Masters Program in **Geospatial Technologies**

SPATIAL-TEMPORAL ANALYSES OF CLIMATE ELEMENTS, VEGETATION CHARACTERISTICS AND SEA SURFACE TEMPERATURE ANOMALY

A Case Study in Gojam, Ethiopia

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Dissertation submitted in partial fulfilment of the requirements for the Degree of *Master of Science in Geospatial Technologies*

UNIVERSIDADE NOVA
UNIVERSITAT JAUME·I
WESTFÄLISCHE WILHELMS-UNIVERSITÄT MÜNSTER

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February 2012

ACKNOWLEDGEMENTS

First and foremost I would like to express my deep appreciation to the European Union an Erasmus Mundus Program for giving me an opportunity to learn master program in Geospatial Technologies. And also I would like to acknowledge my deepest gratitude to Prof. Dr. Marco Painho for his patience, tireless and excellent stimulating guidance and follow up for the thesis to be finished on time.

I would like to express my deepest gratitude to my supervisor, Prof. Dr. Ana Cristina Costa, for her excellent guidance, caring, patience, and providing me with an excellent atmosphere for doing the thesis. I am equally grateful to my co-supervisors Prof. Dr. Edzer Pebesma, and Prof. Dr. Jorge Mateu for their understanding, guidance and encouragement.

Special thanks goes to Prof. Dr. Marco Painho, Prof. Dr. Werner Kuhn, Dr. Christoph Brox, Prof. Dr. Joaquin Huerta and all concerning person's for providing all the facilities and for executing this master program successfully.

I equally would like to thank all the staff member of UJI, IFGI and ISEGI family. I want to extend my sincere thanks to Caroline Wahle from IFGI, Maria do Carmo and Olivia from ISEGI for their great help during my stay at Germany and Portugal.

I would also like to thank to all staff members of ISEGI library, to all my colleagues in the program, Lumiar Residence family and the whole friendly people of Lisbon, Portugal for their help during the different stage of my thesis work and my stay in Lisbon as a whole.

Lastly, I would like to thank my family and wife, Bethel, for all their love, encouragement and support me in all my pursuits. Many thanks to all.

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ABSTRACT

Agriculture is the backbone of Gojjam economy as it depends on seasonal characteristics of rainfall. This study analyses the components of regional climate variability, especially La Niña or El Niño Southern Oscillation (ENSO) events and their impact on rainfall variability and the growing season normalized difference vegetation index. The temporal and spatial distribution of temperature, precipitation and vegetation cover have been investigated statistically in two agricultural productive seasons for a period of 9 years (2000–2008), using data from 11 meteorological station and MODIS satellite data in Gojam, Ethiopia. The normalized difference vegetation index (NDVI) is widely accepted as a good indicator for providing vegetation properties and associated changes for large scale geographic regions. Investigations indicate that climate variability is persistent particularly in the small rainy season Belg and continues to affect vegetation condition and thus Belg crop production. Statistical correlation analyses shows strong positive correlation between NDVI and rainfall in most years, and negative relationship between temperature and NDVI in both seasons. Although El Niño and La Niña events vary in magnitude in time, ENSO analyses shows that two strong La Niña years and one strong El Niño years. ENSO analyses result shows that its impact to the region rainfall variability is mostly noticeable but it is inconsistent and difficult to predict all the time. The NDVI anomaly patterns approximately agree with the main documented precipitation and temperature anomaly patterns associated with ENSO, but also show additional patterns not related to ENSO. The spatial and temporal analyses of climate elements and NDVI values for the growing season shows that NDVI and rainfall are very unstable and variable during the 9 years period. ENSO /El Niño and La Niña events analyses shows an increase of vegetation coverage during El Niño episodes contrasting to La Niña episodes. Moreover, El Niño years are good for Belg crop production.

KEYWORDS

Climate elements and Variability

La Niña or El Niño Southern Oscillation (ENSO)

Normalize different vegetation indices

Remote sensing

Spatial and temporal

ACRONYMS

Belg= Small rainy season: February, March, April and May in Ethiopia

El Niño=The warm phase of the ENSO, and is sometimes referred to as a Pacific warm episode

ENSO=La Niña / El Niño Southern Oscillation

ERSST= Extended reconstructed sea surface temperature

ITCZ= Inter-tropical Convergences Zone

Kiremt= Main rainy season: June, July, August and September in Ethiopia

La Niña=The cool phase of the ENSO, and is sometimes referred to as a pacific cold episode

MODIS = Moderate Resolution Imaging Spectroradiometer sensor

MVC= maximum value composite

NASA= National Aeronautics and space administration

NDVI=Normalize different vegetation indices

QASDS = Quality Assessment Science Data Set

SST = Sea Surface Temperature

SSTA = Sea Surface Temperature Anomalies

USGS= United States Geological Survey

WMO= World Meteorological Organization

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1 INTRODUCTION

1.1 Motivation and Rational

The interaction between climatic elements, vegetation characteristics and sea surface temperature anomalies are not well defined, and there are differences from region to region all over the world. According to many previous studies, the climate parameters and the normalized difference vegetation index (NDVI) have a positive relation in some region (Nicholson et al., 1990); while, it is negative in other regions depending on geographical position, geomorphology, vegetation type, climatic condition and other factors (Zhong et al., 2010). Vegetation condition is dependent on soil type, moisture of soil and type of vegetation in the region; besides, climatic elements such as temperature, rainfall and sea surface temperature. Among those many factors of vegetation dynamics the climatic elements are very unpredictable and variable in a very short period of time, spatially and temporally. Precipitation is much more variable in both time and space than other climatic factors. All other factors of vegetation dynamics are most likely dependent of climatic factors and they don’t vary temporally in a very short period of time like temperature and rainfall. This spatiotemporal variation of climatic elements has great influence on the vegetation dynamics and seasonal agricultural productivities.

In the Gojam region, Ethiopia, the majority of the population depends on rainfall based agriculture and agricultural related activities for their livelihood. Nowadays, the seasonal rainfall is not coming on time and is decreasing in amount (UNFCCC 2010). Rainfall fluctuation has significant long and short term impacts on natural resources particularly forests, lakes, wetlands and rivers. The Gojam people economy is mainly based on rain-fed agriculture. Regardless of the presence of surface and groundwater resources, the failure of seasonal rains seriously affects the region's agricultural activities that leads to food insecurity and other hardships.

Agriculture is the backbone of Ethiopia’s economy and 85% of the population lives in highlands depending on agriculture and favorable climatic conditions, which limits the productiveness of the area. However, in the present time climate variability has changed and unseasoned rainfall is often observed (Conway et al., 2005). High population growth, deforestation, very traditional agriculture techniques and improper use of land have resulted in massive land degradation with losses of fertile soil. Today, many rural families can barely make their living from agriculture. The basic climatic elements such as rainfall and temperature show seasonal or annual fluctuations somewhat different from normal expected climatic conditions, which are very important to agriculture productivity in the area. Ethiopians are facing the consequences of rapid deforestation and degradation of land resources. The increasing of population has resulted in extensive forest clearing; for agricultural use, overgrazing, and exploitation of existing forests, for fuel wood, fodder, and construction materials (Bishaw 2001). Understanding the impact of vegetation dynamics to climate variability and response of vegetation on climate variability at the inter-annual to decadal time scales are desirable.

The El Niño and La Niña events result from the tropical pacific Surface Ocean and atmospheric interaction in the tropics. Although El Niño originates in the Eastern Pacific, its warming effect is rapidly spread by the winds that blow across the ocean altering the weather patterns in more than 60 percent of the planet's surface (Kandji et al., 2006). Some of the major disasters associated with El Niño events include floods, droughts, heavy snowfalls, devastating effects in fish industry and frosts. El Niño and La Niña have positive or negative influence in the timely coming of rainfall. Therefore, the rainy season in Gojam, Ethiopia, depends on El Niño and La Niña events occurring in the tropical Pacific Ocean; besides, the Indian, and Atlantic oceans and other factors. Analyzing El Niño/La Niña-Southern Oscillation ENSO episodes together with other climatic parameters would be helpful for agriculture management. The El Niño and La Niña event are the main causes of Ethiopian climate variability, including the Gojam region. Changes are rapidly occurring in earth surface relating to climate variability and vegetation conditions. Therefore, understanding the interaction between climate elements and vegetation condition in response to climate variability and change in global or regional scales would have great scientific importance. Geostatistics and remote sensing could be helpful for analyzing the El Niño and La Niña events together with other climatic elements and vegetation responses.

Most African country vegetation responds more dynamically to early season rains (Funk and Brown, 2006). The process of one region getting rainfall, particularly in Africa is very complicated and dependent on many things, but mainly on tropical oceans heating and cooling system and its interaction with the earth system. Climate variability is the most important cause of food insecurity in the major part of Africa (Kandji et al., 2006). The El Niño episode had been the cause for crop production deficit relationship to December–January rainfall shortages and February–March NDVI decreases in Zimbabwe (Funk and Budde, 2009).

According to the World Meteorological Organization (WMO, 2011), climate variability represents variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. The term is often used to denote deviations of climatic statistics over a given period of time (e.g. a month, season or year) from the long-term statistics relating to the corresponding calendar period. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Changes in land and vegetation surface can influence the climate; on the other hand, the world's vegetation distribution is largely determined by climate (Woodward 1987). Climate induced variability in semiarid vegetation is a matter of both ecological interest and economical concern, as strong sensitivity in climate can result in rapid land use change (Vanacker et al., 2005; Zaitchik et al., 2007; Klein and Röhrig, 2006). Climate variability is one of the most important factors affecting vegetation condition. Remote sensing plays an important role to monitor and characterize vegetation dynamics that affected by climate variability.

The satellite based vegetation index derivation is one of the research approaches to assess vegetation dynamics and climate change of the earth's surface (Kulawardhana, 2008; Ahl et al., 2006). However, persistent problems limit its full acceptance in ecological research. It can be somewhat difficult to know exactly what vegetation index is more adequate depending on spatial scale. Different studies suggest that it correlates well with leaf area index, green leaf biomass and annual net primary productivity (Ahl et al., 2006; Viña, 2004). In the smaller spatial scales, the vegetation index is partly associated with soil properties, rooting depth and vegetation types. Moreover, little is known quantitatively, regarding the degree to which the spatial variation of the vegetation index depends on rainfall seasonality in tropical rainforest at regional scale (Barbosa and Lakshmi Kumar, 2011). Geo-statistically based spatial and temporal analyses of NDVI and other related climatic parameters would be helpful to understand how they would be related to each other in the area and to make predictions of a parameter based on the signal of another one.

1.2 **Objectives**

The main objective of this study is to analyze time series of seasonal, monthly and yearly NDVI vegetation indices, climatic elements for short and long rainy seasons (Belg and Kiremt) and Sea surface temperature (SST) anomalies, which is the main cause of climate variability in Gojjam, Ethiopia. Belg has a short and moderate rainy season from February to May and Kiremt has the main rainy season from June to September, which is related to the revenue of agricultural activities. It is clear that statistical analyses of climatic elements and vegetation characteristics would help to assess crop production and the vegetation cover in Gojam, Ethiopia.

This study also aims at investigating the statistical relationship between climate parameters, normalized difference vegetation indices (NDVI) and Sea surface temperature anomalies. The analyses will be based on time series of vegetation Indices, ENSO and climatic elements for nine years (2000–2008) and also aims to predict vegetation condition and agricultural products. The study will also assess the ENSO impacts on the spatial and temporal distribution of rainfall and vegetation in Gojam, Ethiopian.

To achieve those study objectives spatial interpolation of climatic elements and NDVI analyses will be performed. Unpredictable and very variable atmospheric circulation patterns, lack of complete data and different topography are some of the limitations that the study will have to face for getting accurate gridded data for climate variability and vegetation dynamics analyses in Ethiopian high land, particularly Gojam.

1.3 Assumptions

It is known that climate change or variability is result of spatial and temporal interaction of climatic parameters with vegetation and other earth-atmosphere component systems. Nowadays, geostatistics are used to explore and describe spatial variation in remotely sensed and ground data; to design optimum sampling schemes for image data and ground data; and to increase the accuracy with which remotely sensed data can be used to classify land cover or to estimate a continuous variable. There is clear rapidly changing of vegetation cover in the earth surface and a seasonal variation of climatic elements in Gojam, Ethiopia, which results food insecurity, increasing carbon fluxes into the atmosphere, drought etc.

Accordingly, the following assumptions are considered:

I-) It is possible to collect different datasets from different sources such as surface temperature, rainfall, sea surface temperature and NDVI, and these elements have some statistical relationship between them.

II-) Geostatistical interpolation techniques are valuable tools for spatial interpolation of the attributes considered and provide important dataset relationship information to agricultural sector and other risks.

III-) The statistical relationship between the climatic parameters and NDVI may be linear, exponential or another types

1.4 General Methodology

Two general approaches of vegetation condition and climatic element analyses will be considered, namely spatiotemporal statistical analyses and spatial modeling.

1.5 Organization of the thesis

The thesis is organized in to six chapters. Chapter one contains introduction of the thesis which explains about the motivation and rational, objectives, assumptions and organization of the study. Chapter two provides Literatures review related to spatial and temporal variation of climatic elements and vegetation characteristic, overview of vegetation distribution and characteristics in relation to climatic elements basically temperature and rainfall in regional and global scale. Chapter three explores the study area particularly land use /land cover and its consequences to the society and ecological balance of the environment, vegetation characteristics and climatic regions. Chapter four explains about materials and methods used for the study, basic climatic elements that is temperature and rainfall, equatorial pacific sea surface temperature anomalies from different NINO station and MODIS 250m NDVI satellite imagery used. This chapter deals with visual interpretation spatiotemporal vegetation conditions and climatic elements. Chapter five provides spatial and temporal analyses of data and interpretation of results and discussion. Finally, Chapter six is a conclusion chapter which provides a brief insight on the vegetation characteristics and climatic elements as well as conclusion and recommendations.

2 LITERATURE REVIEW

2.1 Changes in land use and land cover pattern

In addition to other anthropogenic factors, land-use and land-cover are linked to climate, vegetation and weather in complex ways. Land use/cove change plays an important role in global environmental change. Land cover refers to the physical and biological cover over the surface of land including water, vegetation, bare soil, and/or artificial structures (Shrestha 2008). Land use is a more complicated term. Land use is the action of human activities on their environment such as agriculture, forestry and building construction that alter land surface processes including biogeochemistry, hydrology and biodiversity (Shrestha 2008). In the other hand, according to (ISO, 1996) land degradation is no longer able to sustain properly an economic function and/or the original natural ecological function due to natural processes or human activities (Shrestha 2008, Choudhury and Jansen, 1998). Terrestrial ecosystem is being exposed to the threats of increased climate variability and change causing increased intensity of drought and flood events. Remote sensing and geographical information systems plays an important role in the analyses of land use and land cover change at large scales of earth surface.

The land use and land cover patterns of a region are an outcome of natural and socio–economic factors and of their utilization by man in time and space (Zubair 2006). Driving forces, also referred to as factors, can be categorized as natural and human induced. In the study area, the natural factor may be mostly meteorological or geological phenomena's like intense rainfall, earthquake, steep relief, soil type and climate change. Deforestation, immense agricultural and demographic pressure, as well as plough of grass or bush land caused by the population increase are also human factors. In the last few decades, conversion of grassland, woodland and forest into cropland and pasture has risen dramatically in the tropics (Shiferaw 2011). A significant increase in cultivated land instead of forestland was found to have occurred between 1957 and 1995 in Gojjam (Zeleke 2000, cited in Shiferaw 2011). The most important changes were destruction of the natural vegetation, increased farms, and expansion of grazing land. Vegetation covers as well as crop production shows much variability across the globe depending on the types of crop, the vegetation and the region (Kulawardhana 2008). Vegetation cover on the earth's surface is rapidly changing, and changes are observed in phenology and diversity with respect to distribution of vegetation on the earth's surface.

Even though NDVI vegetation cover analyses doesn't directly show crop production many studies state that there is also a decrease of crop production related to land use/land cover change and climate variability (Crawford 2001). Land use change and increasing of greenhouse gas are two of the most interrelated factors with climate change and variability. They both tend to produce surface warming so that their impact to global ecosystem and society is too hard to resist. Many studies indicated that analyzing and modeling of spatial-temporal features of land use/land cover change either globally or regionally is significantly important for better understanding environmental management for sustainable development(Nellemann et al., 2009; Shiferaw, 2011). According to Nellemann et al. (2009) past soil erosion in Africa might have generated yield reductions from 2-40 percent, compared to a global average of 1-8 percent.

Different studies indicate that vegetation condition could affect and change the climatic zones of Africa; that is, changes in vegetation result in alteration of surface properties and the efficiency of ecosystem exchange of water, energy and CO2 with the atmosphere (Nellemann et al., 2009). According to WMO and IPCC among the regions of the world, Sub-Saharan Africa has the highest rate of land degradation (WMO 2005). Some of the counties that have the worst rate of degradation are (Bwalya 2009 cited in TerrAfrica, 2009): Rwanda and Burundi (57 %), Burkina Faso (38 %), Lesotho (32 %), Madagascar (31 %), Togo and Nigeria (28 %), Niger and South Africa (27 %) and Ethiopia (25 %). Land degradation in sub-Saharan Africa is caused mainly by conversion of forests, woodlands and rangelands to crop production; overgrazing of rangelands; and unsustainable agricultural practices on croplands.

Sub-Saharan Africa is expected to face the largest challenges regarding food security as a result of climate change and other drivers of global change (Easterling et al 2007). Many farmers in Africa are likely to experience net revenue losses as a result of climate change, particularly as a result of increased variability and extreme events. According to (Fischer et al 2005) most climate model scenarios agree that Sudan, Nigeria, Senegal, Mali, Burkina Faso, Somalia, Ethiopia, Zimbabwe, Chad, Sierra Leone, Angola, Mozambique and Niger are likely to lose cereal production potential by the 2080s.

2.2 Global Characteristics of Climate and Vegetation

A simple visual comparison of climate and vegetation on a global scale immediately reveals a strong correlation between climatic and vegetation zones: the moist tropics are associated with tropical forest, the dry subtropics with subtropical deserts, regions of temperate climate with temperate/boreal forests, and polar regions with tundra/polar desert (Brovkin 2002). Alexander von Humbolt was among first geographers to analyses climate-vegetation relationships on a global scale and investigates links between climate and vegetation changes in the past (Brovkin 2002). Although climate–vegetation relationships are very important the mechanism that interconnect the two is not completely understand (Brovkin 2002). Climate in the given context defined as a seasonal course of solar radiation, temperature, precipitation, and primarily determines the predominant type of terrestrial vegetation (e.g., broadleaved forest, grassland) and the biogeochemical properties of the land surface (e.g., CO2 flux, carbon storage in biomass and soil).

Many studies show that climate has changed with varying levels at different regions across the world for the last few decades due to human influence on nature and natural by itself (Solomon et al., 2007; Hulme et al., 1999; Houghton, 1996). Climate affects society and nature in many different ways. On the other hand, climate can be affected by geographical position of region which affects the distribution of plants and animals, the industries activities of man and natural events (Elhag 2006). It is the main cause of migration for human, animal and it also affects man's health and energy levels. Changes in different climatic parameters could affect and influence vegetation cover at varying levels so that equal attention has to be paid on vegetation dynamics and climatic elements. More importantly, the relationships that could exist among these interrelated components have to be identified in order to make accurate and realistic predictions on the changing conditions of the vegetation or climatic parameters. This can also arrange for making safety measures for minimizing the potential risks associated with such changing conditions of climate as well as the ecosystems.

2.2.1 **Global Climate characteristics**

Climate is described in terms of the variability of relevant atmospheric variables such as temperature, precipitation, wind, snowfall, humidity, clouds, including extreme or occasional ones, over a long period in a particular region. The classical period for performing the statistics used to define climate corresponds to at least 3 decades, and it is designated by "climate normal period", as defined by the World Meteorological Organization (WMO). As a consequence, the 30-year period proposed by the WMO should be considered more as an indicator than a norm that must be followed in all cases. This definition of the climate as representative of conditions over several decades should, of course, not mask the fact that climate can change rapidly. Climate can thus be viewed as a synthesis or aggregate of weather in a particular area and for a long time (Goosse et al., 2010). This includes the region's general pattern of weather conditions, seasons and weather extremes like hurricanes, droughts, or rainy periods. Two of the most important factors determining an area's climate are air temperature and precipitation (Goosse et al., 2010).

We must also take into account the fact that the state of the atmosphere used in the definition of the climate given above is influenced by numerous processes involving not only the atmosphere but also the ocean, the sea ice, the vegetation, etc. Climate is thus now more and more frequently defined in a wider sense as the statistical description of the climate system (Goosse et al., 2010). This includes the analyses of the behavior of its five major components: the atmosphere; the gaseous envelope surrounding the Earth, the hydrosphere; liquid water, i.e. ocean, lakes, underground water, etc., the cryosphere; solid water, i.e. sea ice, glaciers, ice sheets, etc., the land surface and the biosphere (all the living organisms) and of the interactions between them (Solomon et al., 2007).

Pidwirny (2006) lists the factors that affect climate:

- The location on the earth
- Local land features like mountains
- The type and amount of plants like forest or grassland
- The altitude
- Latitude and its influence on solar radiation received
- Variations in the Earth's orbital characteristics
- Volcanic eruptions
- The nearness of large bodies of water
- prevailing winds
- Human activities like burning fossil fuel, farming or cutting down forest etc.

The climate of a region will determine what plants will grow there, and what animals will inhabit it. World's biomass is controlled by climate condition

2.2.1.1 Climate Classification System

Climate incorporates the statistics of temperature, humidity, atmospheric pressure, wind, rainfall, atmospheric particle and other meteorological measurements in a given region over long periods. So that there are different types of climate classification systems depending on the climatic element used. The most widely used is Köppen Climate Classification System (Pidwirny 2006). Its classification is based on the annual and monthly averages of temperature and precipitation characteristics, but of setting limits and boundaries fitted into known vegetation and soil distributions were actually carried out in 1918.

According to Pidwirny (2006), the Köppen system recognizes five major climate types (Figure 1). Climate group A, corresponds to Moist Tropical Climates that extend northward and southward from the equator to about 15 to 25° of latitude. In this type of climate all months should have average temperatures greater than 18° Celsius and annual precipitation should be greater than 1500 mm. Based on the seasonal distribution of rainfall there are three minor climate types under climate group A: tropical wet, tropical monsoon, and tropical wet and dry; similarly, latitude extent, subgroup climate type, temperature and the amount of rainfall would define the other climate groups. B-Dry Climates have deficient precipitation during most of the year when potential evaporation and transpiration exceed precipitation; C-Humid Middle Latitude Climates has warm and humid summers with mild winter; D-Continental Climates have warm to cool summers, cold winters and the average temperature of the warmest month is greater than 10° Celsius, while the coldest month is less than -3° Celsius. Finally, E-Cold Climates have year-round cold temperatures with the warmest month less than 10° Celsius and vegetation is dominated by mosses, lichens, dwarf trees and scattered woody shrubs.

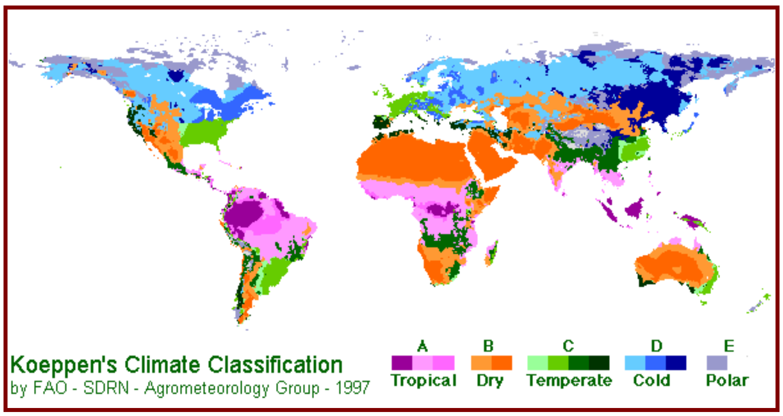

Figure 1 Global Koeppen Climate Classification

Source: Benders-Hyde (2010; accessed October 12, 2011)

2.2.2 Global vegetation characteristics

Vegetation is a general term for the plant life of a region; it refers to the ground cover provided by plants, and vegetation dynamics corresponds to changes in species composition and/or vegetation structure in all temporal and spatial possible extent. The geographical distribution (and productivity) of the various biomes (Figure 2) is controlled primarily by the climatic variables precipitation and temperature (Pidwirny 2006). Green biomass covers nearly three fourths of the earth’s land surface but huge variety could be observed from past experienced in their characteristics which are attributed to the changing conditions of climatic as well as geo-morphological characteristics over the earth surface (Kulawardhana 2008).

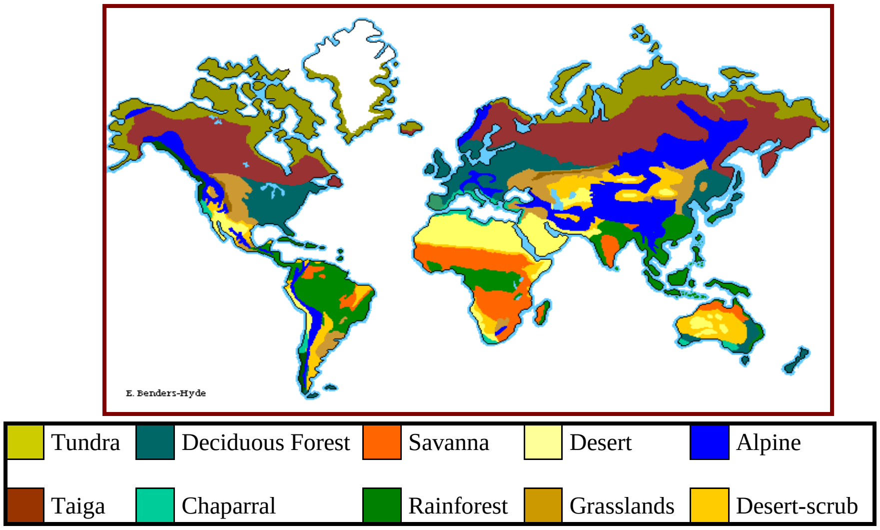

Figure 2 Global vegetation type

Source: Benders-Hyde (2010; Accessed 12 October 2011)

Kulawardhana (2008), describes the main characteristics of each biome as follows: The temperature in a rain forest rarely gets higher than 93 °F (34 °C) or drops below 68 °F (20 °C); average humidity is between 77 and 88%; rainfall is often more than 100 inches a year. while in a deciduous forest the average annual temperature is 50° F and the average rainfall is 30 to 60 inches a year. The climate in grasslands is humid and moist. The savannas are rolling grasslands scattered with shrubs and isolated trees, which can be found between a tropical rainforest and desert biome. Savannas have warm temperature year round. Alpine biomes are found in the mountain regions all around the world. In the Alpine biomes average temperatures in summer range from 10 to 15° C and it goes below freezing in winter. The tundra is the world's coldest biomes with an average annual temperatures of about -70°F (-56°C).

2.3 Relationship between temperature, rainfall and vegetation dynamics

According to an IPCC report (Solomon et al., 2007) due to the increasing of average surface temperature by (about 0.6±0.2°C since the late 19th century, and about 0.2 to 0.3°C over the past 25 years) and reduction of rainfall, a lot of species have been devastated from the planet earth. Additionally, variation of crop production, more frequent and prolonged drought and expanding desertification are being experienced in the Sahel Savanna regions (Chima et al 2011). Appropriate temperature and rainfall are the basics for plants to their development and growth, thus that vegetation as a whole will likely respond to changes in these elements. Rainfall plays crucial role in the vegetation growing cycle and determining factor for agriculture and food security both in semi-humid west and semi-arid east part of Africa (Klein and Röhrig, 2006). So that, detailed understanding of the relationship between rainfall variability and vegetation dynamics is very important.

The relationship between climatic parameters like sea surface temperature, land surface temperature, rainfall and vegetation characteristics vary at different regions across the world. These climatic elements are the main ingredients for plant /vegetation growth in different ecosystems like grassland or cropland. The relationship between rainfall and vegetation is pronounced particularly in Africa. A belt of seasonal rain encircles the globe near the Equator. In June, July, and August, when the rains move north of the equator, Africa's Sahel region (a grassland-savanna landscape south of the Sahara Desert) is dark green, alive with growing plants. As the rain moves south in September, the vegetation also follows. Most of the studies conclude that precipitation is a strong predictor of spatial vegetation patterns. NDVI and precipitation typically co-vary in the same direction (either positive or negative). The atmosphere and the ocean are intimately connected. Ocean temperatures influence rainfall patterns throughout the world, so when ocean temperatures change, rainfall patterns tend to change as well. Scientists monitor changes in ocean temperatures, looking for warmer or cooler than average waters, to predict floods or droughts. Vegetation variability is also strongly related to variations in surface temperature, sea surface temperature and rainfall.

2.4 Global climate variability and vegetation dynamics

Climate variability means the fluctuation between the normally experienced climate conditions and a different or unusual fluctuation of climatic elements in an area, but recurrent, set of the climate conditions over a given region of the world (Solomon et al., 2007). And also refers to a shift in climate, occurring as a result of natural and/or human interference (Elhag 2006). Vegetation distribution is clearly related with climate variability based on “Biosphere feedback theory” which is the interaction between biosphere and atmosphere (Elhag 2006). The reduction or destruction of vegetation cover would increase surface runoff, albedo of the surface (reduce surface absorbing solar energy), reduce soil moisture and others can cause the fluctuation of climatic elements the leads climate variability**.** Climate variability and climate change contribute to the vulnerability via economic loss, hunger, famine and relocation in Africa (Elhag 2006). And in this area since the area’s economy mainly based on agriculture precipitation is much more variable in both time and space than other climate factors. The temporal and/or spatial sensitivity of vegetation dynamics to climate variability will be used to characterize the quantitative relationship between these two quantities in temporal and/or spatial scales.

Climate variability has strong impact on natural resource, vegetation etc. particularly in the areas where they have weak balance between climate and ecosystem like the Sahelian or parts of the Mediterranean region (Elhag and Walker, 2009). Seasonal rainfall is the most important climatic factor influencing livelihoods in the region. All people and their livestock depend on the amount of seasonal rainfall that falls and supports plant growth. Climatic factors such as rainfall and surface temperature determine the availability of moisture for physical, biological and chemical activities occur in plants. Climatic factors can change vegetation growth depending on the levels of water, soil moisture and heat stress for which the vegetation is exposed (Houghton. 2001, cited in Kulawardhana 2008). In such regions it is possible to find a significance statistical relationship between the amount of seasonal rainfall and vegetation cover. Vegetation is a very sensitive part of the ecosystem for climate change. Both the growing season and the total amount of vegetation, together called the vegetation dynamics, are strongly affected by climatic change (Roerink et al., 2003).

2.5 General interactions between the ocean, atmosphere, earth and climate variability

The most well understood occurrence of climate variability is the naturally occurring phenomenon known as the El Niño-Southern Oscillation (ENSO), which results from an interaction between the ocean and the atmosphere over the tropical Pacific Ocean that has important consequences for weather around the globe, particularly in the tropics (NOAA, 2011). The ENSO cycle is characterized by coherent and strong variations in sea-surface temperatures, rainfall, air pressure, and atmospheric circulation across the equatorial Pacific. Sun is a driving force for weather and climate. Rainfall is the primary climatic element that affects the vegetation dynamics in the most part of Africa including Gojam. The El Nino-southern oscillation (ENSO) phenomenon, resulting from the interaction between the surface of the ocean and the atmosphere in the tropical Pacific. ENSO profoundly affects climatic variability in parts of sub-Saharan Africa, including the Sahel, Ethiopia, equatorial eastern Africa and southern Africa, where strong and persistent ENSO events create unique and persistent anomaly patterns in rainfall (Ogutu et al., 2008). The impacts of El Niño on eastern and southern African rainfall exhibit specific spatial-temporal patterns depending on the space-time evolution of each individual ENSO event.

The uneven heating of Earth’s surface (being greater nearer the equator) causes great convection flows in both the atmosphere and oceans, and is thus a major cause of winds and ocean currents. Climate change or variability arises largely from changes to the earth’s heat balance. Many factors can influence this both natural processes and anthropogenic. The oceans influence climate by absorbing solar radiation and releasing heat spatially and temporally needed to drive the atmospheric circulation, by releasing aerosols that influence cloud cover, by emitting most of the water that falls on land as rain, by absorbing carbon dioxide from the atmosphere and storing it for years to millions of years. Climate variability can cause considerable fluctuations in crop yields and productivity. Besides this, the day to day variation of weather and climate, which manifest themselves in the form of hurricanes and typhoons, floods and dry spells often leads to mass displacement of populations and causes damage to food production systems, resulting in food shortages and famine**.**

Numerous efforts (e.g., remote sensing, geostatistics, field experiments etc.) have been made to study land-atmosphere and ocean, but the heterogeneity of land surface properties and the chaotic nature of the atmosphere hamper our understanding of land-atmosphere interaction (Wei et al., 2006). The earth physical climate system and biosphere coexist with thin spherical shell, extending from the deep oceans to the upper atmosphere, that driven by energy from the sun (Foley et al., 1998). The resulting interaction between atmosphere, ocean and terrestrial ecosystems give rise to biogeochemical, hydrological, and climate systems that supports life on this planet. The earth climate is: - partially controlled by fluxes of energy, water and momentum across troposphere. The exchange of energy over the ocean and exchange of water amount with atmosphere primary depending on sea surface temperature. Whereas the flux over the land depends up-on the state of vegetation cover, soil and others (Foley et al., 1998). The surface energy loss cools the land surface, and the net energy gain makes the eastern tropical Pacific warmer. At this point, one could assign the changes in ENSO variability and the mean state of tropical climate to an unexpected energy budget difference over land. It is clear that tropical land cooling and associated atmosphere coupling and/or the alteration of the mean state of the coupled model reduce the amplitude of the surface temperature variability over both the ocean and land.

2.6 Analyses of vegetation dynamics and climate variability using remote sensing

Vegetation has different reflective properties from other land- cover categories. Different vegetation types have different reflective properties than the rest of objects in the earth surface. Due to reflectance, remote sensing made possible to identify vegetation abundance. The integration of satellite remote sensing and GIS was an effective approach for analyzing the direction, rate, and spatial pattern of land use change. Remote sensing techniques provide the most effective method for land-cover and land-use data acquisition, analyzing and monitoring of vegetation (Elhag and

Walker, 2009). Satellite data has become used to relate vegetation indices to climatic parameters, and to provide quantitative description of vegetation growth (Roerink et al., 2003). According to Lambin et al. (2001), Normalize vegetation indices (NDVI) is widely used to analysis vegetation status, health, monitoring of land cover change and land degradation, crop growth monitoring and yield forecasting. The NDVI value, which is derived from visible red and near infrared bands of the satellite images, is being used extensively in studying the vegetation dynamics. Satellite remote sensing data is very sensitive to the presence of vegetation in land surface and can be used to address type, amount, and condition of vegetation. The NDVI values range from -1.0 to 1.0. Places with vegetative cover have values greater than zero and negative values indicate non vegetated surface features such as water, bare soil or the presence of clouds.

Many studies using the NDVI, derived from NOAA⁄AVHRR (advanced very high-resolution radiometer) satellites or MODIS, indicate that in the Sahel zone (including Ethiopia), rainfall, vegetation cover and biomass have direct relationship to each other. However, the relation may vary in terms of their prediction strength and amount of error (standard error or standard deviation), slope and y-axis intercept (Elhag and Walker, 2009). Since vegetation does not respond immediately to precipitation there is a NDVI lag after the occurrence of rainfall that may be up to 3 months. The lag time depending on the climatic zone (being shorter in dry regions than in humid regions) and environmental factors; such as soil type, soil water holding capacity, vegetation type, among others (Chikoore 2005)**.**

In summary, many studies have been carried out for identifying the relationships that could exist among different climatic variables and the vegetation characteristics. These relationships could vary at different regions across the world. However, the findings of the past studies for establishing relationships between vegetation parameters and climatic variables have shown a considerable degree of variability over different temporal and spatial scales. Therefore, it is necessary to establish these relationships locally or regionally depending on their levels of spatial and temporal variability.

2.7 **Geostatistics methods**

Sample data can provide valuable information but due to many constraints it is difficult to get the whole region sample data. So that, geostatistics model predicts the value in unsampled location and quantify the uncertainty of prediction. Meteorological stations are located in sparse and in the places which are often not of interest for different human activity. The value of climate elements cannot be measure in all point of the region but only in sample points. Spatial interpolation may be used to estimate the values in such areas where there is not measurement (Yang et al., 2004). Many research works show the importance of interpolating values of climate variables from stations to large areas (Kurtzman and Kadmon, 1999; van der Heijden and Haberlandt, 2010).

Spatial interpolation can be used to estimate climatological variables at other locations. Although there are several methods to perform this, it can be difficult to determine which one best reproduces actual condition. Each method has advantages and disadvantages depend strongly on the characteristics of the data set: a method that fits well with some data can be unsuitable for a different set of data. Thus, criteria must be found to decide whether the method chosen is suited for the temperature or precipitation data set.

Commonly used interpolation methods in ArcGIS may be either deterministic or stochastic. Deterministic methods don’t use probability theory (e.g. proximal) or on indication of extent of possible errors, whereas stochastic methods provide probabilistic estimate or incorporate the concept of randomness. Spline and Inverse Distance Weighting (IDW) are assessed as deterministic interpolation methods, whereas Kriging is stochastic, which mostly used in ArcGIS (Burrough and McDonnell, 1998). Moreover, Spline and Inverse Distance Weighting (IDW) are exact type of deterministic interpolation methods and Kriging is exact type of stochastic interpolation methods. In exact methods the Local neighborhood search approach generates a surface that passes through its control points. In the other hand, approximate methods the global search approach predicts a value that differs from its known value .

Inverse distance weight (IDW) assigns a default rate of change (power value) that is regularly utilized for interpolation. A common fatal error of GIS analysts is the assumption that spatial dependence is uniform among different variables. Assuming that spatial autocorrelation is spatially constant, as well as constant between two different variables decreases reliability. Kriging provides a more reliable interpolation because it examines specific sample points to obtain a value for spatial autocorrelation that is only used for estimating around that particular point; rather than assigning a universal distance power value. Furthermore, Kriging allows for interpolated cells to exceed the boundaries of the sample range (Chehayeb 2011). Kriging methods are successful in the spatial interpolation of meteorological elements such as temperature, rainfall (Zhou et al., 2005). Geostatistical interpolation (e.g., kriging) is one of the best estimation approach of weather conditions at unsampled locations in which the region is large and limited low density of base stations where the distribution of the station unrepresentative of topographic variability and geographic features (Hunter and Meentemeyer, 2005).

2.8 Literature review summary

This section provides a summary of the most relevant studies related to the topic of this work .

Reference	Summary	Relevance
Nicholson et al. (1990)	The spatial pattern of annual integrated NDVI closely reflects the mean annual rainfall and they are strongly related in East Africa. The relationship between mean rainfall and NDVI may be log- linear or exponential but sometimes they have linear correlation when mean rainfall greater then 1000mm.	They explain vegetation response is strongly dependent on amount rainfall in the Sahel. The study area includes my study area. Scatter plot was used to analyses the correlation.
Zhong et al. (2010)	Different type of Vegetation requires optimal amount of temperature and rainfall to grow up. Depends on type of vegetation or climatic condition NDVI strongly correlated with either with temperature or rainfall	Pearson correlation coefficients used to analyses the correlation. If the annual mean temperature and rain fall less than 1.65.C and 80.5 mm respectively the vegetation hardly grew and limited.
Bai et al. (2005)	Quantitative assessment of land degradation, environment problem and improvement	For general quantitative assessment of biomass, vegetation condition of study area
Ahl et al. (2006)	Climate change or variability predicted to alter vegetation phenology using remote sensing .	MOD13Q1 250m spatial resolution NDVI and other indices is used to analyses vegetation condition.
Elhag and Walker (2009)	African rainfall has changed substantially over the last 60 years; this change has been notable as rainfall during 1961-1990 declined by up to 30% compared with 1931-1960.	Inverse Distance Weighting was used to interpolate temperature and rainfall
Yang et al. (2004)	Different interpolation methods are used to interpolate temperature and rainfall climate data. Climate data is sparsely located so that it is very important to	From the comparison of Statistics of RMSE in Cross Validation of land surface temperature Interpolation Used cokiriging interpolation was the better one.

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Continued

	choose the appropriate interpolation method .	
Zhou et al. (2005)	Spatial temporal variation of rainfall for long time using statistical and geostastical methods .	Kriging methods is successful in the spatial interpolation of meteorological elements.
Ogutu et al. (2008)	Spatiotemporal analyses of climatic elements and ENSO. How tropical pacific ocean circulations affect the rainfall variability of east of Africa	It explains how ENSO affects the rainfall variability of the region and then the rainfall influence to the vegetation dynamics.
NOAA (2010)	Recently updated ENSO/La Niño and El Niño years From NOAA	It is important to compare my result ENSO/La Niño and El Niño years to NOAA result and it is the same .

Table 1 Literature review summary

3 STUDY AREA

3.1 Description of the study area

Gojam is located in the northwestern part of Ethiopia, in East Africa, under Amhara region between 10°58'20.09"N and 37°29'23.68"E. It covers an area of about 28,076 km2 and a population of 4,260,394 (Statistical Agency 2007). This region is distinctive for lying entirely within the bend of the River Gihon (Blue Nile) from its outflow from Lake Tana to and other some part of Ethiopian than to Sudan (Figure 3). The Region shares boundaries with Gonder in the North, Wolo in the East, Awi in the West, Welega, Addis Abebe and Shewa in the South. Depending on the administrative division of the country the region Gojam categorize in to two zones eastern and western Gojam (Figure 7)

From digital elevation model of the region the elevation ranges from the lowest 639m in every border of the region to the highest 4038m in the center. The topography of Gojam divided in to two parts, namely the highlands and lowlands. The highlands are above 1,800 meters above sea level and comprise the largest part of the central, southeastern and southwestern part of region. From most rugged largest continuous chains of mountains and plateaus land mass of its altitude like choke (4038m) in the southeast regions with little of its surface falling below 1800 m in every border of the region (Figure 4).

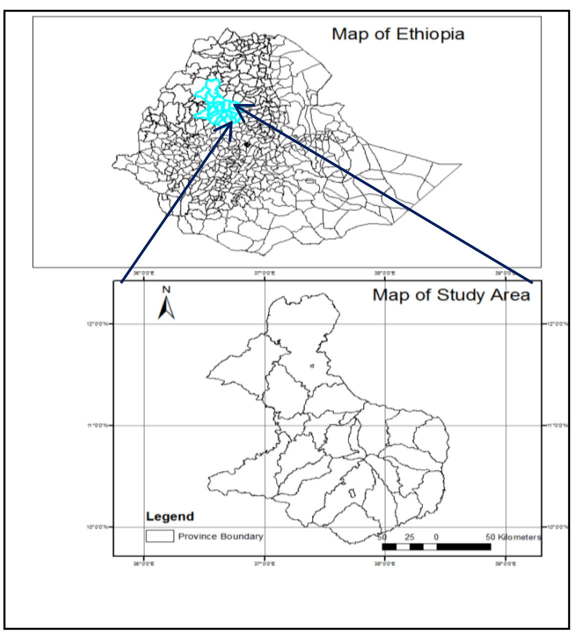


Figure 3 Location of the study area

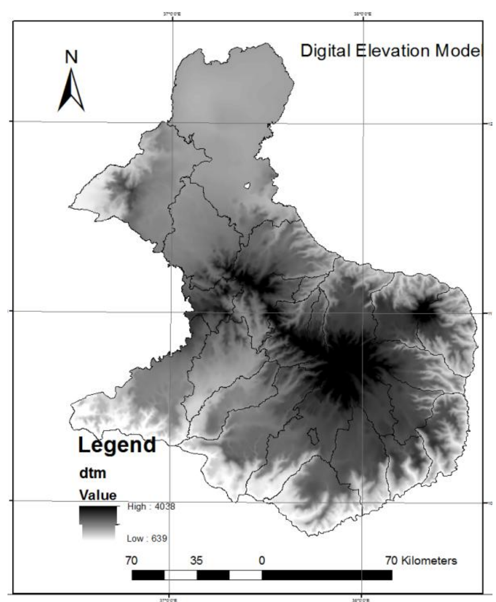


Figure 4 Digital Elevation Model of the study area

3.1.1 **Land use and land cover of Gojam**

The most dominate land use and cover type in the region are forest, scrublands, grasslands, cultivated land, rural settlement and farm land, urban settlements, plantation, water body and croplands (Figure 5). Significant increases in demand for food have resulted in an expansion of croplands by influencing on uncultivated areas like forests, shrub and marginal lands. The expansion of croplands toward forest, shrub and marginal lands, including continuous and over cultivation, has resulted in deforestation and soil degradation. Similarly, increased demands for fuel wood in the absence of alternative sources of energy have led to the destruction of forests. They have also led to the increased use of crop residues and animal dung for fuel rather than using these as sources of organic fertilizer to replace the fertility levels of the soils. The region, Gojam is the center of the economic activity of the country with a large number of the country's population and livestock. Gojam is the source of many of the country's major rivers (including the Blue Nile). Due to improper use of the land and increasing population soil erosion is the main challenge in this region. This long-term effect of soil loss is affecting the ecological balance and survival of a society.

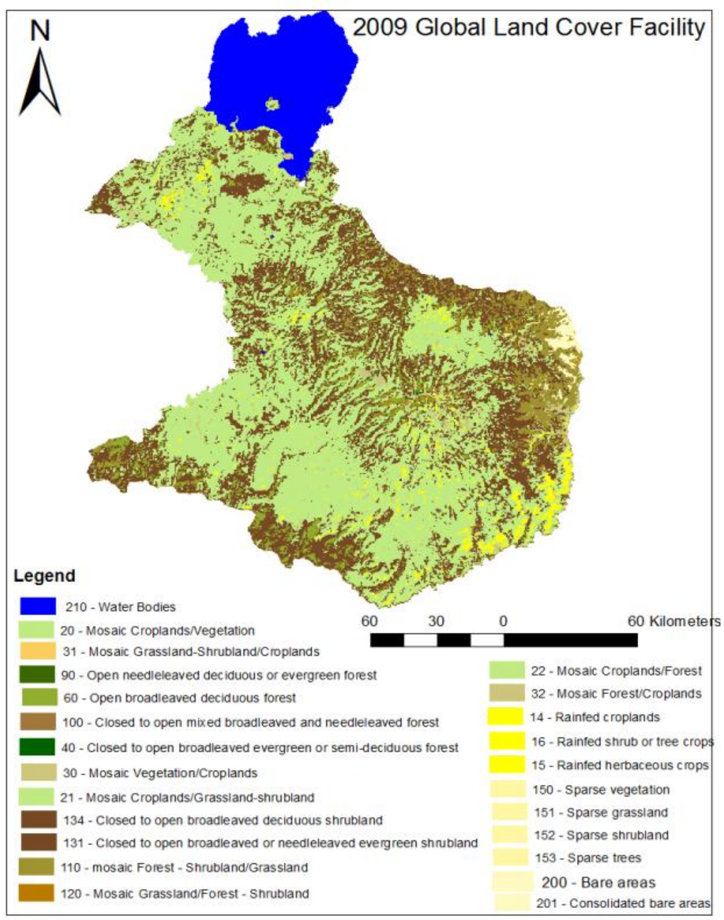


Figure 5 Land cover type of study area

According to Zeleke and Hurni (2001), even in small part of region the spatial and temporal analysis of land use and land cover change in (1957-1995) clearly indicates that a dramatic decrease of vegetation conditions or serious land degradation in the region particularly the natural forest cover declined from 27% in 1957 to 2% in 1982 and 0.3% in 1995; while, cultivated land increased from 39% in 1957 to 70% in 1982 and 77% in 1995. The changes have been dramatic for the traditional agricultural system, and the impacts are now highly visible. Vegetation cover has completely declined, the proportion of degraded lands has increased, the total annual soil loss rate is high and soil productivity is decreasing. Environmental and vegetation degradation has resulted from mismanagement of land resources, overgrazing, deforestation and inappropriate land use systems.

3.1.2 Consequences of land use/cover change on ecosystem and climate variability

The most north part of Ethiopia or particularly Gojam region highly degraded because of intensive agricultural activities and improper natural resource management. The livestock and population is also high in the region. Most highlands of the region are affected by massive land degradation arising from deforestation and cultivation of steep slopes. Other causes of degradation are ineffective or inadequate watershed treatment, and uncontrolled grazing of livestock on steep watersheds. Due to high rates of soil erosion, the soil in many areas eroded down to depths of 20-30cm it is reaching to the lower limits of productivity and has lost much of its capacity to retain moisture (The World Bank 2004, p. 14). So that, this is pushing more and more of erosion prone land to come under cultivation leading to rapid depletion of soil nutrients and associated natural resources denying the people their basic needs for survival. Since recent decades droughts and famines have been occurring at short intervals of less than 10 years (Waktola 1999).

Climate variability and change caused by land degradation in developing country, carbon releasing in to atmosphere from industries in the developed country. Climate change and variability are the main cause of decrease in agricultural product, vegetation, loss of biodiversity, declining soil fertility, drying of lakes desertification and other natural resources in the region. Most highlands of country or region undergone drastic reduction of productivity over the last few decades (Yilma 2009). Land use changes also continue to have a devastating impact on mountain habitats. Climate variability and change has serious direct impacts on natural resources, agricultural output, road and transport services, water intensive-industries, electric power production, and on human health in Gojam, Ethiopia.

3.1.3 **Climatic and Vegetation Characteristics of Gojam**

Gojam is located within the tropics where there is no significant variation in day length and the angle of the sun throughout the year. As a result, average annual temperature in the region are high and variations low. Although latitude mainly influence the overall temperature, the great variations in altitude and slope aspects also have very significant effects on regional microclimates and temperature. Traditional climate classification zone of the region based on elevation is Kola or hot dry tropical between 1500-1800m above sea level, Woina Dega or sub-tropical (1800-2400m above sea level), Dega or temperate (2440-3500m above sea level), and wurch or alpine (over 3500m above sea level) with mean annual temperatures of less than 10°C and rainfall less than 900mm. The most dominant crop in this climatic zone is Barley (Tegene 2002; FAO 1995; Mengistu 2006). Highlands above an altitude of 1500m experiences relatively cool temperature conditions in contrast to the lowlands (Figure 6).

Hot dry tropical (kola) is the zone of desert which includes the following climatic and vegetation characteristics: average temperature of 18-20°C and annual rainfall of 300mm-900mm, thorn shrub vegetation, flora includes acacia; myrtle and zizygium; euphorbia, crops include Sorghum; maize; cotton; tobacco; dura, and sugar cane. Whereas, sub-tropical zone (Woina Dega) zone includes the following: is warm and moderate, the temperature between 15-18°C and annual rainfall varies from 500mm-1500 mm, agricultural products or cereals are soft grains; barley; teff; maize; wheat. And cool (Dega) zone includes the following: the temperature between 10-15°C and rainfall varies from 700mm –1700mm (Tegene 2002). This area is adapted for raising livestock and sustainable growing barley; wheat; teff; beans; flax; temperate fruits, trees include the wild olive; juniper; Kosso tree (Teshome et al., 2007). From KÖPPEN climate classification the region includes H(cool highland climate), Cwb (Warm Temperature Rainy Climate and with dry winter), Cfb (Warm Temperature Rainy Climate and without distinct dry season), Cwc (Warmer temperate winter dry and cool summer) climates in the Ethiopian Highlands, which are of warm to cool mountainous semi-humid to humid characteristics and As (Equatorial summer dry), Aw (Tropical Climate and with distinct dry winter), Am (Tropical Monsoon Rainy Climate and with short dry season)-climates in the lowlands, which are of semi-humid to semi-arid characteristics surrounding the highlands.

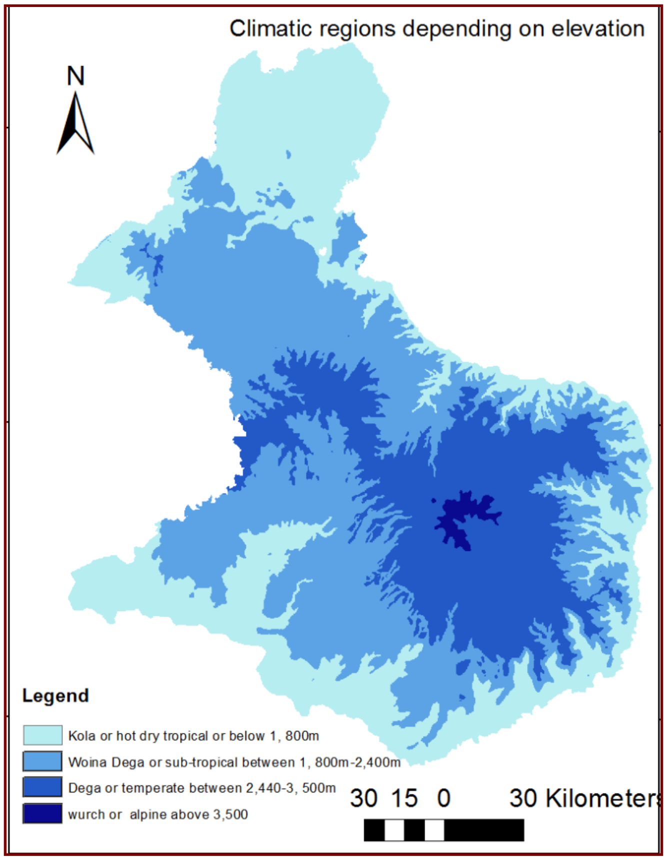


Figure 6 Climatic regions of the study area depending on elevation

The climate of Gojam, Ethiopia is mainly controlled by the seasonal migration of the Inter-tropical Convergence Zone (ITCZ), which follows the position of the sun relative to Earth and the associated atmospheric circulation, in conjunction with the country's complex topography.

Depending on different topography of the region the temperature of the region also variable. The south and central plateau has a moderate temperature with minimal seasonal temperature variation; while, in the lowlands or in most border of region the temperature is more hot and variable. The mean minimum during the coldest season is 11 ° C and the mean maximum rarely exceeds 26 ^{o}c .In most parts of the region, the hottest month come in May immediately before the main rainy season and the reduction of solar radiation by the heavy cloud cover. Although the maximum temperature fluctuated over time in both seasons, Belg season particularly (March, April and May) shows the highest maximum temperature that ranges from 26 ^{o}c to 29^{o}c and Kiremt shows minimum temperature particularly in July and August during 2000-2008 (Figure 19).

According to National Meteorological Agency there are three seasons in the region: Bega (dry season) from October to December, Belg (small rainy season) from February to May and Kiremt (main rainy season) from June to September (Babu 2009). The Belg rains begin when the Saharan and Siberian High Pressures are weakened and various atmospheric activities occur around the Horn of Africa. Low-pressure air related to the Mediterranean Sea moves and interacts with the tropical moisture and may bring precipitation to the region (Seleshi and Zanke, 2004). The high pressure in the Arabian Desert also pushes that low-pressure air from south Arabian Sea into mid- and southeast Ethiopia, which in turn, creates the Belg rains. The beginning of the Belg rain is also the period when the Inter-tropical convergences zone (ITCZ) begins to reach south and southwest Ethiopia in its south-north movement (Wolde-Georgis et al., 2000). For example, the creation of strong low pressure and cyclones in the southern Indian Ocean reduces the amount and distribution of rainfall in Ethiopia. The small rains also contribute to increased pasture for domestic and wild animals. Normal Belg rainfall adds moisture to the soil, enabling land preparation for the Kiremt or summer planting. The short rainy season, the Belg is the result of moist easterly and southeasterly winds and produces rains in March, April and May.

According to many previous studies and National Meteorological Agency of Ethiopia, ENSO has a great impact on Ethiopian, Gojam weather and climate variability (Bekele 1997; Wolde-Georgis et al., 2000). A negative sea surface temperature anomalies (SSTA) or La Niña is strong associated with rainfall deficiency in Belg and excess rainfall in Kiremt season; while, a positive SSTA or El-Nino is mostly associated with normal and above-normal rainfall amounts in Belg and deficiency of rainfall in Kiremt season. Furthermore, the National Meteorological Agency also realized that the sea surface temperatures (SSTs) in the Indian and Atlantic oceans also affect the region weather and climate variability. Most of the drought years are associated with El-Nino events; however, most of wet/flood years are associated with La-Nina episodes.

Rainfall mainly comes from June to September when the Inter-tropical Front, the zone of convergence of winds move towards the north of the country. During this time of the year moist winds from the middle part of the Atlantic Ocean, often referred to as Equatorial Westerly, are down towards this area of low atmospheric pressure and providing rain. Thus, most of the western parts and the highlands that are situated on the direct path of the moist winds capture more rainfalls than the rest of the regions (Teshome et al., 2007). In general, the western side of the region enjoys good and excess amount of rainfall than East, North-East and South-East part of the region. The amount of rainfall, and also the length of the rainy season, decreases north and north-eastwards from the south-western corner of the region. Rainfall fluctuations in the region have had significant short- and long-term effects on natural-resources systems, particularly agricultures, lakes, wetlands and rivers.

4 MATERIALS AND METHODS

4.1 Gridded datasets derived from climate data

Monthly mean maximum, minimum temperature and rainfall data were collected from National Meteorological Agency of Ethiopia. These data were also recorded from 15 Meteorological station placed in the study area for agricultural or rainy seasons (February -September) during the period 2000-2008 (Table 2; Figure 7). Three variables are analyzed in this study: mean monthly, seasonal and yearly rainfall, maximum and minimum temperature. The meteorological stations were irregularly distributed over the study area and doesn’t represent the whole region well. There were a few data gaps and removed by averaging data from the nearest neighbor stations.

Preparation of gridded climate maps was made by interpolation of these records based on the longitude, latitude and elevation of the weather stations. Use of elevation as secondary information for modeling gridded maps was not that much important but the relief or topography of study area has a bit influence on the spatial patterns of climate parameters. The magnitude of elevation ranges from 639 m to 4038 m. The general increase in precipitation with elevation is well known, it is due to fact that hills are barriers to moist airstreams, forcing the airstreams to rise and they act as high-level heat sources on sunny day.

Different interpolation methods were tried in order to increase the prediction accuracy such as inverse distance weighting (IDW), simple kriging, Universal kriging and ordinary kriging. Ordinary kriging method was the best for this study and all raster maps of seasonal precipitation for the study region were constructed using the geostatistical interpolation method known as ordinary kriging (OK). OK relies on the spatial correlation structure of the data to determine the weighting values instead of weighting nearby data points by some power of their inverted distance. Ordinary kriging is an effective spatial interpolation and mapping tool, because it honors data locations provides unbiased estimates at unsampled locations, and provides for minimum estimation variance, i.e. a best linear unbiased estimator (Jantakat and Ongsomwang, 2011).

Monthly mean sea surface temperature **(**SST**)** anomalies of NINO3.4, NINO3, NINO4 region also used from National Oceanic and Atmospheric Administration (NOAA). Since NINO 3.4 has characteristics of both NINO3 and NINO4 most studies consider NINO3.4 SSTA for their study (Babu 2009; Zaroug 2010) (Figure 8). To be classified as a full-fledged El Niño and La Niña episode the Oceanic Niño Index (ONI) must exceed +0.5 [El Niño] or -0.5 [La Niña] for at least five consecutive months.

Stations	Longitude (°E)	Latitude (°S)	Altitude (m)	Rainfall (mm)		Temperature (^oC)	
				Belg (Feb-May)	Kiremt (Jun-Sep)	Belg (Feb-May)	Kiremt (Jun-Sep)
Motta	37.52	11.05	2440	34.01	220.53	23.11	22.21
Debre Work	38.08	10.44	2740	38.72	187.21	9.42	22.99
Adet	37.28	11.16	2080	25.21	210.3	29.02	23.69
Ayehu	36.55	10.45	1725	54.94	211.91	31.36	24.33
Zege	37.19	11.41	1800	14.5	336.12	31.09	26.42
Bahar Dar	37.25	11.36	1770	22.19	321.53	29.63	25.35
Yetemen	38.08	10.2	2060	37.59	255.99	26.01	22.14
Gundil	37.04	10.57	2540	61.13	473.23	24.14	19.88
Dengay Ber	37.33	10.43	2800	58.55	415.72	24.44	18.92
Deke Istifanos	37.16	11.54	1795	11.73	309.9	28.84	25.56
Wegedade	37.13	11.18	2000	39.2	213.68	29.29	26.00
Abay Sheleko	38.41	10.21	2000	54.86	238.96	29.74	27.29
Elias	37.28	10.18	2140	50.82	337.76	29.17	22.42
Shebelberenta	38.2	10.27	2000	40.31	198.16	27.51	23.45
Yetnora	38.09	10.12	2540	38.62	215.42	24.63	19.84

Table 2 Geographical coordinates of the meteorological stations and their mean seasonal rainfall and mean maximum temperature

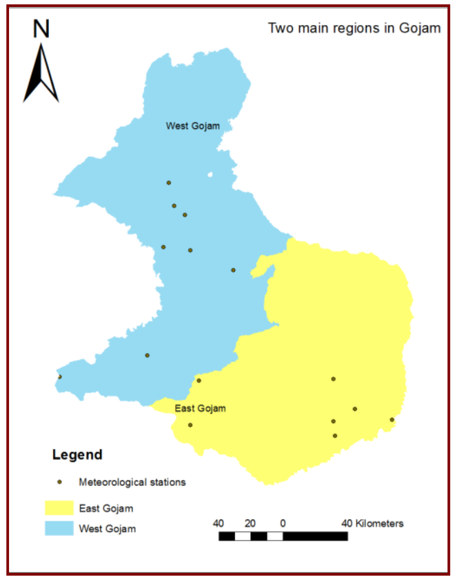


Figure 7 Distribution of the meteorological stations and Administrative regions in Gojam

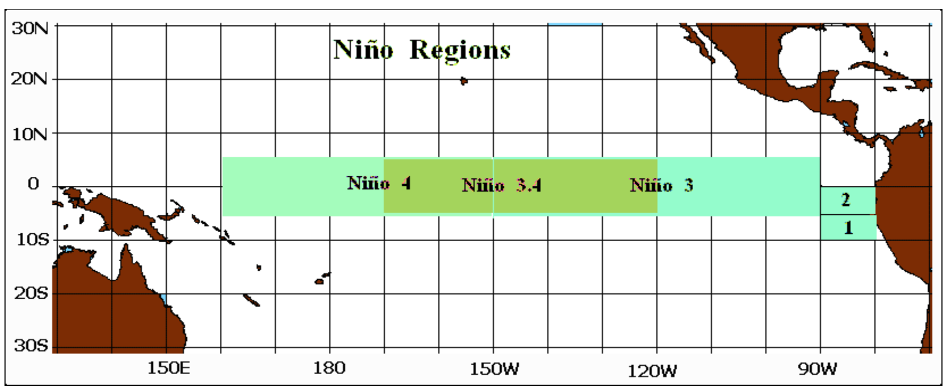


Figure 8 Geographical extent of the currently defined El Niño regions

Source:http://www.cgd.ucar.edu/cas/catalog/climind/TNI_N34/index.html; accessed 3 November, 2011

4.2 Gridded datasets derived from satellite data

The multi-temporal images used (Table 3) were acquired from the NASA Terra (AM-1) satellite's Moderate Resolution Imaging Spectroradiometer (MODIS) sensor. The MODIS 250 m NDVI product (MOD13Q1) 16-day composites provided the needed vegetation phenology data. The MODIS re-projection tool was used to convert HDf file to Geotif and images were resampled using a nearest neighbor operator from their native sinusoidal projection to geographic projection with datum WGS 84. Depending on the MODIS 250m NDVI Quality Assessment Science Data Set (QASDS) information and requirement quality assessment also processed. NDVI pixels that fell below the acceptable QASDS quality level were deleted and flagged. The 16-days composite NDVI data sets were generated using a maximum value composite (MVC) procedure, which selects the maximum NDVI value within a 16-day period for every pixel. This procedure is used to reduce noise signal in NDVI data due to clouds or other atmospheric factors. The monthly NDVI raster map and others such as maximum, minimum and mean NDVI values were extracted by averaging the 16-composite. Negative NDVI values indicate non-vegetated areas such as snow, ice, and water. Positive NDVI values indicate green, vegetated surfaces, and higher values indicate increase in green vegetation.

Digital terrain model also used from United States Geological Survey (USGS) for pre-processing of satellite data and the supplementary statistical analysis in the main part of the study

Satellite system	Sensor	Spatial resolution	Temporal resolution	Time-period/ Acquisition date
NASA	MODIS Terra	MOD13Q1 250m NDVI	16 day composite	From 2000-2008

Table 3 Satellite data used in the study

Although the Normalize difference vegetation index (NDVI) value classification is not specific, depending on previous some studies the vegetation condition of the region classified as High vegetation (values above 0.5), medium vegetation (from 0.292 - 0.5), low vegetation (0.166- 0.292), no vegetation (from 0.1 -0.166) and water body (USAID, 2006; USGS 2011; USGS & USAID, 2005).

4.3 General statistical analysis of vegetation or biomass condition

Quantitative analyses of land degradation or improvement using Maximum minus minimum NDVI and coefficient of variation of NDVI (Bai et al., 2005)(Table 4). Coefficient of variation represents the ratio of the standard deviation to the mean, and it is a useful statistic for comparing the degree of variation from one data series to another, even if the means are drastically different from each other. The higher the CV, the higher is instability or variability in data, and vice versa. It is used to determine the stability or consistency of a data. The dispersion of NDVI values relative to the mean value over time, which can be: 1 positively increasing, 2) positively decreasing, 3) negatively increasing, 4) negatively decreasing, or 5) constant. A positive change in the value of a pixel-level Cv over time relates to increased dispersion of values, not increase NDVI; similarly a negative Cv means decreasing dispersion of NDVI around the mean values, not decreasing NDVI.

Source: Bai et al. (2005) and Tucker et al. (2005)

Max-Min NDVI	**NDVI CV**	**Interpretation of biomass variation**
+	+	Increase of biomass but unstable
-	+	Decrease of biomass but unstable
+	-	Increase of biomass, stable
-	-	Decrease of biomass, stable

Table 4 Combination of NDVI and Cv for biomass detection

4.4 General methodological framework

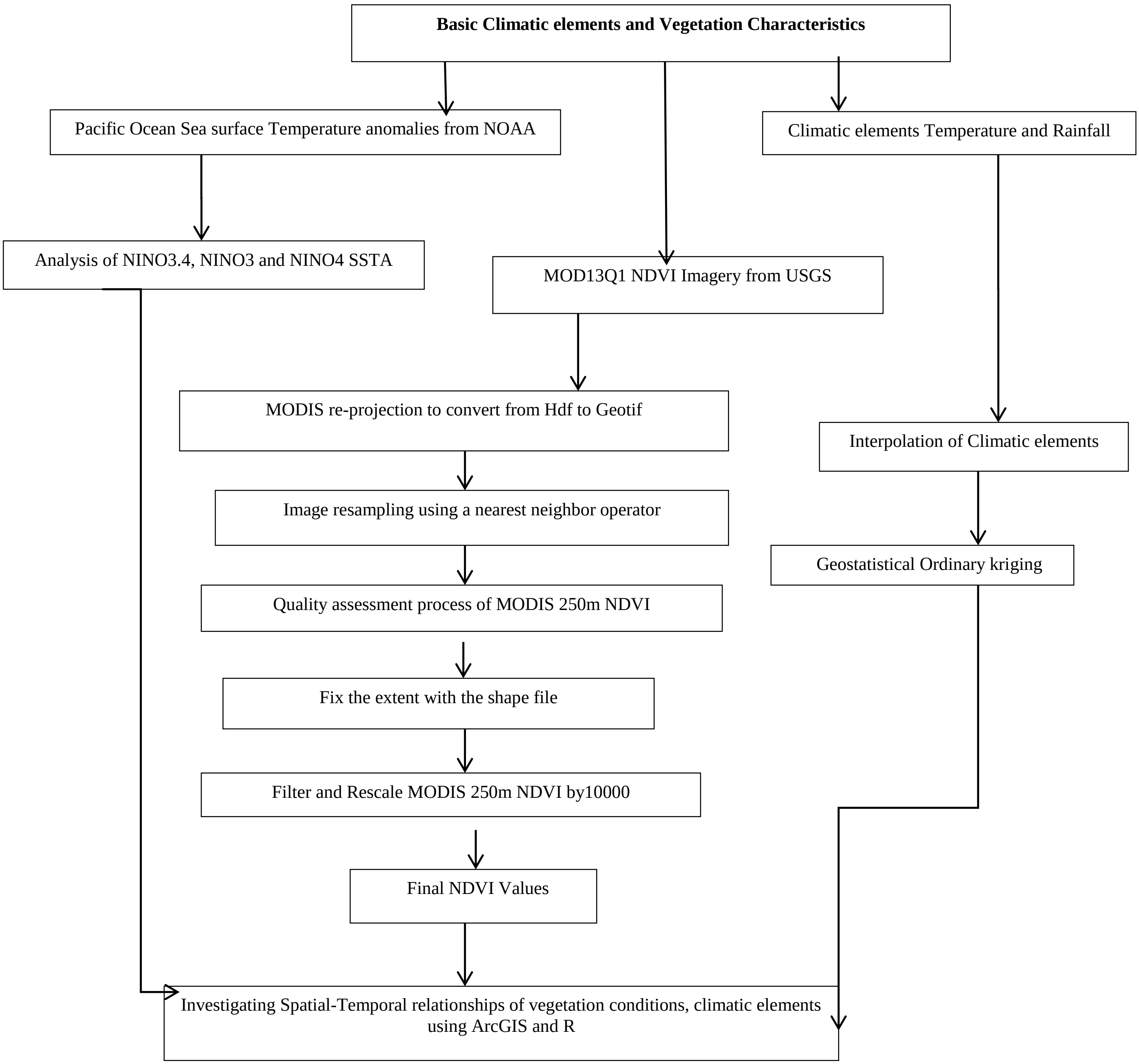


Figure 9 General methodological framework

5 RESULTS AND DISCUSSION

5.1 Spatial and temporal variation of Mean monthly NDVI for Belg and Kiremt season

Generally, there is high vegetation coverage in Kiremt season (June, July, August and September) than Belg (February, March, April and May) from the period 2000 to 2008 due to good amount of rainfall in Kiremt season for plants or crop to grow. Relating to the altitude there is better vegetation coverage in the central part of the region, around choke mountain (the highest plateau of the region) in both seasons. In the other hand, there is less vegetation coverage in the eastern periphery of the region while, better vegetation coverage in the western part of region(Figure 10 and Figure 43). From seasonal quantitative analysis of vegetation coverage in both seasons as shown in (Table 5 and Table 6) there is 77.14 % highest high vegetation coverage class in the year 2002 Kiremt season. Yearly Kiremt season high vegetation coverage class from highest to lowest 2002 (77.14 %) and 2003 (66.59%) consecutively. Highest Kiremt season medium vegetation coverage class is in 2003 (23.24%) while, lowest medium vegetation coverage class and low vegetation coverage is in 2002 (12.74%).

In the Belg season the highest high vegetation coverage class year is 2007 (2.55%) and lowest high vegetation coverage class year is 2004(0.48%). The highest medium vegetation coverage class year is 2000 (58.15%) while, the lowest year 2003 (26.69%). The highest low vegetation class also in 2003 (61.91%).

The result of pacific ocean sea surface temperature anomalies analyses show that 2000 and 2008 are strong La Niña years, but the National Oceanic and Atmospheric Administration (NOAA) includes 2001 and 2007 as La Niña or close to La Niña year as well. In the other hand, 2002 is strong El Niño year and NOAA also includes the years 2003, 2004, 2005 and 2006 (NOAA, 2010). So that, there was a decrease in vegetation coverage in 2000 and 2008 particularly in first two months (February and March) of Belg season due to La Niña episodes and decrease of rainfall amount(Figure 10, and Figure 11). But the total vegetation coverage of Belg season and La Niña episodes is not decrease because of the rest April and May vegetation coverage and rainfall amount increase(Figure 10, Figure 15 and Figure 33). The highest vegetation coverage is in 2002 is due to El Niño episodes. The El Niño episode increase the amount of rainfall in Belg season while, decrease the amount of rainfall in the late Kiremt season. Hence, due to one or two months lag time vegetation coverage increment after the fall of rainfall the vegetation coverage is increase in 2002. The spatial and temporal distribution of rainfall and vegetation coverage have similar pattern that is, maximum vegetation coverage and rainfall amount in the east and north east part of region while, decreasing of vegetation and rainfall west, south, north west and south west part of region(Figure 13, Figure 15, Figure 16, Figure 17 and Figure 43).

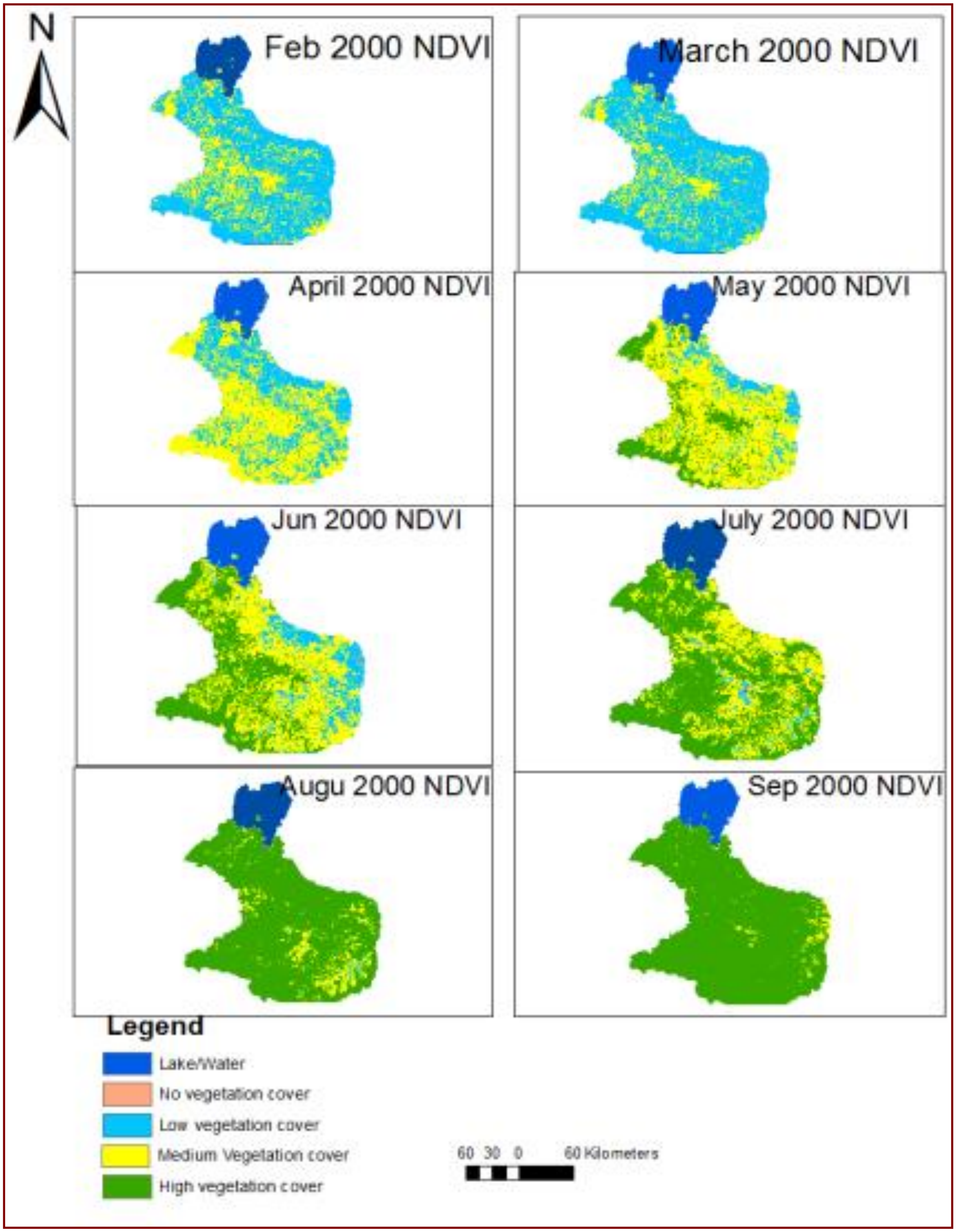


Figure 10 Illustration maps of mean monthly NDVI in rainy season for 2000 La Nina years

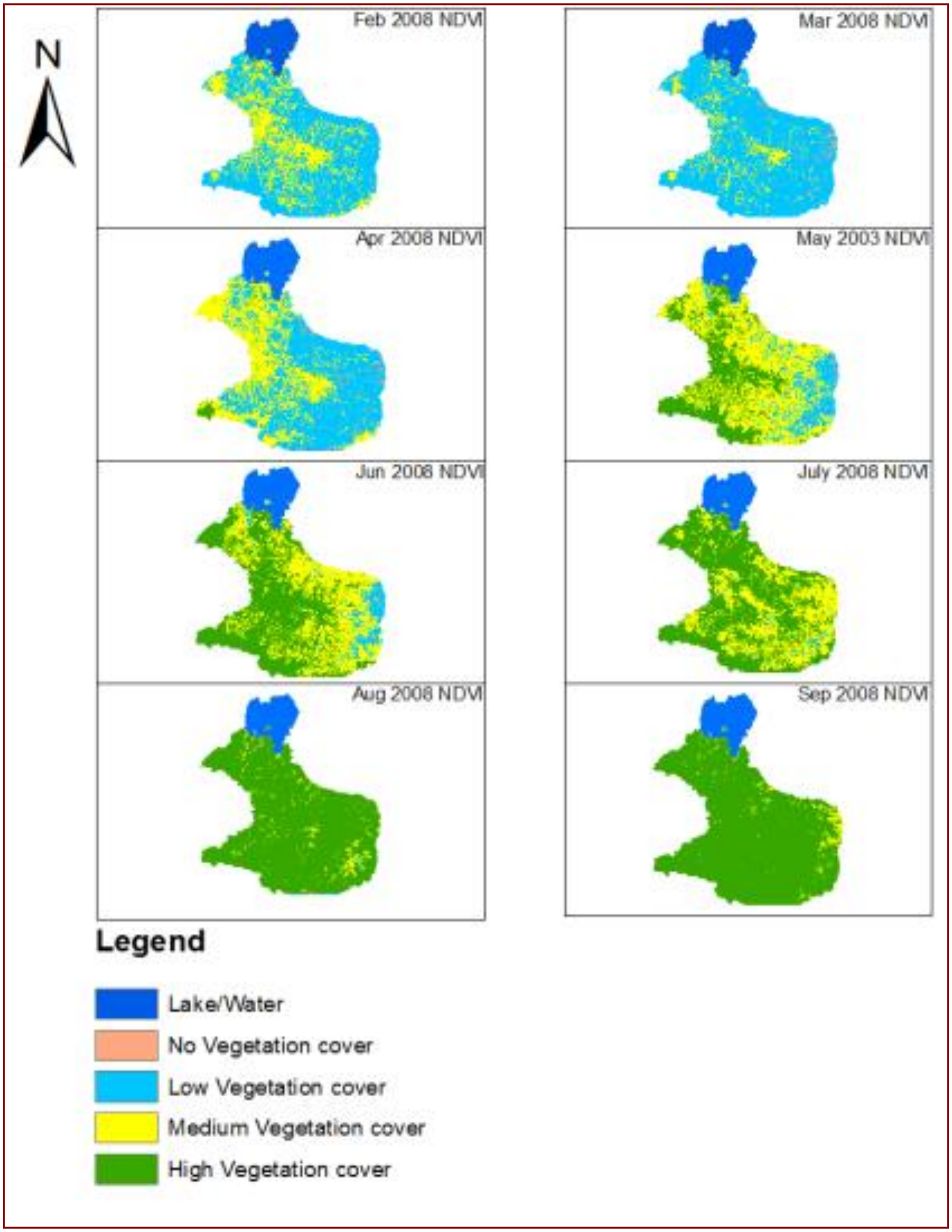


Figure 11 Illustration maps of mean monthly NDVI in rainy season for 2008 La Nina year

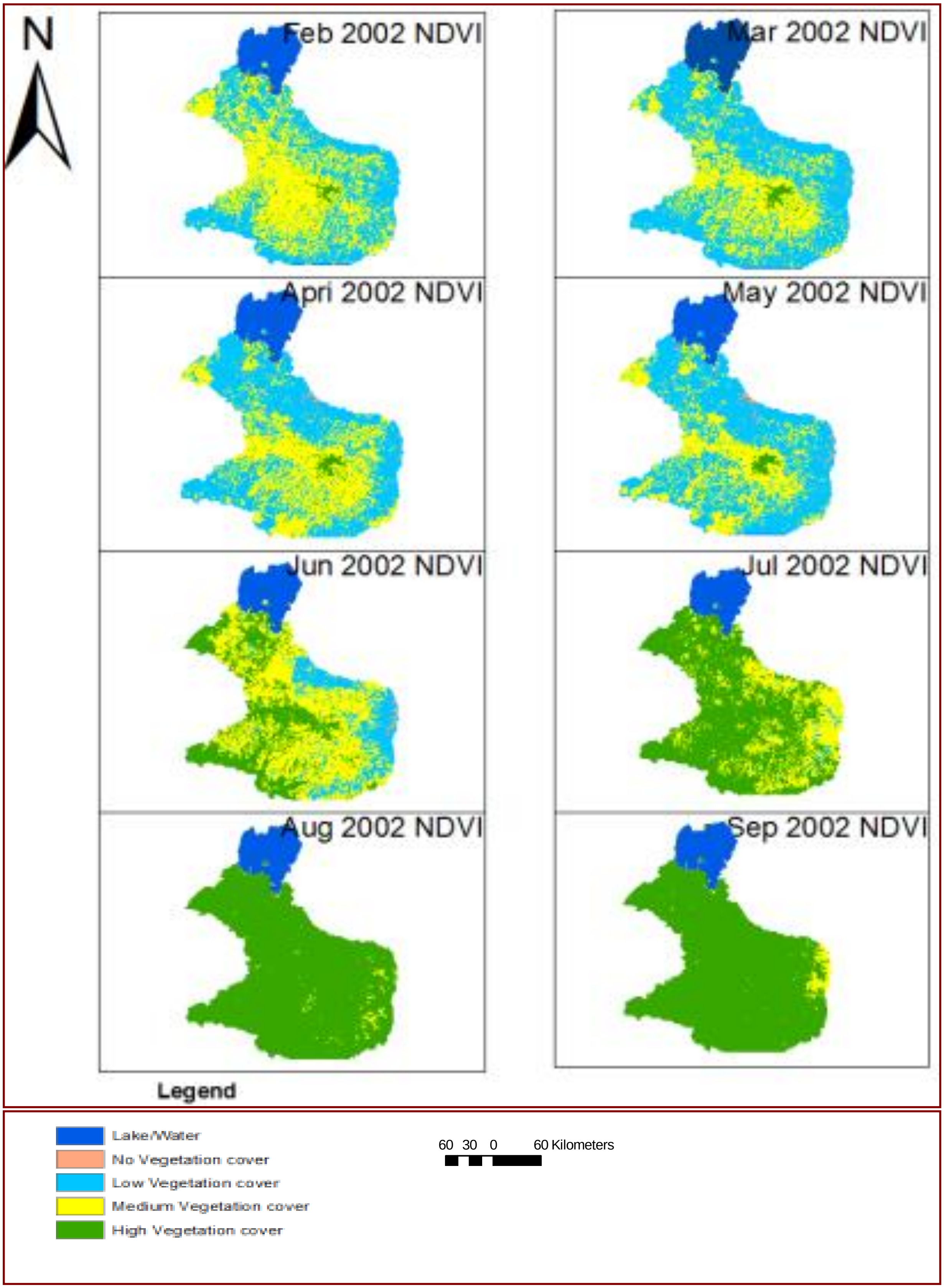
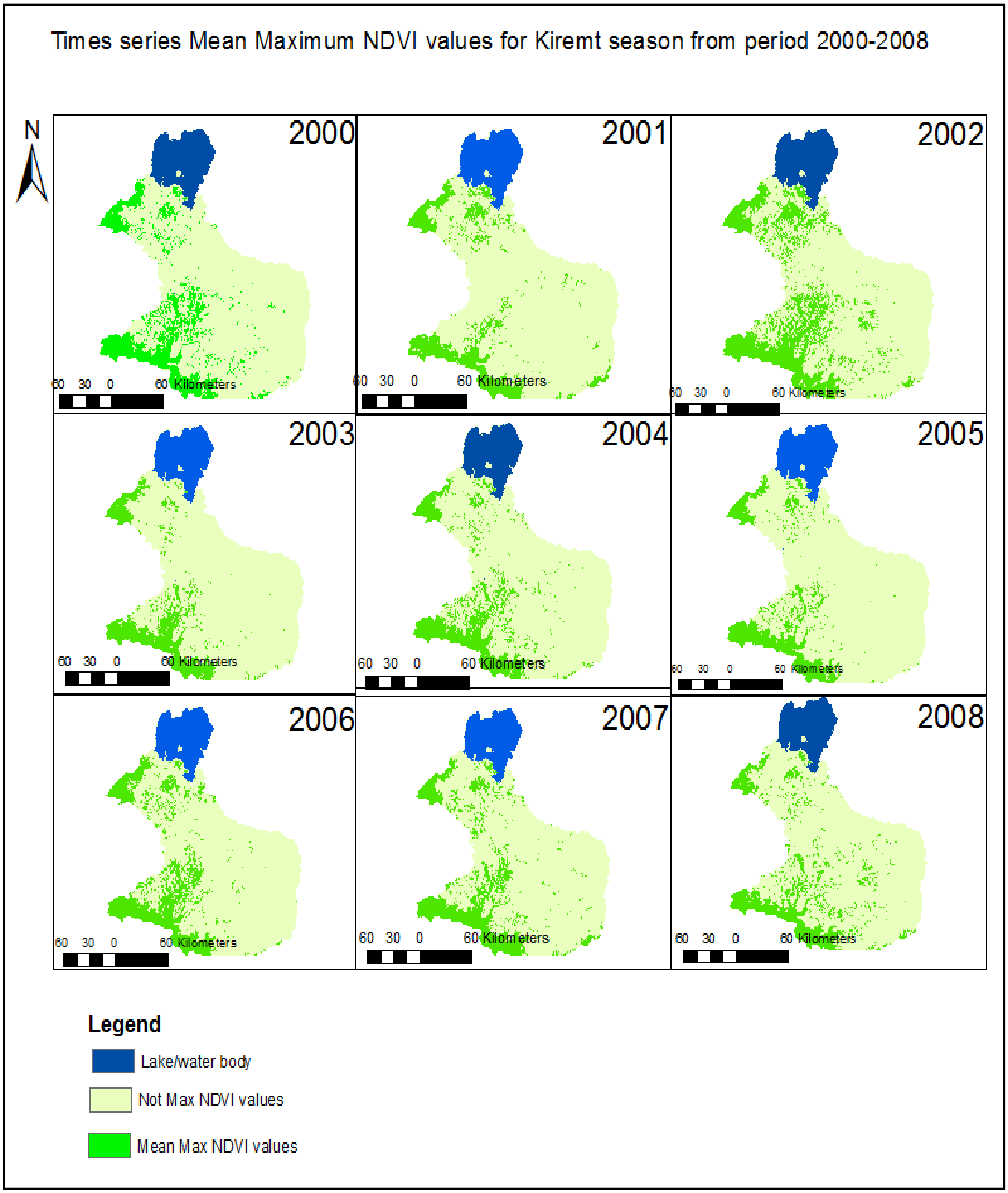


Figure 12 Illustration maps of mean monthly NDVI in rainy season for 2002 El Niño year


Times series Mean Maximum NDVI values for Kiremt season from period 2000-2008
N
2000
2001
2002
2003
2004
2005
2006
2007
2008
60 30 0 60 Kilometers
Legend
Lake/water body
Not Max NDVI values
Mean Max NDVI values

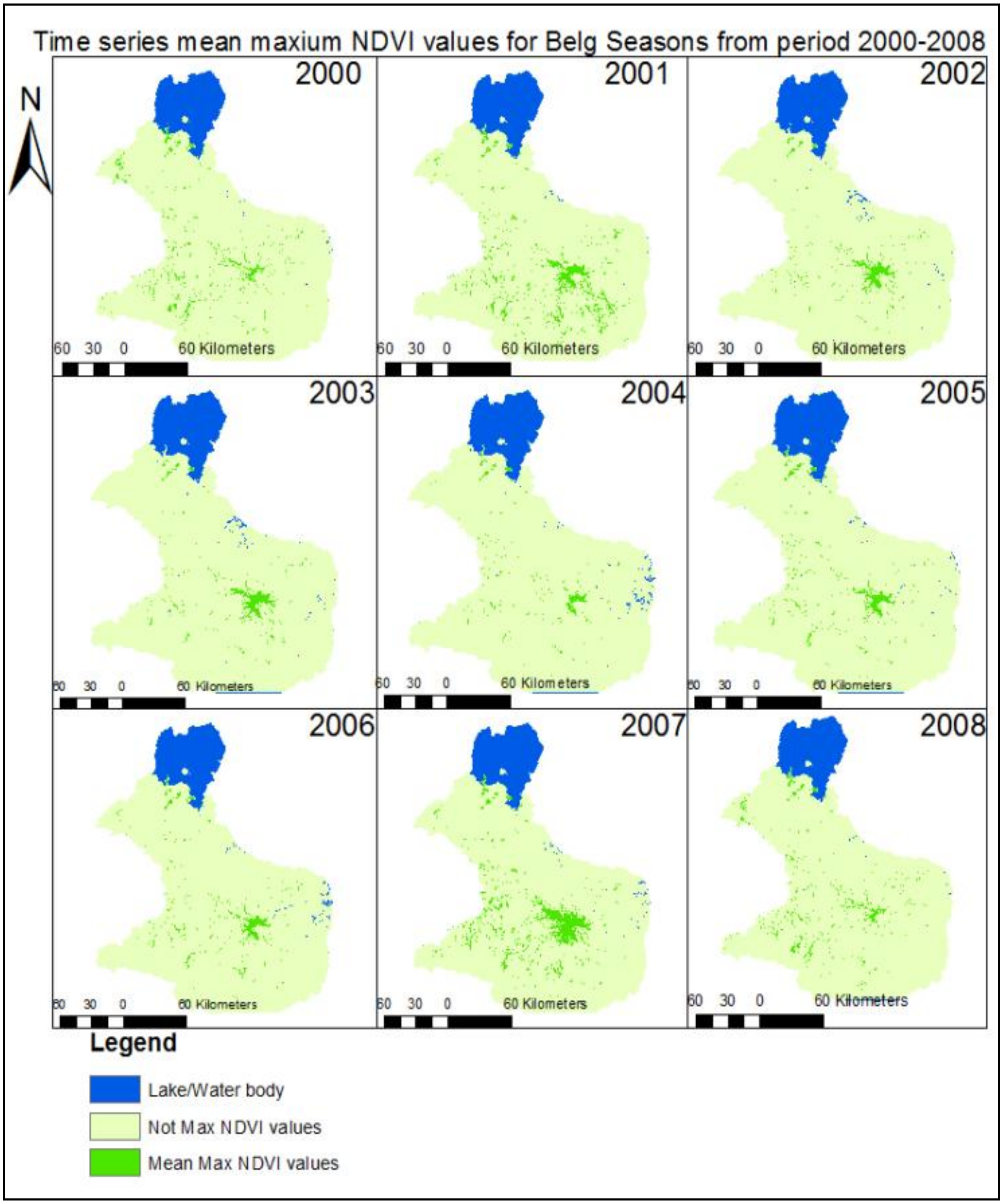


Figure 14 Mean maximum NDVI values areas in Belg season

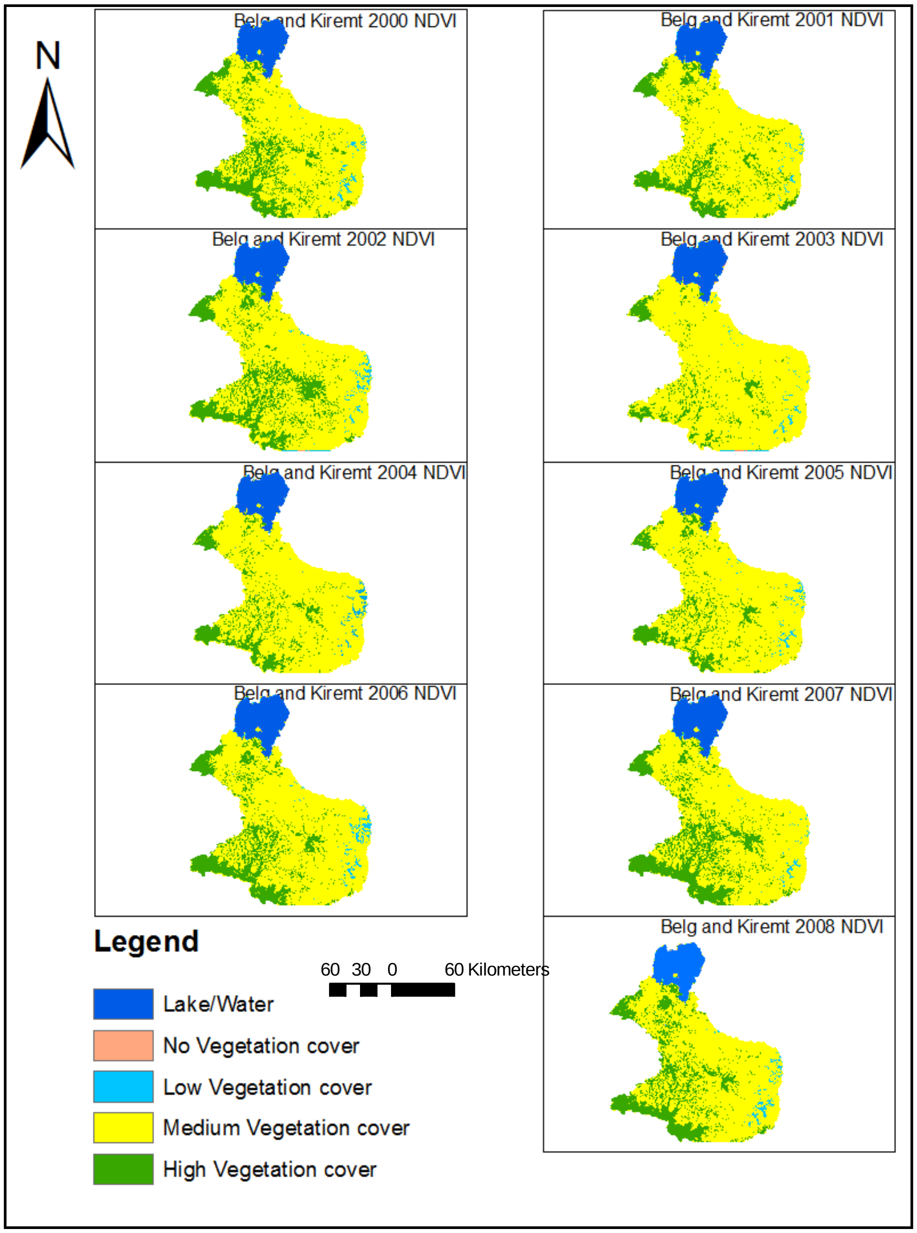


Figure 15 Mean yearly vegetation coverage for rainy season from 2000 - 2008

5.1.1 Quantitative analyses of vegetation coverage in Belg and Kiremt season

The quantitative analyses vegetation coverage shows almost similar quantity of high vegetation coverage that ranges from 70-77 percent in Kiremt season. The medium and low vegetation coverage of Kiremt season also shows similar quantity in the nine years. The Belg season quantitative analyses show high quantity of medium and low vegetation coverage not high vegetation coverage as Kiremt season.

	% of vegetation coverage per year								
Type of vegetation	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
High Vegetation	72.66	68.83	77.14	66.59	75.90	70.10	72.02	74.59	76.61
Medium Vegetation	17.03	20.85	12.74	23.24	13.97	19.69	17.78	15.19	13.19
Low vegetation	0.302	0.32	0.17	0.24	0.18	0.26	0.23	0.27	0.23
No vegetation	0.09	0.10	0.10	0.11	0.10	0.10	0.10	0.10	0.10
Water	9.92	9.89	9.83	9.83	9.85	9.85	9.86	9.86	9.85

Table 5 Kiremt season quantitative vegetation coverage

	% of vegetation coverage per year								
Type of vegetation	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
High Vegetation	0.77	1.76	1.58	1.09	0.48	0.92	0.85	2.55	0.90
Medium Vegetation	58.15	58.01	36.85	26.69	30.42	38.99	47.16	50.47	50.44
Low vegetation	30.94	30.10	51.21	61.91	58.66	49.911	41.66	36.75	38.28
No vegetation	0.18	0.17	0.36	0.40	0.48	0.26	0.43	0.30	0.51
Water	9.96	9.97	9.99	9.91	9.96	9.92	9.90	9.92	9.87

Table 6 Belg season quantitative vegetation coverage

5.2 Spatial and temporal variation of mean seasonal rainfall in Belg and Kiremt

Ordinary kriging considered to be the best methods, as it provided smallest RMSE and ME value for nearly all cases. Since the distribution of sample data points is uneven and sparse IDW interpolation techniques quality is very less and doesn’t cover the whole study area. Ordinary kriging was selected for this study based on how well it has performed on prior years data and because the statistical characteristics of the data in 2002 and 2003 make Ordinary Kriging the appropriate choice of estimator (Table 7). Exponential and stable type of models are used for ordinary Kriging interpolation of seasonal rainfall data (Figure 49and Table 11).

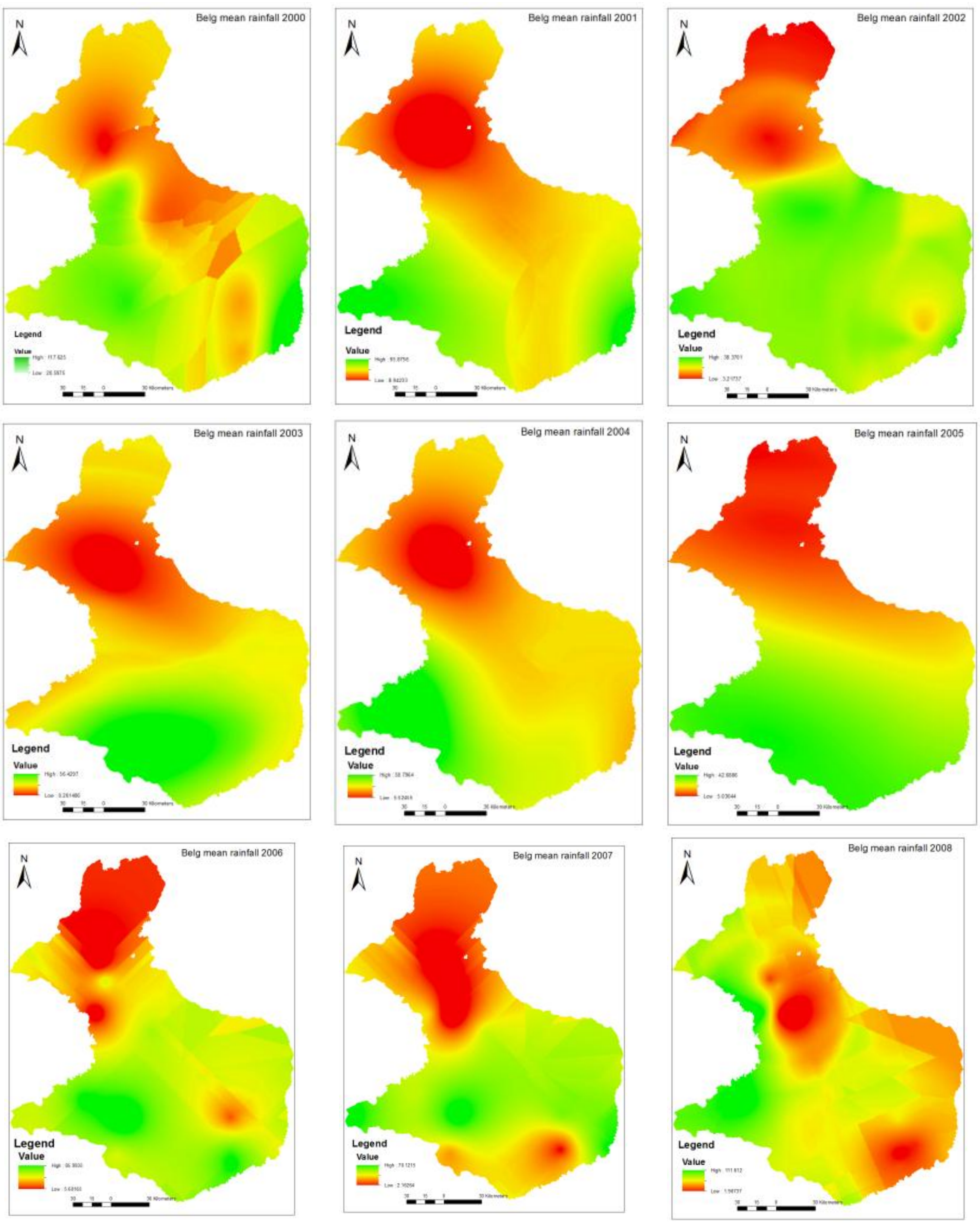


Figure 16 Maps of spatial distribution Belg season rainfall

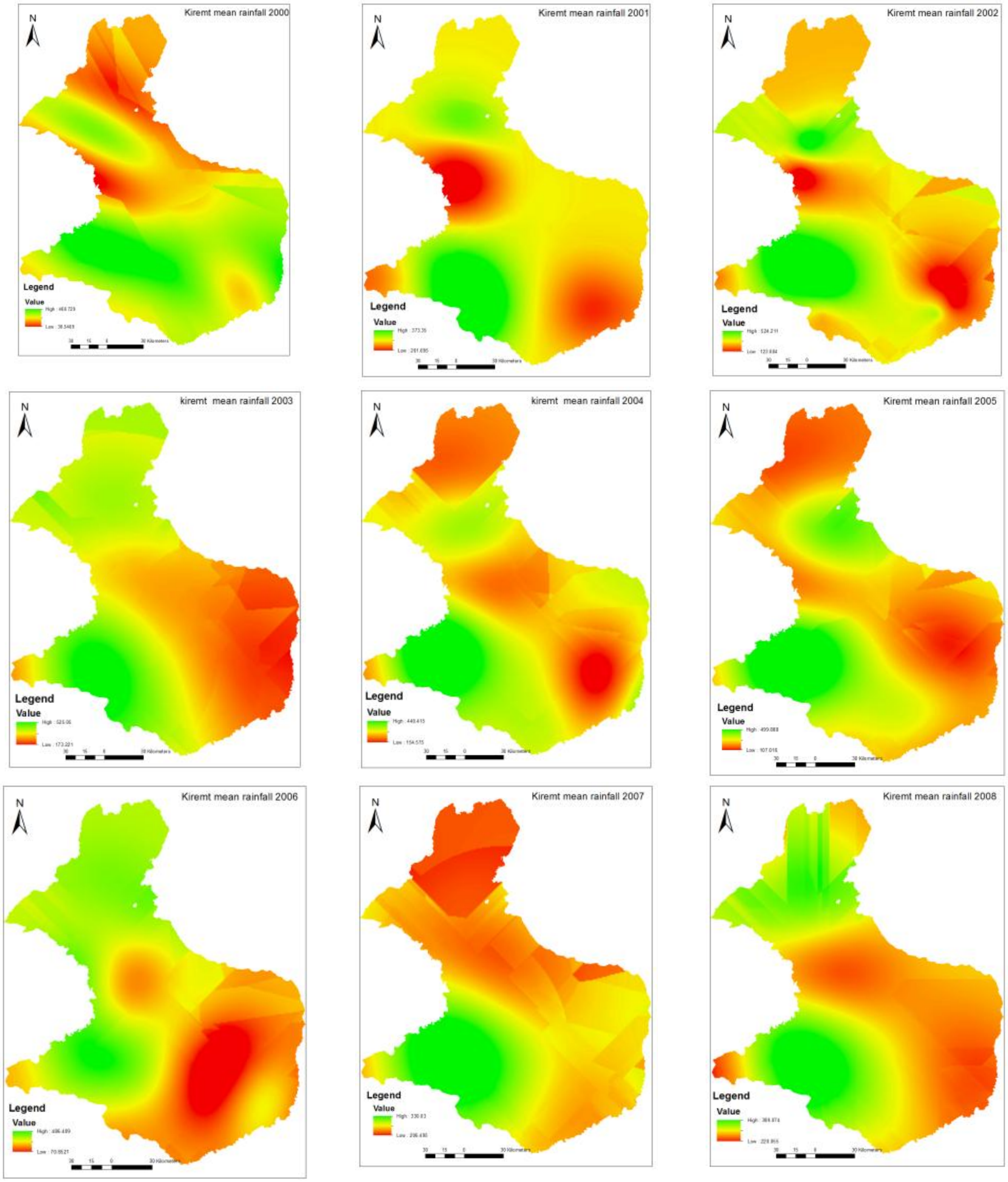


Figure 17 Maps of spatial distribution of Kiremt Season rainfall

Method	Error statistic	Belg season	Kiremt season
Simple kriging (SK)	RMSE	9.30	79.42
	ME	–1.88	–2.82
Universal kriging (UK)	RMSE	9.82	81.56
	ME	0.73	3.71
Ordinary kriging (OK)	RMSE	8.12	45.21
	ME	0.01	1.01
Radial Basis Function (RBF)	RMSE	17.04	65.89
	ME	0.01	1.73
Local Polynomial Interpolator (LPI)	RMSE	21.01	86.03
	ME	1.04	5.03
Global Polynomial Interpolator (GPI)	RMSE	26.9	82.31
	ME	0.12	3.66
Inverse Distance Weighting (IDW)	RMSE	22.18	81.38
	ME	0.67	19.61

Table 7 Summary of error estimators for prediction of mean seasonal rainfall

5.2.1 Mean monthly time series analyses of rainfall for the 2000-2008 period

The variability of rainfall through time is visible in almost the whole years, in both rainy seasons that is in Belg and Kiremt (Figure 18). Statistical time series mean monthly precipitation analysis of Kiremt season (June, July, August and September) shows that increasing of precipitation about and more than 200mm per month i.e. good for vegetation or plant growth almost in the whole years except in the year 2000 and

2007 (Figure 18). Rainfall is the limiting factor in these areas. It governs the crop yields and determines the choice of the crops that can be grown. There was immediate decrease of rainfall from June 300mm per month to 200mm per month and lower in August and September in the year 2002, 2005 and 2007. The spatial pattern of mean annual seasonal precipitation increases in the western or southwestern part of region similar to vegetation; beside to, the variability of rainfall spatially and temporary (Figure 43, Figure 16 and Figure 17). Particularly the *Belg* rainfall is generally considered variable in quantity and distribution. However, some part of the regions receive good amount of rainfall while, the rest get low amount of rainfall.

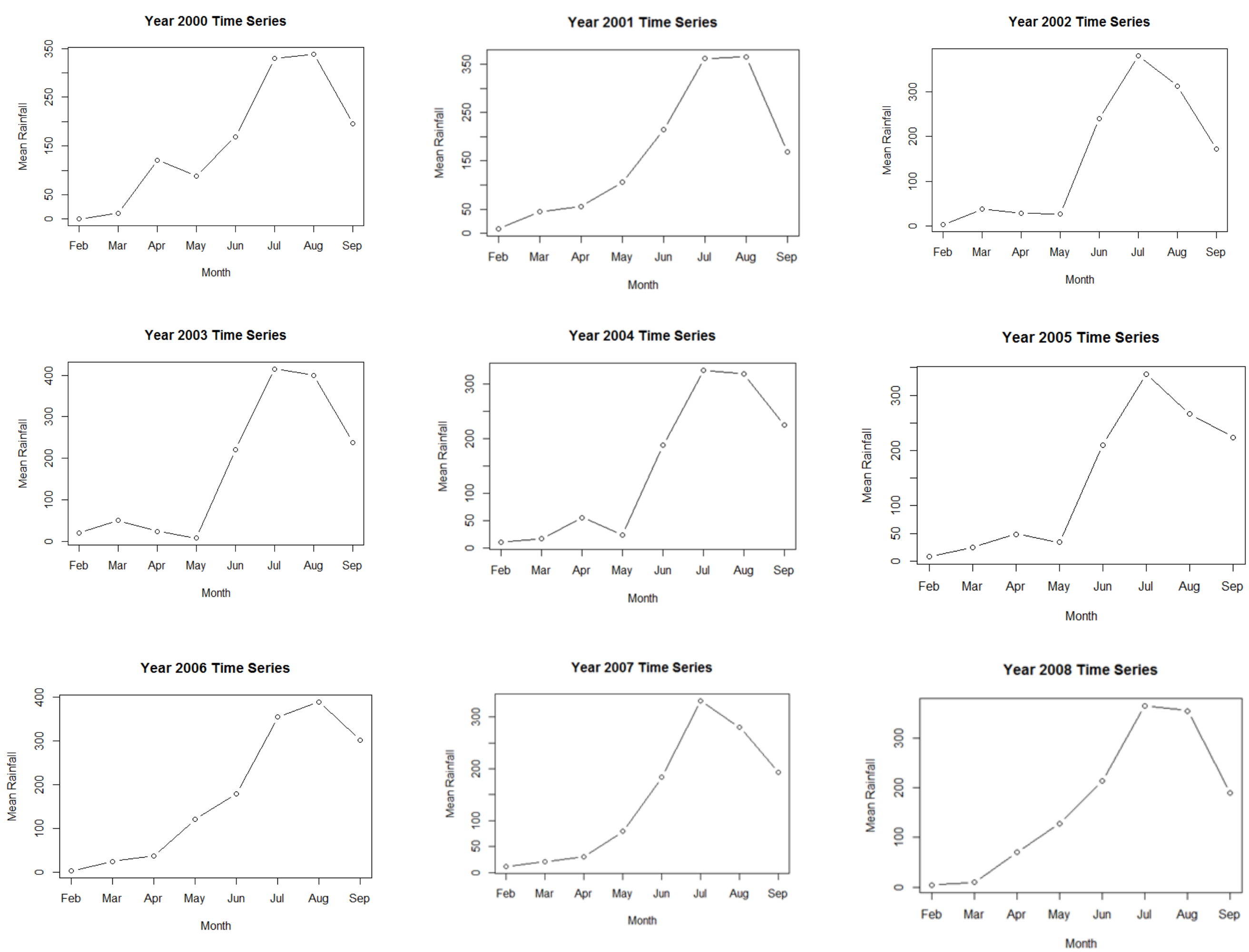


Figure 18 Time series of mean monthly rainfall

5.3 Mean monthly time series analyses of maximum temperature for the 2000-2008 period

Unlike the rainfall and vegetation, mean monthly maximum temperature analyses shows that the increase of maximum temperature greater than 26 ^{o}c in almost the whole Belg season, whereas the decrease of maximum temperature in the Kiremt season particularly in July and August (Figure 19). The immediate decrease of maximum temperature particularly in March or May end of Belg season indicates the starting of main rainy season in almost the whole years(Figure 19). Although the variability of maximum temperature noticeable in both seasons, it is more visible in the Kiremt season than Belg.

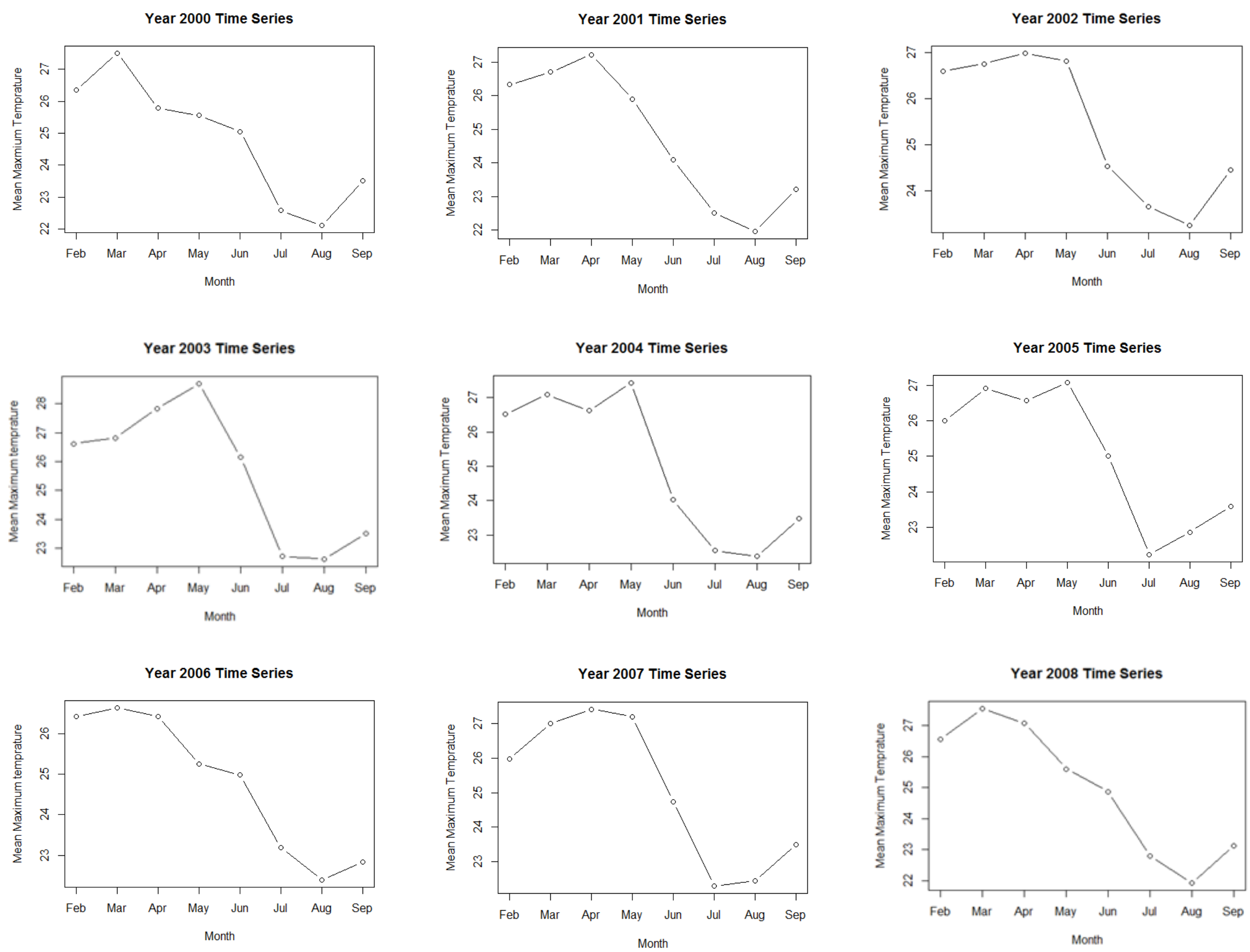


Figure 19 Time of series mean monthly maximum temperature

5.4 **Mean monthly time series analyses of NDVI for the 2000-2008 period**

The small rainy season in Belg helps to moist the soil and for other preparation for the vegetation i.e. plant ,crop ,grassland and others to start growth, so that mean monthly NDVI time series result shows increase of NDVI value after Belg season (Figure 20). Due to the small rainy season in Belg that create favorable condition for vegetation growth, there was immediate increase of NDVI values starting from June the beginning of Kiremt seasons. Spatial and temporal result of NDVI in the regime shows increase of vegetation coverage in Kiremt particularly September, whereas the minimum vegetation coverage in Belg particularly in March and February in almost the whole nine years. As result of strong La Niña episode in the year 2000 it shows the more decrease of vegetation coverage in February and March in similar to rainfall.

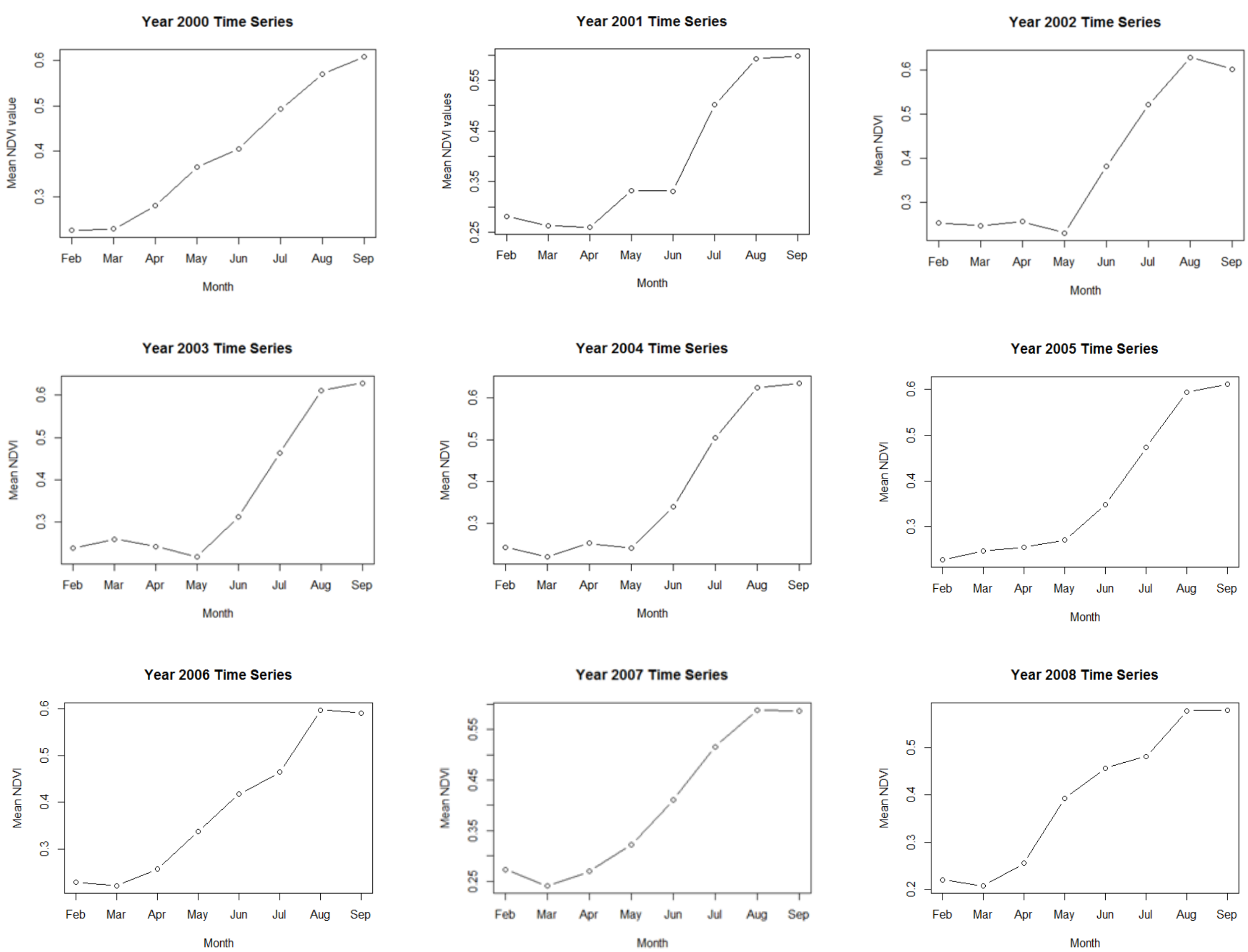


Figure 20 Mean monthly time series analyses of NDVI

5.5 Mean monthly time series analyses of NINO3.4 for the 2000-2008 period

The Oceanic Nino Index (ONI) is based on sea surface temperature anomalies and is defined as the three-month running-mean SST departures in the Niño 3.4 region, based on the NOAA ERSST data. El Nino is characterized by ONI>=+0.5 ^{o}c, while La Nina is based on ONI<=-0.5^{o}c. Fully El Nino episode characterize when five consecutive months of ONI>=+0.5 ^{o}c , whereas the fully La Nina episode ONI <=-0.5 ^{o}c. The year 2000 and 2008 indicates fully La Nina episode and the years 2002 El Nino (Figure 21). La Nina episode decrease the amount of rainfall in Belg season and increase the amount of rainfall in Kiremt, while El Nino increase the amount of rain fall in Belg and decrease the amount of rainfall in Kiremt season of the regime.

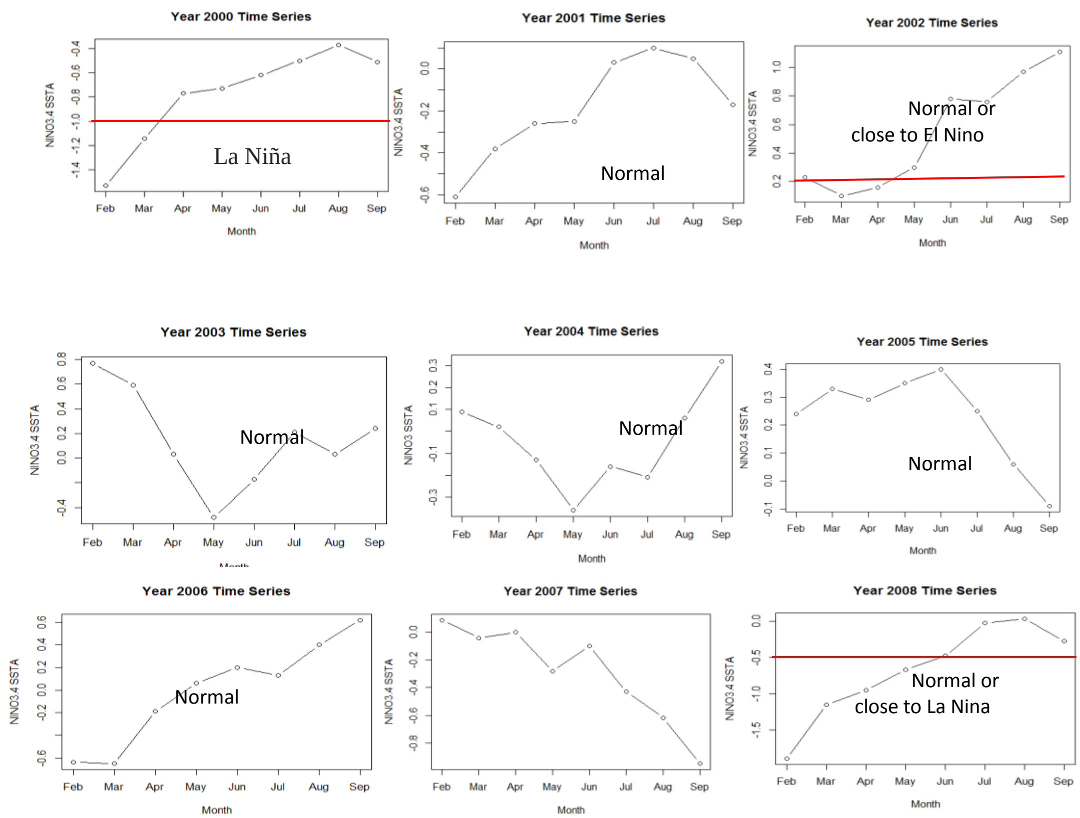


Figure 21 Time series of sea surface temperature anomalies for NINO3.4

5.6 Linear correlation between mean monthly NDVI- and mean monthly rainfall

The correlation result shows strong linear relationship between NDVI and rainfall in the region, which is 0.799 of r^2, P values of 0.002756 and residual standard error of 0.08624 particularly in the year 2004 and almost similar values in the whole year as shown in the (Table 8 and(Figure 22). The scatterplot and map results indicated that the correlations between precipitation and NDVI are positive and exhibits a clear spatial pattern. Precipitation and temperature directly influence water balance, causing changes in soil moisture regime which, in turn, influences plant growth. The coefficient of variation, r^2, indicates that 79 per cent of the variation in vegetation productivity is explained by variation in rainfall in most the years.

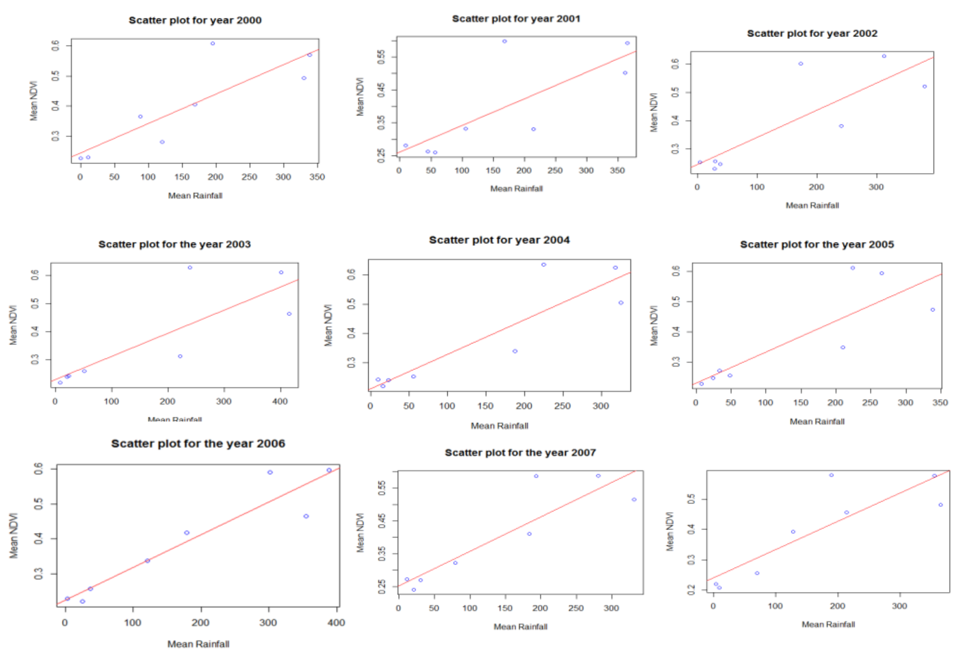


Figure 22 Correlation between mean NDVI and rainfall

5.6.1 Time series maximum and minimum NDVI analyses

In almost the whole years the maximum and minimum vegetation coverage shows the same trend that is low minimum and maximum vegetation coverage in the month February and March. The maximum vegetation coverage in August and September. These vegetation coverage variation is reliance on the seasonal rainfall that falls due to the ENSO effect mainly.

Most of the La Nina episode years that is 2000, 2008 and 2006 shows the maximum NDVI values are below 0.5 in the first two months of Belg season particularly. These reduction of maximum NDVI value in Belg indicates the decrease of rainfall in Belg season due to La Nina episode.

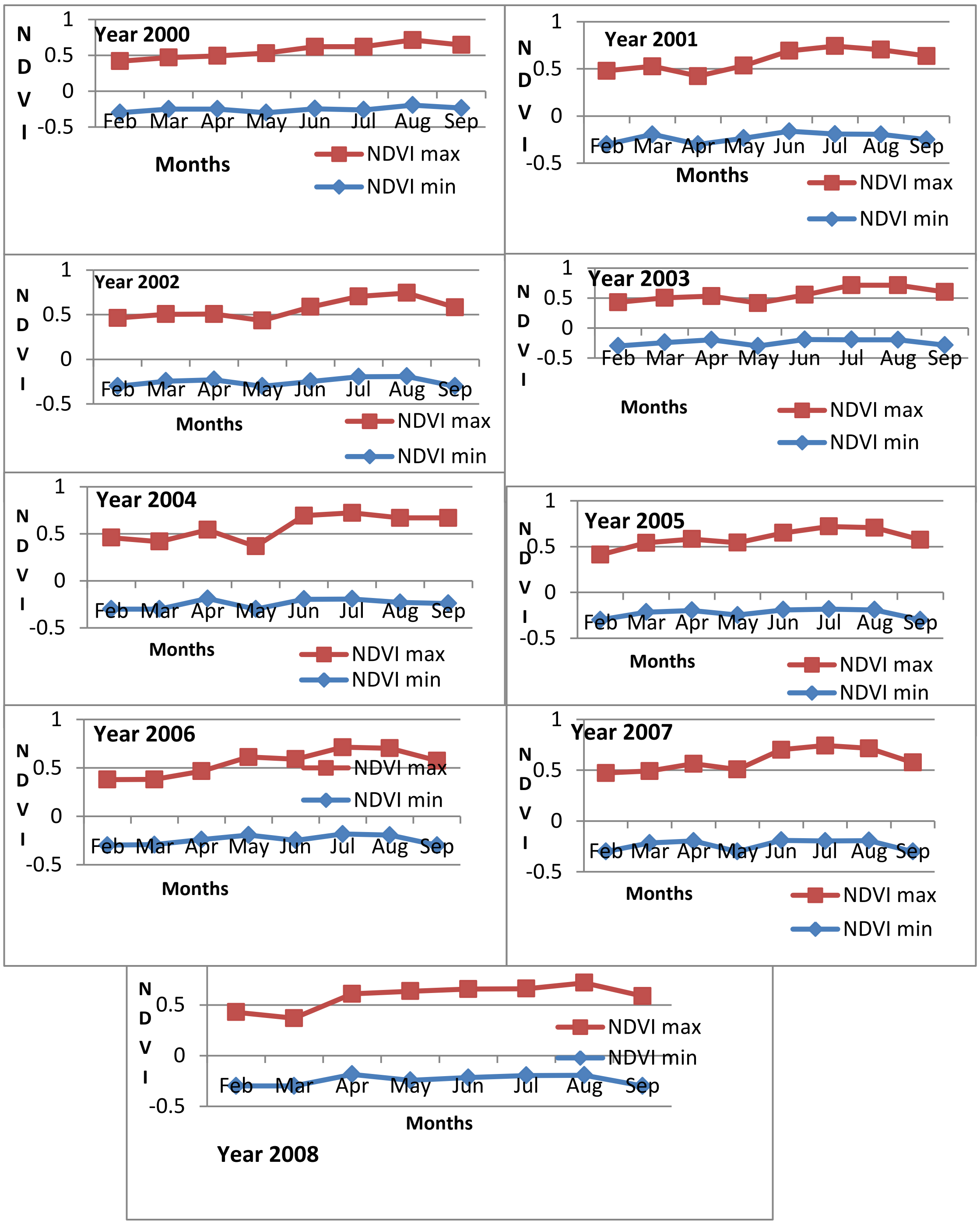


Figure 23 Monthly maximum and minimum NDVI

5.7 Linear correlation between mean monthly NDVI and mean maximum monthly temperature

The scatter plot of maximum temperature and mean NDVI result shows mean maximum temperature negatively correlated with vegetation coverage or NDVI values of the area, which is 0.816 value of r^2, 0.0021 values of p and residual standard error of 0.08252 in the year 2004 and almost similar for another eight years as shown in the (Table 8 and Figure 24). But sometimes the minimum temperature has slightly positive correlation to NDVI, so that temperature also very important climatic element for vegetation to growth depending on the type of vegetation and climatic zone.

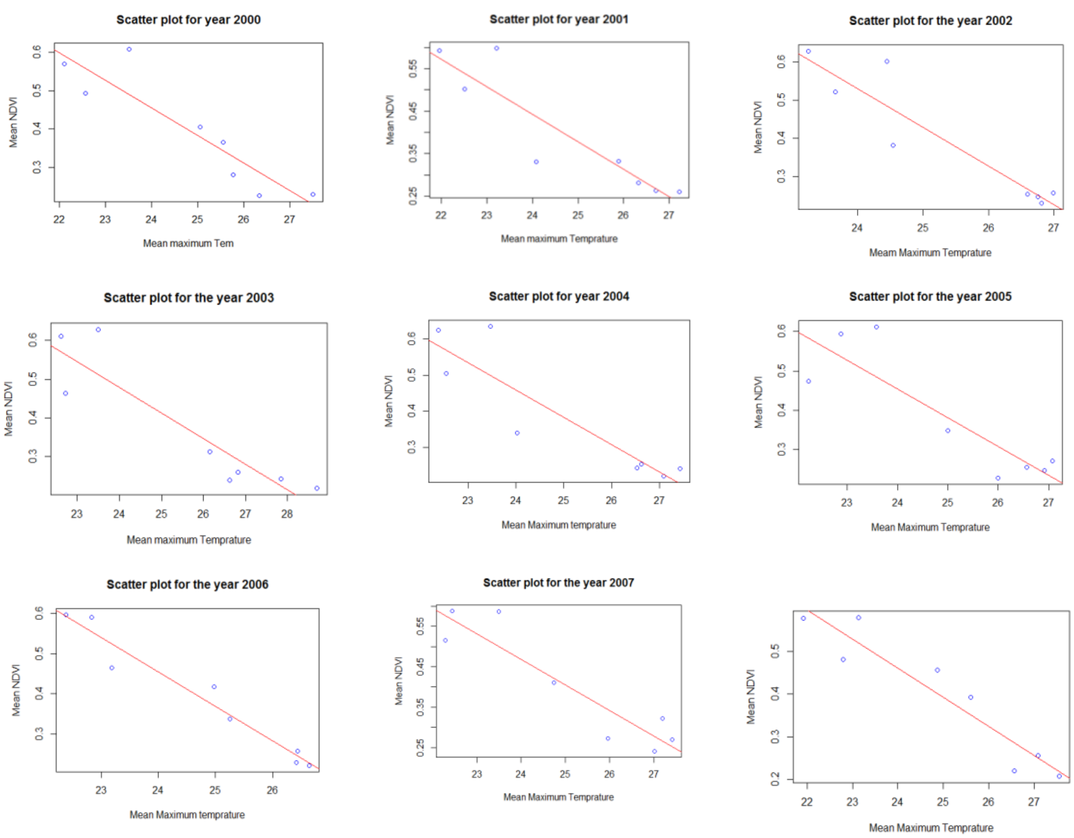


Figure 24 Correlation between mean monthly NDVI and mean maximum monthly temperature

Regression analysis between NDVI, maximum temperature and rainfall

NDVI *versus* rainfall									
YEAR	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
p	0.008174	0.02349	0.0111	0.01184	0.002756	0.009184	0.0003481	0.002517	0.006082
Multiple R^2	0.715	0.6027	0.686	0.6794	0.799	0.7042	0.8977	0.8048	0.7407
Adjusted R^2	0.668	0.5365	0.6336	0.626	0.7655	0.6549	0.8807	0.7723	0.6974
Residual standard error	0.08607	0.09896	0.1026	0.1052	0.08624	0.09336	0.0531	0.0694	0.08396
NDVI *versus* temperature									
YEAR	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
p	0.001577	0.001592	0.0007102	0.001543	0.0021	0.00421	3.248e-05	0.001014	0.0003663
Multiple R^2	0.8323	0.8318	0.8708	0.8335	0.816	0.7695	0.9533	0.8548	0.896
Adjusted R^2	0.8043	0.8037	0.8492	0.8057	0.7853	0.7311	0.9455	0.8306	0.8787
Residual standard error	0.06602	0.06439	0.06585	0.07585	0.08252	0.08241	0.03589	0.05985	0.05317

Linear equation for NDVI *versus* rainfall		**Linear equation for NDVI *versus* temperature**	
2000	NDVI=0.0009802RF + 0.2433817	**2000**	NDVI= -0.7182T + 2.17838
2001	NDVI= 0.0008128RF + 0.2604580	**2001**	NDVI= -0.06476T + 1.9974
2002	NDVI= 0.0009552Rf + 0.2469023	**2002**	NDVI= -0.1012T + 2.9585
2003	NDVI= 0.0008285RF + 0.228489	**2003**	NDVI= -0.06651T + 2.07510
2004	NDVI= 0.001175RF + 0.211507	**2004**	NDVI= -0.07586T + 2.27937
2005	NDVI=0.00103RF + 0.23052	**2005**	NDVI= -0.07284T + 2.20226
2006	NDVI= 0.0009408RF + 0.2234609	**2006**	NDVI= -0.08631T + 2.52687
2007	NDVI= 0.001053RF + 0.252186	**2007**	NDVI= -0.06297 T + 1.97965
2008	NDVI= 0.0009309RF + 0.2408738	**2008**	NDVI= -0.06816T + 2.09619

Table 8 Regression analysis between NDVI, maximum temperature and rainfall

5.8 Correlation between Sea surface temperature anomalies and rainfall

The correlation between Pacific Ocean sea surface temperature anomalies and the region rainfall is not consistence sometimes negative, positive or no correlation at all but most of the time they have positive correlation (Figure 25 and (Table 9). In the fully strong ENSO/ El Nino or La Nina episode years like 2000 and 2002 sea surface temperature and rainfall have positive correlation to each other with P and r2 values 0.005316, 0.7516 and 0.01884, 0.629 respectively (Table 9). In the year 2005 they have weak negative correlation to each other, and in the year 2003 they doesn’t have correlation to each other (Figure 25 and(Table 9).

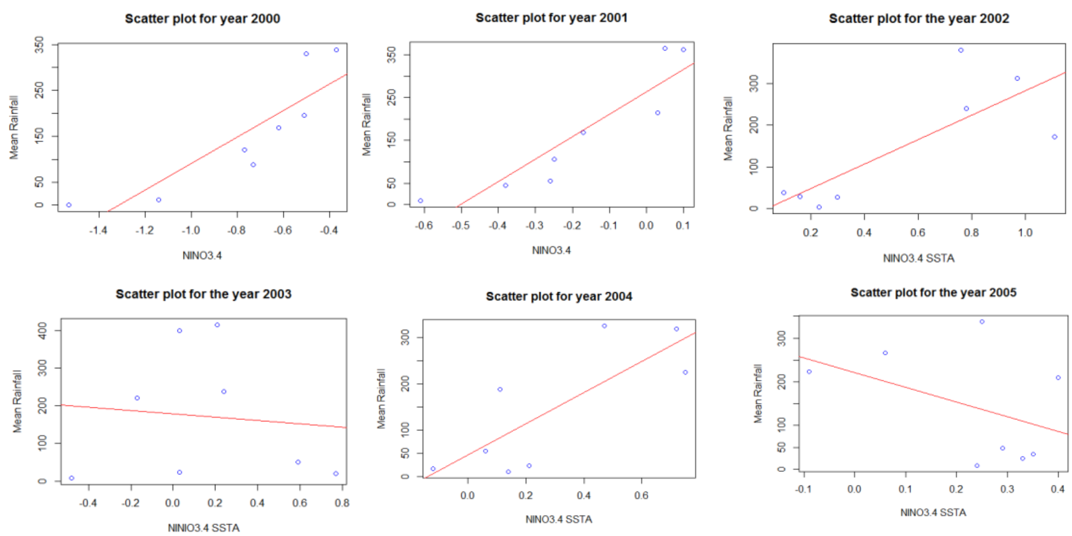


Figure 25 Correlation between sea surface temperature anomalies and rainfall for both seasons

	2000	2001	2002	2003	2004	2005
p	0.005316	0.001542	0.01884	0.8088	0.01914	0.2935
Multiple R^2	0.7516	0.8335	0.629	0.01054	0.6272	0.1809
Adjusted R^2	0.7102	0.8058	0.5672	-0.1544	0.5651	0.04436

Table 9 Regression analyses between NINO3.4 sea surface temperature anomalies and rainfall

5.9 Correlation between elevation and mean rainfall

The spatial pattern of mean precipitation and vegetation in region relative to elevation for nine year analyses shows that somehow weak but positive (Figure 6, Figure 16, Figure 17 and Figure 43). Although production of rainfall is complex and this study doesn’t consider other physical principles that is wind direction and convergence, rain bearing, distance from the sea and others helpful for rainfall production, the statistical correlation between rainfall to elevation also show a little weak positive (Figure 26). Precipitation tends to increase with increasing elevation, mainly because of the orographic effect of mountainous terrain, which causes the air to be lifted vertically, and the condensation occurs due to adiabatic cooling. Rain gauges provide information on precipitation, but existing rain-gauge networks, especially in mountainous areas, are generally not dense enough to reveal variability in precipitation over spatial scales.

The pattern of precipitation is more closely related monsoon activities, Inter-tropical Convergences Zone (ITCZ), upper atmospheric Jet streams, vegetation coverage of area than different of elevation. The Belg season rainfall shows more strong statistical positive correlation and increasing with elevation than Kiremt season rainfall (Figure 33 and Figure 16). The Belg season spatial vegetation coverage pattern is also more visible in elevated or highland areas than lowland areas as we compare it with Kiremt season (Figure 33 and Figure 34). Generally, sub-tropical zone (Woina Dega) agro climatic region, which is closing to 2000m elevation has good amount of about 200mm rainfall per month (Figure 26).

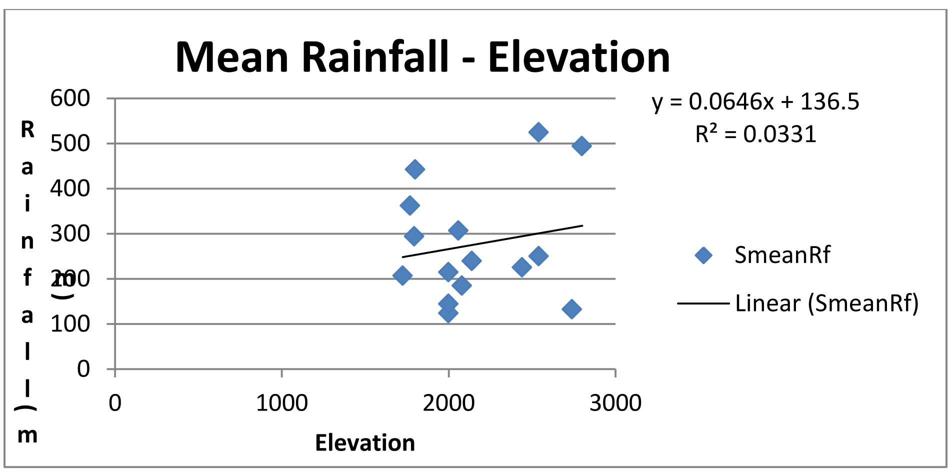


Figure 26 Linear regression between Elevation and Rainfall

5.10 General quantitative statistical analyses of vegetation condition or total biomass

Maximum NDVI indicates maximum green biomass, while minimum indicates minimum green biomass. The different between maximum and minimum NDVI reflects biomass production. The biomass production NDVI max minus NDVI min for Belg season is almost similar for the whole year that is about 0.96 except 0.88 in the year 2006 (Table 10). The biomass production in Kiremt season also similar but somehow more than Belg that is 1.03 almost in the whole years except 0.99 in the year 2001 (Table 10). The Belg and Kiremt season NDVI coefficient of variation shows high instability or variability. Belg season NDVI coefficient of variation is very high in the year 2000 and 2002. Kiremt season NDVI coefficient of variation shows high instability or variability in the year 2002, 2003, 2004, 2005 and stable in the year 2000, 2001, 2007 and 2008 (Figure 27 and Figure 28). Generally, two annual growing season (Belg and Kiremt) biomass production during the nine years indicates that NDVI max minus NDVI min shows increasing, while the NDVI coefficient of variation unstable or highly variable (Table 10).

The correlation coefficient between rainfall and NDVI for different type of land cover like deciduous forest , shrub land and cropland is very much less or insignificant that is R^2=0.4484, R^2=0.5242 than the correlation coefficient between rainfall and NDVI in the total study area land cover type is like R^2=0.7, R^2=0.8 (Figure 46 and Table 8). The NDVI values of Shrub land and deciduous forest is greater than the NDVI values of cropland and grassland (Figure 46). The direct correlation between NDVI and NINO3.4 Sea surface anomalies is very variable some times in most of the years they have strong positive correlation coefficient like 0.722, 0.8868, 0.9082, 0.8645 and 0.7861 in the year 2000, 2002, 2004, 2006 and 2008 respectively (Figure 45). In the other hand, the correlation between NDVI and NINO3.4 sea surface anomalies is strong negative like 0.667 and 0.8039 for the year 2005 and 2007 respectively, and the correlation in the year 2001 and 2003 is either insignificant or very less (Figure 45)

Years	**Belg Season**		**Kiremt season**		**Interpretation of biomass variation**
	Max-Min NDVI	**NDVI CoV**	**Max-Min NDVI**	**NDVI CoV**	
2000	0.977	0.540363636	1.0003	0.396415494	Increase + unstable
2001	0.9112	0.473980309	0.9963	0.394742044	Increase + unstable
2002	0.959	0.615042459	1.0365	0.417493913	Increase + unstable
2003	0.9016	0.527021366	1.0001	0.402264601	Increase + unstable
2004	0.9326	0.544844929	1.0398	0.387440533	Increase + unstable
2005	0.9629	0.552232855	1.021	0.40295858	Increase + unstable
2006	0.8819	0.520306513	1.0354	0.424324324	Increase + unstable
2007	0.9329	0.5274765	1.0286	0.400647126	Increase + unstable
2008	0.9406	0.539033457	1.0255	0.402254921	Increase + unstable

Table 10 General quantitative vegetation condition

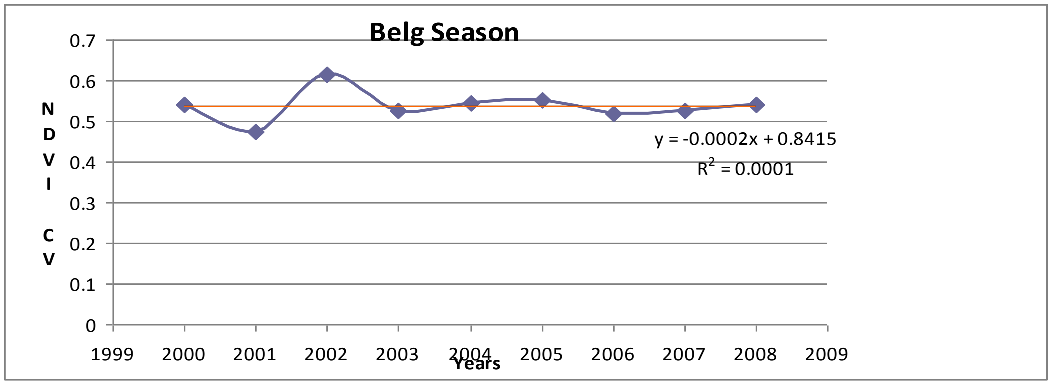


Figure 27 Pattern of Belg season NDVI Coefficient of variation over time

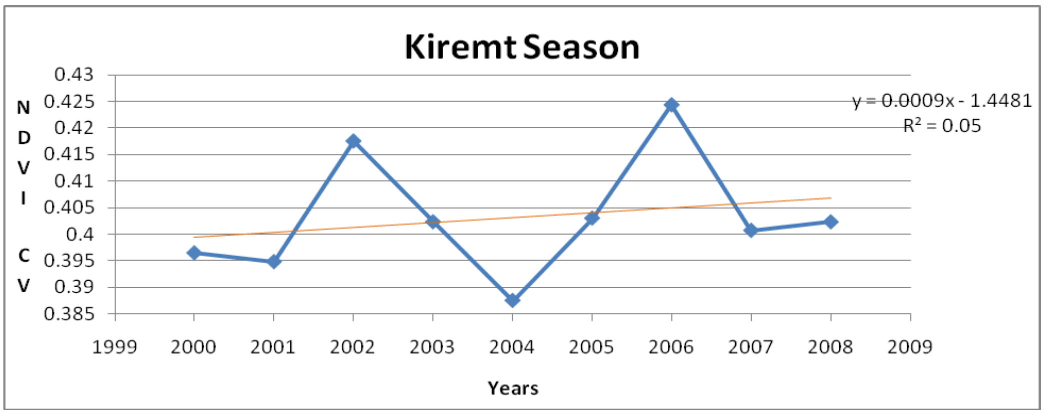


Figure 28 Pattern of Kiremt season NDVI Coefficient of variation over time

6 CONCLUSION AND RECOMMENDATION

The relationship between precipitation and NDVI is very strong and predictable when observed at the appropriate spatial and temporal scale. The phenology of vegetation in all formations closely reflects the seasonal cycle of rainfall. Within the period 2000–2008 there is considerable monthly, seasonal or year-to-year variation in precipitation and NDVI throughout the region of Gojam. The yearly correlation coefficients between NDVI and precipitation are very high, while the correlation between NDVI and temperature are low. The total growing season analyses show that the general temporal or spatial distribution of NDVI in the whole study area corresponds directly with the spatial pattern of average monthly or annual precipitation. Belg season NDVI coefficient of variation analyses shows high instability or variability in both fully strong El Nino or La Nina episodes in 2000 and 2002 but the Kiremt season NDVI coefficient of variation is more highly variable in the whole years.

Gojam is a region in the tropics or in monsoon region, so that tropical pacific ocean circulation effect, that is ENSO/ El Nino or La Nina episodes, has a great impact in the seasonal rainfall variability. The ENSO result shows one clear and full El Nino episode in 2002, which shows total increase of spatial vegetation coverage as compares to La Nina years of 2000 and 2008. ENSO warm phase events (El Nino) were associated with high NDVI values, due to an increase of precipitation in Belg season. Regarding maximum temperature and NDVI the result shows strong negative correlation between each other. But the immediate decrease of maximum temperature, particularly in March or May, indicates that the starting of main rainy season, Kiremt rainfall, and increasing of vegetation growth in almost the whole years. Spatiotemporal analyses of NDVI shows lowest maximum, minimum and mean vegetation coverage in February and March in almost all the years or months, while July and August shows the highest maximum, minimum and mean NDVI values.

The strong El Nino episode year 2002 shows an earlier starting of rainfall in March, while during La Nina episode period year 2000 and 2008 rainfall started later in April. February mean rainfall is becoming almost zero in the whole nine years. The Kiremt season El Nino episode show earlier decrease of rainfall as we compare it to La Nina episode. Generally, year 2003 shows increasing or good amount of rainfall in both seasons, while 2005 and 2007 show decreasing amount of rainfall in both seasons.

February monthly vegetation coverage analyses shows that 2001, 2002 and 2007 have better medium vegetation coverage in the eastern and central part of the region than other years. March vegetation coverage analyses also shows good (but less than February) medium vegetation coverage in those areas and more vegetation coverage in the central part in the years 2001, 2002, 2003 and 2007. April monthly vegetation coverage shows better medium vegetation coverage in the years 2000, 2002 and 2007 than February and March. May monthly vegetation coverage shows more medium and high vegetation coverage in the year 2000, 2001, 2006, 2007 and 2008 than February, March and April. All Kiremt months (June, July, August and September) have shown better high and medium vegetation coverage except some parts of the region in the west peripheries.

It seems that there is a possibility to predict rainfall in Gojam if the SSTAs and El-Nino events could be forecasted in good time ahead. So that it would be very important for decision-makers in order to make more effective management in agricultural and water resources. Besides, all seasonal rainfall dependent sectors can be beneficiary from ENSO forecast ahead as they prepare themselves depending on the seasonal rainfall forecasts. The *Belg* rains are used for land preparation for the main rainy season Kiremt and some crop products such as potato, sorghum and others used to sow if the Belg rain comes earlier. Untimely Belg rainfall means poor land preparation for the main rainy season that leads to increased unwanted infestations of certain pests and reduction of crop production. El Nino episode increases the amount of rainfall in Belg season particularly In February and March. It is advisable for farmers to sow Belg crops during El Nino episode and Belg crop during La Nina episodes.

The total temporal and spatial analyses of climatic elements and vegetation characteristics of the region shows instability or variability of both climatic elements and vegetation coverage during the study period from 2000-2008. Long year data analyses of climatic elements and vegetation coverage including the whole three seasons (Belg, Kiremt and Dry) and advanced statistical techniques would be important to understand the variability. The detail observation of the vegetation map clearly shows spatial and temporal variability of greenness due to rainfall variability of region. ENSO El Nino or La Nina episodes has great influence in the seasonal rainfall of the region which may weaken, increase or dislocate the seasonal rainfall spatially or temporally.

Generally, El Nino warm phase of ENSO shows the increase of vegetation coverage in the region due to earlier starting of rainfall during the El Nino episode. La Nina, the cold phase of ENSO, shows decrease of vegetation coverage in the region due to the late starting of rainfall in the region. The monthly trend analyses of NDVI and rainfall shows strong variability in most of the months but February, March, June and July shows decreasing trend from year 2003-2008.

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APPENDICES

Appendix 1: Some general statistical analyses of climate variables and vegetation condition

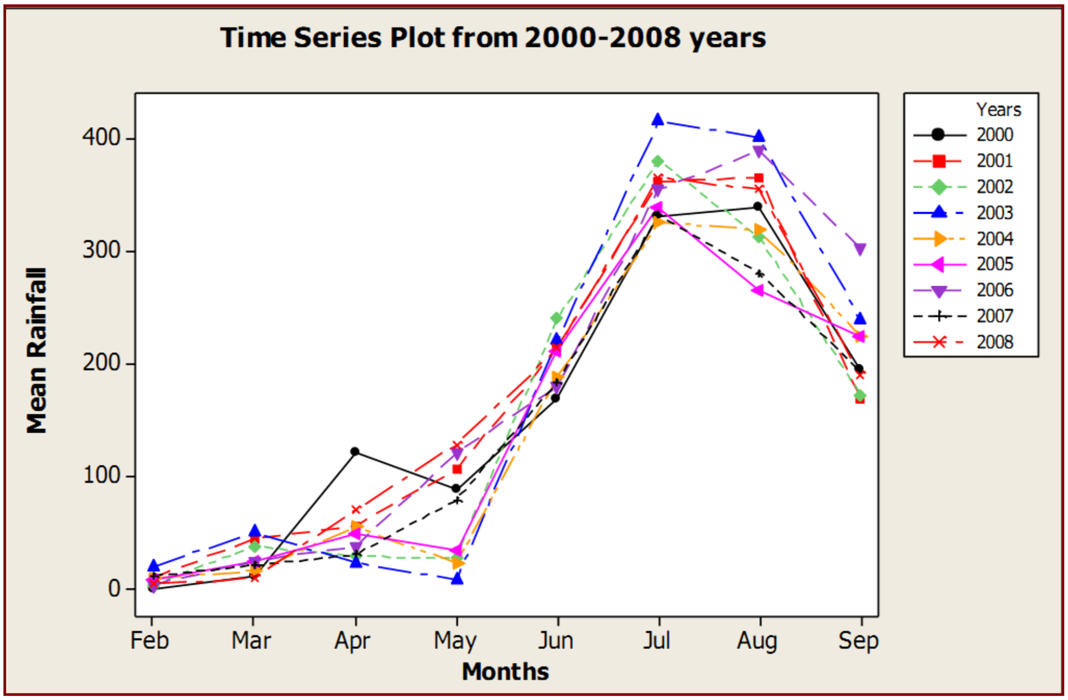


Figure 29 Time series mean monthly rainfall variation from 2000-2008

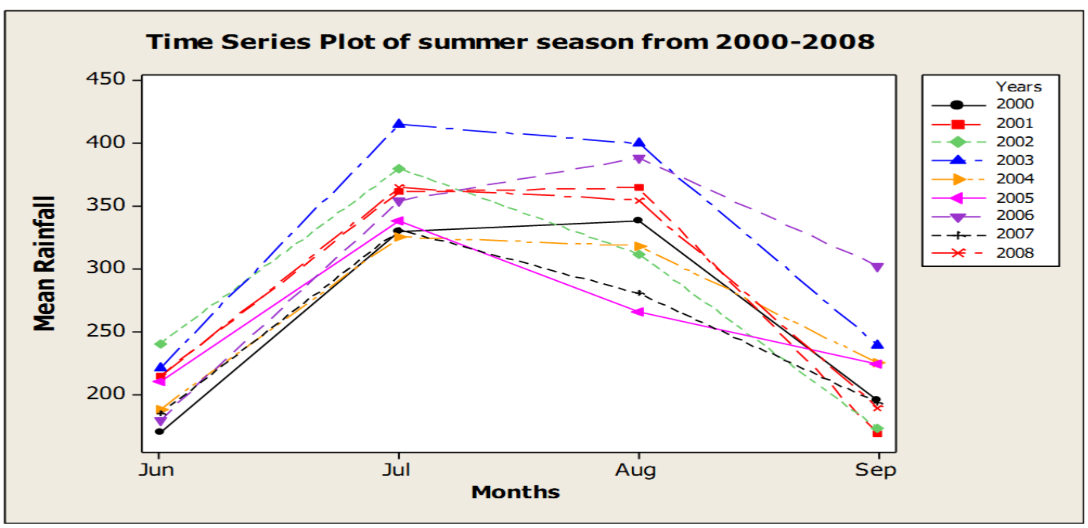


Figure 30 Kiremt or summer season mean monthly rainfall variation from 2000-2008

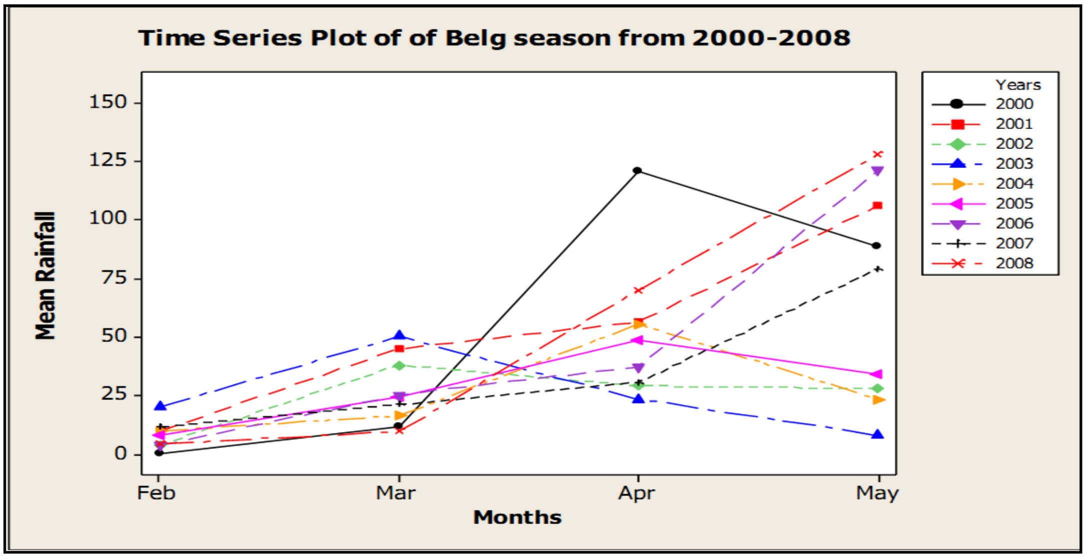


Figure 31 Belg season mean monthly rainfall variation from 2000-2008

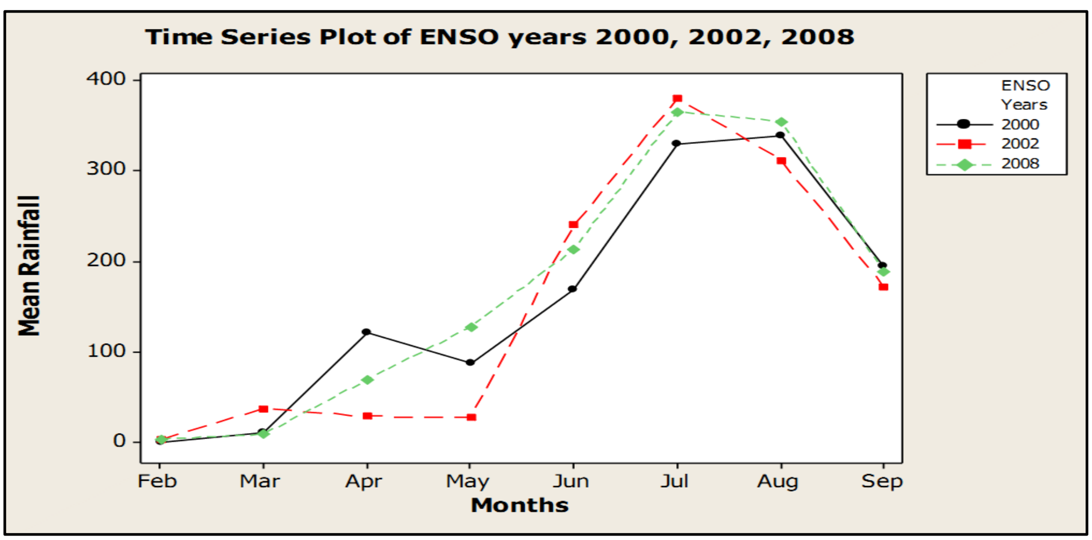


Figure 32 Mean rainfall of ENSO/ La Nino or El Nino years

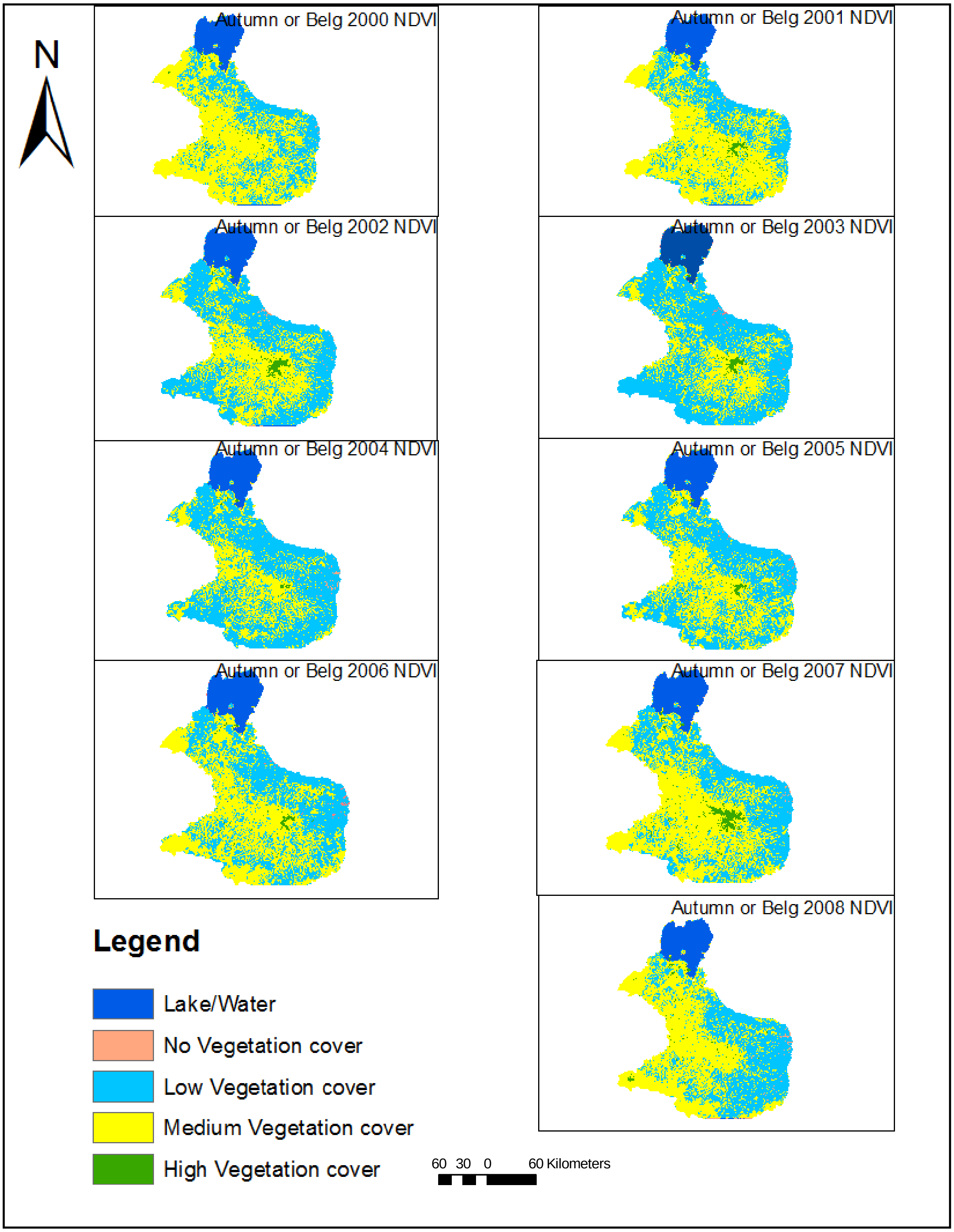


Figure 33 Belg season yearly time series Vegetation coverage from 2000-2008

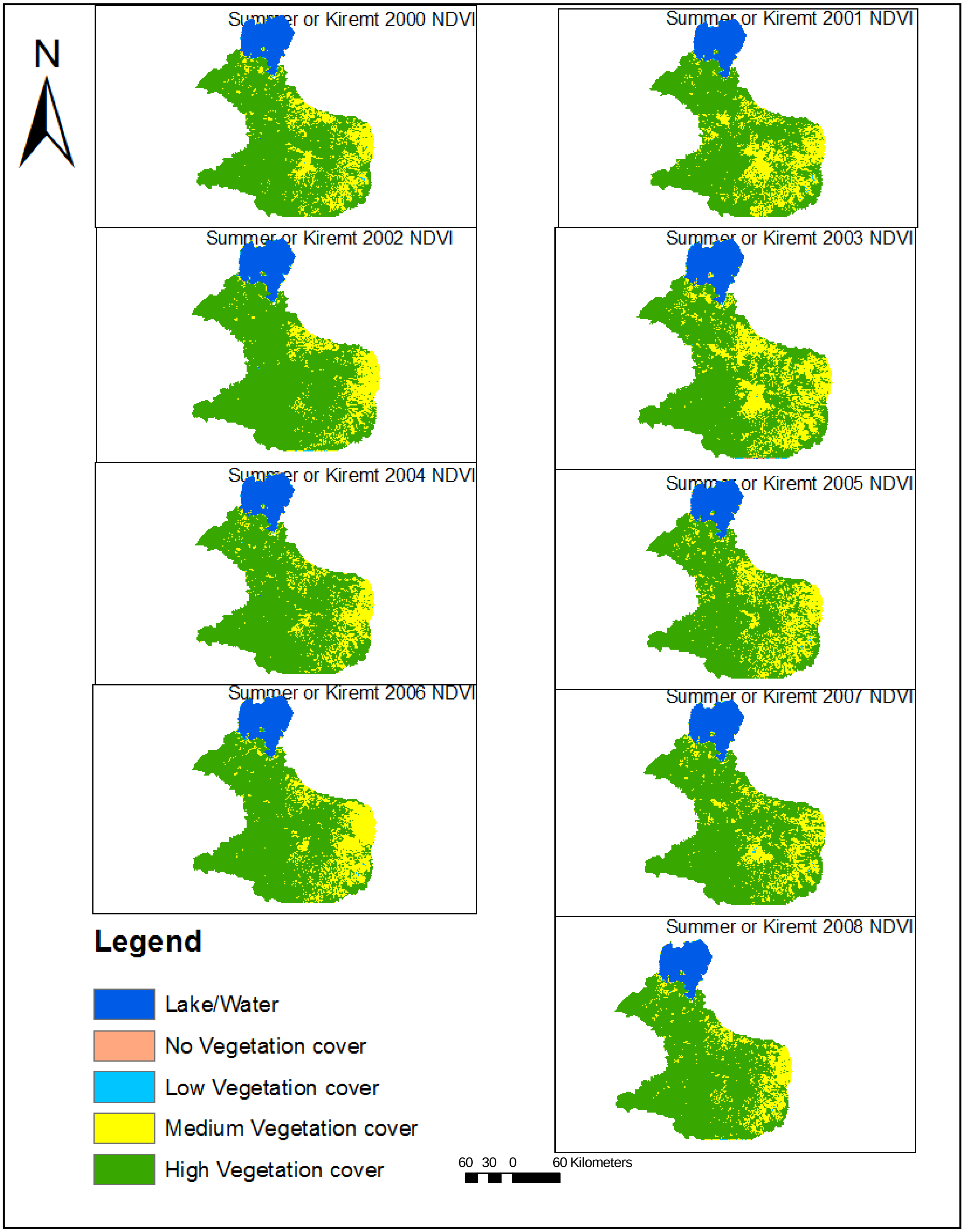


Figure 34 Kiremt season yearly Vegetation coverage from 2000-2008

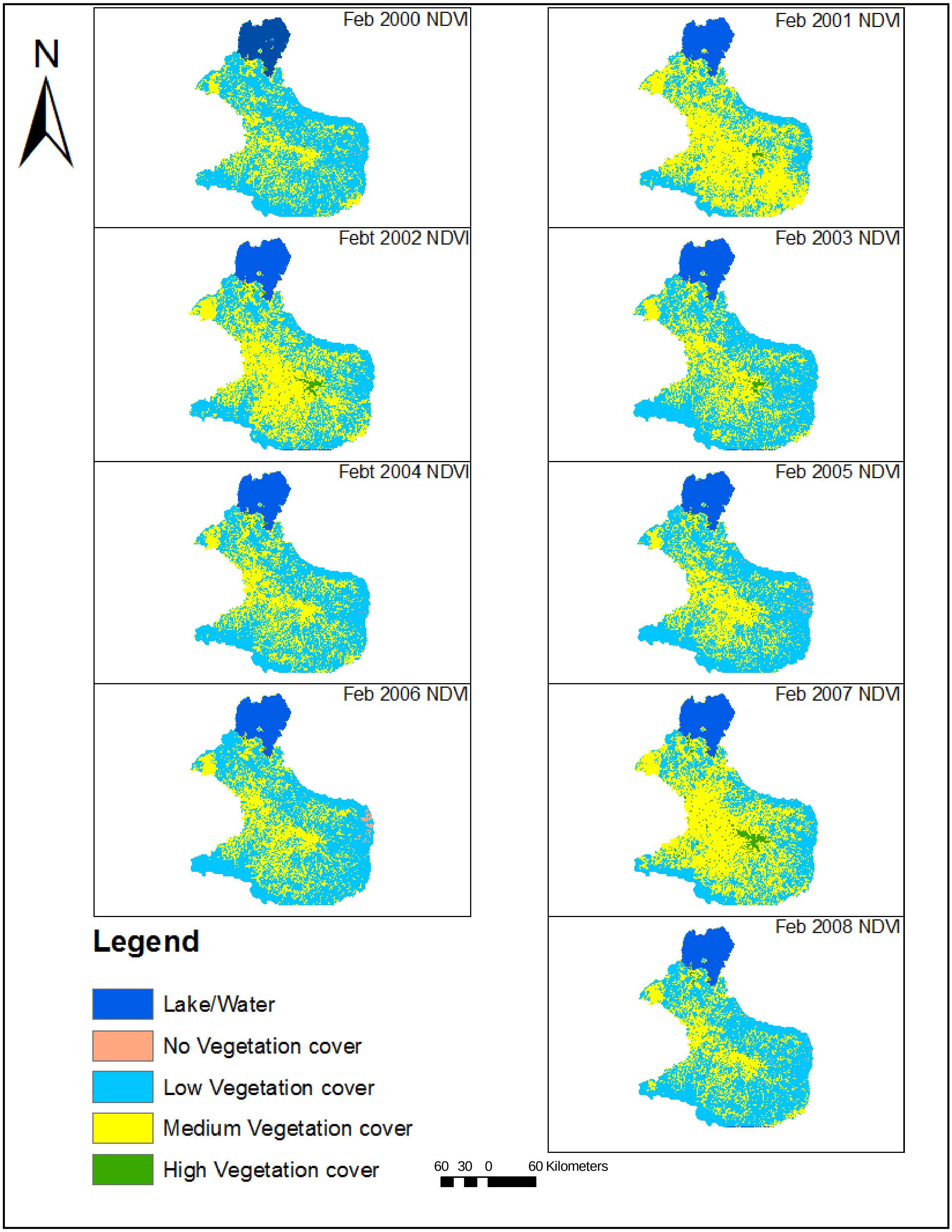


Figure 35 Trend analyses of February monthly vegetation coverage from 2000-2008

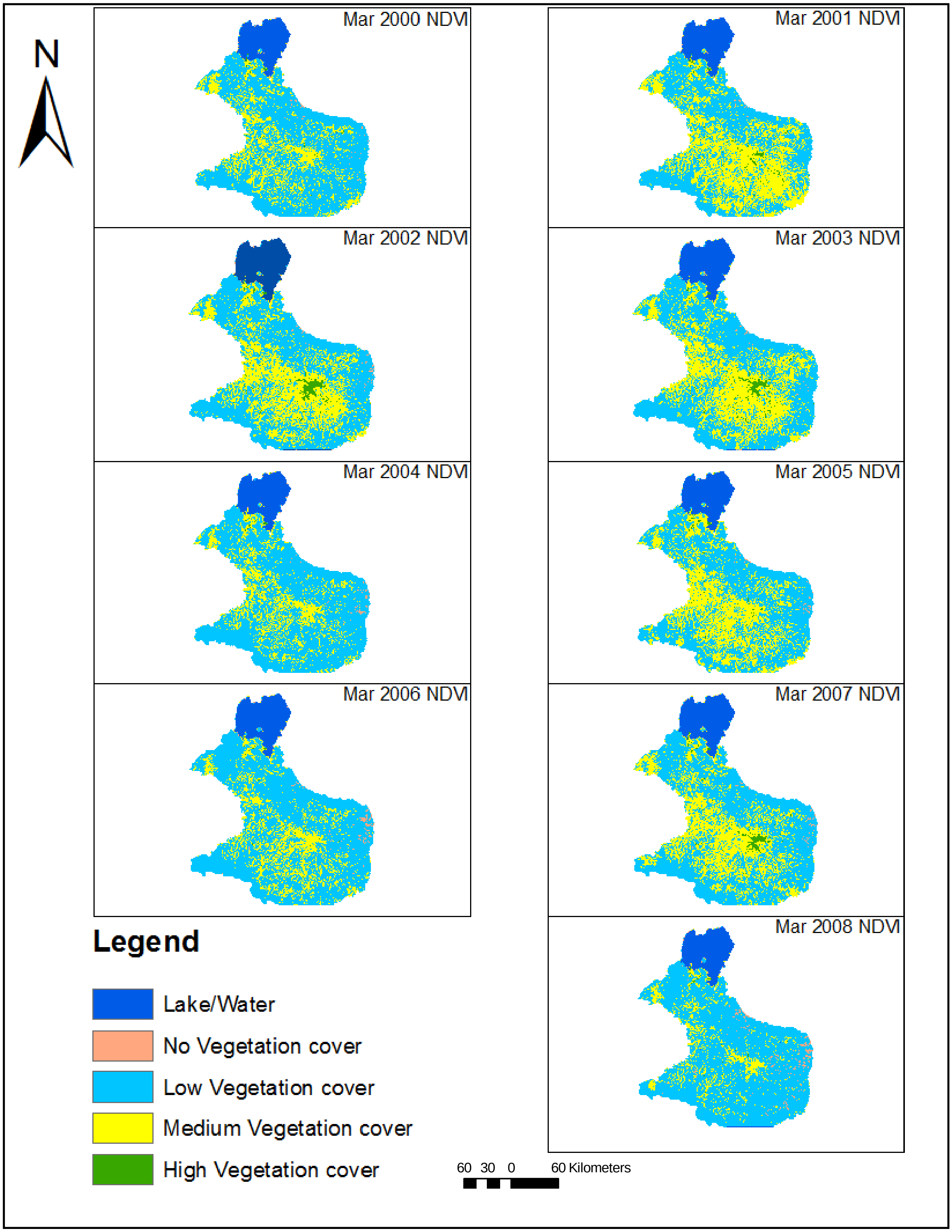


Figure 36 Trend analyses of March monthly vegetation coverage from 2000-2008

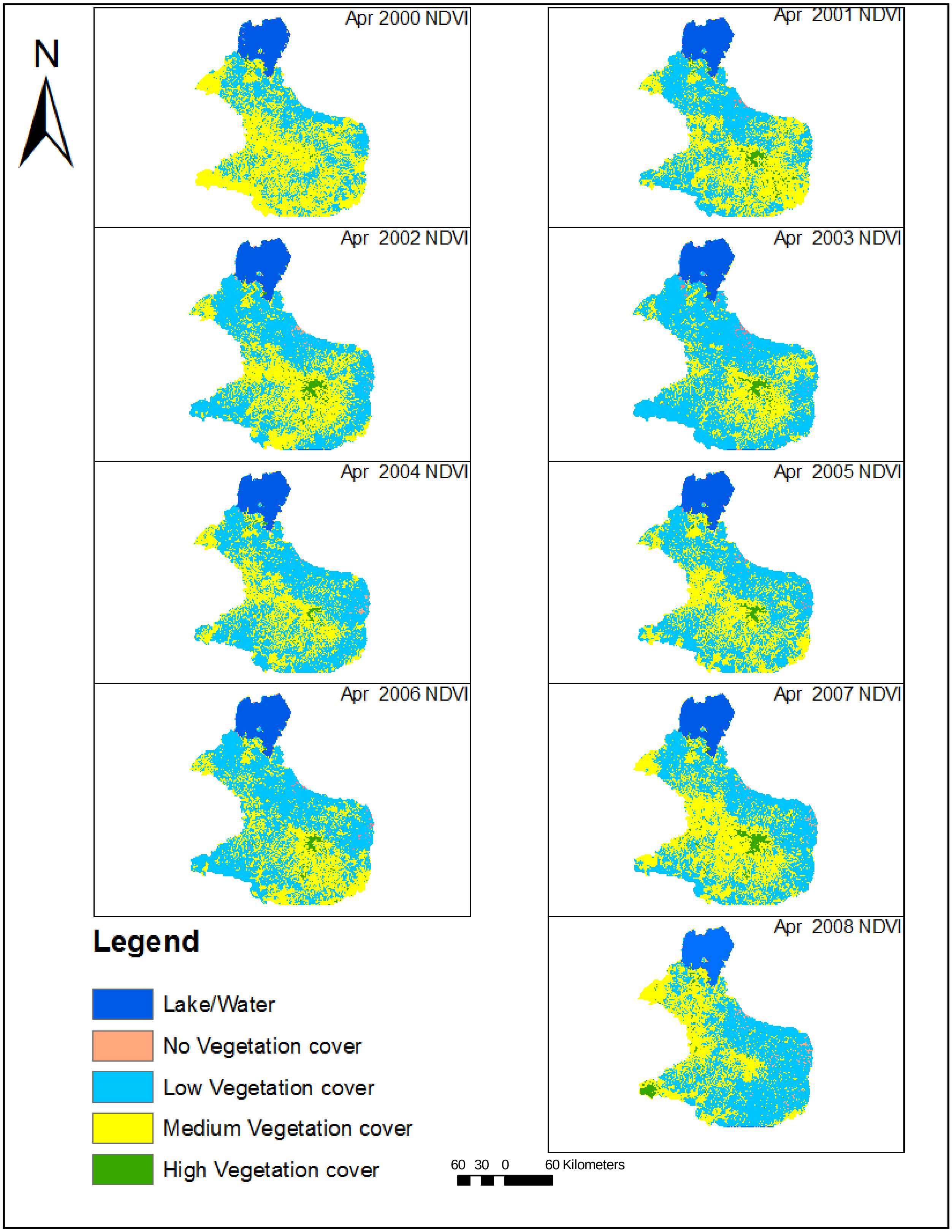


Figure 37 Trend analyses April monthly vegetation coverage from 2000-2008

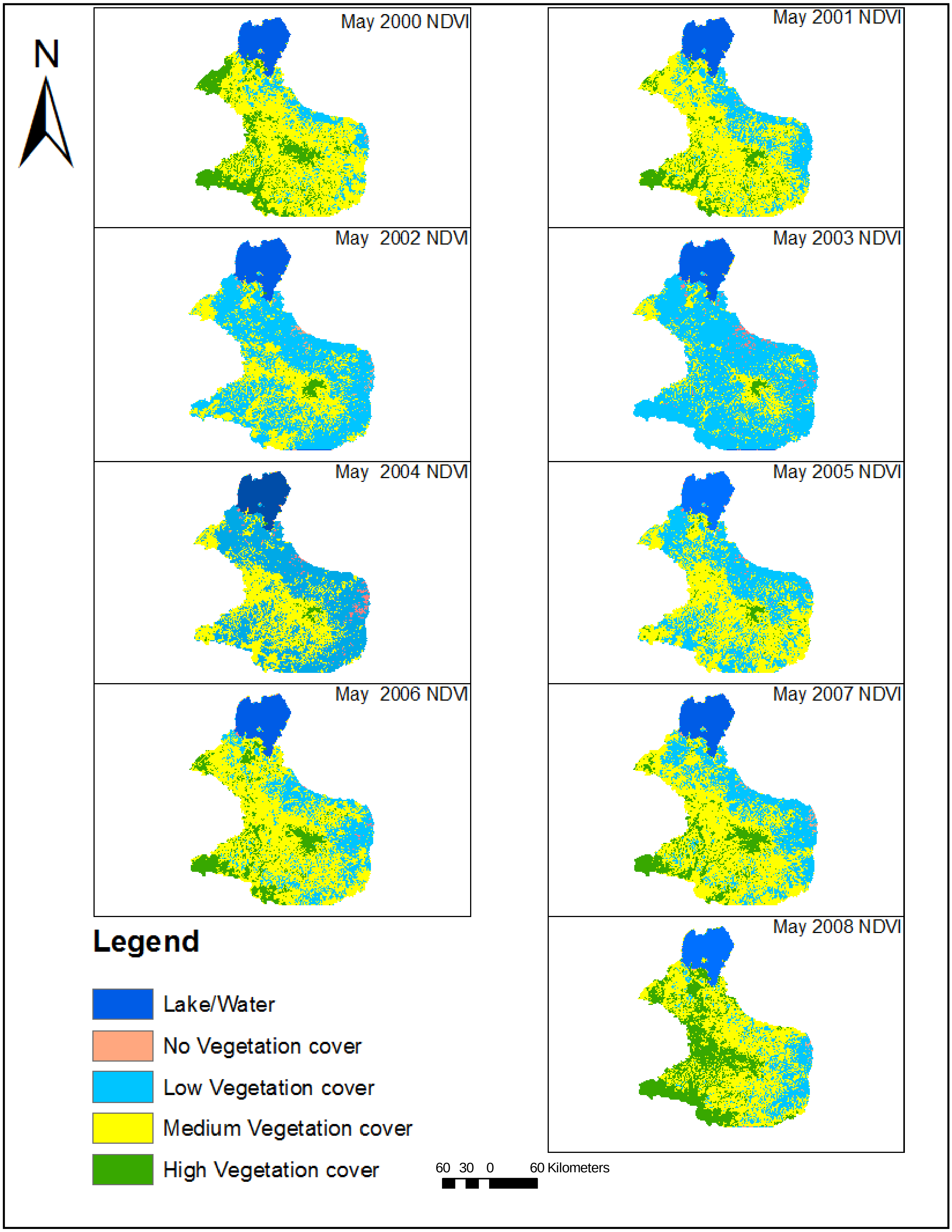


Figure 38 Trend analyses of May monthly vegetation coverage from 2000-2008

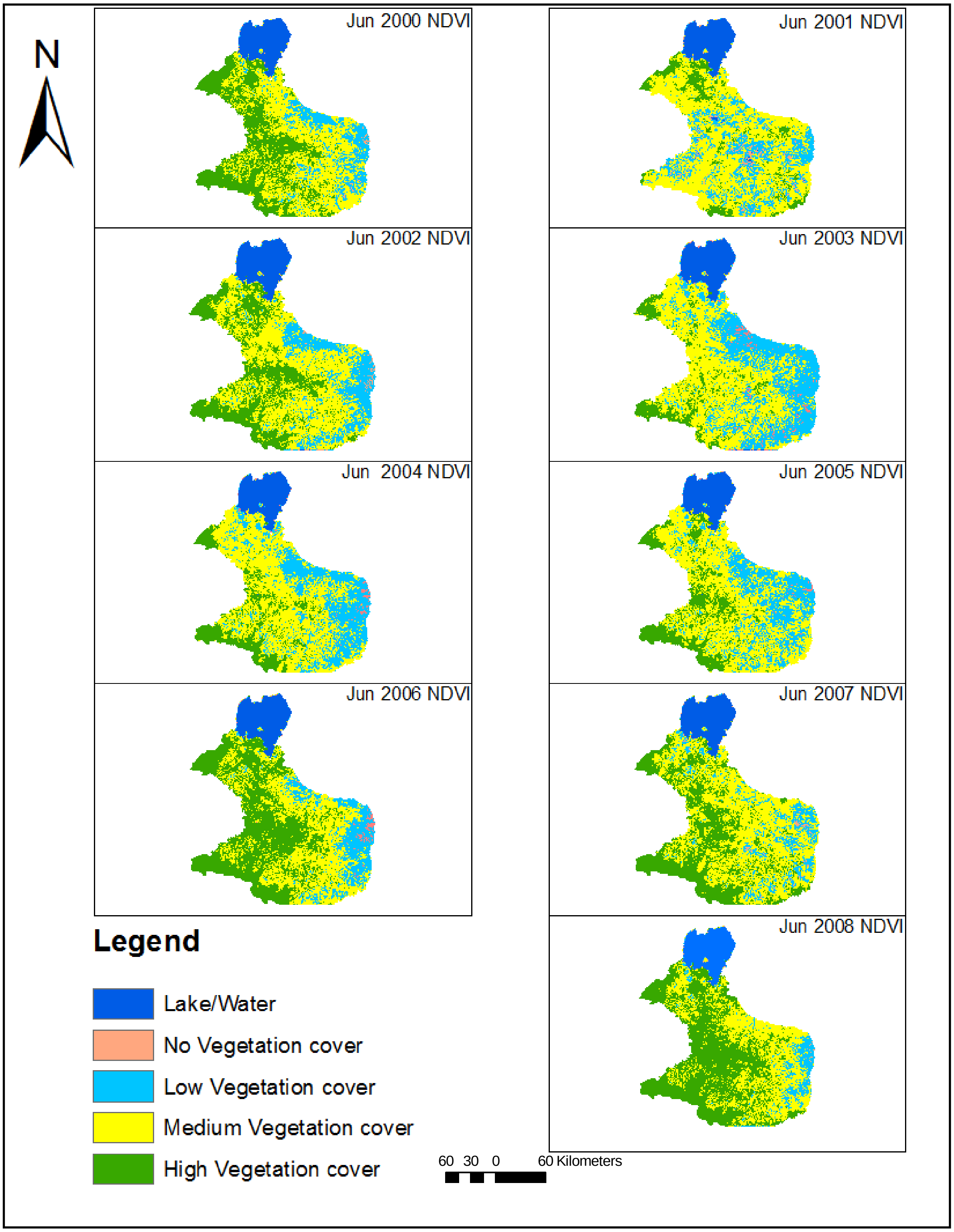


Figure 39 Trend analyses of June monthly vegetation coverage from 2000-2008

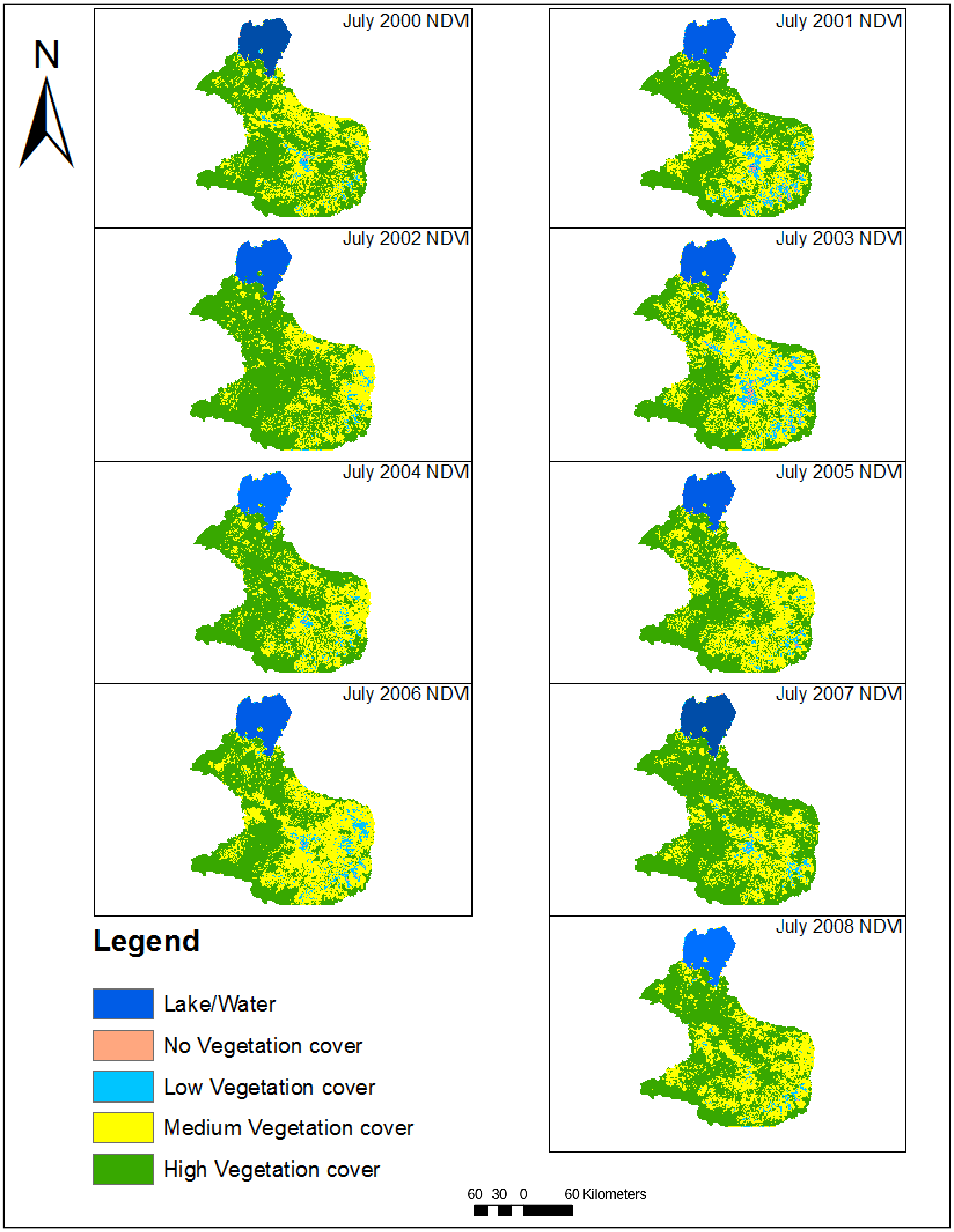


Figure 40 Trend analyses of July monthly vegetation coverage from 2000-2008

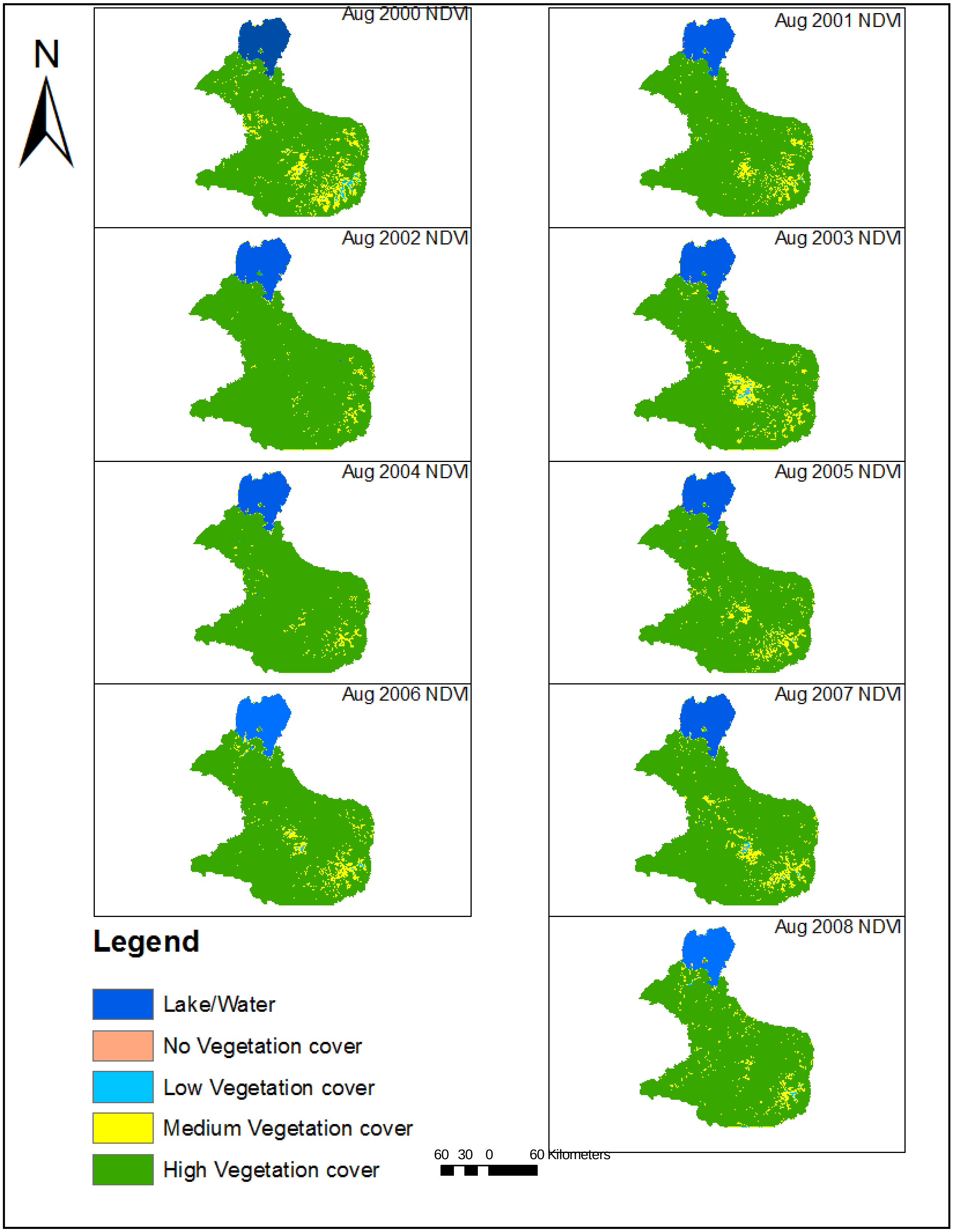


Figure 41 Trend analyses of August monthly vegetation coverage from 2000-2008

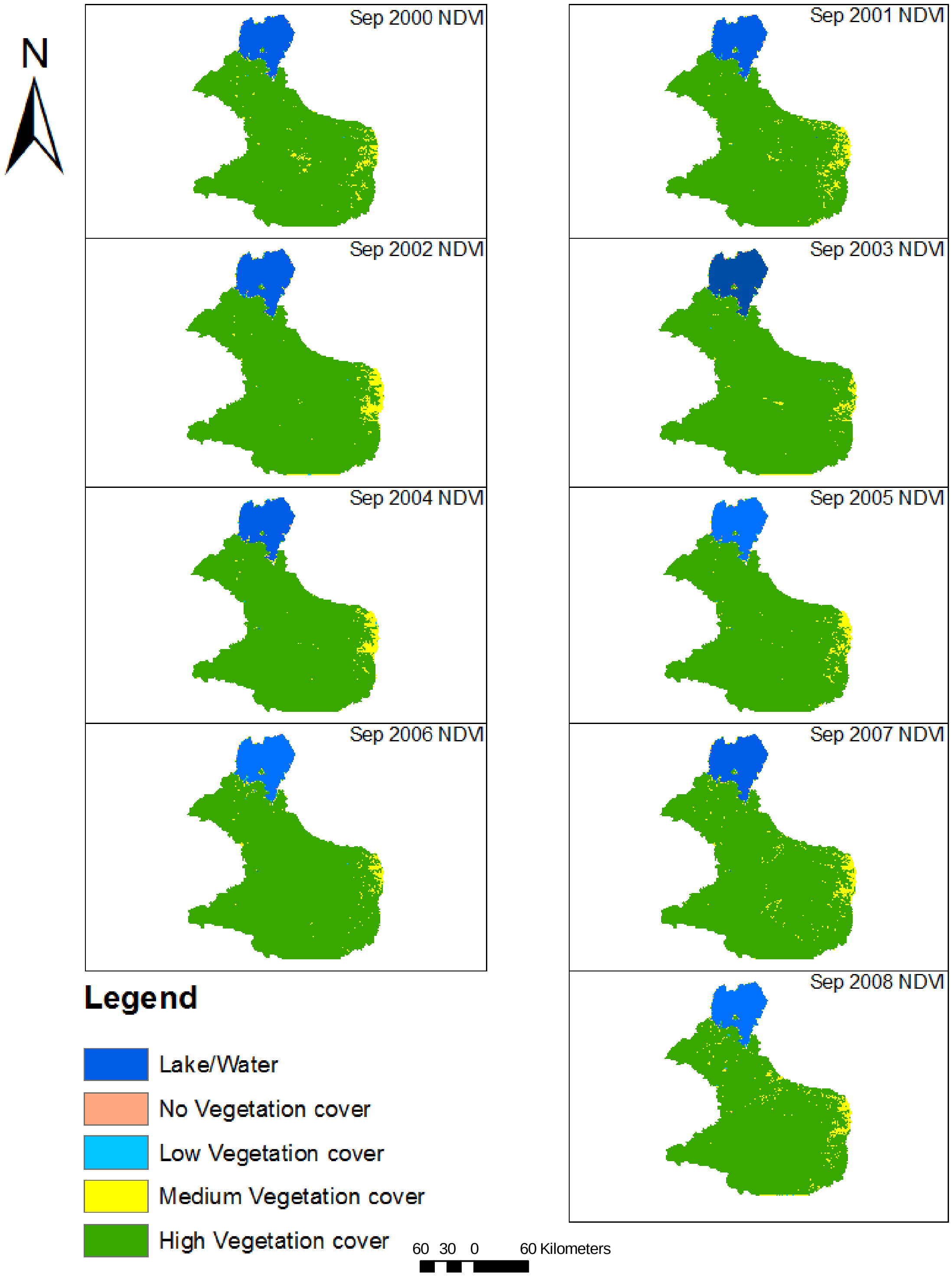


Figure 42 Trend analyses of September monthly vegetation coverage from 2000-2008

Monthly Spatial variation of NDVI During nine years

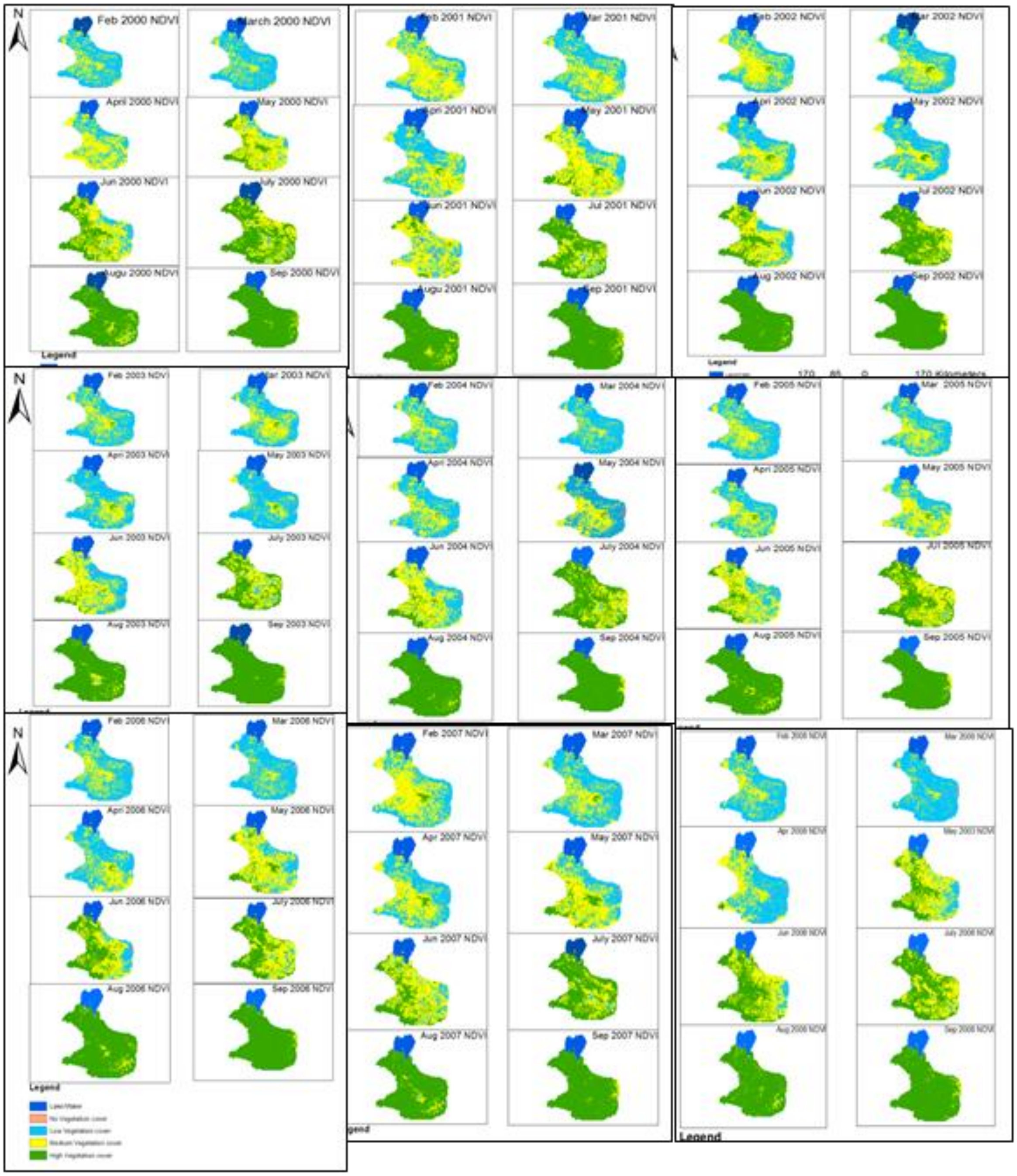


Figure 43 Mean monthly Spatial variation of NDVI in Belg and Kiremt from 2000 - 2008

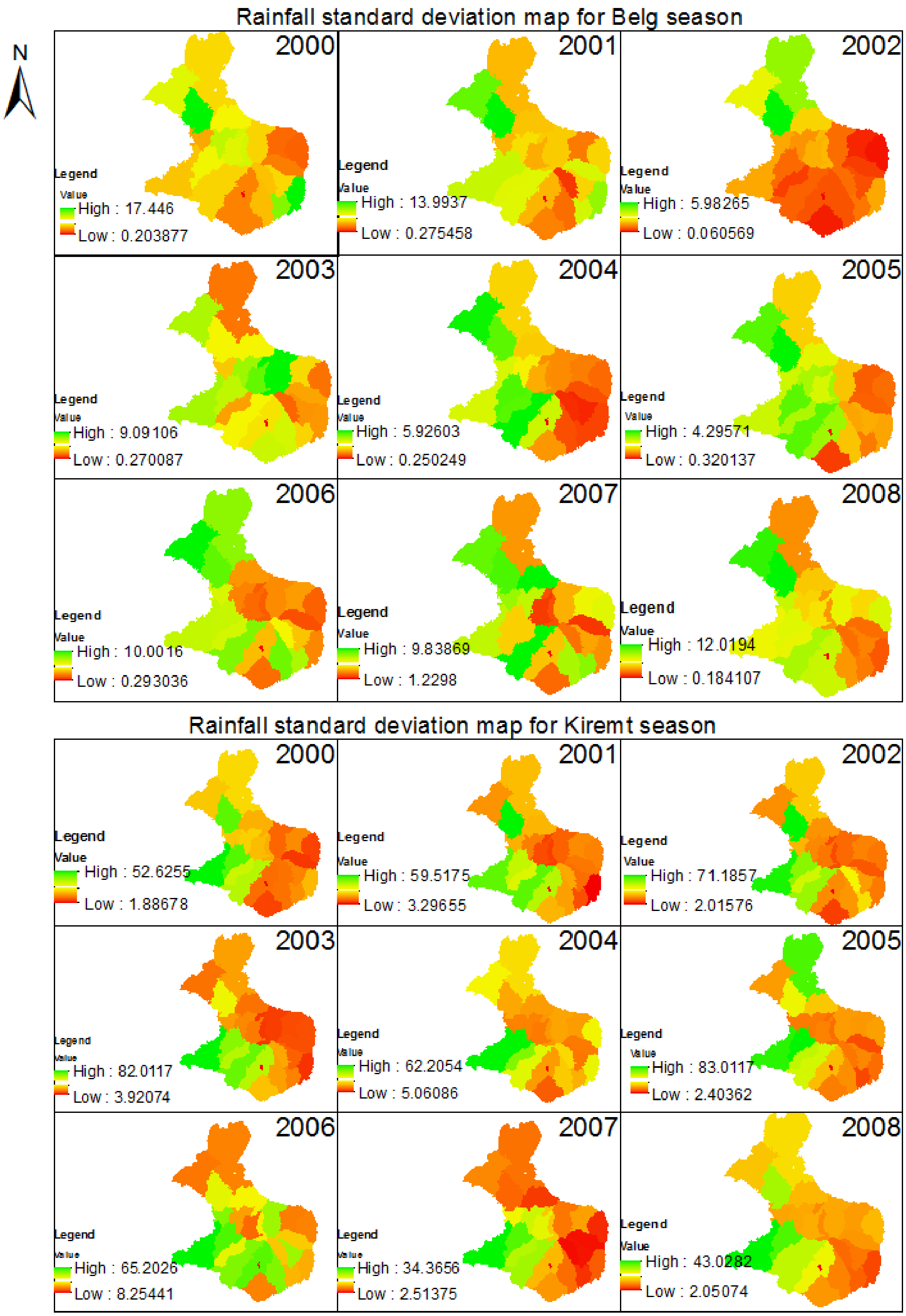
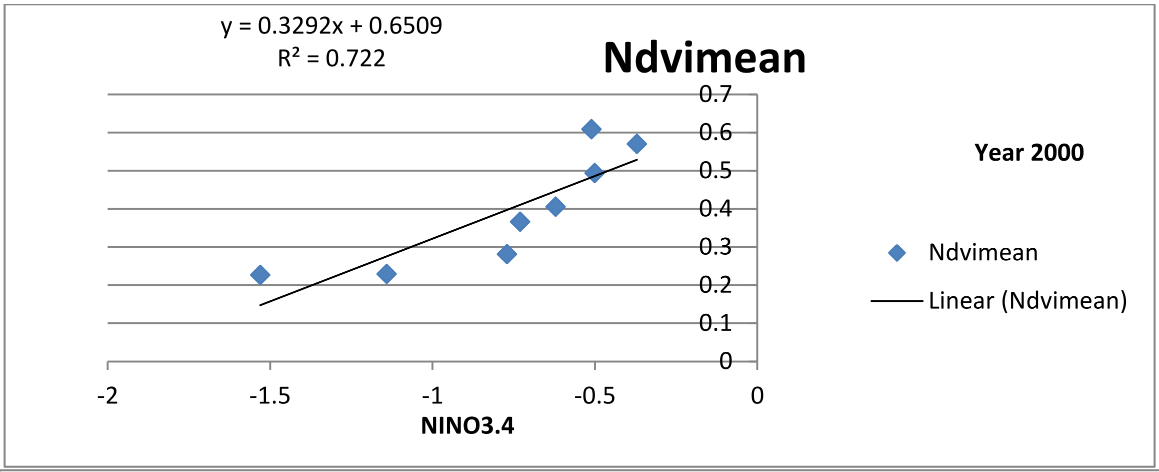
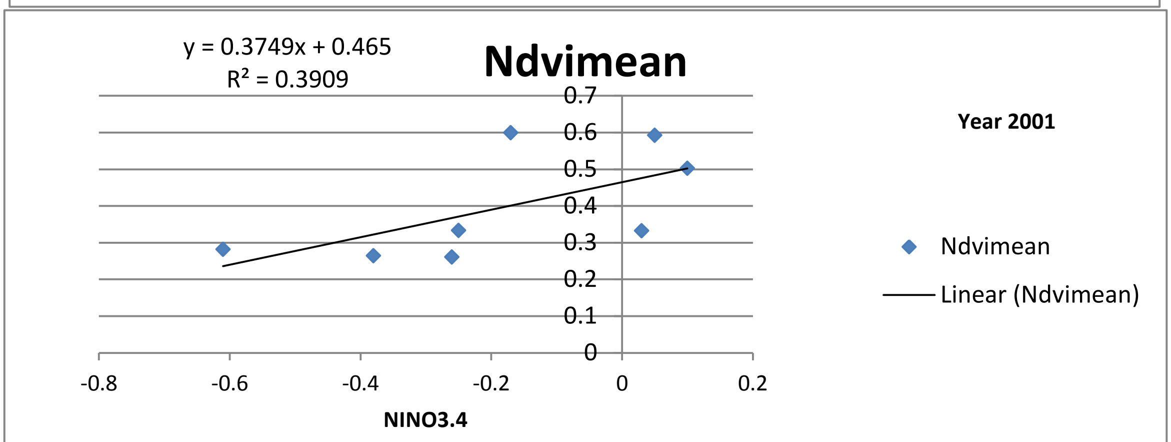
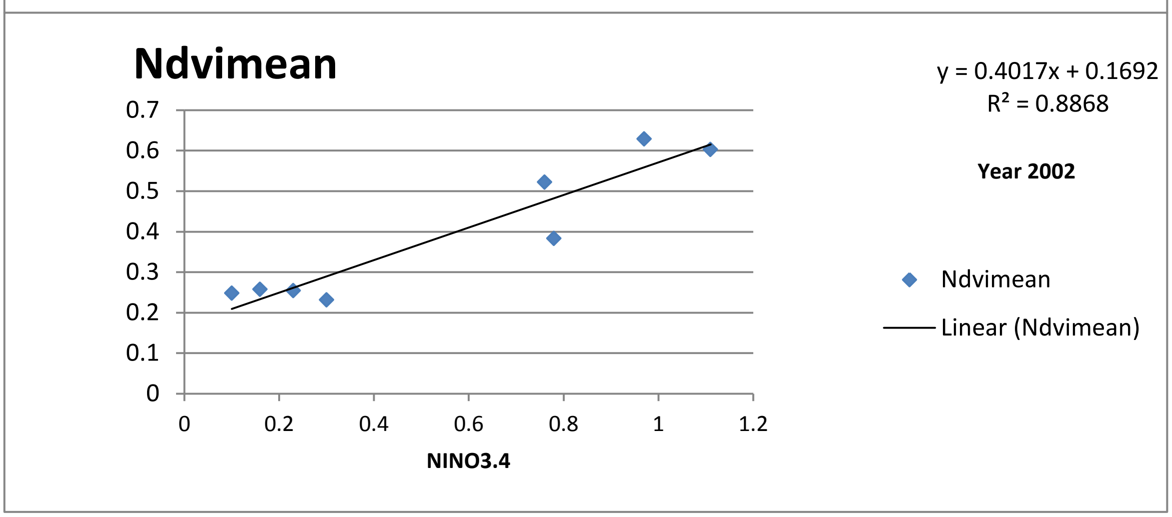


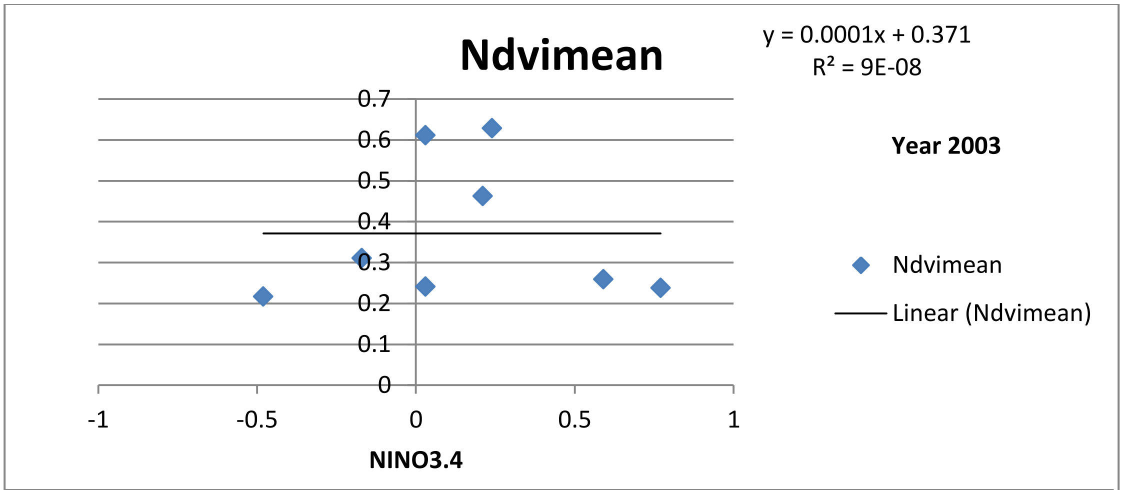
Figure 44 Rainfall standard deviation map associated with kriging for Kiremt and Belg season

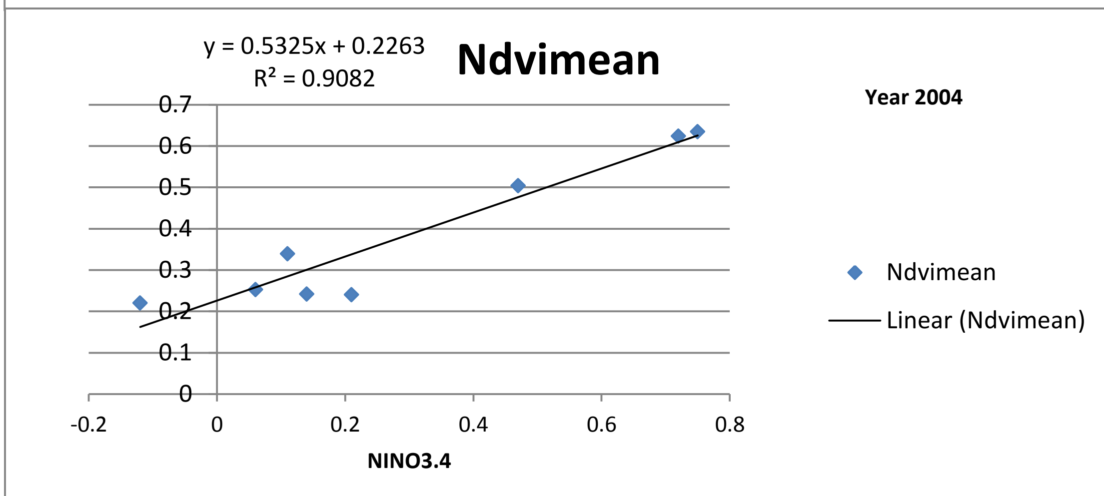
Yearly correlation between mean NDVI and NINO3.4 sea surface temperature anomaly

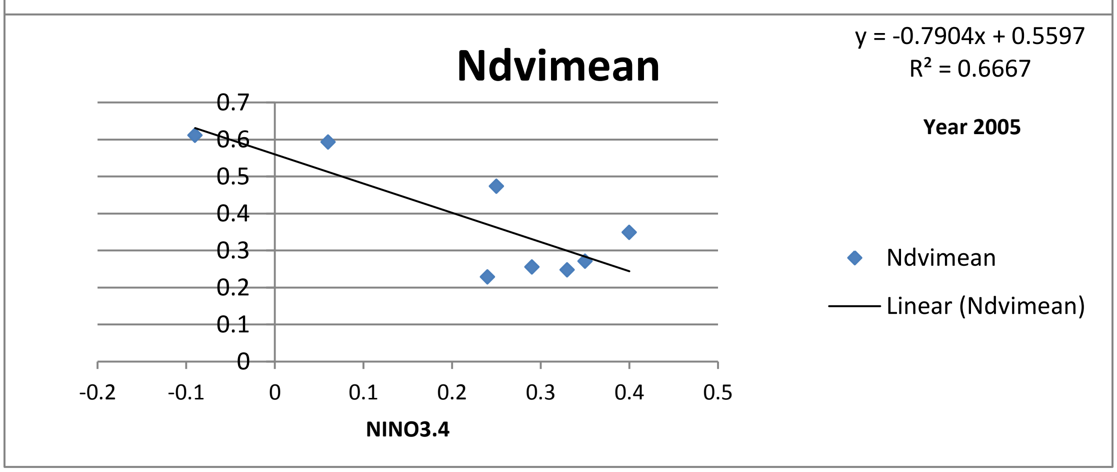







Ndvimean
y = 0.0001x + 0.371
R² = 9E-08
Year 2003
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-1
-0.5
0
0.5
1
NINO3.4
Ndvimean
Linear (Ndvimean)


y = 0.5325x + 0.2263
R² = 0.9082
Ndvimean
Year 2004
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.2
0
0.2
0.4
0.6
0.8
NINO3.4
Ndvimean
Linear (Ndvimean)


Ndvimean
y = -0.7904x + 0.5597
R² = 0.6667
Year 2005
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
NINO3.4
Ndvimean
Linear (Ndvimean)

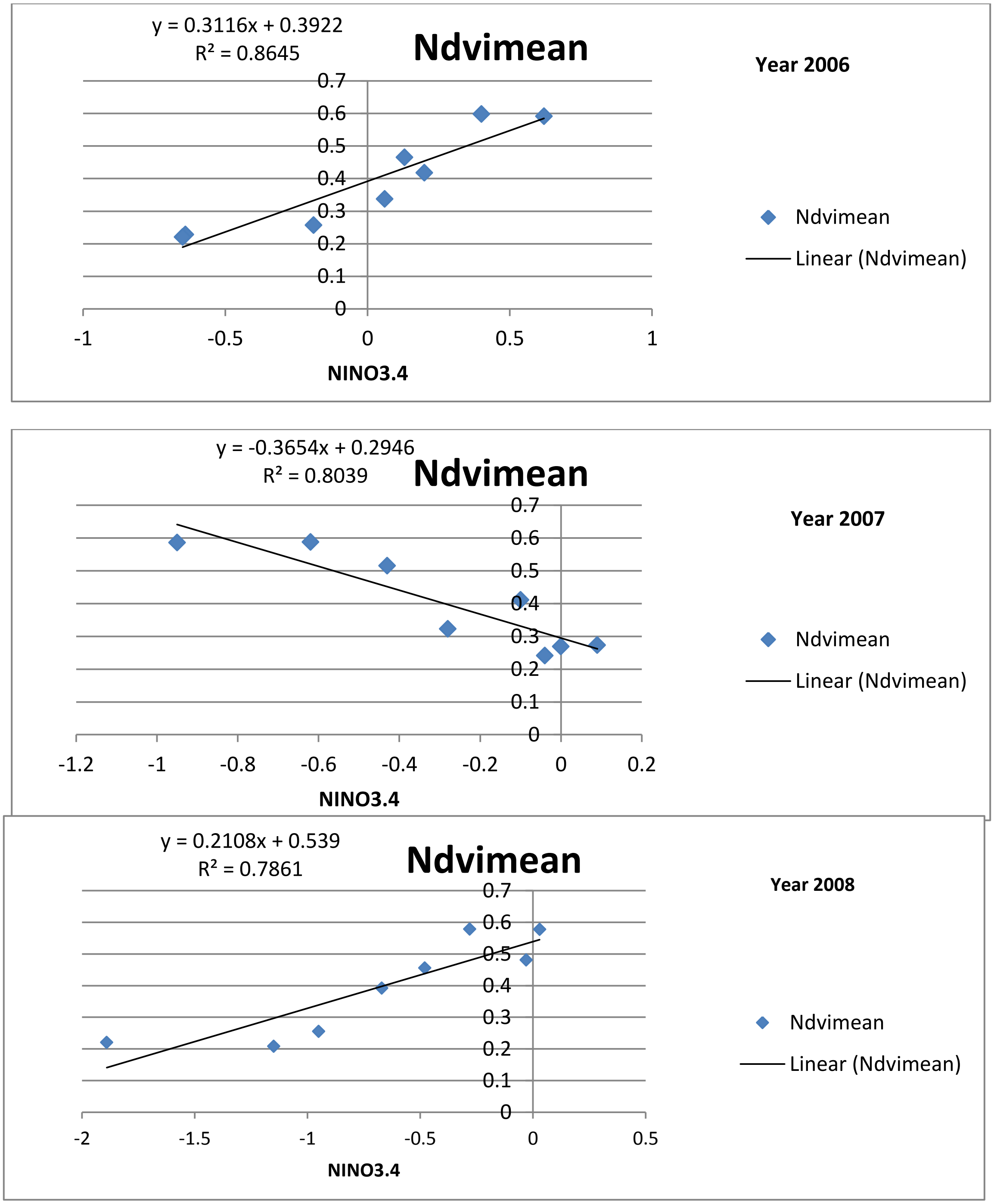


Figure 45 yearly correlation between mean NDVI and NINO3.4 sea surface temperature anomaly

Yearly trend NDVI values for different land cover types for Kiremt and Belg season

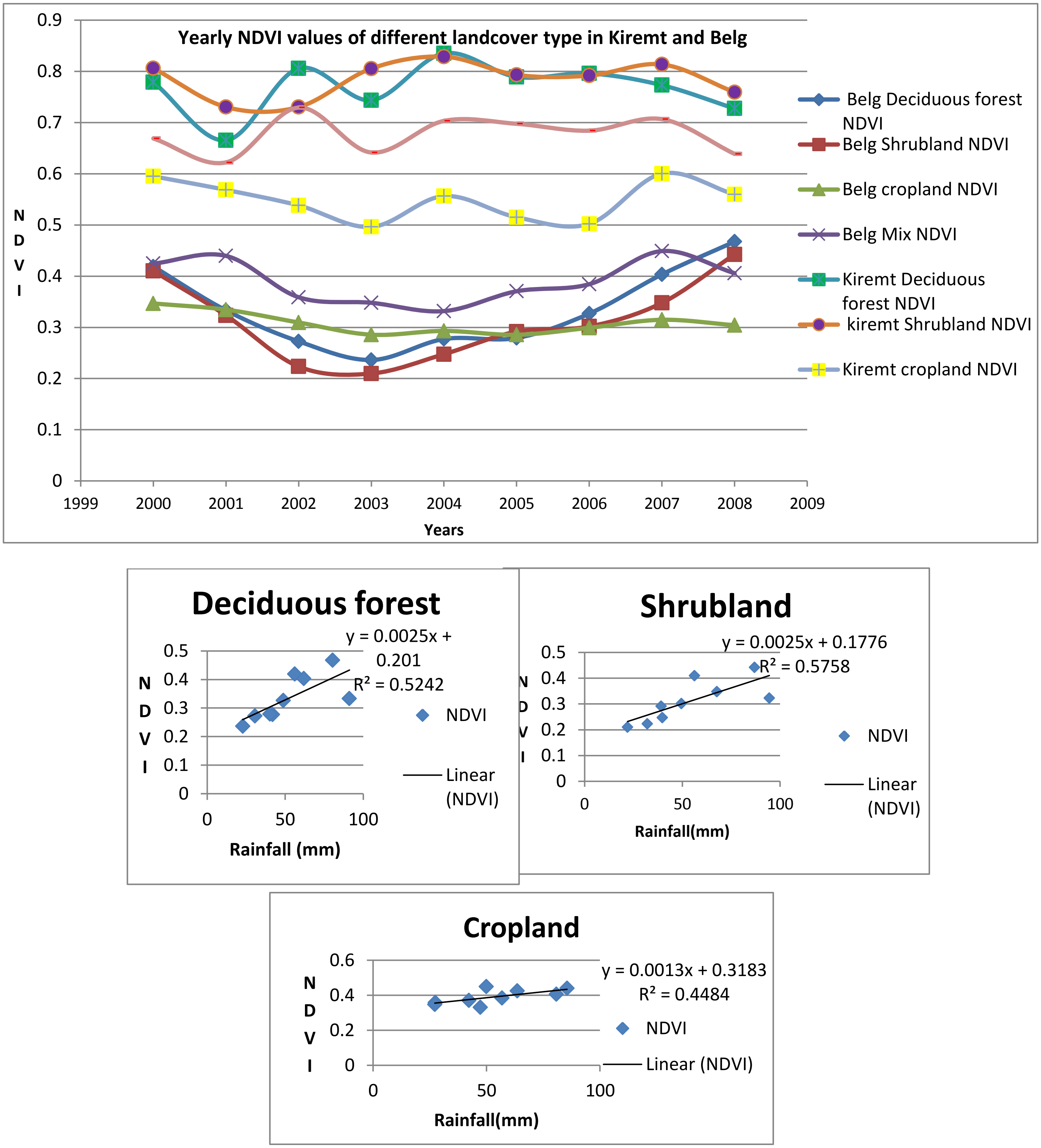


Figure 46 Yearly trend NDVI values for different land cover types for Kiremt and Belg season

Mean monthly NDVI trend analyses

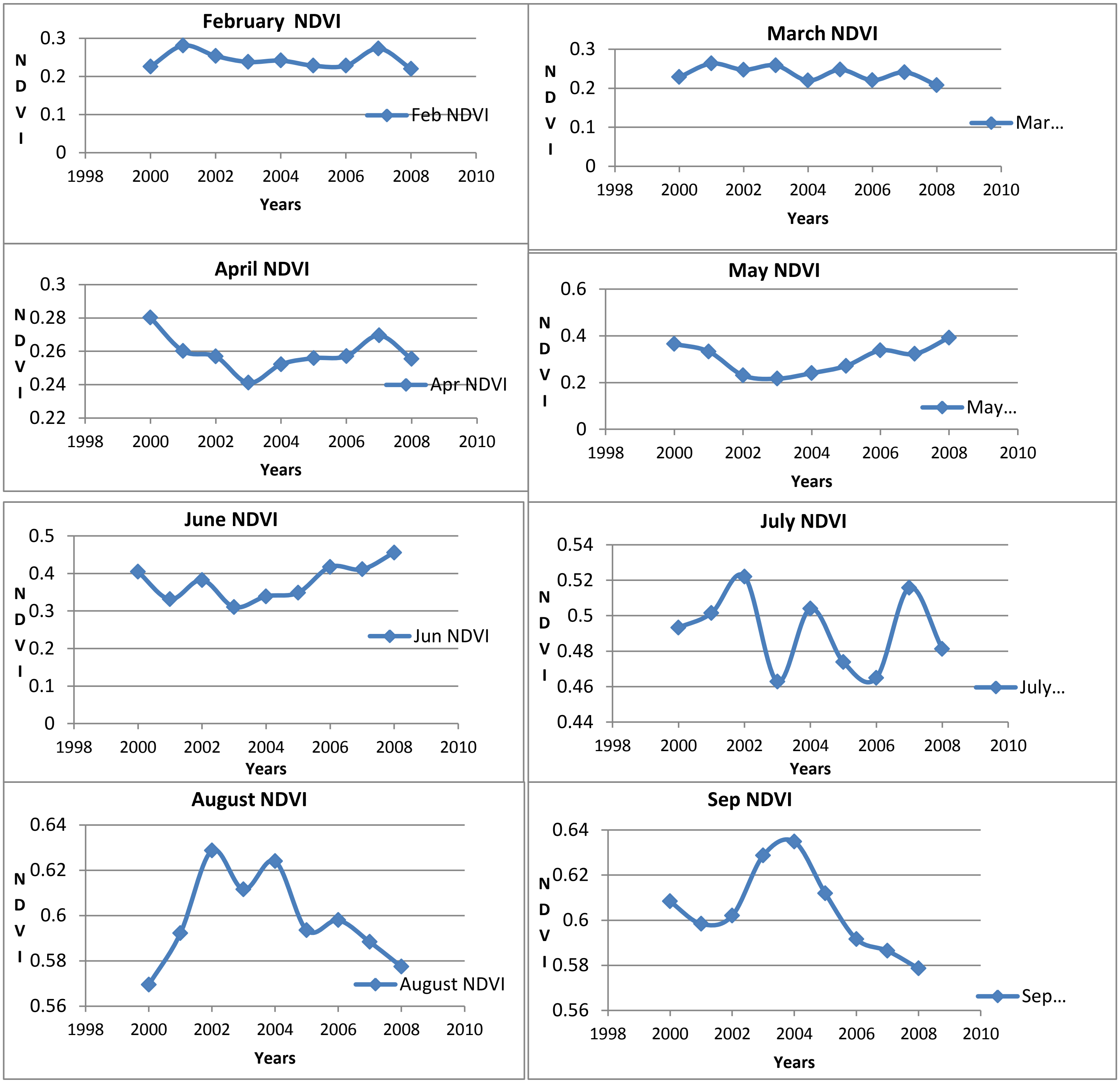


Figure 47 Mean monthly NDVI trend analyses

Trend analyses of mean monthly rainfall

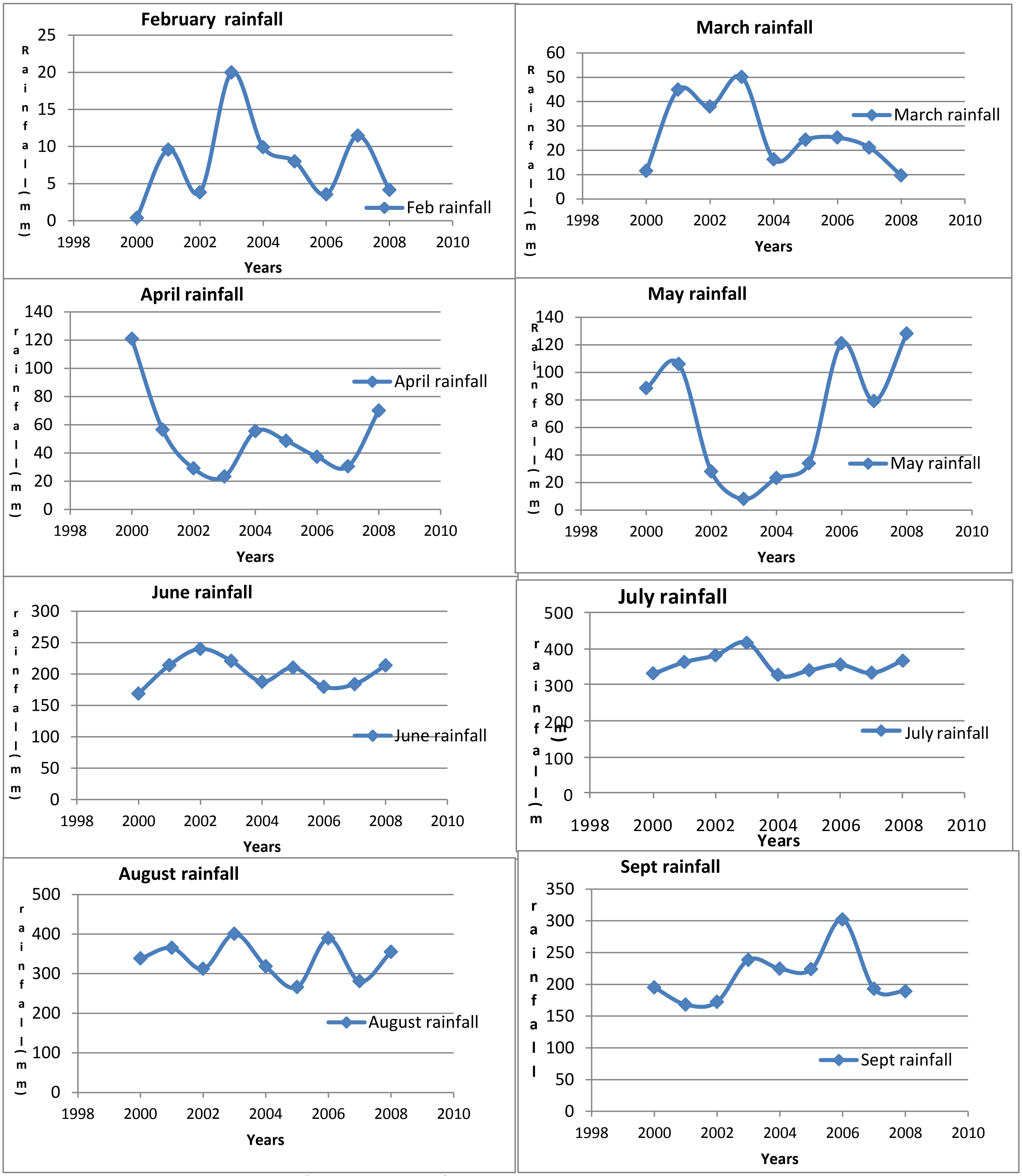


Figure 48 Trend analyses of mean monthly rainfall

Some selected Exponential and stable model semivariograph of interpolated rainfall

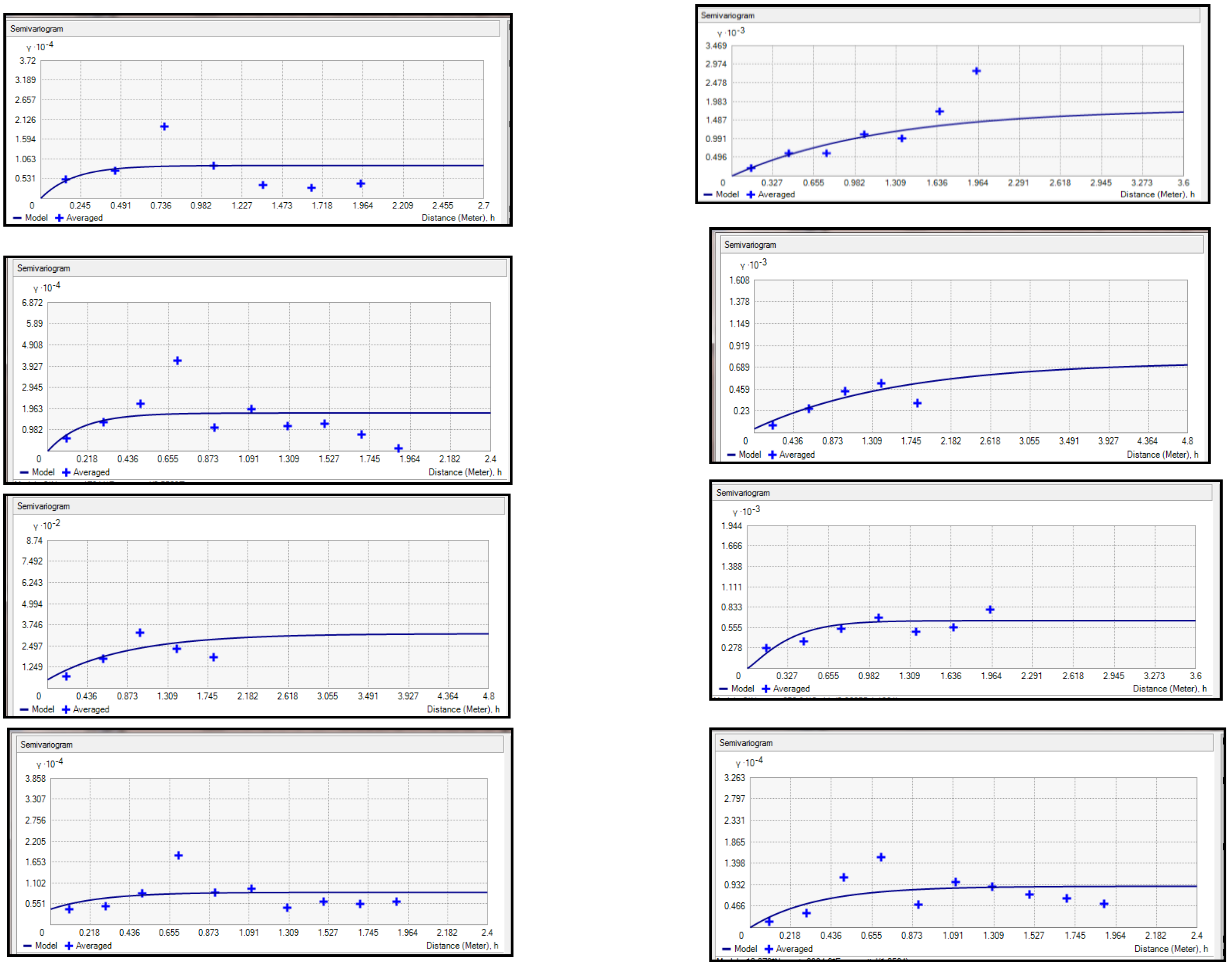


Figure 49 some selected Exponential and stable model semivariograph of interpolated rainfall

Parameters	Exponential model type			Stable model type		
Nugget	0	0	234	48.794282	0	20.605137
Range	0.55236	2.075338	0.552368	1.172235	0.5523682	0.72
Partial sill	562.69796	1308.465305	562.695787	252.5431008	562.695787	20605.1379
Anisotropy	No	No	No	No	No	No

Table 11 exponential and stable Variogram model parameters