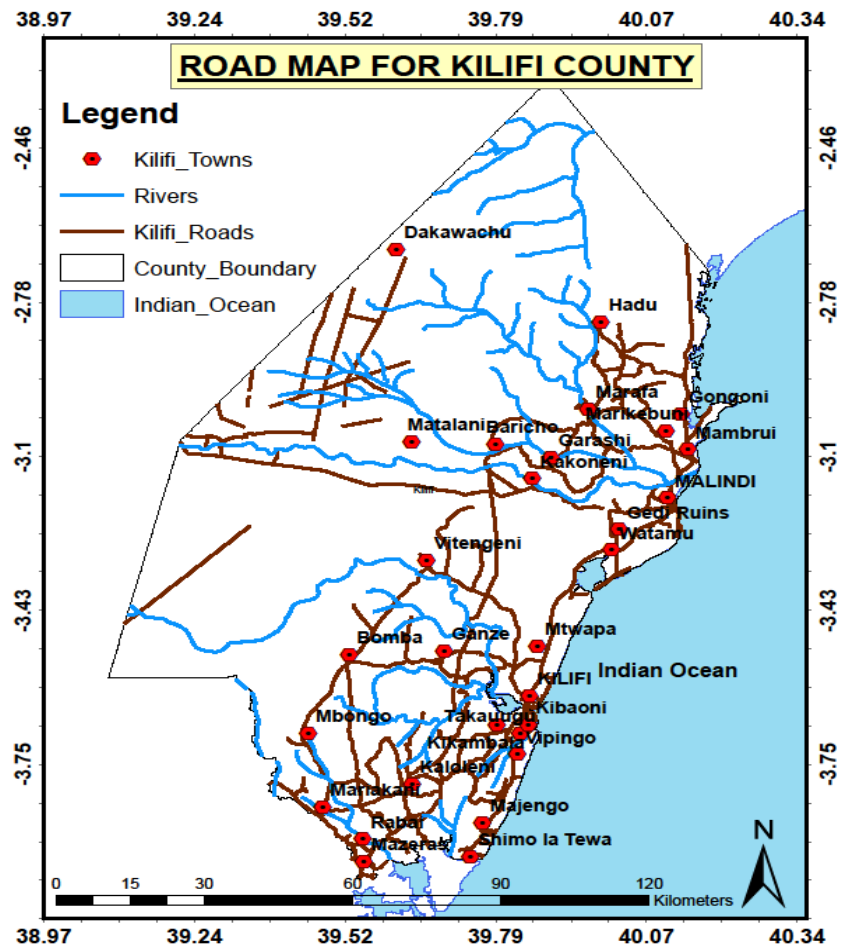


Figure 3.3: Market Centers and the Road Network in Kilifi County

Source: Modified from KCIDP (2013)

3.2.8 Social Economic Characteristics

Farming and fishing are the main income generating activities in the County. Tourism also thrives in the area due to the presence of lovely beaches and creeks along the coastline together with star- rated hospitality facilities. The County also has a rich cultural heritage and sites that also attract tourism sites e.g. the ruins at Mnarani (GOK, 2005). There are other money making ventures accompanying tourism in the area including transportation and different forms of art. Kilifi County hosts a number of public and private beaches and hotels and offers an alternative for beach tourists from other coastal towns (KCIDP, 2013).

Farming for subsistence is distributed throughout the County. Cash crop farming is practiced in Malindi, Magarini, Kaloleni, Kilifi South, Rabai and Kilifi North. Maize, green grams, cow peas and cassava are some of the major subsistence crops found in the area while coconuts, pineapples, cashew nuts, sisal and mangoes are grown as cash crops in the county. The area has eight group ranches and four private ranches for livestock farming- which is also a major source of livelihood in the county. Lately, horticultural farming has been on a steady increase and is usually practiced under irrigation and greenhouses (KCIDP, 2013).

Titanium and iron ore are some of the major minerals that have increased mining activities in the County. Kilifi County is also rich with barites, galena, rubies, pozzolana, gypsum and limestone. Salt is also mined in the area as with sand being harvested in some of the areas. These mining activities have been a source of vegetation loss in the area despite generating hefty amounts of income. Salt

pans and lagoons have increased flooding the area (KCIDP, 2013). Major manufacturing activities that provide employment to the locals include steel and iron sheets, sisal and the Cement industries respectively

3.3 Research Design and Methodology

To achieve the study's objectives, data on drainage density was first obtained through the filling of the sinks in the 30m DEM using the "Fill tool" in Spatial Analyst in ArcGIS 10.2. Drainage basins were then delineated from the DEM. The DEM was then subjected to analysis to determine the flow direction and flow accumulation determined and finally a network of streams and drainage density were generated. Landsat Images were mosaicked to generate a composite which was then clipped to extract the area of study. The mosaic was subjected to unsupervised classification and finally digitized to generate LULC maps and land cover statistics. An accuracy analysis was conducted to establish the margin of error on the land cover maps. Soil distribution maps were generated from the soil data, rainfall distribution maps were generated from rainfall data, while slope maps were obtained from DEM data respectively. The thematic maps on land cover, soil distribution, rainfall, drainage density and slope were converted to raster format, ranked and the Weighted Layer Overlay method applied to generate a flood risk map for the area of study. All these processes were performed in ArcGIS 10.1. Pearson Correlation method was used to establish the relationship between river discharge and land cover changes. Figure 3.4 is a summary of the methodology from the acquisition of data, to data processing and presentation.

3.4 Types and Sources of Data

3.4.1 Primary Data

This is the first hand or the raw data obtained from the field. It involved field measurements on infiltration, collection of points using a Global Positioning System (GPS) for ground truthing and taking of photographs.

3.4.2 Secondary Data

This refers to data from documented literature on the research topic. This data was obtained from documented and undocumented literature such as government and NGOs' publications, journals, strategic and development plans, text book and internet or online sources.

3.5 Sample Design and Sampling

Sampling refers to the method of selecting a representative unit from a population under controlled conditions. The sampling methods in this study were: stratified, purposive and simple random respectively. Collection of field data involved a combination of the three sampling methods as they proved to be interdependent.

Areas were stratified according to land cover and land use type (Table 3.3). The stratified locations were divided into plots of about 20m x 20m. GPS points and land cover information was collected randomly from each of the selected plots. Purposive sampling was employed to identify sites for infiltration experiments.

3.5.1 Target Population

In order to fully achieve the objectives of this study, the target population was selected mainly from three Constituencies of the County including Kilifi North, Kilifi South and Malindi. These areas are dynamic in land forms, land cover, soil types and land use and hence form a representative sample. The logistical arrangements previously mentioned and time constraints allowed a realistic 600 GPS points and 12 infiltration experiments. The situation on the ground is therefore presented rather than generalized.

3.5.2 Data Collection Instruments

3.5.2.1 Observation Guides and Checklists

This method involved the systematic watching/viewing of discrete features on land cover and activities on land use and recording on a template (Appendix I and Appendix II). Field measurements on infiltration were recorded on Appendix II. Checklists helped in ensuring that observations in the field were within the topic of study or interest.

3.5.2.2 Photographs

Photographs enabled the capturing of information on desired sites. The appeal of this technique is in its ability to clearly visualize scenes and scenarios being discussed in words. Photographs were used to show various types of land use and land cover and infiltration experiments' sites and set up.

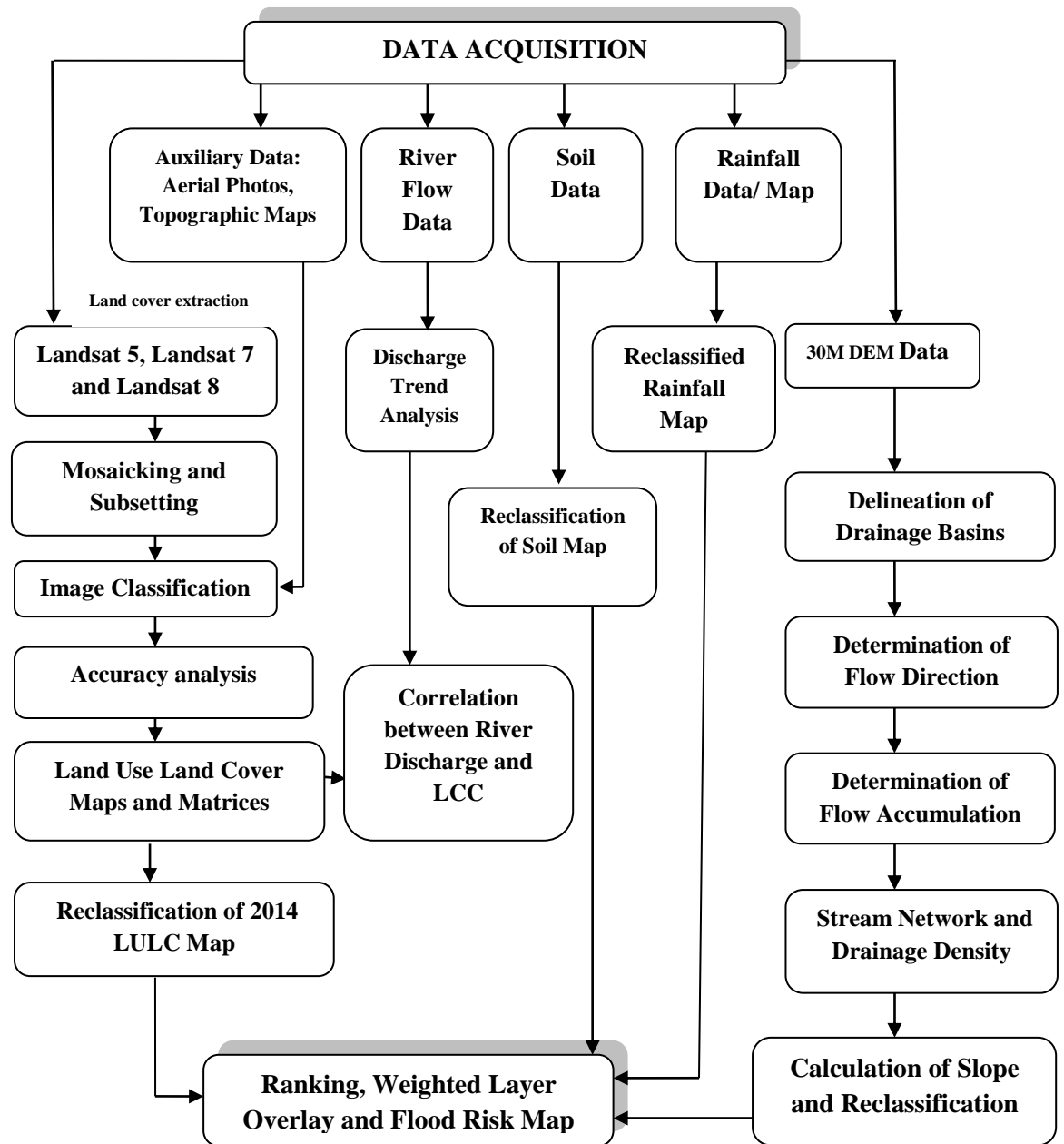


Figure 3.4: Research Design and Flow Model

3.6 Data Description

3.6.1 Remote Sensing Data

A set of Landsat 5 TM, Landsat 7 ETM and Landsat 8 ETM images was used to generate spatial information for 1990, 2000 and 2014 respectively. Landsat 5 TM has a unique feature than the previous Landsat images (2, 3, 4) a sensor (Thematic Mapper) that has better resolution spatially and spectrally (NASA, 2011). This enables the satellite to capture images from a wider view. Landsat 7 was launched in 1999 with an Enhanced Thematic Mapper plus (ETM+). This satellite has an additional eighth band (panchromatic band) with a spatial resolution of 15m that enhances the clarity of the image (NASA, 2011).

These satellite data sets were obtained through the Regional Center for Mapping for Resource Development. Satellite images used in the study were from the dry period- January. Data selection was on the basis of availability of images devoid of clouds, clarity and for analysis LCC for elongated time duration. Images taken during this period have less cloud cover and most of the annual croplands are fallow which is of benefit in discrimination of other land cover classes. The images fall astride two scenes. The images were already orthorectified, georeferenced to the UTM WGS 84 Datum projection and were available in Geotiff format.

Other factors considered in acquisition of Landsat images include their availability of the years in question. Efficacy and simplicity of use of Landsat images makes them a preferred choice for many in LCC analysis as opposed to

other data types (ESRI, 2010). Table 3.2 is a list of the Landsat images used in the study and their dates.

Table 3.2: List of Landsat Images

Image No.	Image Type	Path	Row	Date Taken
1	Landsat 5	166	62	11/ 01/ 1990
2	Landsat 5	166	63	11/ 01/ 1990
3	Landsat 7 ETM	166	62	22/ 01/ 2000
4	Landsat 7 ETM	166	63	22/ 01/ 2000
5	Landsat 8 ETM+	166	62	25/ 01/ 2014
6	Landsat 8 ETM+	166	63	25/ 01/ 2014

Source: Global Information Facility (GIF), 2014 (Through RCMRD)

3.6.2 Digital Elevation Model (DEM)

A DEM was obtained from the CIAT-CSI SRTM (<http://srtm.csi.cgiar.org>) as provided by Jarvis *et al.*, (2008) through the Regional Center for Mapping of Resources for Development (RCMRD) and in decimal degrees and in WGS84 datum. This data had a resolution of 30m. The data was projected into the UTM coordinate system and clipped to fit the extent of the study area.

Information obtained from the DEM included the elevation, stream network for the area, watershed extent, water basins in the area and helped in determining the flow direction and accumulation. The DEM was then reclassified to generate slope angles and stream density which were then overlain to generate a flood risk map for the area.

3.6.3 River Flow Data

River data from station 3HA13 Sabaki Baricho gauging station pertaining to River Sabaki sub-basin was obtained from WARMA. The data covered a period between 1990 and 2012 though there were no readings for some years. This period coincided with the period for which the analysis of land cover for the study was conducted. Raw data from the gauging station comprised of gauge heights (in meters) and river discharge (m^3/s). This data was used to determine the trend of surface runoff flow for the period of study. The river flow data obtained had 95% completeness. Appendix III is the Stream Flow Data used in the study.

3.6.4 Soil Distribution Data

Soil distribution data was obtained from the Survey of Kenya through the Regional Center for Mapping of Resources for Development in Geotiff format. The information obtained from the data included the soil type, the geology and rock structure. Different soil types have different permeability, porosity and infiltration capacities and therefore differing influence on flooding. This added an important aspect in the evaluation of flood risk in the area.

3.6.5 Rainfall Distribution Data

Spatial rainfall distribution is an important factor in evaluating flood risk. Rainfall data used for the risk analysis was from the Tropical Rainfall Measuring Mission (TRMM) obtained through the Regional Center for Mapping of Resources for Development, Nairobi. The data covered the period between January, 1990 and

August, 2013. The data was made available in Geotiff format. The data was already interpolated to create a continuous rainfall raster of the area of study. This data gave a historical trend in Rainfall distribution for all the regions in the area of study. The TRMM data was used in the generation of a spatial rainfall distribution map as it had a higher resolution compared to other rainfall grid maps. Rainfall is one of the parameters used in assessing flood vulnerability and risk.

3.6.6 Ground Truth Data

Field Ground Truth Mapping and aerial photographs downloaded from Google Earth (<http://www.googleearth.com>) were used as sources of auxiliary information. This information was particularly important during classification of images and helped in identification of features to achieve maximum accuracy during the classification process.

3.6.7 Infiltration Data

This data was obtained through field measurements using a Double Ring Infiltrometer on different land cover classes identified. In total, twelve infiltration experiments were conducted in the area using a double ring infiltrometer. The infiltration sites were randomly selected but were guided on water availability and site accessibility. The distribution of infiltration experiments conducted was 3 in the croplands, 2 in the grasslands, 3 in the settlement areas, 2 in the forested areas and 2 in the shrublands- forming a total of 12 experiments. Appendix II is a template used in collection Infiltration data. The recordings were conducted of water level drop (in cm) against time (in min).

3.7 Data Analysis

3.7.1 Determination of the Extent and Nature of LULCC in Kilifi County between 1990 and 2014

The orthorectified and georeferenced images were analyzed on an ArcGIS 10.1 platform. The Landsat images covering the period between 1990 and 2014 were then classified using a combination of unsupervised classification onscreen digitization in ArcView.

3.7.1.1 Mosaicking

Analysis of remotely sensed images started with Mosaicking. Mosaicking refers to the seamless joining and stitching of adjacent imagery (ESRI, 2010). This happens if the Landsat used are from different scenes or dates. The mosaicked images were then subset to extract the extent of the study area. The mosaic tool in ArcGIS 10.1 was used for this analysis.

3.7.1.2 Image Classification

Basic classes were first generated through unsupervised classification while taking into consideration the spectral characteristics of the image. Unsupervised classification was applied because most of the features in the pixels were not easy to identify. However, only wetlands and grasslands could be easily identified. The biggest challenge was separating shrublands and grasslands. Auxiliary information (previous area maps, aerial photographs, and ground truth data) was then used to identify the classes. The images were classified by grouping the cells

with similar reflectance values (ESRI, 2010). The results of the unsupervised classification formed the basis for the land cover extraction process.

Areas with good spectral clustering in unsupervised classification and were easily recognized from ground truthing were taken into consideration while determining the classes. All the mosaic images were subjected to visual interpretation to derive the major LULC classes. The task was performed in ArcGIS 10.1. Digitization was performed onscreen. The classes generated and analyzed for change and classification were; settlement areas, wetlands, croplands, shrublands, forestlands and the grasslands. Information was complimented with aerial photographs and any other information obtained during the field survey (Table 3.3).

Table 3.3: Description of Land Cover Type

Type of Cover		Description
S o u r c e	i) Croplands	Planted crops, Irrigated crops, Perennial Crops
	oii) Forestlands	Planted forests, Woodlots, Mangrove, Riverine forests, Closed canopies
	riiii) Grasslands	Large tracks of uncultivated land with scattered trees used for grazing or as game reserves
	iv) Shrublands	Trees/ bushes with a height of five feet or less, open or closed canopy
	v) Settlements	Villages, Commercial/ Residential structures, Paved surfaces, Roads
	u vi) Wetlands	Ponds, Pans, Seasonal/ Permanent rivers, Marshy Areas, Dams

Source: Modified from Mustard *et al.* (2004)

3.7.1.3 Accuracy Assessment

This refers to a process by which the classified images are evaluated (Lillesand and Kiefer, 2002). The primary reason for this process is to evaluate the correctness of the whole process of classification. Accuracy evaluation for this study was based on the delineation of the various classes, ground truth data and the output of the procedure of unsupervised classification. Reference points were selected from the classified image and compared against images from Google Earth. Accuracy assessment was conducted for each of the images used during the study.

According to Lillesand and Kiefer (2002), there are two forms of accuracy; User's and Producer's. The former corresponds to the error of Commission (inclusion). For instance, several sites of shrublands could be erroneously included in the grassland category. The latter refers to the error of omission, e.g. the number of sites of a particular class being omitted in another reference class. The output of the evaluation in accuracy on images were error matrices; which represent a comparison between the reference class values and the values assigned and accuracy totals in percentages based on the results in the confusion error matrix. Kappa statistics, which reflects the actual agreement and the agreement expected by chance, were also calculated. A Kappa (k) value of 0.85 for instance means that there is 85% better agreement than by chance alone (Lillesand and Kiefer, 2002).

3.7.1.4 Change Detection

The area (in km²) for LULC types was calculated for every year in question and the output compared based on the different classes. This helped in obtaining important statistics used for establishing changes in percentages, the trends and extent of change between 1990 and 2014. The statistics were tabulated and then used to compute into percentages to obtain the trend of change as is indicated in the formula below:

$$\% \text{ Change} = \frac{\text{Difference in Change} \times 100}{\text{Total Change}}$$

3.8.2 Establish the Impact of LULCC on Surface Runoff and Infiltration Capacities

3.8.2.1 Infiltration Rates

Infiltration rates (obtained using a double ring infiltrometer) under different land cover classes were obtained during the field work and later tabulated and analyzed. Infiltration curves were derived from the data showing the relationship between infiltration capacities against time. A detailed analysis was then conducted to establish the relationship between LULCC surface runoff and infiltration capacities.

3.8.2.2 Procedure followed in conducting the Infiltration Experiments using a Double Ring Infiltrometer

An infiltrometer is used to measure infiltration rates (Amount of water percolating the ground with a given period of time). The following procedure is usually followed and was adopted while conducting the field experiments as outlined by Diamond and Shanley (2003); (Plate 3.1 is the infiltration experiment Setup).

- i) Set the experiment on a flat surface on the selected site. The site should be undisturbed.
- ii) Using a hammer, drive the outer and the inner rings to approximately 5cm into the ground. The hammer type should be one that absorbs the impact.
- iii) To reduce the likelihood of hindrances on the measuring float, gently clear the vegetation on the infiltration site. This should be done with caution to avoid disturbing the soil structure.
- iv) The measuring bridges, the measuring rod together with the float are then placed on the inner ring.
- v) Saturate the bigger ring with water to around 5-10cm. This helps prevent lateral flow and helps in enabling measurements only for the infiltration capacity of the saturated soil.
- vi) Fill the inner ring with water to around 5-10cm
- vii) Start the measurements and record the starting time from a clock and the initial level of water from the measuring rod in the smaller (inner) ring. This acts as the reference for proceeding readings.

- viii) Record the readings on a template of rate of the water drop level against time (m/s). (See Appendix II for template).
- ix) Stop measuring only when the drop level reaches a constant value.

The infiltration sites were randomly selected but were guided on water availability and site accessibility. Plate 3.1 shows the setup for a double ring infiltration experiment. All the sites selected for experiments were heterogeneous in soil type; all had sandy, loamy or clay type of soil respectively.

3.9 Stream Flow Data Analysis

There are several indicators and determinants of the rate of runoff after precipitation events. One of them is through the analysis of river discharge data. Trend Analysis was conducted for the available data using mean monthly discharges (1990 - 2012). A correlation analysis was then conducted to determine the relationship of change in river discharge against time. Trend lines were then generated to show the relationship between discharge and time. Charts showing long term discharge trends were also generated. A strongly linear relationship means that there could be a strong influence of LCC on surface flow. The values of the relationship in the equation ranges from between -1 to +1; with the values close to -1 depicting a strong negative linear relationship while values close to +1 depict a strong positive linear relationship between the dependent and independent variable. A value "0" indicates no relationship and this implies that the dependent variable (discharge) was not influenced either positively or negatively by the independent variable (time).



a) Experiment in a cropland



b) Experiment in a shrubland



c) Experiment setup in a grassland



d) Experiment in a cropland



e) Experiment setup in a settlement



f) Experiment setup in a grassland

Plate 3.1: A Double Ring Infiltration Setup at various selected sites

Source (Field Work, 2014)

3.10 Production of a Flood Risk Map

A flood risk map was generated by overlaying reclassified information based on the land cover type, Digital Elevation Model (DEM), drainage density, soil type and spatial rainfall distribution. Land cover type cannot be used to evaluate flood risk in isolation since the surface characteristics are dictated by the aforementioned factors. These factors affect an area's vulnerability to floods in different capacities. The various datasets were converted into raster formats using the image analysis commands in ArcMap. They were then reclassified under the Spatial Analyst Tool and values assigned with a rating scale of 1 to 5 based on their influence on human susceptibility, surface water flow and water infiltration. In the ranking, very high risk areas were assigned value "5", while low risk areas were assigned value "1". All the layers from different datasets were then assigned weights based on their influence on risk posed to humans, overland flow and water percolation after precipitation events and overlain to produce the flood risk map (Figure 4.13).

3.10.1 Flood Risk Zoning Based on LULC

Land cover and land use play a crucial part in water percolation, infiltration and ground water recharge; parameters which are important while assessing flood risk. The land cover map for 2014 was generated bearing six land cover classes; croplands, forestlands, grasslands, settlements, shrublands and wetlands. The classes were then reclassified, ranked and weighted based on their ability to hold water which eventually ends up as flood water. Settlements were given the

highest rank due to human interference with soil structure and infiltration capacity of soils through vegetation removal, urbanization and cultivation. Wetlands were assigned the lowest rank since they act as water sinks and therefore such areas are expected to be waterlogged or flooded whether during the dry or during the wet season. The influence of land cover type on flood risk is usually assessed against soil type and land use activities.

3.10.2 Flood Risk Zoning Based on Soil Type

Soil type and distribution is a major factor controlling the quantity of surface water occurrence. Various soil types have the capacity to influence infiltration differently. The major soil types in the area were identified and reclassified based on their influence on flood risk. The area was found to have clayey, loamy and sandy soils. Areas falling within the clay soils are ranked highly at risk as they have poor porosity and are less permeable (Figure 4.9). Loamy soil areas are considered as moderate in their influence on flood risk. Sandy soil areas considered as low in their influence on flood risk due to their high porosity and permeability.

3.10.3 Flood Risk Zoning Based on Slope

Slope is an important factor in the identification of flood risk areas. 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 (Mustard and Fisher, 2004). On gentle slopes runoff doesn't drain fast as there is low velocity and thus accumulation of much water

after precipitation events is likely to generate into a flood. On steep slopes, surface water moves at very high velocities allowing very little residence time and thus very low chances of flooding in such areas. Spatial Analyst Tool in ArcGIS was used to calculate the slope angles of the DEM. The slope angles were then reclassified to create 5 classes. The slope angles in the area range between 0° and 28.705° . Areas $\leq 1.238^{\circ}$ are relatively flat and are considered to the highest at the risk of flooding. Areas $\geq 10.244^{\circ}$ are steep slope and are the lowest in terms of the risk they pose to flooding. The generated classes were then ranked depending on their influence on flooding. The lowest rank was assigned to the very steep slope because they result to low infiltration and high surface runoff thus less likelihood of flooding. The low slope areas were ranked highly due to their ability to hold water thus making an area more susceptible to flooding.

3.10.4 Flood Risk Zoning Based on Spatial Rainfall Distribution

Rainfall is the main source of flooding. Rainfall amount, distribution and intensity are the main aspects considered while evaluating the influence of rainfall on flood risk. Different types of soils respond to rainfall differently. Soils with high porosity and high infiltration rates allow rain water to drain faster through them compared to soils with a fine texture and small pores. Rain distribution is also influenced by vegetation cover, presence or absence of hills and mountains and availability of water bodies. Annual rainfall data covering the period between 1990 and 2012 formed the basis for the generation of a rainfall map. Analysis of the spatial rainfall distribution data indicated that rainfall amounts ranges between 0 and 1471mm. The average annual rainfall was calculated for this period. The

average annual rainfall for the dry areas is 542mm while the average annual rainfall for the wet areas is 1471mm. This was reclassified into five classes. The classes were then ranked based on their influence on flood risk. Flood risk based on rainfall is evaluated against a susceptible receptive ground. High rainfall amounts imply the potential for floods if the ground is vulnerable and thus such areas were considered to be high risk zones.

3.10.5 Flood Risk Zoning based on the Drainage Network

3.10.5.1 Filling of Depressions

To obtain any hydrological information from DEM raster data, all the crevices are first “filled”. The crevices are also known as sinks (UCAR, 2010). The “Fill” tool was used to execute this function. This tool is found in the “Spatial Analyst” section in ArcGIS 10.1.

3.10.5.2 Flow Direction

The DEM in which all the sinks were filled was used in generating a flow direction raster. The flow direction is important in showing the probable direction of runoff on the DEM. The “Flow Direction” tool in Spatial Analyst of ArcGIS 10.1 was used to establish the path followed by water as it flows downstream.

3.10.5.3 Flow Accumulation

Flow accumulation refers to the cells within the study area to which water accumulates while flowing downstream was then determined. “Flow Direction”

was used as the input in the “Flow Accumulation” tool in Spatial Analyst. Residential areas within those cells which receive more water during precipitation events are more likely to be flooded and are more likely to be flood plains and water bodies or wetlands.

3.10.5.4 Creation of stream Network

To show the path followed by the streams on the DEM, a network of streams was generated from the flow accumulation raster. A reclassification of the low accumulation results was conducted in the Spatial Analyst Tool with streams having a length of 10km (18500 cells) acquiring a value of “1” while streams with lengths less than 10km acquiring a value of “0”.

3.10.5.5 Drainage Density

This refers to the distance between one stream and another (Ouma and Tataeshi, 2014). It’s also an indicator of the total distance covered by each stream in a given area (UCAR, 2010). Drainage density indicates the flood vulnerability indirectly due to its relationship to surface runoff and permeability (UCAR, 2010). The drainage density of an area is obtained from the stream network. The Kernel Density tool in ArcGIS was used to calculate the drainage density and to create a drainage density map.

3.10.6 Flood Risk Zoning Based on Drainage Density

Areas with low permeability have low infiltration rates and are usually characterized with low drainage densities. Flood risk is usually concentrated in

low density areas as there are few channels to drain water and this water ends up as flood water. Areas with high drainage densities are considered to be well drained and are characterized with a highly permeable rock structure and therefore low in flood risk.

The drainage density was reclassified in the Kernel Density Analysis Tool and new values allocated. Reclassification was done using the reclassify command in ArcGIS. Ranking was then done based on the influence of density to flooding; (5) assigned to areas with very low density, (1) assigned to areas with high density (Table 3.4).

3.10.7 Overlay of Layers and Generation of Flood Risk Map

3.10.7.1 Weighted Overlay Method

GIS helps in developing a weighted model to zone out flood risk areas (Ouma and Tateishi, 2014). A common measurement scale of values is applied to diverse and dissimilar parameters to help in the creation of an integrated analysis (Carver, 1991). The inputs of analysis may not however have the same weights. Each individual cell is reclassified into units of suitability and assigned a weight. The weights are then added together and must add up to 100% (Carver, 1991).

In the present study, all thematic layers were integrated in ArcGIS 10.1 platform to create a map depicting different flood risk zones. The input layers were obtained from the following thematic maps: land use and land cover, soil type, slope angles and elevation, rainfall distribution and drainage density. Each of the

pixels in the final integration layer were regrouped into different classes with equal class intervals to divide the area into different zones. Thematic maps are usually reclassified to create integer values instead of ranges/ themes to be used as themes in the model (ESRI, 2010).

The layers obtained from the reclassified land cover classes, the soil map, rainfall map, the stream density and the reclassified slope angles were then added together by overlaying all the thematic layers using the weighted overlay method with the help of the spatial analyst tool in ArcGIS 10.1 to generate a flood risk map. All the thematic layers were considered to have the same probability of influencing flood formation and thus were assigned the same weights (Table 3.4). The choice of weights is as a result of individual opinion and a review of existing literature that gives all the parameters an equal chance to generate a flood as there is no standard formula to generate the weights.

Table 3.4: Ranks and Weights for Thematic Layers

Thematic Layer	Class	Rank	Risk Vulnerability	% weight
Land Cover	Settlements	5	Very High	20
	Cropland	4	High	
	Grassland	3	Moderate	
	Shrubland	2	Low	
	Forestland	2	Low	
	Wetland	1	Very Low	
Slope Angle (Degrees)	0 - 1.238	5	Very High	20
	1.238 - 2.814	4	High	
	2.814 - 5.403	3	Moderate	
	5.403 - 10.244	2	Low	
	10.244 - 28.705	1	Very Low	
Rainfall	542 - 745	5	Very High	20
	745 - 882	4	High	
	882 - 1038	3	Moderate	
	1038 - 1229	2	Low	
	1229 – 1471	1	Very Low	
Soil	Very Clayey	3	High	20
	Clayey	3		
	Loamy	2	Moderate	
	Sandy	1	Low	
Drainage Density (Per km)	0 - 4.569	5	Very High	20
	4.569 - 9.138	4	High	
	9.138 - 13.706	3	Moderate	
	13.706 - 18.275	2	Low	
	18.275 - 22.844	1	Very Low	

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents results and findings from analysis of data divided into three parts based on the objectives. The first section provides the results of the findings related to the use of satellite images to establish the extent and nature of LULCC in the area of study for the period between 1990 and 2014. The second section reports on the findings on the infiltration experiments conducted in the field and the analysis of river discharge data to establish if there is any effect of LULCC on surface runoff. The third section presents findings on the areas in Kilifi County that are at the risk of flooding based on a combination of factors including rainfall, slope, land cover characteristics, soil types and drainage density. Results are presented in form of tables, graphs, charts and maps.

4.2 Landsat Image Processing

4.2.1 Image Preprocessing

The preprocessing procedure carried out on the images included band combination (layer stacking). This provided for different band combination during image classification and therefore allowing ease with which images were interpreted. The outline of the map for Kilifi County was then used to clip the images to fit the area of study.

4.2.2 Classification of Images

The results of the unsupervised classification are as presented in Figures 4.2b, 4.3b and 4.3c respectively. The false composite images used in the identification of the features were RGB= 4:3:2 and RGB= 3:2:1. The choice of these combinations was as a result of the importance of band 4 and band 3 in the definition of the land/water interface and in discriminating vegetation (NASA, 2011). Water absorbs light in band 4 and tends to appear dark bluish in color. In band 3, vegetation absorbs light and appears green in colour, while the settlements or the built- up areas absorb light and appear blue- gray in colour (NASA, 2011). The Landsat images were classified generating six major classes; croplands, forestlands, grasslands, settlements, shrublands and wetlands. The statistics and distribution of the extent for the land cover for the years 1990, 2000 and 2014 as generated through the statistics tool in ArcGIS 10.1 are as presented in Figure 4.1.

Table 4.1: Land Cover Extent for the years 1990, 2000 and 2014

Land Cover Type	1990		2000		2014	
	Area (Km ²)	% of area	Area (Km ²)	% of area	Area (Km ²)	% of area
Croplands	5076.0	40.5	6134.6	49.0	6246.1	49.9
Forestlands	1279.4	10.2	939.4	7.5	690.1	5.6
Grasslands	5477.9	43.6	4653.6	37.2	5030.4	41.2
Shrubland	534.3	4.3	523.0	4.2	220.8	1.8
Settlements	17.7	0.1	23.2	0.2	110.9	0.9
Wetlands	61.9	1.3	240.8	1.9	78.9	0.6
Total	12245.2	100	12245.2	100	12245.2	100

Source: Author (2015)

A comparison in the land cover classes for the years 1990, 2000 and 2014 shows that land cover classes changed variously. The extent for each land cover is as shown in Figure 4.1.

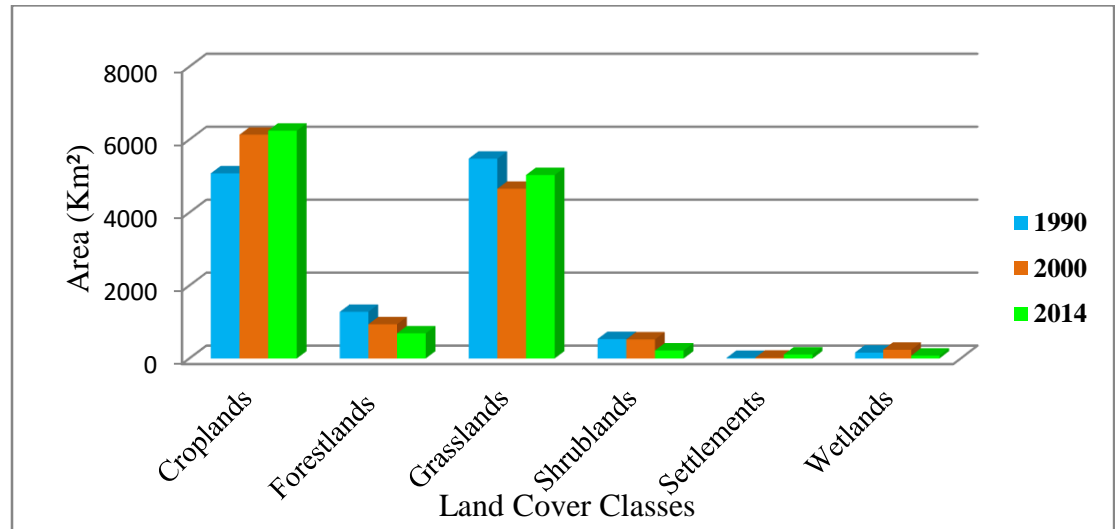


Figure 4.1: Land Cover Extent for 1990, 2000 and 2014

Source: Author (2015)

The results in Figure 4.1 show that grasslands comprised the largest proportion of the total land cover in 1990 with a total spatial coverage of 43.7% while settlements had the least proportion at 0.1%. At 40.5%, croplands also take a big share of total land cover in the area. This is an indication that farming is the major form of land use in the area. Forestlands, shrublands and wetlands formed a cover of 10.2%, 4.3% and 1.3% of the total land cover in the area respectively.

Most of the grasslands are used as grazing areas. The progressive increase in grasslands in the period of study is as a result of forestlands, shrublands and scrublands being cleared. These areas are relatively dry and are found in the inland of Kilifi County. Most of the grasslands are found in the rolling plains and

therefore act as floodplains. Habitation in grasslands increases the people's vulnerability to flooding.

In 1990, wetlands covered 61.9Km² of the total land cover in the study area. In 2000, the size of the wetlands increased to 240.8Km² and then reduced to 78.9Km² in 2014. The increase in the size of area occupied by wetlands is as a result of depressions in the area being inundated with water. The low coverage of wetlands in 2014 is a result of reclamation of the same for agricultural and habitation purposes. See Figure 4.2 for the 1990 mosaic and the LULC map.

In 2000 Croplands increased in spatial extent to be the highest form of land cover in the area occupying 6134.6km². The increase was at the expense of Forestlands, Shrublands and Grasslands which had a spatial extent of 939.4km², 523.0km² and 4653.6km² respectively (Figure 4.3).

In 2014, croplands occupied 49.9% of the total area which was the highest of all the land cover classes. Wetlands had the least coverage at 0.6% in the same year. The Settlements had increased in 2014 to occupy 110.9km² of the total land cover in the area of study (Figure 4.4).

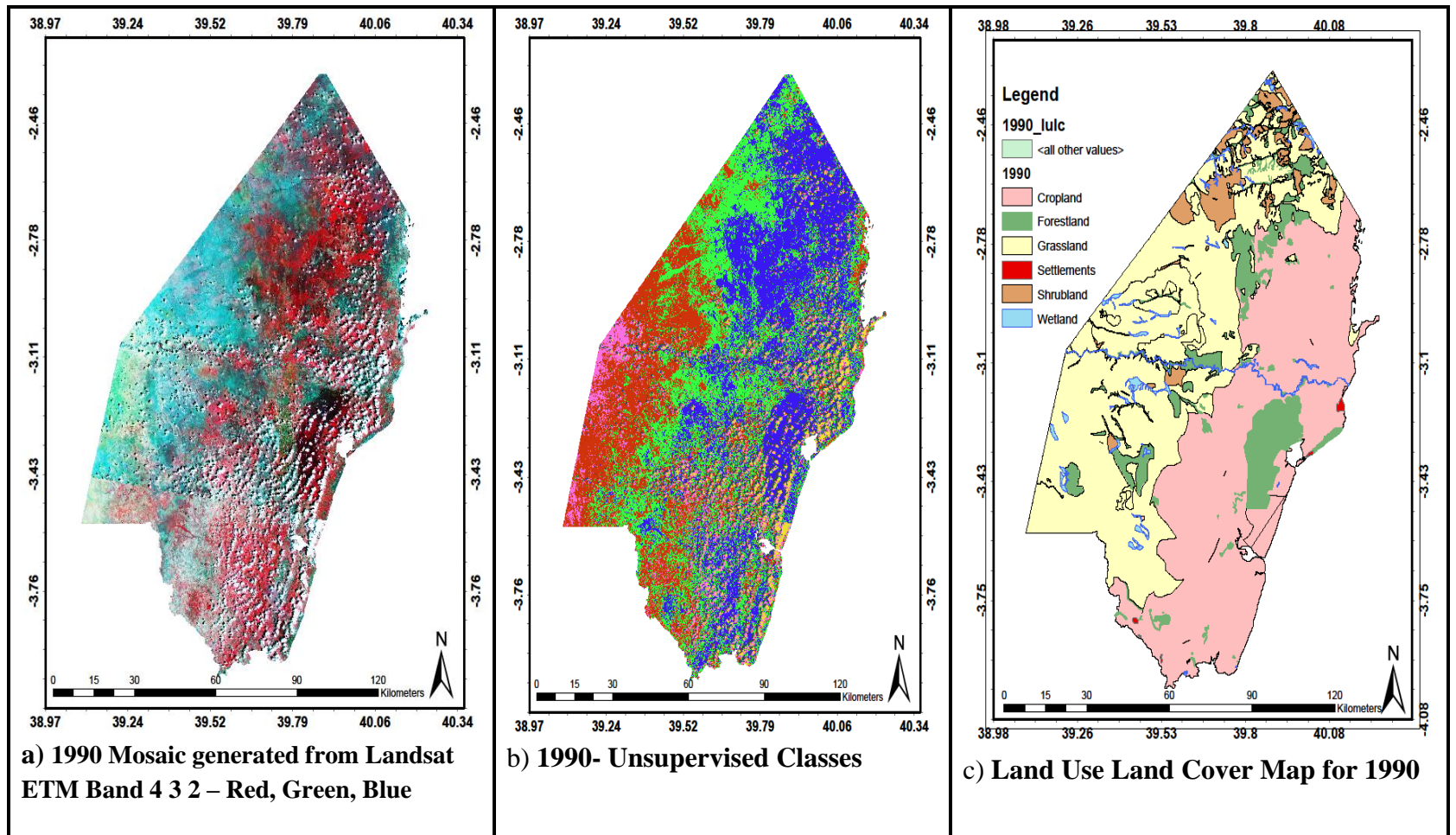


Figure 4.2: (a) Mosaic Image, (b) Unsupervised Classes and (c) LULC Map for 1990

Source: Author (2015)

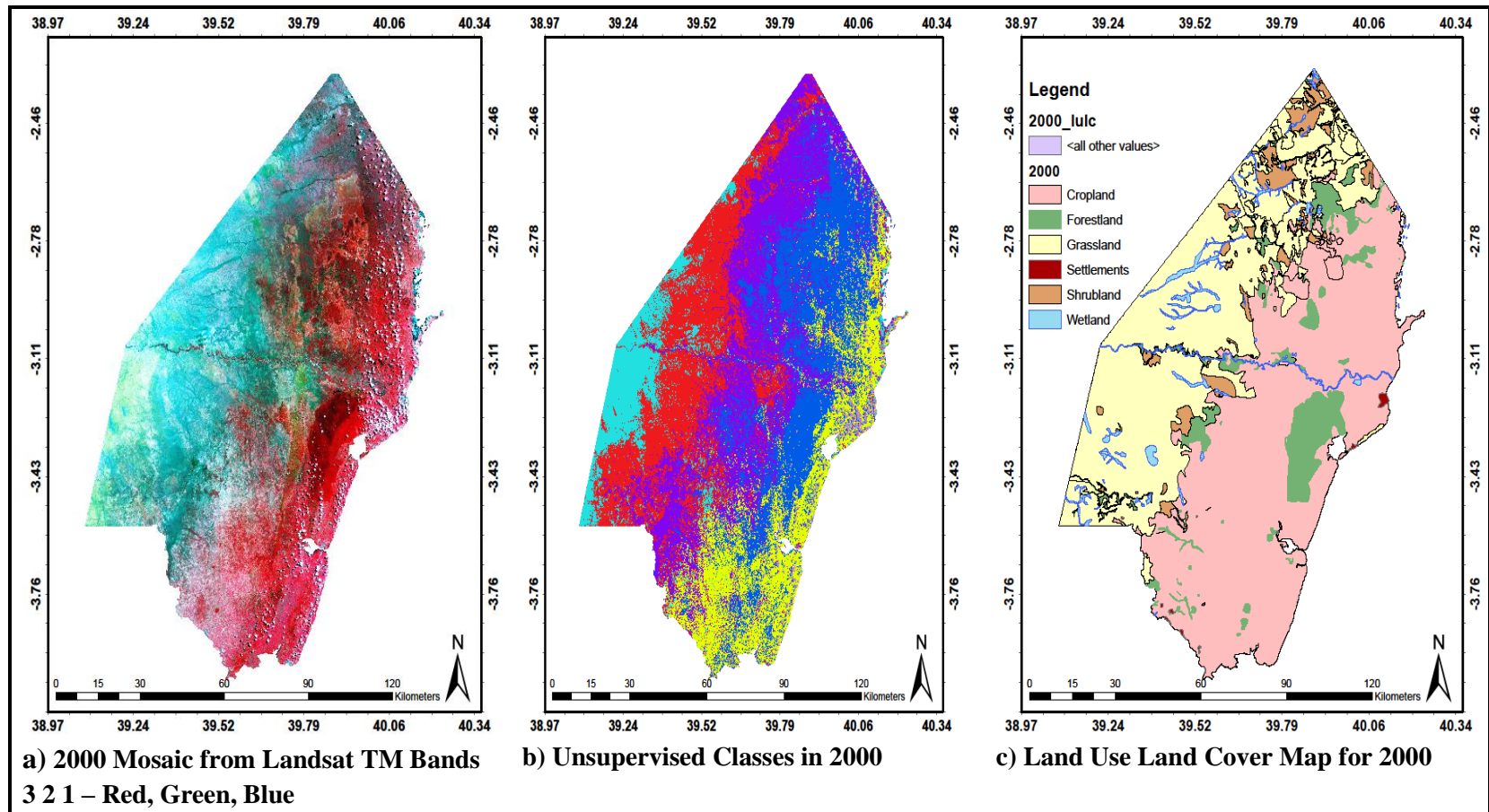


Figure 4.3: (a) Mosaic Image, (b) Unsupervised Classes and (c) LULC Map for 2000

Source: Author (2015)

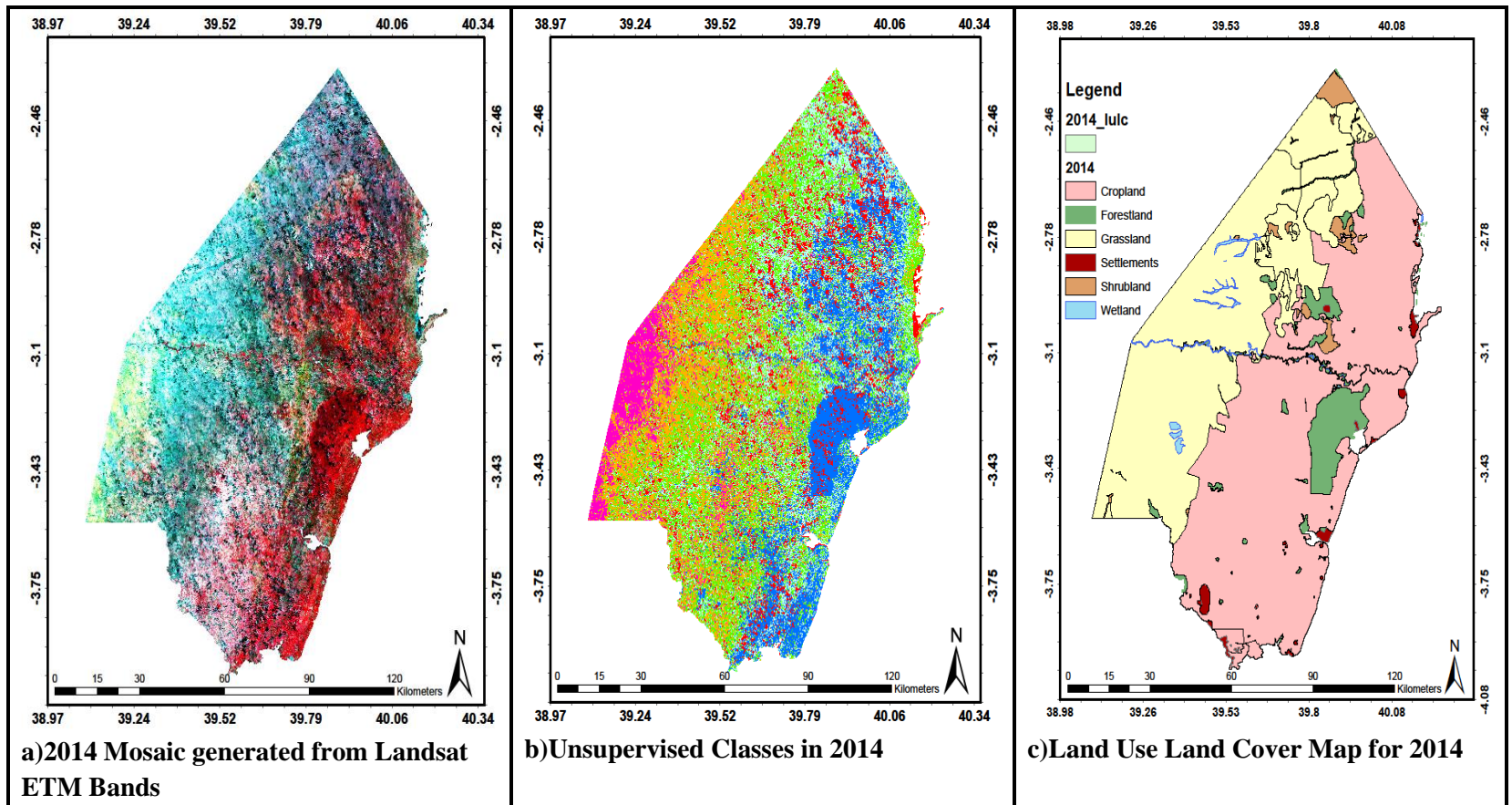


Figure 4.4: (a) Mosaic Image, (b) Unsupervised Classes and (c) LULC Map for 2014

Source: Author (2015)

4.2.3 Spatial and Temporal Changes in Land Cover

The land cover maps were analyzed for changes in between the years 1990 and 2014. The results of the changes are summarized in Table 4.2. The analysis established that there were either gains or losses within the land cover classes in the study area (Table 4.2).

Table 4.2: Spatial and Temporal Changes in Land cover

Land Cover/Use	Change (Km ²)			Change (%)		
	2000 - 1990	2014- 2000	2014- 1990	2000- 1990	2014- 2000	2014- 1990
Croplands	1058.0	112.1	1170.1	20.8	1.8	23.1
Forestlands	-331.0	-249.3	-580.3	-26.1	-26.5	-45.7
Grasslands	-824.3	376.8	-447.3	-15.1	8.1	-8.2
Shrubland	-11.2	-302.2	-313.4	-2.1	-57.8	-58.6
Settlements	5.6	87.7	93.3	93.9	377.9	529.9
Wetlands	78.9	-161.9	48.7	-83.0	-67.2	-51.3

Source: Author (2015)

For the period between 1990 and 2014, croplands increased by 1170.1Km² (23.1%) while forestlands decreased by 580.3Km² (45.7%). In the same period, grasslands decreased by approximately 447.3Km² (8.2%) while shrublands decreased by 58.6%. During this period, there was a gain in settlements which increased by 93.3km² which represents a 377.9% rise. This was the greatest gain for all the classes in proportion. The dynamics in land cover can be attributed to the changes in land use activities in the area.

A change analysis on the classified images indicates that there are different forms of land cover change. The most predominant one is land. For instance, most of the Forestlands and shrublands have either been replaced by croplands, grasslands or settlements. Removal or the decrease in the spatial area under forests or shrublands increases the

chances of flooding in the new land cover classes as there are no filters in form of trees or shrublands to reduce the flow of storm waters to the lowlands. Forests and shrublands also act as sinks or soaks for rainwater through their canopies or litter underneath. Removal of the same and habitation exposes the people living therein to the risk of flooding.

Changes in land cover characteristics are important in determining the level of flood risk in an area. Increased size of settlement areas means an increase in the number of people susceptible to floods due to an increase in the number of inhabitants in the settlements. Exposure to flood risk in the growing settlements is accelerated by the increase in the spatial extent of impermeable surfaces and alteration of natural drainage channels. This inhibits infiltration of water after precipitation events, a factor that contributes to flooding.

Demand for food by the ever growing population has led to an increase in the size of croplands at the expense of forestlands, shrublands and grasslands, most of which serve as flood plains. During flooding events, most farmlands become flooded leading to loss of crop and the economic losses involved. This exposes communities living in those areas and those whose farming is a main source of livelihood to hunger. Continuous ploughing of croplands also loosens the soil increasing the chances of sedimentation of river beds as the top soil is swept off in the process of soil erosion. This raises the water level in such rivers also increasing the chances of flooding.

4.2.4 Accuracy Analysis

Accuracy assessment for this study was based on the delineation of the various classes, ground truth data and the unsupervised classification. Reference points were selected from the classified image and compared against images from Google Earth. Error matrices were generated for each year under study. The overall accuracy in the classification was also generated for the years 1990, 2000 and 2014 together with the kappa statistics. The accuracy analysis generated multiple points within the various classes that were either omitted or wrongly placed in different other classes.

4.2.4.1 Classification Accuracy Assessment for 1990

The land cover map for 1990 had an overall accuracy of 86.7% and kappa statistics of 0.8566. The results for the various classes are as indicated in the table below. The low accuracy levels for this year were attributed to a rather high level of homogeneity in land cover classes causing high spectral similarities. The images from the year also had a high percentage of cloud cover. This led to confusion during classification where many classes were either left out or misplaced in the wrong classes (Table 4.3).

Table 4.3: Error Matrix for 1990

Class	Cropland	Forestland	Grassland	Settlements	Shrublands	Wetlands	Total	Accuracy (%)	
								Producer	User
Cropland	1210	50	22	4	21	2	1309	81.5	80.3
Forestland	43	349	12	5	39	9	457	79.2	73.3
Grassland	56	15	433	2	112	23	641	92.1	80.5
Settlement	12	21	16	70	13	5	137	75.5	78.5
Shrubland	126	66	89	3	389	78	751	72.2	73.2
Wetland	67	88	70	19	92	201	537	80.0	81.1
Column Total	1514	589	642	103	666	318	3832		

Source: Author (2015)

4.2.4.2 Classification Assessment for 2000

The overall accuracy attained for the classification on the 2000 image was 90.2% and Kappa statistics of 0.8912. Images for the year had a low cloud cover compared to the images used in 1990 and thus an improvement in allocation of the right training sites to the right classes. The classes were also more heterogeneous and it was therefore possible to identify classes more easily. The results of the classification are as indicated in Table 4.4.

Table 4.4: Error matrix for 2000

Class	Cropland	Forestland	Grassland	Settlements	Shrublands	Wetlands	Total	Accuracy (%)	
								Producer	User
Cropland	1311	61	12	3	30	10	1427	77.2	82.7
Forestland	50	372	18	5	41	7	493	87.5	79.8
Grassland	42	13	501	1	89	40	684	83.5	76.2
Settlements	10	27	13	53	22	2	136	84.5	85.5
Shrubland	111	51	72	2	421	66	723	73.2	93.2
Wetland	50	79	61	5	101	234	539	81.4	87.7
Column Total	1574	603	690	69	703	359	3993		

Source: Author (2015)

4.2.4.3 Classification Assessment for 2014

In 2014, the overall accuracy obtained from the classification is 92.4% and kappa statistics of 0.9129. In 2014, there was more heterogeneity in the images and thus it was easier to identify the different classes under each cover during classification. As such, there was little misplacement of training sites. The high level of accuracy was possible because the duration between when the images were taken and the time when the images were classified was short and as such the ground characteristics could easily be identified. An increase in bands and resolution improves the clarity of images and thus improvement in accuracy during classification (ESRI, 2010). There was reduced confusion of classes during classification as indicated in Table 4.5.

Table 4.5: Error Matrix for 2014

Class	Cropland	Forestland	Grassland	Settlements	Shrublands	Wetlands	Total	Accuracy (%)	
								Producer	User
Cropland	1222	60	24	5	31	7	1349	87.0	87.5
Forestland	42	315	23	3	39	10	432	91.1	85.0
Grassland	51	20	520	2	92	4	689	78.5	93.2
Settlements	8	32	14	50	25	1	130	90.2	90.2
Shrubland	83	60	69	3	425	70	710	81.0	88.5
Wetland	40	69	58	1	99	215	482	87.5	89.5
Column Total	1446	556	708	64	711	317	3972		

Source: Author (2015)

4.3 Impact of LULCC on Surface Runoff and Infiltration Capacities

4.3.1 Double Ring Infiltration Experiments

Double Ring Infiltration experiments were conducted for each of the land cover classes identified. The major reason the experiments were conducted was to show the different infiltration capacities (m^3/s) for the different sites selected.

The criterion for the selection of the various land cover classes is as indicated in Table 3.3. The infiltration level for each of the land cover classes was calculated and recorded (Table 4.6). A total of twelve infiltration experiments were conducted in the area. The infiltration sites were randomly selected but were guided on water availability and site accessibility.

Table 4.6: Results from Infiltration Experiments

	Site 1			Site 2			Site 3		
	WLR (Cm)	Time (Min)	Soil Type	WLR (Cm)	Time (Min)	Soil Type	WLR (Cm)	Time (Min)	Soil Type
Croplands	18.9	19	L	17.2	22	SL	19.3	19	SL
Forestlands	28.1	5	L	27.7	6	L			
Grasslands	14.7	30	C	13.3	17	SL			
Shrublands	22.5	11	L	26.3	21	C			
Settlements	6.9	28	SL	5.8	21.5	S	6.1	29	L
WRL= Water Level Reading; C= Clay; S= Sandy; L= Loamy; SL= Sandy Loam									

Source: Field Work (2014)

From the results in Table 4.6, the highest infiltration rates are in the sandy soils while the lowest infiltration rates are in the clay soils. However, it is evident that the type of land cover influences the rate at which water percolates into the ground and the depth to which

such water percolates. A total of five infiltration experiments were conducted under the loam type of soil but under different categories of land cover. Two experiments were conducted in the grasslands and shrublands respectively under clay soil. One experiment was conducted in the settlement areas under sandy soils. A total of four experiments were conducted in areas under a mixture of sandy-loam soil type.

From the field experiments, it took an average of 19 minutes for water to fully percolate into loamy soils in the croplands, an average of 5.5 minutes in the forestlands, an average of 11 minutes in the shrublands and an average of 29 minutes in the settlement areas. For experiments conducted under clay soils, it took an average of 30 minutes and 21 minutes for water to percolate the ground in the grasslands and settlement areas respectively. Results for experiments on water percolation conducted under sandy-loam soil type indicated that it took an average of 20.5 minutes in the croplands, 17 minutes in the grasslands and 22 minutes in the settlement areas respectively, while under sandy soils, it took an average of 21.5 minutes in the settlement areas. The water level reading was different for all the experiments probably as a result of the permeability of the type of material lying underneath the soil and the soil depth.

The degree of infiltration and overland (surface) runoff mostly depends on among others the type of soil. The results of the infiltration experiments established that the rates of infiltration are very different depending on the LULC activities. The infiltration capacity of soils impacts significantly on the ability and efficiency of soils for water storage. Water storage capacity is different for all types of soil. Chances of occurrence of floods

increase as a result of a decrease in the soil's infiltration capacity as this leads to an increase in overland runoff. During precipitation events, storm water may exceed the capability of the soil to allow water to pass through. Depending on the soil type, the area might experience flooding.

In the settlement areas, the land is so much paved which creates many impermeable surfaces. The modified land surface becomes hard and thus water takes so much time to percolate into the ground after precipitation events. Some surfaces such as tarmacked roads are totally impermeable to water after precipitation events. Most of the precipitation falling in the settlement areas flows in form of surface runoff and accumulates in other areas and this has an impact on groundwater recharge and soil inundation (Mustard *et al.*, 2004). According Johnson (2008), the speed of runoff is highest in the settlement areas as it is difficult for water to percolate the ground and thus most of the water uses the available streams (including the paved surfaces) to flow to other areas, often with increased speed and volumes. Water runs over the surface and accumulates in the low lying plains, often causing flooding and erosion.

Most of the forestlands, shrublands and scrublands are often undisturbed and thus the degree of water infiltration is highest and speed of runoff is lowest in these areas. Leaves and trees in these areas reduce the force with which the raindrops hit the earth's surface, thereby slowing down the speed of runoff. This allows more time for water absorption by plant roots and permit more time for ground water percolation. This explains why the infiltration rates were highest in these areas during the experiments.

The degree of infiltration in the grasslands is moderate as most of the areas classified as such are used as grazing lands. The grasslands are also relatively undisturbed. This makes these areas moderate in terms infiltration. The speed of runoff is also moderate in these areas as the grass and other scattered vegetation slow down the runoff as it moves downward the streams.

The croplands have low infiltration rates due to compaction of soil during tilling and weeding. The infiltration rates in the croplands might differ depending on whether the experiments are conducted in irrigated lands or in croplands, the type of crop planted on a piece of land, whether experiments are conducted in fallow or cultivated lands or depending on the equipment used for cultivation of land. Mechanized croplands have their soils more compacted and as such have low rates of infiltration and an increased speed of runoff. Croplands where no mechanization is conducted have relatively high infiltration rates as the soil is not highly compacted. In irrigated areas, the infiltration rates are low as the soil is saturated with water while in the on irrigated areas the infiltration rates are high as the soil is not saturated with water (Mustard and Fisher, 2004).

From the results on infiltration, settlement areas generate more runoff that ends up in streams or as flood waters. This is so because the soils therein absorb the least amount of water as a result of compaction from human activities. The vegetated areas including forestlands and shrublands generate the least amount of storm runoff as water into the ground at a relatively high rate. Soils in vegetated areas have high organic matter and are

less compacted. Floods are therefore least likely to be experienced in the forestlands and shrublands as very little rainfall ends as runoff. Soils in shrublands have moderate rates of infiltration and therefore moderate amounts of runoff are likely to be generated.

4.3.2 Stream flow Analysis

This study endeavored to establish any possible linkage between LUC and surface runoff. As such, river data was used with discharge as the parameter. It was therefore important to acquire river data covering the entire period of study (1990- 2014). The data was acquired for station 3HA13 at the Sabaki gauging station along River Sabaki. Acquiring a trend line covering the period between 1990 and 2012 was not possible as the data with the longest convergence covered the period between 2000 and 2012. Trend analysis was conducted for the available data using monthly mean discharges. Trend line equations were generated using the regression coefficient method. A time series trend analysis was therefore conducted for the period between the years 1990 and 1994 and the years between 2000 and 2012. Graphs showing the trend of discharge (m^3/s) against time were generated in Excel (See Figures 4.5 and 4.6 respectively).

The computed trend analysis of the river discharge data for the area indicates that there were changes in the amounts discharged over the period for which the data was available. The stream discharge for Sabaki River is characterized by rise and falls for the period between 1990 and 2012. The results are based on the contribution of catchments that form River Sabaki within the County. Despite the changes, the river exhibited a general decline in water volume as indicated by the trend lines.

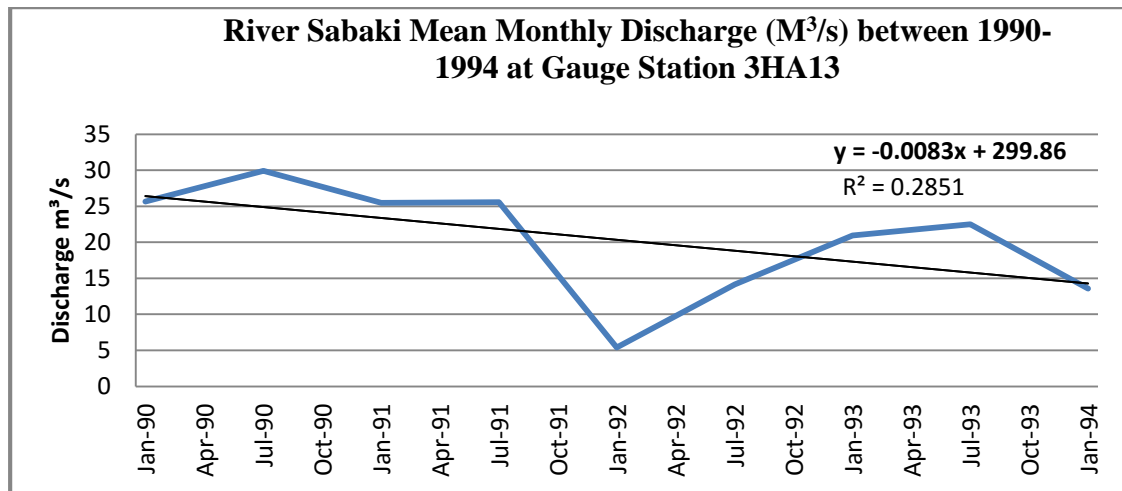


Figure 4.5: Flow Trend for River Sabaki at station 3HA13 between 1990 and 1994

Source: Author (2015)

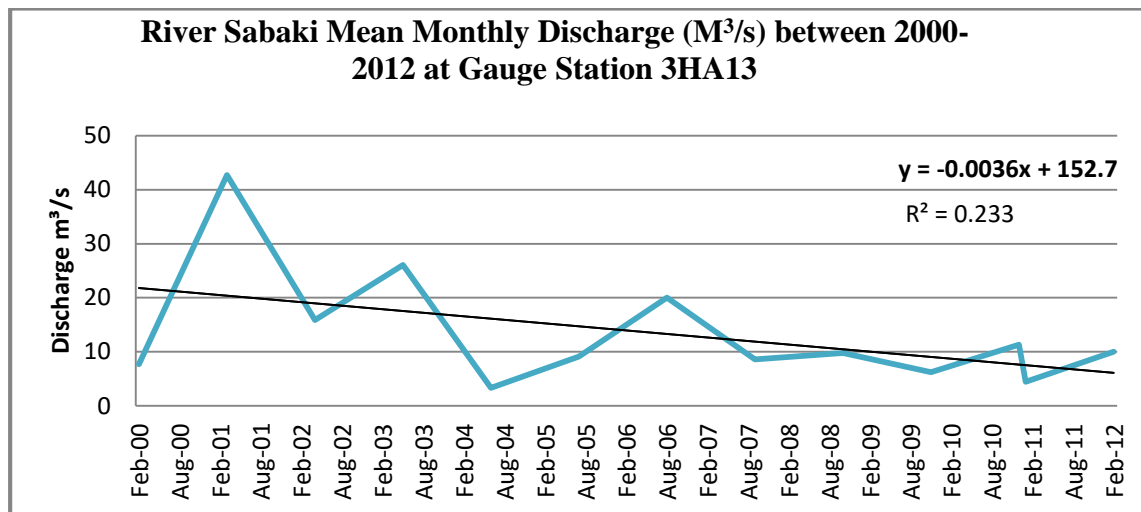


Figure 4.6: Flow Trend for River Sabaki at station 3HA13 between 2000 and 2012

Source: Author, (2015)

Over the period between 1990 and 1994, correlation between vegetation (forestlands and shrublands) loss and Sabaki River discharge was positive with 28.5% (0.053² or 0.285) of their variation in common. This implies that vegetation loss declined as discharge declined too. Between 2000 and 2012 the correlation between vegetation loss and the

river discharge was 23.3% (0.233 or 0.482^2) of their variation in common. These results indicate that vegetation (forestlands and shrublands) and river discharge declined in unison. However, the trend line for the period for which data was available does not converge with the period between 1990 and 2000 for which Landsat Images were analyzed. The analysis indicates that the trend was inconsistent with the amount of discharge in January, 1992 dropping significantly to $5.4\text{m}^3/\text{s}$ before rising again. The value of R^2 for the period between 2001 and 2012 was 0.233 which indicates a relationship between the changes in river discharge albeit not significant. The longest convergence of data obtained for the station is between the years 2000 and 2012. The strength, weakness or clarity of the relationship on a scale of 0 to 1 is obtained from the proportion of the variation in common between two or more variables. As the value increases, the strength of the relationship between variables increases too.

Vegetation is vital as it influences the amount of stream discharge. Analysis of land cover changes in the area indicates that shrublands and forestlands have been on a decreasing trend over the period of study. Vegetation loss increases the amount of solar radiation and consequently increased evaporation on the soil surface, while high evaporation rates increase the amount of atmospheric humidity. The impact of this is that rainfall formation takes longer time as moisture convergence and cloud formation declines. This alters rainfall distribution and this explains the periodic falling of heavy and intense rainfall. Decline in vegetation cover is associated with reduced interception of rainfall and infiltration and increased overland runoff. The rise and falls in stream discharge in the area can therefore be associated with the LULCC in the area.

4.4 Flood Risk Map for Kilifi County

Different key factors were considered while creating a flood risk map. Vulnerability for this study was evaluated against different physical parameters including; land cover characteristics, geology (soil type), topography (slope angles), hydrology (drainage density), and rainfall (spatial distribution). The result was a flood risk map combining all these factors.

4.4.1 Flood Risk Zoning Based on Land Cover Distribution

Land cover is an important and a predominant aspect in assessing an area's susceptibility to flood risk. This is because the land cover characteristics not only affect the use into which land is put into, but also its influence with respect to soil infiltration and soil stability. Land cover computation indicates a decrease in the spatial extent of forestlands, shrublands and grasslands at 580.3km², 313.4km² and 447.3km² respectively between 1990 and 2014. Vegetation, whether in the form of grasslands or even crops, impacts on the capacity of soils to act as sponges or soaks. High rate of surface runoff is more likely on bare grounds than on vegetated grounds. Forestlands and shrublands reduce the impact of rainfall and reduce the amount of water that ends up in the form of surface runoff. Impermeable surfaces as characterized in the settlement areas in form of concrete, roads, buildings and paved areas decrease the percolation of water into the soil and increase the amount of surface runoff. This is an indication that LULC characteristics are important parameters in evaluating an areas' vulnerability to flood risk.

The land cover distribution map for 2014 was used as a parameter. The class distribution depicts dynamic forms of land cover and land use. Six classes were generated. These were croplands, forestlands, grasslands, shrublands, settlements and wetlands. The classes were then reclassified into five classes based on the influence on flood risk and the exposure of humans to risk. Habitation areas are more likely to be found in areas categorized as settlements while habitation is least likely to be on the wetland areas. In many cases, constructed drainage lines and culverts in the urban areas are usually too small to accommodate storm water which causes water to overflow on the roads and pavements after precipitation events. The problem is compounded by huge amounts of poorly disposed solid waste which clogs the drainage systems. Land cover characteristics and land use activities therefore only compound on the flood risk posed by a soil's infiltration capacity, the nature of slope on which land use activities are conducted or the geology of the areas under each LULC category as it influences on the drainage system. Changes in land use and land cover; especially the removal of vegetation increases an area's chances to flooding.

The highest rank was assigned to the settlements as these are the areas with the lowest soil infiltration capacities and are highly devegetated. These areas are also characterized with impermeable surfaces as a result of the paved surfaces including road networks and modified drainage. Removal of vegetation to create room for settlement areas and create more land for cultivation alters the soil structure. The lowest rank was assigned to the wetlands as they often flooded and therefore are not inhabited by humans unless they are reclaimed (Figure 4.7).

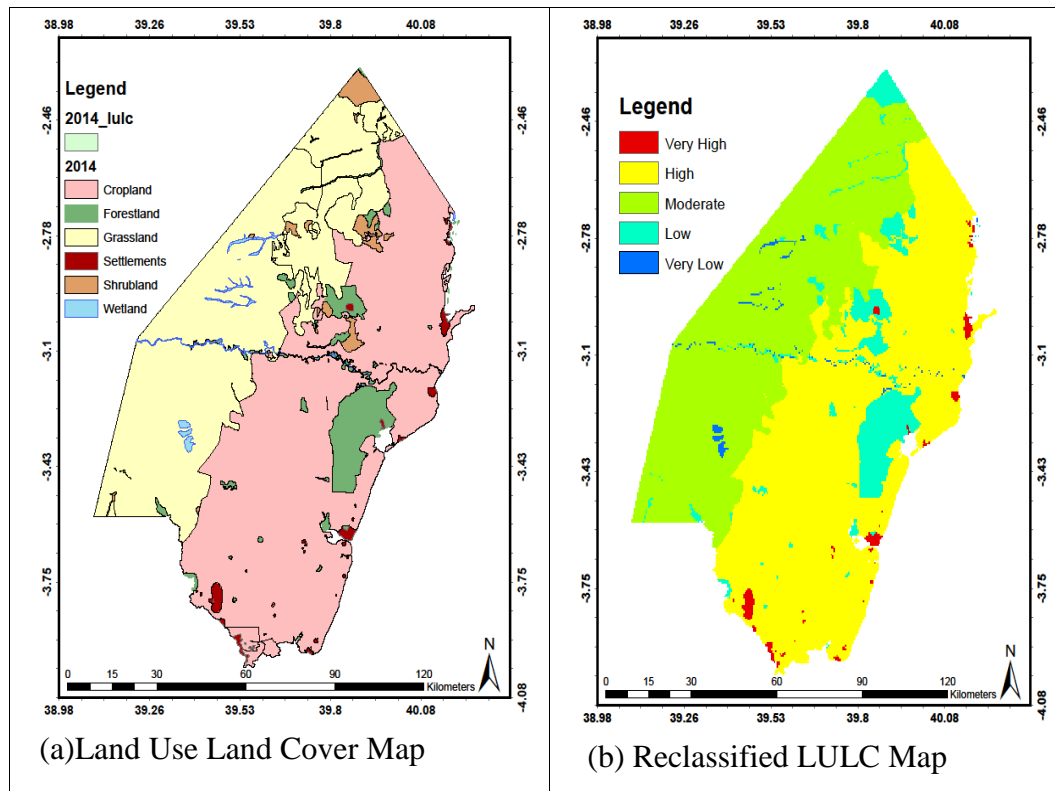


Figure 4.7: (a) LULC Map and (a) Reclassified LULC Map

Source: Author (2015)

4.4.2 Flood Risk Zones Based on Slope Angles and Elevation

Different areas in the study area fall under different slope categories; low, medium or steep. The slope map in this study was prepared from the Kilifi DEM. The classes of slope with lesser values were allocated higher ranks as their angles are not steep. Classes with the highest slope values were assigned lower rank for flooding values. Such areas do not permit accumulation of water that eventually causes flooding. The greatest flood risk will be areas falling at a flat terrain, have soils with low infiltration capacities and poor drainage like clay, are devoid of vegetation and the land use activities therein hinder percolation especially in settlement areas (Figure 4.8).

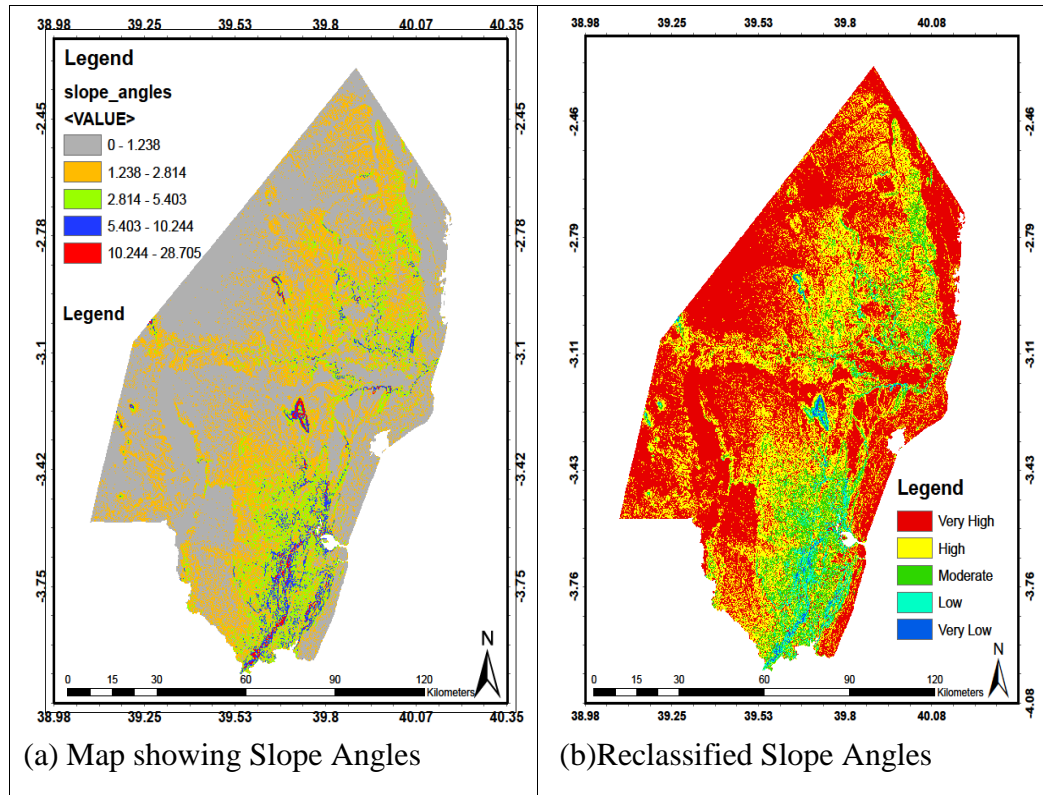


Figure 4.8: (a) Slope Map and (b) Reclassified Slope Map of Kilifi County
Source: Author (2015)

Slope is one of the predominant factors used while assessing flood risk in the area. The lower the slope angles of a particular area, the closer they are to the water level. Thus, areas falling at the lowest point of the elevation have the highest likelihood of inundation in the event of precipitation. From the analysis, the areas covered by each category were as presented in Table 4.7.

The results indicate a gently rolling slope. The majority of the area falls within a flat terrain- areas falling $\leq 1.238^\circ$, which was ranked “very high” in the assessment of the risk factors causing floods. The steep slopes, ≥ 10.244 occupy the least area. Areas at the slope range between 2.814° - 5.403° are considered as moderate in steepness. These areas have a

moderate risk of getting floods as runoff will take long to accumulate to levels that could be considered to pose a flood risk. Storm water also moves at a relatively high speed and thus poses little risk of flooding. Areas above 10.244° are steep and therefore water storm water moves at relatively high speeds and as such, these areas are not at the risk of flooding. Slope and elevation play a crucial role in terrain stability (Ouma and Tateishi, 2014). Slopes often influence the direction of flow of surface and amount that flows into an area. Slope also affects the conversion of precipitation to river discharge. It often dictates the direction taken by storm water, duration of water percolation into the soil and the amount of water that ends up as recharge for underground aquifers. The steepness of a land surface determines the nature the relationship between geology, lithology and nature of drainage. Flat surfaces that don't permit fast flow of surface runoff are at more risk as they are vulnerable to flooding compared to the steep areas that allow fast flow of storm water (Ouma and Tateishi, 2014).

Table 4.7: Area under Each Slope Angle Category

Slope Angle (Degrees)	Area (Km²)	% Area
0 – 1.238	6520.5	53.3
1.238 – 2.814	3012.5	24.6
2.814 – 5.403	1487.9	12.1
5.403 – 10.244	446.8	3.7
10.244 – 28.705	777.6	6.3
Total	12245.3	100

Source: Author (2015)

4.4.3 Flood Risk Zones Based on Soil Type

The grouping of soils in the case of this study was based on type. Soils in the County were categorized into five; very clayey, clayey, loamy, sandy loam and sandy (See Table

4.8 for area under each category and Figure 4.9 for soil distribution map). The classes were then reclassified into three major classes and ranking was done and the soil type with the capacity to generate high flood rates was assigned “3” while the soil type with the least likelihood of generating into a flood was assigned rank “1”.

Soil texture impacts heavily on flooding. Sandy soils allow water to pass through them faster compared to other soil types due to their large soil particles and thus little runoff is experienced. Clay soils have fine particles, are less permeable and allow buildup of runoff for a longer period of time compared to other soil types. The implication of this is that areas with clay soils are more prone and more likely affected by flooding. Other factors important while assessing the impact of soil type on flooding are the soil structure and infiltration capacity. These help in determining the ability of the soil to absorb water. Different soil types have different infiltration capacities. Floods occur in areas where soils have low infiltration capacity as this generates more surface runoff. Floods occur if runoff accumulates at a rate higher than the soil’s capability to allow for percolation or infiltration.

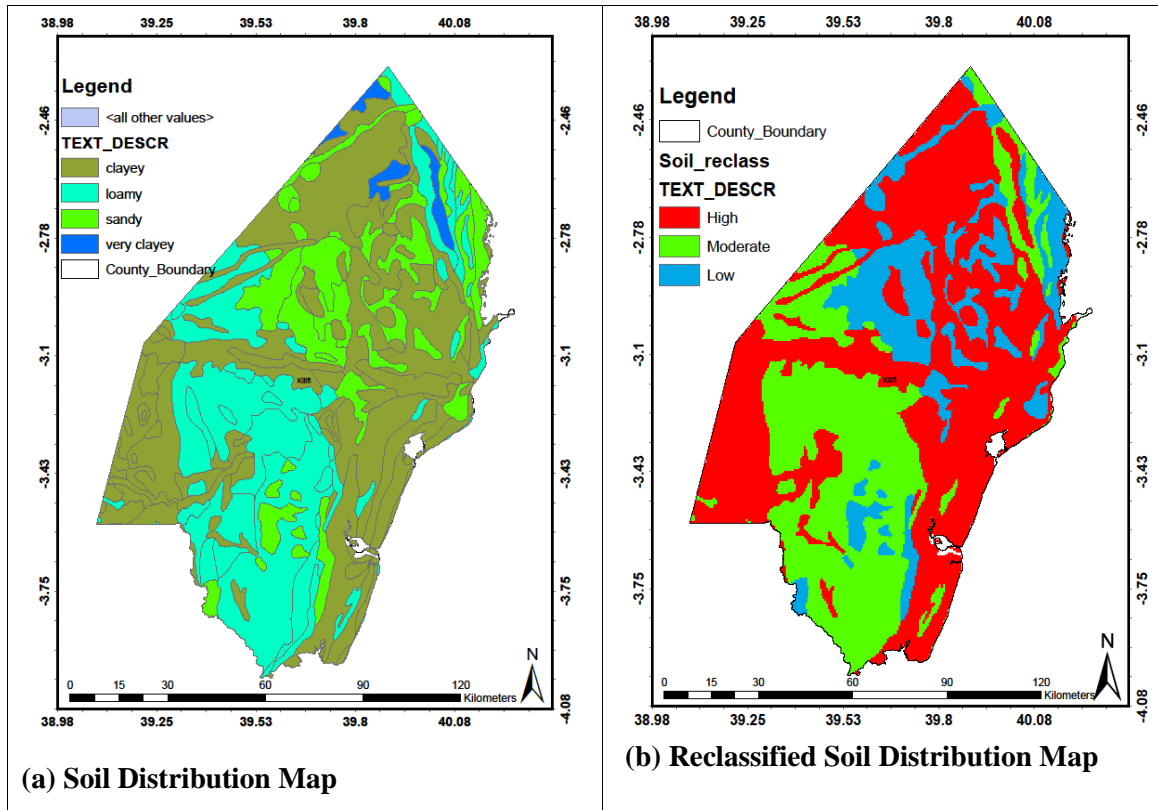


Figure 4.9: (a) Soil Map and (b) Reclassified Soil Map

Source: Author (2015)

Table 4.8: Summary of the Areal Extent under each Soil Type

Soil Type	Area (Km ²)	% Area
Sandy	2601.3	21.3
Loamy	4800.4	39.1
Clayey	4004.4	32.7
Very Clayey	839.8	6.9
Total	12245.9	100

Source: Author (2015)

4.4.4 Flood Risk Zones Based on Spatial Rainfall Distribution

Heavy rainfall is the major cause of floods. Floods occur mainly in areas of heavy rainfall when available drainage systems are unable to convey excess water to the flood plains or

water bodies or when the soil does have the capacity to absorb excess water; mainly because they have reached the saturation point. Amount of runoff is related to the amount of rainfall experienced in an area. In cases of heavy rainfall, water level rises above river banks, dams or lakes and starts overflowing leading to flooding (KRCS, 2013).

Rainfall occurring within the confines of a catchment is relevant for flooding but the contribution by rainfall amounts from upstream catchments cannot be ignored too as they contribute to a river's flood risk. Spatial distribution of rainfall was generated using annual rainfall data and based on locations mean annual rainfall. A mean annual rainfall for the years between 1990 and 2013 was used. The data was already interpolated using the Inverse Distance Weighing (IDW) and was in the form of a continuous raster form covering the area within the area of study. Five classes were generated from the data. The generated rainfall classes were then reclassified and ranked based on their influence on flood risk. Areas with the highest mean annual rainfall are considered to be more at risk of flooding than areas with the least rainfall. High rainfall areas were assigned rank "5" while the areas with the least rainfall were assigned rank "1" (See Figure 4.10). From the rainfall map, areas near the coastline receive the highest rainfall amounts. It follows therefore that if the settlement areas therein have flat terrain and have types of soil that are less permeable; there is a likelihood of them being flooded after precipitation events.

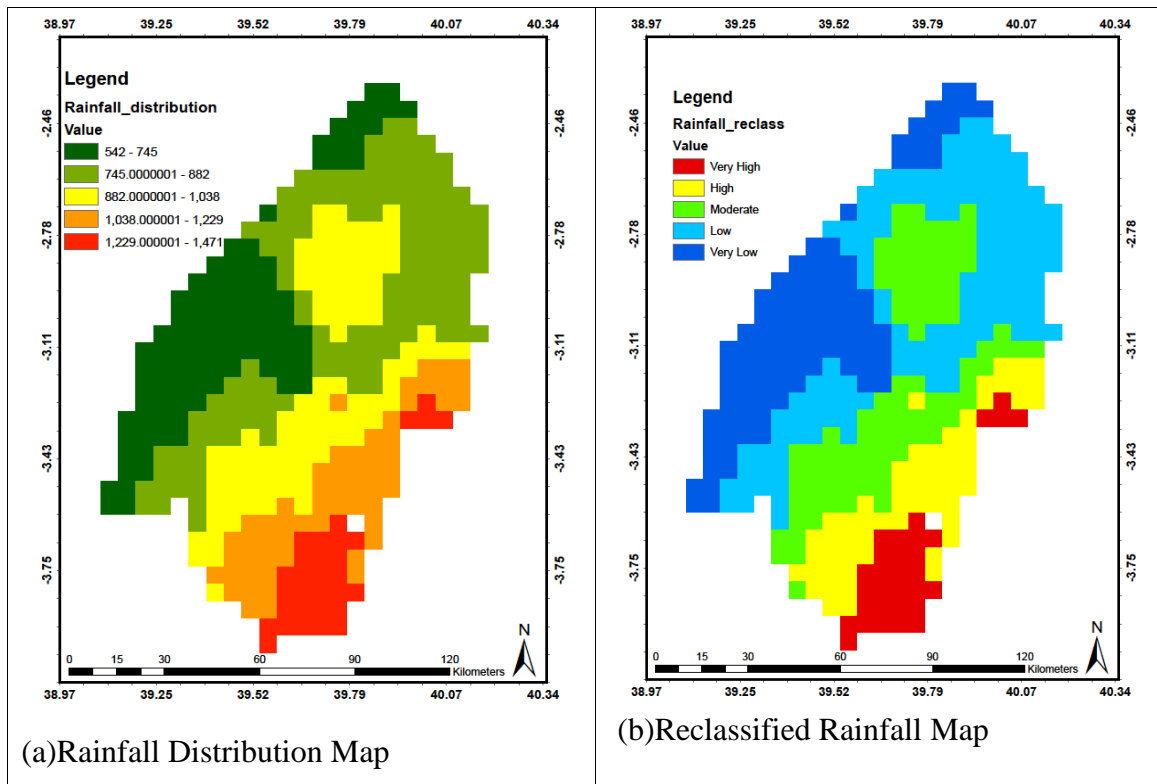


Figure 4.10: (a) Rainfall Distribution Map and (b) Reclassified Rainfall Map

Source: Author (2015)

4.4.5 Risk Zones Based on Drainage Density

Drainage system is related to the nature of soil and rock structure and properties. Areas with high drainage density are highly susceptible to erosion and result to massive sedimentation on the lower grounds. A watershed adequately served with stream channels should have a density greater than or equal to five. Moderately and poorly drained areas have densities ranging between 1 and 5 and less than 1 respectively. The study area is characterized with first, second and third order streams. For this study poorly drained areas were allocated the highest ranks while the well-drained areas were assigned lower ranks.

Density analysis established that the main drainage system of the area comprises of River Sabaki as the main river. Other rivers identified are Rivers Laga Buna, Gandi, Rari and Rare respectively. The area is also characterized with seasonal rivers which also get inundated during rainfall events. Analysis of drainage density in the area indicated that the density ranged between 0 and 22.85. The drainage density was then reclassified into five. Areas with the lowest drainage density were ranked with value “5” while the areas with the highest drainage density were ranked as “1”.

From the stream network generated, the flow direction is oriented towards the lowest points and in particular towards the Indian Ocean (Figure 4.11b). The drainage pattern is formed mainly of the perennial Sabaki River. There are also second and third stream orders that form a dendritic drainage pattern (Figure 4.12b). However, the effect of river drainage on flood risk is dictated by among other factors, the geology and the soil type, rainfall amount and the evapotranspiration rates. Analysis of drainage density indicated that the areas that were highest at the risk of flooding were not particularly located along the river lines but at the periphery areas of the county. The implication of this is that the rivers pass through areas that are well drained and have high infiltration capacities.

The 30m DEM shows that the elevation of Kilifi County ranges between -20m and 530m above sea level. The darkest gray shade represents the lowest areas. DEM was used to generate the flow direction, flow accumulation and the stream network of the area. The flow direction map shows the cells to which water is more likely to accumulate as it flows down slope. Cells with the greatest values are located at the lowest points and as

such form accumulation points thus defining the flow direction. Water will flow towards the will the highest values (Figure 4.12a).

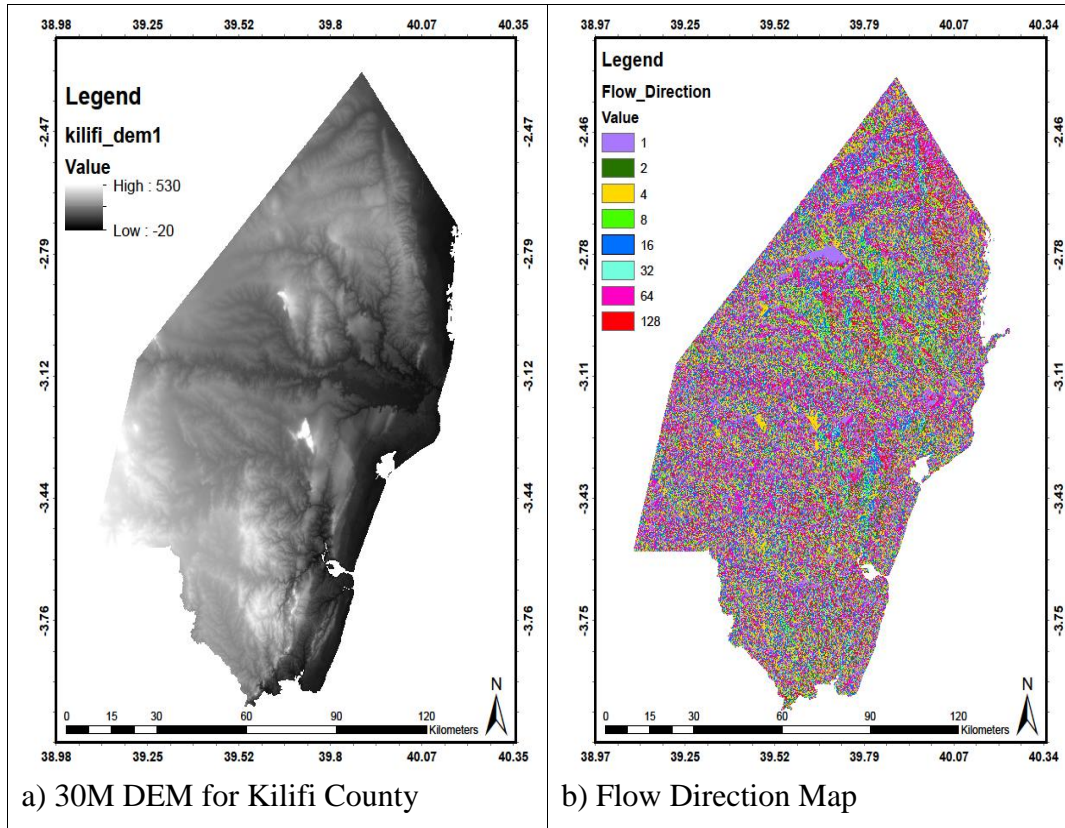
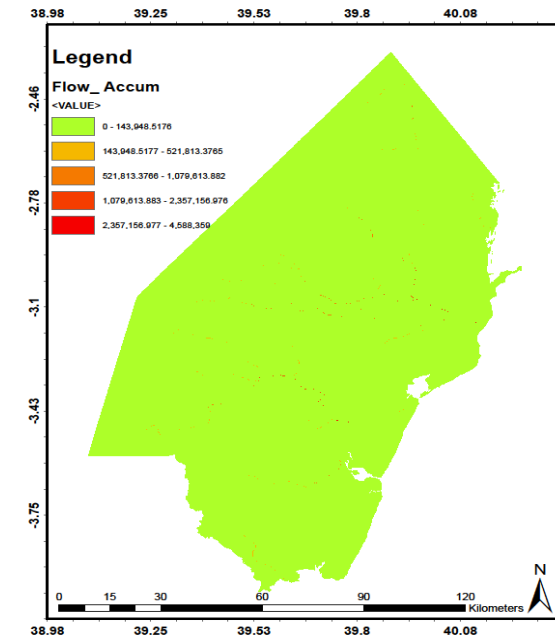
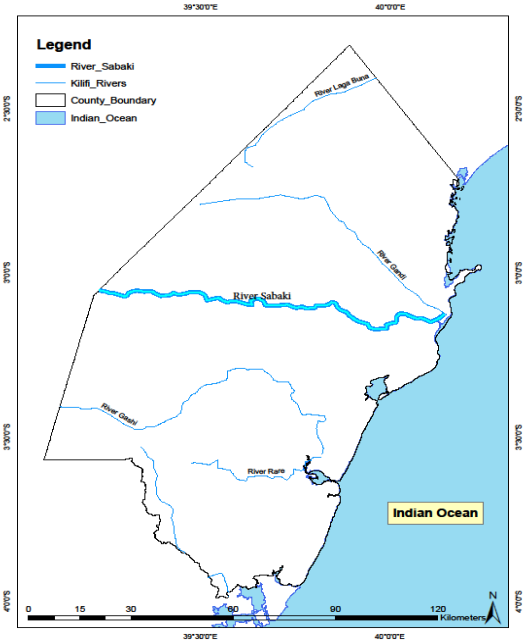


Figure 4.11: (a) DEM and (b) Flow Direction Map

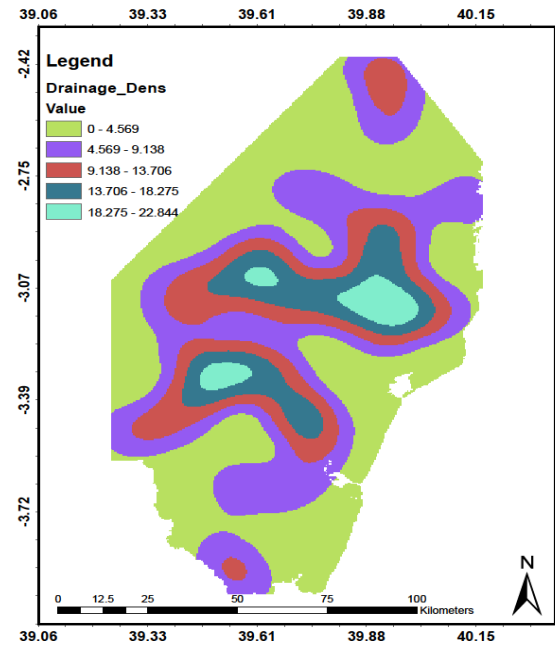
Source: SRTM, 2014



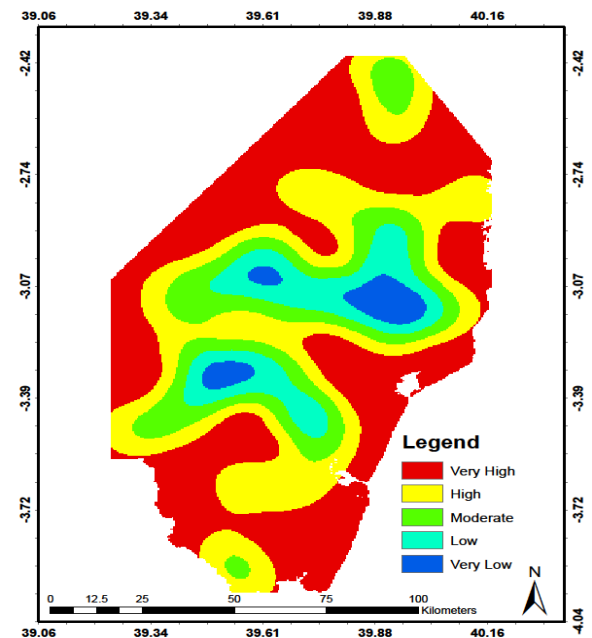
a) Flow Accumulation Map



b) Major River Network



c) Drainage Density Map



d) Reclassified Drainage Density

Figure 4.12: (a) Flow Accumulation Map, (b) Stream Network, (c) Drainage Density and (d) Reclassified Drainage Density

Source: Author (2015)

4.5 GIS Weighted Overlay Analysis

The flood risk areas were obtained by combining the different thematic layers. The weighted overlay method was used for this study using the Spatial Analyst tool in ArcGIS. Ranks were apportioned for every individual layer and equal weights allocated. The output was a flood risk map with four risk areas namely; very high, high, moderate and low (Figure 4.13). The “very low” risk areas seemed to be negligible as the overlay procedure did not recognize or generate them. The map output demonstrates that, the study area is dominated by high flood risk zone which covers the largest area. The very high risk zones are concentrated in the Eastern side of the area and along the Indian Ocean. Major towns including Mtwapa, Kilifi, Watamu and Malindi are found in this zone. These areas are the major settlements as classified in the land use map (Figure 4.7). They are mostly characterized with clay soils and are the bottom- most part of the slope. The very high risk areas also fall along the coastline. This also exposes them to the risk of coastal flooding due to their proximity. Most of the areas in the croplands and the grasslands fall within the High risk zones.

The flood risk map depicts the concern, the environment formation and the population’s vulnerability in the areas that are prone to the hazard; thus the risk map takes into account, areas of human settlement and activities like towns, roads, rivers, and the cultivated areas. Land cover changes increase the susceptibility of an area to the risk of flooding. The land cover maps, figures and percent changes all inform different forms of conversions and modifications. This includes reduction in the extent of vegetation cover

in the area which in turn exposes the area to increased surface runoff and possible overflow of low lying areas where most settlement areas are located.

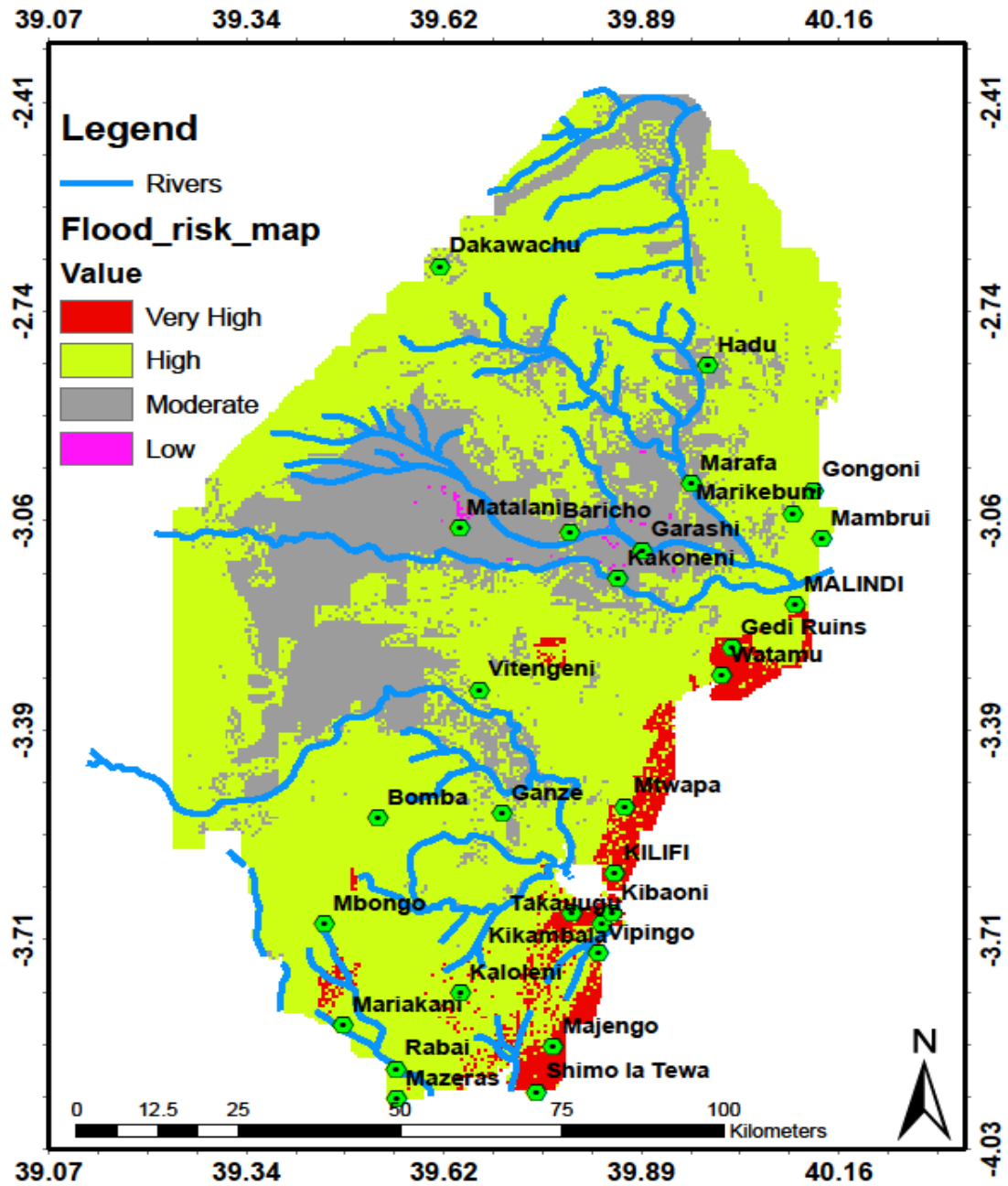


Figure 4.13: Flood Risk Map for Kilifi County

From the flood risk map “very high” risk areas are located in the South Eastern side of the County and along the coastline. Locations falling under this category are Malindi, Watamu, Gede, Sokoke, Ngerenya, Tezo, Kilifi Township, Mavueni, Ziani, Junju, Mtwapa, Bamburi, Mariakani and Bamba. This category occupies 1224.6Km² of the total. The “High” risk areas are to be found in Adu, Fundisa, Gongoni, Geshi, Magarini, Jilore, Matsangoni, Ganze, Mitangani, Tsangasini, Mwanamwinga, Kayafungo, Ruruma, Rabai, Miritini, Ribe, Kambe, Chasimba, Kaloleni and Jibana. The “High” risk areas have a total coverage of 6375.3Km² of the total area. “Moderate” risk areas are found in Chakama, Bungale, Maraja, Garashi, Dagamra, Langobaya, Ndigiria, Vitengeni, Dungicha and Mrima wa Ndege and occupy 4163.6Km² of the total area of the County. The “Low” risk areas are located in Chakama, Langobaya, Garashi, Dagamra and Jilore and occupy 122.5Km² of the total area. The Summary of the area coverage under each risk category is as presented in Table 4.9.

Table 4.9: Risk Category and Area of Coverage

Risk Category	Area (Km²)	% Area
Low	122.5	1.1
Moderate	4163.6	34.0
High	6735.3	54.9
Very High	1224.6	10.0
Total	12446	100

Source: Author (2015)

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of the Findings

This study endeavored to identify areas in Kilifi County that are prone to flooding and to generate a GIS- based flood risk map. The focus was on Kilifi County in the Kenyan Coast. Landsat Images for the years 1990, 2000 and 2014 were used to establish the changes that have occurred in land cover in the area over time. Additionally, the study sought to establish infiltration capacities in different selected sites and different soil types by the use of a double ring infiltrometer. A time series trend analysis was also conducted on River Sabaki discharge data for the years between 1990 and 2012 to establish if there has been an influence on such trends occasioned by land cover changes. Finally, a flood risk map identifying the various flood prone areas was generated using a land cover map for 2014, spatial rainfall distribution data, soil map, stream density and slope.

A total of six land cover classes were identified and extracted from the Landsat images as the major land cover classes in the area. They are croplands, forestlands, grasslands, shrublands, settlements and wetlands. The study found that there were land cover changes of varying proportions during the period 1990 - 2014. The vegetated area including forestlands, shrublands and grasslands; which are important in reducing the impacts of floods have reduced with time at the expense of croplands and settlement areas. The classified images were then assessed for quality through determination of the

classification accuracy for the years in question. The overall accuracy increased from 86.7% to 90.2% and to 92.4% for the years 1990, 2000 and 2014 respectively.

Infiltration experiments conducted in the area established that infiltration capacities are different for different soil types. Sandy soils have the highest infiltration rates while clay soils have the lowest infiltration rates. Analysis of discharge data established that the relationship of change in flow with time was not significant. Between 1990 and 1994, the value for r^2 was 0.2851 while in the period between 2000 and 2012, the value for r^2 was 0.233 which means there could be an influence by LULCC on discharge by land cover changes but it's not significant.

The contributing factors or parameters used in the production of the flood risk map were identified as rainfall, drainage density, soil type, LULC and the nature of slope of the area. Thematic reclassified maps were generated with the use of several image processing techniques and GIS operations at different scales. Each of the thematic and reclassified data sets were processed to fit the same scale. A GIS weighted overlay analysis of all the thematic layers was carried out to generate a final composite flood risk map. From the analyses, the following results were computed:

- i) There are six major types of land use in the area informed by the nature of land cover. They are croplands, grasslands, shrublands, settlements, forestlands and wetlands.

- ii) The major soil types in the area can be classified as very clayey, clayey, loamy, sandy loam or sandy.
- iii) 53.3% of the area has its slope angles between 0° and 1.238° while the remaining 46.7% have their slope angles ranging between 1.238° and 28.705° .
- iv) The Mean annual rainfall in the study area ranges between 542mm and 1471mm.
- v) The stream network densities identified in the study area range from between 0 and 22.844km.

The total area covered by the high risk zones was found to be 54.9%, while the area covered by very high risk, moderate zones and low risk zones was found to be 10%, 34% and 1.1% of the total area respectively.

5.2 Conclusions

The outcome of this and other related studies needs to be get to the end user including the land use planners, stakeholders, emergency and contingency planners and the community members. This would help improve the map by including the possible and specific flood areas, evacuation routes, disaster related facilities and the most appropriate flood mitigation strategies. Strategies that are meant to enhance the resilience to flood risk include the application of early warning systems and evacuation plans, safety standards for different forms of land use, spatial plans for all areas, recovery mechanisms, damage

compensation and insurance measures among other interventions. Different zones call for different levels of protection. It is prudent to have the knowledge on where floods take place first during flood events. This would help limit the damage that might be caused by the flood and help enhance the safety of the people and their property in the flood prone areas. Floods cannot be completely averted as long as the nature of land use, land cover and physical development continue to extend to the flood prone areas. It's therefore only prudent that relevant authorities put into place the necessary mitigation measures to avert crises.

Most interventions to floods are often reactive and there is therefore the need to adopt precautionary measures against flooding. Flood risk maps are therefore crucial as they form the grounds on which important decisions regarding flood mitigation and prototypes are made. Moreover, these outputs must therefore be presented or reach the relevant agencies for awareness, decision making and quick response during flood emergencies as a measure to reduce flood risk as this will help integrate different interests, opinions, land potential and land use conflicts in an area.

The findings in this study confirm that GIS techniques provide disaster management proponents with an opportunity for efficient, coherence and utilization of spatial data. The flood risk map produced in this study integrates the effect of different parameters. Just a short period of precipitation data may not be enough to give a good visualization since it is not only the hydrological features that contribute to flooding, but an integrated

response of the ground surface. Some of the areas receive very little rainfall but are still at risk due to the ground cover characteristics and the type of land use in those areas, the soil type, drainage network characteristics and the nature of slope. The beauty of the approach followed while conducting this study is that it can be applied at all scales so long as the data required is available. A review of existing literature indicates instances where flood risk maps have been generated at national or even regional levels. Some of the advantages of the flood risk mapping technique is that they are user friendly, cost effective and the ease with which the maps are made available.

5.3 Recommendations

5.3.1 Data needs

Though the research was able to identify different flood risk zones through adoption of GIS technology, there is need to conduct a more comprehensive flood risk analysis that would incorporate vital information regarding the geological and physical characteristics of the area. This is only possible if enough and appropriate data on the drainage density, river flow, precipitation and rainfall distribution were available. The study therefore recommends the need for creation of databases with regards to rainfall, geology, stream flow, river discharge and land use/ land cover characteristics. Some of the databases available should be updated as the data available is either outdated or has some the data missing.

5.3.2 Suggestions for Further Research

Kilifi falls within the Coastal area of Kenya. With continued changes in climatic conditions and land use and land cover characteristics and loss of coastal vegetation including Mangroves, the area is exposed to the risk of coastal flooding thereby increasing the vulnerability of the people to flooding. There is therefore the need for research on the possible effects of shifting tides to flooding, the impact of subsurface waters to flooding and the possible impacts of sea water intrusion into ground water aquifers that might cause a rise in sea level therefore leading to flooding.

The study only considered runoff from one station along river Sabaki with only a focus on the section that runs through Kilifi County. More research is therefore needed to ascertain the possible contribution of upstream watersheds and catchment to runoff and consequent flooding of the area.

The main focus of the study was on Kilifi County. However, further research is needed so as to cover the whole Coastal area covering counties adjacent to the area of study, including Mombasa, Lamu, Kwale, Taita Taveta and Tana River as they also have similar climatic, geological and geographic characteristics.

5.3.3 Policy and Institutional recommendations

The policy and institutional framework for flood management in Kenya is under one broad framework that covers all other disasters and hazards that affect the country. There lacks specific policies or institutions that address the challenges posed by flood risk. There is need to have at least an institution whose sole mandate is to address the management of floods given that floods are one of the major hazards experienced in the country. The institution should also be empowered with the capacity to address all the steps involved in the management of floods including, preparedness, response, recovery and resilience. The establishment of effective strategies and structures for flood mitigation usually takes into consideration different forms of floods in specific locations. Flood risk maps should be incorporated into planning designs to encourage investment in the mitigation of floods by the relevant stakeholders. The consumers of this information in Kenya include the national government, County government of Kilifi, the Kenya Red Cross Society, the community and the academia.

REFERENCES

- Adeoye, N, Ayanlade, A. and Babatimehin, O. (2009). "Climate change and menace of floods in Nigerian cities: socio-economic implications", *Advances in Natural and Applied Sciences*, 3 (3), 369-377.
- Balabanova, S. and Vassilev, V. (2010). "Creation of flood hazard maps", *BALWOIS 2010* Ohrid, Republic of Macedonia available at http://balwois.com/balwois/administration/full_paper/ffp-1560.pdf, last accessed April 10, 2014.
- Barredo, J. I., Engelen, G. (2010). *Land Use Scenario Modeling for Flood Risk Mitigation Sustainability*, 1327-1344.
- Briassoulis, E. (2000). Analysis of Land Use Change: Theoretical and Modeling Approaches. In *The Web Book of the Regional Science*. S. Loveridge (ed.). West Virginia University, Regional Research Institute, Morgantown, WV.
- Calder, I. (1992). Hydrological Effects of Land Use Change, in *Handbook of Hydrology*, edited by D.R. Maidment, pp. 13.11-15, McGraw- Hill, New York.
- CEOS, (2003). *The Use of Earth Observing Satellites for Hazard Support: Assessments and Scenarios*. Final Report of the CEOS Disaster Management Support Group (DMSG).
- Christiansen, L. and Subbarao, K. (2004). Toward an Understanding of Household Vulnerability in Rural Kenya. World Bank Policy Research Working Paper 3326. Washington D.C.: World Bank
- Costa, J. (1975). Effects of Agriculture on Erosion and Sedimentation in the Piedmont Province, Maryland. *Geological Society of America Bulletin*. (86) 1281-86.
- Diamond, J. and T. Shanley (2003). "Infiltration rate assessment of some major soils." *Irish Geography* **36**(1): 32-46.
- Environmental Systems Research Institute (ESRI) (2010). ArcGIS Desktop 10.1 Help, Using the NDVI process, available at http://webhelp.esri.com/arcgisdesktop/10.1/index.cfm?id=6097&pid=6096=Understanding_multivariate_classification. Accessed on 10th March, 2014.
- European Commission (EC) (2007). "Directive 2007/60/EC of the European Parliament and of the Council of 23 October, 2007 on the assessment and management of flood risks", *Official Journal of the European Union*, L288/27-34

- Farley, K.A., Jobbagy, E., Jackson, R. (2005). Effects of afforestation on water yield: a global synthesis with implications for policy. *Global Change Biology*, (11) 1565-1576.
- Field, R., Masters, H. and Singer, M. (1982). Porous Pavement: Research, Development, and Demonstration. *Journal of Transportation Engineering* **108** (3): 244–258.
- Forte, F, Strobl, R O and Pennetta, L (2006). “A methodology using GIS, aerial photos and remote sensing for loss estimation and flood vulnerability analysis in the Supersano-Ruffano- Nociglia Graben, Southern Italy”, *Environmental Geology*, 50, 581–594.
- Geospatial Innovation Facility (GIF) (2014), *RS/GIS Quick Start Guides, Landsat Spectral Band Information*, available at <http://gif.berkeley.edu/documents/Landsat%20Band%20Information.pdf>, last assessed June 30, 2015.
- Geological Society of London (GSL) (2001). *The Earth in Our Hands; Flooding* http://www.geolsoc.org.uk/pdfs/floods_aw.pdf . Accessed on 11th April, 2014.
- Government of Kenya (2005). Malindi District Development Plan 2005 – 2010: for Implementation of the National Policy for Sustainable Development, National Coordinating Agency for Population and Development: Nairobi.
- GOK (2009). *National Policy for Disaster Management in Kenya*. Government of Kenya Ministry of State for Special Programmes (MSSP). Government Press. Nairobi
- Griffin, D.W., Garrison, V., Herman, J. and Shinn, E. (2001). African desert dust in the Caribbean atmosphere: Microbiology and public health, *Aerobiologia*, 17(3): 203–213.
- Grigalunas, T. and Congar, R. (1995). “Environmental Economics for Integrated Coastal Area Management: Valuation Methods and Policy Instruments.” *Regional Seas Reports and Studies*: No.164.UNEP.
- Hall, M. J. (1984). *Urban Hydrology*, Elsevier Applied Science Publishers, London and New York.
- Haber, J. (1994). A Practical Method for Estimating the Impact of Land-Use Change on Surface Runoff, Groundwater Recharge and Wetland Hydrology. *Journal of the American Planning Association*, 60(1): 95-108.
- Huggel, C, Kääb, A, Haeberli, W, Krummenacher, B, (2003). “Regional-scale GIS models for assessment of hazards from glacier lake outbursts: evaluation and

- application in the Swiss Alps”, *Natural Hazards and Earth System Sciences*, 3 (6), 647–662.
- Ishaya, S, Ifatimehin, O. and Abaje, I. (2009). “Mapping flood vulnerable areas in a developing urban centre of Nigeria”, *Journal of Sustainable Development in Africa*, 11(4) 180-194.
- Jahne, B., (2002). Digital Image Processing 5th revised and extended edition, Springer Verlag Berlin Heidelberg, Germany.
- Jarvis A, Reuter, H I, Nelson, A and Guevara, E (2008), *Hole-filled Seamless SRTM Data V4*, International Centre for Tropical Agriculture (CIAT), available at <http://srtm.csi.cgiar.org>, last assessed October 1, 2014.
- Jeb, D. and Aggarwal, S. (2008). “Flood inundation hazard modeling of the River Kaduna using remote sensing and geographic information systems”, *Journal of Applied Sciences Research*, 4 (12), 1822 – 1833.
- Jensen, J.R. (2004). Digital change detection. Introductory image processing: A remote sensing perspective pp.467-494. Prentice-Hall: New Jersey.
- Johnson, R. (2008). *The Role of Catchment Land Use Planning in Flood Risk Management*. Paper presented at a Workshop on Flood Management in Local Planning, Austria/Slovenia.
- Kenya National Bureau of Statistics (KNBS) (2010). *Kenya Population and Housing Census Report 2009*. Government Printer, Nairobi.
- Kenya Red Cross Society (KRCs), 2013. Status of Floods in Kenya. KCRS.
- Kilifi County Integrated Development Plan (KCIDP) 2013- 2017 (2013). Government Printer, Nairobi
- Kim, Y., Engel, B. A., Lim, K. J., Larson, V. and Duncan, B. (2002). Runoff Impacts of Land-Use Change in Indian River Lagoon Watershed. *Journal of Hydrologic Engineering* 7, (3): 245-251.
- Kitheka, J. (1997). Coastal tidally-driven circulation and role of water exchange in the linkage between tropical coastal ecosystems. *Estuarine Coastal and Shelf Science*, 45, 177- 187.
- Kwak, Y. and Kondoh, A. (2008). “A study on the extraction of multi-factor influencing floods from RS image and GIS data; a case study in Nackdong Basin, S.Korea”, *The International Archives Of The Photogrammetry, Remote Sensing And Spatial Information Sciences*, ISPRS Congress Beijing 2008, 37, Part B8, (8),421- 426.

- Labarda, R. Q. (2009). Watermaster Helps Control Sipalay Flood. Southeast Asia Construction, Feature Project.
- Lambin, F., Baulies, X., Bockstael, N., Fischer, G., Krug, T., Leemans, R., Moran, E. F., Rindfuss, R. R., Sato, Y., Skole, D., Turner, B. L. and Vogel, C. (1999). Land Use and Land Cover Change (LUCC): Implementation Strategy. IGBP Report 48. IHDP Report 10. IGBP, Stockholm, 125.
- Lillesand, T. M. and Kiefer, R. W. (2002) Remote Sensing and Image Interpretation. John Wiley and Sons Pte Ltd, Inc. pp 444-449.
- Macleod and Congalton. (1998). A Quantitative Comparison of Change Detection Algorithms for Monitoring Eelgrass from Remotely Sensed Data. *Photogrammetric Engineering & Remote Sensing*. Vol. 64. No. 3. p. 207- 216.
- Meyer, W. (1995). Past and Present Land-use and Land-cover in the U.S.A. Consequences. p.24-33.
- Mustard, J. and T. Fisher (2004). Land Use and Hydrology. In Gutman, G., Janetos, A., Justice, C., Moran, E., Mustard, J., Rindfuss, R., Skole, D., Turner, B.L. & Cochrane, M (Eds.), *Land Change Science: Observing Monitoring and Understanding Trajectories of Change on the Earth's Surface* (pp. 257-276), Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Mustard, J., R. DeFries, T. Fisher & E. Moran (2004). Land Use and Land Cover Change Pathways and Impacts. In Gutman, G., Janetos, A., Justice, C., Moran, E., Mustard, J., Rindfuss, R., Skole, D., Turner, B.L. & Cochrane, M (Eds.), *Land Change Science: Observing Monitoring and Understanding Trajectories of Change on the Earth's Surface* (pp. 411- 430), Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Naef, F., Scherrer, S. and Weiler, M. (2002). A Process Based Assessment of the Potential to Reduce Flood Runoff by Land Use Change. *Journal of Hydrology*, 267: 74-79.
- National Aeronautics and Space Administration (NASA) (2011a), *The Landsat Program*, available at <http://landsat.gsfc.nasa.gov/about/landsat1.html>, last assessed November 2, 2014.
- Nyarko, B.K., (2000). "Application of a rational model in GIS for flood risk assessment in Accra, Ghana". *J. of Spatial Hydrology*, 2 (1), pp 1-14.
- Obura, D. (2005). Resilience and climate change: lessons from coral reefs and bleaching in the Western Indian Ocean. *Estuarine, Coastal and Shelf Science* 63:353–372

- Ochiewo, J. (2004). Changing fisheries practices and their socioeconomic implications in South Coast Kenya. *Ocean & Coastal Management*, 47: 389-408.
- Ochola, S., Eitel, B. and Olago, D. (2010). Vulnerability of schools to floods in Nyando River catchment, Kenya. *Disasters*, 34(3), 732-754.
- Ouma, O. and Tateishi, R. (2014). Urban Flood Vulnerability and Risk Mapping Using Integrated Multi-Parametric AHP and GIS: Methodological Overview and Case Study Assessment. *Water Journal*. 2014 (6), 1515 – 1545.
- Okoth, D. (2010), Malindi's Poor Toil to Bring Salt to the Table, Standard newspaper, published 24th February, 2010. Accessed on 10th March, 2014.
- Ologunorisa, T. and Abawua, M. (2005). "Flood risk assessment: a review", *Journal of Appl. Sci. Environmental Management*, 9 (1), 57 – 63.
- Onyancha, C. and Nyamai, C. (2014). Lithology and Geological Structures as Controls in the Quality of Groundwater in Kilifi County, Kenya. *British Journal of Applied Science & Technology*, 4(25): 3631-3643.
- Onywere, S., Getanga, Z., Mwakalila, S., Twesigye, C. and Nakuranda, J. (2011). Assessing the Challenge of Settlement in Budalangi and Yala Swamp Area in Western Kenya Using Landsat Satellite Imagery. *The Open Environmental Engineering Journal*. 4, 97 - 104
- Paeth, H., Fink, A., Susan, P., Keis, F., Machel, H. and Sammie, C. (2010). "Meteorological characteristics and potential causes of the 2007 flood in sub Saharan Africa", *International Journal of Climatology*, Published online in Wiley InterScience.
- Peterson, T., Ortega, M., Bartley, J., Sanchez, V., Sobero´ J., Buddermeir, H. and Stockwell L.(2001). Future projections for Mexican faunas under global climate change scenarios. *Nature*, 416, pp. 626–629.
- Riebsame, W.E., Meyer, W.B., and Turner, B.L. II. (1994). Modeling Land-use and Cover as Part of Global Environmental Change. *Climate Change*. Vol. 28. p. 45
- Sinha, R., Bapalu, G.V., Singh, L.K., and Rath, B., (2008). "Flood risk analysis in the Kosi river basin, north Bihar using multi-parametric approach of Analytical Hierarchy Process (AHP)". *J. Indian Soc. Remote Sens.* **36**, pp 293–307.
- Tanavud, C., Yongchalermchai, C., Bennui, A. and Densreeserekul, O. (2004). "Assessment of flood risk in Hat Yai Municipality, Southern Thailand, using GIS", *Journal of Natural Disaster Science*, 26(1), 1-14.

- Turner, M. G., (1989). Landscape Ecology: the effect of pattern on process. *Annual Review Ecological Systematics*. 20: pp. 171-197.
- University Corporation for Atmospheric Research (UCAR) (2010). *Flash Flood Early Warning System Reference Guide*, United States of America, available at http://www.meted.ucar.edu/hazwarnsys/ffewsrsg/FF_EWS.frontmatter.pdf. Last accessed 12th December, 2014
- UNEP (2008). Eastern Africa Atlas of coastal resources: UNEP Regional Reports and Studies, No. 1 Nairobi, Kenya
- United Nations Development Programme (UNDP, 2011). *Kenya natural disaster profile*. Enhanced Security Unit.
- Wisner, B. (1979). "Flood prevention and mitigation in the People's Republic of Mozambique", *Disasters*, 3 (3), 293 – 306.
- Yahaya, S, Ahmad, N, Abdalla, R F (2010). "Multicriteria analysis for flood vulnerable areas in Hadejia-Jama'are River Basin, Nigeria", *European Journal of Scientific Research*, 42 (1), 71-83.
- Zeleeke, G. and Hurni, H., (2001). Implications of land use and land cover dynamics for mountain resource degradation in the northwestern Ethiopian highlands. *Mountain Research and Development*, (21), 184–191

APPENDIX I: OBSERVATION CHECKLIST

GENERAL INFORMATION					
Date and Time	Location	GPS Location	Altitude	Area Photograph	Land Use Activities
	Constituency..... Ward..... Village.....	X..... Y.....		
TERRAIN/ LANDSCAPE DATA					
Land form	Relief Type		Runoff Characteristics		
-Smooth	-Flat	-Hilly	Runoff channels		
-Medium	-Steep	-Undulating	Eroded areas		
-Coarse	-Mountainous		Runoff characteristics		
LAND USE LAND COVER DATA					
Biophysical Components	Type	Use	Density	Remarks	
Vegetation	Forest Shrubland Grassland Scrubland				
Wetland	Rivers Streams Ocean Dam Pans				
Settlement/ Built up area	Transport lines Industrial Institutions Towns				
Open Ground	Bare soil Rock				
Croplands	Crop types Irrigated Non Irrigated				

APPENDIX II: INFILTRATION EXPERIMENT MATRIX

GENERAL INFORMATION					
Date	Location	GPS Location	Area Photograph	Land Cover characteristics	Land use activities
	Constituency..... Ward..... Village.....	X..... Y.....			
Experiment No.					
Time			Infiltrometer Reading		
1.	Start Time		Initial Reading		
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
11.					
12.					
13.					
14.					
15.					
16.					
17.					
18.					
19.					
20.					
Stop time			Final Infiltrometer reading		

APPENDIX III: RIVER FLOW DATA FOR SABAKI AT STATION 3HA13

	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
1990	25.66	20.46	19.43	35.11	32.18	30.72	29.9	26.75	24.23	23.45	33.16	32.71
1991	25.49	22.04	24.3	25.15	30.7	31	25.58	23.85	22.41	21	27.9	18.02
1992	5.4	4.28	23.85	20.07	23.5	22.51	14.17	12.54	10.31	10.44	16.98	18.8
1993	20.94	15.58	18.36	31.32	25.46	25.06	22.94	20.67	18.75	18.37	29.6	26.72
1994	13.57	8	7.86	18.14	22.79	18.08						
2000	7.65	7.7	8.63	14.53	8.17	10.22	13.4	10.14	10.25	12.33	18.1	22.35
2001	23.45	18.31	42.72	36.53	16.83	14.02	9.42	9.52	8.06	6.82	9.8	11.85
2002	8.98	7.41	8.57	15.88	9.02	10.8	7.13	6.88	5.98	7.74	8.59	11.26
2003	9.27	6.22	6.62	6.72	26.09	16.12	9.94	5.98	5.98	6.02	5.22	8.08
2004	3.74	8.97	10.2	3.74	11.47	3.3	0.32	9.2	10.7	5.08	4.38	5.56
2005	5.98	7.62	5.98	8.58	9.34	6.6	9.1	14.32	6.8	7.6	7.25	6.54
2006	5.4	20.2	33.65	40.2	23.4	12.4	24	20	14	12.2	12.56	10
2007	19.78	12.23	7.33	13.23	13.69	11.63	9.85	11.51	8.6	6.56	12.37	9.31
2008	11.1	9.52	8.95	9.04	14.46	18.2	20.1	15.4	15.2	9.8	10.12	8.9
2009												5.52
2010	8.27	4.6	22.33	24.4	21.32	11.81	10.72	5.84	4.98	4.95	13.22	11.34
2011	4.45	5.74	14.43	15.91	4.13	5.63	6.28	5.43	5.2	9.1	26.93	22.97
2012	14.94	10.04	7.32	47.01	38.13	12.05	12.25	11.8				

SOURCE: WARMA (2014)