REMOTE SENSING AND GIS-BASED ASSESSMENT OF LAND DEGRADATION DRIVEN BY CLIMATE AND LAND USE CHANGES IN NASARAWA STATE, NIGERIA

BY

BISSADU, Kossi Dodzi
MTECH/SNAS/ 2013/4214

WEST AFRICAN SCIENCE SERVICE CENTRE ON CLIMATE CHANGE AND ADAPTED LAND USE
FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

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THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF TECHNOLOGY IN CLIMATE CHANGE AND ADAPTED LAND USE

OCTOBER, 2015

DECLARATION

I hereby declare that this thesis titled "Remote Sensing and GIS-based Assessment of Land Degradation driven by Climate and Land Use Changes in Nasarawa State, Nigeria" is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) have been duly acknowledged.

BISSADU, Kossi Dodzi ………………………….

MTECH/SNAS/2013/4214 SIGNATURE/DATE
FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA, NIGERIA

CERTIFICATION

This thesis titled ‘‘Remote Sensing and GIS-based Assessment of Land Degradation driven by Climate and Land Use Changes in Nasarawa State, Nigeria’’ carried out by BISSADU, Kossi Dodzi (MTech/SNAS/2013/4214) meets the regulation governing the Award of Degree of Master of Technology (M Tech) of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

Prof. M.I.S. Ezenwa …..………………….

Supervisor Signature & Date

Dr. A.A. Okhimamhe ……………………..

Director, WASCAL CC and ALU Signature & Date

Prof. M.G.M. Kolo …………………….

Dean, Postgraduate School Signature & Date

DEDICATION

I dedicate this work to my lovely family, my Mother (Gblokpor Afi), late Father (Bissadu Kodjo Senam) and Tutor (Henri Eklu), my Brothers (Kokou, Mensah and Paul) and Sister (Tanti), and in a very special way to my unshakable wife (Mrs Kludje-Konou Yawa Elisabeth).

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ABSTRACT

Land degradation is one of the worldwide threats to the ecosystem, thereby reducing its capacity to provide the adequate ecosystem services. Sub-Saharan Africa is known as one of the most threatened regions by land degradation due to both the change and/or variability in the climate conditions and human activities**.** The impact of both climate and land use changes on land degradation was assessed in Nasarawa State, Nigeria. The focal points of this study were to assess how the climatic condition and land use changed in the study area and to appraise their impacts on land degradation, especially soil erosion by water. Temperature and rainfall data were collected for a time period of 34 years for two meteorological stations of Nasarawa State (Doma station representing the South and Kokona station representing the North. Rainfall and temperature patterns and trends were assessed using Standardized Precipitation Index, Thermal Anomaly Index, Innovative Trend Analysis, CUSUM test, and Sen and Man-Kendall rank test. For the climatic analyses, the software EXCEL 2013, XLSTAT 2015, SPSS 20.0 and MATLAB programming tools were used. Landsat satellite images of the years 1986, 1999 and 2015 were classified using maximum likelihood to produce LULC maps for 1986, 1999 and 2015 coupled with change detection in ENVI 5.1 and ArcGIS 10.0. Revised Universal soil Loss equation (RUSLE) model was used to model soil erosion for the periods 1981 and 2014 and soil erosion change trend and actuality were assessed based on multi-criteria rules methods with the help of ArcGIS 10.0, 3DEM, Global mapper and EXCEL 2013 analysis tools. The conservation priorities were then identified based on the erosion actuality and change trend. The mean temperature is increasing at the rate of 0.034°C/year (0.047°C/year in the South and 0.021°C/year in the North), the same significant increasing trend was observed in the minimum temperature at the rate of 0.098°C/year and 0.066°C/year in the South and North respectively. Only the maximum temperature did not change significantly in the study area. The rainfall equally increased at the rate of 6.39mm/year and 2.3mm/year in the South and North respectively. Land use/cover changed significantly from 1986 to 2015 and savannah shrub was the most depleted land cover (from a coverage of 78% of the landmass in 1986 to 53% in 2015) followed by savannah woodland (from 6% to 0.64%). However, agricultural land increased from 7.5% to 17%, settlements from 6.5% to 15% and degraded land or bare soil from 0.86% to 8%.The change in land use/cover pattern and climate conditions significantly impacted 27.47% of the total landmass of the study area with 15.45% and 12.02% observing improvement and deterioration status respectively. Thus, the soil erosion status improved in overall for the past 34 years. However, all the local government areas experienced some degree of deterioration of soil. About 99% of the total area need implantation of soil conservation strategies and 2% need an urgent intervention to prevent the area from the occurrence of disastrous erosion. Nasarawa, Keana, Karu, Akwanga, Lafia and Wamba are the regions of great concern for the degrading status of their land. It was concluded that changes in land use/cover and climate conditions contributed to the degradation of land (especially soil erosion by water) in Nasarawa State. Finally, implementation of sustainable land use management and mainstreaming erosion control practices in agricultural policy of the State were the major recommendations drawn up from the study.

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ABBREVIATIONS, GLOSSARIES AND SYMBOLS

CO_2: Carbon dioxide

DEM: Digital Elevation Model

EPIC: Erosion Productivity Impact Calculator

FAO: Food and Agriculture Organisation

FEM-FIDA: Fonds pour l'Environnement Mondial – Fonds International pour le Développement Agricole

GIS: Geographic Information System

ha: Hectare

IPCC: Intergovernmental Panel on Climate Change

LBRBDA: Lower Benue River Basin Development Authority

LULCC: Land- Use Land-Cover Change

MK: Mann-Kendall

mm: Millimetre

RECTAS: Regional Centre for Training in Aerospace Survey

RUSLE: Revised Universal Soil Loss Equation

SLUM: Sustainable Land Use management

SWCS: Soil and Water Conservation Society

Tons: Tonnes

UNCCD: United Nations Convention to Combat Desertification

UNDP: United Nations Development Programme

UNEP: United Nations Environment Programme

UNFAO: United Nations Food and Agriculture Organization

USGS: United States Geographical Survey

USLE: Universal Soil Loss Equation

WHO: World Health Organization

WMO: World Meteorological Organization

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Land degradation can be defined as the reduction in the capacity of the land to provide ecosystem goods and services and assure its functions over a period of time for the beneficiaries of these (http://www.fao.org/nr/land/degradation/fr/, retrieved on 24 June 2014 at 12:07pm). Land degradation is a global problem as pointed out by United Nations Environment Program (UNEP, 2008). Agricultural land degradation is increasing on global scale (Bai, Dent, Olsson, and Schaepman, 2008). Adam and Eswaran (2000) reported that many hectares of farmland are being yearly affected.

According to the United Nations Convention to Combat Desertification (UNCCD, 2012), Land degradation affected roughly 250 million of people in the world. Moreover, one billion of people in almost 100 countries are presently at risk. The poorest, the most marginalized and the politically weak people are among the people at risk. Only 11% of the land of the world can be considered as Class I which must feed the 6.3 billion of people today and the expected 8.2 billion by 2020.

According to UNCCD, the Sub-Saharan region of Africa recorded the highest rate of land degradation, with the estimation of 0.5-1% of cropping productivity loss each year. Therefore, Africa is especially threatened since 46% of the continent is affected by land degradation.

Land degradation is firstly due to unsustainable farming practices, urbanisation and industrialisation, and secondly to increase in extreme events, such as flash floods and droughts. In addition, Climate change can aggravate land degradation through spatiotemporal change in the patterns of temperature, precipitations, solar radiation and winds (World Meteorological Organisation, WMO, 2005). Soil erosion by water is one of the major causes of land degradation worldwide; soil erosion by water will probably be increased due to changes in the amount and erosive power of rainfall (Nearing, 2001).

1.2 Statement of the Problem

Climate change has been one of the most hotly engaging environmental issues of debate in recent times. Climate change has been impacting different ecosystems particularly those already fragile, and land degradation, which has been occurring worldwide due to land use practices and changes, is worsening by the pronounced change in climatic condition. According to Ojo, Oni and Ogunkunle (2003), climate variability and change have occurred in time and space in Nigeria and that will continue in the future.

Nasarawa State has been experiencing fewer droughts while observed rainfall pattern appears to be increasing, and this also includes temperature pattern (Shuaibu, 2014). This change in yearly and seasonal rainfall is projected to continue associated with changes in river flow, flooding and water quality, and the distribution in the ecosystems (Adefolula, 2000; World Health Organization, WHO, 2008).

Land in Nasarawa State has been degraded and will continue to degrade owing to the change in its climatic condition associated with the rapid change in land uses (inasmuch as the state population is growing rapidly with unbelievable urbanization of the whole state). It is well known that the first agricultural production factor is land which is regarded as practically limited and an irreplaceable finite resource (Agboola and Olatubara, 1993) that must be well managed to sustain agricultural production in Nasarawa State; wise and sustained land management is the unique guarantee for food security. Most of the previous studies carried out in the area to tackle this phenomenon did not go beyond a simple assessment of land degradation. Therefore, to enable secured and adaptive land uses to be designed, planned and implemented, the present study seeks to find out the trend and rate of the change of the climate and land use, and to evaluate how both these climate and land use changes drive the degradation of the different lands.

1.3 Justification of the Study

The rapid growth of the world's population led to the increase of demand for food, water, energy and space for urbanization and development. This situation is impacting on the land use. Natural vegetation such as forest, woodland are being converted into agricultural land and built-up area to meet this demand. Consequently, cropping intensity will increase in the future, as less land becomes available for agriculture (Bruinsma, 2003). This situation associated with climatic variations or changes are well known as major drivers of the degradation of the land which affect biodiversity and socio-economic livelihoods of the world population (http:www.development-durable.gouv.fr).

African countries are counted among the most affected by land degradation, maintaining their population in extreme poverty, and the current state of land of these countries is alarming. A thorough attention must be paid to this threatening phenomenon for quick actions, policies and strategies design and implementation, for the combat against desertification and land degradation in general is a combat that must be won [Fonds pour l'Environnement Mondial – Fonds International pour le Développement Agricole , (FEM-FIDA), 2002].

Assessing the state of land degradation on small and large scales is required to handle efficiently this phenomenon in Nigeria, especially in Nasarawa State. Therefore, this work titled 'Remote Sensing and GIS-based assessment of land degradation driven by climate and land use changes in Nasarawa State' will help to have profound understanding of the pattern and trend of the climatic conditions in the area and its impact on land degradation (particularly on soil erosion). It will also enable a better understanding of how changes in land use contributed to land degradation in the past degradation, and will therefore permit us to identify soil conservation priorities for each region within the study area. This work will consequently help in proposing, designing, planning and implementing sound and sustained land uses of the area. Such finding can also be extrapolated to other parts of the country with similar conditions.

1.4 Initial Assumptions

The study will achieve its ultimate goal based on the assumptions that:

i- Climate has been changing in Nasarawa State and has been impacting negatively on land;

ii- Land use has changed and is a major cause of land degradation, mostly soil erosion by water;

iii- Assessing land degradation in terms of its type, degree and extent could help in better planning and management of the limited available lands to ensure food security while combating climate change.

1.5 Scope and Limitations of the Study

The aspect of climate change that was look at in this study was limited to temperature and rainfall pattern and trend analyses. Flood events were the climatic extreme that was covered by the present study and for the past 34 years (1981-2014). Besides, two meteorological stations (Doma and Kokona) data were used for the study. Also, two types of land degradation were studied: land cover degradation (land bareness) soil erosion by water. The Landsat images of the years 1986, 1999 and 2015 were employed for land use change and land-cover degradation studies. Soil erosion assessment was carried out for the last 34 years (1981-2014). All these different periods were chosen in accordance with the limited time-bound allocated to the study and the availability of the required data. The present research was conducted in ten Local Government Areas (LGAs) of Nasarawa State (Eight Local governments areas for the four districts) associated with two other local governments (Keffi and Lafia) selected for their high population densities, this is due to limited time and technical challenges related to the available data and their collection which prevented us from covering the whole State.

1.6 Aim and Objectives

The present study was aimed at assessing the impact of both climate and land use changes on the land degradation in terms of soil erosion by water and land bareness, with the view to identify the state conservation priorities and to propose adaptive practices and uses of the different lands. The specific objectives were to:

- Determine the general pattern and trend of rainfall and temperature for the last 34 years (1981-2014) ;
- Characterize the flood events for the same time period and predict possible flood events;
- Determine the land use change and degraded area in Nasarawa State using Landsat satellite images of the time period of 1986, 1999 and 2015;
- Assess the spatio-temporal change of soil erosion in Nasarawa State for the past 34years (1981-2014).

1.7 Research Questions

The research questions this study was targeted to answer included the following:

- What is the general pattern and trend of rainfall and temperature of the study area from 1981 to 2014? ;
- How are the flood events in Nasarawa State from 1981 to 2014 and how will they be like in the future? ;
- How had the land use and degraded area changed within Nasarawa State during the last 30 years? ;
- How has soil erosion changed in time and space from 1981 to 2014?

1.8 Presentation of the Study Area

1.8.1 Geographic Location of the Study Area

Nasarawa State is located in Nigeria, between latitude 8-9^o north and longitude 7-8^o east and is bounded by Kaduna State in the north, Abuja Federal Capital Territory in the west, Kogi and Benue States in the west, and Taraba and Plateau States in the east. (Figure 1.1)

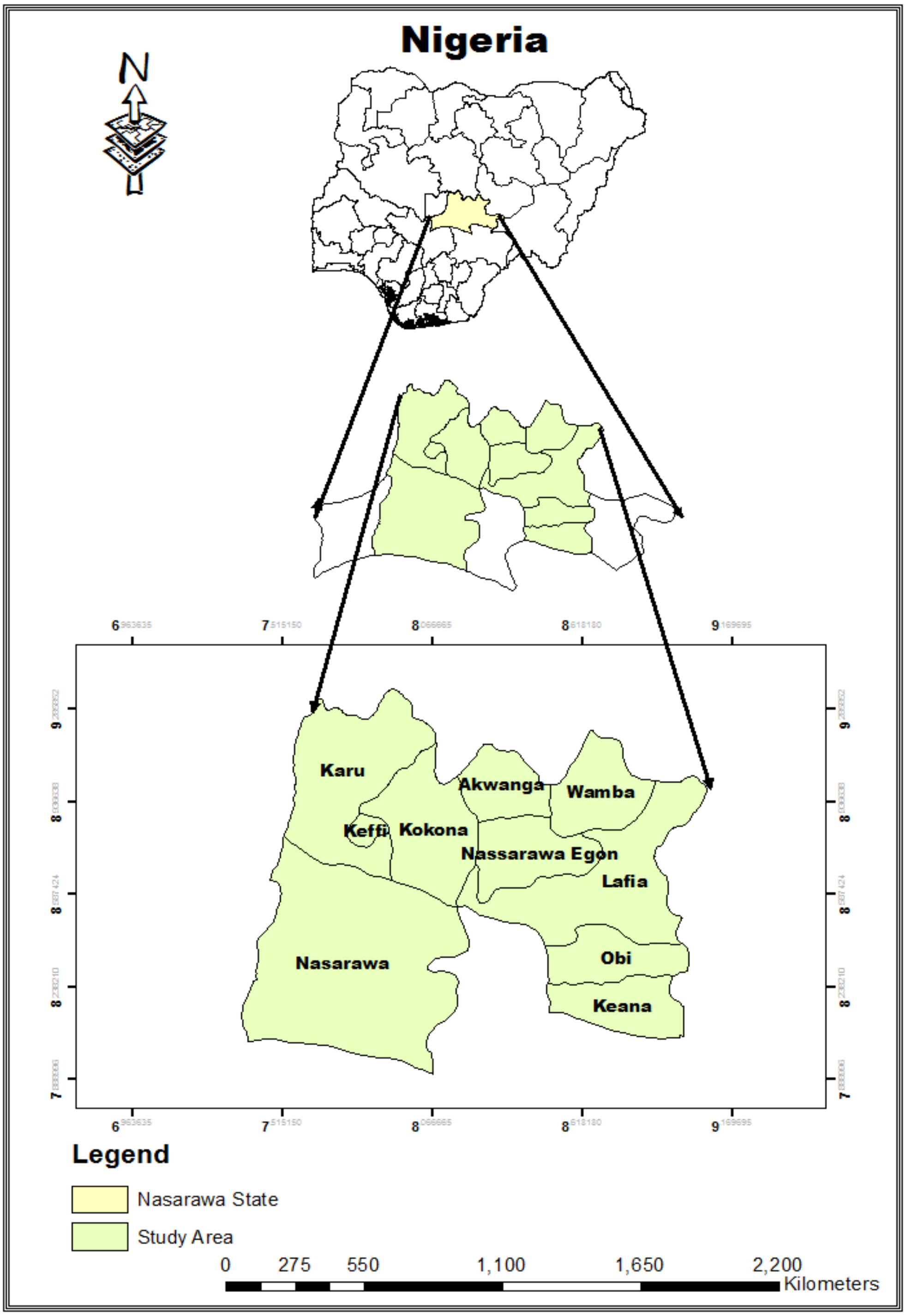

Figure 1.1 Location of the Study Area

(Source: Author's Study, 2015)

1.8.2 Climate

The tropical climate is dominant within the study area; the mean precipitation is about 1200mm with about 90% of it falling from April to October. The dry season occurs when north easterly wind blows from Sahara desert across Nigeria in south westerly direction which brings in the cold harmattan winds with little or no rain. The annual mean temperature in the region is 24.4°c. It is hot during the day and moderately warm at night which creates a high rate of evaporation and increases the demand for water. The two seasons are influenced by the movement of air masses namely the tropical maritime air mass which is moist and warm and move across the country from the Atlantic ocean in the south-westerly direction and lead to rainfall. The tropical continental air mass originates in the Sahara deserts and moves from the north-easterly direction across the study area and it leads to dry season.

The relative humidity is marked by the two seasons (dry and wet) and show a marked decrease from the early morning to the afternoon throughout the year. From the month of January, the relative humidity is higher (about 80%) compared to the afternoon (about 30%) throughout the year (en.wikipedia.org/wiki/Nasarawa_state).

1.8.3 Soils of Nasarawa State

The formation of soil resulted from myriads of factors such as the types of rock, the local climate, organic matter, topography of the area and time.

Strong relationships exist between the types of soils in the area and forming processes; this is because most parts of the state have undergone series of climatic and vegetative shifts.

A number of soil types have been identified in most parts of the state to include Ultisols, Alfisols, Entisols, Inceptisols and Vertisols.

Ultisols: They are characterized by clay accumulation in the subsoil and with low supply of bases in the lower horizon. Base saturation decreases rapidly with depth and most of the bases are in the organic or mineral horizon (Shuaibu, 2014).

Alfisols: These soils are typical of grassland regions and are characterized by the presence of an argillic horizon with a high base status. The parent materials comprise crystalline acid rocks, high quartz and lower iron; thus the soils are lighter in the texture. Kaolinite clays dominate, with some small amount of 2:1 clay lattice often present which results in the soil with low Cation Exchange Capacity but with high base saturation (>35).

Entisols: They are developed on inselbergs and wooded hills. Most of the soils are developed at the base of wooded hills and resulted in the type of soil with high proportion of rock fragments and stones in the profile. Their organic matter content is low while biological activity is also very low. The soils are primarily basements Entisols that have sandy texture in the upper profile. The agricultural development potential of these soils is generally low. These types of soils are found around Keffi, Akwanga, Wamba, Kokona, Nasarawa and Nasarawa Eggon areas (Shuaibu, 2014).

Inceptisols: These soil types occur on recently accumulated alluvial sediments of flood plains. They are commonly found in valleys of the main rivers in the state (e.g Mada, Uke, Akwanga, Lafia and Benue). In the southern Local Government areas of Keana, Obi, Awe, Lafia and south of Nasarawa, there is wide coverage of alluvial soils and this occurs in the north where most rivers are deeply entrenched. The soils are poorly drained almost throughout the year and with soil water table being high. Drainage and oxidation of these soils lead to the formation of large concentration of sulphates in subsoil. The availability of Al, Mn and Fe may increase to levels toxic to plants. The agricultural productivity of these soils is high especially for irrigation development (Shuaibu, 2014).

1.8.4 Vegetation

The vegetation type within Nasarawa State is mainly guinea savannah. Largely the vegetation is characteristic of the southern guinea savannah and some elements of the northern guinea savannah with intersession of thicket, grassland, and tree savannah, fringing woodlands or gallery forest along the valleys (IIoeje, 1984). This is sometimes called parkland savannah or woodland savannah. The southern guinea savannah has a rainy season that lasts for a period of six to seven months with mean annual rainfall between 1100mm and 1200mm. It is dominated by woody species such as *Afzelia africana, Terminalia macroptera, Daniella oliveri, Parkia biglobasa and Khaya senegalensis*, while grass species include *Andropogon gayanus, Andropogon pseudapricus, Bekeropsis uniseta*. The northern guinea savannah has no clear distinction with the southern guinea savannah. However, the mean annual rainfall is between 1000mm and 1600mm. The dominant woody species in this area are similar with the southern guinea savannah tree species.

1.8.5 Topography

The topography of the State is made up of gentle undulating terrain with series of steep slopes towards Benue plain. The study area is located between Benue valley and Jos plateau. The northern part of Benue trough is characterized by lowlands which form a continuous plain about 10km wide which gradually slopes from the foot of the plateau towards the slightly steeper slopes descending from the foot of the plateau escarpment. South of the northern lowlands of the plateau where Nasarawa State is situated is an area of transition; only part of it can be regarded as part of Benue plain.

The northern half consists of a number of different landscapes. Its northern most section is a broken country of 840m and narrow valleys. At the foot of the hills lies Keffi plain at the elevation of 350-500m, the southern half belongs to Benue plain. It is generally higher in the east and has steeper slopes towards the river. Nasarawa State is situated between the Haderi (Alheri), and Kurafe (river Uke), which form eastern and western border of the town. The rivers have their confluence about south west of the town.

1.8.6 Agriculture

Agricultral production is the major economic activity in the State. The most cultivated crops are *Oryza sativa* (Rice), *Discorea sp* (Yam), *Sorghum vulgare* (Guinea corn), *Zea mays* (Maize), *Arachis hypogea* (Groundnut), *Vigna unguiculata* (Beans or Cowpea), *Manihot exculentis* (Cassava), *Saccharum officinanum* (Sugar cane), *Cucumis melo* (Melon or egusi), *Glycine max* (Soyea bean), *Ipomea batata* (Sweet potato) and *Pennisetum typhoides* (Millet) . Agriculture in the area is highly rain-fed; however some small scale cropping takes place during dry season. Animal rearing is another agricultural activity mainly held by Fulani.

CHAPTER TWO

2.0 LITERATURE REVIEW

This study is worth to be carried out due to the fact that land degradation threatens not only the food security, but also undermines the socio-economic strength of the countries or States that are experiencing it. Then, our study is aimed at assessing the state, extent and degree of land degradation in Nasarawa State with a particular importance of its major drivers: land use and climate changes. This chapter reviews the concepts and case studies related to the subject.

2.1 Conceptual Framework

Land degradation is a worldwide problem tackled by many researchers, policy-makers, Governments and land users. It is a biophysical process that alters the ability of the land to provide its services. Soil erosion by water is pointed out as the major form of land degradation which occurs at global scale. It is more pronounced in the tropical region due to the high rainfall erosivity observed in the region. It is a natural process that can be enhanced by some factors to the more noticeable state such as rill, sheet or gully erosion. The prominent factors are land use/cover changes and the variations in climate conditions.

Land use change affects the state and the composition of the land surface that can reduce or increase the erosion of the topsoil. The variation in climate condition, which can be characterized as climate variability or change, is noted as a major contributor to the reduction or increase of soil erosion. The paramount climate parameter in the process of soil erosion by water is precipitation. The change in precipitation regimes, as mostly observed in tropical region, usually affects the degree, extent and intensities of soil erosion by water. Soil erosion is significantly menacing the world's food security and occurs as the direct result from land use malpractices and continuous change in global, regional and local climate conditions.

2.2 Review of related Concepts

2.2.1 Land Degradation

Land degradation is a process in which the bio-physical environment value is affected by a combination of human-induced processes acting upon the land (Conacher and Conacher, 1995). It is one of the major environmental challenges experienced worldwide and results from natural and anthropogenic factors Kombe and Kreibich, 2000).

2.2.2 Main Types of Land Degradation

According to Gretton and Salma (1996) and (Peter, 2002), the types of land degradation include soil erosion (by water and wind), soil fertility loss, soil salinity and acidity, land cover depletion, and so on,

In the tropics, soil erosion is of the most important type of land degradation, and the major factors determining the occurrence and the severity of soil erosion include the nature of soil, land surface, vegetation cover, climatic characteristics and human activities (Abegunde, Adegoke, Onwumere and Dahiru, 1999). Also, the bareness of most of agricultural land due to malpractice and the expansion of built up area have been considered as a serious threat to the farm lands in many states of Nigeria.

2.2.3 Major Drivers of Land Degradation

Drivers are causes of land degradation and the major drivers include unsustainable land use, lack of erosion control, commercial and industrial development, climate variability and change (Brabant, Darracq, Egue and Simonneaux, 1996). Land degradation is especially due to over-cropping of arable lands, malpractice in cropping and grazing, increase in built up areas reducing agricultural areas (Ifatimehin, 2000). All these causes are enhanced by the climate change impact such as rainfall and temperature anomalies, increased in number and intensities of climate extremes (drought and floods).

2.2.4 Climate Change

Climate change is the change in the long-term average weather ranging from decades to millions of years. It may be changes in average weather or in weather event distributions. It can be restricted to a specific area or may occur worldwide (Intergovernmental Panel on Climate Change, IPCC, 2007). Causes of Climate Change or variability are external forcing factors that alter the pattern of the climate over time. There are natural external forcing factors and anthropogenic forcing factors (Goosse, Crespin, de Montety, Mann, Renssen and Timmermann, 2012).

Solar irradiance variations and explosive volcanism are the two important causes accounted for the natural external forcing factors (Naveau, 2014). Explosive volcanism has cooling effect on the climate and is short-lived (Free and Lanzante, 2009; Schurer, Hegerl, Mann, Tett, and Phipps, 2013), whereas solar irradiance variations has warming effect on the climate.

Anthropogenic forcing accounts more for heating effects on the climate, known as global warming (America's Climate Choices, 2010). More than half of the increased surface temperature observed is probably due to the increased concentrations of anthropogenic greenhouse gases (GHG) (Fyfe, Gillett and Thompson, 2010). Also, human-related forcing (anthropogenic) which is dominated by GHGs, contributed to the warming of the troposphere, while that dominated by ozone- depleting substances contributed to the cooling of the lower stratosphere (Gillett, Arora, Matthews, Scott and Allen, 2008).

Climate change has many consequences: rise of sea level that has been menacing coastal regions, sea acidification that is dangerous for aquatic ecosystems (MacKenzie, Gislason, Möllmann and Köster, 2007; Nellemann, Hain and Alder, 2008), increase in intensity of weather extremes such as drought and floods, decrease of biodiversity (Pimm, Russell, Gittleman and Brooks, 1995; Millenium Ecosystem Assessment, MEA, 2005) or extinction of some species (Jarvis, Lane and Hijmans, 2008; Food and Agriculture Organization, FAO, 2007), decrease in agricultural productivity, and increased water insecurity (especially in most vulnerable areas). Moreover, Climate change is projected to impact land and water for agricultural production (Fisher, Tubiello, Van Velthuizen and Wiberg, 2007).

2.2.5 Concept of Land Use Change

Land use is “the total of all arrangements, activities and inputs that people undertake in a certain land cover type” (United Nations Food and Agriculture Organization, UNFAO, 1997). Land-use change, usually couple with land cover change (LULCC) is a general term for the human modification of Earth's terrestrial surface. Though humans have been modifying land to obtain food and other essentials for thousands of years, current rates, extents and intensities of LULCC are far greater than ever in history, driving unprecedented changes in ecosystems and environmental processes at local, regional and global scales.

Recently it is pointed out that land use change is part of the main causes of changes in climate. According to World Bank Environment Department (1993), Changes in land use, associated with fossil fuel use are known as the major anthropogenic sources of carbon dioxide release into the. From 1850 to 1998, about 136(+55) Gt carbon gas has been emitted as carbon dioxide into the atmosphere as a result of land use changes, predominantly from forest ecosystem (IPCC, 1998).

2.2.6 Drivers of Land Use Change

Drivers are the causes of land use change and there are underlying causes and proximate causes (Eric, Helmut and Erika, 2003). Underlying causes are the fundamental forces that corroborate the proximate causes of land use land cover and operate to alter one or more proximate causes (Leemans, Lambin, McCalla, Nelson, Pingali and Watson, 2003). A complex of social, political, economic, demographical, technological, cultural and biophysical variables form the underlying causes (Geist and Lambin, 2002; Ledec, 1985; Contreras-Hermosilla, 2000).They operate from outside the local communities that manage the land at regional or global levels. On the other hand, proximate causes occur at the local level (individuals, households or communities).

Land use change is generally caused by factors that operate gradually or occur intermittently (Lambin *et al*., 2001). From literature, we have found that a combination of some fundamental causes drive land use change. They include (Marquette, 1998; Pichon, 1997; Walker, Perz, Caldas and Silva, 2002):

- Resource scarcity resulting in an increase of production's pressure on resources
- Opportunities changes created by market;
- Intervention from outside;
- Loss of resilience and increased vulnerability; and
- Changes in social structural organisation, in access to resources.

2.2.7 Soil Erosion Concept

Soil erosion, according to Morgan (1995), is a biophysical process leading to the detachment and transportation of soil particles due to the action of wind and water. It occurs in three stages: (1) soil detachment, (2) transport, (3) deposition of eroded particles (Saha, 2004). The kinetic energy of raindrop or wind break down the soil aggregates which provoke their detachment. Then, the movement of water or wind transports these detached particles. Based on the erosive agents, there are two types of erosion: erosion by water and erosion by wind. Soil erosion by water can be classified into five main forms: splash erosion, sheet erosion, rill erosion, gully erosion, valley or stream erosion. It is controlled by some factors such as (Ande, Alaga and Oluwatosin, 2009; Pande, Prasad, Saha and Subramanyam, 1992):

- **Rainfall intensity and runoff**

Rainfall and its associated runoff erosivity includes drop size distribution and intensity of rain, amount and frequency of rainfall, runoff amount and velocity.

- **Soil erodibility**

Soil erodibility is the susceptibility of soil to erosion, and is determined by inherent soil characteristics, such as texture, structure, soil organic matter content, clay minerals, exchangeable cations and water retention and transmission properties.

- **Topographic factors**

They are slope gradient and length. The amount of soil loss by water increases as long as the slope becomes steeper. Moreover, the longer the slope length, the greater soil erosion.

- **Vegetation**

The potential of soil loss increased in the area of no or little vegetative cover of plants and or crop residues. Vegetative cover reduces the impact of raindrop and splash, slows down the surface runoff and facilitate surface water infiltration.

- **Conservation measures**

Known as support practices, they contribute in reducing soil erosion by water. Land management has a direct effect on the overall erosion problem.

Erosion by wind is mostly observed in arid and semi-arid regions. It is controlled by soil erodibility, soil surface roughness, climate, vegetation cover, and unsheltered distance.

2.2.8 Revised Universal Soil Loss Equation (RUSLE) Model

RUSLE model is the adapted form of USLE model developed by Renard *et al.* (1997) to evaluate the long-term annual average soil loss over an area. RUSLE model describes the interaction effect of climate, soil, topography and land use to cause rill and sheet erosion. It has been widely used to quantify soil loss, evaluate soil erosion risk, and It has been extensively used to estimate soil erosion loss, to assess soil erosion risk, and to guide in designing of conservation plans for different land uses (Millward and Mersey, 1999; Boggs, Devonport, Evans and Puig, 2001; Mati and Veihe, 2001; Angima, Stott, O'Neill, Ong, and Weesies, 2003). It is an empirical equation which estimate soil erosion by water as a function of six causative factors such as (Renard *et al.*, 1997): rainfall and runoff erosivity, soil erodibility, slope length and steepness, soil cover management, and conservation. The model is as follows:

$$A= R \times K \times LS \times C \times P \qquad (2.1)$$

Where:

A = Estimated Average annual soil loss: units are expressed in (tons per acre per year)

R = Rainfall Erosivity Factor: This factor shows the amount of soil loss due to runoff erosion, it is the ratio between the soil loss amounts and the rainfall agresivity. It depends on the rainfall intensity as well as the annual total (Toy and Foster, 1998).

K = Soil Erodibility Factor

L = Slope length factor

S= Slope steepness

LS are called topographic factor and is constant over time if any human intervention is made.

C= Soil cover management factor

P= conservation practice factor

2.3 Review of Previous Studies

Climate change, land use land cover change and their respective impacts on land degradation, especially on soil erosion by water have been investigated by many researchers across the world.

From various scholars, the most popular indicators of assessing climate change and variability in a region are changes in temperature, evapotranspiration, rainfall, sea level rising, increasing disruption in the pattern of climate associated with increased frequencies and intensities of extreme weather (Ahmad and Ahmed, 2000; IPCC, 2001a; NAST, 2000). According to Olaniran (2002), Ayaode (2003) and Odjugo (2005), Nigeria is experiencing the basic features of climate change and variability; they have found from their studies that some localities are experiencing the climatic extremes as a result of increasing temperature and heavy rain. Also, Nkomo, Nyong and Kulindwa (2006), Molega (2006), and Nnodu, Onwuka and Okoye (2007) have confirmed the occurrence of extreme weather conditions such as uneven rainfall pattern, floods and sea level rise in Nigeria. A decrease in rainfall from 1911 to 1980 has been observed in Nigeria (Ayoade, 2003; Federal Ministry of Environment, 2003). Besides, there was a sharp increase in temperature in the country between 1971 and 2005 (Mabo, 2006; Ikhile, 2007), and according to Odjugo (2005) this increasing temperature is already in Nigeria. Adefolalu (2007) carried out a study on temperature and rainfall variations in the semi-arid regions of Nigeria. He found that increased temperature and decreased rainfall have been observed in the semi-arid region of Sokoto, Katsina, Kano, Nguru and Maiduguri. Moreover, Obioha (2008) and Odjugo (2005) have reported the decrease in rainfall in Nigeria, particularly in the northern part. Other climate change and variability indicators observed in Nigeria have been reported by many researchers

(Fasona and Omojola, 2005; Chindo and Fisher, 2005; Ikhile, 2007; Umoh, 2007). Nigeria is vulnerable to climate change, firstly due to the dependency of her economy to climate sensitive natural resources (IPCC, 2001b), secondly it is located in the tropics and along coastal region, and finally various socio-economic, demographic, and policy trends limit her adaptive capacity to climatic change (Okali, 2004).

On the other hand, land use change occurs worldwide due to population growth, technological changes, and climate variability and change. Various studies were carried out to assess land use change. For instance, Abbas, Muazu and Ukoje (2010) conducted a research on mapping land use/cover and change detection in Kafur Local Government Area of Katsina, Nigeria. Using remote sensing and GIS techniques, they found that there were changes in the different land use land cover types identified in the area, however the changes are not statistically significant. They concluded that land management in the study area was actually good. Hussien (2009) carried out in Ethiopia a comparative study on land use/cover change between 1972 and 2005 in two locations (BLUE NILE AND AWASH BASINS). He used remote sensing and GIS methods for the study and discovered that there were real changes in land use land cover in the two locations and the changes vary from decade to decade. Natural vegetation, especially shrub land depleted in overall due to the expansion of cultivated land. They observed from the study that land degradation was increased due to these changes. They finally concluded that land use/cover changed between 1972 and 2005 over the two locations in such a way that land degradation was increased and climatic conditions in the study areas got worse with shortening of rainy season and increase in temperature.

Moreover, Eludoyin, Wokocha and Ayolagha (2011) carried out a GIS-based assessment of land use/ cover changes between 1986 and 2000 in OBIO/AKPOR L.G.A., Rivers State, Nigeria. They found that four of the seven different land use land cover types identified in the area observed decreased in their surface areas. They are farmland, mangrove, primary forest and sparse vegetation. On the other hand, secondary forest, built up area and water land use types increased during the period under study. They thus concluded that land use/cover in the region under study changed over time whereby some increased while others reduced in terms of spatial extent; however, the trio of mangrove, sparse vegetation and primary forest require adequate attention for their sustainability and management because of their diverse roles in protecting the fragile ecosystem.

Sunday and Umar (2013) examined the spatio-temporal change in land use land cover from 1987 to 2012 in Suleja LGA, as well as, the rate of change and responsible factors. They employed post classification method to assess the land use and change with Landsat and Nigeria Sat-1 images of the years 1987, 2001 and 2012 and identified four land use land cover types such as bare surface, built-up area, farmland and vegetation. They found that urban development was the major responsible of the significant change in land use land cover in Suleja. These land use land cover changes lead to environmental degradation, biodiversity loss and infrastructure overload.

Whilst some researchers focused their studies on the impacts of climate change on soil erosion, others were mostly concerned with the impacts of land use land cover changes on soil erosion, particularly on erosion by water. Thus, several researches have been conducted to estimate the impact climate change has on land degradation, especially on soil erosion as the major type of land degradation. In United Kingdom, Favis-Mortlock and Boardman (1995) carried out a study on climate change impact on water erosion by applying the model called the Erosion Productivity Impact Calculator (EPIC). They discovered that 26% of increase in soil erosion was observed with 7% increase in precipitation. In fact, climate change increases the frequency, length and intensities of flood that exacerbate soil erosion.

Besides, in South Africa, Schulze (2000) predicted, by applying CERES-Maize and ACRU models, a 10% increase in precipitation would lead to 20-40% increase in runoff, thereby aggravating soil erosion by water. Leek and Olsen (2000) conducted a research on the effect of rainfall erosivity on soil erosion by water and found that 24-78% of increase in rainfall produce 8 to 17% of increase in soil erosion. In China, Gao and Yu (2002) conducted a study and found that climate change of the past 40years would have decrease soil erosion. Soil and Water Conservation Society, SWCS (2003) carried out a similar study and discovered that soil erosion is highly sensitive to changes in precipitations.

Land use change not only impacts the climate, but also increases land degradation, especially in terms of soil erosion. Numerous researches were carried out to assess the impact of land use change on land degradation and in a particular on soil erosion. In South Africa, Schulze (2000) carried out a study and found that changes in land use increased bare soil coverage, thereby exacerbating soil erosion.

In Italia, Armando, Attilio and Montanari (2002) assessed the effects of land-use changes on annual average gross erosion. They applied the Universal Soil Loss

Equation model (USLE) and discovered that numerous changes in land use have occurred in the various regions of Italy. These changes can have local, regional or global impact on soil erosion. Symeonakis, Calvo and Arnau (2003) carried out a research on the linkage between land use changes and land degradation in China. They found that there was a strong relationship between changes in land use pattern and land degradation. The change that occurred by the removal of native vegetation to other land uses increased the degradation of the land, while the increase in greenness of the land reduced drastically the extent and degree of degradation of the land.

Amir, Iraj, Maryam and Hans (2010) conducted a study on land use change and soil degradation in North of Iran and found that the change in land use and cultivation, especially from undisturbed forest to completely deforested area resulted in soil degradation and the most important properties of the soil that are degraded are Cation exchange capacity, electrical conductivity, soil organic carbon, total nitrogen, and pH; however, the change in land use and intensive cultivation has no significant impact on soil particles (sand, clay and silt) distribution in their study area.

In Thailand, Wijitkosum (2012) investigated the impacts of land use changes on soil erosion in Pa Deng Sub-district, Adjacent Area of Kaeng Krachan National Park. He found that soil erosion decreased as land use changed from bare land in 1990 to forest in 2010. They also discovered that soil erosion risk increased when the land use changed from forest in 1990 to agricultural area in 2010 or from community in 1990 to agricultural area in 2010.

2.4 Conclusion

In the works reviewed, researchers have tried to use different data (satellite data, soil and climate data) associated with different models to predict the impact of land use and rainfall changes on land degradation, especially on soil erosion by water. Their findings confirm that change in rainfall pattern associated with change in land use land cover can widely affect land degradation. They have predicted particularly how much soil loss can vary from any change in rainfall amount, and they conclude that the decrease as well as increase in rainfall can lead to soil erosion increase as well as decrease in soil erosion owing to the effect of the other factors included in the prediction. However, the previous works mostly focused on the impact of either climate change (especially rainfall change) or land use land cover change on soil erosion. They minimized the combined actions of climate and land use changes on soil erosion. Moreover, they did not pay much attention to the conservation priorities in their researches, since their models could not allow such further works. Besides, some few works based on multi-criteria method made an attempt to identify these conservation priorities without paying much attention to the combined action of changes in climate and land use/cover patterns. Therefore, this study has the merit to combine the quantitative model with multi-criteria analysis to, not only predict the impact of both climate and land use/cover changes on soil erosion, but also to determine the urgent need for soil and water conservations in the study area.

CHAPTER THREE

3.0 MATERIALS AND METHODS

This chapter dealt with the different types of data that were collected and the methodologies of their collection and analyses to assess the impact of climate and land use changes on land degradation in the study area. This study tried to look at how Changes in land use and climate have been contributing to land degradation in terms of degraded areas expansion and soil erosion.

3.1 Description of Data collected

The data required to answer each of the research questions are summarized in Table 3.1.

Table 3.1 Types of Data collected to answer the Research Questions

Research Objectives	Type of data collected
Analysis of the general pattern and trend of rainfall and temperature of the study area from 1981 to 2014	- Monthly minimum temperature data from 1981 to 2014 - Monthly maximum temperature data from 1981 to 2014 - Monthly rainfall data (1981-2014)
Characterisation and prediction of flood events	- Total annual rainfall data (1981-2014)
Land use/degraded land cover change	-Landsat images for the years 1986, 1999 and 2015
Assessment of spatio-temporal change of soil erosion	- Total annual Rainfall data for the last 34years for rainfall erosivity - Digital Elevation Models (DEMs) data for topographic factors (LS) calculation - Soil map for soil erodibility computation - Soil samples (for soil texture analysis) - Landsat images for the years (1986, and 2015) for land cover factors (C) calculation

(Source: Author's Study, 2015)

3.2 Data Collection Methods

3.2.1 Climatic Data

Total monthly rainfall, monthly minimum and maximum temperature data for Doma and Kokona meteorological stations of Nasarawa State were collected from the Lower Benue River Basin Development Authority (LBRBDA) at Makurdi, Benue State. Table 3.2 shows the different climatic parameters collected and their sources of collection. Minimum and maximum temperature, and rainfall data were collected for a period of 34 years (1981-2014).

Table 3.2 Meteorological Data obtained from the LBRBDA

Stations	Year	Type of data	Source
Doma	1981-2014	Rainfall, Temperature	LBRBDA
Kokona	1981-2014	Rainfall, Temperature	LBRBDA

(Source: Author's Study, 2015)

As two meteorological stations data were insufficient for spatial interpolation for the determination of rainfall erosivity, additional total annual rainfall data were acquired for eight additional meteorological stations surrounding Nasarawa State. These data were collected from the Food and Agriculture Organisation Programme (FAOClim2) at the Regional Centre for Training in Aerospace Surveys (RECTAS) in Ife, Oyo state (Nigeria).

3.2.2 Soil Data

Soil map of the study area was collected from the Regional Centre for Training in Aerospace Survey (RECTAS) at Ile-Ife, Osun State. Five different soil types were identified from the soil map collected. They are Entisols, Alfisols, Ultisols, Inceptisols and Vertisols. For the computation of soil erodibility, soil texture, profile permeability, structure and soil organic matter content were the required soil parameters. Soil profile permeability data were collected through soil profile analysis. Soil structure was obtained by physical test of soil. These two parameters were collected from soil survey. Soil organic matter content and texture data were obtained from the laboratory analysis of the soil sampled from each soil type identified.

3.2.2.1 Soil survey

To collect soil permeability data, one soil pit (with 1.5mX1mX1m dimension) was dug for each soil type identified and with the Munsell chart the soil permeability was characterized based on the soil profile colours. The soil structure was defined through physical hand touch of the different soils. Four bulk soil samples were taken from each soil type at a depth of 0-20cm and were brought to the soil laboratory of College of Agriculture Lafia (Nasarawa State) for sol organic matter content and texture (% silt, %clay and % sand) determination.

3.2.2.2 Laboratory Analysis

Soil particle analysis was carried out in the laboratory using Bouyoucos (1962) hydrometer method.

3.2.3 Topographic Data

For the computation of topographic factors such as slope length (L) and steepness (S),

30 mX30m resolution spatial Digital Elevation Models (DEM) data was freely downloaded from the United States Geological Survey's (USGS) SRTM website (ftp://e0srp0lu.ecs.nasa.gov/srtm).

3.2.4 Landsat Satellite Data

Low spatial resolution Landsat images covering the study area (path 188 and row 54) were downloaded from the United States Geographical Survey (USGS) website (www.glovis.usgs.gov), and their characteristics were presented in Table 3

Table 3.3 Characteristics of LANDSAT Images

Date Acquired	Spacecraft ID	Sensor	Path and row (p ,r)	No of Bands
2015-02-02	LANDSAT 8	OLI TIRS	p188r54	11
1999-11-13	LANDSAT7	ETM+	p188r54	7
1986-01-17	LANDSAT5	TM	p188r54	7

(Source: Author's Study, 2015)

3.3 Data Preparation

3.3.1 Climatic Data

Monthly rainfall, monthly minimum and maximum temperature data for the period 1981-2014 were used to generate total annual rainfall, annual minimum temperature (Tmin), annual maximum temperature (Tmax) and annual mean temperature (Tmean) values in EXCEL 2013.

3.3.2 Soil Data

The map of dominant soils of the area was scanned, and with ArcGIS 10.0, was geo-referenced, mosaicked and digitized. The different polygons of soil digitized were exported, converted into raster format and resized to fit the 30mX30m dimension of Landsat and DEM data for easy overlay during soil erosion modelling.

3.3.3 Satellite Imagery Data

The time series images of the study area were imported into ENVI 5.1 and were enhanced using linear stretch with saturation so as to improve on the visual quality of the image features for good interpretation of different features. For each year image, the different bands for producing false colour composite image (Red, Green, and Blue) were stacked. A shape file of the study area was produced in ArcMap 10.0 to subset the study area after image classification. DEM data were corrected in ArcGIS 10.0 to remove some disturbances and noise that could cause a problem when computing a consistent drainage pattern. Low-pass filtering was used to correct the DEM raw data. 3DEM software was then used to subset the study area in form of polygon.

3.4 Data Analysis

Statistical, graphical and programming tools in Microsoft Office Excel, SPSS, MATLAB, and XLSTAT were primarily employed in the analysis and result presentation of climate data. Additional tools in ENVI 5.1, ArcGIS 10.0 and 3DEM were used for rainfall erosivity spatial modelling, land use land cover classification, land use and degraded area detection, and soil erosion modelling and assessment.

3.4.1 Rainfall Pattern and Trend Analysis

Before performing time series analysis, homogeneity and normality (Skewness and Kurtosis) tests were done. Rainfall pattern of the study area was analysed through the calculation of Standardized Precipitation Index (SPI) coupled with the plot of standardized rainfall anomalies. SPI was calculated as follows:

$$\mathrm{SPI} = \frac{(\mathrm{Xi} - \overline{\mathrm{X}})}{\sigma} \qquad (3.1)$$

Where Xi is annual rainfall, $\bar{X}$ is the long-term annual mean rainfall and σ is the standard deviation. Also, trend analysis of the rainfall was done to illustrate the trend of rainfall in the study area; and for this, three statistical analyses were performed.

Firstly, Innovative Trend Analysis (Sen, 2012) was done to determine the nature of the trend exhibited by the rainfall. It also helped in identifying whether there is an abrupt change in rainfall trend or not. It consists of dividing the dataset into two equal subsections, the second subsection will be plotted against the first subsection on Cartesian coordinate system; then 45° trend free line was drawn to demarcate the coordinate system into two triangles (upper and lower). From this graph, the analysis was done to find whether the trend is monotonic or non-monotonic, and whether the trend is increasing or decreasing.

Secondly, Cumulative Sum Chart (CUSUM) test (Taylor, 2000) was performed to determine the time periods of abrupt change and the change points (years of change). This test was computed as follows:

Step1: Determine the average of the annual total rainfall

$$\bar{X} = \frac{\sum_{i=1}^{n} Xi}{n} \qquad (3.2)$$

Where $\bar{X}$ is the mean value, Xi are the annual values, and n is the number of observations;

Step2: compute the CUSUM values ($\sum_i$) recursively based on the assumption that $\sum_o$ equal to zero, then

$$\sum_{i} = \sum_{i-1} + (Xi - \bar{X}) \qquad i = 1,2,3 \ldots\ldots, n \qquad (3.3)$$

Step3: plot CUSUM chart for the rainfall against the time period under study.

Finally, Sen's slope was calculated and trend significance at 95% level of confidence was tested using Mann_kendall rank test (Gadgil and Dhorde, 2005; Modarres and da

Silva, 2007; Tabari, Somee and Zadeh, 2011), which uses only the relative values of all terms in the series Xi. The steps that were taken for this test are:

Step1: The annual rainfall values were replaced by their ranks Ki;

Step2: The statistic P was computed using the following procedures: compare the rank of the first value (K1) with those of the later values from the second to the nth value, the later values whose ranks exceed the rank of the first value was counted and denoted as n1, the procedure was repeated for the values of rank K2, K3, K4….K (n-1). P was computed as follows:

$$P = \sum_{i=1}^{n-1} ni \qquad (3.4)$$

Step3: Statistic T was computed using the following equation:

$$T = \frac{4P}{N(N-1)} - 1 \qquad (3.5)$$

Where N is the number of observations

This gives us T of Mann-kendall test.

Step4: The above 'T' was thus used as basis of a significance test by comparing it with

$$(T)_t = 0 \pm tg\sqrt{\frac{4N+10}{9N(N-1)}} \qquad (3.6)$$

Where tg is the desired probability point of the Gaussian normal distribution. For comparison, tg at 0.05 point was taken.

3.4.2 Temperature Pattern and Trend Analysis

Before performing temperature time series analysis, homogeneity and normality (Skewness and Kurtosis) tests were done. Annual mean thermal anomaly indices were calculated for the maximum (Tmax), minimum (Tmin) and mean (Tmean) temperatures for the analysis of temperature pattern in the study area. Thermal anomaly index (S) was calculated as follows:

$$S = \frac{(Xi - \overline{X})}{\sigma} \qquad (3.7)$$

Where S is the thermal anomaly index, Xi is the annual temperature (minimum, maximum, or mean), $\bar{X}$ is the long-term average temperature, and σ is the standard deviation. Trend analysis and change detection for the minimum, maximum, and mean temperatures were done with Innovative Trend Analysis, CUSUM test, and Mann-Kendall test. These methods were described in sub-section 3.5.1.

3.4.3 Flood Events Characterization and Prediction

The intensity of flood events was characterized by using Okoloye, Aisiokuebo, Ukeje, Anuforom, Nnodu and Francis (2013) extremes categorization's table (Table 3.4).

Table 3.4 Categorization of the Intensities of Climate Extremes

INTENSITY	DEPARTURE RANGES FOR	
	Floods	**Droughts**
Moderate	0 to + ½ σ	0 to – ½ σ
Large	½ σ to + σ	½ σ to - σ
Severe	+ σ to +2 σ	- σ to -2 σ
Disastrous	More than +2 σ	More than -2 σ

(Source: Okoloye *et al.*, 2013)

In view to determine the probability of occurrence of each category of flood events identified, probability of exceedance (Pe) of each categorized value was calculated. The

Pe is expressed as the percentage of time that a considered value was exceeded. The Weibull method was used and was expressed as follows (Chow, Maidment and Mays, 1988):

$$Pe = \frac{m}{(n+1)} \times 100 \qquad (3.8)$$

Where, m is the rank of each value arranged from highest to lowest and n is the total number of observations. Finally, annual rainfall was plotted against probability to determine the probability of occurrence of each category of the climatic extremes identified.

3.4.4 Land Use Change and degraded Area Detection

Land use land cover change was detected through pre-processed Landsat images (of 1986, 1999 and 2015) classification. The classification based on ground-truthing was carried out with false colour composite images. Maximum likelihood classification was performed in ENVI 5.1 with accuracy assessment (Appendices C, D and E). Thereafter, classified images were subset using the shape file of the study area. These subset images were converted into vector and brought into ArcGIS for land use land cover map production and statistics extraction.

3.4.5 Assessment of spatio-temporal Change of Soil Erosion

The RUSLE model (Renard *et al.*, 1997) was applied to predict soil loss. This model was chosen because it was mostly used in West Africa with more accurate and realistic results. This model uses six (06) factors to quantify annual soil erosion and is expressed as follows:

$$A= R*K*LS*C*P \qquad (3.9)$$

Where A is the annual soil loss (tonne ha^{-1} $Year^{-1}$), R is the rainfall erosivity factor (MJ mm $ha^{-1}h^{-1}$), K is the soil erodibility factor (tonne ha MJ^{-1} mm^{-1}), L is the slope length factor (dimensionless), S is the slope steepness factor (dimensionless), C is soil cover management factor (dimensionless) , and P is dimensionless factor for soil conservation practices.

- **Rainfall erosivity factor (R)**

The 34 years rainfall data were divided into two (1981-1997 and 1998-2014) and the erosivity factor R was determined for the two periods for each of the ten meteorological stations (Appendix F). The method of Roose (1977) was used and was expresses as follows:

$$R= 0.5H \qquad (3.10)$$

Where, H is the sixteen-year average annual rainfall.

These R values were used to generate a semi-variogram for determination of the theoretical fitting model and its parameters. Ordinary kriging was used to interpolate, from the theoretical model and its parameters, the R values over the study area. The interpolated R image was resized to fit 30mX30m dimension and the R factor map was produced for the study area.

- **Soil erodibility factor (K)**

The soil erodibility factor values for the five soil types were computed using Bouyoucos (1935) equation as follows:

$$K= 2.8 X10^{-7}M^{1.4} (12-A) +4.3x10^{-3}(B-2) + 3.3x10^{-3}(C-3) \qquad (3.11)$$

Where

K= Erodibility factor

M= ((100-% Clay)*(% Sand+% Silt); (3.12)

A= % of Organic matter content;

B = soil structure code (very fine granular = 1, fine granular = 2, coarse granular = 3, lattice or massive = 4);

C = profile permeability class (fast = 1, fast to moderate fast = 2, moderately fast = 3, moderately fast to slow = 4, slow = 5, very slow = 6);

The soil textural classification triangle was used to determine soil structure code (B) and soil profile permeability class (C) by applying the method of United States Department of Agriculture (USDA, 1983).

The proportion (%) of Sand, Clay and Silt was calculated as follows:

$$\%sand = \frac{\text{Sample weight} - \text{40seconds readings}}{\text{Sample weight}} \times 100 \qquad (3.13)$$

$$\%Clay = \frac{\text{8hours reading}}{\text{Sample weight}} \times 100 \qquad (3.14)$$

$$\%\,Silt = 100 - (\%sand + \%Clay) \qquad (3.15)$$

After having computed the K values of the different soil types, the georeferenced soil map was brought into ArcGIS 10.0 and the soil erodibility factor map was generated by using Reclass tool.

- **Topographic factors (LS)**

LS-factor map was established from 30m*30m Digital Elevation Model data. LS was generated from slope and flow accumulation in ArcGIS 10.0. Slope was generated from the DEM. To generate flow accumulation, spurious cell sinks within the DEM were filled to produce depressionless DEM; and by using filled DEM, flow directions of each pixel were calculated. Then, from the flow directions, flow accumulation was calculated.

The LS factor was computed using the method of Wishmeier and Smith (1978) as follows:

$$LS = (\text{Flow accumulation} * \text{Cell value} / 22.1)^m (0.065 + 0.045\, S + 0.0065\, S^2) \qquad (3.16)$$

Cell value is the resolution of DEM, and m ranges from 0.2-0.5 depending on the slope. Table 3.5 was used for determination of m-values.

Table 3.5 m-value

Slope (%)	m-value
>5	0.5
3-5	0.4
1-3	0.3
<1	0.2

(Source: Yilman and Ebru, 2009)

- **Soil cover management factor (C)**

Land use/cover maps of 1986 and 2015 established in the third objective of the study was used to create the C-factor map. The different land use/cover classes were assigned their corresponding C-values from reported values found in different literature described in Table 3.6.

Table 3.6 Land Cover-C values used in different Studies

	Land-use land-cover	C-factor value	References
1	Forest	0.02	Hurni (1988)
2	Grassland	0.01	Eweg and van Lammeren (1996)
3	Farm land	0.17	Hurni (1988)
4	Shrub	0.02	Costick, 1996
5	Bare land	0.6	BCEOM (1998)
6	Water body	0	BCEOM (1998)
7	Urban	0.05	Hurni (1988)

(Source: Author’s compilation, 2015)

- **Soil conservation practices factor (P)**

To run this model, no conservation practice was considered. Therefore, the support value of P= 1 was used for soil loss prediction.

With ArGIS 10.0, the different factor-maps were fuzzy-overlaid to generate soil erosion map of the two periods (1981 and 2014). Based on the erosion rate classification of Chinatu (2007), soil erosion rates were then classified into five: no erosion, slight, moderate, severe and very severe erosion. Based on this classification, the spatio-temporal soil erosion change was assessed in three steps: assessment of change in erosion risk, analysis of trend in erosion transformation and identification of soil conservation priorities for the study area. The assessment of the change in soil erosion risk was done through image differencing of the soil erosion risk images of the years 1986 and 2014. The change statistics was then computed for the assessment of spatio-temporal change in each erosion risk class. Trend analysis was done based on the change of one erosion risk class into other class. Conservation priorities definitions were done by applying multi-criteria rules method with two different scenarios: The first scenario was based on the erosion actuality and change, whilst the second was based on the soil status of the year 1986 and the trend of soil erosion transformation.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This chapter presents the analysis of the data in view to assess the change in climate and land use in Nasarawa State and their impacts on land degradation, especially on soil erosion by water.

4.1 General Pattern and Trend of Rainfall and Temperature in Nasarawa State

The homogeneity test of temperature and rainfall time series showed that the data are homogenous (Appendix A), thus the variation observed in the data is much more time-dependant. Besides, the data are not normally distributed (Appendix B).

4.1.1 General Pattern of Rainfall and Temperature

4.1.1.1 Rainfall Pattern

The Standardized Precipitation Index (SPI) developed by Mackee, Doesken and Kleist (1993) is the statistical analysis tool which was used to assess the pattern of the rainfall at a given location. It helps in identifying whether any given year is drier or wetter than normal based on a specific threshold. According to the Nigerian Meteorological Agency (NiMET), three standard thresholds are defined for Nigeria, and they are (Akama, 2014):

- Less than -1,1: Drier than Normal
- Between -1,1 and +1,1: Normal
- Greater than +1,1: Wetter than Normal

Based on this classification of NiMET, the rainfall over Doma (Figure 4.1) shows a normal condition from 1981 to 2001 except the year 1992 which was drier than normal.

There was a high variation in the rainfall pattern over Doma from 2002 to 2007 with alternately drier and wetter than normal years, and thereafter a normal situation began from 2008 up to 2014. The year 2003 (with SPI value of -1.5) was the driest for the past 34 years, and this year could be characterised as severely dry year (WMO, 2012). Unlike the year 2003, the year 2005 with the SPI value of +3 was the wettest and could be characterised as extremely wet year.

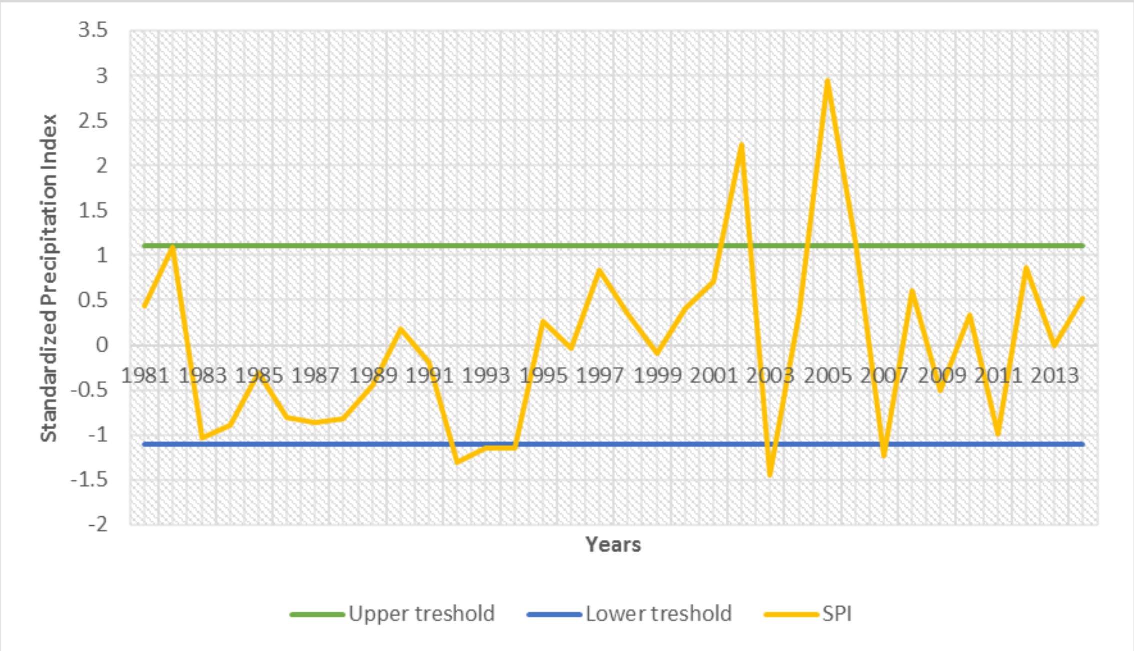

Figure 4.1 Rainfall Anomalies at Doma Station

The rainfall at Kokona (Figure 4.2) shows a normal condition from 1981 to 1992 with three drier than normal years (1985, 1990, 1992). More wetter than normal years were observed from 1993 to 2000 followed by several years of drier than normal from 2001 to 2004. Normal conditions were observed from 2005 to 2014. The year 1985 was the driest while the year 1993 was the wettest.

Unlike Doma which observed only one period of drier than normal years, Kokona has two different periods of drier than normal conditions. However, the two stations experienced more normal precipitation conditions than other patterns. The two stations equally observed only one period of wetter than normal years (Doma: 2002-2006, Kokona: 1993-2000). From year to year analysis, the northern part of Nasarawa State (represented by Kokona station) observed 18.18% of drier years against 12.12% of wetter years, whereas the southern part (represented by Doma station) experienced 15.15% of drier years against 06.06% of wetter years. Therefore, the southern part of Nasarawa State experienced more normal conditions (79% of the years) than the northern part (70% of the years). This could be due to the desertification effect which is extending from the northern Africa towards the southern Africa, creating therefore drier condition in the northern Nasarawa.

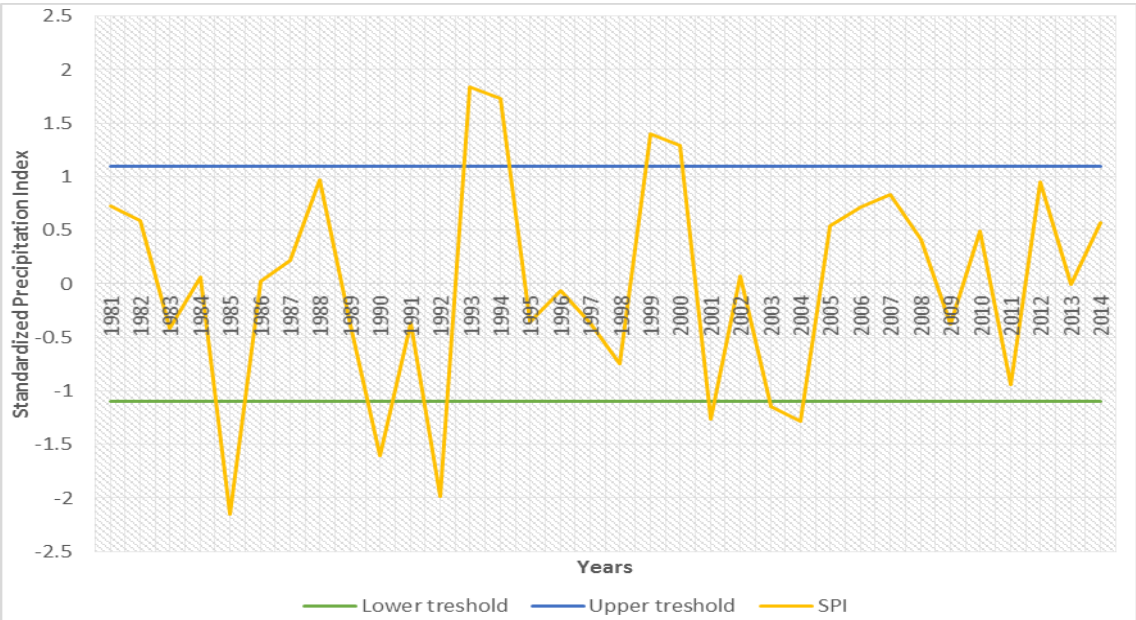

Figure 4.2 Rainfall Anomalies at Kokona Station

4.1.1.2 Temperature Pattern

The thermal anomaly index is an index used to analyse the pattern of the temperature, whether it is hotter or colder than normal. The temperature departure classification key of NiMET (Akama, 2014) states that:

- From -3.5 to -0.5 : Colder than normal,
- From -0.5 to +0.5 : Normal
- From +0.5 to +3.5: Warmer than normal

Thermal anomaly index for maximum temperature (MaxTindex), minimum temperature (MinTindex) and mean temperature (MeanTindex) is shown in Figure 4.3 for Doma and Figure 4.4 for Kokona. 27.27% and 30.3% of the total years under study are hotter than normal for the maximum temperature of Doma and Kokona respectively, the hotter years were been observed at Doma and Kokona between 1981-2002 and 2011-2014 respectively. The same statistics were obtained for the colder years with regard to the maximum temperature. Colder years were mostly observed from 2002 to 2010. For the minimum temperature, hotter years have been observed from 2001 till 2014 for the two stations, whereas colder years occurred from 1981 to 2000 for the two stations with few years of normal pattern.

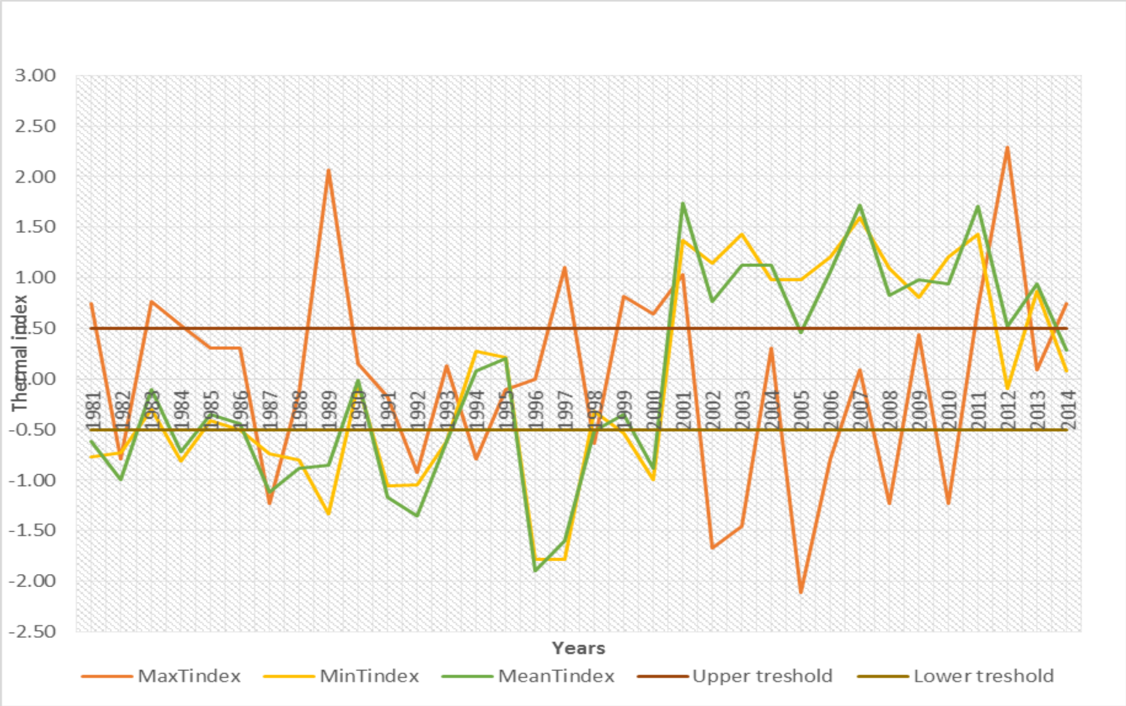

Figure 4.3 Temperature Anomalies at Doma

The mean temperature exhibits two main patterns at Doma: many colder years before 2000 and hotter years thereafter. The mean temperature over Kokona exhibits more complex pattern for the past 34 years, mixed pattern of colder and hotter years from 1981 to 2000, colder years between 2001 and 2010, and hotter years from 2011 to 2014. This high variability in the pattern of the mean temperature over Kokona could be probably due to high variation in land use and cover types, affecting the different climatic processes. Despite these different patterns shown in the mean temperature over the two stations, warming climate is generally observed.

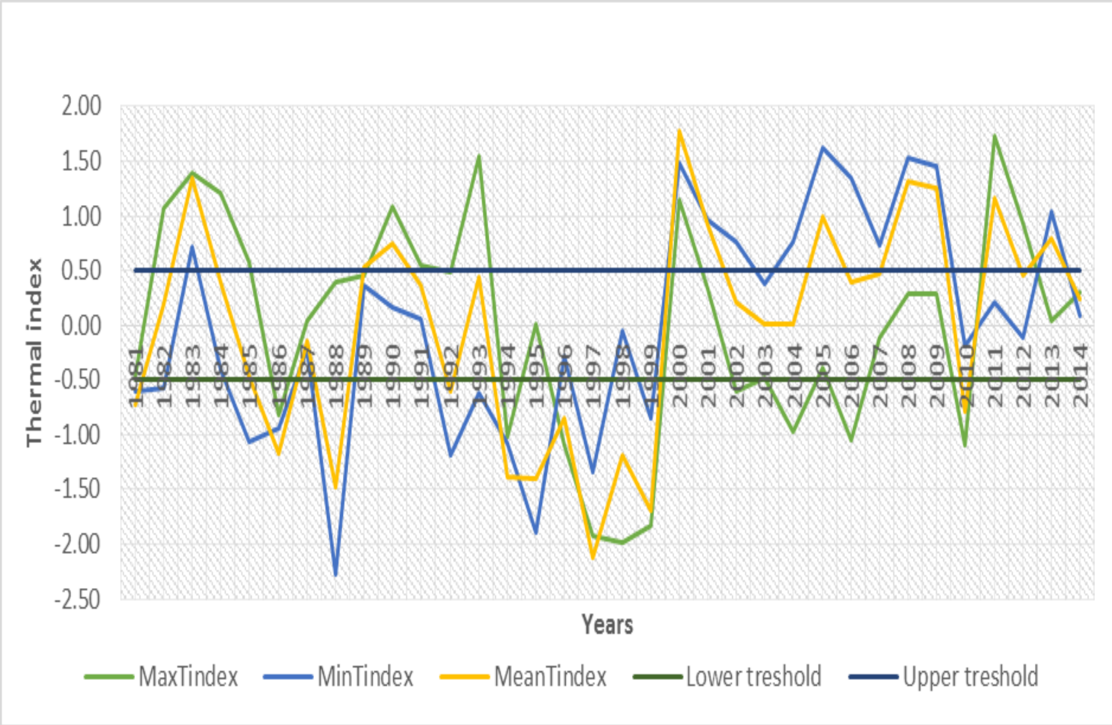

Figure 4.4 Temperature Anomalies at Kokona

4.1.2 Nature of the Trend of Rainfall and Temperature in Nasarawa State

The innovative trend analysis method is a graphical tool that helps in visualizing the nature of the trend in rainfall or temperature, whether the trend is monotonic or non-monotonic (scatter points located at one side of the diagonal line or not), decreasing or increasing (scatter of points of start from the upper part and end up at the lower part of the diagonal line, or the reverse).

4.1.2.1 Nature of the trend of the rainfall over Nasarawa State

From the analysis of Figures 4.5 and 4.6, rainfall has non-monotonic trend for the two stations. Doma as well as Kokona experienced an increasing trend of the rainfall. Increasing trend implies an increase in the amount of the total annual rainfall over the years. On the other hand a non-monotonic trend signifies different trends and rates of change in the rainfall. Therefore, Nasarawa State had been experiencing an increase in the rainfall from 1981 to 2014 due to the increase in forested area associated with other local conditions.

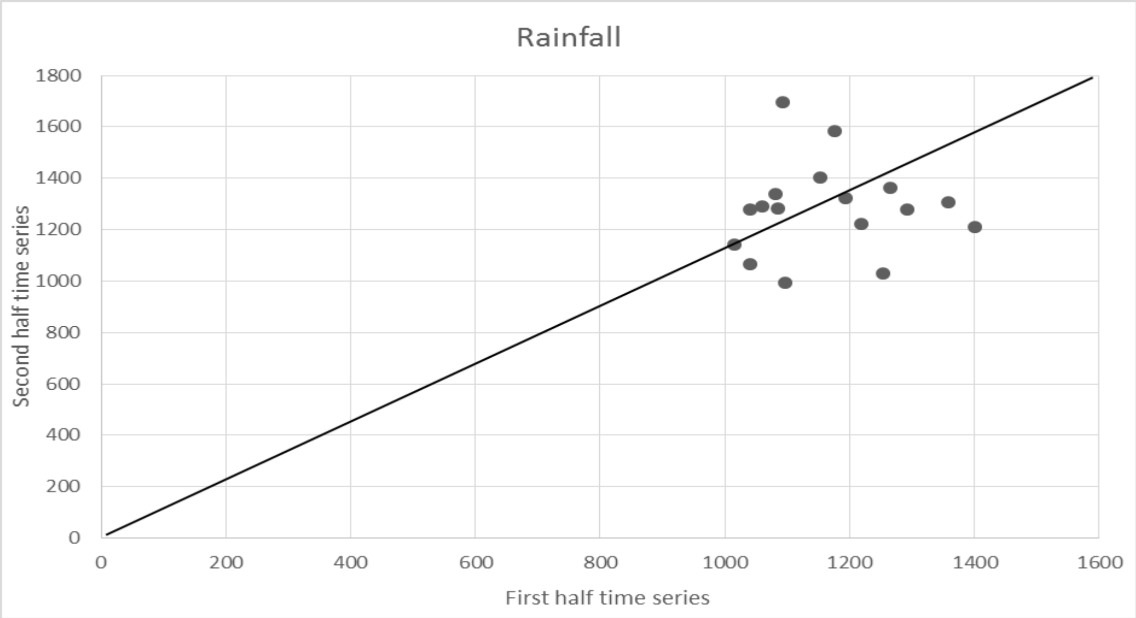

Figure 4.5 Innovative Trend Analysis plot of the Rainfall at Doma

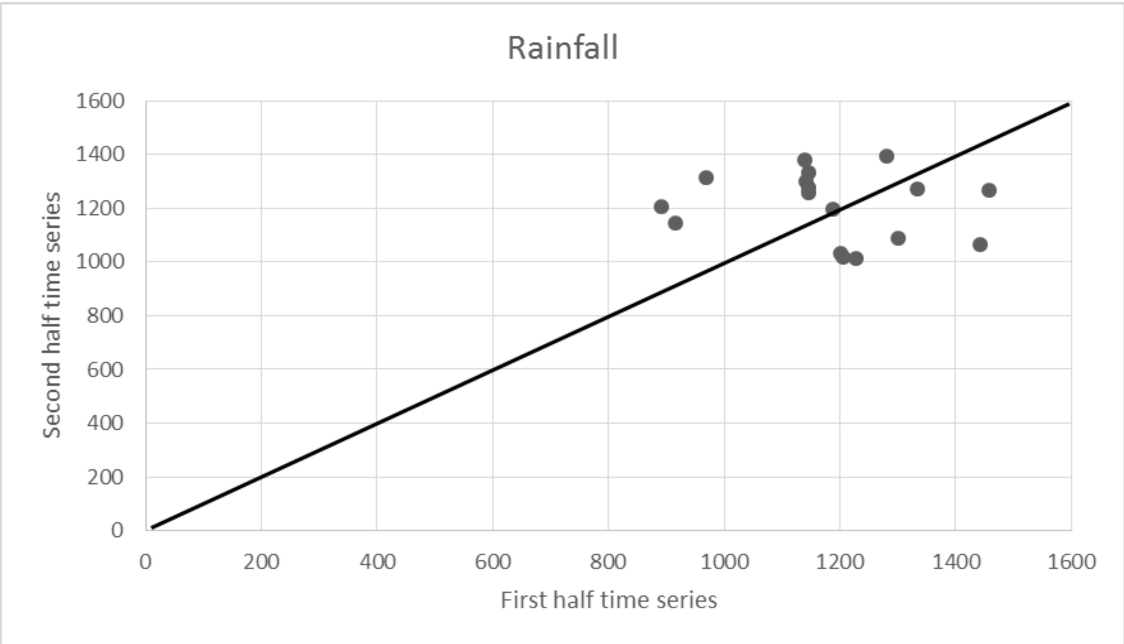

Figure 4.6 Innovative Trend Analysis plot of the Rainfall at Kokona

4.1.2.2 Nature of the trend of the temperature over Nasarawa State

The maximum, minimum and mean temperatures of Nasarawa State have non-monotonic trend for the last 34 years (Figures 4.7 -4.12). Non-monotonic trend in climatic parameters has been reported by many scholars (Noorunnahar and Arafat-Rahman, 2013; Sen Roy and Balling, 2004; Shapiro, Aleynik and Mee, 2010**).** The maximum temperature showed a decrease at Kokona (Figure 4.8), but that of Doma has a more complex trend (Figure 4.7). The minimum as well as the mean temperature has an increasing trend at the two stations (Figures 4.9 - 4.12).

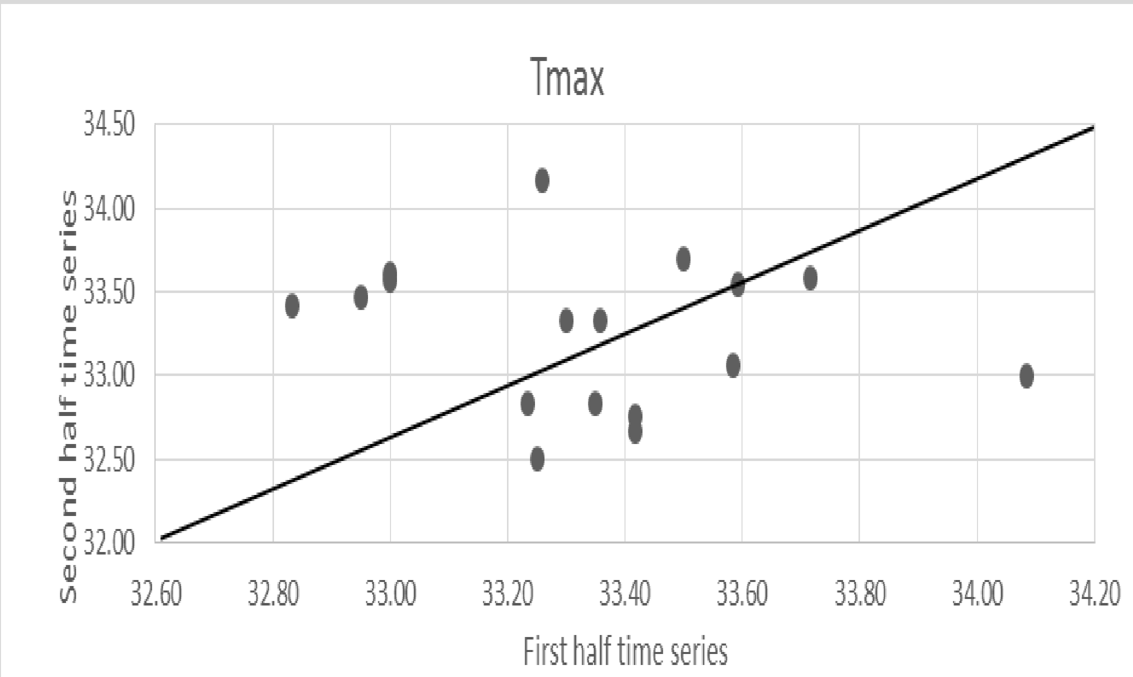

Figure 4.7 Innovative Trend Analysis plot of the maximum Temperature at Doma

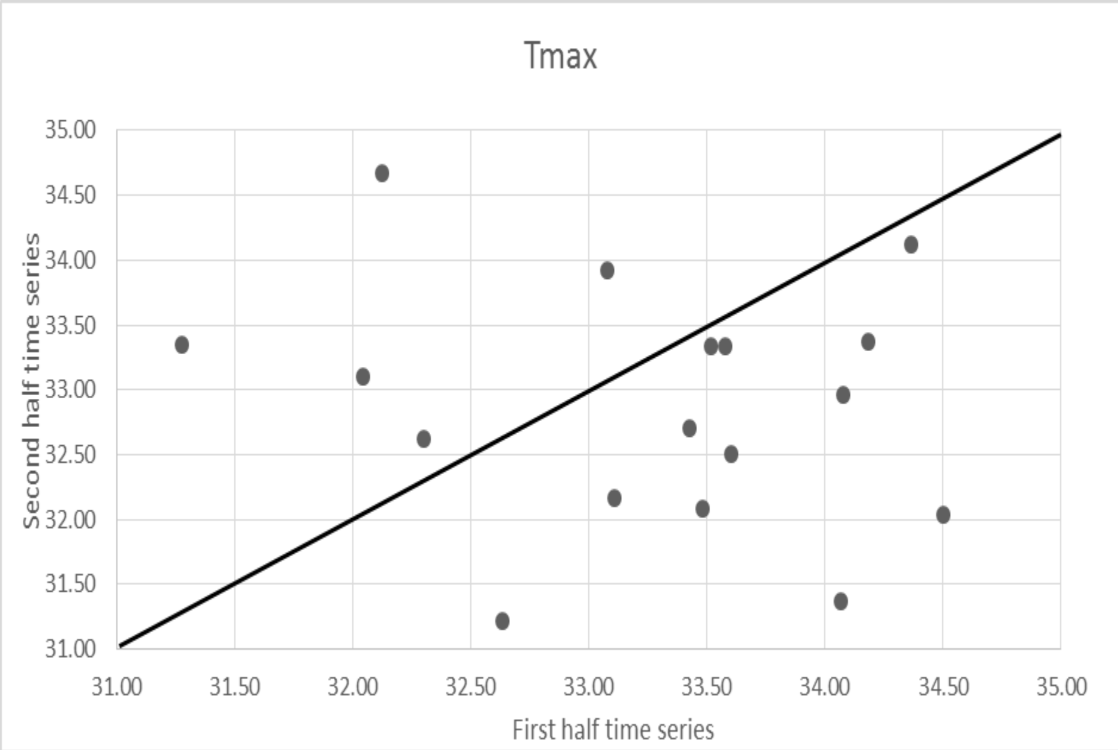

Figure 4.8 Innovative Trend Analysis plot of the maximum Temperature at Kokona

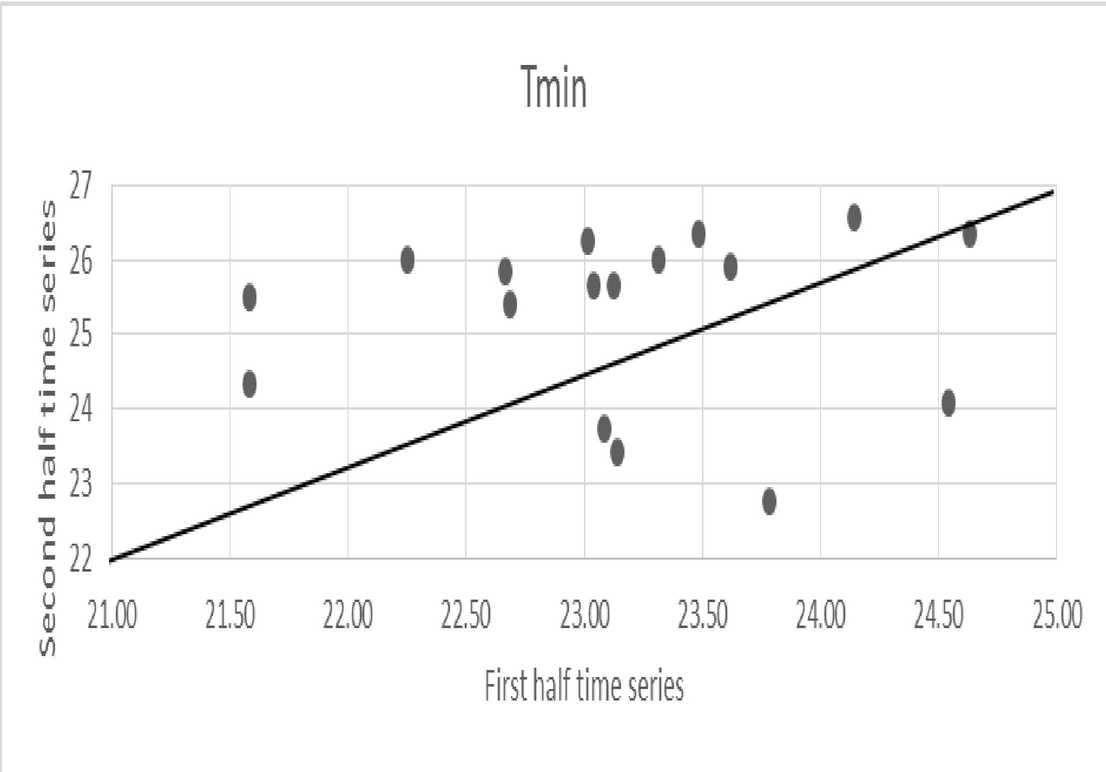

Figure 4.9 Innovative Trend Analysis plot of the minimum Temperature at Doma

Figure 4.10 Innovative Trend Analysis plot of the minimum Temperature at Kokona

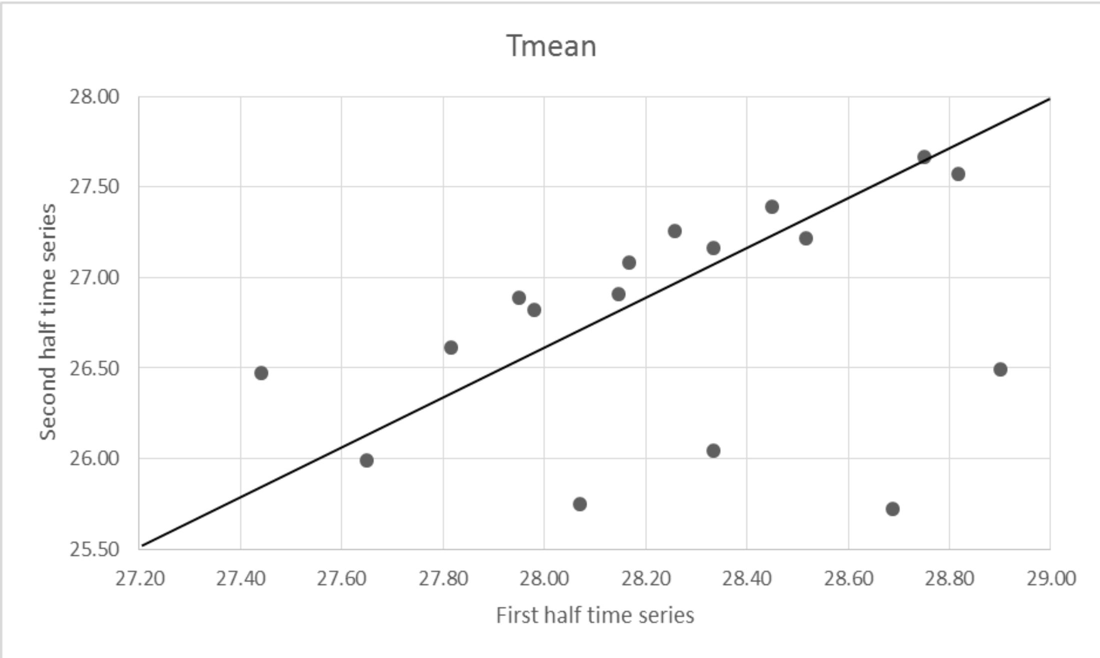

Figure 4.11 Innovative Trend Analysis plot of the mean Temperature at Doma

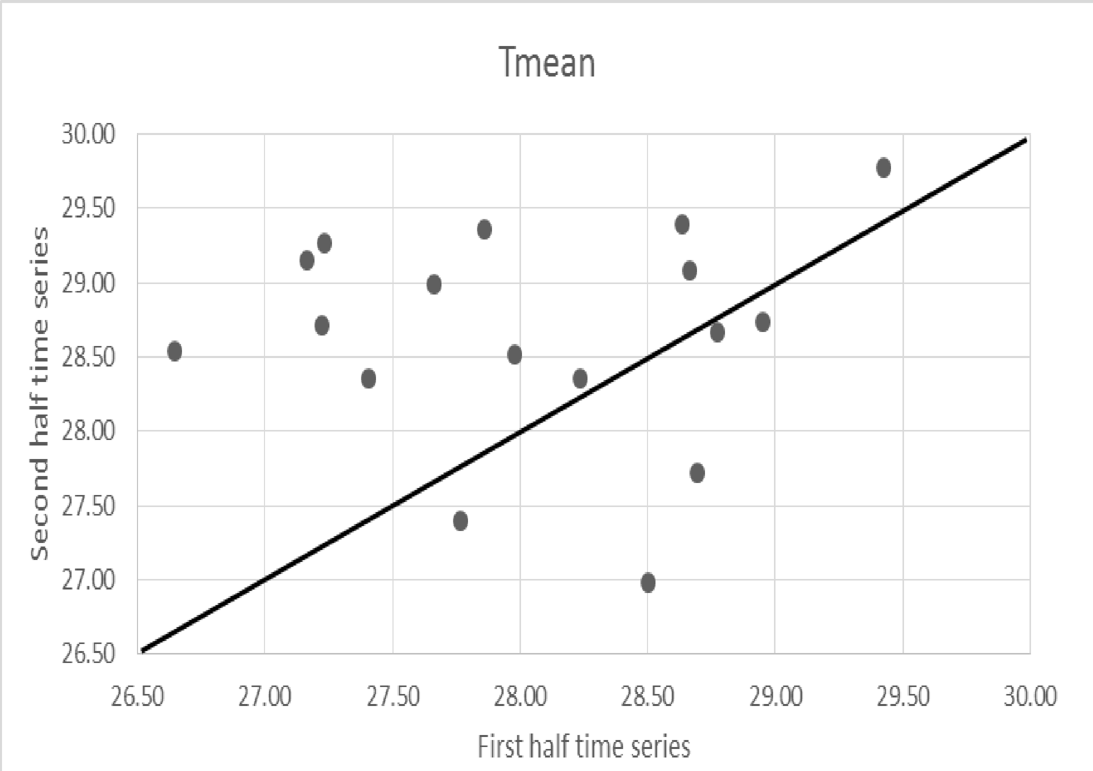

Figure 4.12 Innovative Trend Analysis plot of the mean Temperature at Kokona

4.1.3 Determination of the different Trend Periods

Cumulative Sum chart method is one of the powerful graphical methods used to identify the years of the different trends or changes and the period or length of each of the trend. The CUSUM charts of the rainfall, maximum, minimum and mean temperatures for the two stations are presented in Figures 4.13 to 4.16. The rainfall over Doma exhibited four (04) obviously different trends and three (03) at Kokona (Figure 4.13; Table 4.1).

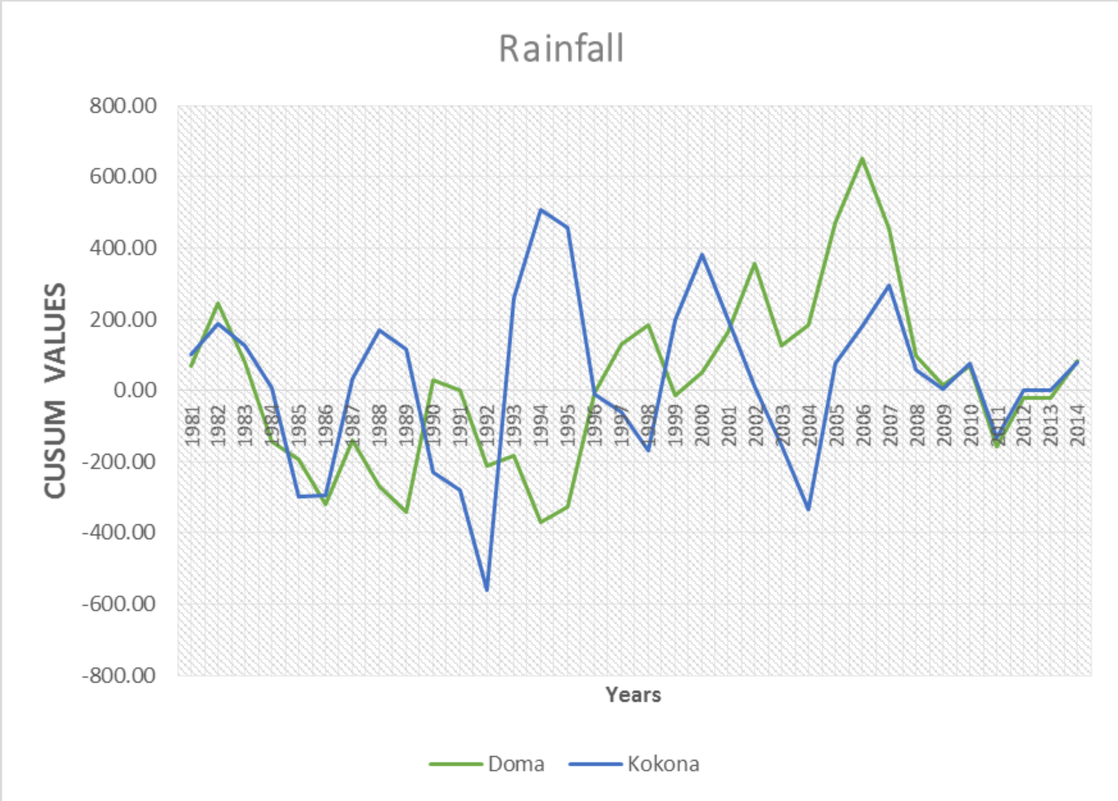

Figure 4.13 CUSUM chart showing the different Change Periods in Rainfall

The maximum temperature has two trend periods at Doma and three at Kokona (Figure 4.14, Table 4.1), whereas the minimum temperature has three and two different trend periods at Doma and Kokona respectively (Figure 4.15; Table 4.1). The mean temperature has four and two different trend periods at Doma and Kokona respectively (Figure 4.16; Table 4.1).

These different increasing and decreasing trends observed in the temperature and rainfall over Nasarawa State could suggest the existence of large inter-annual variability as observed by Gbetibouo (2009) and Buba (2009). According to Bunting, Dennet, Elston and Milfort (1976), such trends may have potentially disastrous consequences on the well-being of the people and the economics.

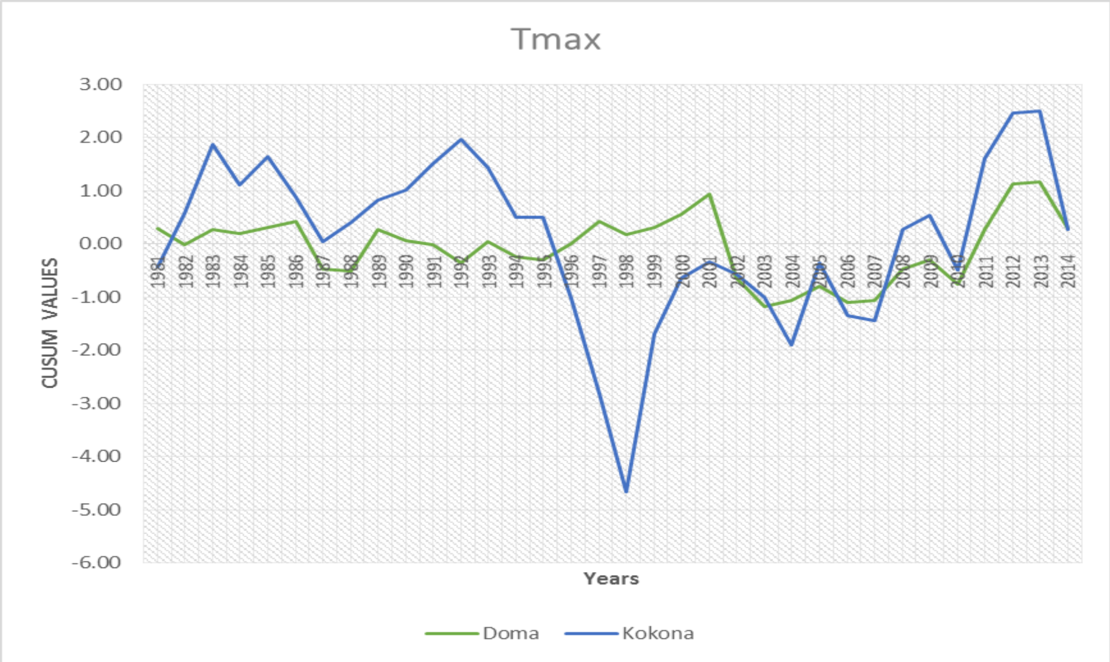

Figure 4.14 CUSUM chart showing the change Periods in maximum Temperature

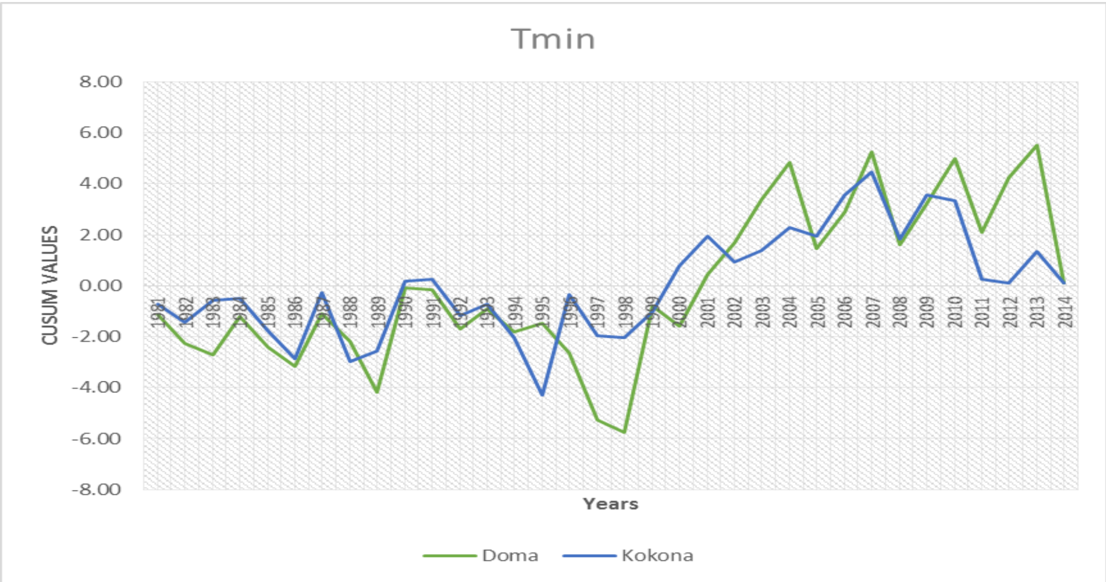

Figure 4.15 CUSUM chart showing the change Periods in minimum Temperature

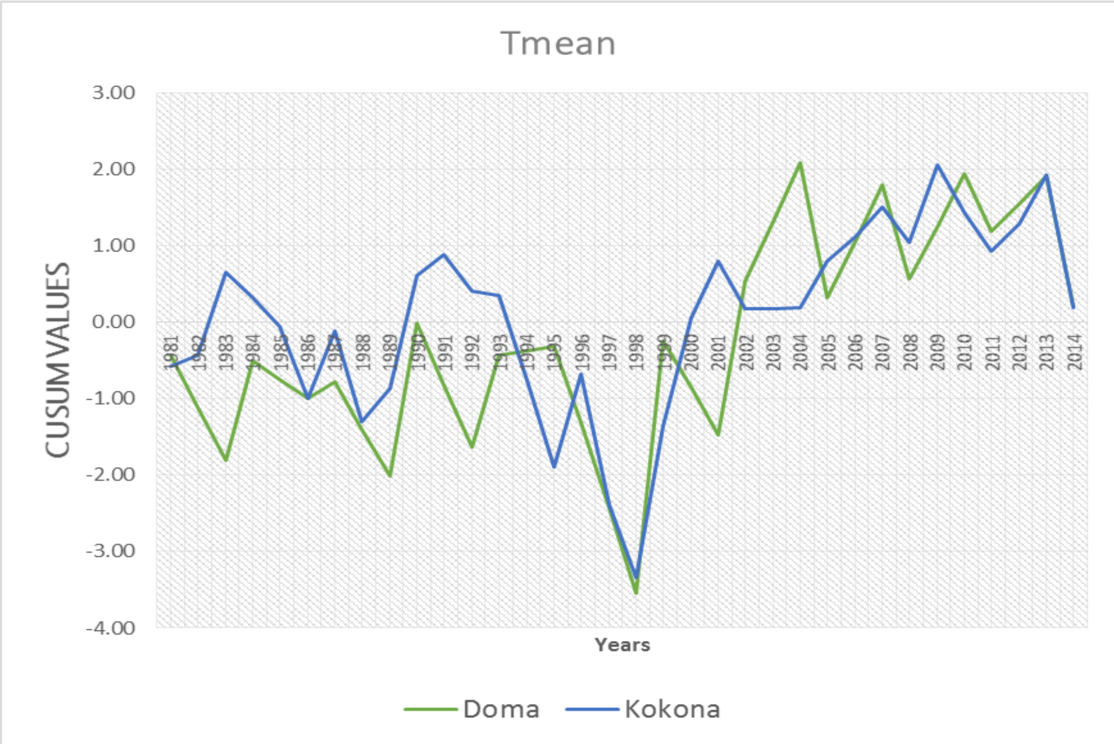

Figure 4.16 CUSUM chart showing the change Periods in mean Temperature

4.1.4 Determination of the Trend Slopes and their statistical Significances

The Sen's slope statistics is an improved method which is used to determine the slope of the different trends observed for rainfall and temperature at different periods, and Mann-Kendall test (MK) is used to test the significance of the slope (Sen, 1968; Kendall, 1975; Mann, 1945). The result of the analysis for Sen's slope and MK is presented in Table 4.1. Nasarawa State had been experiencing variations in the trend of rainfall and temperature, and for the past 34 years an increasing trend was observed in the rainfall (6.39mm/year at Doma and 2.3mm/year at Kokona) as well as in the minimum temperature (+0.098°C/year at Doma and +0.066°C/year at Kokona). However, the increase observed in the rainfall at Kokona was not statistically significant. While the northern part of the State was experiencing a decrease in the maximum temperature (-0.019°C/year), the southern part observed an increase in the maximum temperature (+0.008°C/year). However the magnitude of the trend is not statistically significant for the whole State.

The general trend in mean temperature from time series showed that the mean temperature is gradually increasing in the study area (+0.047°C/year at Doma and +0.021°C/year at Kokona). This agreed with the IPCC's fourth assessment report (2007) which stated that from the 1970s to the present day, all decades have been hotter than the average of the previous 100 years with records showing that global linear warming trend over the last 50 years of 0.13°C (0.10°C to 0.16°C) per decade is nearly twice that for the last 100 years. Buba (2009) also found increasing trend everywhere in northern Nigeria

Table 4.1 Sen Slope and statistical Significance of the different Trends in Rainfall and Temperature

Station name	Data type	Period of trend	MK	SS
DOMA	Rainfall	1981-1994	-1	-6.16
		1994-2006	1	18.59
		2006-2014	1	7.25
		1981-2014	1	6.39
	Maximum temperature	1981-2001	0	0.008
		2001-2014	1	0.074
		1981-2014	0	0
	Minimum temperature	1981-1998	0	-0.044
		1998-2004	0	0.229
		2004-2014	0	-0.194
		1981-2014	1	0.098
	Mean temperature	1981-1995	0	0.017
		1995-1998	0	0.481
		1998-2004	0	0.25
		2004-2014	0	-0.019
		1981-2014	1	0.047
Kokona	Rainfall	1981-1992	0	-19.367
		19992-1994	0	-15
		1994-2004	0	-18.5
		2004-2014	0	-5.406
		1981-2014	0	2.299
	Maximum temperature	1981-1995	0	-0.055
		1995-1998	0	-0.412
		1998-2014	0	0.071
		1981-2014	0	-0.019
	Minimum temperature	1981-2001	0	0.018
		2001-2014	0	-0.066
		1981-2014	1	0.066
	Mean temperature	1981-1998	1	-0.084
		1998-2014	0	0.018
		1981-2014	0	0.021

NB: 0= no significant trend, 1=positive trend, -1= negative trend

(Source: Author's Study, 2015)

4.2 Flood Events Characterization and their probabilistic Prediction

4.2.1 Characterization of the past Flood Events

An event is climatologically considered as flood event when the amount of rainfall observed for a particular day, month or year is beyond a well-defined threshold (Okoloye *et al.*, 2013). Annual rainfall values associated with the different thresholds defined by Okoloye *et al.* (2013) were plotted in Figures 4.17 and 4.18. At Doma, 21.21%, 12.12%, of the years are years of moderate (rainfall amount between average and average + half of standard deviation) and large flood (rainfall amount between average + half of standard deviation and average+ one standard deviation) events respectively, each of the severe and disastrous flood events were observed for only 6.06% of the 34years (Figure 4.17).

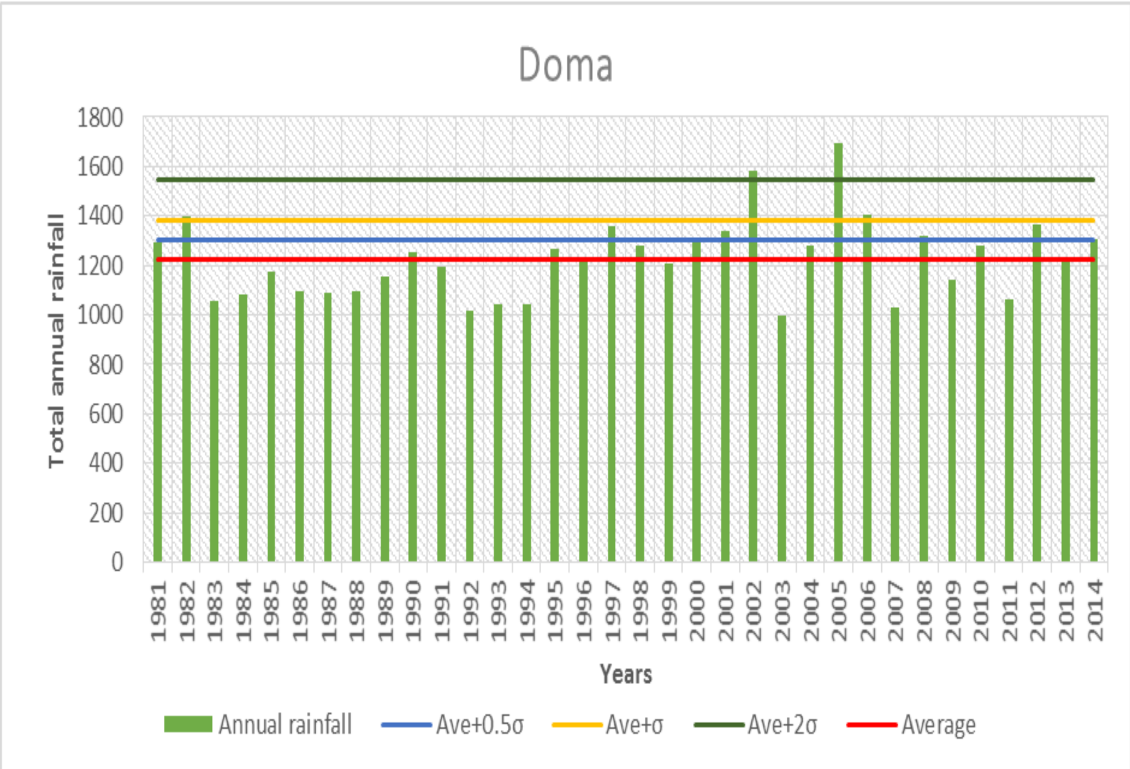

Figure 4.17 Plot of different past Flood Events at Doma

For Kokona, 15.15%, 18.18%, 12.12% of the 34 years are of moderate, large and severe flood events respectively; and Figure 4.18 Clearly shows that Kokona did not experience any disastrous flood events for the past 34 years.

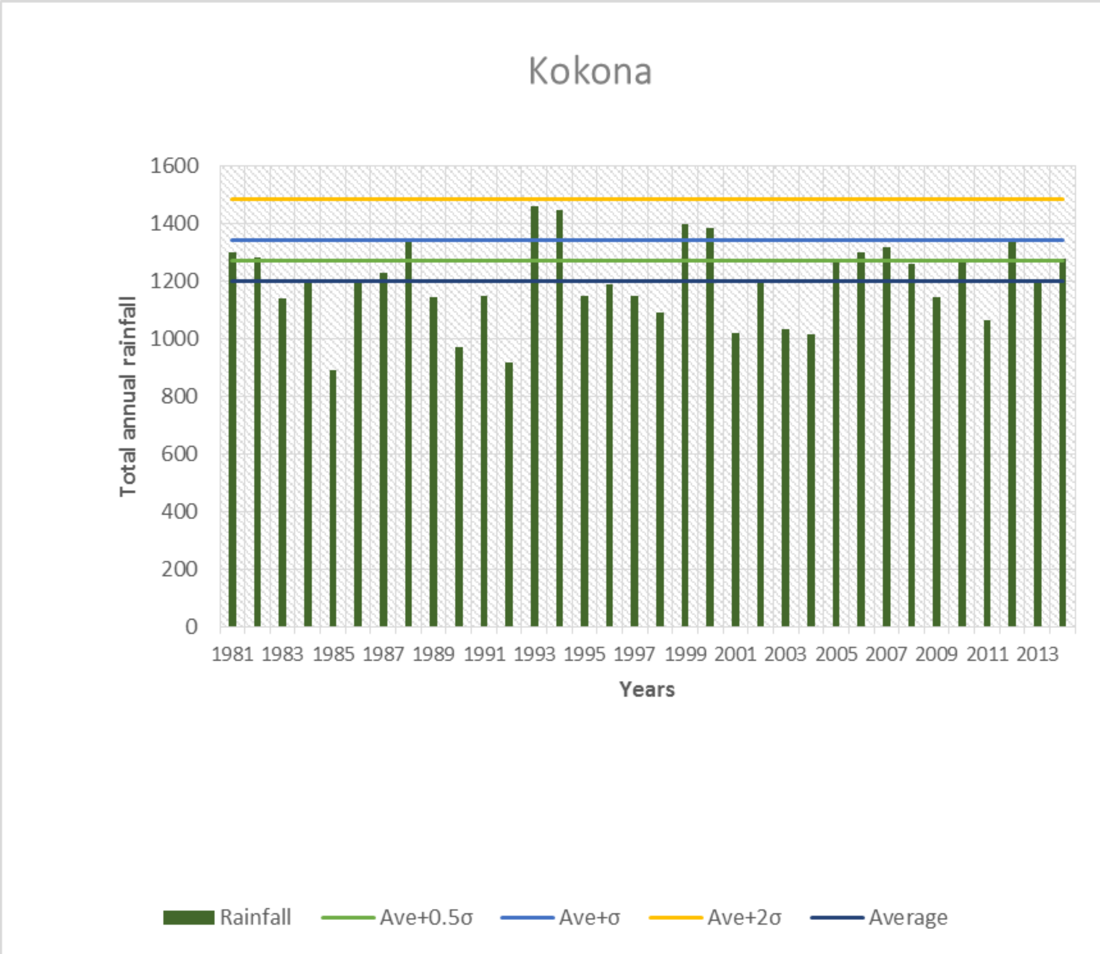

Figure 4.18 Plot of different past Flood Events at Kokona

The statistics extracted from the analysis of Figures 4.17 and 4.18 show that the two stations experienced flood events for about 45.45% of the past 34 years, with the southern part having observed more variability in the flood events than the northern part. While Kokona epxerienced more severe flood years (4years) than Doma, the latter observed two years of disastrous flood events that Kokona did not experience. This situation could probably contribute to the higher magnitude of increasing trend of rainfall at Doma.

From decadal comparison, the flood frequency increased from decade to decade for the two stations as shown in Table 4.2. Klein and Konnen (2003) stated that when there is change in rainfall, it will affect water availability and quality which can result in flooding as such affect human settlements and infrastructure. Such impacts will affect the socio-economic development of the regions, therefore pollution, land degradation and population increase will be affected (United Nations Development Program, UNDP, 2006).

Table 4.2 Decadal Comparison of Flood Event Frequency for Doma and Kokona

	Frequency of flood events (%)		
	Decade 1	**Decade 2**	**Decade 3**
Doma	27.27	54.55	63.64
Kokona	36.36	36.36	63.64

(Source: Author's Study, 2015)

4.2.2 Probabilistic Prediction of the future Flood Events

Figure 4.19 shows the plot of the total annual rainfall against its probability of occurrence (in percentage) in the future at Doma and Kokona with a coefficient of determination of 0.96 for Doma and 0.90 for Kokona. The probability to have the threshold of moderate flood event being exceeded is 36% for Doma and 37% for Kokona. This means that Nasarawa State could probably experience moderate flood event two of the five upcoming years. Similarly, the probablity of exceeding the treshold of large flood event is 21% for Doma and 22% for Kokona, meaning that large flood event could probably be experienced one year over the five upcoming years. However, the patterns of the severe and disastrous flood events were more complex and were not captured by the probablisitic method. Therefore they were not predicted.

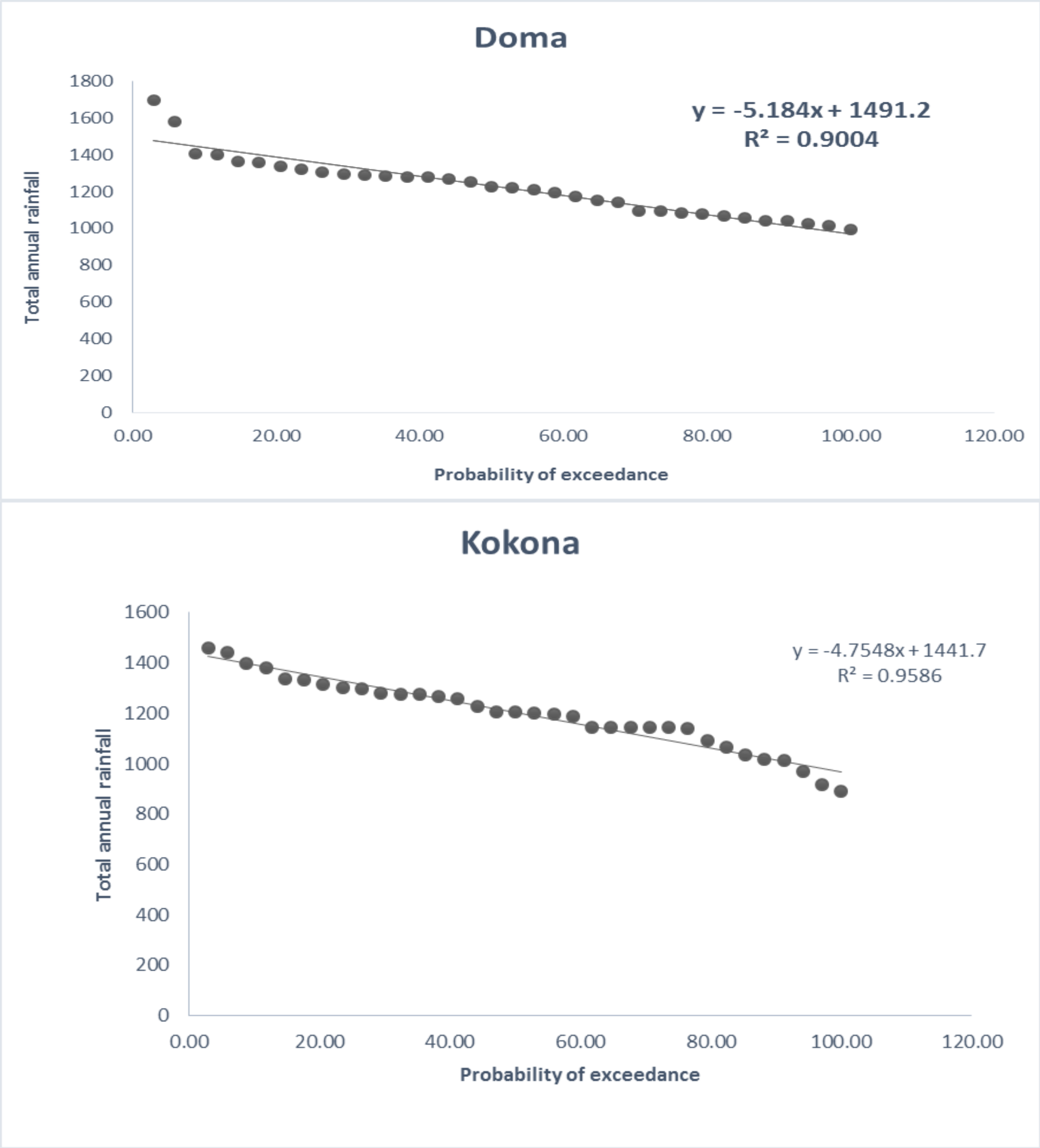

Figure 4.19 Plot of the total annual Rainfall against its Probability of Exceedance

4.3 Land Use Change and degraded Area Detection

The relative distribution of land use land cover classes within the study area in 1986 (Figure 4.20), 1999 (Figure 4.21) and 2015 (Figure 4.22) is represented in Table 4.1. Seven land use land cover types were Seven land use/land cover classes were identified and described as follows:

1. Water bodies: they include rivers, streams, lakes, etc.

2. Woodlands: Woodland encompasses areas with comparatively closely spaced trees with or without mixtures of tall grasses, and dense vegetation along river or stream courses

3. Shrub lands: they are areas largely dominated by relatively short woody trees or vegetation with height often less than 13 feet (4m), which often possess several perennial stems.

4. Bare surface (degraded area): this includes bare lands, excavated lands, cleared farmlands and open fields.

5. Settlements: this class includes residential and commercial houses, roads, any built-up area

6. Agricultural land: It includes farmlands and animal husbandry

7. Forest: Trees and woody vegetations

Figure 4.20 showed the map of land use land cover (LULC) of 1986, Shrubland covered the majority of the total landmass of the study area (78.34%). Agricultural land, settlements, wood land, bare surface or degraded area, forest and water body covered 163,606 ha (7.53%), 141,366 ha (6.5%), 125,438ha (5.75%), 18,765ha (0.86%), 10,777ha (0.49%) and 10,618ha (0.48%) respectively in a descending order.

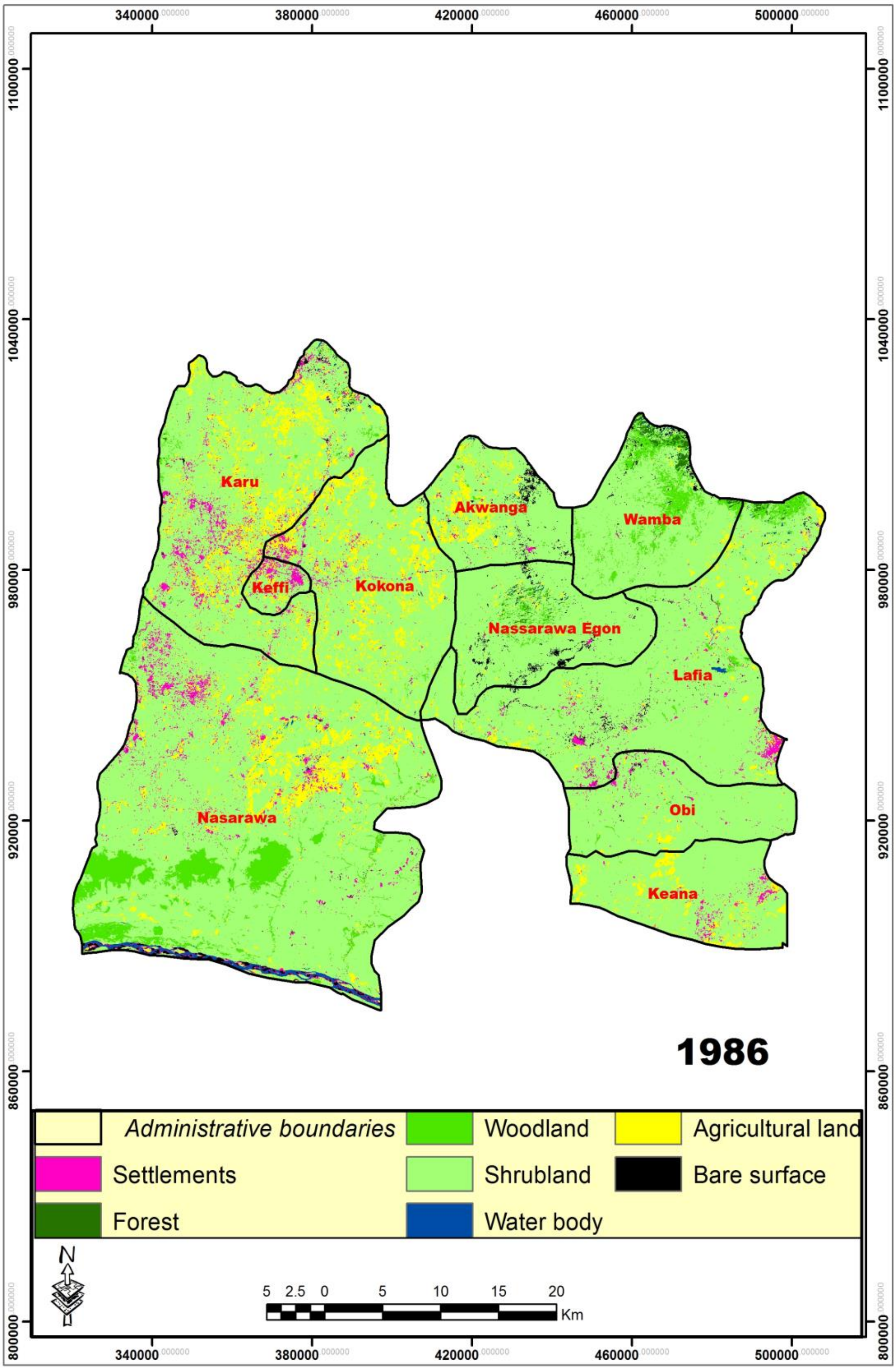

Figure 4.20 LULC Map of 1986

However, in 1999, the coverage of different land use land cover shifted (Figure 4.21). Shrub land was still maintaining its position as the widest coverage, but reduced to 46.28 % of the total landmass. Settlements, forest, water body, agricultural land and bare surface increased to 10.78%, 2.209%, 0.726%, 8.759% and 26.915% respectively whilst wood land reduced to 4.341% (Table 4.2).

It is evident from the aforementioned statistics that much land related activities such as farming, construction and residential activities have taken place by 1999. The high proportion of bare soil or degraded surface observed in 1999 compared to that of 1986 could probably be due to the combined action of the change in land use practices (shift from fully soil cover crops to little soil cover crops, leaving much farmland bare after harvest) and the climatic conditions which prevailed in 1999. The increase of water body in 1999 could be the consequence of the removal of woody species which covered some water bodies in 1986, allowing the satellites to fully detect all the water bodies within the study area.

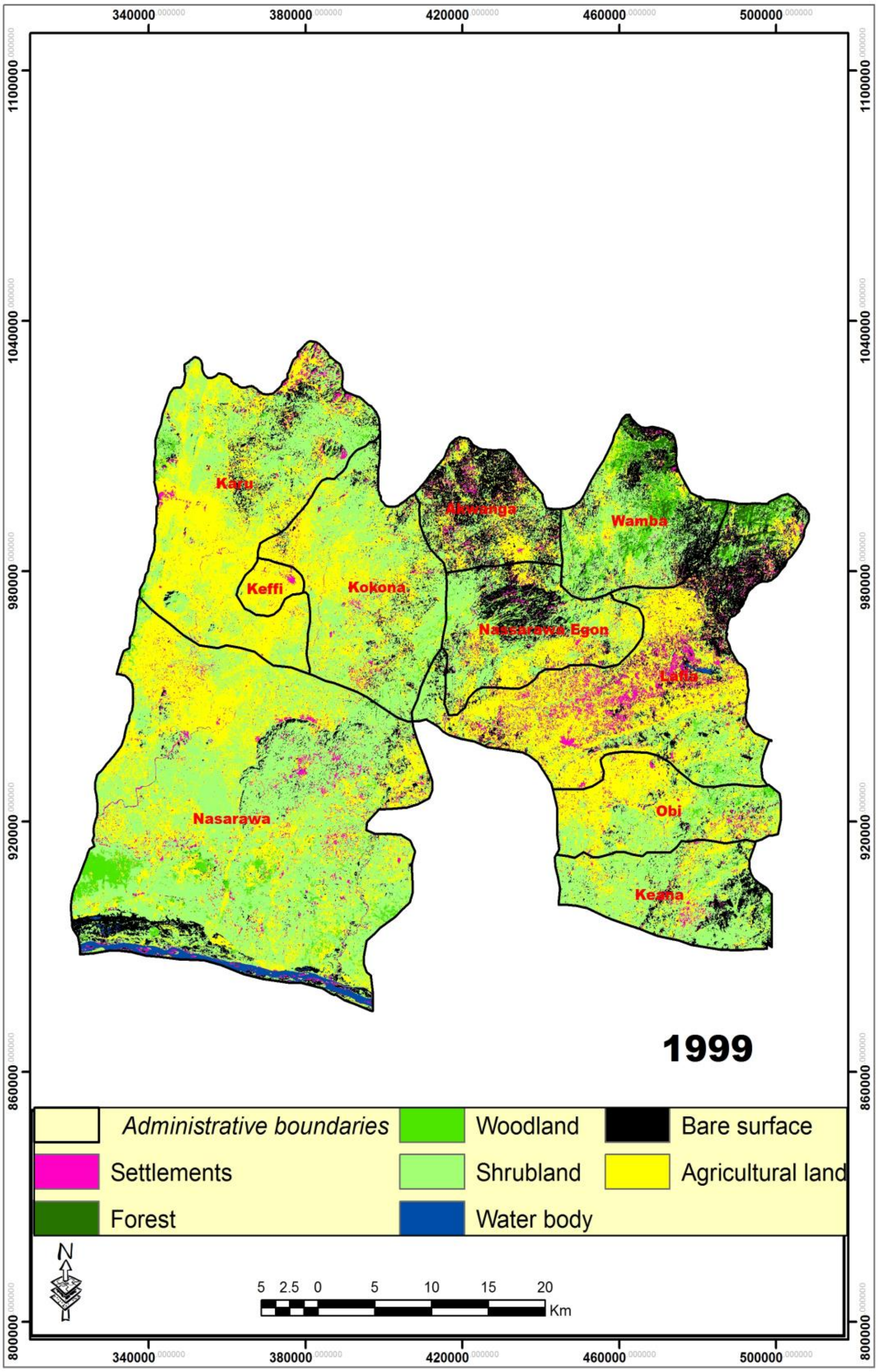

Figure 4.21 LULC Map of 1999

Similarly, by 2015, land use/land cover had a significant shift in the coverage as shown in Figure 4.22. Shrub land has maintained its position as the widest coverage, increased to 52.584% of the total land mass compared to that of 1999. Settlements (14.94%), forest (6.79%), agricultural land (16.64%) have increased in coverage compared to their surface areas in 1986 and 1999. A drastic decrease was observed in wood land (only 0.64% left) compared to that of 1986 and 1999. The same decrease was observed with water body (0.36%) in comparison to that of 1986 and 1999. Generally, woodlands are situated along the water bodies, their removal exposed the water surface to high rate of evaporation that could probably yield in seasonal drying up of some streams, rivers, etc., thereby reducing the water bodies. Though the surface area of degraded land decreased (8.04%) compared to that of 1999, it remains greater than its coverage of 1986.

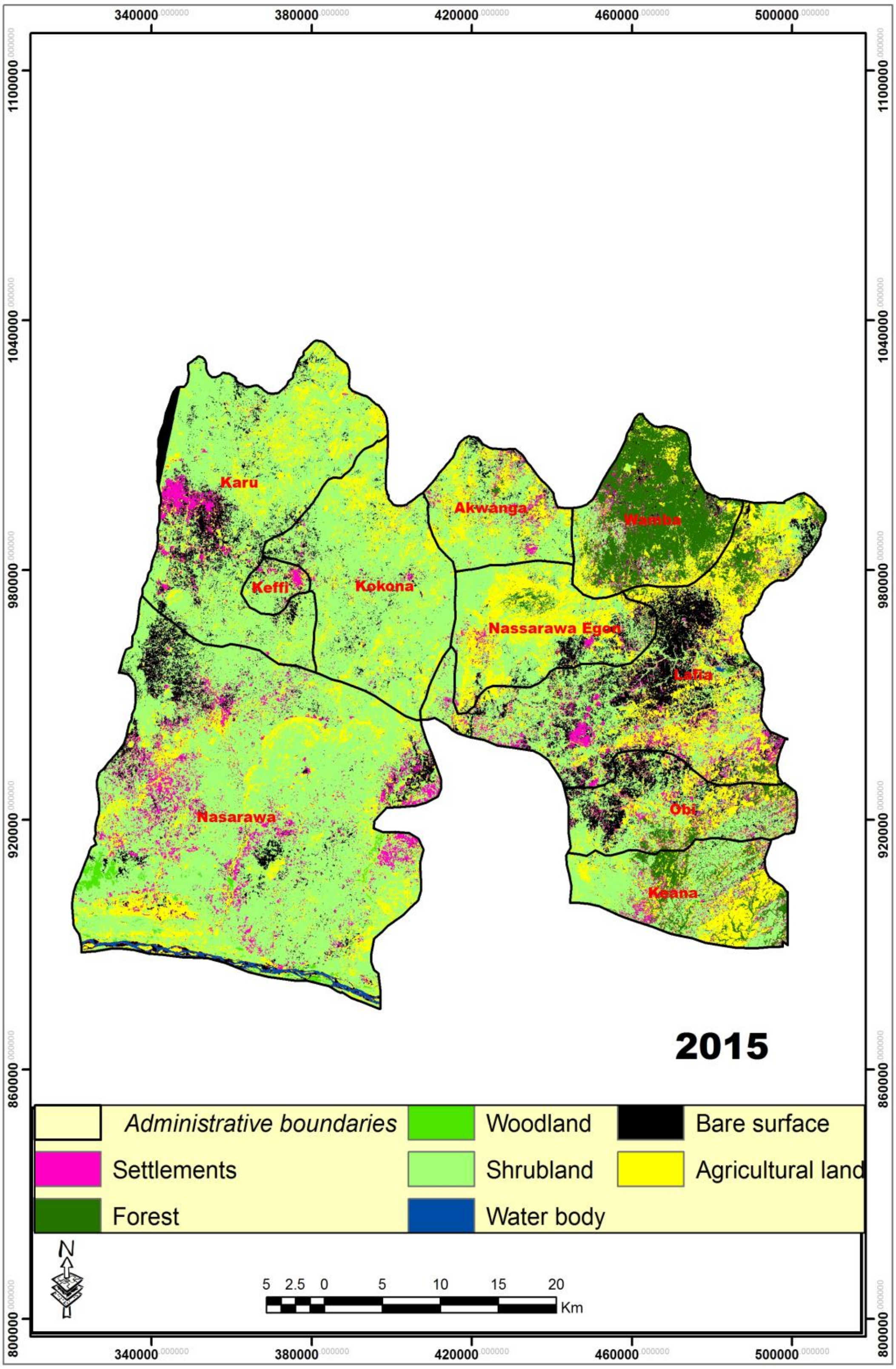

Figure 4.22 LULC Map of 2015

Within this 30 year period, Shrub recorded the highest net change in percentage at 25.76% of the total area and water body had the least at 0.128 %. Agricultural land, settlements, bare soil, forest and wood land had 9.11 %, 8.44 %, 7.18 %, 6.29 % and 5.13 % respectively (Table 4.2).

Table 4.3 Area change in Land Use Land cover between 1986 and 2015

	Surface area (ha)			**Surface area (%)**			**Net change (%)**			**Rate of change (%)**		
	1986	**1999**	**2015**	**1986**	**1999**	**2015**	**1986-1999**	**1999-2015**	**1986-2015**	**1986-1999**	**1999-2015**	**1986-2015**
Settlements	141,366	234,279	324,711	6.51	10.78	14.94	4.28	4.16	8.44	0.31	0.26	0.28
Forest	10,777	48,000	147,487	0.50	2.21	6.79	1.71	4.58	6.29	0.12	0.29	0.21
Woodland	125,438	94,313	13,906	5.77	4.34	0.64	-1.43	-3.70	-5.13	-0.10	-0.23	-0.17
Shrub	1,702,251	1, 005,324	1,142,557	78.34	46.27	52.58	-32.08	6.32	-25.76	-2.29	0.40	-0.86
Waterbody	10,618	15,769	7,830	0.49	0.73	0.36	0.24	-0.37	-0.13	0.02	-0.02	-0.004
Agriculture	163,606	190,314	361,591	7.53	8.76	16.64	1.23	7.88	9.11	0.09	0.49	0.30
Bare soil	18,765	584,822	174,739	0.86	26.92	8.04	26.05	-18.87	7.18	1.86	-1.18	0.24
Total	**2,172,821**	**2,172,821**	**2,172,821**	**100**	**100**	**100**						

(Source: Author’s Study, 2015)

The highest loss was observed in shrub land, 25.76% of loss for the past 30 years. According to Bruisma (2003), expansion of Agricultural land in the world was the major beneficiary of the forest and shrub depletion. In this study, agricultural land recorded the highest increase in coverage (197,943.99 ha). This is in agreement with the observation of Bruinsma (2003). Moreover, Shuaibu (2014) found that settlements have been increasing in Nassarawa State, therefore increasing the demand for land use such as cultivation to meet the food demand of the population.

There was an increase in forest during the past 30 years, and from the analysis of Figures 4.20, 4.21 and 4.22, it reveals that forests are mostly located at the mountainous areas where human access is restricted. Those sparse forests located at non mountainous areas in 1986 were destroyed thereafter and only those located at the mountainous areas were expanded. The decrease of degraded area (bare soil) in 2015 compared to that of 1999 was probably due to the increase in rainfall that allowed grasses to cover some degraded surface. Some part of the bare surface was equally converted into residential settlements.

4.4 Assessment of spatio-temporal Change of Soil Erosion

4.4.1 Erosion Factors

The erosion factors in RUSLE include rainfall and run-off erosivity factor (R), soil erodibility factor (K), topographic factors (LS), cover management factor (C) and control practice factor (P) (Nyakatawa, Reddy and Lemunyon, 2001).

❖ **Rainfall Erosivity (R)**

The rainfall erosivity factor for the periods 1981-1997 and 1998-2014 are shown in Figures 4.23 and 4.24 respectively. For the first period (1981-1997), the lower erosivity value range was 567-583 MJ mm ha-1h-1 and was observed at the eastern part of the study area, thus this part is less vulnerable to erosion (Estifanos, 2014). This value increases from the eastern to the western part of the State, with the highest value range (625-643 MJ mm ha-1h-1) obtained at the southern west part; this part is mostly vulnerable to rainfall erosivity.

The Figure of the second time period (Figure 4.24) shows the same pattern as the first period; however the highest value range shifted from the southern west to the western central and northern Nasarawa. An increase R values was obtained for the second period compared to the first period values (minimum from 567 to 609 MJ mm $ha^{-1}h^{-1}$, maximum from 643 to 676 MJ mm $ha^{-1}h^{-1}$). The spatial change in the R value presented in Figure 4.25 reveals that the highest decrease was observed at the southern west part while the highest increase was obtained at the mountainous region located at the North East of the State. The increase in R value observed in many regions of Nasarawa State is due to the increase of the annual rainfall amount (2.3mm/year to 6.4mm/year) within the State (found from the previous results, Table 4.1).

There was an overall increase in rainfall and its erosivity from the first period to the second. According to Klein and Konnen (2003), when there is change in rainfall characteristics, it will affect water availability which can result in flooding. This flooding situation is pointed out by Faruqui, Biswas and Bino (2001) to affect land degradation, especially soil erosion by water.

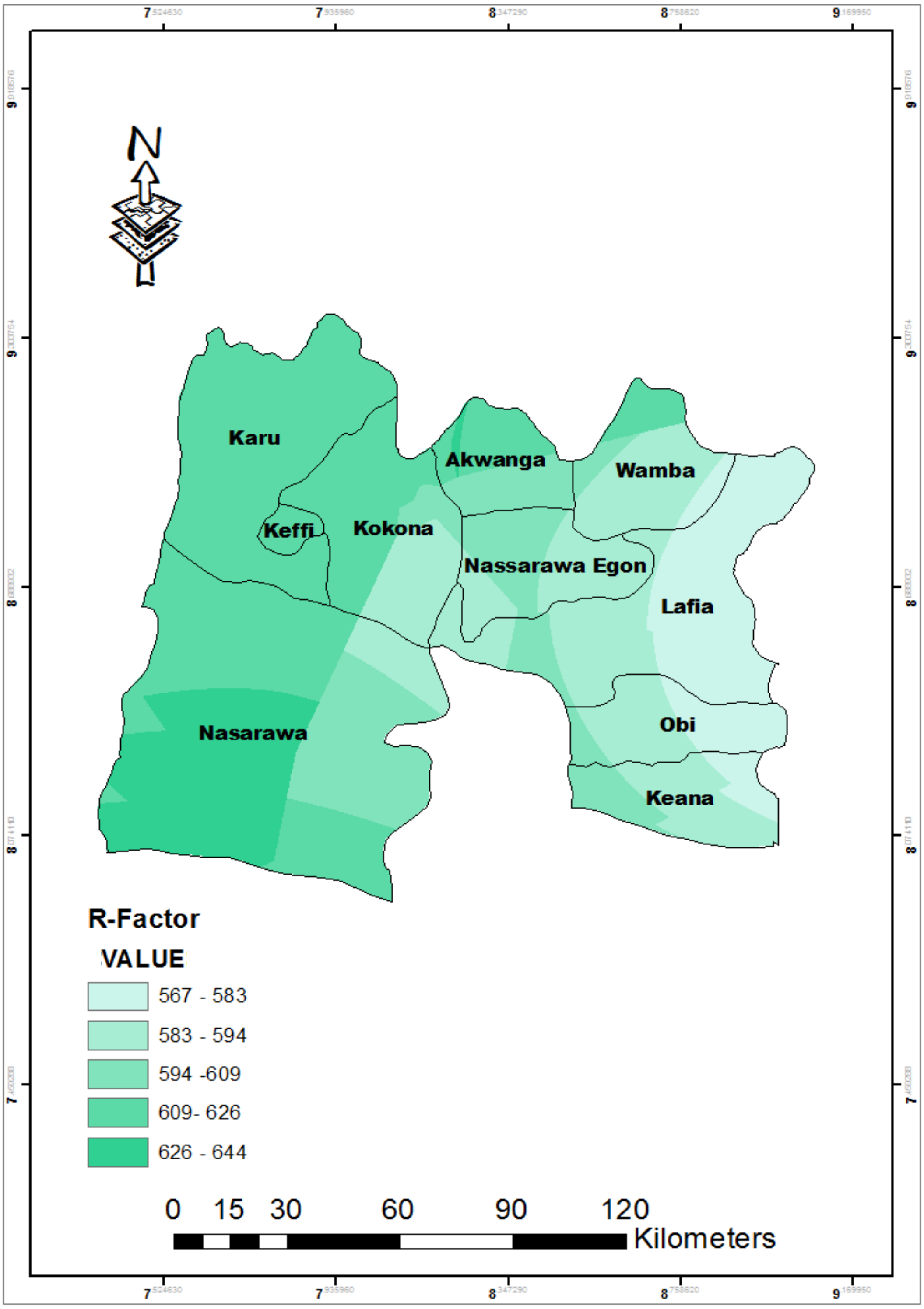

Figure 4.23 R- factor Map of the Period 1981-1997

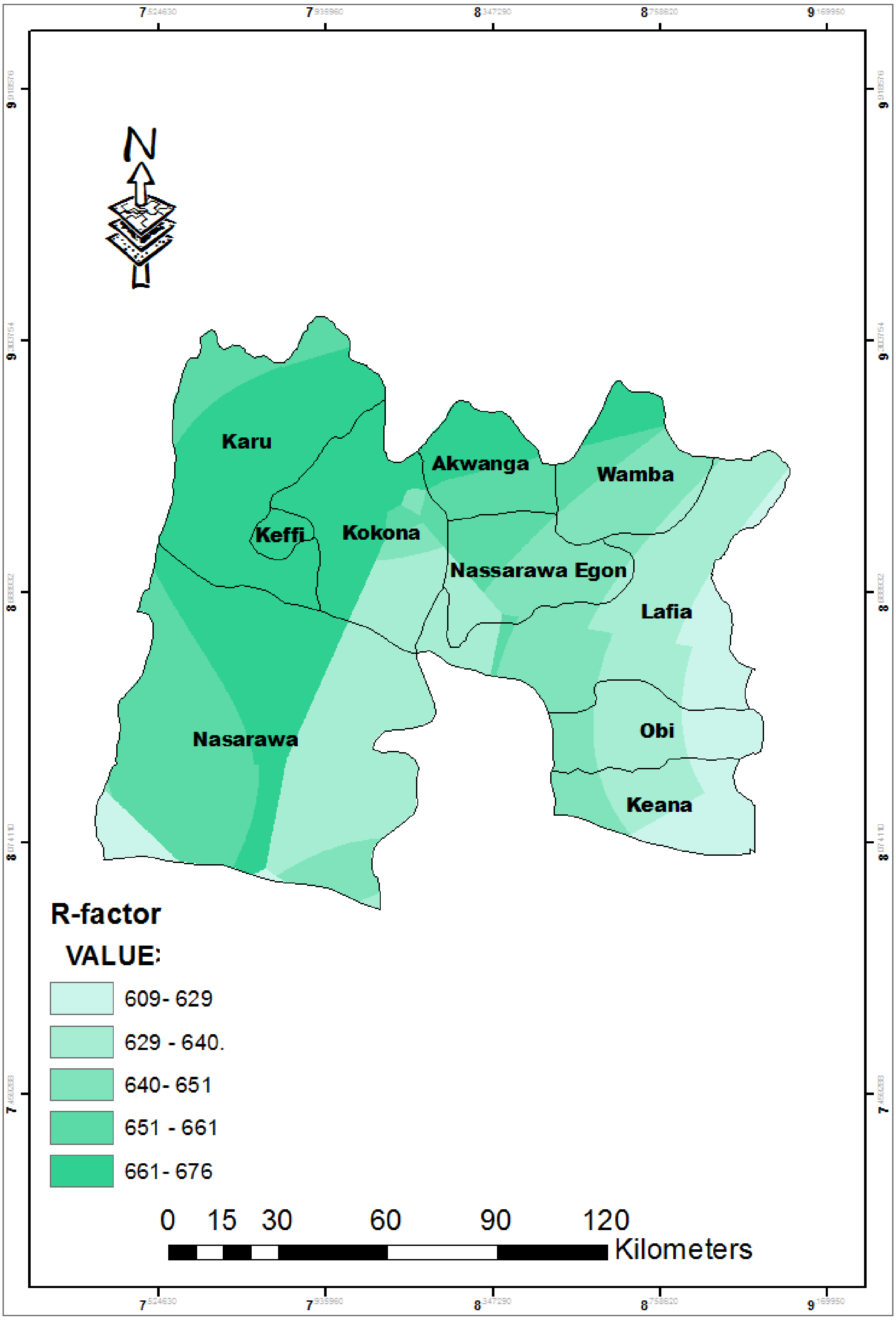

Figure 4.24 R-factor Map of the Period 1998-2014

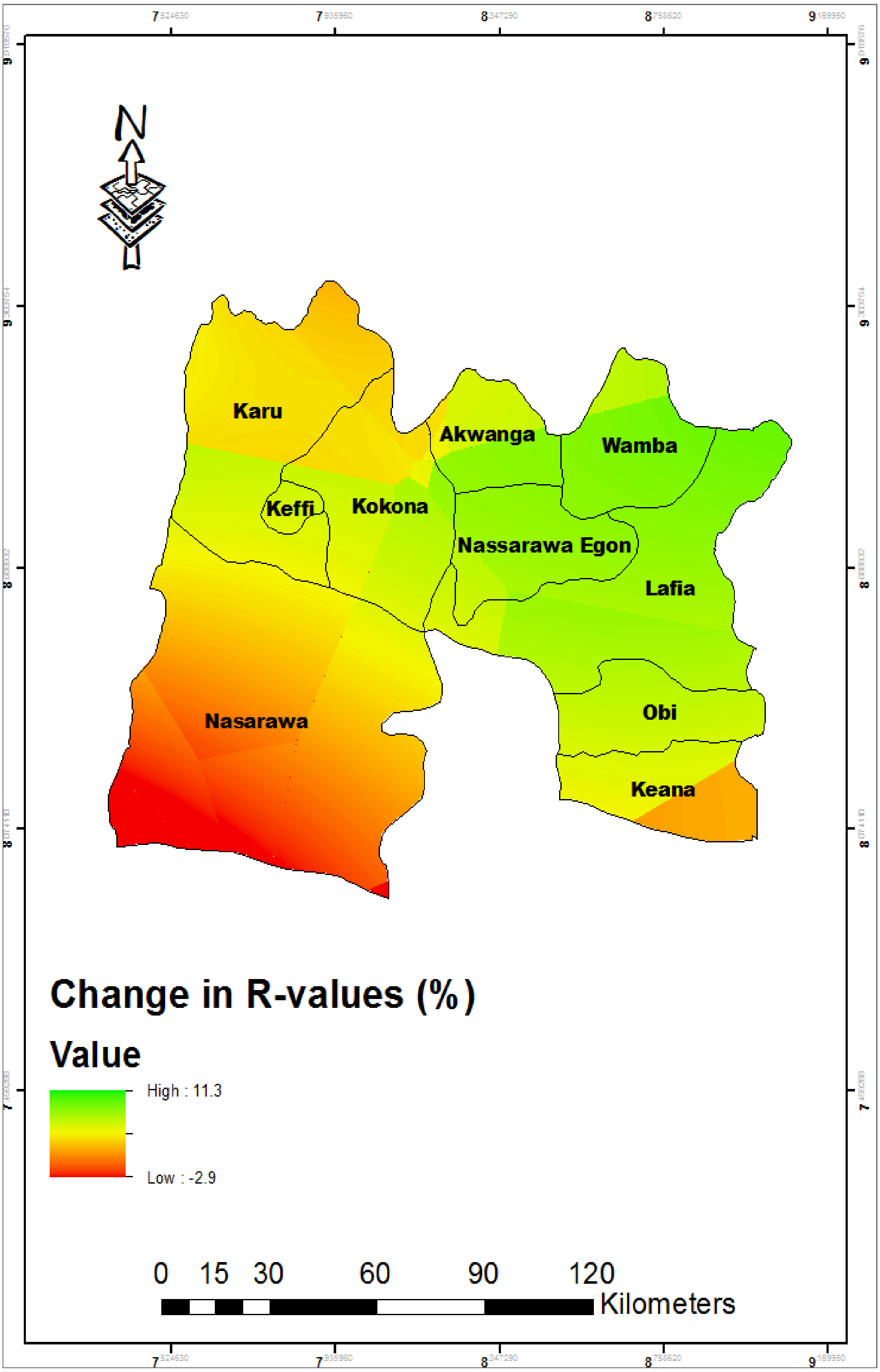

Figure 4.25 Change in the R-factor from 1981 to 2014

❖ **Soil Erodibility Factor (K)**

The study area has five soil units as shown in Figure 4.26 and these soil units are Alfisols, Entisols, Ultisols, Inceptisols and Vertisols. The soil parameters required for the computation of soil erodibility are: percentage of organic matter (%OM), percentage of clay (%Clay), of silt (%Silt) and sand (% Sand), soil structure code and soil profile permeability class. The values for the different parameters mentioned previously for each soil unit were obtained from soil survey and laboratory analysis, and are summarized with their corresponding K-value in Table 4.4. The high k-factor value indicates more vulnerable soil type to soil erosion and the smaller value shows less vulnerable soil type to erosion. As presented in Table 4.4 and Figure 4.27, the high k-factor value is shown in Alfisols which are found in Obi and Keana Local Government Areas. This type is sandy and can be easily detached by raindrops. Vertisols are the less vulnerable in the study area and are mostly located in northern Lafia local government area. This type of soil is very content high clay that make it very difficult to be detached by raindrops.

Table 4.4 Calculated K- value for the different Soil Units of the Study Area

Soil Units	%OM	% Sand	%Silt	%Clay	Textural class	Structure code	Permeability class	K-value
Alfisols	0.96	77	5	17	SL	2	2	0.25
Entisols	0.98	67	12	20	SL	2	2	0.13
Inceptisols	1.00	68	10	21	SCL	3	4	0.11
Ultisols	1.20	60	15	24	SCL	3	4	0.10
Vertisols	1.80	8	30	60	Clay	4	5	0.09

NB: SL= Sandy loam, SCL= Sandy clay loam

(Source: Author’s Study, 2015)

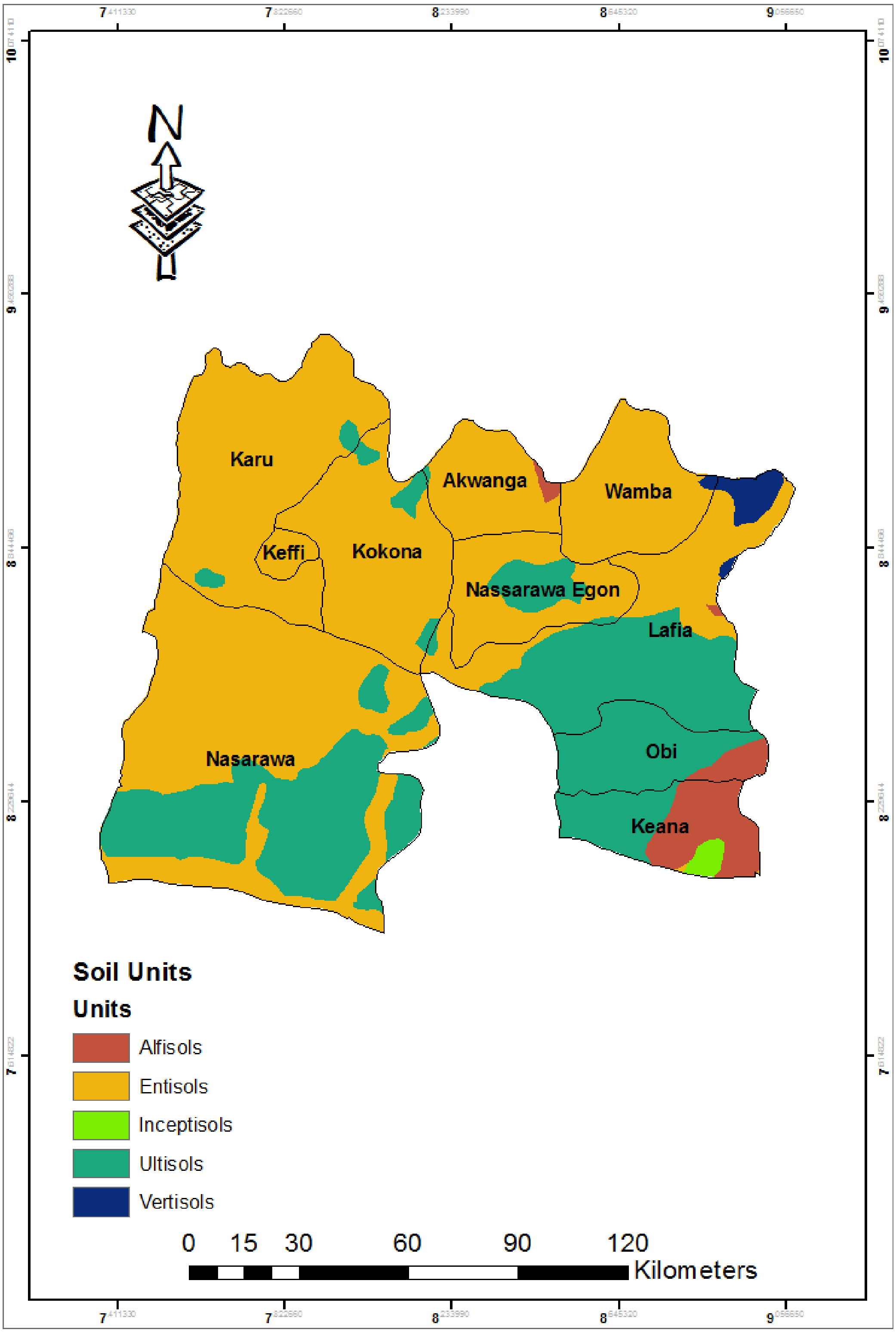

Figure 4.26 Map of the Soil Units of the Study Area

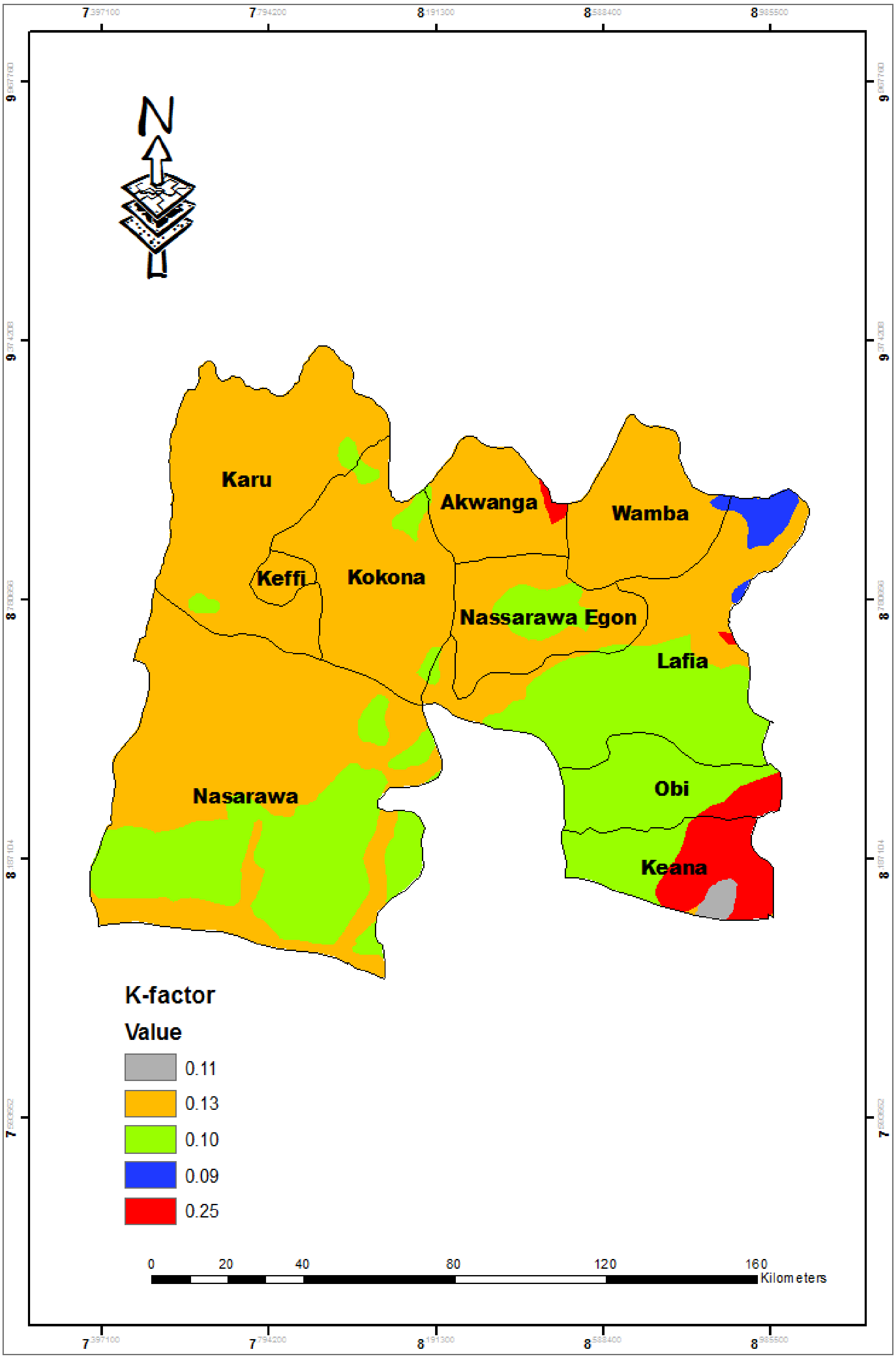

Figure 4.27 K- factor Map of the Study Area

❖ **Topographic Factor (LS)**

The LS factor accounts for the effect of topography on erosion in Revised Universal Soil Loss Equation. The LS-factor map is shown in Figure 4.28, and the values are ranged from 0.1 to 42.7, the lower value for a region means that the region contributes less to the erosion, whereas the higher value implies a greater contribution to erosion. The lower LS values are mostly found at the southern part where the landscape is almost flat with many river basins, and the higher values are found at the mountainous areas where the slope is steep.

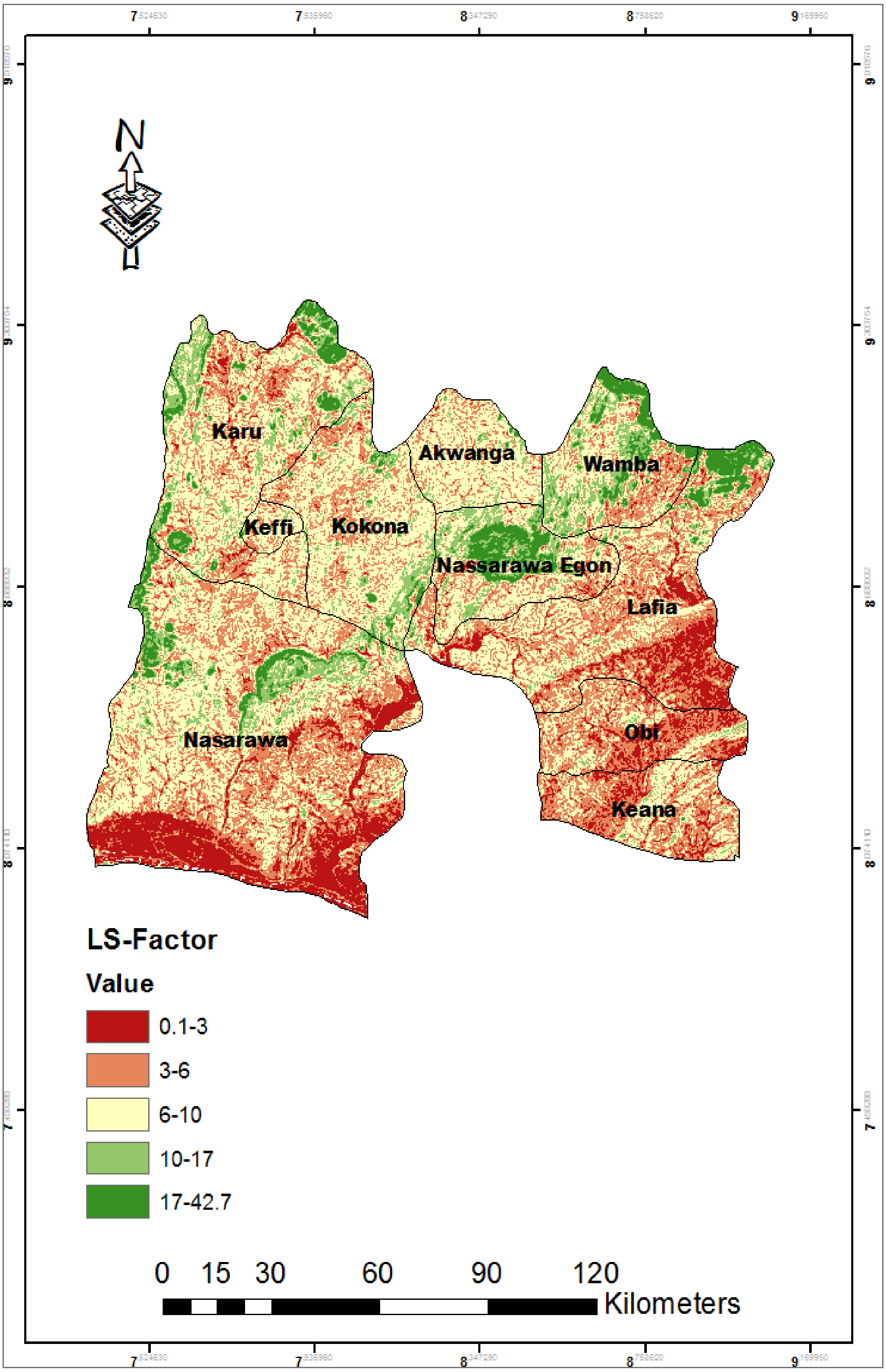

Figure 4.28 LS-factor Map of the Study Area

❖ Soil Cover Factor (C)

The soil cover management factor expresses the effect of vegetation on the rate of soil loss. C factors pertaining to different types of vegetation and soil conservation methods are important, since they can be used to predict the extent of soil loss reduction. The C-factors for the two time periods (1986 and 2014) of soil erosion modelling is represented in Figure 4.29 and 4.30. The high C-value is assigned to the degraded land or bare soil, signifying that it is the most vulnerable to erosion. The lower value is assigned to the forest as land cover, for it is the best land cover that prevents soil from erosion. However, we assigned the value zero to the water body based on the fact that water covers completely the soil and let the ground beneath the water to be less erodible. The spatial coverage of degraded area or bare soil has increased from 1986 to 2015, thus the spatial coverage of higher C-value increased for the past 30 years, exposing more land to erosion by water.

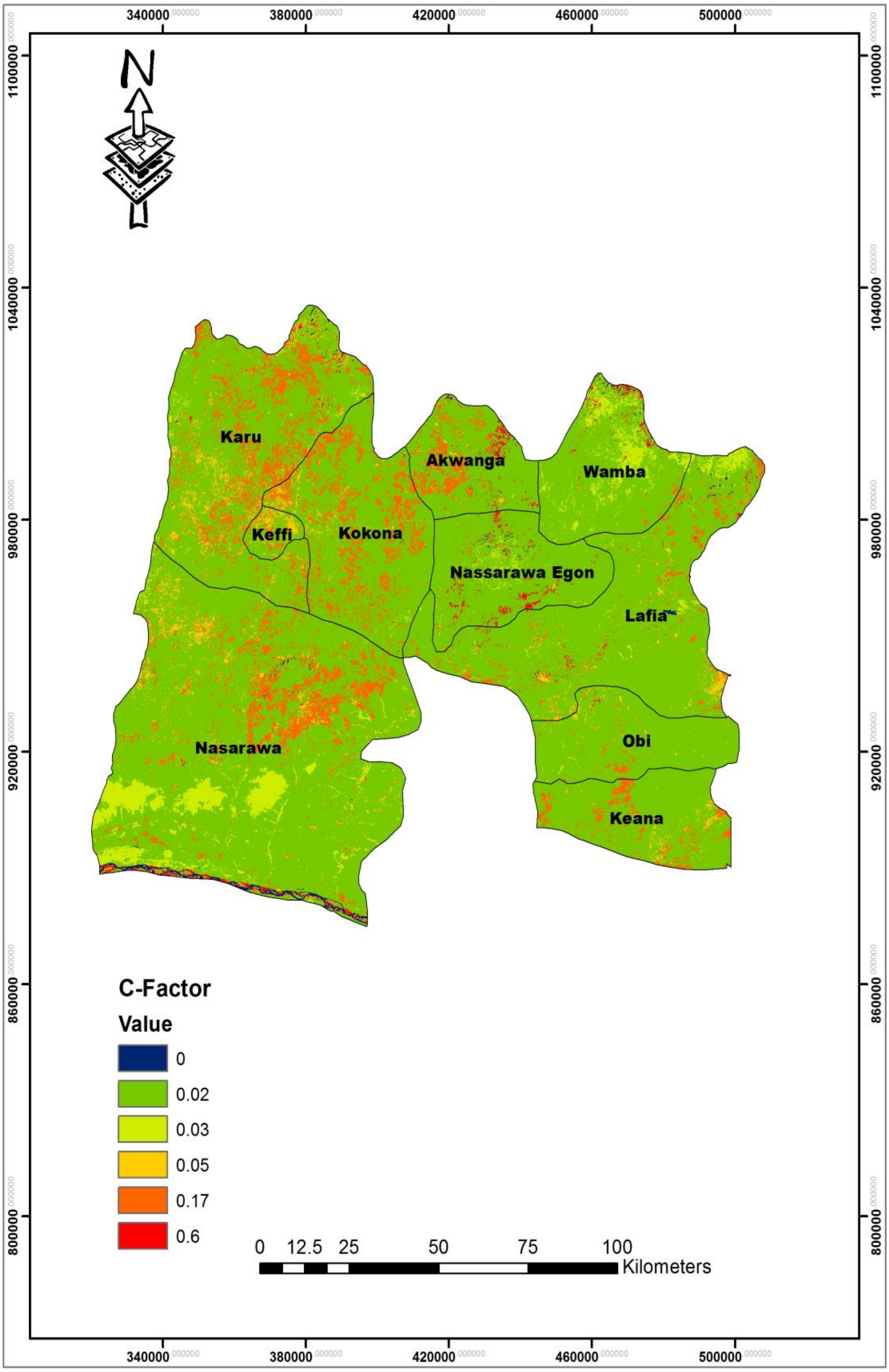

Figure 4.29 C-factor Map of the Study Area in 1986

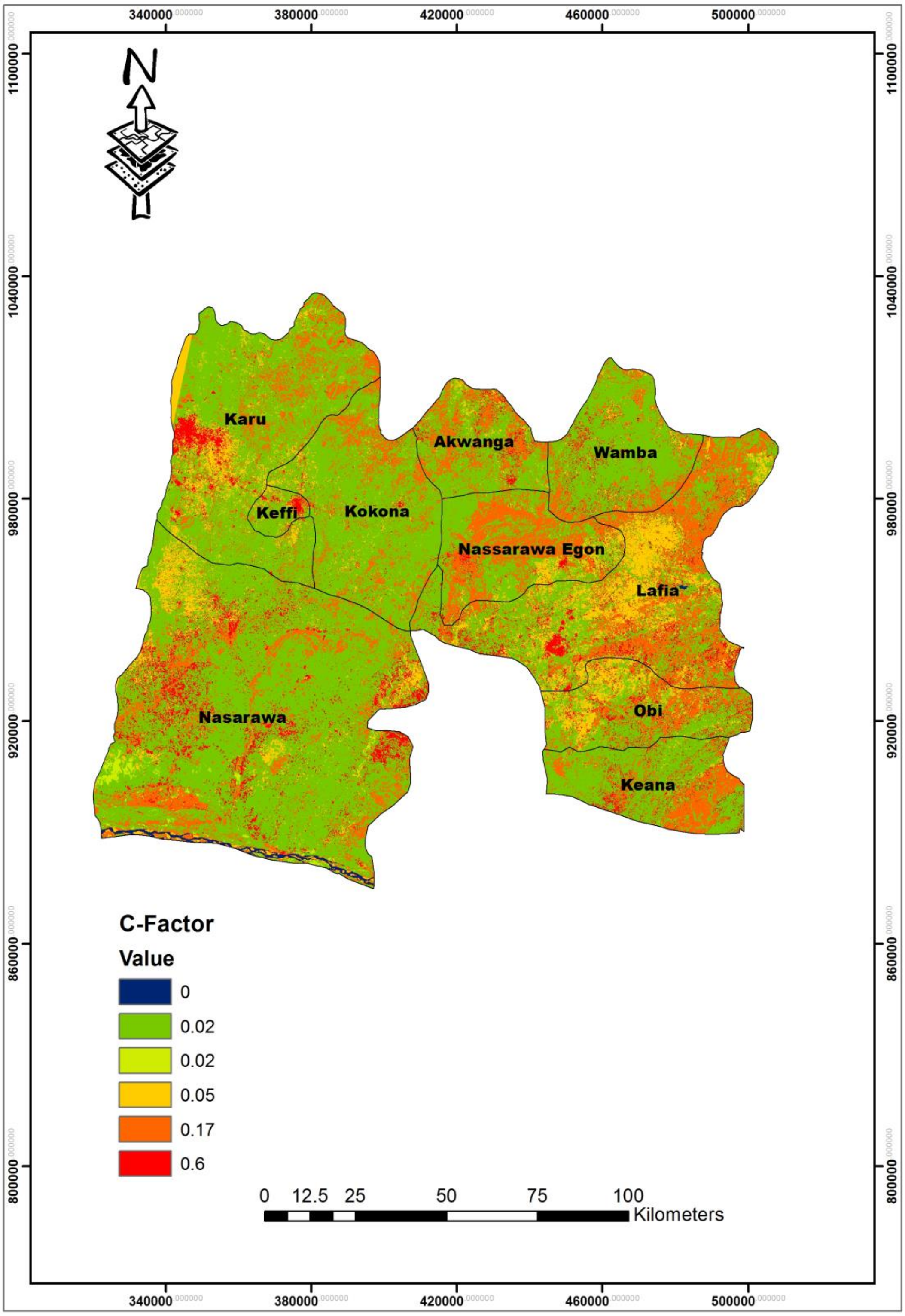

Figure 4.30 C-factor Map of the Study Area in 2014

4.4.2 Assessment of the Change in Soil Erosion Risk

Five classes of soil erosion risk were observed in the study area between 1981 and 2014. These erosion risk classes are: no erosion (0-1tons/ha/year), slight erosion (1-5tons/ha/year), moderate erosion (5-10tons/ha/year), severe erosion (10-20tons/ha/year) and very severe erosion (>20tons/ha/year). The largest coverage of erosion risk class in 1986 was very severe erosion, representing 42.80% of the total landmass (Figure 4.31). Severe, slight, moderate and no erosion risks covered 841,106 ha (38.81%), 249,039ha (11.49%), 143,884ha (6.64%) and 5,679ha (0.26%) respectively in a descending order.

However, during the second period (2014), soil erosion risk classes have shifted in coverage as shown in Figure 4.32. Very severe erosion still maintaining its position as the widest coverage, increased to 45.10% of the total landmass. Moderate and no erosion increased to 9.89% and 0.85% respectively whilst slight and severe erosion classes reduced to 10.37% and 33.80% respectively (Table 4.4).

Within this 34 year period, moderate erosion risk class recorded the highest net change in percentage at 5.01% of the total area and no erosion risk class had the least at 0.02 %. The decrease of the coverage in slight and moderate erosion classes could probably be due to the decrease in rainfall erosivity and re-vegetation of some bare soil area which rendered the soil less vulnerable to erosion. However, the increase in other erosion classes could be the consequence of the increase in rainfall erosivity and bare soil that could convert some classes into other classes, thereby explaining the decrease in the moderate and no erosion classes (Lihui, Jinliang, Yun, Yanxia and Pengpeng, 2013). The eroded areas decreased from 1,768,785ha (81.61%) in 1981 to 1,709,991 ha

(78.9%) in 2014. It can be concluded that eroded area declined while soil erosion was improved in the study area.

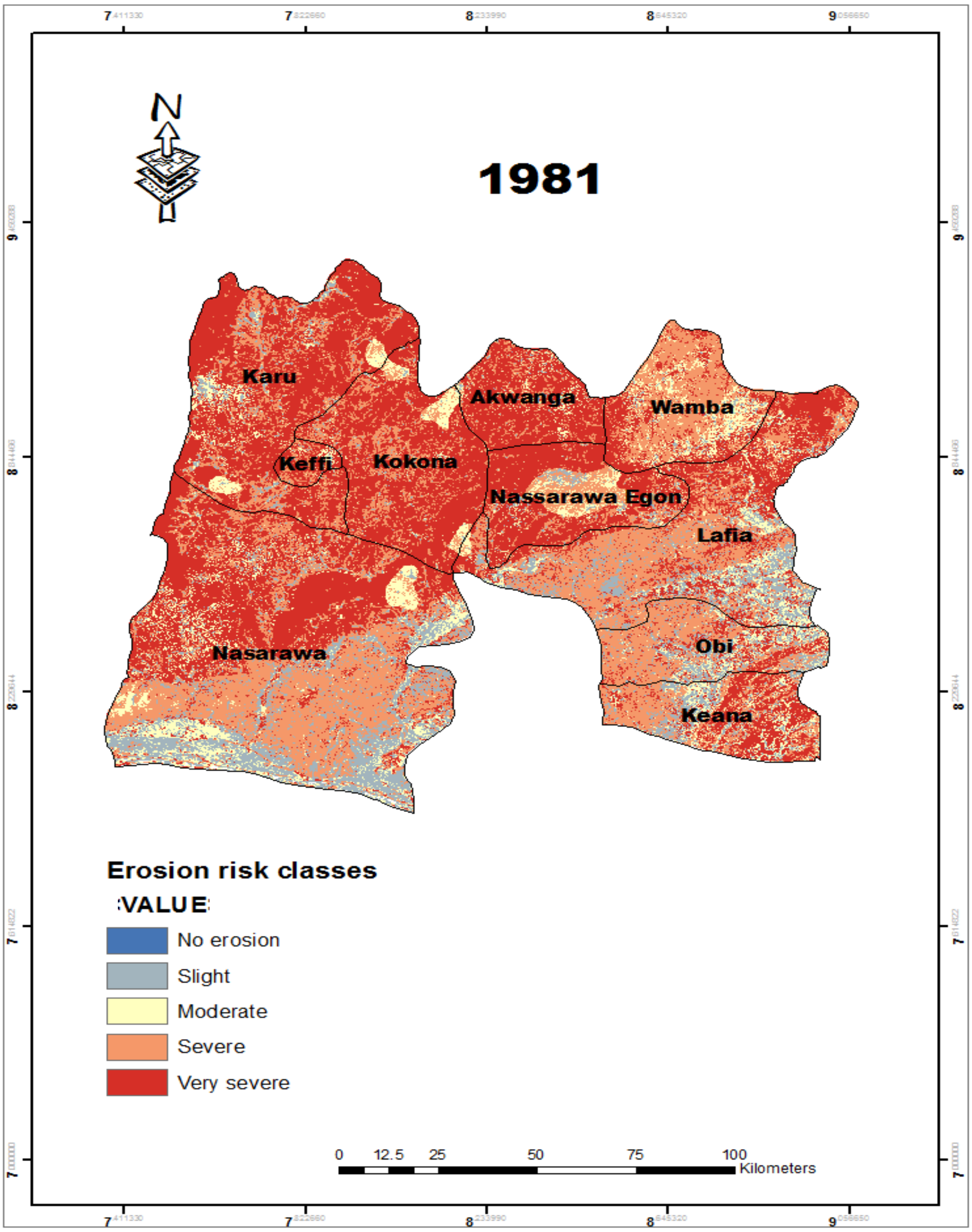

Figure 4.31 Spatial Distribution of Soil Erosion for the Year 1986

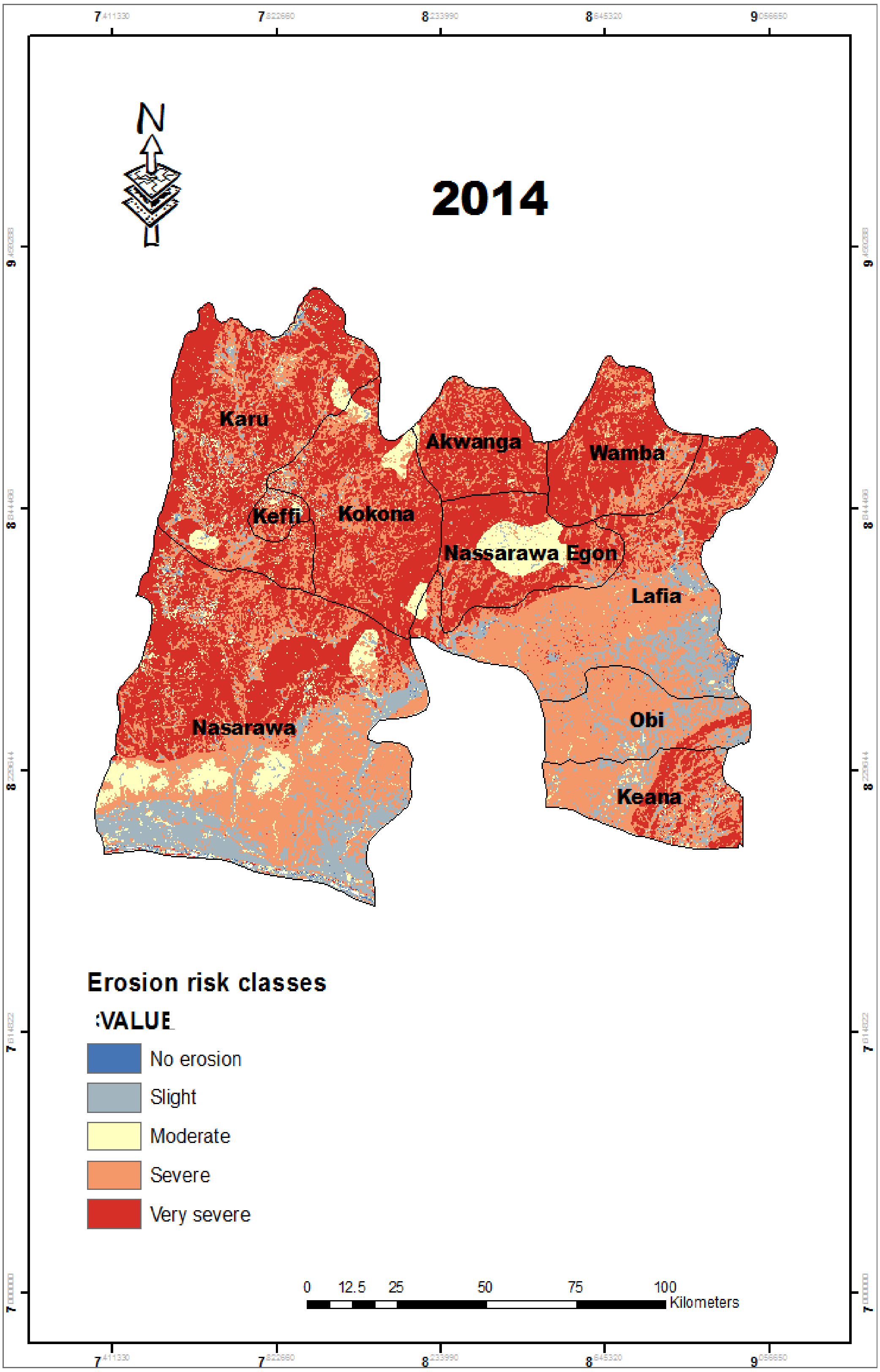

Figure 4.32 Spatial Distribution of Soil Erosion for the Year 2014

Table 4.5 Soil Erosion rate Change between 1981 and 2014

	Surface area (ha)		**Surface area (%)**		**Net change (%)**	**Rate of change (%)**		
Periods **Erosion classes**	**1981**	**2014**	**1981**	**2014**	**1981-2014**	**1981**	**2014**	**1981-2014**
No erosion	5,679	18,355	0.26	0.85	0.58	0.02	0.02	0.02
Slight	249,039	224,721	11.49	10.37	-1.12	0.72	0.68	-0.03
Moderate	143,884	214,320	6.64	9.89	3.25	0.41	0.39	0.10
Severe	841,106	732,575	38.81	33.80	-5.01	2.43	2.28	-0.15
Very severe	927,679	977,416	42.80	45.10	2.29	2.68	2.52	0.07
Total	**2,167,387**	**2,167,387**	**100**	**100**				

(Source: Author's Study, 2015)

Figure 4.33 shows the spatial distribution of the change in soil erosion rate. The higest increase in soil erosion rate was 600% and was observed in all the local government areas. Wamba was the most affected by the higher increase in annual soil loss. This could be due to the increase in the rainfall and associated with the steepness of the landscape over this area. The increase of soil loss observed in the south could be the consequence of the high population density and land use malpractices. Decrease in soil erosion rate was observed over the study area and it could be due to the recent greeniness in the northern mountainous regions and the decrease in the rainfall intensity in the south. 51% of the total area observed a change in soil erosion, with 32% of decreased erosion rate and 19% of increased erosion rate (Table 4.5).

These findings are in agreement with Pruski and Nearing (2002) who stated that erosion increased significantly where rainfall increased, while both increase and decrease was observed where rainfall decrease. The increase in erosion status in area with decrease in precipitation can be caused by the change in land use pattern. This was confirmed by Gao and Yu (2002) who stated that 40 years of climate change would have contributed to the decrease in soil erosion, but land use change only overcompensated this decrease, increasing therefore water erosion by a factor of eight.

Percentage change in soil erosion rate is higher than that of rainfall and its run-off erosivity. This was found out by SWCS (2003). They discovered that changes in rainfall regime can profoundly affect soil erosion and concluded soil erosion by water is sensitive to alteration in rainfall regime. Symeonakis *et al.* (2003) found out a similar result and concluded that there is a significant relationship between land use change and land degradation, especially soil erosion.

The surface area that underwent decreased change is almost double of that of increased change, thus land use/cover and climate changes over the past 34 years contributed in overall to the amelioration of soil erosion status in the study area. Lihui *et al*. (2013) found a similar result from their study carried out in China. However,Wamba and Keana are seriously threatened by increased soil erosion, followed by Nasarawa, Obi , Lafia and Karu where a particular attention must by paid.

Table 4.6 Statistics of the Change in Soil Erosion Rate between 1981 and 2014

	Surface area (ha)	**Surface area (%)**	**Rate of change (%)**
Increase	407,133	18.78	0.57
No change	1,063, 260	49.06	1.49
Decrease	696,994	32.16	0.97
Total	**2, 167, 387**	**100**	

(Source: Author's Study, 2015)

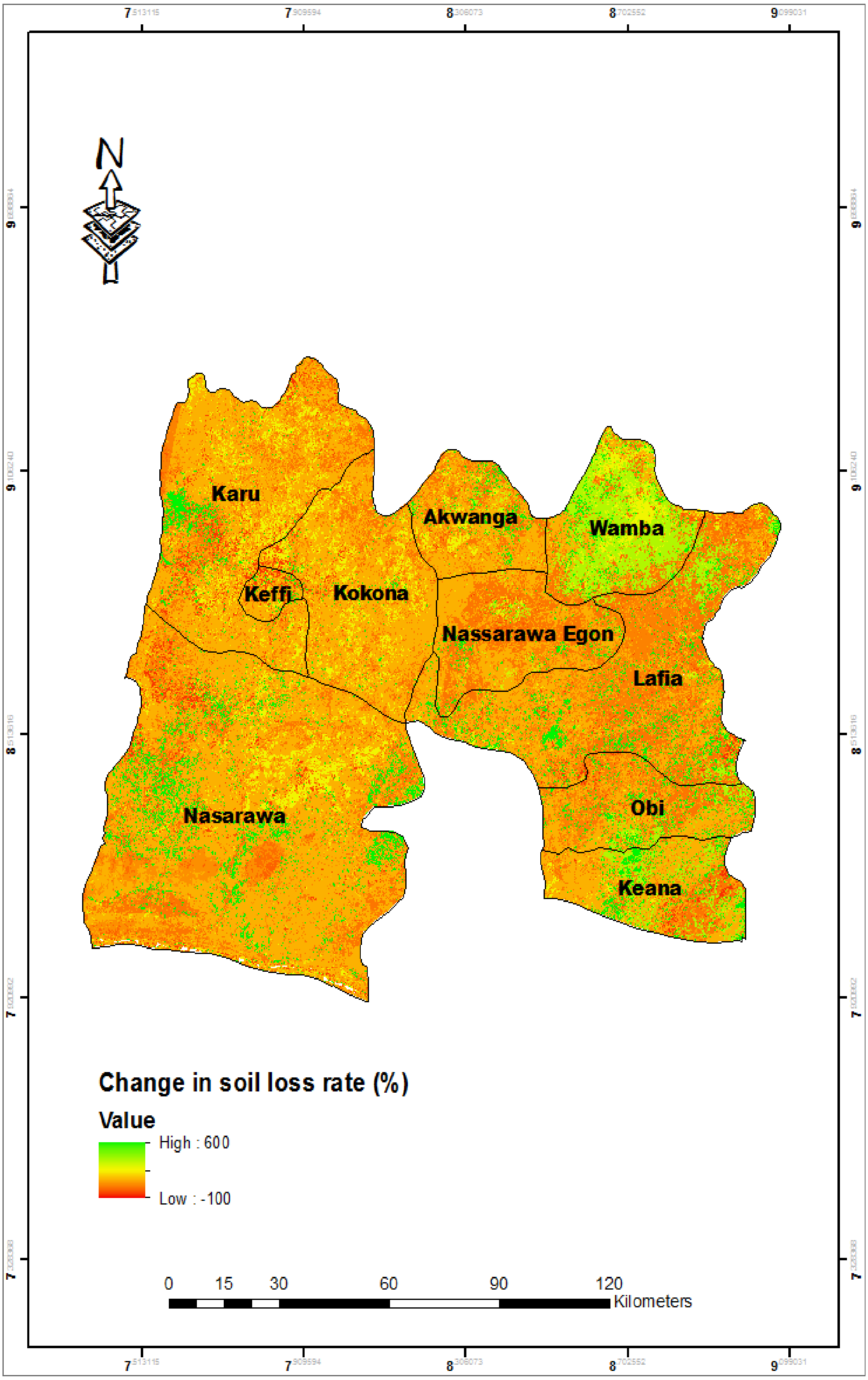

Figure 4.33 Change in Soil Erosion Rate from 1981 to 2014

4.4.3 Trend Analysis of Erosion Grade Transformation

The values of 1, 2, 3, 4 and 5 were assigned to the erosion risk of ‘no erosion’, ‘light erosion’, ‘moderate erosion’, ‘ severe erosion’ and ‘very severe erosion’ respectively. Then, erosion risk of 2014 was subtracted from that of 1981 pixel by pixel. If the output pixel is +1, the erosion risk of the pixel was considered as increased one grade. If the output pixel is -1, then erosion risk decrease one grade, and so on. If the result is zero, then the erosion risk remained unchanged. Therefore, 9 classes of erosion trends, each class represents one grade class. They include 4 decrease classes, 4 increase classes and 1 unchanged class.

Based on the aforementioned, erosion grade change map was obtained (Figure 4.34). Table 4.6 showed the statistics for the different grade change. Unchanged class covered the majority of the total landmass (72.53 %). Thus, 27.47 % of the total area observed a real change in erosion grade transformation as a direct and noticeable result of the combined action of climate and land use/cover changes. More improvement was observed in the area (15.45% of improvement against 12.07% of deterioration), suggesting that soil erosion status improved from 1981 to 2014 in Nasarawa State. Lihui *et al*. (2013) found similar improvement in soil erosion status from their study carried out in China.

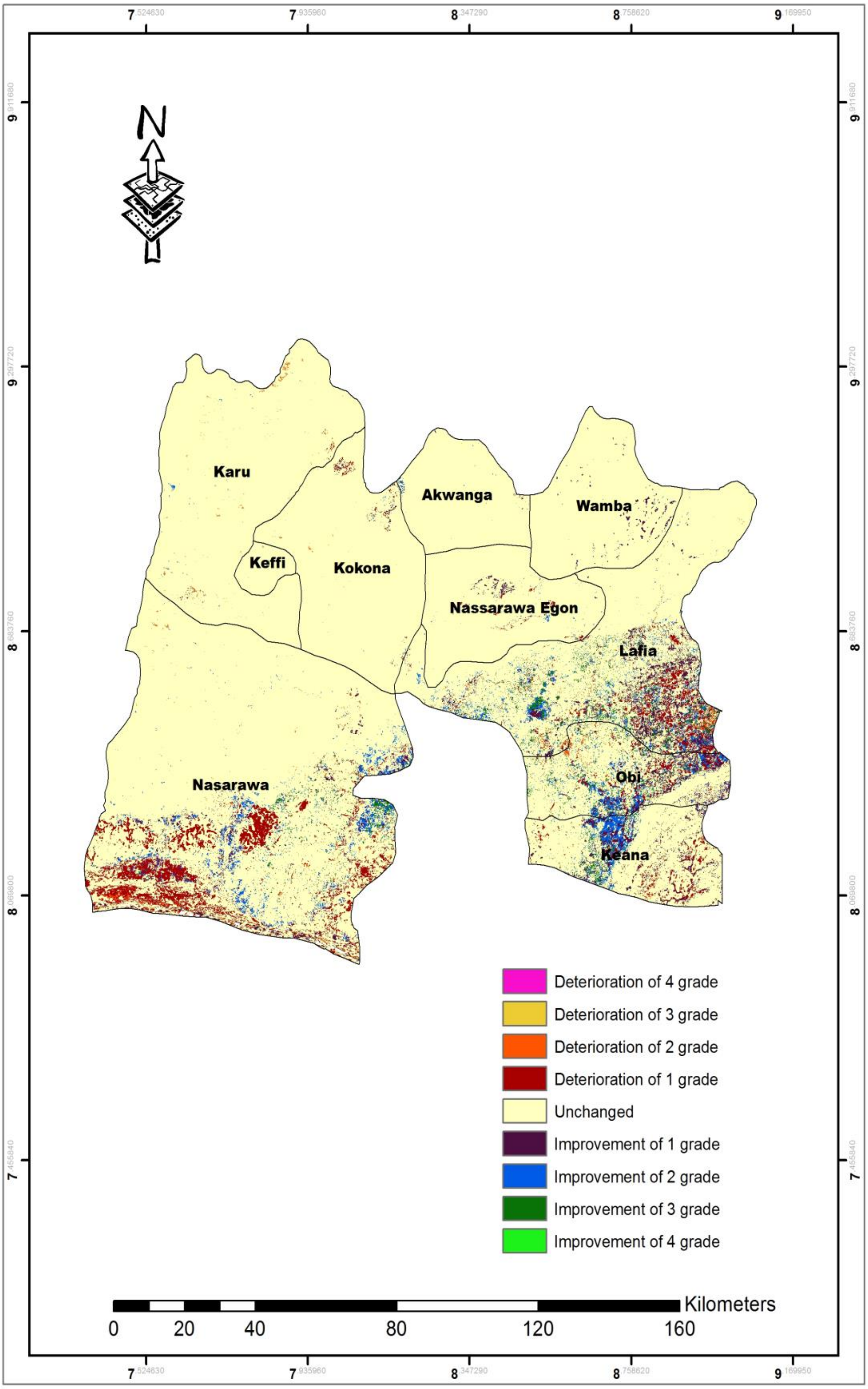

Figure 4.34 Spatial distribution of change in erosion grade

Table 4.7 Area distribution of erosion grade transformation between 1981 and 2014

Erosion grades	Surface are (ha)	(%)
Deterioration of 1 grade	12	0.001
Deterioration of 2 grade	924	0.043
Deterioration of 3 grade	122,921	5.671
Deterioration of 4 grade	136,595	6.302
Unchanged	1,572,015	72.530
Improvement of 1 grade	280,868	12.959
Improvement of 2 grade	49,636	2.290
Improvement of 3 grade	4,415	0.204
Improvement of 4 grade	1	0.000
Total	**2,167,387**	**100**

(Source: Author's Study, 2015)

4.4.4 Conservation Priorities in the Study Area

Defining soil conservation priority is an important tool for policy-makers of Nasarawa State in planning soil and water conservation of the State. Each priority level indicates the specific need for erosion control. The definition of conservation priority requires the consideration of both the erosion actuality and change trend. Therefore, two scenarios were used to define these conservation priorities in the present study.

❖ **Scenario 1**

This scenario is based on the assumption that the total surface area will be considered with all the different trend situations, whether the area is unchanged, improving or deteriorating. Then, areas with the same current erosion grade can have different conservation priority due to the change in soil erosion risk. The conservation priority of unchanged area was defined based on the erosion actuality. For this study, we adapted the multi-criteria method used by Zhang, WU, Zeng, Yan and Yuan (2010) (Table 4.7).

Table 4.8 Multi-criteria decision Rules for Conservation Priorities Definition

		Erosion grade of 2014				
		No erosion	**Slight erosion**	**Moderate erosion**	**Severe erosion**	**Very severe**
Erosion grade in 1986	No erosion	V	III	II	I	I
	Slight	V	IV	III	I	I
	Moderate	V	IV	III	II	I
	Severe	V	IV	IV	II	I
	Very severe	V	V	IV	III	I

(Source: Author's Study, 2015)

Figure 4.35 showed the conservation priority map of the study area while Table 4.8 presented the related statistics.

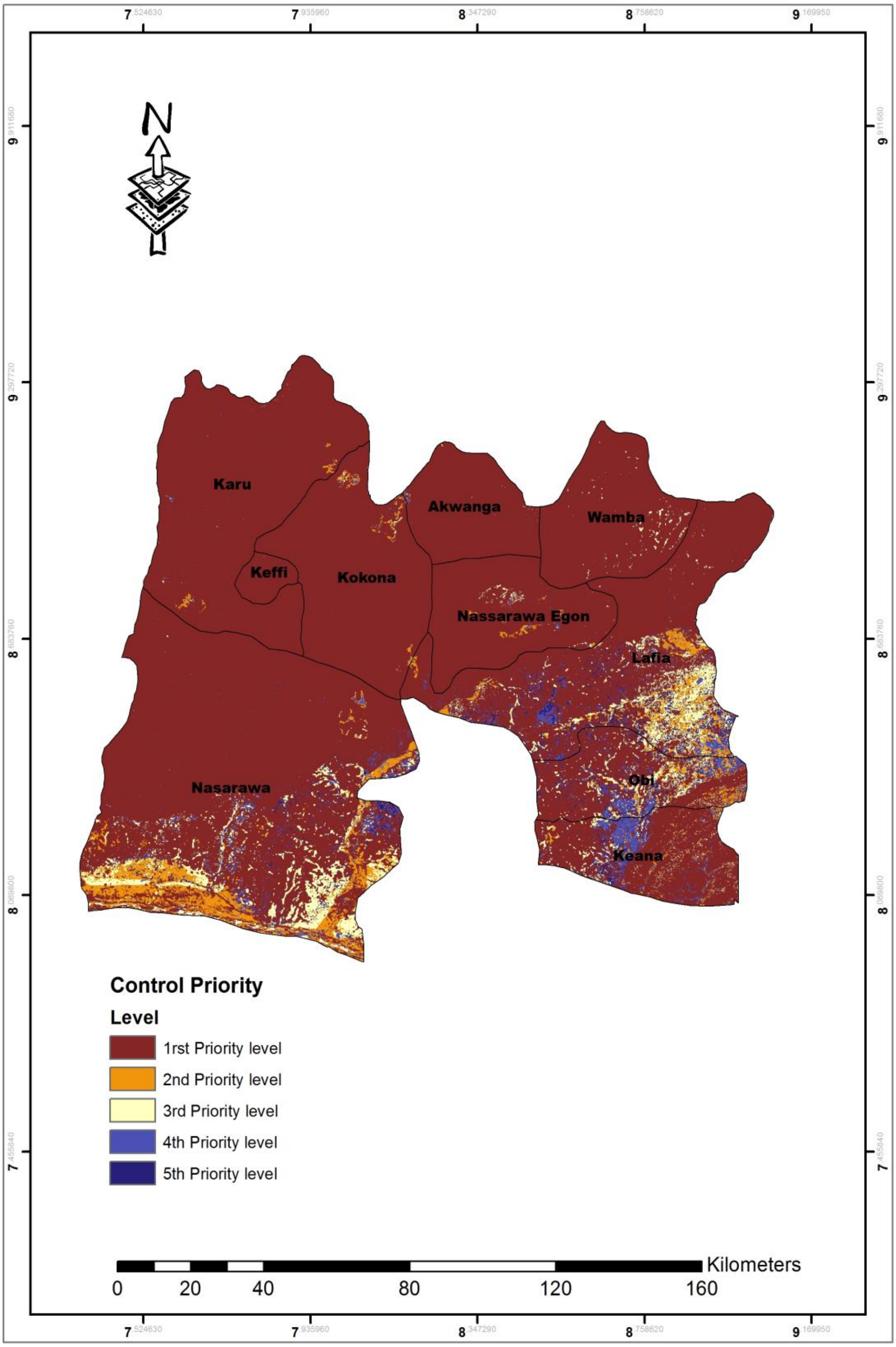

Figure 4.35 Conservation Priority Map of the Study Area

Table 4.9 Area Distribution of the different Priority Level

Priority level	Surface area (ha)	Percentage (%)
1st Priority level	793,909	36.63
2nd priority level	726,802	33.53
3rd priority level	379,587	17.51
4th priority level	249,851	11.53
5th priority level	17,238	0.80

(Source: Author's Study, 2015)

Table 4.8 and Figure 4.35 show that the first two conservation priority levels (Levels 1 and 2) cover almost all the local government areas of the study area (70.16%) with serious erosion situation. They must be managed by implementing appreciable conservation practices in the future. Areas of levels 3 and 4 comprise area with stable erosion status with slight change; they covered 29.04% of the area and need minor conservation strategies in the future. Level 5 covers area of low erosion and accounted for 0.8% of the total, and does not need erosion control. Unlike Lihui *et al.* (2013), who found that only 7% of their study area are of first two conservation priority levels associated with large coverage of lower conservation priority levels, Nasarawa State has large area with first two conservation priority levels associated with small area with lower conservation priority levels. This indicates that Nasarawa State is really threatened by soil erosion risk.

- **Scenario 2**

The control priority is defined based on the assumption that the current trend of erosion will continue the same way in the future, then the unchanged and improving areas will continue to perform in the same way. Therefore, the areas with high priority will be the areas already degraded and those that experienced deterioration. This scenario helps in identifying areas that must be urgently managed to prevent further deterioration or additional degradation due to the future change in climate and land use patterns. This scenario identifies erosion priorities based on the erosion status in 1986 (as baseline) and the variation in erosion grade transformation. Three levels of urgent priority were defined: Low level (L) where a future conservation planning is required, medium level (M) where control strategies must be implemented starting from the very next years, and high level (H) where urgent control practices must be adopted to avoid disastrous erosion status that could affect the livelihood of the people in the study area. Thus, Table 4.9 presents the multi-criteria decision rules used to identify the areas of urgent conservation priorities.

Table 4.10 Multi-criteria rules used for identifying urgent Conservation Priorities

		Erosion risk in 1986				
		No erosion	Slight erosion	Moderate erosion	Severe erosion	Very severe erosion
Erosion grade variation	Deterioration of 1 grade	L	L	M	H	H
	Deterioration of 2 grade	L	L	M	H	H
	Deterioration of 3 grade	L	M	H	H	H
	Deterioration of 4 grade	M	M	H	H	H
	Unchanged	M	M	M	H	H
	Improvement of 1-5 grades	L	L	L	L	M

(Source: Author's Study, 2015)

Figure 4.36 shows the different areas of urgent conservation priorities and the related statistics are presented in Table 4.11. From the statistics, 2.38% of the total area needs the implementation of very urgent conservation strategies to halt the current trend of soil deterioration. Medium level of conservation priorities is required for 10.39% of the surface area, whilst 87.23% of the area is of low urgent conservation priority. High urgent conservation priority is found in all the local government areas, stating that the whole study area is concerned with the urgent need for soil erosion control. Nevertheless, four local governments are of great concern for this urgency, and they are Nasarawa, Karu, Akwanga and Wamba. It is noteworthy that despite the overall amelioration in the soil erosion status in the study area, some local government areas are seriously threatened by the impact of the changes in climate conditions and land use/cover pattern. As rill and sheet erosions are serious soil degradation phenomena that undermine the productivity of the soil, a thorough attention must be paid to these areas to ensure food production in the area.

Table 4.11 Area Distribution of urgent Priority Levels

Urgent priority levels	Surface (ha)	Surface (%)
Low	1,890,615	87.23
Medium	225,226	10.39
High	51,546	2.38
Total	**2,167,387**	**100**

(Source: Author's Study, 2015)

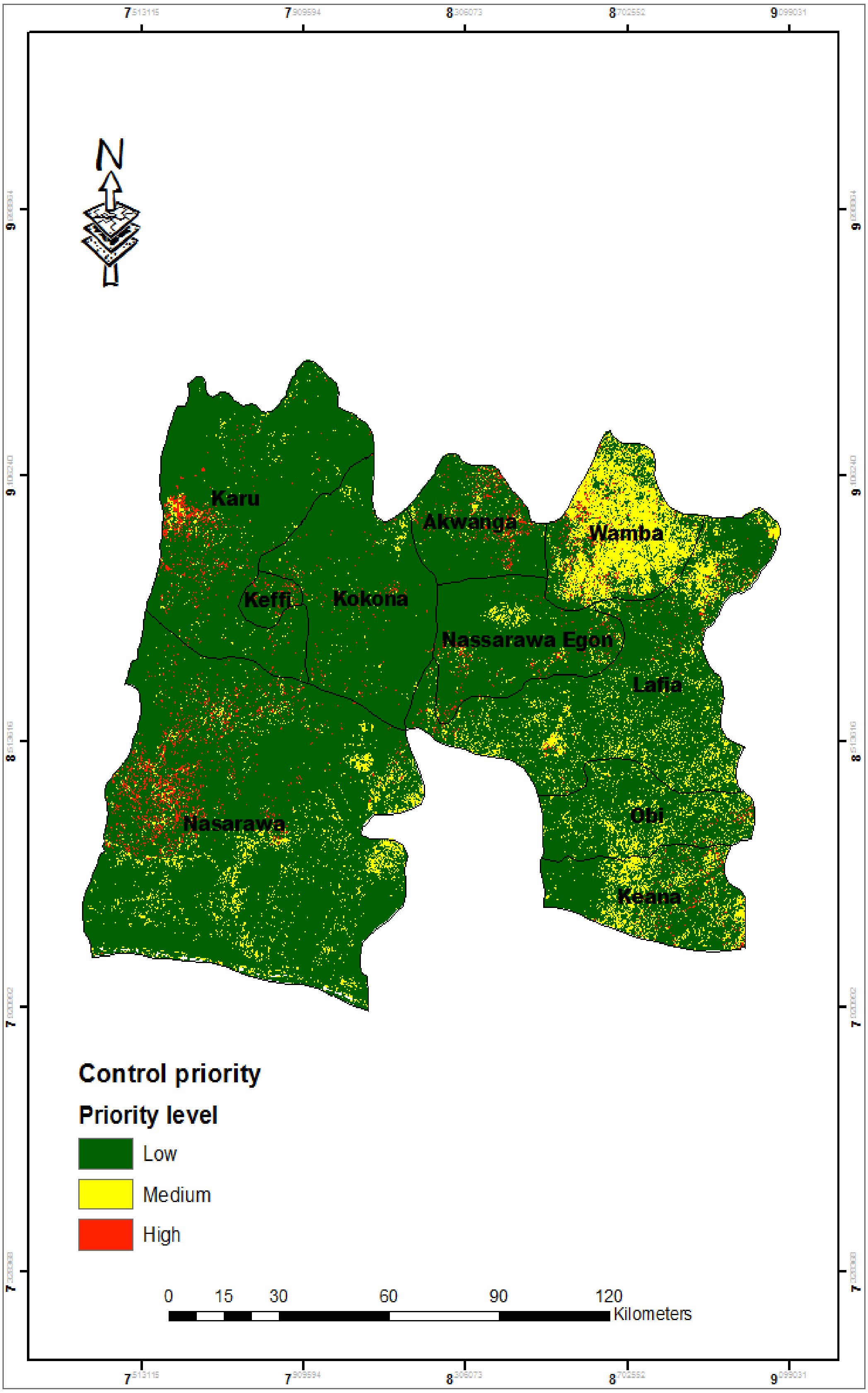

Figure 4.36 Urgent Priority Map for Erosion Control

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

This chapter dealt with the summary, conclusion and recommendations of the study. The aim of the present study was to assess the impact of climate and land use changes on land degradation in Nasarawa State from 1981 to 2014.

5.1 Summary

Nigeria's population growth, technological development, market opportunities associated with change in human behaviour and desire lead to land use/cover distribution change over the country. Also, change in climatic conditions was observed over the country with different impacts on various land resources. These changes contribute to the degradation of the land, especially to soil erosion. Nasarawa State which lies between Latitude 8-9°N and Longitude 7-8°E is concerned with rill and sheet erosion. This is why the current study was aimed at assessing the impact of both climate and land use changes on land degradation, particularly on soil erosion by water with a view to define the soil conservation priorities for the study area. The assessment was done for the time period of 1981 to 2014 with the use of statistical, remote sensing and GIS tools. Several methods were used for data collection and analysis.

For instance, to assess the general pattern and trend of rainfall and temperature, monthly data of rainfall, minimum and maximum temperatures for the period of 1981-2014 were collected from the Lower Benue River Basin Development Authority at Makurdi, Benue State. These data are from Kokona and Doma meteorological stations of Nasarawa State. Statistical analyses such as SPI, TAI, Innovative Trend Analysis, CUSUM test, Sen'slope and Man-kendall rank test (at 5% of significance level) were employed by using the software EXCEL, XLSTAT, MATlab. The results revealed a high variability in the pattern associated with increasing trend of the rainfall and temperature for the two meteorological stations.

Annual rainfall data were used to characterize the flood events and to predict their probable occurrence in the future. Statistical methods were also applied for this purpose and the results revealed that flood events occurred in the study area during the period under study. The flood frequency increased from decade to decade and this will probably continue in the future.

To assess the change in land use and detect degraded area, Landsat images of the years 1986, 1999 and 2015 were freely downloaded from the USGS website. The images were processed and maximum likelihood classifications were done in ENVI 5.1. Seven land use land cover types were identified: forest, shrub land, woodland, agricultural land, water body, settlements and degraded area (bare surface). With the help of ArcMap 10.0, land use land cover map of the three periods were produced and statistics extracted. Change detection statistics were performed in EXCEL 2013. Shrub land and woodland decreased at a high rate whilst agricultural land and settlements increased at a very high rate, thus the study area observed a real change in its land use land cover. Degraded area expanded from 1986 to 2015.

To assess the spatio-temporal change in soil erosion and define the conservation priorities, annual rainfall data for ten meteorological stations were collected, DEM data were downloaded from USGS website, soil map was acquired from RECTAS, soil data were collected through soil survey and laboratory analysis. Global mapper, 3DEM, ArcMap10.0, ArcView 3a were the software used to carry out all the required analyses. RUSLE and multi-criteria rules were the methods employed for the purpose. The results revealed that the study area experienced serious erosion risk and less than 1% of the total area needs not to be managed as far as erosion control is concerned. Wamba, Keana, Karu, Obi, Lafia and Nassarawa are the local government areas of great concern.

5.2 Conclusion

Temperature and rainfall used in this study as climate parameters show significant change in their patterns and trends for the time period under study. The mean temperature over Nasarawa State shows a warming trend due especially to the increase of the minimum temperature at the rate of 0.066°C/year and 0.098°C/year for the southern and northern part of Nasarawa State respectively (0.082°C/year in average). Similarly, the State experienced an increase of rainfall at the average rate of 4.3mm/year (6.39mm/year for the south and 2.3mm/year for the north). From the aforementioned, it is obvious that Nasarawa State experienced the changing in climate for the past 34 years. The increasing trend in rainfall caused flood events in the State for roughly 15 of the past 34 years, and these flood events would probably continue in the future.

Land use/cover changed considerably in the State from 1986 to 2015. Savannah shrub is the most affected losing 26% of its coverage whilst an increase in the coverage of built-up area and agricultural land were observed as result of human activities and population growth. Land use malpractices caused an increase in the coverage of degraded area, especially the complete removal of the natural vegetation from the land surface, exposing the soil to erosion by wind and water. Though the mountainous regions where human access is limited have seen their forest coverage being increased, some spots of forest were completely removed from 1986 to 2015. Therefore, land use land cover of Nasarawa experienced a significant change for the past 34 years that caused or contributed to the degradation of land in Nasarawa State.

Moreover, soil erosion occurred in the study area (less than 1% of the surface area of the study area did not experience erosion) and was changing in time and space in terms of extents and intensities. 51% of the landmass of the study area experienced a significant change in soil erosion rate (32% of decrease and 19% of increase) due to the change in climate and land use pattern and trend. Areas considered as eroded decreased from 81.61% of the total area in 1986 to 78.9 % in 2014, thus, erosion status declined in the study area from 1981 to 2014. In term of soil erosion grade variation, 72.53% of the landmass remains unchanged whilst 27.47% observed change in the grade as direct result of changes in rainfall erosivity and land use/cover. Improvement in soil erosion grade was observed for 15.45% of the area as against 12% of deterioration. Thus, erosion transformation was improved in the recent years in the study area. However, deterioration in soil erosion was observed in all the local governments of the study area and five local governments (Nasarawa, Karu, Wamba, Lafia and Keana) are of most concern.

From the point of view of conservation priorities, less than 1% of the landmass need not to be managed as far as erosion control is concerned, whilst 2% requires urgent action to prevent disastrous and irreversible erosion status. Though erosion status got better in the recent years, it is certain that Nasarawa State has been threatened by a serious rill and sheet erosion phenomenon that could negatively affect the soil productivity, thereby reducing agricultural production in the State. It can be concluded that the inappropriate change in land use associated with a change in climatic condition over Nasarawa State is contributing to land degradation, especially land bareness and soil erosion and this could continue if no real and concrete action is undertaken to prevent or reduce it, especially in some local government areas such as Wamba, Keana, Karu, Obi, Lafia and Nassarawa.

5.3 Recommendations

Based on the outcomes of the present study, the main recommendations are proposed as follows:

- Sustainable land use management (SLUM) should be encouraged and implemented by policy-makers of the State. Sustainable soil and land use planning, adoption of adapted agricultural practices and tree planting (Agroforestry for instance) could be the core pillars for the SLUM in the State.

- Soil erosion control practices should be advocated as best soil and water management that will reduce to some extent the intensity and coverage of harmful erosion phenomenon. This is more urgent for Wamba, Keana, Obi, Karu, Nasarawa and Lafia.

- A scientific study should be conducted to evaluate the spatio-temporal evolution of cropping systems and agricultural practices and their impacts on land degradation with a view to draw up strategies for implementation of climatic and environmental friendly cropping systems and agricultural practices.

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APPENDICES

Appendix A: Homogeneity test (Pettitt's test) for rainfall and temperature data

	Rainfall		**Maximum temperature**		**Minimum temperature**	
	Doma	**Kokona**	**Doma**	**Kokona**	**Doma**	Kokona
K	81.000	81.000	168.000	168.000	238.000	238.000
t	11	11	12	12	18	18
p-value	0.507	0.511	0.07	0.08	0.07	0.01
Alpha	0.05	0.05	0.05	0.05	0.05	0.005
Confidence interval	] 0.494-0.520[	] 0.498-0.524[	] 0.005-0.009[	] 0.005-0.010[	] 0.01-0.019[	] 0.00-0.00 [

(Source: Author's study, 2015)

Appendix B: Normality test for temperature and rainfall time series

	Rainfall		Maximum temperature		Minimum temperature	
	Doma	KOKONA	Doma	KOKONA	Doma	KOKONA
Skewness	0.860	**-0.29**	0.025	**-0.29**	0.061	**-0.22**
Kurtosis	1.134	-0.319	0.029	-0.628	-1.197	-0.471

(Source: Author's study, 2015)

Appendix C: Accuracy assessment of the Maximum likelihood classification of the satellite image of the year 1986

Confusion Matrix: C:\Users\KOSSI\Desktop\Dermier\1986\Maxlike_1986

Overall Accuracy = (5418/5449):99.4311%
Kappa Coefficient = 0.9933

Ground Truth (Percent)

Class	Settlements	Forest	Woodland	Shrub land	Water body
Unclassified	0.00	0.00	0.00	0.00	0.00
Settlements	99.32	0.00	0.00	0.00	0.35
Forest	0.00	98.79	1.00	0.00	0.00
Woodland	0.00	1.10	99.00	0.00	0.00
Shrub land	0.00	0.00	0.00	100.00	0.00
Water body	0.00	0.00	0.00	0.00	99.30
Agricultural	.00	0.00	0.00	0.00	0.35
Bare soil	0.68	0.11	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00

Appendix D: Accuracy assessment of the Maximum likelihood classification of the satellite image of the year 1999

Confusion Matrix: C:\Users\KOSSI\Desktop\Dermier\1999\Maxlike_1999

Overall Accuracy = (6706/6830):98.1845%
Kappa Coefficient = 0.9783

	Ground Truth (Percent)				
Class	Settlements	Forest	Woodland	Shrub land	Water body
Unclassified	0.00	0.00	0.00	0.00	0.00
Settlements	98.45	0.00	0.00	0.00	0.77
Forest	0.00	94.46	3.92	0.00	0.06
Woodland	0.00	5.35	95.99	0.00	0.00
Shrub land	0.00	0.18	0.09	99.92	0.13
Water body	0.00	0.00	0.00	0.00	98.59
Agricultural	0.00	0.00	0.00	0.08	0.19
Bare soil	1.55	0.00	0.00	0.00	0.26
Total	100.00	100.00	100.00	100.00	100.00

Appendix E: Accuracy assessment of the Maximum likelihood classification of the satellite image of the year 2015

Confusion Matrix: C:\Users\KOSSI\Desktop\Dermier\2015\Maxlike_2015

Overall Accuracy = (8184/8244):99.2722%
Kappa Coefficient = 0.9909

	Ground Truth (Percent)				
Class	Settlements	Forest	Woodland	Shrub land	Water body
Unclassified	0.00	0.00	0.00	0.00	0.00
Settlements	98.83	0.00	0.00	0.00	0.39
Forest	0.00	100.00	0.00	0.00	0.00
Woodland	0.00	0.00	99.66	0.00	0.00
Shrub land	0.00	0.00	0.34	100.00	0.00
Water body	0.00	.00	0.00	0.00	99.48
Agricultural	0.07	0.00	0.00	0.00	0.13
Bare soil	1.09	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00

Appendix F: Complementary Meteorological stations used for erosivity interpolation

Station ID	Station Name	Longitude	Latitude	Elevation
07KDN0	KADUNA	7.45	10.06	642
09BCH0	BAUCHI	9.82	10.28	609
17ZR00	ZARIA	7.68	11.13	664
67NG00	ENUGU	7.55	6.47	137
76LKJ0	LOKOJA	6.73	7.08	44
78MKR1	MAKURDI	8.62	7.68	97
95BD00	BIDA	6.02	9.01	143
98JS00	JOS	8.9	9.87	1285

(Source: FAOCLIM2, 2000)