FACTORS AFFECTING RECENT VEGETATION CHANGE IN NORTH-EAST LIBYA

GHADA. M. A. AHWAIDI

Ecosystems and Environment Research Centre

School of Environment and Life Sciences

University of Salford

Salford, M5 4WT, UK

Submitted in Partial Fulfilment of the Requirements of the Degree of Doctor of Philosophy, 19 July 2017

Contents

List of tables

List of figures

Acknowledgements

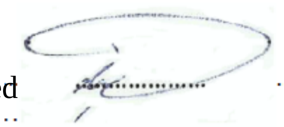
I would like to express my deepest appreciation to my academic supervisor, Professor Mark Danson, for his excellent guidance, encouragement and support for completing this study. He continually delivered to me a sense of scholarly inquiry and reasoning in regard to this research as well as being patient in teaching me how to discover a theoretical background for my study and helping me to understand the basics of remote sensing. This dissertation would not have been possible without his support and help. I would also like to express my sincere gratitude to my co-supervisor, Dr Richard Armitage, for providing valuable insight and guidance over the past four years. He was willing to answer my countless questions and to advise a statistical design for this study.

I would especially like to thank Catriona Nardone, the Research Support Officer at the School of Computing, Science & Engineering and School of Environment & Life Sciences at the University of Salford, for helping me every year in my registration and answering all my questions about the university and all the staff in my school.

I would like to thank all my family and friends in Libya and in the UK, who supported my decision to study in the UK, which was a wonderful experience for me. Finally, I would like to extend a very special thanks to my husband Nasser Almgariaf, for his endless dedication and support. He was always there cheering me on and standing by through the entire process. Also my special thanks go to my children, Saad, Mohammed and Bushra, for teaching me English language in my home, and helping me to correct my writing, especially my son Saad.

Declaration

I declare that the work presented in this thesis has not previously been submitted for a degree or similar award at Salford University or any other institution. To the best of my knowledge and belief, no material in this thesis has been previously published or written by another person, except where due reference is made. I further agree to give permission for "fair use" copying of this thesis for scholarly purposes.

Signed 

Date …07/ 12/ 2017…..

Abstract

Over the last few decades global warming and human intervention have led to changes and deterioration in natural vegetation across the world. The Al Jabal Al Akhdar, in north east Libya, is one of those areas that have experienced changes in land cover. This region has environmental and economic importance in providing suitable habitat for wildlife and providing services for local communities and cities in the Libyan Desert. The overall aim of this thesis was to evaluate the factors which have affected vegetation cover change in the Al Jabal Al Akhdar region over the last 42 years.

There were three key objectives to this research: (1) to assess changes in natural and semi-natural vegetation cover in the north-east of Libya using forty years of satellite image data, (2) to assess land cover change and the effects of human activities in the study area over a period of 42 years, (3) to assess the factors affecting vegetation change in the study area. A further objective was to assess climate change in the study area using the climate data which was available from three climatic stations as climate change may be responsible for vegetation cover change in the areas that have low human activity.

To address these objectives, remote sensing techniques were used to assess vegetation cover change and the changes in human activity from 1972 to the present. Satellite images provide data that cannot be collected by traditional methods and provide a historical archive of what the landscape looked like in the past. This study used multi-temporal Landsat images, which are freely available, for the period from 1972 to the present and provide the key temporal record of vegetation change on the Earth. Vegetation Indices (NDVI, SAVI and EVI), derived from the spectral reflectance of leaves and canopies, were used to assess the changes in vegetation cover over time. Image classification was also used to characterise the nature of land cover change, in particular the impact of human intervention.

A key finding related to Objective (1) was that some areas have experienced a statistically significant change in vegetation indices over the 42 years which was interpreted as a change in vegetation cover in the areas in question. A key conclusion related to Objective (2) was that land cover had changed in the study area over the period of study. The influence of human activities was exerted through increased

land use and decreased areas of forest and shrubland in the region. The outputs of the above-mentioned objectives and the effects of climate change were used to assess Objective (3), to detect which factors caused vegetation cover change in the Al Jabal Al Akhdar region. The main factors causing vegetation change were the effects of human activities in the areas adjacent to human settlements, while in the sparsely populated areas in the south of the study area, vegetation cover changes may be related to recent climate change.

In conclusion, although the number of available Landsat images used to delineate the changes in vegetation cover was limited, the methods used to interpret the images for vegetation indices and image classification were invaluable in determining important results for the objectives of the thesis. The results obtained from assessing vegetation cover and land cover change and patterns of changes are major steps towards filling the information gap and creating a database for monitoring land cover in the study area. This effort will contribute towards facilitating decision-making on mitigating the impact of land use dynamics on land cover as well as provide a basis for future research.

CHAPTER 1: INTRODUCTION

1.1 Introduction to the research

Vegetation is a key component of ecosystems (Briales & Ravenel, 2013). It is involved in the regulation of various biogeochemical cycles, for example, water, carbon and nitrogen (Buriánek et al., 2013); affects soil development by increasing productivity; and provides habitat for wildlife (Briales and Ravenel, 2013). Every plant species has physiological characteristics that allow it to live in a certain range of temperatures, moisture, soil acidity, solar radiation, evaporation and nutrients (Hoffmann, 1998). Changes in these characteristics lead to changes in vegetation phenology, primary productivity, biomass and the distribution of vegetation types (Krishnaswamy et al., 2014).

Climate is one of the factors that has a significant effect on the characteristics of vegetation. Changes in climatic elements such as temperature, precipitation, humidity and evaporation affect directly or indirectly affect vegetation dynamics (Langgut et al., 2011). Climate has changed significantly over the past five decades as a result of increased incidence of greenhouse gases in the atmosphere and CO_2 emissions produced by such human activities (IPCC, 2014), such as deforestation, industrial development and the burning of fossil fuels for transport and energy production (McMichael et al., 2003; Chmura et al., 2011). Recent changes in climate include increases in temperature and changes in precipitation patterns, and these changes have impacted on terrestrial ecosystems (Horion et al., 2013). Global climate change has led to changes in vegetation dynamics (Lei et al., 2014), such as ".. an increase in growing season duration and changes in photosynthetic activities" (Horion et al., 2013, pp, 20). Temperature is one of the strongest determinants of plant growth and increases in temperature, as a result of climate change, lead to increases in the rates of respiration and transpiration, which might lead to decreased carbon storage in soil due to increased respiration rates (Gerber et al., 2004; De Long, 2016). Changes in temperature and rainfall may cause plant stress and carbon loss (Gerber et al., 2004), and may also affect vegetation growth and agricultural activity.

Human activity, in concert with local factors such as climate change, has also caused vegetation change, for example, increased population has led to significant land cover change globally since the mid-1950s (Foster, 1998). This is a result of the exploitation of areas which were covered by ‘natural vegetation’ and have been transformed by human activities, such as agriculture, urban and industrial development (Estes et al., 2012). These changes have caused degradation in soil productivity, soil erosion, desertification and decreases in plant and animal biodiversity (Wang et al., 2004; Mansour et al., 2012).

The Mediterranean basin is one of the areas likely to be most susceptible to climate change (Liberato et al., 2011). Evidence indicates that the climate in the region has changed since the beginning of the 20th century (IPCC, 2014), with mean annual temperature increasing by 0.75°C from the mid-20th century (Osborne et al., 2000). Precipitation has decreased in terms of total annual rainfall, and interannual variance of precipitation across different regions of the Mediterranean has been noted. Philandras et al., (2011), for example, examined monthly precipitation totals from 1900 to 2010 at 40 meteorological stations in the Mediterranean basin to investigate the trends in rainfall in the region. The precipitation data were collected from the World Climate Data and Monitoring Programme (WCDMP) of the World Meteorological Organization. The study indicated declining trends of annual precipitation totals over the period of 1901–2009 in the Mediterranean region as a whole although some areas have recorded fluctuating trends of rainfall, such as in northern Africa, southern Italy, and the western Iberian Peninsula (Philandras et al., 2011).

During the second half of the 20th century the Mediterranean region experienced changes in regional vegetation in response to climate change, drought and land use change (Ivits et al., 2014; Jiguet et al., 2011; Lasanta & Serrano, 2012). Climate change has affected the structure and productivity of vegetation (Osborne et al., 2005), while human activity in the last few decades has impacted on some areas in the Mediterranean region. Increased urbanization, agriculture, industry, fires, uncontrolled grazing, salinization, pollution and deforestation in the region, have caused degradation of natural vegetation as a result of human-induced pressure on ecosystems in the region (Ispikoudis et al., 1993; Zalidis et al., 2002).

Natural vegetation in north eastern Libya comprises plants that have grown without human intervention (El-Barasi et al., 2011). The area belongs to the semi-arid/ arid natural vegetation of the Mediterranean (Bukhechiem, 2006). The perennial trees of the

Maquis are the main vegetation in the region, with *Juniperus phoenicia* one of the most important components of the vegetation. This is a perennial evergreen that comprises an estimated 80% of the total perennial tree cover in the Al Jabal Al Akhdar region (Al Mukhtar, 2005). The natural vegetation is found at the highest elevations and is concentrated in the Al Jabal Al Akhdar (Green Mountains) region which is the study area for this research. It is the richest region of biological diversity in the country (Hegazy et al., 2011). The Al Jabal Al Akhdar region is located in the south of the Mediterranean basin and is located in the Mediterranean climate zone (Figure1.1).

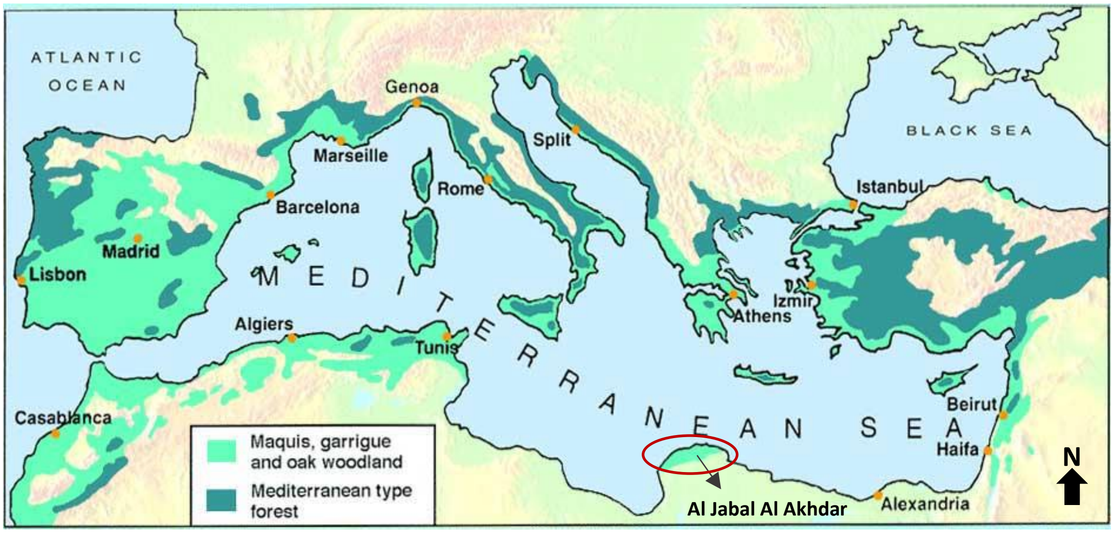


Figure 1.1: The Mediterranean basin and Al Jabal Al Akhdar region in Libya (Source: Google, 2017)

Natural vegetation of the Al Jabal Al Akhdar has a significant impact in the region in terms of providing suitable habitat for wildlife (Hegazy et al., 2011), providing nutrients for the soil, stabilization of the soil and preventing erosion. The north-facing slopes, where there is extensive farmland, provide vegetables and fruits for local communities in the region and the cities of the Libyan desert (Ben Khaial & Bukhechiem, 2005). In addition, the natural vegetation in the region is economically important for the local population, in terms of providing medicinal herbs, aromatic plants, honey, traditional industries for tourists, and provides milk, eggs and meat from the livestock which feeds on the natural vegetation (Al Mukhtar, 2005).

In recent years, a number of local studies (Al Mukhtar, 2005; Ibrahim, 2006; Ben Khaial & Bukhechiem, 2005) have examined the natural vegetation in the Al Jabal Al

Akhdar region of Libya and have confirmed that there has been a decrease in the natural vegetation cover. These studies relied on fieldwork to examine vegetation in different places in the study area. The studies were limited due to the rugged terrain of the region in terms of mountain cliffs and deep valleys with difficult access. By monitoring the dynamics of semi-arid/ arid natural vegetation in the Al Jabal Al Akhdar using remote sensing techniques, it is possible to map a large area that cannot be accessed by other means. In addition, remote sensing can provide a long temporal record of land surface observations dating back to 1972. This research will investigate natural vegetation dynamics in the Al Jabal Al Akhdar region using remote sensing techniques and examine changes in vegetation cover over the last 42 years in an attempt to determine the factors that have caused those changes. Although climate change is potentially an important factor, there are only three climatic stations in the study area. Therefore, it is not possible to examine spatial changes in climate within the study area. The research therefore used the available climate data on a station basis to provide a general picture of climate change in the Al Jabal Al Akhdar.

1.2 Research aims and objectives

The main aim of this study is to assess the natural and semi-natural vegetation dynamics of the Al Jabal Al Akhdar region and examine the factors affecting vegetation change.

Vegetation cover has changed in the Mediterranean region due to climate change (Colombaroli & Tinner, 2013; Ivits et al., 2014; Jiguet et al., 2011; Lasanta & Serrano, 2012) and human activities (Muñoz-Rojas et al., 2011; Pérez-Hugalde et al., 2011; Sluiter, 2006). Overall this study attempts to decouple the effects of climate change and human activity, in relation to vegetation cover change, by examining the influence of each factor in the study area. This will be achieved by identifying the relationships between the areas that have experienced change in vegetation cover and the spatial distribution of human activities. Trends of temperature and rainfall at three stations are examined in order to give insights into the general climate trends in the study area, since the climate change may be responsible for vegetation cover change in the areas that have no influence from human activity.

This is the first study to investigate vegetation cover for the whole of the Al Jabal Al Akhdar using remote sensing techniques. A few local scale studies have examined the natural vegetation of the region, but most of these studies have adopted field work and studied a limited number of sites in the Al Jabal Al Akhdar, because of difficult topography and problems encountered when accessing certain areas such as deep valleys. The natural vegetation of the Al Jabal Al Akhdar has environmental and economic importance because it is the only region with evergreen forests in Libya. Much of the rest of the country is desert and so the study area is of key importance in soil stabilization and prevention of erosion, and its contribution to nutrient cycling (Ageena et al., 2013). In addition, the region is a focus of agricultural activity and provides products such as vegetables, fruit and livestock for the local cities in north east Libya. So, this study will examine the interaction of human-induced vegetation change and climate-induced vegetation change, and attempt to assess the variation of the factors affecting vegetation change in the study area since the 1970s.

The aims of the study can be split into the following three specific objectives (Figure 1.2).

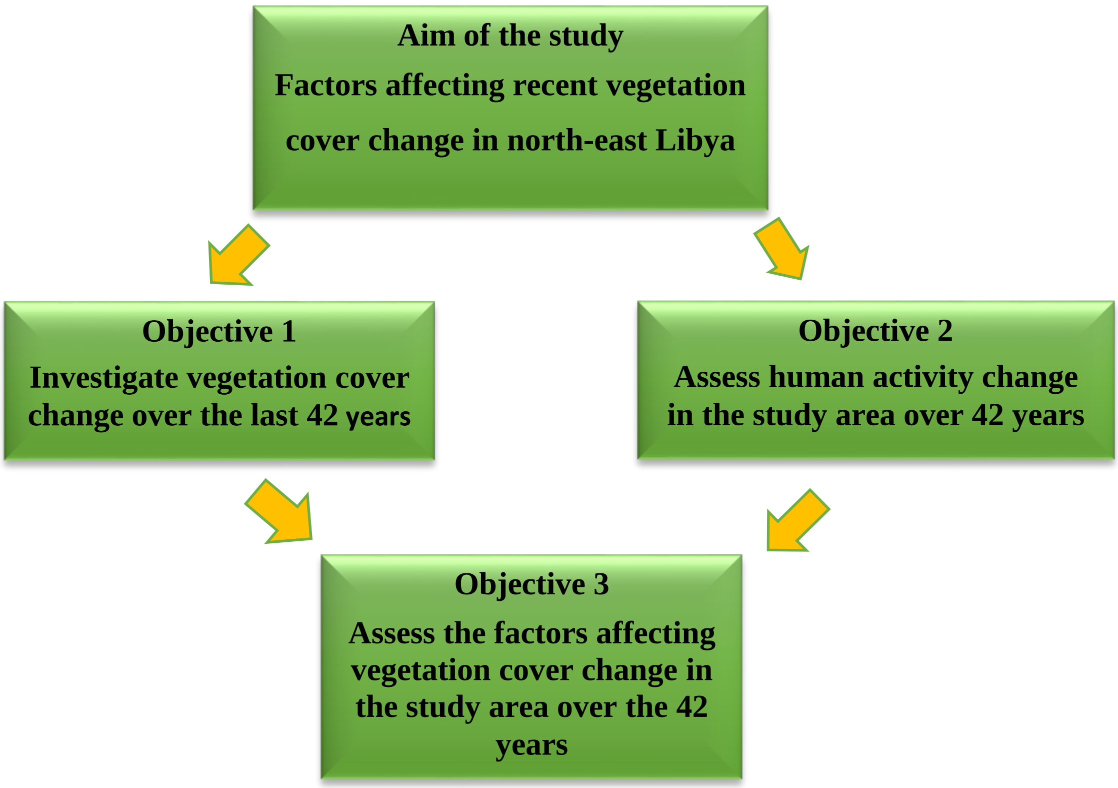


Figure1.2: An aim and objectives of the research

OBJECTIVE ONE: To assess changes in natural and semi-natural vegetation cover in the north-east of Libya using the 42 year satellite image data record

This objective evaluates the change in vegetation cover in the Al Jabal Al Akhdar using remote sensing techniques, in particular multi-temporal Landsat images which are available for the period from 1972 to the present. The satellite imagery provides information that cannot be collected by traditional methods due to difficulties in accessing the area, and provides the only medium-term record of vegetation change on the Earth (Lasanta and Vicente-Serrano, 2012). This objective used Vegetation Indices (VI), in particular the Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI) and Enhanced Vegetation index (EVI) as proxies of vegetation cover to assess the changes. Vegetation index change images were used to determine the changes in vegetation cover in the region. This objective led to the specific research question:

Has the vegetation cover of the Jabal Al Akhdar as determined using spectral vegetation indices changed over the period 1972 to the present?

OBJECTIVE TWO: To assess the changes of human activities in the Jabal Al Akhdar

Human activity affects vegetation cover through different land use activities (Estes et al., 2012). These include urbanization, water management, agricultural development and other forms of land use management. In order to assess semi-natural and natural vegetation cover change, it is necessary first to account for the changes in human activity and identify regions where human activity has increased?

The political situation has changed in Libya since 2011 and several illegal activities can be observed in the area, e.g. illegal charcoal-burning, overgrazing, collection of medicinal plants for commercial and folk medicine use, cutting down trees, etc. without control in the areas that have natural vegetation.

This objective was established to assess human activity changes in the Al Jabal Al Akhdar, through examining land cover change across the area over 42 years. To achieve this objective, a time series of Landsat imagery was used to investigate changes in land cover across the study area. The research classified satellite images in order to identify land cover changes and generate thematic maps of land cover over the period of study.

This objective used a land cover mapping approach in the Al Jabal Al Akhdar together with Libyan population data to determine the concentration of population and its relation to human activity, especially the activities that could not be observed on the satellite images such as grazing and logging to produce fuel. The aim was to produce a map of human activity across the study area, allowing identification of areas of high and low human activity. This objective led to a specific research question:

Has land cover changed in the Jabal Al Akhdar over the period 1972- present?

OBJECTIVE THREE: To assess the factors affecting vegetation change in the study area

Vegetation in the study area is affected by many factors which cause spatial and temporal change in vegetation cover. This objective was used to determine the factors which affect vegetation cover change in Al Jabal Al Akhdar. To achieve this objective, the research used results of the first objective, spatial maps of vegetation cover change in the region, in combination with the result from the second objective, a spatial map of human activity that identified areas of high and low activity across the study area. To examine the influence of human activity on vegetation change, the research overlaid the human activity map with the vegetation change map to examine spatial correspondence. The expectation was that the areas that have experienced vegetation change would be the same areas that had dense populations and a variety of human activities. Areas with vegetation change and sparse populations may be responding primarily to climate change. This objective led to the main research question:

What factors have caused vegetation cover change in the Al Jabal Al Akhdar over the period 1972- present?

1.3 Thesis structure

This thesis is organised in such a way as to achieve its objectives, through eight chapters, and these chapters are briefly described as follows:

Chapter 1 is a general introduction to the contents of the research.

Chapter 2 presents a general background literature review on the factors impacting on vegetation cover change, including climate change and human activity. In this chapter, research focusing on vegetation cover change in the Mediterranean region, important factors affecting vegetation change, and the role of remote sensing for detecting the vegetation change in the region are presented. The chapter also includes general background principles of remote sensing and its application to vegetation change detection.

Chapter 3 is devoted to the general background of the study area in terms of its location, topography, soil, water resource and vegetation cover. In addition, analysis of climate data from three stations in the study area, focusing on temperature and precipitation, is presented in order to assess changes in climate during the period of the study.

Chapter 4 outlines the methodologies which are used to achieve the research aims and objectives. The chapter presents the different applications of remote sensing data that have been applied to assess vegetation, land cover and land use change. The chapter also contains a discussion of image pre-processing and also presents the vegetation indices that are used to assess the vegetation dynamics in the study area. The chapter illustrates the image classification methods used to map the land use and land cover change and investigates how the relationships with population data are assessed. At the end of this chapter, the method which is applied to investigating the climate change in the stations of the study area is presented.

Chapter 5 assesses the vegetation cover change in the study area, which is the first objective of the thesis, using Landsat imagery. In this chapter, the research generates vegetation index images from the satellite data in order to measure the vegetation cover change over the study period. The chapter outlines the statistical methods that were developed to detect statistically significant changes in the vegetation index time-series data.

Chapter 6 assesses land cover change over the study period. This chapter addresses the second objective and presents the classification method that was used to assess land cover change. The classified images are reclassified to present each class in order to calculate the areal extent for each category in the study area and present the changes over the period of the study. The results of the changes are outlined at the end of this chapter.

Chapter 7 provides spatial analysis for the factors that affect vegetation change. This chapter presents the results of overlaying the vegetation cover change with the results concerning land use and land cover change, and population data. The results show factors that have a significant effect on vegetation cover change in the study area.

Chapter 8 is dedicated to a discussion of this research and conclusions reached.

CHAPTER 2: LITERATURE REVIEW

This chapter contains an introduction to the background literature and techniques that are both relevant to and applied through this thesis. It includes background information relating to vegetation change and the factors which cause it. This chapter explains both the positive and negative influences of climate change and human activity on vegetation cover in the Mediterranean region. The applications of remote sensing to vegetation change detection are reviewed, with technical details and examples of previous successful applications and investigations of a similar nature in the Mediterranean region.
Finally, this chapter identifies research gaps and the relationship to previous work already performed in this field in the study area, and also how this work is original in its own right and adds to current existing knowledge. This chapter provides the background required to both justify the methods and interpret the results presented throughout this thesis.

2.1 Introduction

Natural vegetation includes all plants that grow naturally without human intervention (Gregory et al., 2012), growing in 'natural' climatic, soil and landform conditions (Hoffmann, 1998). Changes in these conditions lead to changes in vegetation phenology, primary productivity and the distribution of vegetation types (Krishnswamy et al., 2014). The Mediterranean basin is characterized by a special biodiversity (Combourieu-Nebout et al., 2015). The vegetation is a complex mixture of species which vary between Eurasian vegetation to the north and the east of the Mediterranean basin, and the desert vegetation of the Sahara-Arabian region in the south (Langgut, et al., 2011). Consequently, the Mediterranean region is one of the most globally diverse regions with over 25,000 native and endemic plant species (Abbott & Le Maitre, 2010; Colombaroli & Tinner, 2013; Beltrán et al., 2014).

2.2 Vegetation cover change in the Mediterranean region

Vegetation cover is a key indicator of long-term vegetation change in ecosystems (Trodd & Dougill, 1998). Vegetation of the Mediterranean region comprises a variety of forests, which grow in elevated areas which are characterized by particular temperature and rainfall conditions, and shrubs and herbaceous plants, which grow in coastal areas and at a low altitude with lower levels of precipitation (Hegazy et al., 2011).

Land cover in the Mediterranean has been changing since the end of the 1940s due to drivers which include climate, land use and socio-economic changes (Fox et al., 2012; Lavorel et al., 1998). The change in vegetation cover has varied from area to area across the region, for example, the forest area in southern France increased between 1965 and 1976 by 2428 km^2 per year, whereas the forest area in Tunisia decreased over the same time period by 130 km^2 per year (Shoshany, 2000).

There has been an increase in areas impacted by drought, land cover change and land use changes in the region, such as the expansion of agricultural areas, pasture and urban development. For example, there was an increase in the total urban area from 30.1 ha to 393.8 ha between 1950 and 2003 in a Mediterranean catchment area near St Tropez, France (Fox et al., 2012), and less than 5% of primary vegetation remained unaltered (Pérez-Hugalde et al., 2011).

Vegetation cover of some areas in the Mediterranean region has been monitored using observations from remote sensing to detect land cover change (Li et al., 2012). Remote sensing has a proven track record for monitoring fire disturbance and desertification in many areas in the Mediterranean region (Shoshany, 2000). Several observations confirm that there was an increase in shrubland cover between 1981 and 1991 in eastern Turkey and the Maghreb region of North Africa (Algeria, Morocco and Tunisia) (Osborne & Woodward, 2001; Horion et al., 2013). In other areas there was a decrease in vegetation cover due to climate change and human activity (Shoshany, 2000).

Overall, the natural vegetation cover of the Mediterranean region has changed over time. This change differs from area to area and has been either positive or negative. There was a variety of factors affecting on vegetation cover, such as climate change, drought, human activity, fire and desertification. Most of these factors have had a negative effect on vegetation and caused decreasing vegetation cover or changes in the structure or distribution of vegetation.

2.3 Factors affecting vegetation change

2.3.1 General factors affecting vegetation change

Natural vegetation at a given place is determined by abiotic factors, in particular climate, landform and soil related characteristics (Jing-Yun et al., 2002). Each plant lives within a certain range of temperature, moisture and soil conditions (Hoffmann, 1998), and any change in abiotic conditions may lead to a change in the structure and distribution of vegetation (Jing-Yun et al., 2002).

There are various factors impacting on global vegetation change; these factors could have a direct or indirect effect on vegetation, some of them rapid and others slow. Significant factors affecting vegetation change include both natural and anthropogenic factors (Prentice, 1986; Soleimani et al., 2008). These factors control the growth and distribution of vegetation. Natural factors include climate, soil, water availability and terrain (Haferkamp, 1988), whereas anthropogenic factors are human activities which affect or change the land cover (Lepart & Debussche, 1992). Soil may affect vegetation by changing the quantity of organic materials, quality of the detritus, and root respiration (Raich & Tufekcloglu, 2000). However climate is one of the main controllers of vegetation growth and distribution (Langgut, et al., 2011). For example, the dominance of Mediterranean maquis with lower tree populations and taller steppe vegetation in the South East Mediterranean area, compared with the evergreen and sclerophyllous forests in the western and central region, is due to a moisture gradient (Langgut, et al., 2011). The projections of climate change for 2016–2035 in southern Europe made by the IPCC (2014), taking into account an increase in temperature, predict a possible reduction in forest and semi-natural vegetation and an increase in the risk of desertification in some areas such as Sicily, one of the Italian regions most threatened by land degradation (La Mela Veca, et al., 2016). Climate change could significantly affect terrestrial ecosystems (Horion et al., 2013), and lead to a change in vegetation phenology, primary productivity and biomass (Krishnswamy et al., 2014; La Mela Veca, 2016). As Horion et al. (2013, p.20) states, “primary productivity increased globally by 6% between 1982 and 1999 due to climate changes”.

During the second half of the 20th century, the Mediterranean region experienced large changes in regional vegetation in response to drought and land use change, which included the effects of economic development on the environment (Colombaroli and Tinner, 2013; Ivits et al., 2014; Jiguet et al., 2011; Lasanta &Serrano, 2012). The effect of climate change on vegetation is more difficult to predict. It can irreversibly convert plant community composition, structure, and function. It may also, cause sharp modifications in species and their habits (Jiguet et al., 2011: pp, 407). Human activity may have a longer term effect on natural vegetation than climate change. It could be rapid and occur within days or weeks (McMichael et al., 2003; IPCC, 2007). However, it is clear that the impact of land use and land cover change together with climate change could lead to a deterioration in the biodiversity of the Mediterranean region over this century (Muñoz-Rojas et al., 2011).

2.3.2 Effects of human activity on vegetation change in the Mediterranean region

Human activity is one of the main factors affecting vegetation change (McMichael et al., 2003). Vegetation cover has changed since the middle of the 20th century as a result of an increase in population, which turn has caused an increasing demand for food, which in turn led to an increase in agricultural land and urban areas (Foster, 1998; Estes et al., 2012). Over the last ten years, land use has changed in rural areas across the Mediterranean as a result of the intensification of agriculture, fires, urbanization and tourism (Pérez-Hugalde et al., 2011). Recent land cover change in the Mediterranean has been associated with extensification of human activity (Sluiter, 2006). Global warming, climate change and desertification are caused by anthropogenic emissions of carbon dioxide (CO2), while the influence of land use and land cover change combined with climate change have led to a deterioration in the biodiversity of the Mediterranean since the mid-20th century (Muñoz-Rojas et al., 2011). Thus, these areas will be more sensitive to the risks of flooding and desertification due to loss of vegetation cover, which protects the soil from erosion and reduces evaporation, which in turn, affects soil moisture (Fox et al., 2012).

Human interventions over the millennia, through changes in vegetation cover caused by land use change and fires, have resulted in local extinctions of plants, including rare endemics and economically valuable species (Colombaroli and Tinner, 2013). Fire is one of the most important factors shaping the patterns of vegetation around the world (Fyllas & Troumbis, 2009), and most fires are caused by human activity. While climate change and land use have changed vegetation composition and its distribution, fire disturbance can lead to the degradation of ecosystems by directly affecting topsoil, seeds and vegetation (Colombaroli & Tinner, 2013).

On the other hand, human intervention has also had a positive impact on vegetation cover by keeping ecosystems open and diverse. For example, the impact of fire on the evolution of plants has been an important factor in the Mediterranean region as some species need fire to grow (Naveh, 1975), and diversity in grassland provides a much diversified range of food sources (Colombaroli & Tanner, 2013). Reforestation has taken place in many countries in the Northern Mediterranean region as a result of the policies of countries. For example, the forests in Spain, France and Portugal have been re-established causing an increase in forested areas during the period 1950 to 2010 , due to the reforestation actions of the EU, which has overseen the conversion of agricultural areas or grassland to forests (Fuchs et al., 2012), especially in the areas that have experienced degradation in vegetation cover as a result of human activity, such as in the mountainous and watershed headwaters areas where reforestation has reduced soil erosion and prevented an increase in desertification (Blondel, 2010: Dale et al., 2000).

2.3.3 Effect of climate change in the Mediterranean region

The Mediterranean region is an area which has experienced significant climate change (Liberato et al., 2011). Studies conducted by the IPCC fourth and fifth reports (2007, 2014), Michaelowa (2006) and Giorgi & Lionello (2008), confirm that the climate in the region has been changing since the beginning of the 20th century. The countries most impacted by climate change are in North Africa and the eastern Mediterranean region (IPCC, 2014). The climate of the Mediterranean is characterized by hot, dry summers and mild winters with a large intra-annual variability in rainfall (De Luis et al., 2001; Et-Tantawi, 2005). Temperatures increase greatly towards the Sahara desert. The coastal areas of North Africa typically have a dry summer with precipitation occurring in the winter months. Climate change in the Mediterranean region is related to an increase in the mean annual temperature and changes in precipitation patterns in the region (Abbott & Le Maitre, 2010).

The mean annual temperature in the Mediterranean region has increased by 0.75 °C since 1970 (Osborne et al., 2000), with expectations of increases of 1 - 3°C between 2010 and 2039, 3 - 5°C by mid-century (2040–2069) and of 3.5 -7°C by the end of the century (2070–2099) (Abbott & Le Maitre, 2010; Lelieveld et al., 2012). The period 1976 –1994 has been described as a climatic warming period in the Mediterranean region (Osborne et al., 2000) because of increased temperatures, recurrence of droughts and fluctuations in the amount and distribution of rainfall.

Increases in temperature have led to increased drought in the second half of the 20th century in the Mediterranean region (Lelieveld et al., 2012), and the frequency and intensity of droughts in the 21st century are expected to increase (Cook et al., 2014), which is partly due to an increase in evaporation. Furthermore, high temperatures may lead to an increased risk of fire, which may raise serious problems for Mediterranean ecosystems in terms of damage to large areas of vegetation and soil (De Luis et al., 2001). As a result, the above-mentioned climate changes have had a negative impact on terrestrial ecosystems (Horion et al., 2013). For example, primary productivity of vegetation decreased during the extremely hot summer in Europe in 2003 (Jiguet et al., 2011).

Precipitation has shown marked variation throughout the Mediterranean basin (Osborne et al., 2000). Changes in the total annual rainfall and the inter-annual variance of precipitation differ across the regions of the Mediterranean basin (Lavorel et al., 1998). The mean annual rainfall has decreased over the Mediterranean region between latitudes 40°N and 45°N, with concentrations of rainfall occurring during a few months each year which has resulted in an increase in droughts (Combourieu-Nebout et al., 2015; Osborne et al., 2000; Karas, 1997). Areas which receive more precipitation north of 45°N, will be drier as a result of increased evaporation and changes in the seasonal distribution of rainfall and its intensity (Karas, 1997). For example, during the recurrent droughts in the early 1990s, which occurred in the south of the Mediterranean basin, some areas in the east and west of the region experienced intense rainfall and extreme cold events (Combourieu-Nebout et al., 2015; Osborne et al., 2000; Rivaes et al., 2013).

Climate change has influenced vegetation (Lei et al., 2014; Morales et al., 2007), with changes in growing season length and vegetation productivity (Ivits et al., 2014). Some species have benefited from changes of temperature or rainfall and others have not (Abbott & Le Maitre, 2010). For example, some areas in the region experienced an increase in productivity and length to the growing season while the drought events between 1999 and 2010 allowed the Mediterranean ecosystems to adapt in terms of vegetation phenology and productivity (Ivits et al., 2014). Plants have adapted to drought conditions by growing deeper roots to access water, and having a decreased leaf area and a thicker epidermis layer to reduce the transpiration and respiration processes (Osborne et al., 2000).

On the other hand, some types of vegetation have been damaged by drought and warming conditions. For example, drought has affected forests in terms of structure, canopy shape and biodiversity (Dale et al., 2000), and has increased tree mortality and negatively affected crown condition between 1987 and 2007 in the southern European forests (Jiguet et al., 2011).

Temperature change is the largest factor influencing all plant growth processes, such as photosynthesis, transpiration, respiration, the breaking of seed dormancy and seed growth (Brovkin, 2002). Each type of vegetation species has an optimum temperature and a minimum requirement of heat. If the temperature decreases below a critical level, the plant stops growing. Increased respiration and transpiration due to increased temperature leads to decreased photosynthesis, which affects growth and may lead to physiological drought and death of plants (Berendse, 2005; Brovkin, 2002; Taub, 2010). The structure of the plant may change in response to increases in temperature, such as decreased leaf area to reduce the transpiration process and water loss from the plant (Podleśny & Podleśna, 2013).

Observed changes in climate include a marked decrease in precipitation in the Mediterranean basin (De Dios et al., 2007). Precipitation has both a direct and indirect impact on vegetation in that it affects, for instance, plant growth and soil moisture directly, while indirectly impacting soil respiration which leads to limited microbe activity in the soil (Reichstein et al., 2003). In addition, increasing precipitation may lead to flooding, soil erosion and removal of nutrients from the soil which plants rely on for growth (Chmura et al., 2011; Mistiming et al., 2011). Changes in the pattern of rainfall may also affect forest growth because the trees are accustomed to growing within a given climatic condition (De Dios et al., 2007).

2.4 Approaches to monitoring vegetation change

Monitoring vegetation change involves making repeated measurements, usually of the same sample units, to assess changes in composition, structure and condition over time; it also involves permitting investigation of the processes that influence such changes (Elzinga et al, 1997). To assess and detect vegetation change, it is necessary to use multi-temporal data sets to identify vegetation change over long periods (Alqurashi & Kumar, 2013). There are several methods of monitoring vegetation change, some of which rely on ground-based measurement such as the cover of vegetation, the density of vegetation and leaf area index (Pears, 1990). Other methods use remote sensing techniques to detect vegetation change over longer periods (Hansen and Loveland, 2012).

Ground-based measurements are used to monitor vegetation in a small area, and rely on field work and direct measurement of parts of plants, such as the leaf area index; thus, it inevitably takes a long time to examine vegetation change (Kasturirangan, 1996). Remote sensing has the capacity to detect changes by way of providing a long temporal record of land surface observations. It is used to monitor large areas with high spatial resolution; all generated information is based on electromagnetic radiation emitted or reflected from an object (Suwanprasit and Srichai, 2012; Hansen and Loveland, 2012; Trodd and Dougill, 1998). Remote sensing data are of considerable value because they allow analysis of data both temporally and spatially. Time-series remote sensing data can reveal trends in vegetation cover change (increase or decrease) over long periods of time (Hill et al., 2008). Geographic Information Systems (GIS) have the potential to spatially model information about land use and land cover changes (Symeonakis et al., 2004). GIS uses multiple layers, such as topographic maps, soil maps, and vegetation maps to extract useful information in terms of trends and changes using statistical and analytical functions (Sluiter, 2006).

2.4.1 Ground based measurement of vegetation

Ground-based measurement of vegetation can be used to determine the composition of vegetation in a given area; however, it is impossible to measure large areas (Kasturirangan, 1996). Investigating the changes in vegetation cover, density and structure of plants generally requires long-term studies to examine and monitor the changes (Pears, 1990). There is a variety of quantitative ground-based measurements that can be used, as discussed below.

2.4.1.1 Vegetation cover

Vegetation cover may be defined as the proportion of the ground that is obscured by plant materials above ground such as leaves, stems and flowers (Wilson, 2007). It is a measurement of the whole community without categorizing plants into species (Li et al., 2015, pp, 6). It "values the proportion of the ground surface covered when the high parts of each plant are projected perpendicularly down on to the ground. Cover values are expressed as a percentage of total area of the sampling unit" (Pears, 1990, pp, 23). The photographic method calculates vegetation cover from a picture (Hall, 2001; Roush et al., 2007), but this method will may not be useful when the cover of plants is overlapping, because plants can have leaves and stems creating a combined cover, which can take values that exceed 100%. Leaves and stems of a plant do not often completely obscure the ground (Seefeldt & Booth, 2006). Meanwhile, the visual estimation method is the most common method of estimating cover because it does not require specialist equipment, although it may require the ability to identify plants by species to reveal the entire coverage of each species. To measure coverage across a study area, an average of the cover of an individual species is usually taken to estimate overall total cover (Pears, 1990; Seefeldt & Booth, 2006). However, a drawback of visual estimation is the inaccuracy of the results of measurement (Pears, 1990), because it is subjective, and determined by differences appertaining to each individual observer (Wilson, 2011).

2.4.1.2 Leaf area index

Leaf area index (LAI) is an important measure for monitoring vegetation dynamics as it is related to various biophysical processes within and below the canopy (Fan et al., 2009). LAI is the total one-sided area of leaf tissue per unit ground surface area [LAI = leaf area / ground area, m2 / m2] (Breda, 2003). This measurement depends on the composition of vegetation, the stage of development, season and site conditions, and is used in models to estimate vegetation productivity, evapotranspiration and photosynthesis (Fan et al., 2009). It differs from vegetation cover measurement such as the photographic method, by directly measuring the tissue of leaf per unit ground surface area. LAI can be measured directly by harvesting leaf tissue and quantifying the leaf surface or indirectly by using various techniques, such as hemispherical photography or the use of optical instruments (Weiss et al., 2004).

2.4.1.3 Density

Density is another measurement of vegetation. It is a quantitative measure of the number of plants per unit area or is derived from measurement of the distance from one plant to the next nearest plant (Alhamad, 2006). It is useful to determine the changes in population structure and productivity of dominant species. Density determination can be very time-consuming, especially when plants are small and numerous (Warmink, 2007).

2.4.2 Remote sensing of vegetation change

Remote sensing is used in many applications including land cover classification, soil moisture measurement, forest classification, snow mapping and sea ice type classification (Gandhi et al., 2015). Remote sensing is the observation and measurement of objects on Earth, the atmosphere and oceans from a distance (Suwanprasit & Srichai, 2012). It detects radiation which is reflected from the Earth's surface or emitted energy from the Earth (Chuvieco & Huete, 2010). The radiant energy signal is transmitted from the object to the sensor in the form of electromagnetic radiation, enabling measurement of information about the object from afar (Solaimani et al., 2001). Electromagnetic energy reaching the earth's surface from the sun is reflected, transmitted or absorbed and these waves consist of the entire set of wavelengths or frequencies. The EM spectrum ranges from the shortest wavelengths (gamma rays, x-rays) up to the long wavelengths (visible, infrared) used in telecommunication (Chuvieco & Huete, 2010). Spectral signatures are the values of reflectance at different wavelengths for features on the Earth such as water, sand, roads, forests, etc, which are measured by remote sensing techniques (Shaw & Burke, 2003). The differences in spectral signatures are used to help classify satellite images into spectrally similar classes (Aggarwal, 2004).

The visible (VIS) spectrum ranges between 0.4 and 0.7 µm, and is divided into three regions. The blue region ranges between 0.4 and 0.5 µm, and is used for atmosphere and water imaging. Green (0.5 to 0.6 µm) is used for imaging vegetation and deep water structures. Red (0.6 to 0.7 µm) is used for imaging man-made objects, and deep water up to 9 m, soil, and vegetation. The Near-infrared (NIR) region is 0.7 to 1.2 µm, and it is used primarily for imaging vegetation (Chuvieco & Huete, 2009). The Mid-infrared (MIR) 1.2 to 8 µm, is used for imaging vegetation, soil moisture content, and some forest fires. Thermal-infrared (TIR) ranges between 8 and 14 µm, and is used for imaging geological structures, thermal differences in water currents, fires, and for night time studies (Chuvieco & Huete, 2009; Campbell, 2002). Different types of vegetation cover can be identified through their spectral behaviour in the form of reflected radiation across these different wavelength regions (Bannari et al, 1995).

2.4.2.1 Spectral response of vegetation

Vegetation has a unique spectral signature which enables it to be distinguished from other types of land cover (Jiménez & Díaz-Delgado, 2015). The spectral response of vegetation depends on such factors as the orientation and height of the sun in the sky (solar elevation angle), the health of vegetation, and the state of the atmosphere (Shaw & Burke, 2003). Differences in the water content, pigment, carbon content and nitrogen content in plants are responsible for the variation in spectrum (Silleos et al., 2006).

The spectral reflectance of vegetation can be measured in three major wavelength regions (Figures.2.1):

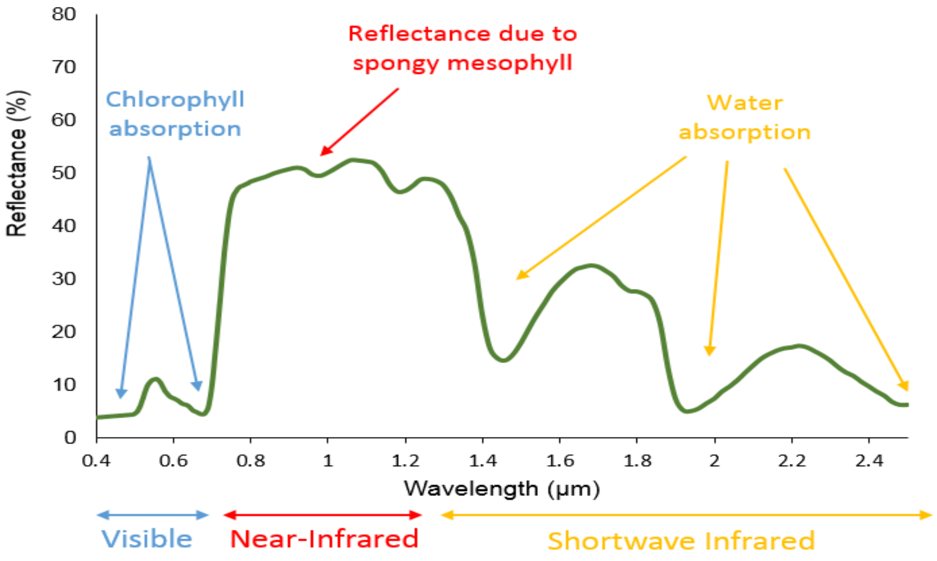


Figure 2.1: Spectral signature of green vegetation (Source: GSP216)

(i) Visible wavelengths (0.4-0.7 m): low reflectance, high absorption, and minimum transmittance. Here, the reflectance of vegetation is low in both the blue and red regions of the spectrum, due to absorption of radiation by chlorophyll for photosynthesis (Cracknell, 2007), but there is a slight reflectance peak in the green band, which is the reason why growing vegetation appears green.

(ii) NIR (0.7-1.3 nm): high reflectance and transmittance, very low absorption. The reflectance is high due to the cellular structure in the leaves (Roder &Hill, 2009). Hence, vegetation can be identified by the high NIR (Kharuk et al., 1992).

(iii) MIR (1.3- 2.5 nm): both reflectance and transmittance generally decrease from medium to low, while absorption increases from low to high (Roder &Hill, 2009). Internal leaf structure has some effect, but the reflectance is largely controlled by leaf tissue water content (Mather, 1996).

The spectral reflectance may be used to distinguish between vegetated and non-vegetated areas on remotely sensing imagery, and demonstrate differences between the species (Mather, 1996). However, it is affected by factors such as soil nutrient status, the growth stage of vegetation and colour of the soil (which may be affected by recent weather conditions) (Kharuk et al., 1992; Roder &Hill, 2009). The values of reflectance may also be used to estimate physical properties of the vegetation, such as leaf area or biomass production ((Jiménez & Díaz-Delgado, 2015).

2.4.2.2 Vegetation Indices (VI)

Vegetation indices (VI) are derived from the spectral reflectance of leaves and canopies, as measured by remote sensing sensors and are used to detect changes in vegetation cover (Cihlar et al., 1991). VI are indicators that describe the greenness or relative density and health of vegetation in a satellite image and may be related to the amount of photosynthetically active radiation absorbed by a plant canopy, and therefore to physiological processes, such as photosynthesis, occurring in the upper canopy (Huete, 2012). VI were developed to extract the plant signal only, however, the soil background, moisture conditions, solar zenith angle, sensor view angle and the atmosphere may alter VI values in complex ways (Jackson & Huete, 1991).

Over forty vegetation indices have been developed during the last two decades in order to assess vegetation response and minimize the effects of the factors described above (Bannari et al., 1995; Gandhi et al., 2015). The three VI used in this study to examine vegetation cover change based on a remote sensing technique are described in the next section.

2.4.2.2.1 Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) measures green leaf biomass (Cihlar et al., 1991). It is also used to estimate the fraction of vegetation cover and also the exact percentage of the vertical projection of vegetation (branch, stem and leaves) in an area of the land surface (Li et al., 2015). The NDVI is calculated as a ratio difference between measured canopy reflectance in the red and near infrared bands respectively (Gandhi et al., 2015). The red and near infrared wavelengths are sensitive to the presence of green vegetation. Lower reflectance from vegetation in the red band is caused by chlorophyll absorption, so the red wavelength can distinguish between dry areas and green areas. The high reflectance from vegetation in the near-infrared band is caused by the refraction of radiation within the leaf due to leaf cellular structure. Near-infrared wavelengths can therefore monitor the density and distribution of vegetation and distinguish between plants, soil and water (Bannari et al, 1995). The NDVI is widely used as an indicator of vegetation productivity and as a measure of the vegetation cover (Wang et al., 2004; Andela et al., 2013). The NDVI is calculated for each pixel in a satellite image using the following equation (Equation 2.1):

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \qquad [2.1]$$

where NIR is the near infrared reflectance and RED is the red reflectance. NDVI values range between -1 and +1, where maximum theoretical greenness is at NDVI= 1 and less vegetated or non-vegetated areas have values close to zero (Box et al., 1989; Jin et al, 2008). NDVI can indicate vegetation cover change for a certain area through a time series of the NDVI images (Wang et al., 2004; Ahl et al., 2006).

2.4.2.2.2 Soil Adjusted Vegetation Index (SAVI)

The spectral reflectance of a plant canopy is the combination of the reflectance spectra of plant and soil components (Rondeaux et al., 1996). The background and brightness of soil exert a considerable influence over canopy spectra and the calculated vegetation indices. For example, darker soil increases the amount of vegetation estimated and gives higher values for the vegetation index (Huete, 1988). Soil background is one of the challenges facing remote sensing for monitoring vegetation (Gilabert et al., 2002), since the effect of soil brightness and colour exert considerable influence on vegetation on VI (Bannari et al, 1995). Soil-adjusted indices such as SAVI have been introduced to address this issue. It is an important step towards describing dynamic soil-vegetation systems from remotely sensed data and attempting to reduce the influence of the soil. SAVI assumes that most soil spectra follow the same soil line when Red and NIR are adopted against each other. This is “the linear relationship between the reflectance in red and near infrared wavelengths of bare soil reflectance with varying amount of moisture roughness"

(Gilabert et al., 2002, pp. 303), and minimizes soil brightness influences on spectral vegetation indices involving red and near-infrared (NIR) wavelengths. (Rondeaux et al., 1996). To calculate SAVI from images, the following equation is used (Equation 2.2):

$$SAVI = \frac{NIR - RED}{(NIR + RED + L)} * (1 + L) \quad [2.2]$$

where L is an adjusting factor of 0.5, which has been found to be the optimal in reducing soil effect over the full range of canopy covers (Huete, 1988).

2.4.2.2.3 Enhanced Vegetation Index (EVI)

The Enhanced Vegetation Index (EVI) was proposed by the MODIS Land Discipline Group to provide spatial and temporal information regarding global vegetation (Matsushita et al., 2007). With the launch of the MODIS sensors, NASA adopted EVI as a standard MODIS product, which is distributed by the United States Geological Survey (USGS) (Sesnie et al., 2012). The enhanced vegetation index (EVI) was developed as an alternative vegetation index to reduce the influence of atmospheric conditions on vegetation index values, and correct for canopy background signals (Jiang et al., 2008).

EVI differs from NDVI because it tends to be more sensitive to canopy differences like leaf area index (LAI), canopy structure and plant phenology while NDVI only responds to the amount of chlorophyll present in the plant (Rondeaux et al., 1996). It uses a red band and near infrared band to capture vegetation amount and a blue band to remove the influence of atmosphere from the red band. It is computed using the following equation (Equation 2.3):

$$EVI = G \times \frac{(NIR - RED)}{(NIR + C1 \times RED - C2 \times Blue + L)} \quad [2.3]$$

where NIR, RED, and Blue are atmospherically-corrected surface reflectance wavelengths, and C1, C2, and L are coefficients to correct for atmospheric conditions (i.e., aerosol thickness). For the standard MODIS EVI product, L=1, C1=6, and C2=7.5. EVI has the ability to improve vegetation monitoring by minimizing soil and atmospheric influences (Rondeaux et al., 1996).

This research uses these specific indices because NDVI is effective for measuring a low-density of vegetation cover (Andela et al., 2013). Consequently, the NDVI proved useful for monitoring the vegetation in the study area due to its ability to monitor an area that has a low-density of vegetation cover. The SAVI was used because there are many types of soil in the study area. The reflectance of these soil types varies and can affect reflectance of areas that have low vegetation. The research used EVI to remove the impact of the ground below the vegetation, especially areas with a high density of vegetation because the material on the ground may affect the vegetation value.

2.4.2.3 Image classification

Image classification methods can be used to create thematic maps and detect land cover change (Gallego, 2004). Classifying satellite images to present the distribution of different land cover types across an area and comparing these classified images over different periods can show how the land cover changes (Elhag & Boteva, 2016). Land cover classification provides a picture of the distribution of land cover at a given time (Aplin, 2004).

The process involves sorting the pixels in a digital image into a finite number of individual classes, or categories of data, based on the spectral value in each pixel in an area that has been chosen for classifying (Lillesand and Kiefer, 1987) (Figure 2.2). The technique of classification can be applied to raw images but it should preferably be carried out on atmospherically corrected data (Chuvieco & Huete, 2010). Atmospheric correction is a process of removing the impacts of gases, water vapour, aerosols, dust and pollutants from the satellite image (Chuvieco and Huete, 2010).

Classification methods are based on two major categories of image classification technique: unsupervised and supervised classification (Jensen, 2005). One of the advantages of unsupervised classification is that it requires minimum input from the analyst (Campbell, 2002). Therefore, when the analyst does not have enough knowledge and information about a study area, this method may be more useful for classification. Unsupervised classification is used when the outcomes (groupings of

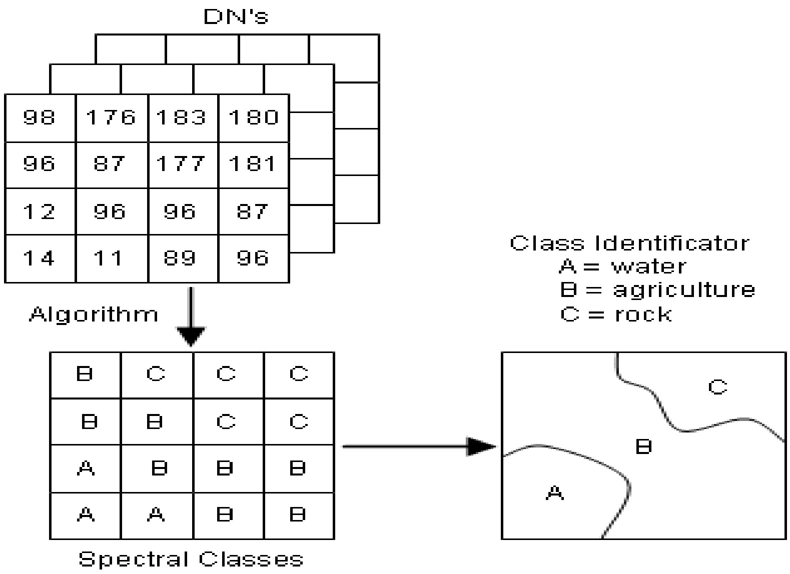


Figure 2.2: Satellite image classification modelling (source: CCRS, 1998).

pixels with common characteristics) are based on the software analysis of an image without the user providing sample classes (Jensen, 2005).The computer uses clustering techniques to determine which pixels are related spectrally and groups them into classes (Chuvieco and Huete, 2010). The analyst can specify the desired number of output classes but otherwise does not aid in the classification process (Liu, 2005). The analyst then determines the land cover identity of these spectral groups by comparing the classified image data with ground reference data (Lillesand & Kiefer, 1987). In supervised classification, the analyst can select sample pixels in an image that is representative of specific classes using his knowledge about the study area (Chuvieco and Huete, 2010). These training areas (input classes) are used as references to classify pixels that have the same reflectance in the image (Jensen, 2005). Many analysts use a combination of supervised and unsupervised classification processes to develop a final output analysis and classified maps (Liu, 2005).

2.5 Remote sensing of vegetation change in the Mediterranean

Remotely sensed data have potential value for vegetation change detection. Many studies have used remote sensing data and VI to detect vegetation change in the Mediterranean basin and the factors which have caused this change. Some of these studies have examined the influence of climate change on vegetation change in different areas in the region and others have used the remote sensing technique to examine the impact of human activity on land cover in some areas of the region. In general these studies have confirmed that land use in the Mediterranean region has undergone widespread transformation in recent decades, due largely to changes in socioeconomic development, which have had a strong effect on land cover. For example, Lasanta et al. (2012) used Landsat images to analyse abrupt and gradual changes in the land cover types from 1984 to 2012 in the middle Ebro valley, Spain. They found that time-series of high spatial resolution satellite images and the application of remote sensing provided a useful approach to identifying abrupt and gradual changes in land cover processes, which are not available using classical analytical approaches.

Land cover has changed in many areas due to urban expansion, industrial activity, the establishment of land irrigation and agricultural expansion. Other areas have gradually changed as a result of global warming and drought. These areas showed rates of change that were lower in magnitude than those directly transformed by human activity (Bajocco et al., 2012).

The study by Osborne & Woodward (2001) assessed evergreen sclerophyllous shrub vegetation, comprised of species such as *Quercus coccifera* and *Pistacia lentiscus* at sites in eastern Turkey and the Maghreb region of North Africa (Algeria, Morocco and Tunisia), between 1981 and 1999. The study used a model designed to estimate the NDVI from absorption of photosynthetically active radiation (PAR) and near-infrared radiation (NIR), which were estimated on a ‘per unit ground area’ basis for vegetation and soil components. Secondly, total absorbed and incident fluxes were used to obtain reflection coefficients for PAR and NIR at the vegetated land surface, from which the NDVI was calculated. The model also reproduced observations of diurnal and seasonal variation in photosynthesis, stomatal conductance, evapotranspiration and soil water content in sclerophyllous vegetation, and adequately estimates NPP and LAI at shrubland sites throughout the Mediterranean region.

The study compared the results of NDVI with the time-series of the NDVI derived from NOAA-AVHRR data for the study area from 1981 to 1991 and the results indicated an increasing trend for NDVI in the study areas in both results, noting that an increase in the NDVI could have been caused by changes in canopy structure which were driven by variation in precipitation and rising atmospheric CO2, and not increasing temperature.

Hill et al. (2008) confirmed in their research that the Iberian Peninsula area had undergone widespread land use transformations which had had an influence on vegetation cover. This study was based on time-series analysis of 1-km regulation NOAA–AVHRR images, to assess vegetation dynamics in the study area using the NDVI. The results indicated that decreased vegetation cover was mainly caused by fires which in turn caused an increase in desertification and a decline of vegetation productivity after disturbance. Drought or human activity caused these fires in the areas which have undergone a decrease in vegetation cover.

Symeonakis et al. (2004) studied the relationship between land cover and land use changes and land degradation in two Mediterranean sites, which were, firstly, in the north of the Alicante province in southeast Spain and, secondly, on the Aegean island of Lesbos, Greece, using remote sensing. This study used Landsat images for both sites, Landsat MSS (July 1978 and May 1975), TM (August 1999) and ETM+ (August 2000). The results showed increases in degradation and runoff, and erosion in the areas that were exposed to forest fires, urbanization, and overgrazing. This study identified the main cause of land cover change to be human intervention in the areas having natural vegetation.

Some studies such as those of Stefanidis et al. (2016), Sluiter (2005), Alqurashi & Kumar (2013), and Symeonakis et al. (2006), examined land cover in the Mediterranean region using classification of remote sensing images such as Landsat, NOAA AVHRR and ASTER imagery. These studies indicated the effectiveness of the classification method to monitor the changes in land cover. They observed changes in land cover or land use in different areas in the Mediterranean region over different periods of study, and they confirmed that vegetation cover had changed due to human activity in recent years.

Stefanidis et al (2016) analysed spatial-temporal changes of land cover and land use at a catchment scale of two connected lakes in Greece, Lake Vegoritis and Lake Petron, from 1972 to 2011. The study was based on classification of historical land cover and used a series of Landsat images from 1972 to 2011. Also, climate data and temporal series of water levels were analysed to investigate the potential role of climate variability on lake hydrology and water quality. Results showed that a combined effect of climate and human-induced land cover changes appeared to be responsible for the environmental changes in these lakes. Regarding the effect of climate, it appears that the precipitation trend declined, which correlated with water level fluctuations, whereas, the results of classification showed that between 1972 and 2011, almost 28% of Lake Vegoritis and 13% of Lake Petron catchment areas were replaced by cultivation.

Symeonakis et al. (2006) used Landsat TM and ETM+ data from various dates spanning 14 years from 1987 to 2001 to assess land use and cover change in a Spanish coastal area as a trial site for the Mediterranean region using classification methods. The key result for this study was that land cover changed over the period of study with a decrease in forest and shrublands as a result of an increase in human activities such as agriculture and urban development. The study confirmed the effectiveness of remote sensing to assess long-term land cover change.

Sluiter's (2005) study examined the Peyne area, approximately 60 km west of Montpellier France, to determine and describe changes in vegetation communities. This study used three ways to detect any changes: multi-spectral ASTER, Landsat 7 ETM+ data, and a time series of eight aerial photograph mosaics from 1946 to 2000 using GIS. Furthermore, it analysed and classified remote sensing imagery of the area to determine the changes in land cover. This study demonstrated that it was possible and useful to develop a land cover change model to detect the changes and factors which caused land cover change and which can be validated by remote sensing data. The result indicated vegetation cover had changed over the time and this result was confirmed by the three methods used.

2.5.1 Remote sensing of vegetation change in Libya

Only a few studies have examined vegetation change in Libya using different remote sensing methods. El Tantawi (2005) assessed climate change in Libya and desertification of the Jifara Plain in the west of Libya using geographical information systems (GIS) and remote sensing techniques. This study assessed the climate at eleven climatic stations located in north-west Libya as little information was available for southern Libya. The work also investigated the changes of vegetation cover in some parts of the Jifara Plain and the desertification in these areas using Landsat classification imagery. The study used climate data from the Libyan Meteorological Department in Tripoli and used NDVI derived from atmospheric correction of Landsat MSS (1976), TM (1987-1990) and ETM+ (1999-2002).

The main results showed that the temperature had increased over most of Libya from 1946 to 2000 and large spatial variations of mean annual temperatures were observed from north to south over Libya, explained by several factors (urban heat islands in cities located in northern Libya and greenhouse gases resulting from the oil industries) (Figure 2.3).

Over the period 1976-2000, annual minimum and maximum temperature trends were positive over all of Libya, except Benina in north-east Libya for which a negative trend of maximum temperature was computed (Figure 2.4). In terms of precipitation, over the period 1976-2000, the trends for annual precipitation totals were negative over most of Libya, indicating decreased precipitation at eleven stations across Libya. However, this does not correspond with the results of the examination of rainfall at the stations of the study area in chapter 3, which showed a fluctuating trend of rainfall across the study area over 57 years.

The Jifara Plain located in north-west Libya, is exposed to desertification and has seen significantly degraded quantity and quality of vegetation from 1976 to 2001, as a result of climate change, landforms, overgrazing, over-cultivation, population growth and deforestation for agriculture in semi-arid lands around settlement areas. Soils have been degraded and vegetation cover has declined in many parts of the region. (Figure 2.5).

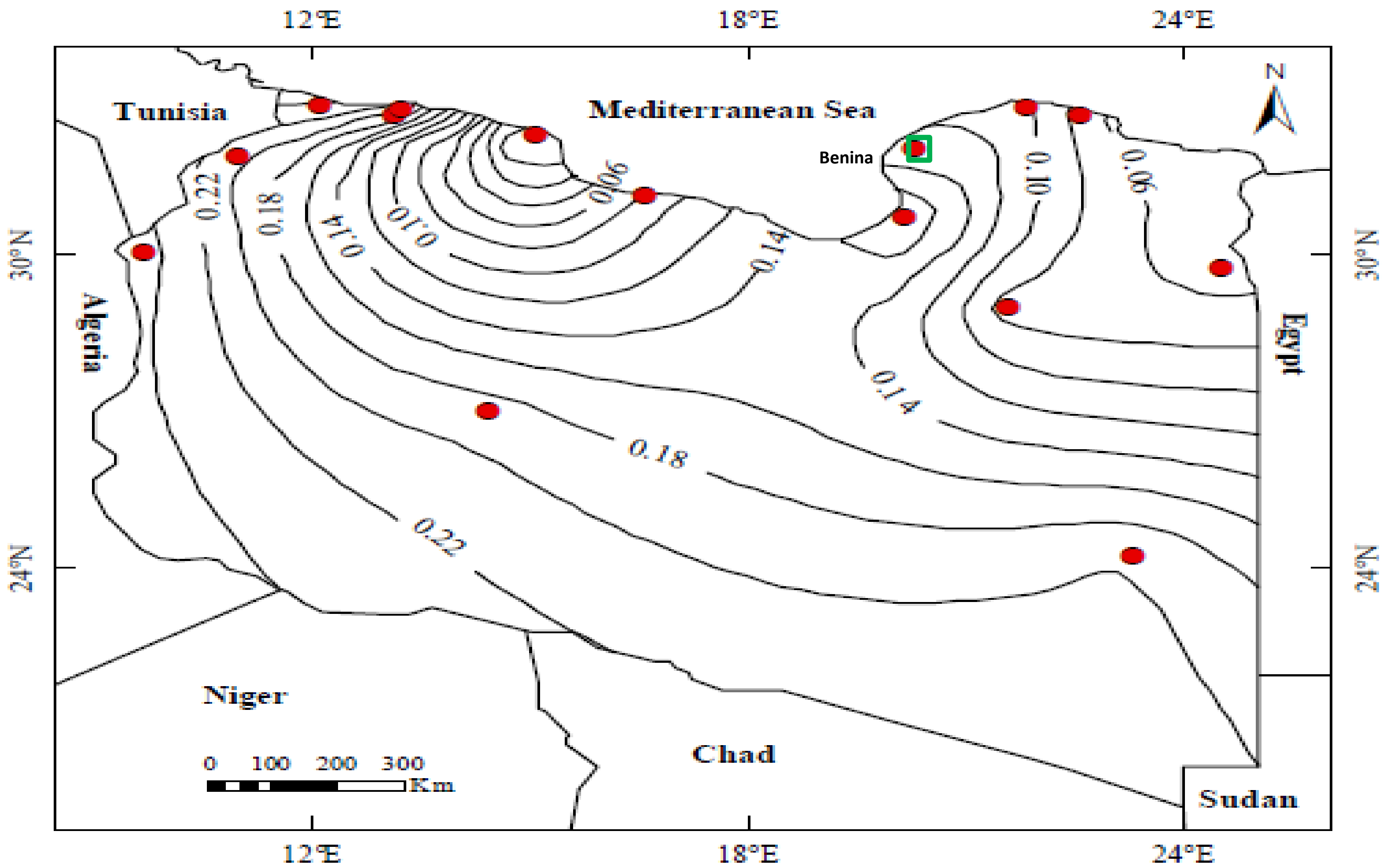


Figure 2.3: Regionalization of mean annual temperature trends (°C) in Libya, 1946-2000 (Source: El Tantawi, 2005).

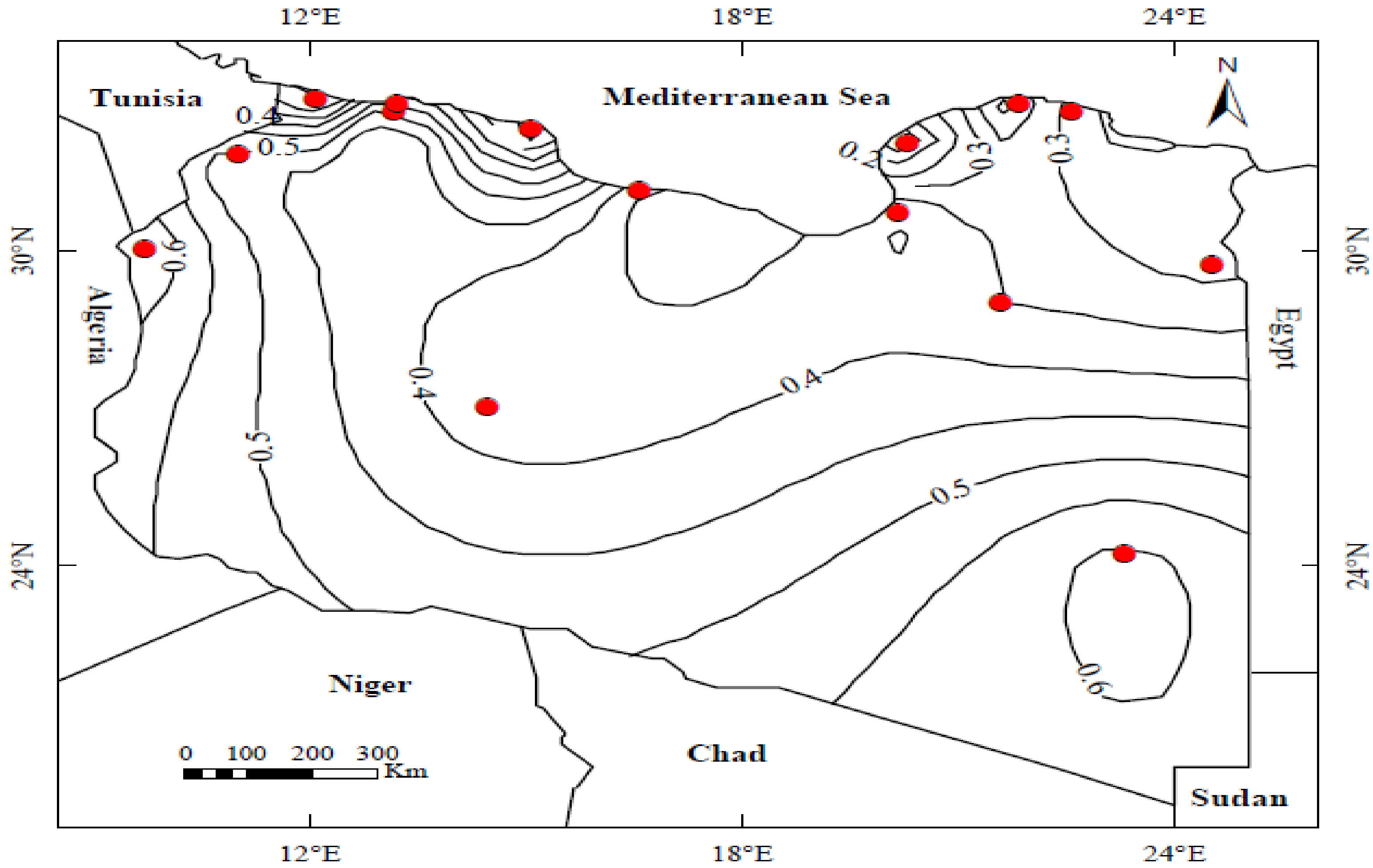


Figure 2.4: Regionalization of mean annual temperature trends (°C) in Libya, 1976-2000 (Source: El Tantawi, 2005).

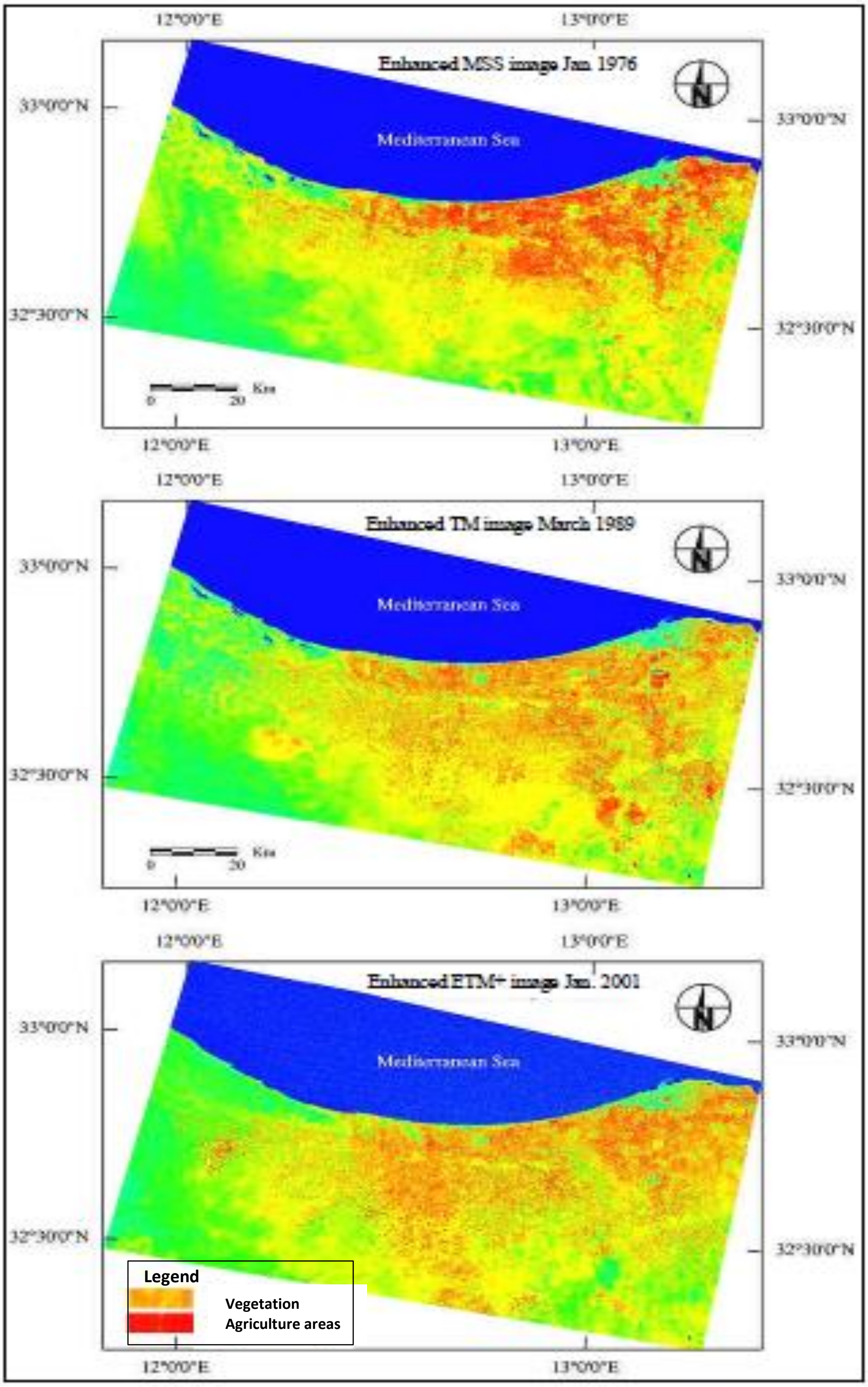


Figure 2.5: Change detection of vegetation and agricultural lands in north Jifara Plain 1976, 1989 and 2001 (Source: El Tantawi, 2005)

Figure 2.5 showed the classification of land cover into cropland and natural vegetation in some parts of the Jifara Plain and an increase in the area of cropland from 1976 to 2000 along with declining vegetation cover across the study area.

In Oune's (2006) study, multi-temporal Landsat TM imagery was used to assess land cover change in south west Tripoli in the west of Libya, from 1988 to 2000 using classification techniques, Soil Adjusted Vegetation index (SAVI) and selecting fifty random areas in 2004 in the south-west of Tripoli to confirm the results of the classification. A Geographic Information System was used to combine and interpret a range of parameters (land cover, soil type, topography, climate, etc.). The study classified SAVI images of 1988, 1992, 1999 and 2000, with VI values of between 0.1 and 0.9 to map vegetation of various densities over the study area and classify the images into four classes. Very high density of vegetation was classified as equal to or greater than 0.4, while high density of vegetation ranged between 0.4 and 0.3, with medium density ranging between 0.3 and 0.2 and low vegetation density between 0.2 and 0.1 (Figure 2.6). A key result of the analysis of the images was detection of vegetation degradation in the study area as a result of increased use of marginal lands for crops and grazing due to population growth. Accelerating soil degradation and erosion due to inappropriate agricultural practices, and escalating deforestation due to a growing need for fuelwood, building materials, cropland and urban expansion were also found.

2.5.2 Remote sensing of vegetation change in Al Jabal Al Akhdar region

Previous local-scale studies in Libya were limited in terms of spatial coverage and spatial resolution. Some researchers adopted fieldwork to study sites in the Al Jabal Al Akhdar area, but due to the rugged terrain of the region with its mountain cliffs and deep valleys, access to the area was difficult. The most recent study (Ibrahim, 2008) carried out in this region examined vegetation change from 1982 to 2006. This study used remote sensing data for assessing desertification conditions in the Al Jabal Al-Akhdar region using the NDVI derived from previous sensors, in particular the NOAA-Advanced Very High Resolution Radiometer (AVHRR) (1982-2006)

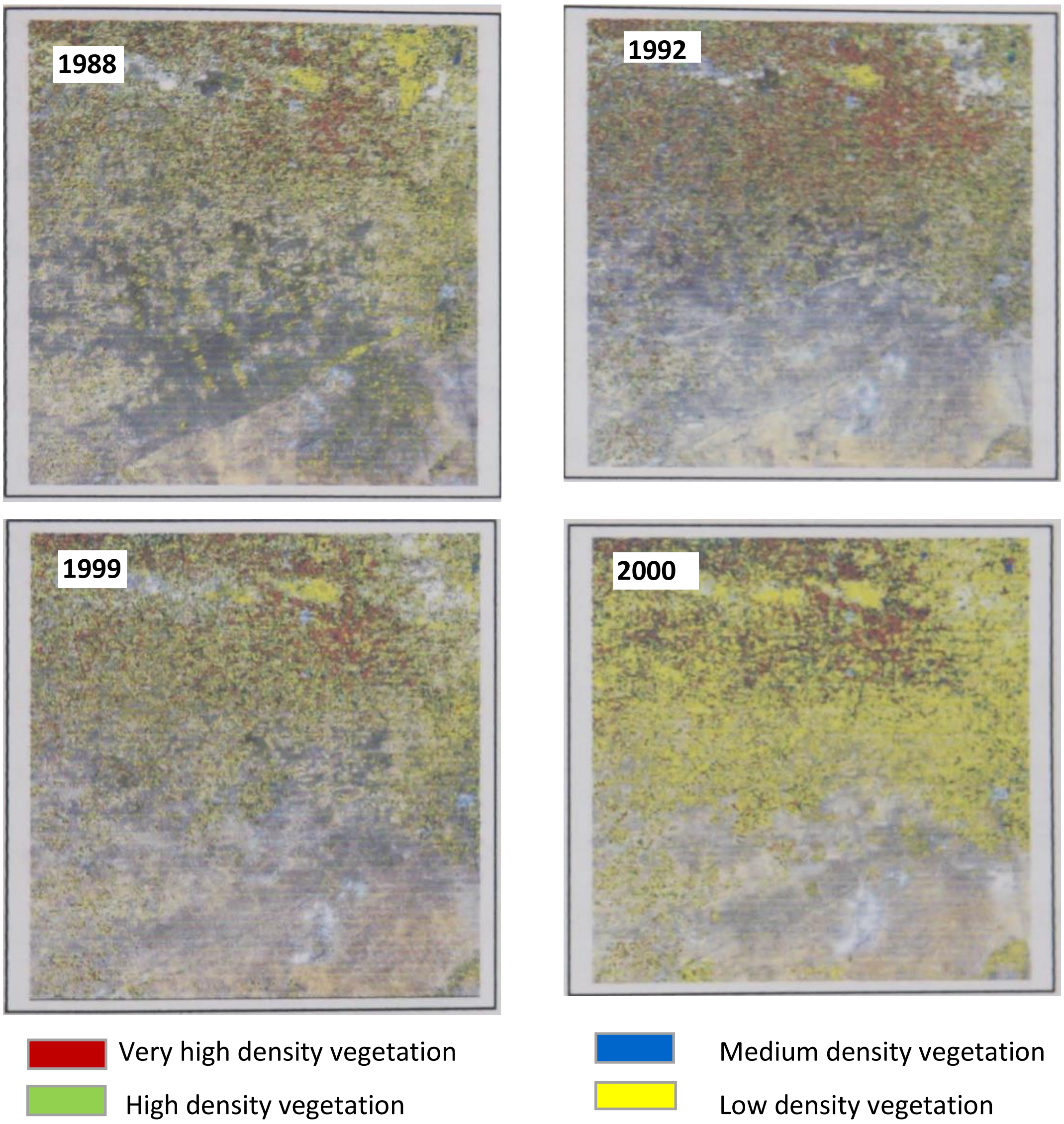


Figure 2.6: Various vegetation density classes in years 1988, 1992, 1999 and 2000 (Source: Oune, 2006).

with a resolution of 1 km and Moderate Resolution Imaging Spectrometer MODIS (2001-2006) with a spatial resolution of up to 250 x 250 m.

This study used the mean annual rainfall statistics to detect the effect of rainfall on vegetation change and concluded that annual rainfall for the purposes of the study varied between the south and north of the area.

This agreed with spatial distribution patterns of NDVI which ranged from -0.3 to 0.00 in the southern part of the area, to 0.10 to 0.62 in the northern part of the study area. All results of the NDVI analysis indicated a decrease in vegetation cover across the study area (Figures 2.7 & 2.8). The spatial distribution patterns of NDVI ranged between less than -0.3 and 0.00 in the southern part of the area to more than 0.10 - 0.62 in the northern part of the study area. This is consistent with the results of the precipitation trend, where the northern part of the area received the greatest amount of rainfall.

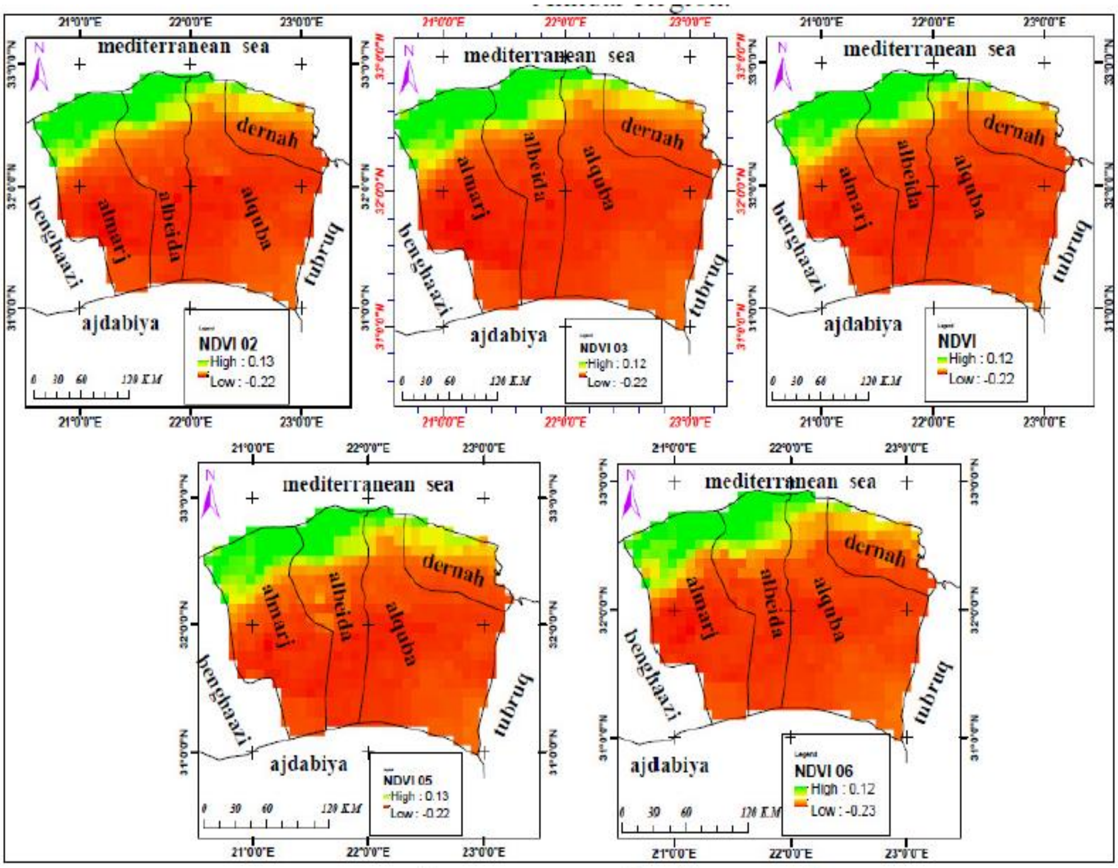


Figure 2.7: Spatial distribution of annual mean of AVHRR NDVI (2001-2006), in Al Jabal Al Akhdar region (Source: Ibrahim, 2008).

The figures show the differences in NDVI values between AVHRR and MODIS from 2001 to 2006. The NDVI values from AVHRR sensors were lower than those from the MODIS sensor because of atmospheric effects (Fensholt & Sandholt, 2005). The data from the NOAA sensor were possibly affected by noise and significant data gaps because of issues with the on-board scan motor.

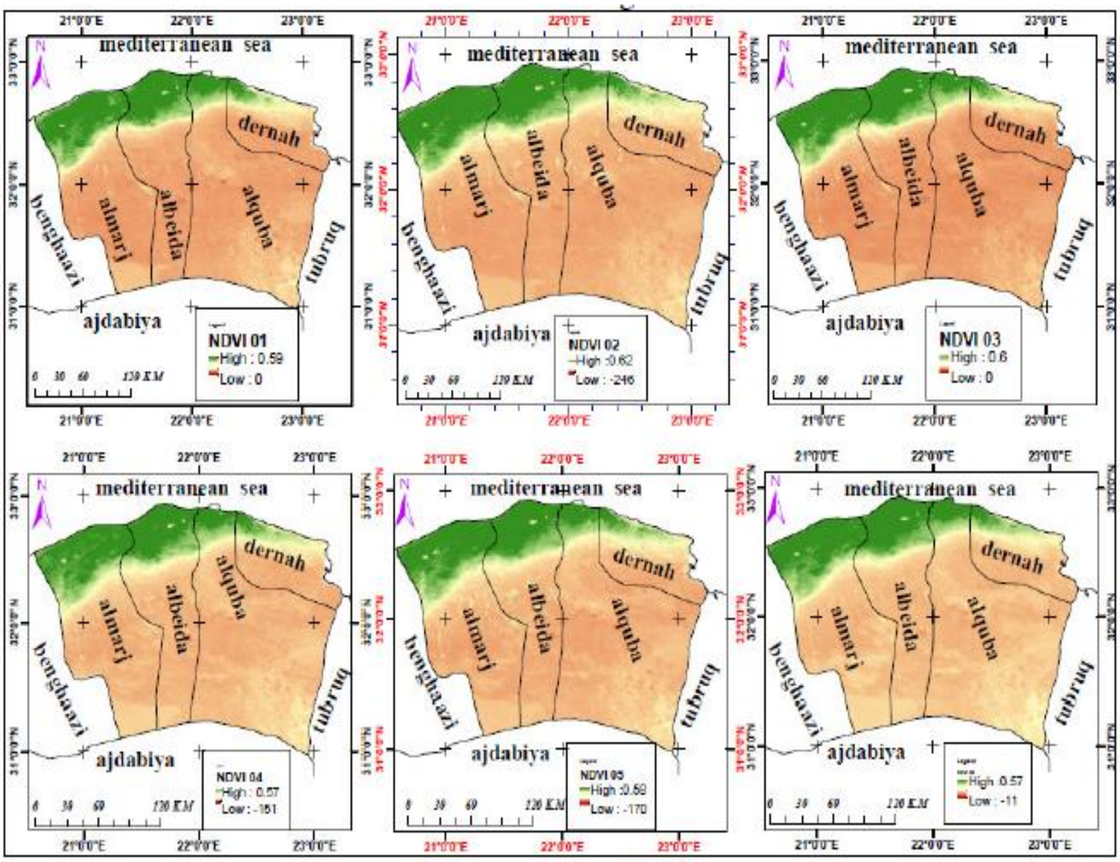


Figure 2.8: Spatial distribution of annual mean of MODIS NDVI (2001-2006), in Al Jabal Al Akhdar region (Source: Ibrahim, 2008).

2.6 Other studies of vegetation change in the region

In recent years, a number of local studies have examined the natural vegetation in the Al Jabal Al Akhdar region (Al Mukhtar, 2005; Ben Khaial and Bukhechiem, 2005; Ibrahim, 2006; Libyan Agriculture Department, 2004). These studies relied on fieldwork, ground measurements of vegetation cover and leaf area index to assess the vegetation in some parts of the region. They confirmed that there has been a decrease in the semi-natural and natural vegetation cover of the region. The region has dense forests of Maquis of *juniper*, *Lentisc* trees, and also bromegrass, canary grass, bluegrass, and ryegrass. Meanwhile, Hegazy et al. (2011) and Al Mukhtar (2005) have suggested that there has been a decrease in the average tree and shrub growth, that some parts of trees have died, and that desertification is on the increase in the south of the Al Jabal Al Akhdar region.

The Libyan Agriculture Department (2004) estimated that the area of natural forests in the Al Jabal Al Akhdar region was approximately 320,000 ha at the beginning of the 1970s, which had declined by 2004 to about 299,000 ha. This deterioration is particularly evident for the *juniper* tree, a *perennial*. Some species are approaching extinction, such as sage, orchid family types and pistachio atlantics. The perennial trees of the Maquis are the main vegetation species in the region, with *Juniper Phoenicia* being one of the most important components of vegetation.

2.7 Conclusion

The effectiveness of remote sensing techniques to monitor vegetation change has been demonstrated in the studies of El Tantawi (2005), Hill et al. (2008) and Lasanta et al. (2012). Although remote sensing provides multi-temporal data sets and examines large areas over long periods of time, the technique has still seen very little use for monitoring vegetation in Libya. This research is the first study to examine the vegetation dynamics of the Al Jabal Al Akhdar area using high spatial resolution Landsat (3 0m) data to test a long-term data record for vegetation cover change in the study area. The research will also be the first study of vegetation cover change using three different vegetation indices NDVI, SAVI and EVI. The research will also determine the factors which affect vegetation dynamics in the region, focusing on climate change and human activity. Most of the previous studies (Al Mukhtar, 2005; Ben Khaial and Bukhechiem, 2005) have assessed only the vegetation in the region without exploring the controlling factors.

The next chapter presents the study area and assesses the recent climate change in the Al Jabal Al Akhdar.

CHAPTER 3: BACKGROUND ON THE AL JABAL AL AKHDAR REGION

This chapter contains an introduction to the study area. It presents information relating to the natural environment of the study area including the location, topography, climate, the water availability and information about the population of the area. This chapter illustrates the distribution of vegetation in the study area in relation to topography. Finally, the chapter investigates the climate change at three meteorological stations in the study area. It presents the climate data and the methodology used in the study.

3.1 Introduction

Libya is located on the south coast of the Mediterranean in North Africa. It is situated between 19° 29’- 32° 55’ N and 9° 24’- 25° 02’ E and covers an area of approximately 1,750,000 km². Most of the land area is desert with nearly 90.5% of the area classified as very barren, 7.5% barren, 1.5% semi-barren, and only 0.5% categorized as sub-humid (Ageena et al., 2013; El-Tantawi, 2005). The main concentration of population is in the mountains in the north-east and the north-west of Libya. Jabal Nafusah (960 m) is the highest point in north-west Libya, and Al Jabal Al-Akhdar at 880 m above sea level is the highest in the north-east (El-Tantawi, 2005).

3.2 Location of the study area

Al-Jabal Al-Akhdar is an upland area. It is located between 32° 00’- 32° 58’N and longitudes 19° 56’- 23° 09’E (Al Mukhtar, 2005). The total area of the region is about 7,800 km^2, which extends for a distance of over 300 km along the Libyan coast (Bukhechiem, 2006), including the most vegetated part of the country (Bukhechiem, 2006; Al Mukhtar, 2005). The wide region is characterized by a variety of natural environments that are caused by variation in geology, topography, climate, water resources, soil and natural vegetation (Figures 3.1 & 3.2). Distance from the sea and altitude cause important variations in climate (Ben Khaial and Bukhechiem, 2005).

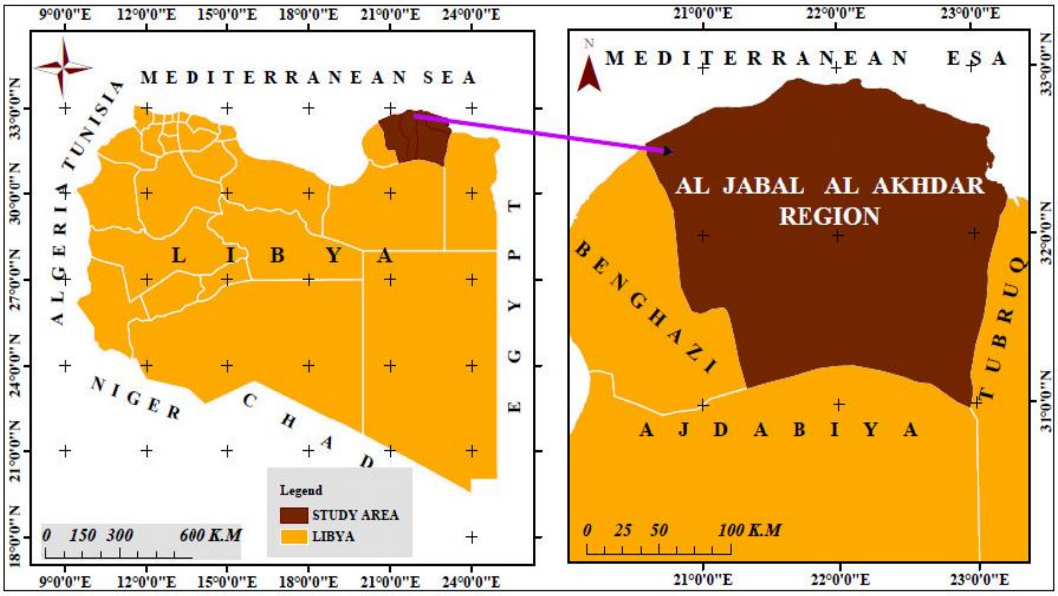


Figure 3.1: The site of Al-Jabal Al- Akhdar in the North East of Libya (Source: Ibrahim, 2008).

Figure 3.2: The Al-Jabal Al Akhdar in the north east of Libya (Source: Google Earth, 2017).

The study area is a high plateau which varies in elevation from one region to another. The elevation of the coastal plain is approximately 26 m above the sea level in the north and more than 600 m in the south (Bukhechiem, 2006). The north side of the plateau descends steeply towards the coast and consists of steep cliffs which separate it from the sea by a coastline which differs in breadth from one place to another (Al Mukhtar, 2005).

3.3 Topography and landforms

Al Jabal Al Akhdar is a medium altitude plateau (Ben Khaial and Bukhechiem, 2005). It consists of three edges and two long terraces extending parallel to the coast (Al Mukhtar, 2005). The terraces differ in breadth and length from one area to another. The highest area on the ridge of Al Jabal Al Akhdar is the Sidi Al Hamri (800 metres above sea level) which extends for a distance of approximately 40 km along the watershed of Al Jabal Al Akhdar. There are many large valleys descending from the watershed of Al Jabal Akhdar through the north and south interfaces of the mountain, to ending up at the sea in the north, and the desert in the south. Each topographical feature is described below.

3.3.1 The coastal plain

The coastal plain extends from the first edge of the Al Jabal Al Akhdar and the coastline, with a length of about 85 km. In general its breadth ranges between 2 km at estuaries to a few metres in some parts of the coastline (Ben Khaial and Bukhechiem, 2005).

3.3.2 The first rim and terrace

The first rim and terrace are located on top of the first edge. The landforms of the terrace are diverse with elevation ranges between 200 and 400 m above sea level, and a width exceeding 10 km in some places, and less than 10 km in others. The terrace is dissected by many valleys that cross the northern slopes of the Green Mountain such as Cove valley, Mmlouh valley, Mashhour valley, Hyena, Tirah, and Al Mahbol valleys. The importance of this area lies in agricultural production and pastoral activities especially around estuaries where fertile soils occur (Ben Khaial & Bukhechiem, 2005).

3.3.3 The second rim and terrace

The second rim and terrace are located south of the first terrace with elevation ranges between 500 and 700 m above sea level and an increase in height to the south towards the third rim (Bukhechiem, 2006). The landforms are very complex compared with the first terrace with surfaces dissected by several deep valleys.

3.3.4 The third rim

The third rim is smaller in area than the first and second rim. It is the high point of the Al Jabal Al Akhdar, an area of the Sidi Al Hamri, and is located at the watershed of Al Jabal Al Akhdar, which divides the valleys sloping to the north, which come to an end at the sea, and valleys sloping to the south, which end up at the semi desert area in the south of the Al Jabal Al Akhdar.

The Sidi Hamri is the highest area of the Al Jabal Al Akhdar at altitudes reaching up to 880 m above sea level (Ben Khaial and Bukhechiem, 2005). The land is predominantly level compared with the previous parts, and large parts of this territory are exploited by human activities such as agriculture and livestock production (Al Mukhtar, 2005) (Figure 3.3).

3.3.5 The south slope of the Al Jabal Al Akhdar

The southern slopes of the Al Jabal Al Akhdar descend gradually towards the south. The majority of the terrain is undulating, rugged and covered by rock. This slope is incised by many seasonal water courses that end in water bodies surrounded by low slopes south of Al Jabal Al Akhdar. This water remains for relatively long periods and is often used for watering animals and plants (Al Mukhtar, 2005). The most important valleys are the Tnamilo, Al Aker, Qurna, Al Hamama and Samalos, which is the largest and most important valley on the southern slopes of Al Jabal Al Akhdar, covered by mud sediments known as Al balta (Ibrahim, 2008).

3.4 The soil of study area

There are several types of soil in the Al Jabal Al Akhdar, and they differ in their mechanical and chemical properties. Distribution of soil is influenced by landforms and its relationship with climatic elements, especially temperature and rainfall. There are five types of soil in the region: Terra Rossa, Rendzina, Lithosol, Regosol and saline soils (Ben Khaial and Bukhechiem, 2005). Terra Rossa (red soils) is concentrated in parts of the first terrace, and appears in some parts of the west of the coastal plain. In addition there are sub-types of Terra Rossa in the southern parts in the Al Jabal Al Akhdar (Al Mukhtar, 2005). Rendzina (dark, greyish-brown) is usually formed by the weathering of soft rock types: usually carbonate rocks

Figure 3.3: Land forms of north- east Libya including the Al Jabal Al Akhdar (Source: WesternDesertBattle Area1941 en.svg).

(dolomite, limestone, marl, chalk) (Ben Khaial and Bukhechiem, 2005). It is concentrated in sub-humid areas in some places on the first and second terraces and some parts of the coastal area in the region. It is characterized by low organic matter content, alkaline, with a depth of more than one metres, although it also includes a range of shallow calcareous soil (Al Mukhtar, 2005).

Lithosol and Regosol soils have similar structure and both of them are shallow rocky soils, and mixed with gravel stones with the proportion of gravel greater than that of coarser material. Lithosol covers the hills and plateaus of Al Jabal Al Akhdar while Regosol covers the north slopes and the slopes of valleys (Ibrahim, 2006). The saline soils are spread across hills and the southern plains of the Al Jabal Al Akhdar and in valleys on the north and the southern slopes of the region (Bukhechiem, 2006).

3.5 Water resources in the study area

The main Libyan water source is groundwater which supplies about 88 % of the population. There is some seasonal surface water which collects in valleys. Libya has five water basins three of them in the north, Jafara plain, Al Jabal Al Akhdar, and Al Hamada Al Hamra and two in the south, Murzuq and El-Kufra-Serir. The water in the northern basins has declined sharply in the last few decades with fluctuations in precipitation and increases in population leading to increases in the consumption of groundwater and subsequently in the increased drilling of wells, which have consequently caused salinity in the water, rendering it unusable for drinking (FAO, 2005).

A massive water pipeline project, called the Great Man-Made River (GMR) project was initiated in 1984, which was designed to transport 2 million cu m of water per day from 270 artesian wells via 2,000 km of pipeline to the coast from underwater aquifers in the south to Sirte and Benghazi in the north. The basins in the south are large but not renewable (El-Tantawi, 2005).

Dams were built in the northeast and northwest of the country to store rain water. The water source in the study area relies mainly on valleys that are filled by water during the rainy season, especially when rainfall is more than 40 mm per day^{-1} (Ben Khaial and Bukhechiem, 2005). Sixteen small and medium-sized dams located in the largest valleys have a storage capacity of roughly 385 million m^3 and an average annual supply capacity of 60.6 million m^3 y^{-1} in the winter (FAO, 2005).

3.6 Vegetation of the Al Jabal Al Akhdar region

The natural vegetation in the study area varies between forests, shrubland, coastal plain and low vegetation in the semi-arid areas (Figure 3.4). The research divides the vegetation of the region into three sections dependent on topography: the vegetation of the coastal plain, the highlands, and the internal region.

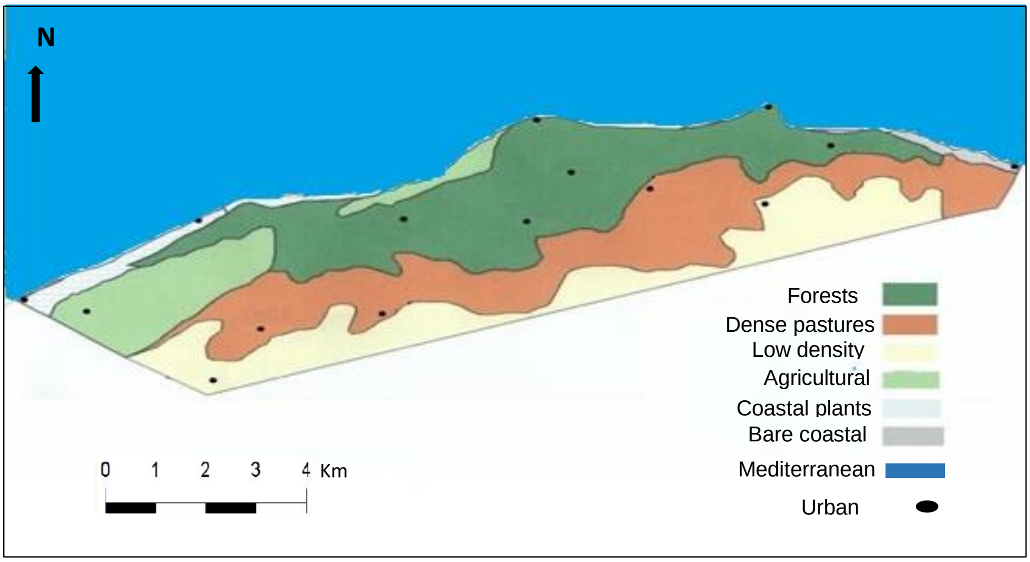


Figure 3.4: Vegetation distribution in Al Jabal Al Akhdar (Modified from: Mukhtar, 2005).

On the coastal plain region, the species of plants tolerate the lack of rain and increase in soil salinity (because it is near the sea). The species include Acacia spp, Borassus, Cistus spp. *Urginea maritime*, and *Malva parviflora* (Feng, et al., 2013; Hegazy, et al., 2011). The vegetation is characteristically short and well-spaced with small leaves, mixed with some sea grass that grows in rocky crevices and on the surfaces of slopes and the terraces.

The density of this vegetation is lower in the east, while increasing in the south towards the foot of the Al Jabal Al Akhdar, with Maquis type vegetation which spreads over the northern slopes of Al Jabal Al Akhdar with *Juniperus phoenica* and *Pistacia lantiscus* (Al Mukhtar, 2005). The highlands include the northern slope of

Al Jabal Al Akhdar. This region is characterized by dense tree cover and shrubs of Mediterranean types as well as landform, calcareous soils and semi-wet climate in most of the northern slopes (Al Mukhtar, 2005; Bukhechiem, 2006; Hegazy et al., 2011). Shrubs include *Juniperus phoenica, Arbutus pavarii, Pistacia lantiscus, Cupressus sempervirens, Eucalyptus camaldulensis, Meliaazedarach* and *Oleaeuropaea* (Feng et al., 2013). There are tree species in the valleys, such as cypress, Aleppo pine, oak, and mixed communities (Figure 3.5). The trees and shrubs are considerably less dense from north to south as a result of lack of precipitation, drought, soil type and landform, and the influence of the desert climate.

Figure 3.5: The vegetation on the northern slopes of the Al Jabal Al Akhdar (Source: http://ports.com /libya/port-of-ras-el-hilal/photos).

The internal region includes the southern slopes of the Al Jabal Al Akhdar. This region is characterized by high temperatures, and rainfall of less than 50 mm y^{-1}. The vegetation is characterized by its ability to tolerate severe drought and high temperatures, with short stature species such as *Acacia flava*, *Aristidaacutiflora*, *Euphorbia abyssinica*, *Calligonum comosum*, *Acacia senegali, and Cordiaafricana* (Feng et al., 2013; Hegazy, et al., 2011), *Zizyphus lotus, harmala* , *Solanum nigrum, Tamarix aphylla*, *Urtica urens* and *Peganum* (Al Mukhtar, 2005) (Figure 3.6).

Over the last forty years there have been changes in the semi- natural and natural vegetation cover in the Al Jabal Al Akhdar which may be the result of climate change and /or human activity (Al Mukhtar, 2005). In the Al Jabal Al Akhdar region, human activities include deforestation, overgrazing, fires, burning trees to cultivate crops and the growing of fruit trees, all of which may lead to change in land use and vegetation cover.

Figure 3.6: Natural vegetation south of the Al Jabal Al Akhdar (Source: Feng et al., 2013).

These activities usually often occur in sensitive areas such as mountain slopes, shallow soils or rocky areas and may cause a reduction in vegetation cover and degradation of ecosystem studies (Oune, 2006).

3.7 The population distribution

The population of Libya was approximately 5.6 million in 2006 and about 6.6 million in 2010 (General Directorate of Documentation and Information, 2010), with an average growth of 2.37 % y-1 and an average birth rate of about 27.17 /1,000/y-1 and an average death rate of 3.48/1,000/y-1. More than 75% of the population lives along the coastal zone which extends over 1980 km and is about 1.5 % of the total area of the country (Ageena et al., 2013). The Al Jabal Al Akhdar is the second area of population concentration with 21% after the Jifarah plain and the Misratha area in the western coastal region with 54 % of the Libyan population (FAO, 2005).

Most Libyan inhabitants are young, with 33% of them under 15 years old. The population density differs varies from 150 inhabitants km^2 in the northern regions to less than 1 per km^2 in other parts of the country (FAO, 2005).

3.8 The human activity in the region

There is a variety of human activity in the study area such as agriculture, traditional industries, grazing and the services sector. Agriculture contributes to about 28 % of GDP in the region and provided employment for about 5 % of the total population in 2005. Industry contributes to about 8% and the services sector more than 41% in the region (Ben Khaial & Bukhechiem, 2005). Furthermore, livestock breeding is carried out in private farms as well as grazing.

In 2011 the political situation changed in Libya and these changes impacted on state policy regarding agriculture and other activities. In the absence of controls, the agricultural and urban areas were expanded after 2012 to areas having natural vegetation. Overgrazing was also rampant while deforestation and fires were also on the increase due to lack of control by the government.

3.9 Conclusion

Due to the location of Al Jabal Al Akhdar in the south of the Mediterranean basin, variations in geology, topography, climate, water resources, soil and natural vegetation, have given the Al Jabal Al Akhdar a wide variety of natural environments.

These environments provide suitable habitat for wildlife and provide many services for the local population. The natural vegetation has economic importance for local communities in terms of providing medicinal herbs, aromatic plants and traditional industries for tourists. The deterioration of the surface conditions that are vital to plant growth caused by shifting cultivation, bush burning or overgrazing are very destructive for the flora. Therefore, studying changes in natural and semi- natural vegetation cover will be important in the long-term to assess changes within the region, especially after the recent political upheavals in Libya.

CHAPTER 4: RESEARCH METHODOLOGIES

The purpose of this chapter is to provide an overview of the methodologies used in this research. The work will first involve analysis of the spatial and temporal distribution of vegetation change across the study area using time-series satellite imagery. Land cover change and population data will then be examined along with, and related to general observed climate change patterns. The research will focus on vegetation cover change in the Al Jabal Al Akhdar (Green Mountain) area in north-east of Libya, aiming to assess the influence of climate change and human activity over the last 42 years.

4.1 Overview of research methodologies

The first objective aims to assess vegetation cover change which requires an approach reliant on time series Landsat imagery starting from 1972. Landsat data sets are available at a relatively high spatial resolution, cover large areas, and are ideal for the aims of this research. However, one of the challenges of satellite-based land cover characterization is removing the extraneous influences of factors which may affect the reflectance of the vegetation (Benediktsson et al., 2012). Therefore, it was necessary to first correct the images by removing atmospheric and topographic effects in order to derive a series of cross-calibrated images of the study area. To assess the aim that there had been a change in vegetation cover during the period of study, a series of eleven images, available for the study area, was used to measure the change in green vegetation cover. This approach used time-series of NDVI, SAVI and EVI indices to detect major vegetation cover changes in the Al Jabal Al Akhdar over the period 1972-2014. Once the pattern of increase or decrease in vegetation cover had been established (see chapter 5), the research then attempted to explain the factors causing these patterns.

The second objective aims to assess the effects of human activity in the region. The research used Libyan population data and a population distribution map from the LandScan global population database, to map the general picture of the density of human activity. In addition, the time series of Landsat images of the study area was used to examine the relationship between changing land cover and land use, and the population distribution.

The third objective aims to investigate the factors affecting vegetation change in the study area using the outputs of the first and second objective. The research evaluated the climate change in the study area, as a sub-objective, in the previous chapter, using time-series of climatic data, especially temperature and rainfall, at three stations in the region. The approach identified the trends in temperature and rainfall between the 1940s and 2003, and gave insights into the general climatic trends in the study area. With this as background, the research then examined the relationship between land cover and land use change and the vegetation change patterns in the VI images. It then determined the contribution of human-induced vegetation change, and mapped areas of low human impact and significant vegetation cover change.

Objectives are addressed using quantitative data analysis techniques that use both descriptive and qualitative data interpretation. Detailed methodologies are presented for assessing vegetation cover change, land cover change and spatial analysis of factors affecting vegetation change in the study area.

4.2 Approach to assessing vegetation cover change

Satellite imagery provides data that cannot be collected by traditional methods in places with difficult access, and the Landsat series of satellites provide the only medium-term record of vegetation change on the Earth (Lasanta and Vicente-Serrano, 2012). This study relied on high spatial resolution satellite images of (79 m) MSS, and (30m) TM, ETM and OLI, to monitor vegetation cover change in the Al Jabal Al Akhdar. The reasons for selecting Landsat data were:

(i) The approach aimed to use remote sensing techniques to cover the whole study area, including those areas that cannot be accessed by other means, and to investigate the vegetation across the region.

(ii) The current research differs from previous studies in the region by adopting high spatial resolution Landsat (30 m) to examine a long-term record for monitoring vegetation cover change in the Al Jabal al Akhdar region from 1972 to the present.

The previous study (Ibrahim, 2008) used sensors with 1 km spatial resolution and examined the vegetation from 1982 to 2006. The high spatial resolution (30 m) used in this research means that the fine detail of local-scale vegetation change will be revealed at scales never examined before in this region.

The research collected 11 images from different Landsat sensors to obtain a cloud-free image series and cover the whole study area over an extended period of time. There were up to 200 images from Landsat MSS, TM, ETM and OLI, for the study area but just 11 images were usable due to cloud cover, or being in a different season (Table 4.1). The research specifically used the images which were acquired in the same season to 'avoid' cover changes related to seasonal differences in vegetation growth.

Table 4.1: Landsat images used in the study area

Satellite	Sensor	Bands	Spectral Range	Path-Row	Pixel	Scene	Images used
L 1-3	Multi Spectral scanner (MSS)	1,2,3,4	0.5 - 1.1 µm	183-37	79 m	185 X 185 km	1972-1978 1986
L 4-5	Thematic Mapper (TM)	1,2,3,4,5,7	0.5 - 1.1 µm	183-37	30 m		1987-2003 2006
L 7	Enhanced Thematic Mapper Plus (ETM+)	1,2,3,4,5,7 6.1, 6.2 Thermal 8 Panchromatic	0.450 - 2.35 µm 10.40 - 12.50 µm 0.52 - 0.90 µm	183-37	30 m 60 m 15 m		1999-2001
L 8	Operational Land Imager (OLI)	1,2,3,4,5,6,7, 9,10 11 8 Panchromatic	0.45- 12.51 µm 0.50 - 0.68 µm	183-37	30 m 15 m		2013-2014

Source: USGS, 2017

Seasonal difference can contribute to the variability of spectral responses. The Vegetation Index (VI) values are higher during the wet season (December, January and February), than the dry or hot season (June, July and August), when VI values are low (Xie et al., 2008). An increase in precipitation in the wet seasons may improve moisture availability for plants and thus lead to an increase in plant growth that may be critical or at least partially account for increase vegetation cover and increased in the VI (Chuvieco & Huete, 2010; Roerink et al., 2003). The research collected the images which were close to the same season, which is between July and October in different years (Table 4.2).

Table 4.2: The dates of Landsat images which were downloaded for the study area.

Sensor	Date
MSS	7/9/1972
MSS	2/9/1978
MSS	6/10/1986
TM	30/9/1987
TM	10/9/2003
TM	5/9/2006
TM	23/8/2010
ETM	25/10/1999
ETM	26/7/2001
OLI	8/9/2013
OLI	22/7/2014

4.2.1 Initial image processing

In spite of the availability of Landsat images it was a significant challenge to ensure that these images were useable to show the change in vegetation cover in the study area. The images required pre-processing to produce images that were valid for study and the approach used is presented in the following sections, specifically atmospheric and topographic correction processes applied to the Landsat data.

4.2.1.1 Atmospheric correction

The atmosphere has a significant impact on the solar radiation that is reflected by the Earth's surface and recorded by satellite sensors (Nazeer et al, 2014). The atmosphere is composed of many gases, water vapour, aerosols, dust and pollutants (Chuvieco and Huete, 2010) and these components affect satellite images through absorption and scattering (Lillesand and Kiefer, 1987). Atmospheric correction is therefore necessary for satellite imagery data to determine 'true surface reflectance' values. For the purposes of atmospheric correction, a radiance value is converted into reflectance data in remotely sensed imagery (Tuominen & Lippinga, 2011). Several proposed methods for removing the influences of atmosphere from satellite images are described below.

4.2.1.1.1 LEDAPS

The Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) was originally developed through the NASA Terrestrial Ecosystems Program and the NASA Applied Sciences Program (Maiersperger et al., 2013). The LEDAPS method uses Landsat TM5, ETM+7 and OLI 8 images, metadata, and daily atmospheric data to remove the influence of the atmosphere and produce atmospherically corrected surface reflectance products (Feng et al., 2013). It also generates cloud masks for images that are covered partially by the clouds. LEDAPS relies on deriving "the aerosol optical thickness from each Landsat acquisition and independently correcting each acquisition assuming a fixed continental aerosol type" (Ju et al., 2012, p. 176). The research collected the available surface reflectance images (with the atmospheric correction) from the Earth Explorer website for the study area. The LEDAPS-corrected images were for 1987, 2003, 2013 and 2014. These images were used to correct other images to surface reflectance using the empirical line method.

4.2.1.1.2 Empirical line correction

Empirical line correction is another atmospheric correction method that uses information that is embedded in the image (Tuominen & Lipping, 2011). The empirical line method uses the raw digital numbers (DN) in an image together with ground reflectance data from some source (Tuominen & Lipping, 2011; Song et al., 2001). To test the approach, two images from the same month for different years were used, one was an image without atmospheric correction (DN) and other was a surface reflectance image that had the LEDAPS atmospheric correction applied. The first step was to select 50 targets at different sites for the (DN) image of AL Jabal Al Akhdar and the same targets in the surface reflectance image. These targets ranged from very bright to very dark and later applications of the method assumed that their reflectance had not changed between the dates of imagery used. The research therefore collected targets from roads, quarries and the sea because they were assumed not to have changed over time. The second step was to identify the values of the pixel in each band of the image at each of the 50 chosen sites (50 pixels), which were used as reference points for comparison with the DN image. The same process was repeated with all bands in the both images.

The third step was to identify the relationship between each band in the DN image and the others in the surface reflectance image using the equation (y= DN x +b) and build an image for each band with atmospheric correction using Model Maker in ERDAS Imagine. This approach built seven new bands and removed the influence of the atmosphere using an ERDAS model.

The result showed the relationship (R^2) between the values of pixels in each band in the images with and without atmospheric correction (Figure 4.1).

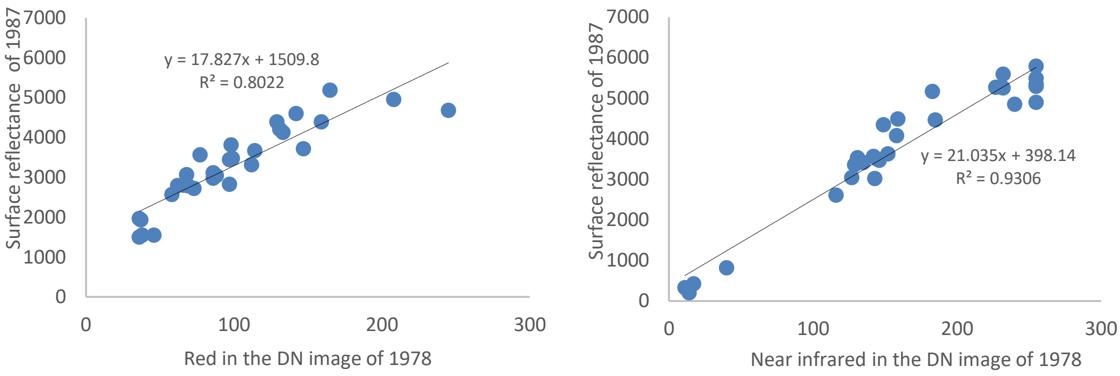


Figure 4.1: The relationship between red (a) and near infrared (b) values at 50 sites in the DN image of September 1978 and surface reflectance image of September 1987.

The research applied the method on other images that had no atmospheric correction using the available surface reflectance images. The research chose pairs of images that were recorded in the same month to avoid difference of weather conditions that may have affected the reflectance of targets (Table, 4.3). In terms of Landsat MSS images, which had four bands, the research applied the method on those bands and built new images without atmospheric effects.

Table 4.3: Methods applied to remove the influence of the atmosphere from the Landsat images selected for this study

Sensor	Data	Surface reflectance	Empirical line corrections applied	Image pair selected	R^2 Red waveband	R^2 Near-infrared waveband
MSS	7/9/1972			1972 and 1987	0.67	0.66
MSS	2/9/1978			1978 and 1987	0.80	0.93
MSS	6/10/1986			1986 and 1987	0.84	0.93
TM	30/9/1987					
TM	10/9/2003					
TM	5/9/2006			2006 and 2003	0.62	0.77
TM	23/8/2010			2010 and 2014	0.71	0.74
ETM	25/10/1999			1999 and 1987	0.91	0.95
ETM	26/7/2001			2001 and 2014	0.85	0.93
OLI	8/9/2013					
OLI	22/8/2014					

The results showed a significant positive relationship between the red and near infrared DN for all wavebands and surface reflectance. Therefore, applying the empirical line method was successful with these images and the influence of atmosphere was removed from the whole time-series of satellite data.

4.3 Calculation of Vegetation Indices

To achieve the aim of assessing the vegetation cover change, the approach used vegetation indices which are combinations of surface reflectance at two or more wavelengths that are designed to quantitatively evaluate vegetation cover (Bannari et al., 1995), and are designed to maximize the difference in reflectance between vegetation and other surface types. The VI used were the Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI) and Enhanced Vegetation Index (EVI) as described in chapter 3.

The approach generated eleven VI images from the Landsat images and stacked them together as one image with 11 layers. A linear regression image which finds the best-fit straight line through the points was generated for every pixel in the image (Hoffmann, 2010). The equation (VI =Year * b + a) (where Y is the VI reflectance of the pixel and X is time) was used to investigate the time-dependent change in VI for every image pixel (Appendix 1). A regression image was then computed to test for trends in the VI in each pixel.

Correlation coefficients images were also generated from the VI image stacks to test which pixels showed statistically significant changes in vegetation cover. Finally, the approach classified both regression and correlation images to highlight the areas that had seen a significant change (see chapter 5).

4.4 Image classification

To achieve the objective of assessing the impact of human activity in the study area, the time series of Landsat imagery was next used to investigate changes in land cover and land use across the study area. As an initial step, it was necessary to correct the images by removing the topographic effects and correct the aspect and slope direction effect on image reflectance.

4.4.1 Topographic correction

Topographic variation has an influence on the spectral reflectance of the land surface and thus affects the value of the pixel in an image (Svoray & Carmel, 2005). The position of the sun in addition to topography can greatly affect the illumination angle and the amount of light that is reflected at any point on the Earth’s surface. Slopes facing the sun receive higher radiance and appear brighter (Zhang and Li., 2011), while slopes oriented away from the sun appear darker when compared to a horizontal geometry (Richter et al, 2009) because they receive less radiation. The topographic effect is the difference in illumination due to the slope direction relative to the elevation and azimuth of the sun (Zhang and Li., 2011).

To reduce topographic influences in the imagery, the approach used a Digital Elevation Model (DEM) for topographic correction of the 30m resolution Landsat TM and the 79m resolution Landsat MSS (Figure 4.2), and produced images with more evenly illuminated terrain without topographic effects. In this process, the research used the "Lambertian Reflectance Model" in the Topographic Normalization section of the ERDAS Field Guide and input each Landsat image and DEM for the study area into the process.

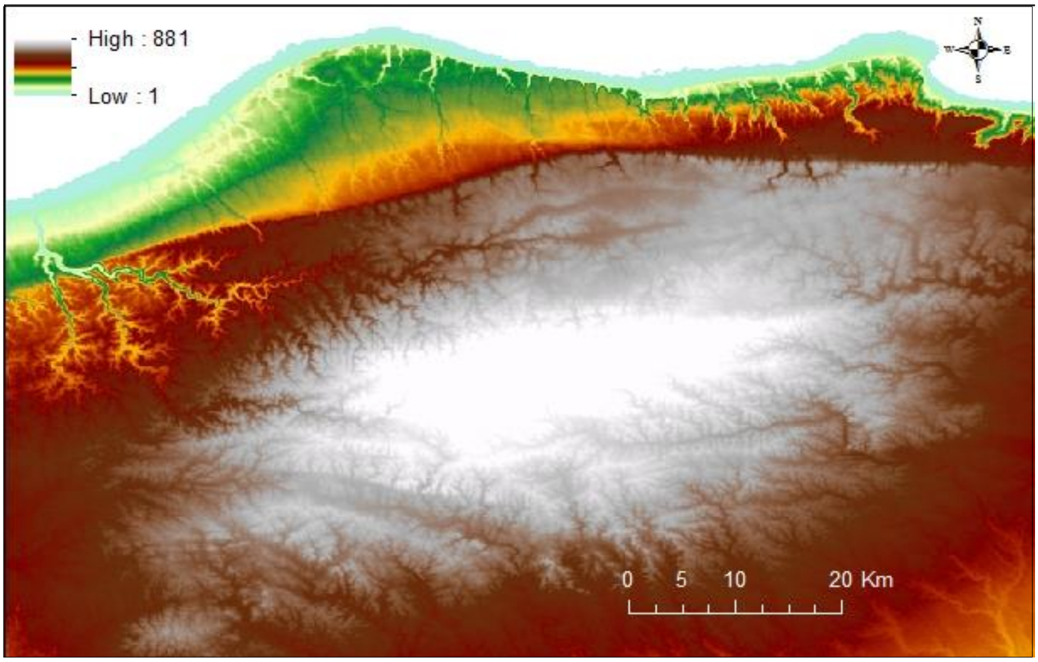


Figure 4.2: Digital Elevation Model (DEM) of Al Jabal Al Akhdar (height in m)

This model requires sun azimuth and sun elevation for the image, this information being normally available in the data header of the Landsat image file. The solar azimuth and elevation of the input file sensor at the time of data acquisition were entered and units (metres) of DEM obtained from the DEM image file data were chosen. The researcher entered this information and the new image was generated after removing the influence of topography. The approach also generated images of the slope and aspect representing the orientation of the land surface (Figures 4.3, 4.4 & 4.5).

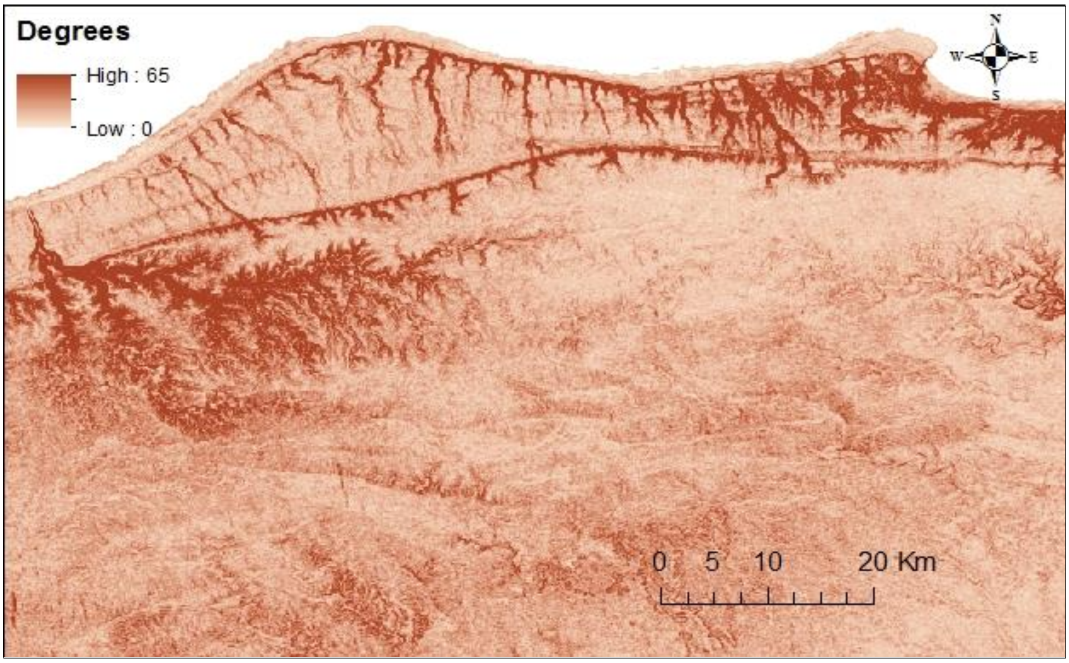


Figure 4.3: The slope (by degrees) of the study area derived from DEM

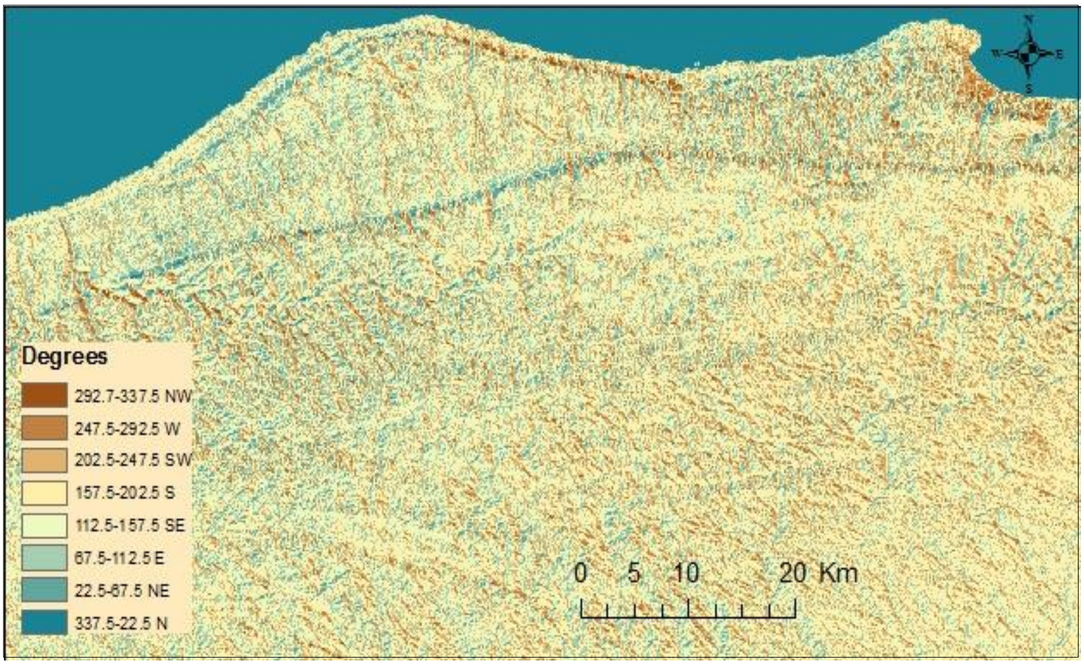


Figure 4.4: The aspect (by degrees) of slopes in the study area derived from DEM

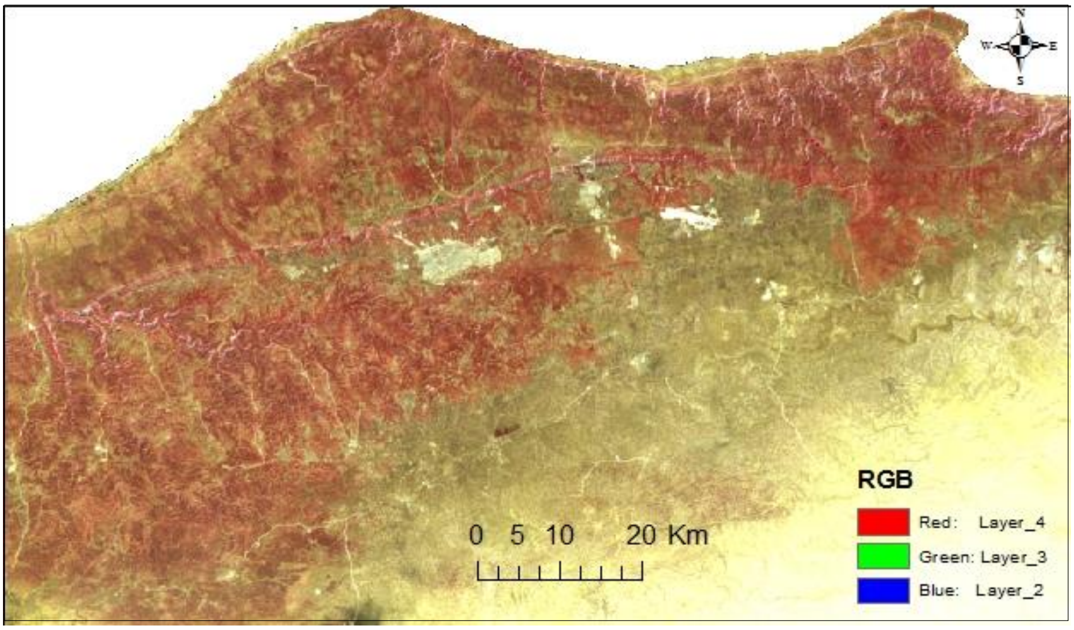


Figure 4.5: TM image of Al Jabal Al Akhdar for 1987 as true colour composite with topographic correction.

The topographic correction is an important process for classification of the remote sensing images. The research also tested the influence of topographic correction on VI values by comparing random pixels in the NDVI image of 1987 after topographic correction with the NDVI image without corrections in (Figure 4.6).

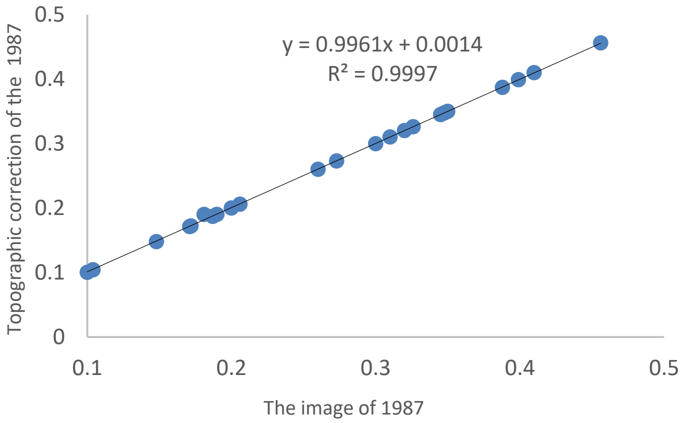


Figure 4.6: Comparison between the NDVI values in two images of 1987 with and without topographic corrections.

The research applied topographic correction on the NDVI image of 1972 (Figure 4.7), and the result found no significant difference, thus indicating that the VI are not sensitive to topographical effects and so images were used without topographic correction. To further evaluate the accuracy of the result, the approach collected pixels from the images of 1972 with and without topographic correction. The result again illustrated the strong relationship between the NDVI values in 1972 thus the topography had no effect on the NDVI values.

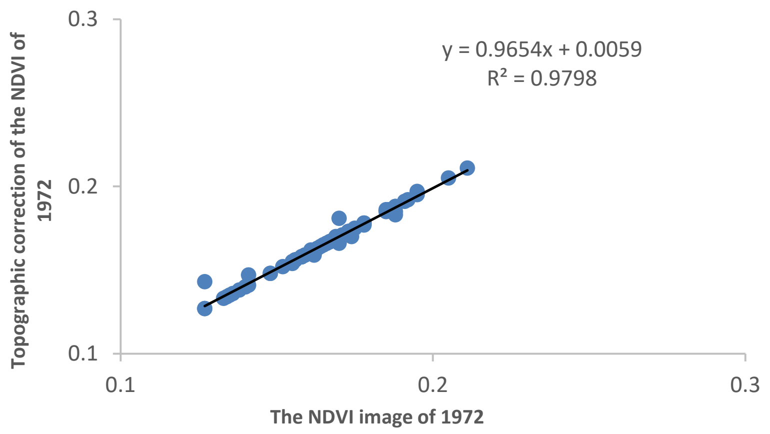


Figure 4.7: Comparison the NDVI values with and without topographic correction in two images of 1972.

4.4.2 Image classification

The research used image classification methods to categorize all the pixels in an image into one of several land cover classes, and also used the 11 images to assess the change in land cover and land use over the study period. The intention of the classification process was to identify the distribution of different land cover types across the area and compare these classified images over different periods to assess how the land cover changed.

Image classification is based on two major categories of image classification: unsupervised (calculated by software) and supervised (human-guided) classification (Jensen, 2005). Unsupervised classification is a method which classifies data based on their inherent spectral similarities without the analyst's intervention and these groupings are called "clusters" (Liu, 2005). This requires minimum input from the analyst (Campbell, 2002), who determines the number of clusters to generate

(Lillesand & Kiefer, 1987). The software then groups pixels that are similar and places them into classes using clustering algorithms (Chuvieco and Huete, 2010). Class labelling is subsequently done by the analyst.

In supervised classification, the land cover classes depend on the analyst to select sample pixels in an image using his or her knowledge about the study area such as personal experience of the region, experience with thematic maps, or by way of on-site visits (Chuvieco and Huete, 2010). These samples of pixels are called "training areas" which represent each known land cover category that appears in the image (Liu, 2005). The software then uses these training sites (input classes) as references to classify all other pixels in the image (Jensen, 2005). This research used supervised classification in ERDAS Imagine to classify the land cover in all images of the study area and these data were used to determine the influence of human activity. Arc-GIS software was also used to create a display and analyse geospatial data in layers (Childs, 2004), in particular, to map the influence of human activity on vegetation index cover change in the study area. Eleven land cover classes were used, based on background information and knowledge of the study area.

4.5 Libyan population data

Libyan population data were used to determine the distribution of population and the relationship with human activity especially, the activities that were difficult to classify on the satellite images such as grazing and areas that had seen logging to produce fuel. Thus, it was thought that the distribution of population may be of help to determine these areas. Libyan population data for 2012 were collected from ORNL's LandScan™ at a resolution of approximately 1 km, and included a table of the census counts, gender, and map of the distribution of the Libyan population (Figure 4.8). LandScan provides global coverage of populations and relies on the use of a high-resolution remote sensing data. The Libyan population distribution was analysed in Arc-GIS software to compare population and land cover. In this way, the research assessed the diversity of land cover and land use change based on population, and used this to infer the likely impact on vegetation index cover changes. To assess the effect of human activity, the research firstly overlaid the vegetation index change map, and land cover and land use change maps to identify the relationships between the areas that had experienced vegetation index change, and the land cover or land use of these areas.

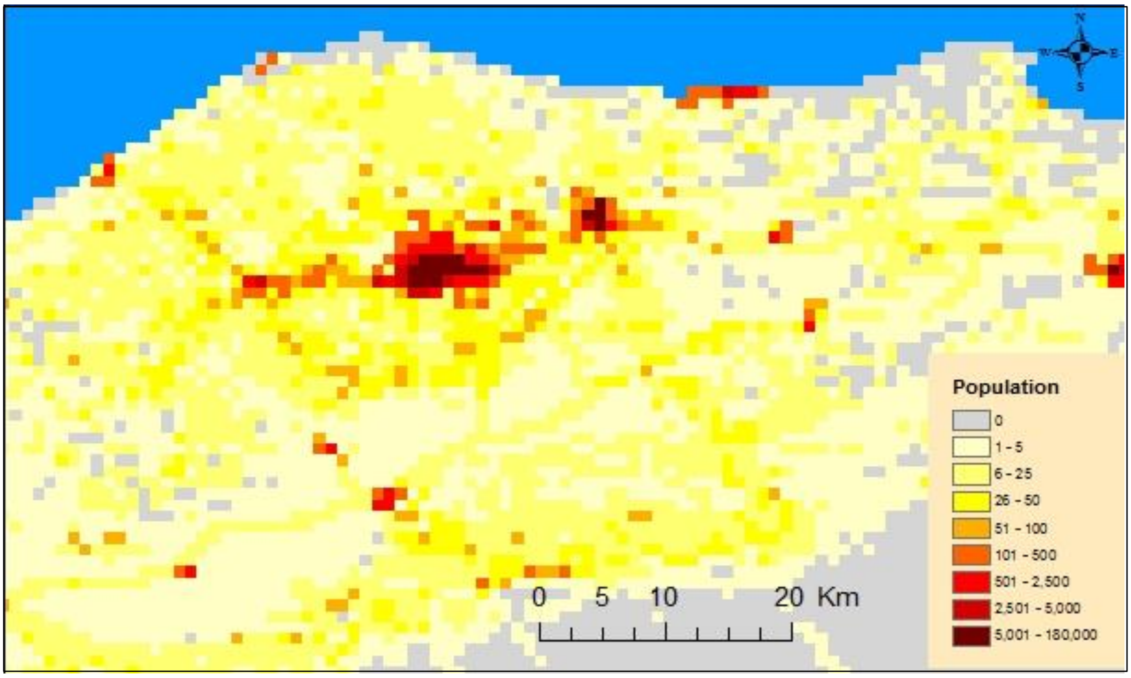


Figure 4.8: The distribution of Libyan population data in the Al Jabal Al Akhdar region in 2012

Second, the research overlaid the vegetation index change maps on the Libyan population map to determine the relationship between the population distribution and the areas that experienced significant VI change.

Third, the research overlaid the maps of land cover and land use change with population data to determine the distribution of population in each class of land cover change in the images of 2013 and 2014 and determine the effect of population on land cover change.

4.6 Conclusion

This chapter has presented an introduction to the subsequent research chapters, presenting a brief explanation of the methodologies that were used to achieve the research aims and objectives, and to analyse the data used for each objective, including climate data, satellite images and Libyan population distribution data. The chapter showed the applications of remote sensing to derive vegetation index data that were used to assess the vegetation dynamics in the study. Although there were few available images for the study area, which was one of the limitations in the statistical analysis of the spatial and temporal distribution of vegetation cover, the use of vegetation indices was effective in remapping the recent change of vegetation cover in the study area and provided a database of sources for vegetation cover change analysis in the area.

It also showed the importance of image pre-processing that was applied to the Landsat images to make them usable for analysis. To assess human activity, the chapter presented the classification methods which were used for measuring land cover change. In terms of investigating the factors affecting vegetation change, the chapter briefly explained the methods used to assess the factors using the results of the first and second objectives and also the result of climate change analyses. The chapter also used the population data to determine the relationship between the distribution of population and land cover change. Population data can be effective as sources for studying human activity and determining the areas undergoing human activities which cannot be observed from satellite imagery. The next chapter will focus on vegetation change detection in the study area.

CHAPTER 5: RECENT CLIMATE CHANGE IN THE AL JABAL AL AKHDAR

This chapter examines climate change in the study area over the period 1946- 2003 through available climate data from the main three climate stations located in the study area. The approach uses statistical analysis to assess significant trends of temperature and rainfall in order to provide the general picture for climate trends in the study area which may be one of the factors affecting vegetation change in the region.

5.1 Introduction

The Libyan climate varies between Mediterranean in the north-eastern region (Al Jabal Al Akhdar Mountains) and north-western region (Naffosa Mountains) of Libya and the desert in the centre and south of the country. The climate of Al Jabal Al Akhdar is actually influenced by both Mediterranean and desert climate systems, and thus air masses of continental and maritime origin impact on its climatic characteristics (El-Tantawi, 2005; Ageena, 2010). The climate of the study area therefore varies from coastal Mediterranean on the north-facing slopes, to semi-arid and desert on the south-facing slopes (Al Mukhtar, 2005; Bukhechiem, 2006).

The climate of the study area differs from one area to another due to the variation in elevation; for example, there are differences between the measurements of stations in the climate elements on the northern slopes of the Al Jabal Al Akhdar, due to differences in elevation and the distance from the sea (Bukhechiem, 2006). As a result of these factors, the mean daily temperature differs between the various climate stations of the Al Jabal Al Akhdar. It was 23.7°C at Shahat station (in the mountains) and 28.4°C in Darnah (on the coastal plain) in August (the warmest month of the year) over the period 1945 to 2003 (El-Tantawi, 2005), while the mean daily temperature at Al Makhili station in the south of the region for the same time period was about 29°C.

January and February are the coldest months in Libya. At Shahat the mean daily temperature in January is about 10°C, whilst in Dernah it is 14.80 °C, due to the influences of elevation and its location next to the sea, which makes it warm compared to other parts of the region (Bukhechiem, 2006). The mean daily temperature decreases to 11.7°C in January at Al Makhili station in the south.

In general, there are no large differences in climate in the northern parts of Al Jabal Al Akhdar, there are no large differences in climate in the northern parts of Al Jabal Al Akhdar, but there are clear differences in the southern part, taking into account the impact of the semi-desert climate (Ben Khaial and Bukhechiem, 2005).

The largest percentage of the total annual precipitation in the Al Jabal Al Akhdar region occurs in the winter and autumn seasons (El-Tantawi, 2005; Ageena, 2014). The winter is most important for precipitation in the region because of the influence of storms originating over the Atlantic and moving toward the west of the Mediterranean basin and impinging upon the western European coasts and North African coasts (Giorgi & Lionello, 2008). The northern slopes receive the highest average rainfall (Al Mukhtar, 2005); for example, the monthly mean rainfall in January at Shahat station is 124 mm yr^{-1} and at Darnah it is 58 mm yr^{-1}; these averages decrease in August to 2 mm yr^{-1} in Shahat and 0.3 mm yr^{-1} at Darnah over the period 1946 to 2003. The mean annual rainfall is 563mm yr^{-1} at Shahat and at Darnah station on the coast it is about 266 mm yr^{-1} over the period 1946 to 2003. The southern slopes receive no more than 100 mm yr^{-1}; for example, at Al Makhili station the mean annual rainfall is 125 mm yr^{-1}, and in the south the rainfall average is less than 50 mm yr^{-1}, and even less in the Al Balat area in the north of the desert due to its location away from sources of water vapour (the sea) and the impact of the desert climate on the region (Bukhechiem, 2006).

5.2 Assessing climate change in the study area

Climate data provide a reliable source of information for analysis of climate change and are usually available over a long period of time (Ageena et al., 2012). In this study, the climate data were used to examine changes in climate elements in the study area over 57 years. The meteorological data were collected from the Libyan National Meteorological Centre (LNMC) and were available from 1946 to 2003 from three main climate monitoring stations within the province (Table 5.1), plus some sub-stations which provided just one climatic element, such as rainfall or temperature (Table 5.2) (Figure 5.1).

Table 5.1: Main climate stations in north-east Libya

Station	Latitude (N)	Longitude (E)	Elevation (m)	Distance from the sea (km)	Observation period	Type of data
Darnah	22° 38' 44"	22° 38' 44"	10	0	1946-2003	Synoptic
Shahat	21° 52' 78"	21° 52' 78"	620	13	1946-2003	Synoptic
Benina	20° 16' 45"	20° 16' 45"	129	20.5	1946-2003	Synoptic

Source: Libyan National Meteorological Centre (LNMC), 2003.

Figure 5.1: The locations of climatic stations in the study area (Source: Google Earth, 2017).

Table 5.2: Sub-climate stations in the north-east of Libya

Station	Latitude (N)	Longitude (E)	Elevation (m)	Distance from the sea (km)	Observation period	Type of data
Ras Al helal	32° 51' 9"	22° 16' 16"	10	0	1959-1988	Rainfall
AL Abraq	32° 47' 84"	21° 57' 70"	400	13	1963-1990	Rainfall
Al Qubah	32° 46' 80"	22° 13' 17"	250	15	1946-2003	Rainfall
Ayn Marah	32° 46' 45"	22° 22' 47"	250	6.9	1963-1979	Rainfall
Al Faidia	32° 41' 25"	21° 45' 50"	550	25	1960-1981	Rainfall
Al Qayqab	32° 43' 85"	22° 05' 56"	701	30	1965-2003	Rainfall
Susah	32° 53' 22"	21° 56' 26"	10	0	1960-1981	Rainfall
Al Byadah	32° 33' 48"	21°15' 13"	365	15	1991-2003	Rainfall

Source: Libyan National Meteorological Centre (LNMC), 2003.

The research examined temperature and rainfall trends in the study area because they are the main elements that impact directly or indirectly on the other climatic elements and any changes in those elements may affect vegetation dynamics (Ageena, 2010).

The approach taken used a number of statistical tests that are a simple way to assess temporal changes in climatic data. The mean annual maximum and minimum temperature, and the mean annual rainfall, were examined to identify the trends between 1946 and 2003. In this study, the mean annual temperature and precipitation data were divided into a long-term period (1946-2003) and two short-term periods (1946-1971 and 1972-2003), to investigate variations in temperature and rainfall during these different periods, with the second period relating directly to the satellite image record adopted later in the research.

Time–series data are normally assessed using statistical methods to test for significant trends in the variables of interest. The Mann-Kendall trend test was used to assess trends in the climatological time series data. It is “a nonparametric test and does not require the data to be normally distributed and has low sensitivity to abrupt breaks due to inhomogeneous time series” (Karmeshu, 2012, p.4). The research computed the Mann-Kendall tau using SPSS software to test for changes in the climate of the study area, and detect the significant trends of temperature and rainfall (Karmeshu, 2012; Pohlert, 2015). The research used the test on the assumption that the distribution of the climate data is not normal and is used to confirm the related results of linear regression and correlation coefficient analysis.

Regression was used to determine the differences between independent (time; x) and dependent (temperature or rainfall; y) variables (Chatterjee & Hadi, 2006) to assess the significance of change in temperature and rainfall over the period of study. Pearson’s Correlation Coefficient was used to determine the strength of linear relationships between the annual rainfall and time (Higgins, 2006), to determine if there was a relationship between them. Pearson’s correlation coefficient provides a measure of the degree of association between X (time) and the Y (temperature or rainfall) when the sample is drawn from a bivariate normal distribution. The statistical significance of the correlation between X and Y is tested using the correlation coefficient (R). Regression analysis makes a range of assumptions about the underlying data and so the non-parametric trend test described earlier was also applied. The climate of the region differs from one station to another due to location, landform, elevation and distance from the sea. Climate stations of the study area are Darnah, Benina on the coastal plain of the Al Jabal Al Akhdar and Shahat in the mountains. This section includes a brief description of the climatic characteristic of these stations.

5.2.1 Darnah station

The climate of Darnah is characterized by a hot dry summer and warm winter. The mean monthly temperature was between 29 °C in June (the warmest month of the year) and 13°C in December (the coldest month) over the period 1946- 2003, with mean annual temperature of approximately 23°C.

The rainy months at the station extend from October to April due to the low pressure systems which are formed in the Mediterranean basin during this period. The mean rainfall ranges between 58 mm in January (the highest amount of rain in the year), and 0.2 mm in August (the lowest amount of rainfall in the year) (Figure 5.2). The mean annual rainfall was about 267mm yr^{-1} in the period 1946-2003.

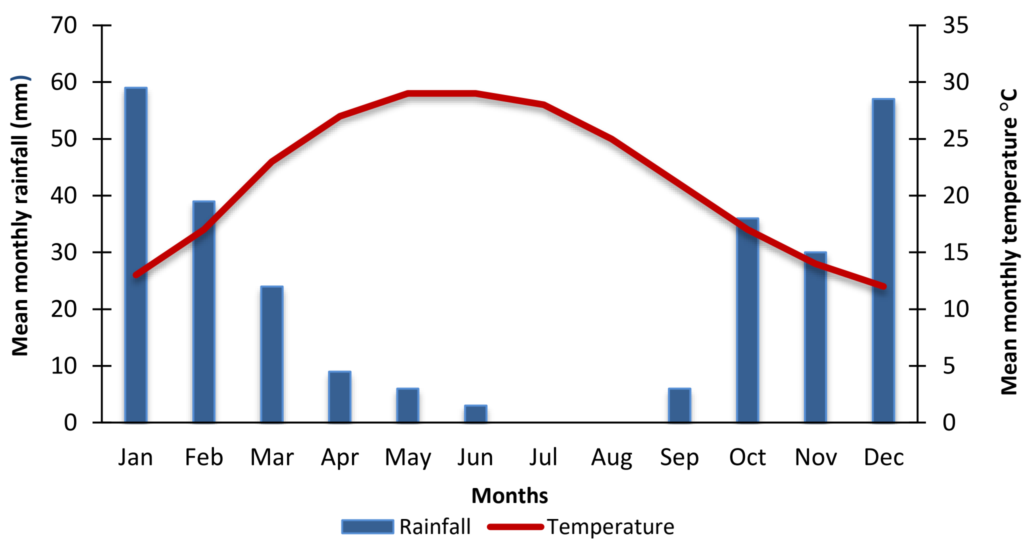


Figure 5.2: Mean monthly temperature and rainfall at Darnah (1946-2003).

5.2.2 Shahat station

Shahat station is located at 32°47' 31″ N and longitude 21°52' 78″ E on the second terrace of the Al Jabal Al Akhdar at an elevation of 620m above sea level, and 13 km from the sea (Bukhechiem, 2006). In this mountain station the mean annual temperature is about 16.5°C. The mean monthly temperature ranges between 15°C in April to 23.6°C in July (the warmest month in the year) and decreases to 9°C and 10°C in January and February respectively over the period of 1946- 2003.

Shahat station received the highest rainfall in the north east Libya during the period at 563 mm yr^{-1}, whereas rainfall ranged between 53 mm in October to 123 mm in January (Figure 5.3). Overall, the diversity of natural factors in the Al Jabal Al Akhdar such as elevation, landforms, location next to the sea and natural vegetation have led to differences in temperature and rainfall across the region (Ageen, 2010; Al Mokhtar, 2005; Bukhechiem, 2006), although the differences are small between the coastal stations compared with the mountain stations.

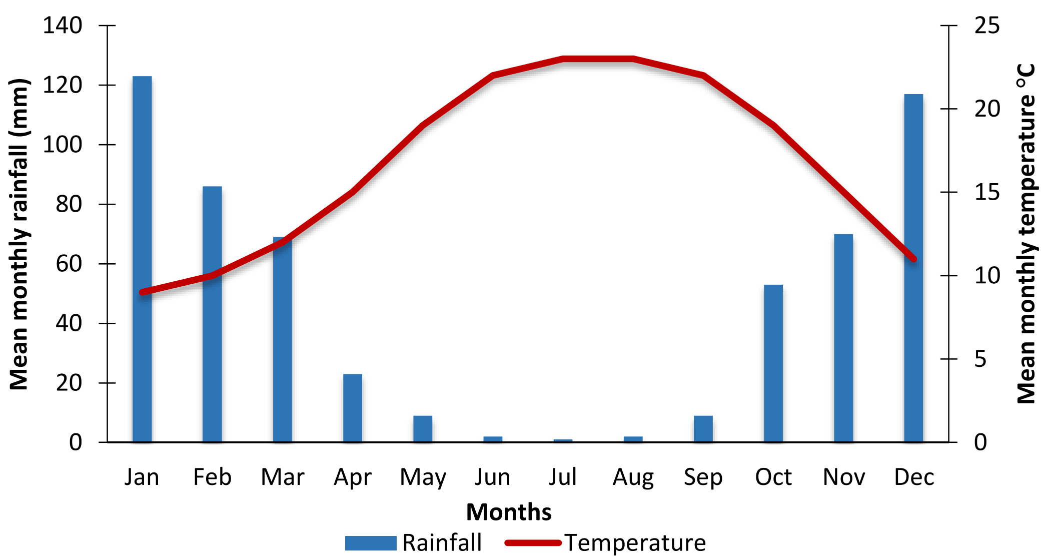


Figure 5.3: Mean monthly temperature and rainfall at Shahat (1946-2003).

5.2.3 Benina station

Benina is located in the north-west of the coastal plain of the Al Jabal Al Akhdar. It is located 20.5 km from the sea at 129 m above sea level (Al Mukhtar, 2005). The climate data in this station are available from 1946 to 2010. The mean annual temperature is (20 °C) at the station. The mean monthly temperature increases from April (20°C) to August (27°C) and decreases to 12.6°C in January (the coldest month in the year) over the period 1946 to 2003.

In terms of rainfall, the mean annual rainfall was about 270 mm. Rainfall is concentrated in mid-autumn and the winter. The mean monthly rainfall ranges between 70 mm yr^{-1} in January (Figure 5.4).

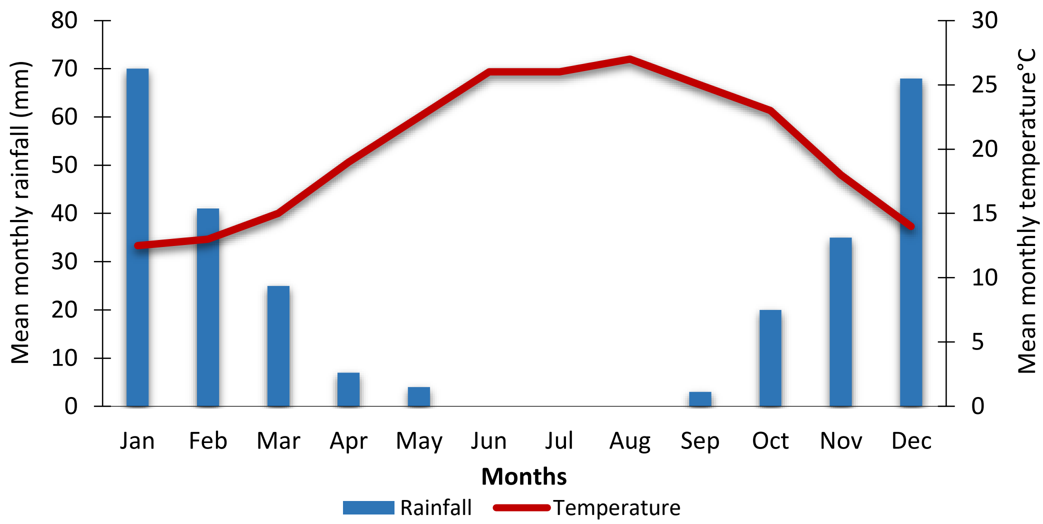


Figure 5.4: Mean monthly temperature and rainfall at Benina (1946-2003).

5.3 Recent temperature changes in the study area

The temperature differs in the region in terms of temporal and spatial distribution and so it is important to identify the thermal characteristics of the region to observe the changes in the trends of temperature in the study region during the 57 year period examined.

5.3.1 Long-term trends of temperature at the stations in the study area (1946-2003)

The approach investigated a long time-series of the mean annual, maximum and minimum temperature at the Al Jabal Al Akhdar stations that permits consideration of general long-term changes and differences in rates of change to test for variations in temperature.

5.3.1.1 Long-term trends in mean annual temperature in the stations of the study area (1946- 2003)

The mean annual temperature is the average temperature for the entire year at any given area. The mean annual temperature in the Al Jabal Al Akhdar region ranges between 20.1°C and 16.5 °C over the study period (Table 5.3). The coefficient of variation (CV) of the mean annual temperature was 2% (Darnah), 2.54 % (Shahat) and 2.39 % (Benina). The long-term trend of mean annual temperature differs from year to year and from one station to another because of the aforementioned local factors (Figures 5.5, 5.6 & 5.7).

Table 5.3: The mean annual temperature, Mann-Kendall Tau (M-K) and correlation coefficient (R) for the study stations.

Station	Period	Mean annual T °C	CV %	M-K	Sig (p)	R	Sig (p)
Darnah	1946-2003	21.4	2.00	0.331	0.001	0.523	< 0.001
Shahat	1946-2003	16.5	2.40	0.272	0.003	0.349	0.007
Benina	1946-2003	20.1	2.39	0.242	0.001	0.465	< 0.001

The Mann-Kendall test and the correlation (R) produced the similar statistical significance trends for the mean annual temperature at Darnah, Shahat and Benina (Table 5.3) which were all significant (p= 0.01). This indicates that the means annual temperature increased at all stations for the period 1946-2003.

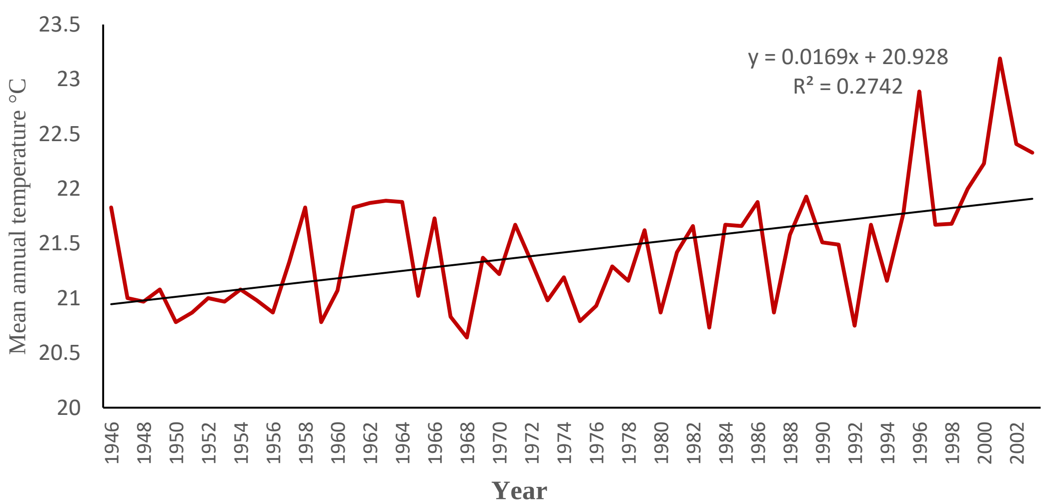


Figure 5.5: The mean annual temperature at Darnah over the period of study.

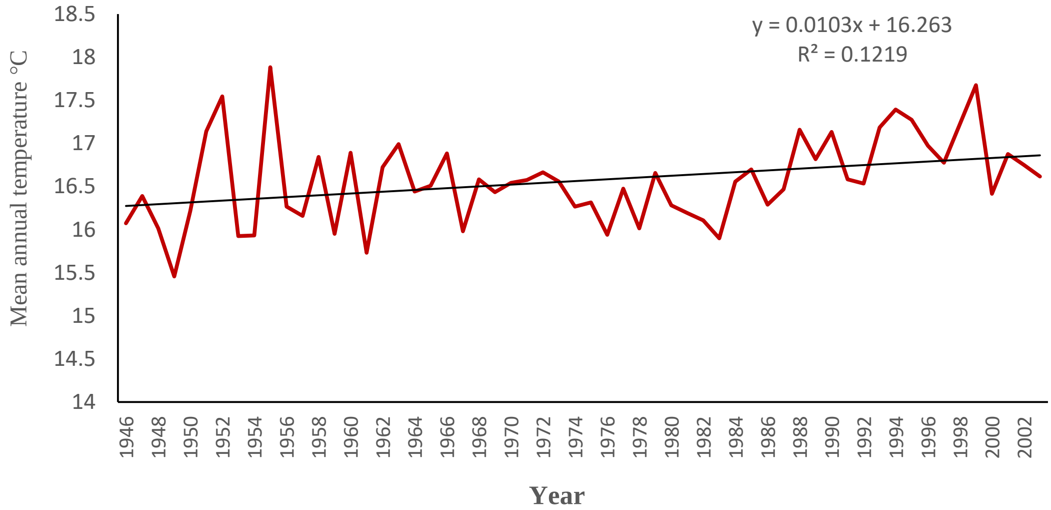


Figure 5.6: The mean annual temperature at Shahat over the period of study.

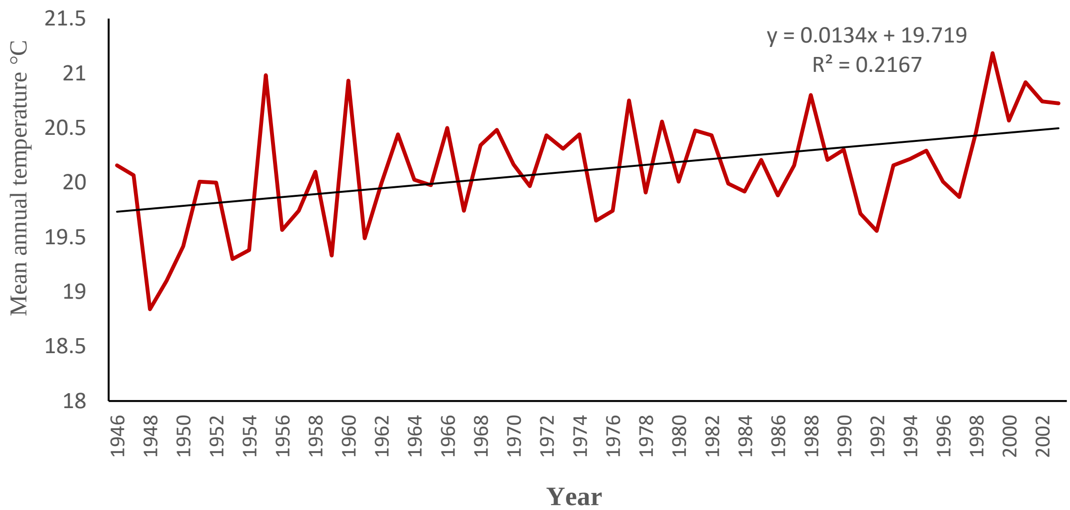


Figure 5.7: The mean annual temperature at Benina over the period of study

Correlation coefficient (R) indicated an increase in the mean annual temperature across the region over the period of 1946 to 2003. This result confirmed the results of previous studies that temperature have increased in the Mediterranean basin since the mid- 20th century, with some spatial variability in these rates (IPCC, 2014; Ageena et al, 2010).

5.3.1.2 Long term trend of the mean annual maximum temperature at the stations of study area (1946- 2003)

The maximum temperature is the highest temperature measured during the day. Estimating the changes in trends of the mean annual maximum temperature is based on long-term climatic data from 1946 to 2003 in the region (Figures 5.8, 5.9 & 5.10).

The mean annual maximum temperature was 23.4°C, 20.5°C and 25.6°C at Darnah, Shahat and Benina respectively with a coefficient of variation (CV) of 1.72 % at Darnah, 2.34 % at Shahat and 2.16 % at Benina.

Table 5.4: The mean annual maximum temperature and Mann-Kendall (M-K) and correlation coefficient (R) for the study area stations.

Station	Period	Mean annual Max °C	CV %	M-K	Sig (p)	R	Sig (p)
Darnah	1946-2003	26.1	1.72	0.311	0.001	0.434	0.001
Shahat	1946-2003	20.5	2.34	-0.113	0.210	-0.171	0.199
Benina	1946-2003	25.2	2.16	0.132	0.144	0.175	0.187

Regarding the Mann-Kendall and correlation coefficient results, there was no significant increase in the long-term trend of mean annual maximum temperatures at Shahat and Benina for the period 1946-2003. In contrast, at Darnah station the result showed a significant trend in the mean annual maximum temperature over the same period with both tests.

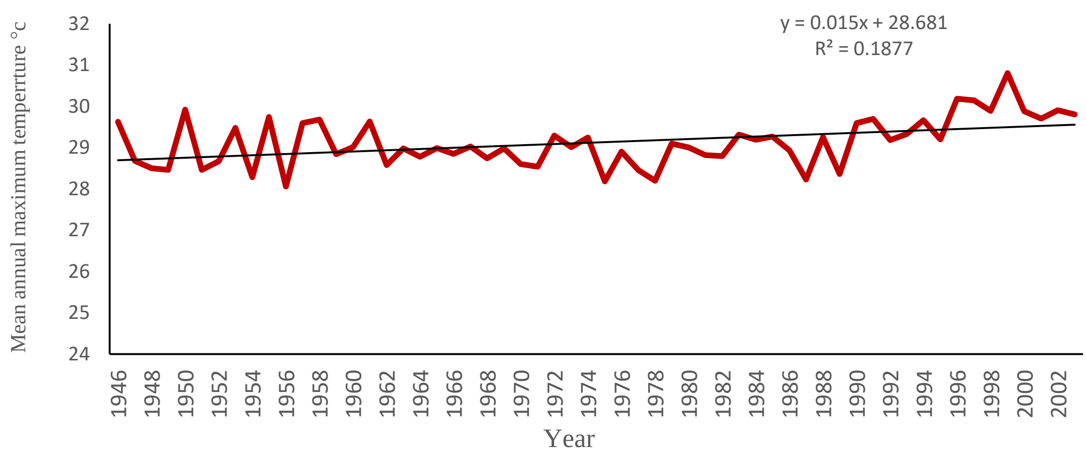


Figure 5.8: The mean annual maximum temperature at Darnah over the period of study.

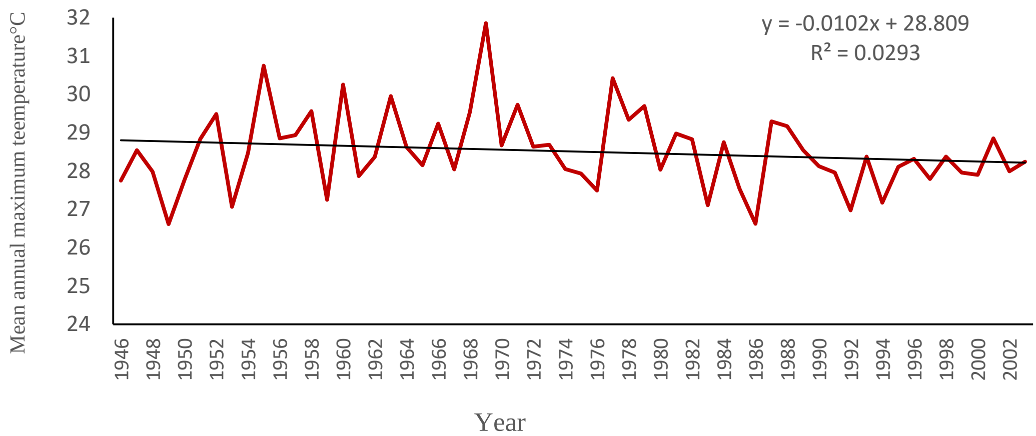


Figure 5.9: The mean annual maximum temperature at Shahat over the period of study.

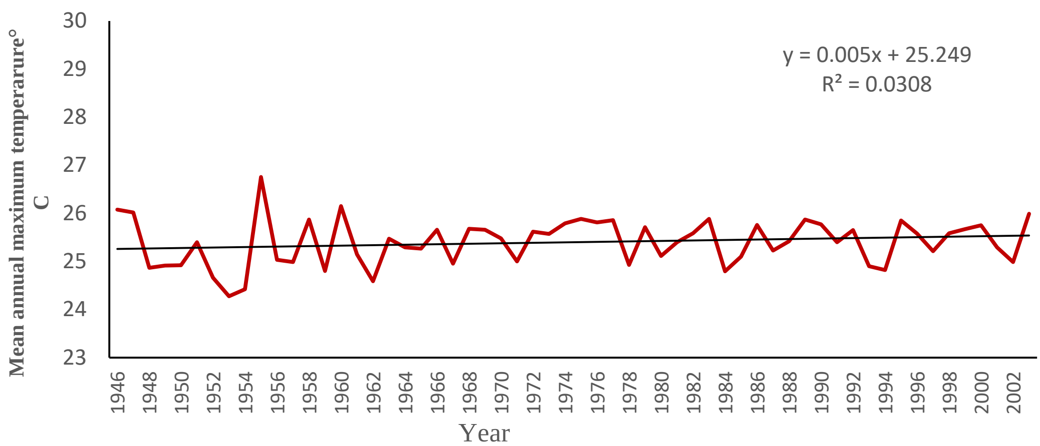


Figure 5.10: The mean annual maximum temperature at Benina over the period of study.

5.3.1.3 Long term trend of the mean annual minimum temperature at the stations of study area (1945- 2003)

The minimum temperature is the lowest temperature measured during the day. Analysis of the minimum temperature in the study area stations was undertaken to determine the variations in the minimum temperature trends (Table 5.5).

Table 5.5: The mean annual minimum temperature and Mann-Kendall (M-K) and correlation coefficient (R) for the study area.

Station	Period	Mean annual min °C	CV %	M-K	Sig (p)	R	Sig (p)
Darnah	1946-2003	14.7	3.26	0.244	0.007	0.353	0.006
Shahat	1946-2003	12.4	11.54	0.277	0.002	0.457	<0.001
Benina	1946-2003	15	5.26	0.635	<0.001	0.820	<0.001

The difference in mean annual minimum temperature at the coastal stations and mountain station was clear. At Darnah and Benina it was 14.7 °C and 15 °C, whereas at Shahat in the mountains it was 12.4 °C (Figure 5.11, 5.12 & 5.13).

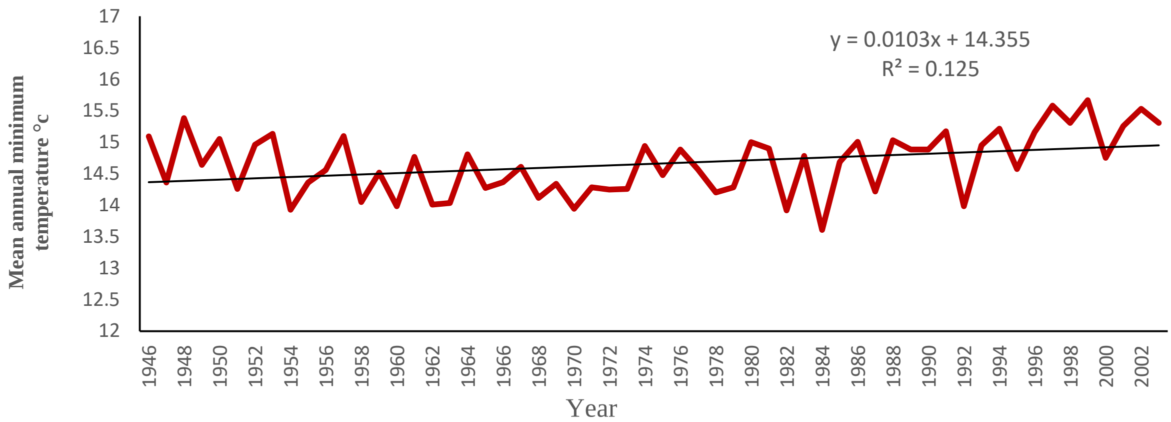


Figure 5.11: The mean annual minimum temperature at Darnah over the period of study

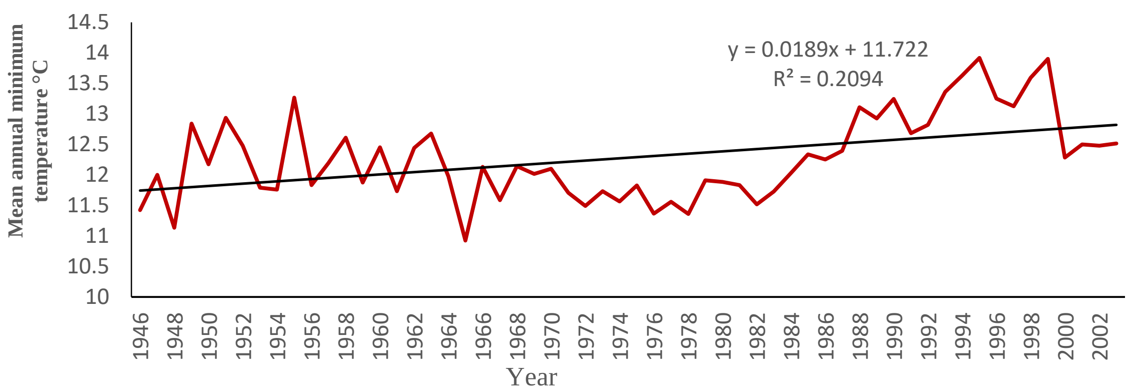


Figure 5.12: The mean annual minimum temperature at Shahat over the period of study

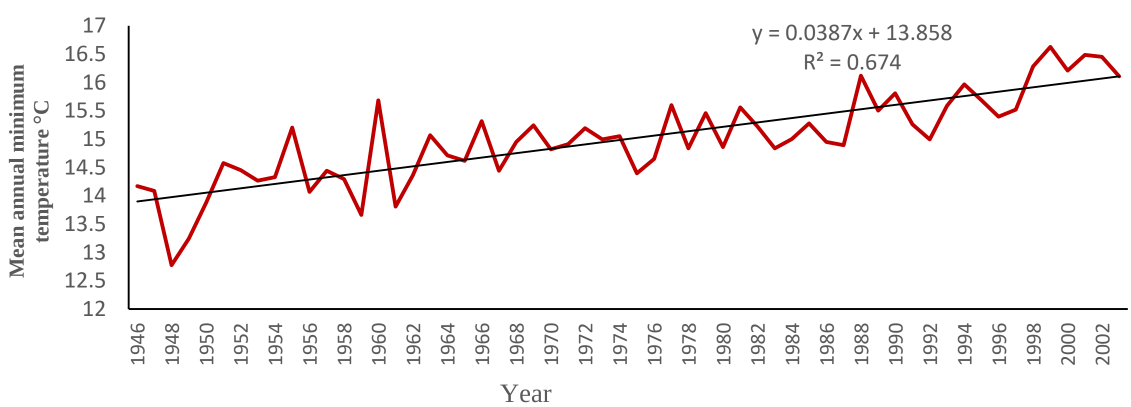


Figure 5.13: The mean annual minimum temperature at Benina over the period of study

The results of the M-K trend confirmed that the trends of mean annual minimum temperature was significant at all the stations over the period of study (1946-2003), at a significance level of 0.01 in Darnah, Shahat and Benina respectively.

According to the correlation coefficient (R) of the mean annual minimum temperature trends, the results indicated a statistical significant increase at the 0.01 level, at all three stations.

5.3.2 Short term trends of temperature in two periods (1945-1971) and (1972-2003) at the stations

To investigate the variability of temperature over different periods, and the changes in the mean annual, maximum and minimum temperature at the Al Jabal Al Akhdar stations, the approach divided the period of study into two short periods 1946-1971 and 1972-2003.

5.3.2.1 Short term trends in mean annual temperature during two periods (1945-1971) and (1972-2003) at the stations

Dividing periods of climate data into two short periods for analysis permits consideration of general short-term changes and shows the variability of temperature during 31 years (1972-2003) compared to the 25 first year period (1946-1971) (Ageena, 2010) (Table 5.6).

Table 5.6: The mean annual temperature, (M-K) and (R) for two short periods in the study area.

Station	Period	Mean annual T °C	M-K	Sig (p)	R	Sig (p)
Darnah	1946-1971	21.3	0.165	0.242	0.258	0.204
	1972-2003	21.5	0.521	0.001	0.680	<0.001
Shahat	1946-1971	16.4	0.151	0.280	0.144	0.483
	1972-2003	16.6	0.402	0.001	0.592	<0.001
Benina	1946-1971	20	0.253	0.071	0.403	<0.05
	1972-2003	20.3	0.174	0.163	0.300	0.095

The trends of the mean annual temperature for two short periods, can be compared at all stations (Figures 5.14, 5.15 & 5.16).

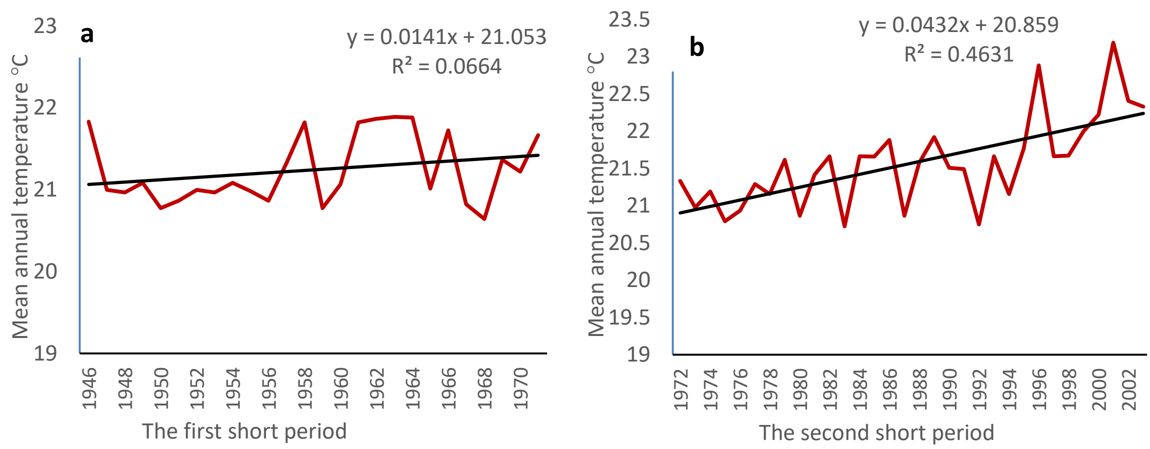


Figure 5.14: Two short periods study a (1946-1971) and b (1972-2003) at Darnah

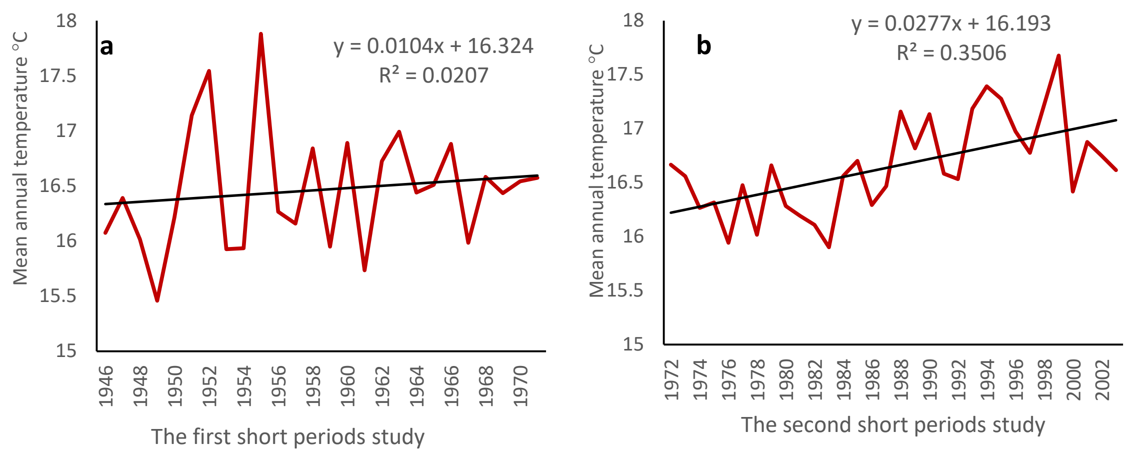


Figure 5.15: Two short periods study a (1946-1971) and b (1972-2003) at Shahat

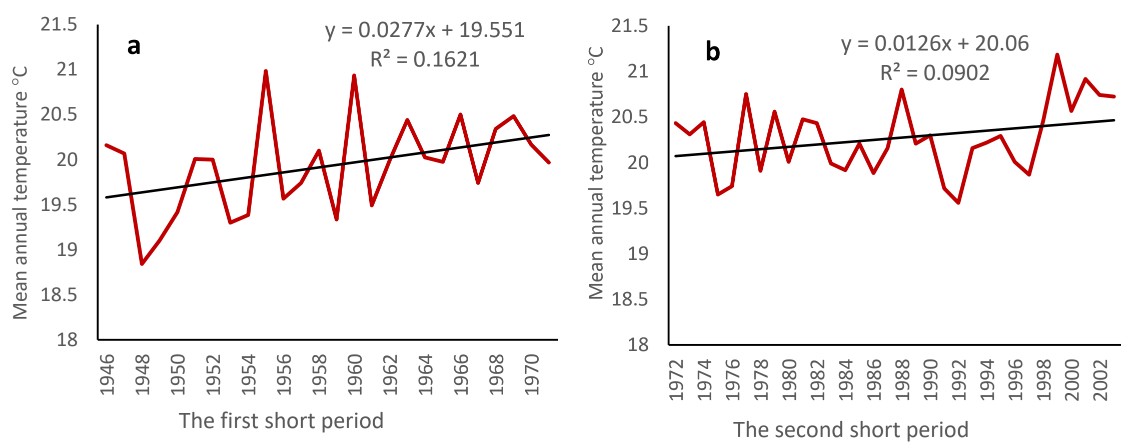


Figure 5.16: Two short periods study a (1946-1971) and b (1972-2003) at Benina

The graph of mean annual temperatures indicates an increase in the temperature in the first and second period of study with a small difference in the second period. The trends at Shahat and Darnah increased without statistical significance in the first period except Benina which recorded a significant increase in the period 1946- 1971. However, the trends of mean annual temperature increased significantly at Darnah and Shahat in the second period (p= 0.01). The results of the Mann-Kendall test confirmed that the second period recorded an increase in the mean annual temperature, more so than in the first period at Darnah and Shahat stations.

The trends in mean annual temperature at the Al Jabal Al Akhdar climate stations reflect an increase in mean annual temperature in the Mediterranean region of 0.75°C over the 50 years as confirmed by the IPCC in their fifth assessment report (IPCC, 2014).

5.3.2.2 Short term trends in mean annual maximum temperature over two periods (1945-1971 and 1972-2003) at the stations

By comparing the difference between the short periods the mean annual maximum temperature in the second period was higher than the first period of study at all stations (Table 5.7).

Table 3.7: The mean annual maximum temperature, (M-K) and (R) for two short periods in the study area

Station	Period	Mean annual max °C	M-K	Sig (p)	R	Sig (p)
Darnah	1946-1971	25.9	-0.052	0.708	-0.119	0.564
	1972-2003	26.2	0.516	<0.001	0.694	<0.001
Shahat	1946-1975	20.4	0.317	0.023	0.429	0.029
	1976-2003	20.5	-0.174	0.163	-0.258	0.153
Benina	1946-1975	25.4	0.427	0.111	0.056	0.785
	1976-2003	25.7	-0.083	0.506	-0.126	0.491

The table shows there was no large difference in the maximum temperature between the first and second periods at all stations where, the maximum temperature increased slightly in the second period at the stations.

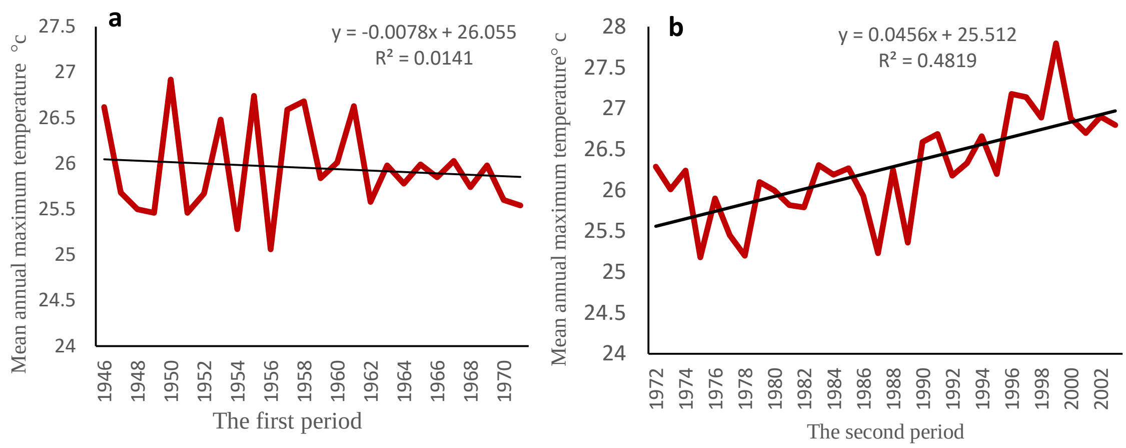


Figure 5.17: Two short periods of maximum temperature a (1946-1971) and b (1972-2003) at Darnah

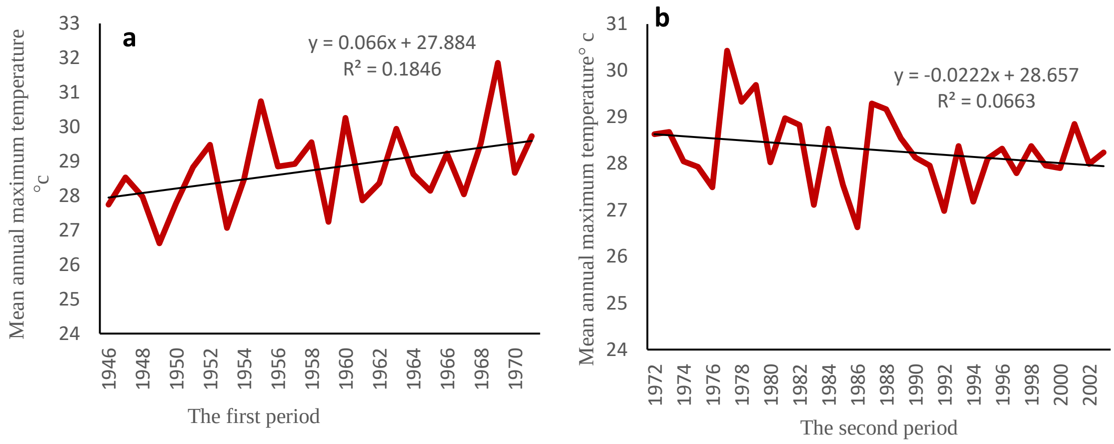


Figure 5.18: Two short periods of maximum temperature a (1946-1971) and b (1972-2003) at Shahat

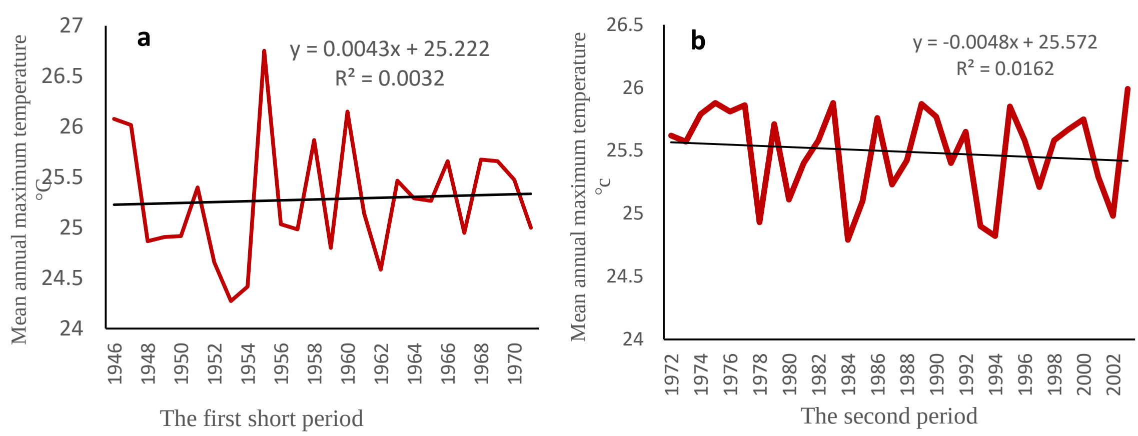


Figure 5.19: Two short periods of maximum temperature a (1946-1971) and b (1972-2003) at Benina

The mean annual maximum temperatures were small at the stations over the two different periods of study. At Darnah, the difference was 0.3°C between the first period (25.9 °C) and the second period (26.2°C) and at Benina it was 0.3°C, however, at Shahat the trend increased by just 0.1°C from the first period (20.4°C) to the second (20.5°C).

Regarding the Mann-Kendell and correlation (R), the mean maximum temperature has decreased at Darnah station in the first period and increased significantly in the second period, however, the trends at Shahat and Benina show decrease at the second period

5.3.2.3 Short term trend in mean annual minimum temperature in two periods (1945- 1971 and 1972 – 2003) at the station

Analysis of the trend in mean annual minimum temperature indicated an increase in the trend significantly during the second period of study (1972-2003) at all the region stations with a difference of up to 0.3°C at Darnah and 0.2°C at both of Shahat and Benina (Table 5.8).

Table 5.8: The mean annual minimum temperature and Mann-Kendall (M-K) and correlation coefficient (R) for two short periods in the study area.

Station	Period	Mean annual min °C	M-K	Sig (p)	R	Sig (p)
Darnah	1946-1971	14.5	0.308	0.027	-0.510	0.008
	1972-2003	14.8	0.446	<0.001	0.592	<0.001
Shahat	1946-1975	12.3	-0.089	0.523	-0.114	0.579
	1976-2003	12.5	0.601	<0.001	0.758	<0.001
Benina	1946-1975	14.9	0.438	0.002	0.602	0.001
	1976-2003	15.1	0.533	<0.001	0.759	<0.001

The mean annual minimum temperatures at Darnah and Shahat have decreased in the first period of 1946 -1971 and increased in the second period of 1972- 2003 (Figures 5.20, 5.21 & 5.22). In contrast, Benina recorded an increase over the first and the second periods. The results of the M- K and R indicated there was a decrease in the trend of mean annual minimum temperatures in the first period at Darnah and Shahat but without statistical significance. In the second period the trends show statistically significant increases at all the stations. It is worth noting Benina recorded statistically significant increasing trends in the first and second periods of study.

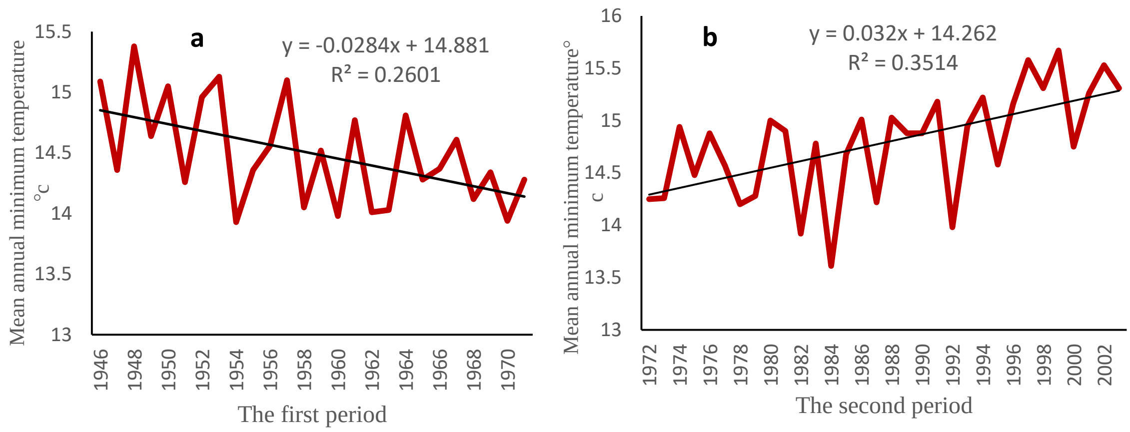


Figure 5.20: Two short periods of minimum temperature a (1946-1971) and b (1972-2003) at Darnah

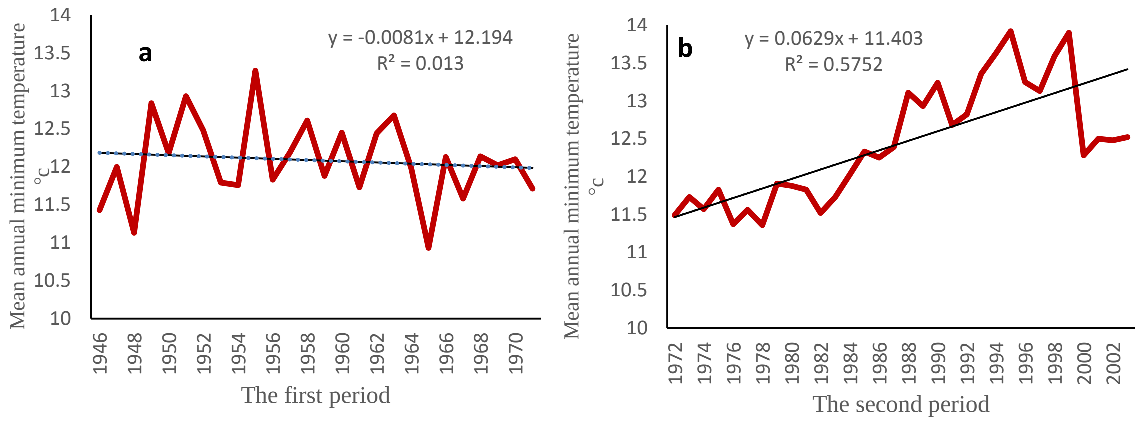


Figure 5.21: Two short periods of minimum temperature a (1946-1971) and b (1972-2003) at Shahat

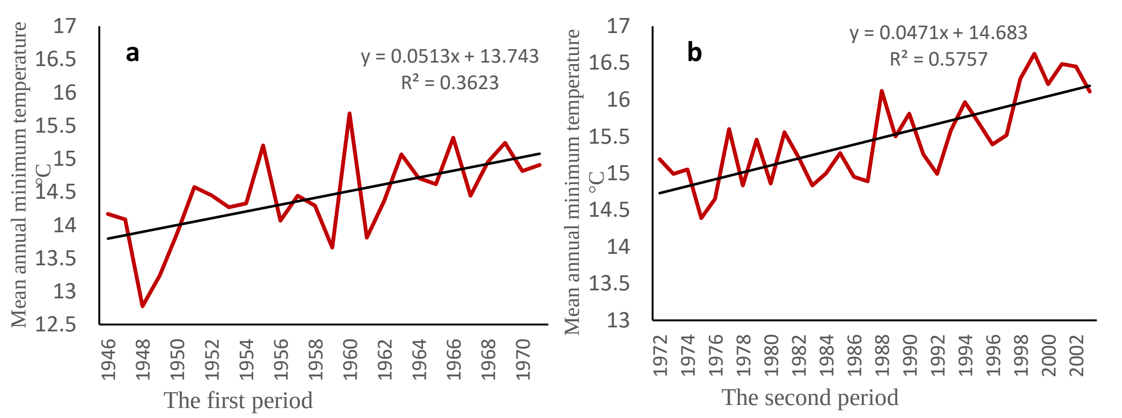


Figure 5.22: Two short periods of minimum temperature a (1946-1971) and b (1972-2003) at Benina.

5.3.3 Summary of temperature trends

The results of temperature variability were comparable with previous studies that have examined the changes and trends in temperature across Libya, including the climate stations of the study area (e.g. El-Tantawi 2005, Bukhechiem 2006 and Ageena 2010). All these studies confirmed that there was an increase in temperature in Libya. The change rates are supported by El-Tantawi (2005), who identified an increase in temperature variation of between 0.2 and 0.19 °C across Libya from 1946 to 2000 and Ageena (2010) who found an increase in temperature by 0.024 °C during the period 1945-2010.

The mean annual temperature in the Mediterranean region has increased by 0.75 °C during the last few decades (IPCC, 2014; Osborne et al., 2000), with expectations of increases of 1 to 3°C between 2010 and 2039. Al Jabal Al Akhdar is located in the south of the Mediterranean basin; therefore it is affected by climate change in the region. The key results of this analysis are:

(i) There was a difference in the average temperature between the stations of the region which may be due to the effect of factors such as the influence of landform, altitude, proximity to the sea and differences in vegetation cover in the region.

(ii) The linear regression analysis indicated there were weakness and strengths in the relationships expressed by R value for increased trends of temperature over the period of study.

(iii) Analysis of the mean annual temperature in the Al Jabal Al Akhdar indicated a slight increase in temperatures during the period of 57 years (1946-2003). In the two different short periods the average mean annual temperature in the second period (1972-2003) was higher than the first period (1946-1971) in all stations by 0.2°C in both Darnah and Shahat and by 0.3°C at Benina station.

(iv) There was an increase in mean annual maximum temperature over the period of study (1946-2003), especially in the second period at Darnah and Benina by 0.3°C compared with the first period. However, the trend at Shahat recorded a slight increase over the periods of study, i.e. 0.1°C from the first period (20.4 °C) to the second (20.5 °C).

(v) The trends of mean annual minimum temperature have increased at all the stations of the study area. However, at Darnah and Shahat the trends decreased in the first period with statistical significance at Darnah. In contrast, the mean annual minimum temperature at Benina has a statistically significant increase over the 57 year period.

(vi) The results of the Mann- Kendall and the Correlation Coefficient were similar at all stations in terms of the statistical significance for an increase or a decrease in the temperatures at all stations of the study area and at different periods (Table 5.9).

Table 5.9: Comparison of the results of mean annual temperature at the Mann-Kendall and R

Station	1946-2003		1946 - 1971		1972 - 2003	
	M-K	**R**	**M-K**	**R**	**M-K**	**R**
Darnah	✓	✓	×	×	✓	✓
Shahat	✓	✓	×	×	✓	✓
Benina	✓	✓	×	×	×	×

(✓) statistically significant trend, (×) no significant trend.

Overall, the results of examinations of temperatures in the Al Jabal Al Akhdar region have confirmed that temperature has changed since the 1950s in the area.

5.4 Recent precipitation patterns in the study area

The patterns of precipitation differ in the Al Jabal Al Akhdar region in terms of temporal and spatial distribution. To identify the variation of rainfall trends, the approach investigated the trend of mean annual rainfall over the 57 year period at the climate stations in the study area. Precipitation data were collected from the Libyan National Centre (LNMC). The approach collected the rainfall data from 11 stations, of which 3 are synoptic stations, and 8 are rain stations distributed across Al Jabal Al Akhdar. These stations were divided into the coastal stations (Darnah, Benina, Ras Al helal and Susah), and the mountain stations (Shahat, Al Abraq, Al Qubah, Ayn Marah, Al Faidia, Al Qayqab and Al Fatayah). To determine the variations and pattern of rainfall trends in the region over the 57 years (1945-2003), the research has relied on the mean annual rainfall at the stations in the study area over the long period and two short periods (1946-1971) (1972-2003).

5.4.1 Long-term trends in mean annual precipitation at the stations in the study area (1945- 2003)

To determine the general patterns in the long-term and any variations in rainfall trends, the approach investigated long time-series of the mean annual precipitation using the data available from Darnah, Shahat and Benina (1946-2003) in the Al Jabal Al Akhdar region (Table 5.10, Figures 5.23, 5.24 & 5.25).

Table 5.10: The mean annual precipitation, the Mann-Kendall (M-K) and correlation coefficient (R) at the stations over the period (1946-2003)

Station	Period	Mean annual mm	CV%	M-K	Sig (p)	R	Sig (p)
Darnah	1946-2003	266	28.16	0.051	0.569	0.014	0.916
Shahat	1946-2003	563	20.46	-0.088	0.331	-0.131	0.327
Benina	1946-2003	270	30.06	0.001	0.989	0.028	0. 831

The mean annual rainfall is the average of amount of rainfall for the entire year at any given area. The mean annual rainfall ranges between 266 $mmyr^{-1}$ and 270 $mmyr^{-1}$ at coastal stations with a coefficient of variation (CV) of 28.16% at Darnah, and 30.06% at Benina over the period of study. In the mountain stations, Shahat receives approximately 563 mm yr^{-1} which is the highest amount of rainfall in the northeast of Libya with (CV) of 20.46%.

The trend of mean annual rainfall has fluctuated over the period of study at all stations without clear trends at the coastal stations and decreased at Shahat station in the mid of1970s. The 1950s and 1970s periods witnessed a decline at all stations whereas, the 1990s is characterized by increased rates of rainfall.

Regarding M-K and R results, there were no significant trends for the mean annual rainfall at all stations of the study area. The changes in the pattern of rainfall in the study area in terms of change the amounts of rainfall in the months were similar to the change of precipitation patterns in the Mediterranean region as respond to the global warming (Abbott & Le Maitre, 2010; IPCC, 2014).

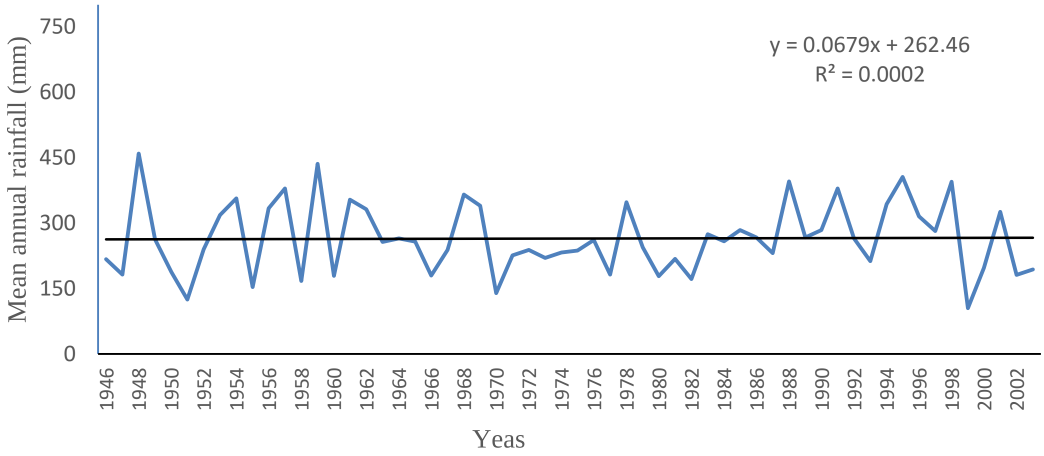


Figure 5.23: The mean annual rainfall at Darnah station over the period of study

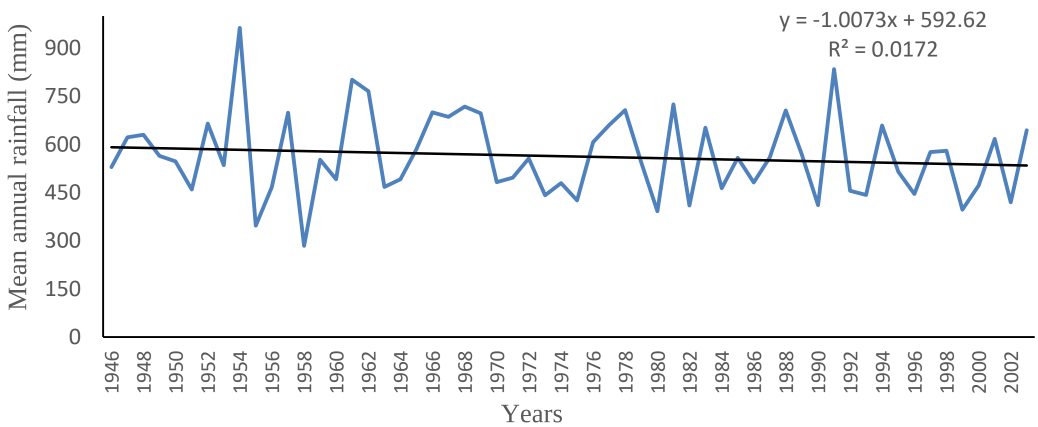


Figure 5.24: The mean annual rainfall at Shahat station over the period of study

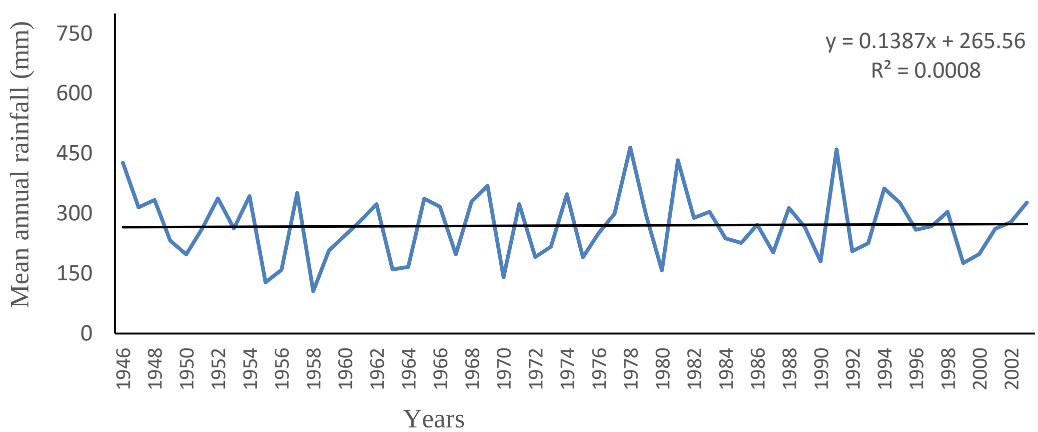


Figure 5.25: The mean annual rainfall at Benina station over the period of study

For example, a strong drying trend starting in the early 1960s in southern Europe – Turkey region and the Levant with increased precipitation rates in the late 1990s, (Lelieveld et al. 2012), and this was similar to the trends of rainfall at the study stations.

5.4.2 Short term trends in mean annual precipitation over two periods (1945-1971) and (1972-2003) at the stations

To examine the trend of mean annual rainfall over different periods, the rainfall data was divided into two short periods 1946-1971 and 1972-2003 at the main station stations, plus short different periods at 8 the rain stations across the region to give a general picture about the pattern of rainfall across the study area (Tables 5.11).

Table 5.11: The mean annual precipitation, (M-K) and (R) for two short periods at the stations.

Stations	Periods	Mean annual (mm)	M-K	Sig (p)	R	Sig (p)
Darnah	1946-1971	267	0.007	0.137	0.003	0.987
	1972-2003	262	0.137	0.270	0.149	0.415
Shahat	1946-1971	586	0.077	0.582	0.081	0.693
	1972-2003	544	0.008	0.948	-0.028	0.880
Benina	1946-1971	264	0.046	0.741	-0.125	0.543
	1972-2003	275	0.026	0.833	-0.014	0.940

The table shows the changes in the mean annual precipitation at the stations in the study area over the second period of study (1972-2003) (Figures 5.26, 5.27 & 5.28). Regarding the Mann-Kendall and R tests, there were no statistically significant trends for either period at the stations in the region over the different periods, however, it is worth noting that at Benina station the rainfall trend decreased in both the periods of study and Shahat the trend deceased in the second period (1972-2003).

There was a decrease in the average rainfall in Darnah and Shahat stations by 5 $mmyr^{-1}$ and 43 $mmyr^{-1}$ respectively in the second period compared with Benina which saw an increase on average of 11 mm yr^{-1}.

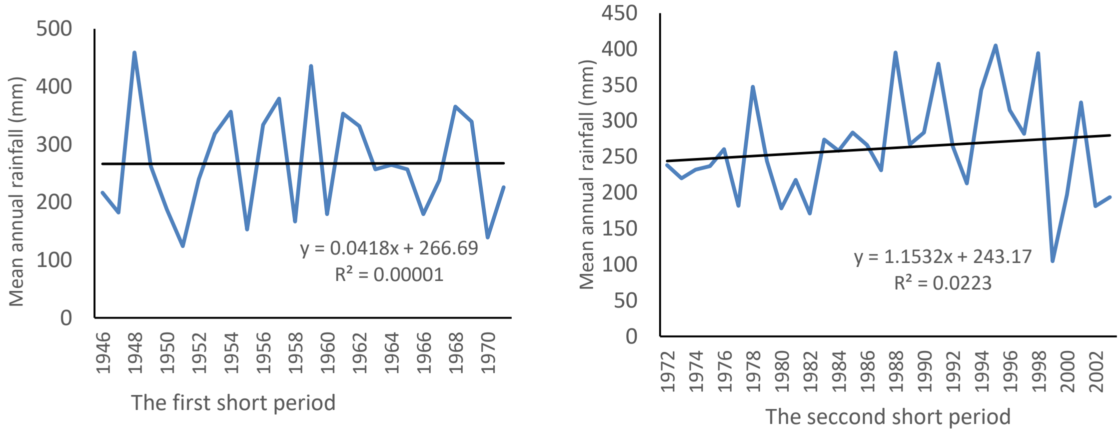


Figure 5.26: Two short periods of mean annual rainfall a (1946-1971) and b (1972-2003) at Darnah

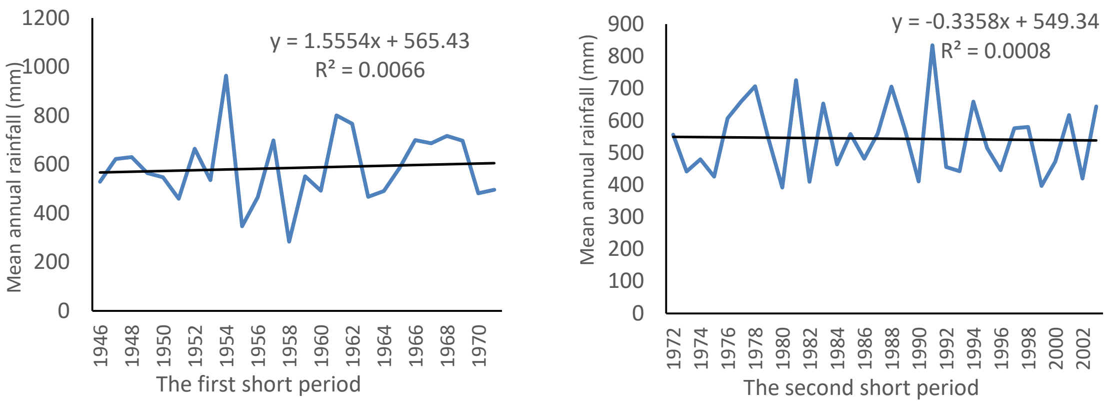


Figure 5.27: Two short periods of mean annual rainfall a (1946-1971) and b (1972-2003) at Shahat

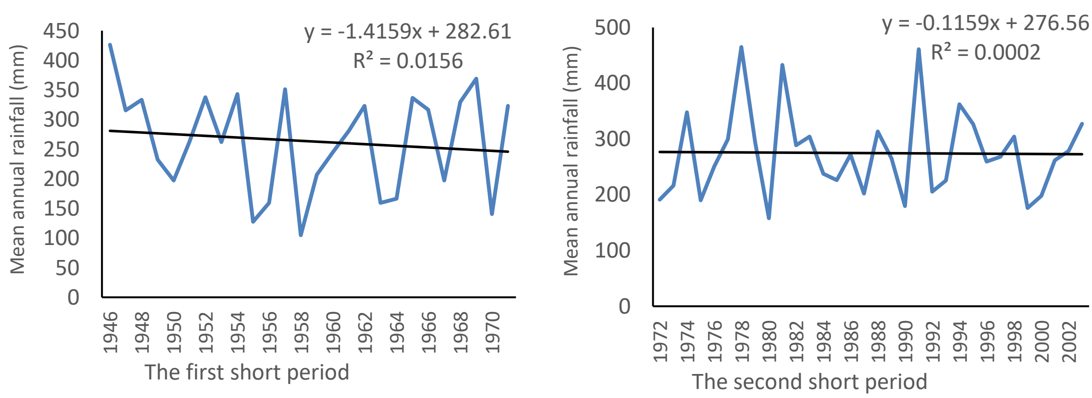


Figure 5.28 Two short periods of mean annual rainfall a (1946-1971) and b (1972-2003) at Benina

To identify the variation pattern of precipitation in the Al Jabal Al Akhdar, the mean annual rainfall for the rest of the stations was calculated (Table 5.12) and presented in graphs (Figures 5.29 to 5.36).

Table 5.12: The mean annual rainfall, (M-K) and (R) at rain stations in the Al Jabal Al Akhdar in different periods

Station	Mean annual mm	CV %	M- K	Sig (p)	R	Sig (p)
Al Faidia	419	36.9	-0.039	0.800	-0.169	0.452
Al Qayqab	332	30.9	0.296	0.024	0.357	0.057
Al Byadah	299	4.53	-0.091	0.535	-0.076	0.723
AL Abraq	398	40.2	0.093	0.489	0.185	0.346
Al Qubah	563	20.5	-0.088	0.331	-0.131	0.327
Ayn Marah	325	46.9	0.147	0.410	0.110	0.674
Ras Al helal	384	36.3	-0.154	0.232	-0.164	0.385
Susah	372	31.9	-0.203	0.185	-0.239	0.284

The pattern trends of annual precipitation differed between the stations and there was no similarity between the mountain stations (Al Faidia, Al Qayqab, Al Byadah, Al Abraq, Al Qubah and Ayn Marah), which have the same topography and distance from the sea, where the trends of annual rainfall have fluctuated from station to station at different periods.

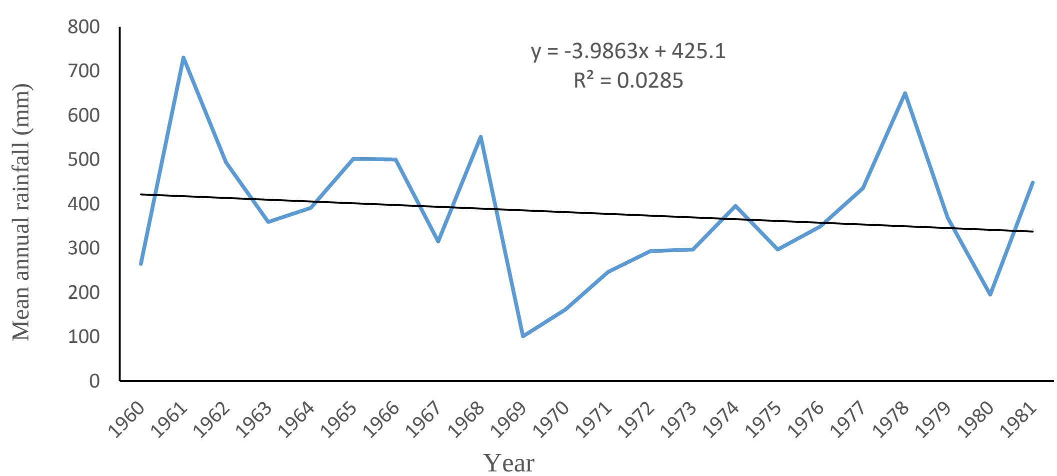


Figure 5.29: The mean annual precipitation (mm) at mountain station of Faidia (1960-1980)

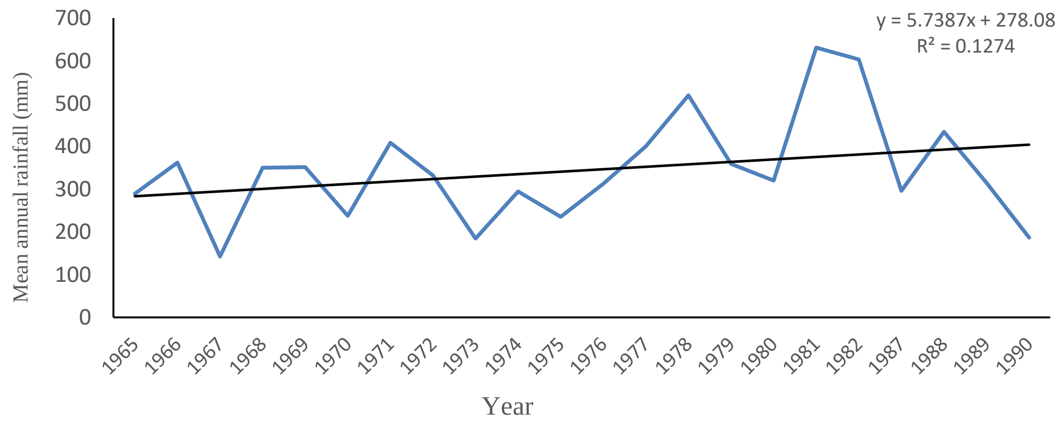


Figure 5.30: The mean annual precipitation (mm) at mountain station of Al Qayqab (1965-1990).

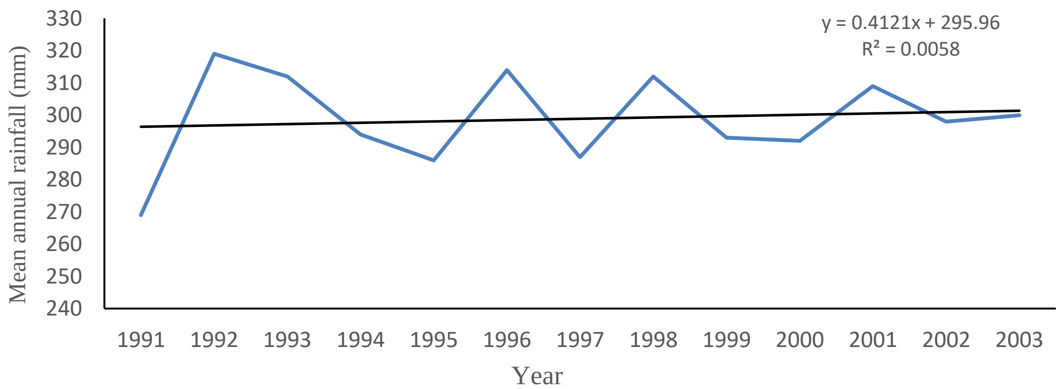


Figure 5.31: The mean annual precipitation (mm) at mountain station of Al Byadah (1991-2003)

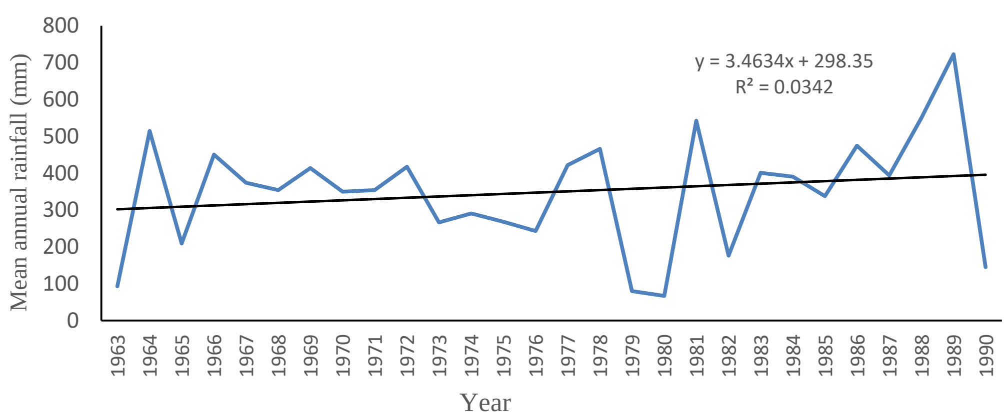


Figure 5.32: The mean annual precipitation (mm) at mountain station of AL Abraq (1963-1990)

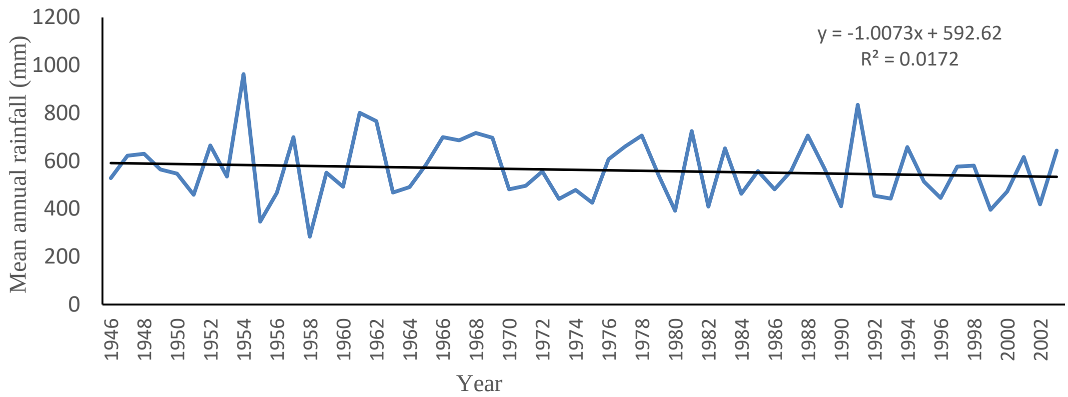


Figure 5.33: The mean annual precipitation (mm) at mountain station of Qubah (1946-2003).

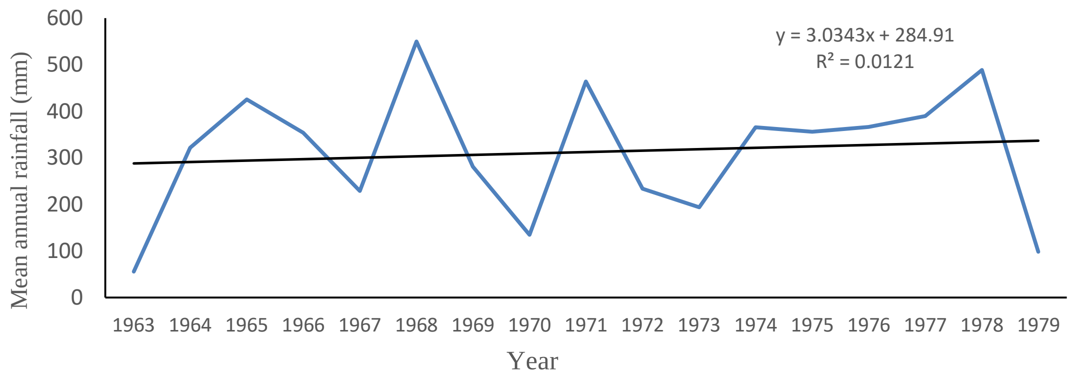


Figure 5.34: The mean annual precipitation (mm) at mountain station of Ayn Marah (1963-1979)

In contrast, the coastal stations recorded a decrease in the mean annual rainfall during the different periods (Figures 3.35 & 3.36).

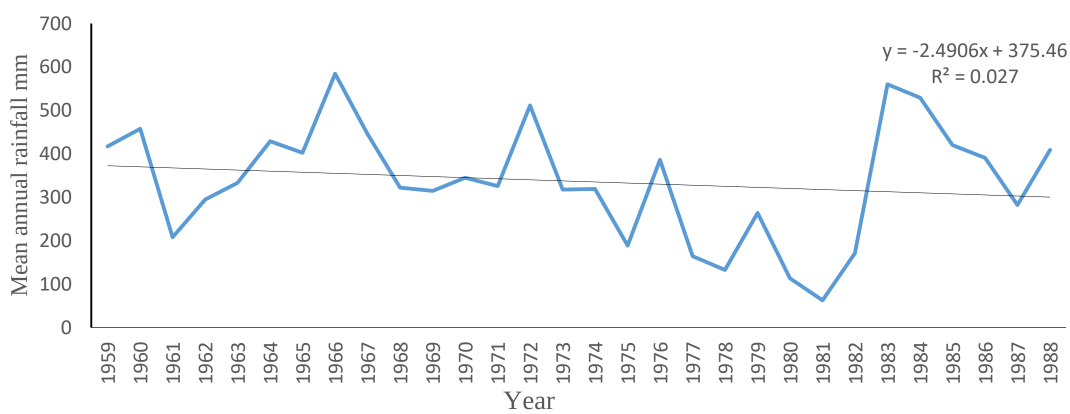


Figure 5.35: The mean annual precipitation (mm) at coastal station of Ras Al Helal (1959-1987)

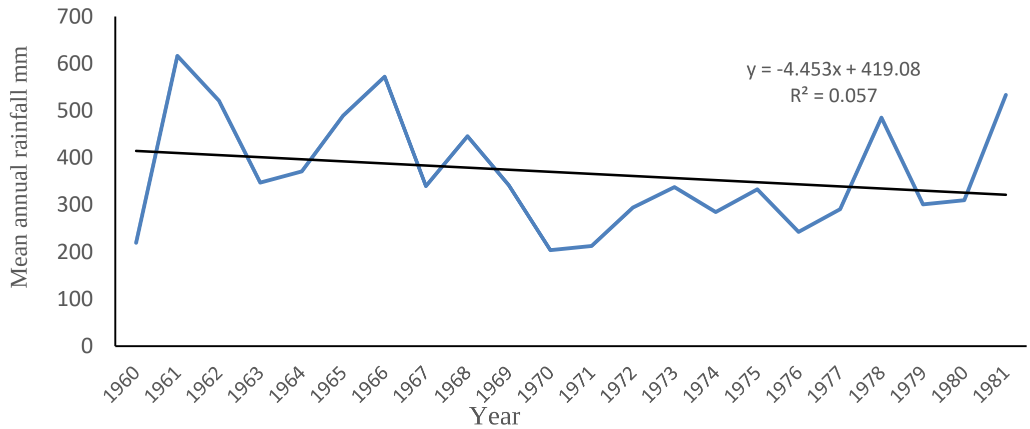


Figure 5.36: The mean annual precipitation (mm) at coastal station of Susah (1960-1981).

5.4.3 Summary of precipitation trends

The results of the patterns of precipitation indicated spatial and temporal changes in the Al Jabal Al Akhdar area over the last 57 years. These changes in the trends of rainfall were similar to the precipitation pattern changes in the Mediterranean region as a result of global warming. The key results of this study are as follows:

(i) The trends of mean annual rainfall have fluctuated at all stations without clear trends over the periods of study (1946-2003).

(ii) The period of the 1950s and 1970s witnessed a decline at all stations, whereas the 1990s was characterized by increasing rates of rainfall.

(iii) Change in a spatial and temporal precipitation were found at the mountain stations in terms of increases or decreases in the average rainfall, in spite of, the distance between the rain stations of no more than 30 m, whereas the coastal stations had the similar trends whether they be increases or decreases.

(iv) The results of Mann-Kendall confirmed the result of correlation coefficient (R), in terms of an increase or decrease in the trends of rainfall at the station of study area. The results indicated there were no significant trends for the mean annual rainfall over the period of study (Table 5.13).

Table 5.13: Comparison of the results of mean annual rainfall at the Mann-Kendall and R

Station	1946-2003		1946 - 1971		1972 - 2003	
	M-K	R	M-K	R	M-K	R
Darnah	×	×	×	×	×	×
Shahat	×	×	×	×	×	×
Benina	×	×	×	×	×	×

(×) no significant trend.

5.5 Correlation coefficient between long trend of the mean annual precipitation and the mean annual temperature at the stations (1946-2003)

To identify the relationship between increases in the temperature and changes in patterns of precipitation in the Al Jabal Al Akhdar, a correlation coefficient was used to determine if there was relationship between the mean annual temperature and the mean annual precipitation over the 57 years (Table 5.14).

Table 5.14: The Correlation coefficient between precipitation and mean annual temperature in the study area (1945-2003).

Station	Period	Mean annual T °C	Mean annual P mm	R
Darnah	1945-2003	20.1	266.2	0.035
Shahat	1945-2003	16.5	562.9	- 0.31
Benina	1945-2003	20.1	269.6	0.038

The analysis of correlation showed there was no relationship between the mean annual temperature and the mean annual rainfall at the stations in the region. Thus, the increase in temperature, which has occurred in the region was not associated with the change in the pattern of rainfall.

5.6 Summary

Analysis of the correlation coefficient (R) showed that there was no relationship between the annual temperature and annual rainfall at all the stations, furthermore, the annual temperature trend increased after 1975, a period when warming occurred, as IPCC confirmed in their fourth and fifth reports (IPCC, 2007; IPCC 2014). While it is true that the mean annual rainfall fluctuated over the period of study (1945-2003), there was no clear trend for the precipitation in the study area.

5.7 Conclusion

The analysis of climate data from the study stations provided a general picture for the climate of the study area and identified any changes in the climate of the study area which in turn may have an effect on the long term vegetation cover.

Overall, the conclusion is that the mean annual temperature has increased significantly in the study area with fluctuations in rainfall over the 57 years. These results were similar to the climate change of the Mediterranean region, in terms of increases in temperature, although there was no trend for the rainfall. Many studies of vegetation change in the Mediterranean region (mentioned in chapter 2), have confirmed that climate change has affected productivity and the structure of vegetation cover.

Climate change may be a factor affecting vegetation change in the study area, especially in the south of the Al Jabal Al Akhdar where there is a lack of rainfall and an increase in temperature in addition to the influence of the desert in the south of the study area. The next chapter presents an examination of the vegetation change over 42 years in the study area.

CHAPTER 6: VEGETATION INDEX CHANGE DETECTION IN THE STUDY AREA

This chapter presents an assessment of vegetation cover change in the study area over the period 1972- 2014 through the use of a time-series of three different vegetation indices.
The approach uses a pixel by pixel statistical analysis to test for significant trends in vegetation indices. Maps of significant trends are generated to show the spatial distribution of change in the study area.

6.1 Introduction

Detection of vegetation cover change in the Al Jabal Al Akhdar region requires a long-term record of data for vegetation cover in order to monitor the changes over a long period of time. Multi-temporal Landsat image data are free, with spatial resolutions of 79 m (MSS) and 30m (TM, ETM+ and OLI), and are available for the period 1972 to the present for the study area. The research selected eleven images because they were cloud-free, obtained within a three-month window in summer/ autumn and covering the study area. These data sets were pre-processed to surface reflectance as described in chapter 4.

6.2 Objective one

The main goal in this chapter is to assess vegetation cover change using remote sensing vegetation indices and to map the temporal and spatial variation in the indices across the study area as a first step towards assessing the factors which caused these changes. The objective proposes that there has been a decrease in vegetation cover over the period of study. The research therefore tests this by assessing trends in vegetation index changes in the study area.

6.3 Detection of vegetation cover index changes

Vegetation indices allow mapping of vegetation cover based on the characteristic reflectance patterns of green vegetation. The approach used three VI to analyse the images: Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation

Index (SAVI) and Enhanced Vegetation Index (EVI). The research masked the sea for all the analysis and used a consistent rectangular spatial frame to define the study area.

These specific indices were chosen because of the diversity in vegetation cover density in the study area, and in order to assess the vegetation without the influence of other factors such as the atmosphere, soil and vegetation. The NDVI was used so as to assess the vegetation cover even in areas with low density of vegetation (Wang et al., 2004). The SAVI was used to assess the vegetation cover without the influence of the brightness or colour of the soil, which may have an effect on VI values in the areas that have low vegetation (Huete et al., 1998). The EVI was used to remove the influence of atmospheric conditions on vegetation cover estimates and correct the canopy background reflectance signal in areas that have dense vegetation (Jiang et al., 2008).

6.3.1 Normalized Difference Vegetation Index (NDVI)

The research generated the NDVI images from Landsat images using ERDAS Imagine software (Figure 6.1).

6.3.1.1 Long term NDVI dynamics over 42 years (1972 – 2014)

1972 was the first year when Landsat data became available, so the research used an image from this year as the starting point for comparing the different NDVI values. In order to estimate NDVI changes, the research created a time-series of the NDVI to cover all the years to form a single image with 11 layers (images) using ERDAS Imagine. The NDVI time-series is illustrated with the combination of bands 1, 2 and 3, which represented three years, for example 1972 is represented by the blue band, 1978 by green and 1987 by red (Figure 6.2).

6.3.1.2 Linear regression of NDVI values per pixel

To assess the trend of vegetation cover in each pixel of the VI images, the research applied a regression equation using ERDAS Imagine to generate a regression slope

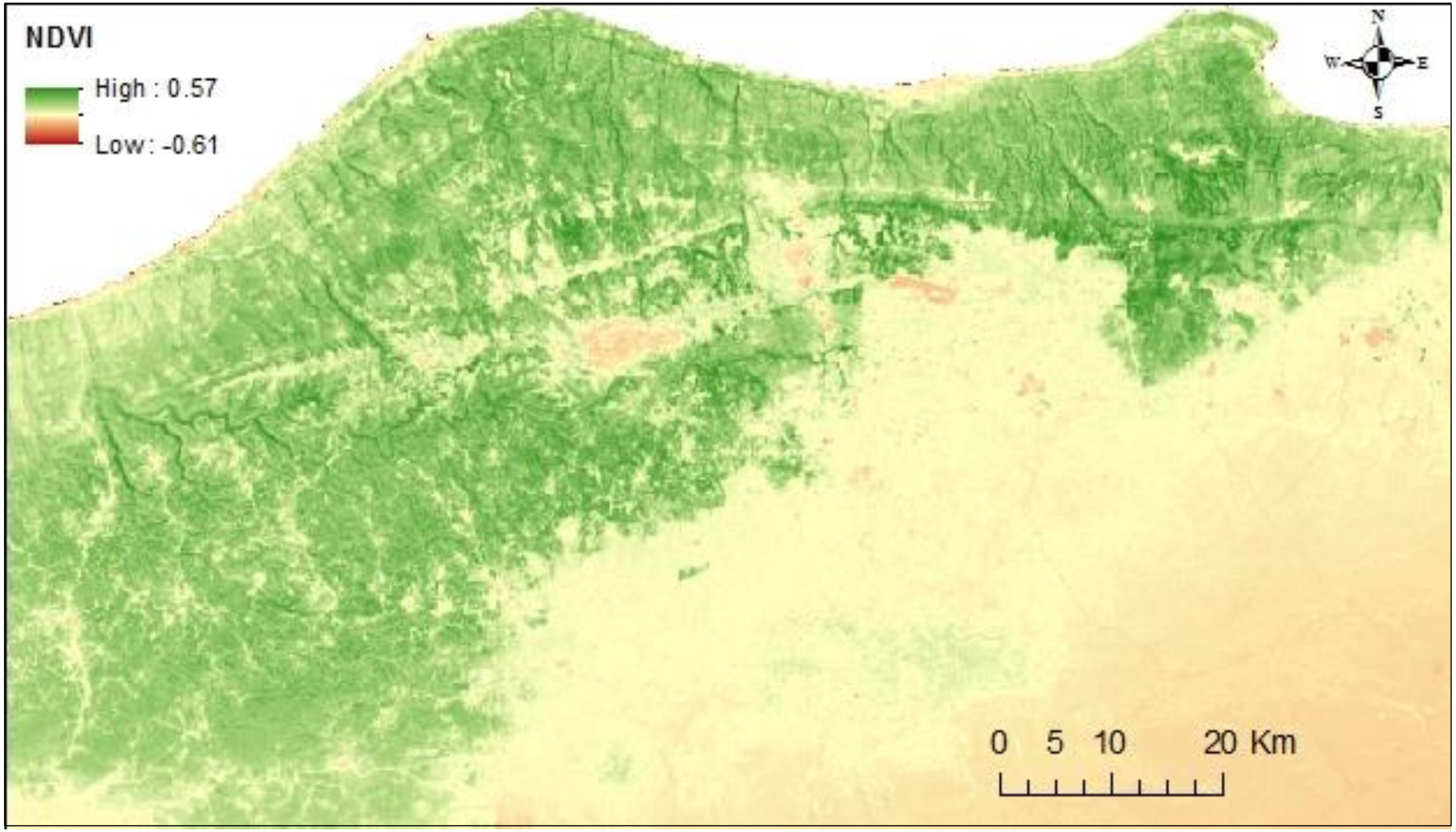


Figure 6.1: NDVI image generated from Landsat TM image, September 1987.

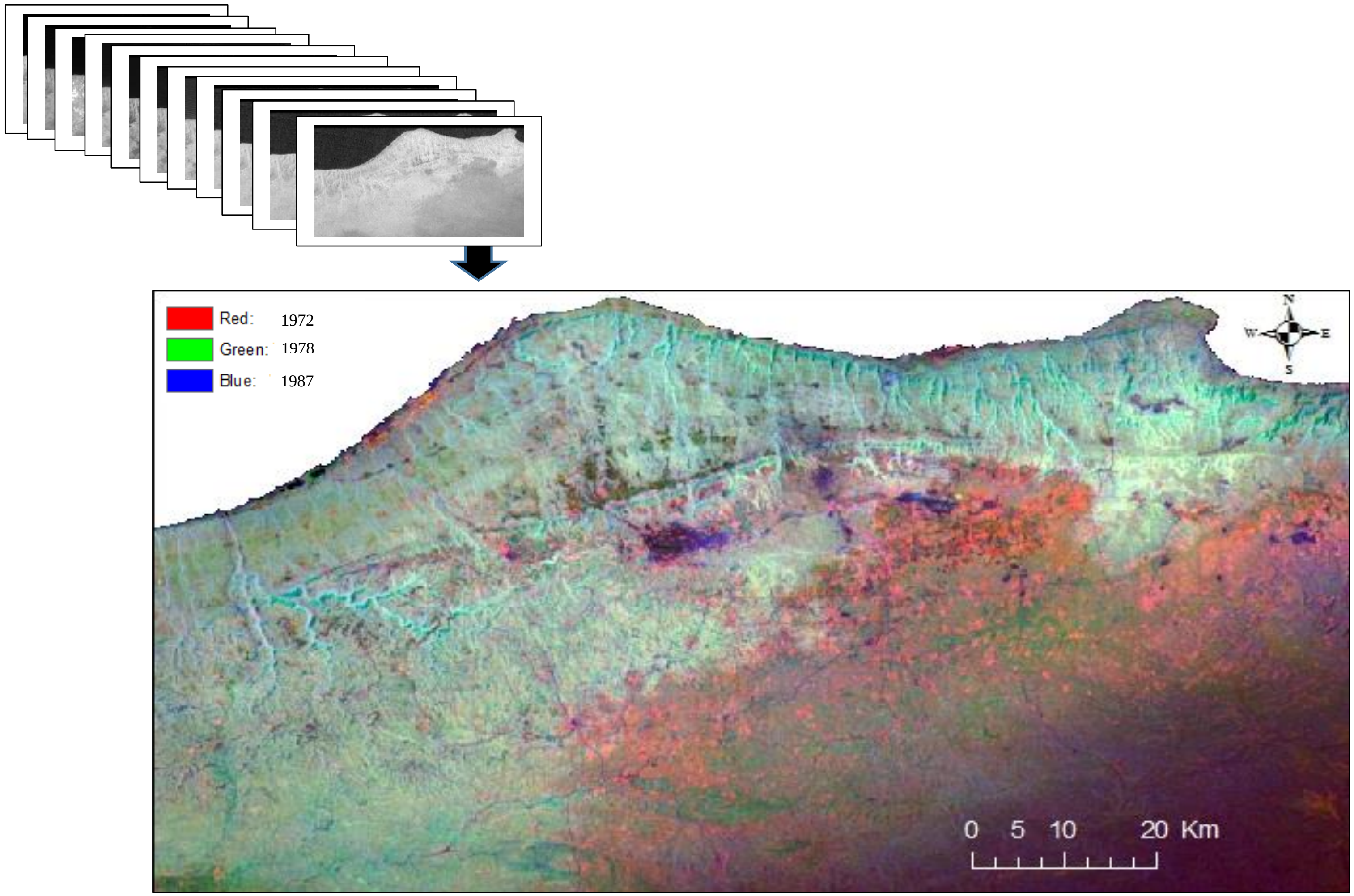


Figure 6.2: Generation of NDVI time-series image

image for NDVI (y) against the time period (i.e. year) (x) for each pixel in the image. In ERDAS Imagine the regression and correlation coefficient are applied to two images, therefore, the research used the same components of the regression slope equation (∑x, ∑y, ∑xy and ∑y2) to apply to 11 images.

Step 1: Find the following data from the time series of NDVI images: Σx, Σy, Σxy, Σx^2, Σy^2. X represents the years of the images (1972, 1978, 1986, 1987, 1999, 2001, 2003, 2006, 2010, 2013 and 2014) and X is the difference between the years (1972 represents 0). Follow these steps to create a table (Table 6.1) and find Σ x and Σx^2.

Table 6.1: Σ x and Σx^2.

Images	x	x^2
1972	0	0
1978	6	36
1986	14	196
1987	15	225
1999	27	729
2001	29	841
2003	31	961
2006	34	1156
2010	38	1444
2013	41	1681
2014	42	1764
∑	277	9033

Step 2: The research calculated ∑y using Model Maker in ERDAS Imagine and generated the image of ∑y, where y was the NDVI value in each pixel in the images (layers), and ∑y is (layer 1+ layer 2 + layer 3 + layer 4....+layer n). $\sum y^2$ is ∑ ((layer 1* layer 1)+(layer 2* layer 2)+(layer 3* layer 3)+….(layer n* layer n)).

Step 3: Insert the data into Model Maker and calculate the slope for each pixel in the time series of the NDVI image (there is no need to find a); b is the slope of the line and a is the y –intercept (Chatterjee & Hadi, 2015) (see appendix 1) (Figure 6.3). The regression slope is given as equation 6.1:

$$b = (n \sum xy)-(\sum x) (\sum y) / (n\sum x^2-(\sum x)^2). \qquad [6.1]$$

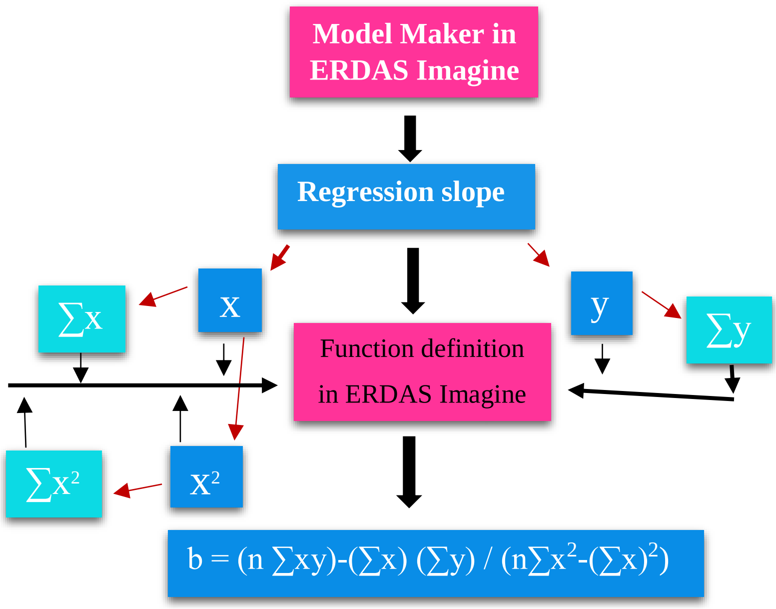


Figure 6.3: The steps of the regression slope computation

Each pixel has a regression slope value and presents the trend of NDVI over the period for every pixel. The research generated the NDVI slope image using the previous equation on the NDVI time-series image in ERDAS Imagine. If the value of the slope is positive it means there is an increase in the NDVI trend and a negative value signifies a decrease in NDVI over the 42-year period. The output image of the regression slope NDVI analysis indicated the trend of VI in each pixel over the 42 years. The values of the regression slope ranged from -0.004 to 0.001. Pixels with a negative value (-) experienced a decrease in VI, while in contrast the pixels with positive values (+) experienced an increase in VI.

The histogram of the NDVI slope values (Figure 6.4) shows the distribution of the values from -0.004 to 0.003 with most pixels showing a negative slope, which means there was a trend of decreasing NDVI over the period of the study (Figure 6.5). A density sliced image of the NDVI slope image was created that divided the positive and negative classes, to represent the areas that had positive and negative VI change (Figure 6.5). Most of the study area showed a trend of decreasing NDVI.
The linear correlation coefficient (r) was also calculated for every pixel to assess the strength of the relationship between time and NDVI for each pixel.

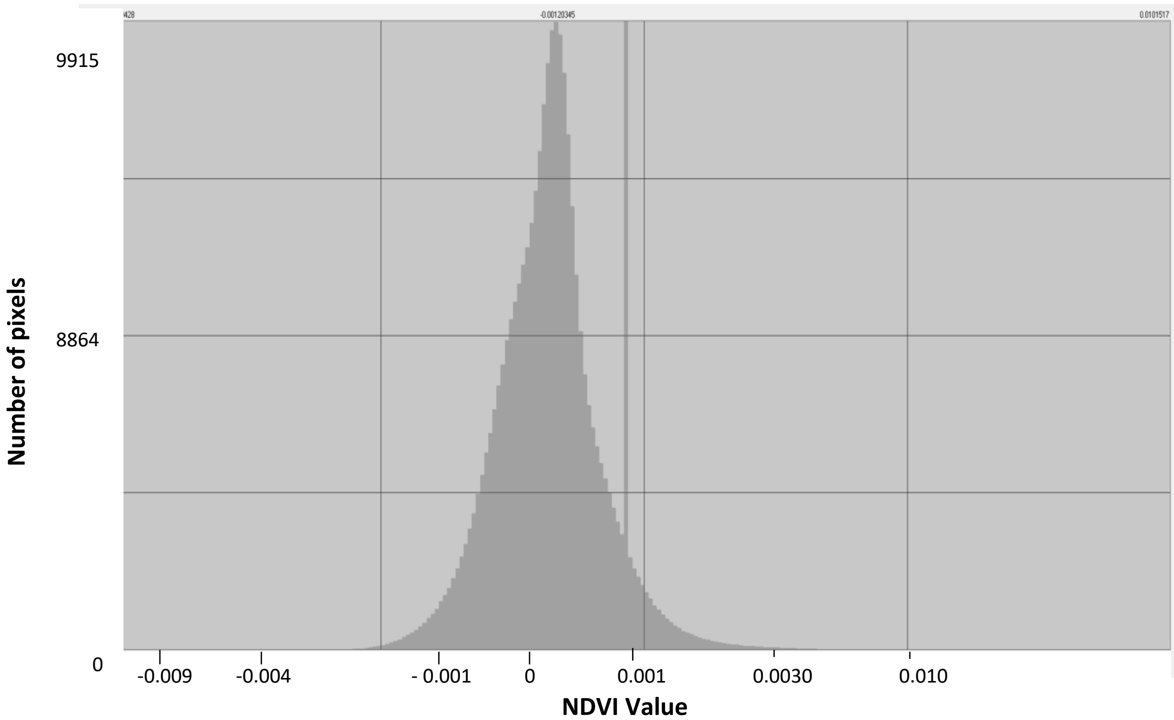


Figure 6.4: The histogram of the NDVI regression slope.

6.3.1.3 NDVI correlation coefficient images

The correlation coefficient (r) was used to investigate the strength of the linear relationship between the VI and time, to determine which pixels showed a statistically significant relationship (Sedgwick, 2012) and then determine which pixel had a statistically significant change in the VI over the time. In ERDAS Imagine the correlation coefficient was applied to 11 images, therefore, the research used the same components of the regression slope equation Σx, Σy, Σxy, Σx^2, Σy^2 to calculate the correlation equation for 11 images using Model Maker in ERDAS Imagine (Figure 6.7). The formula for the correlation coefficient equation is given in 6.2 below:

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}} \qquad [6.2]$$

where r = correlation, n = 11 (NDVI images), x = time and, y = NDVI value (Figure 6.8)

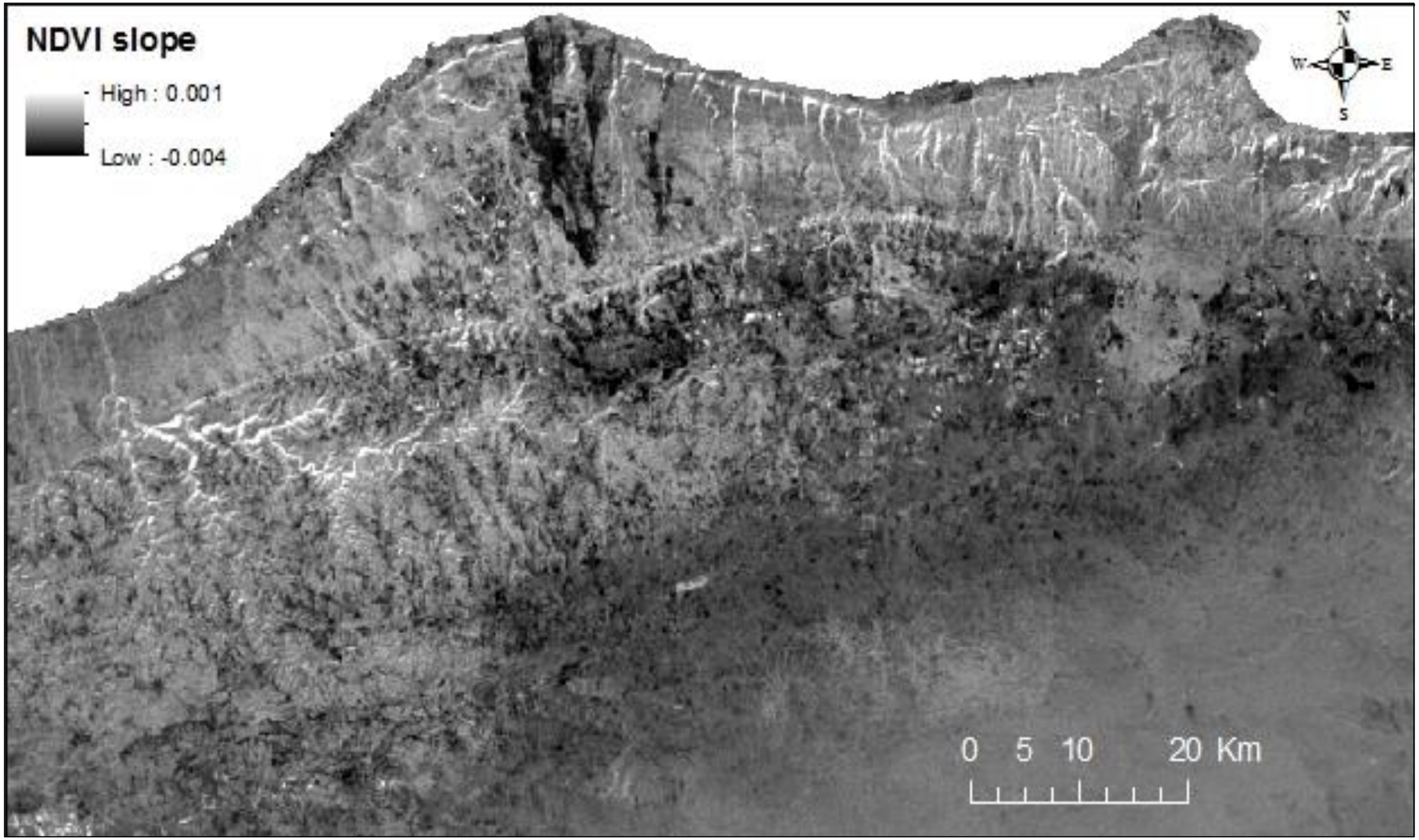


Figure 6.5: The NDVI regression slope image

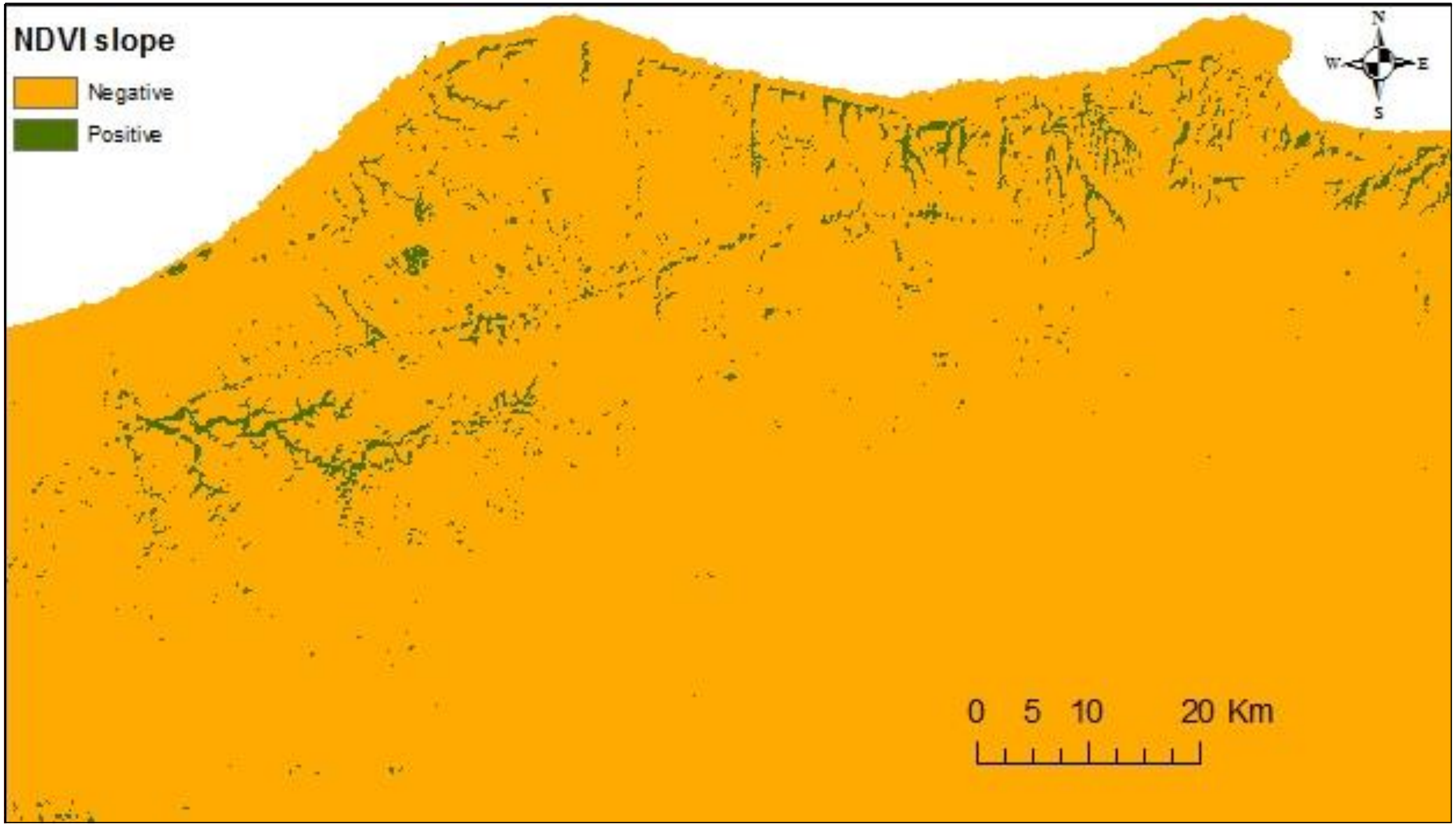


Figure 6.6: The classified NDVI regression slope image

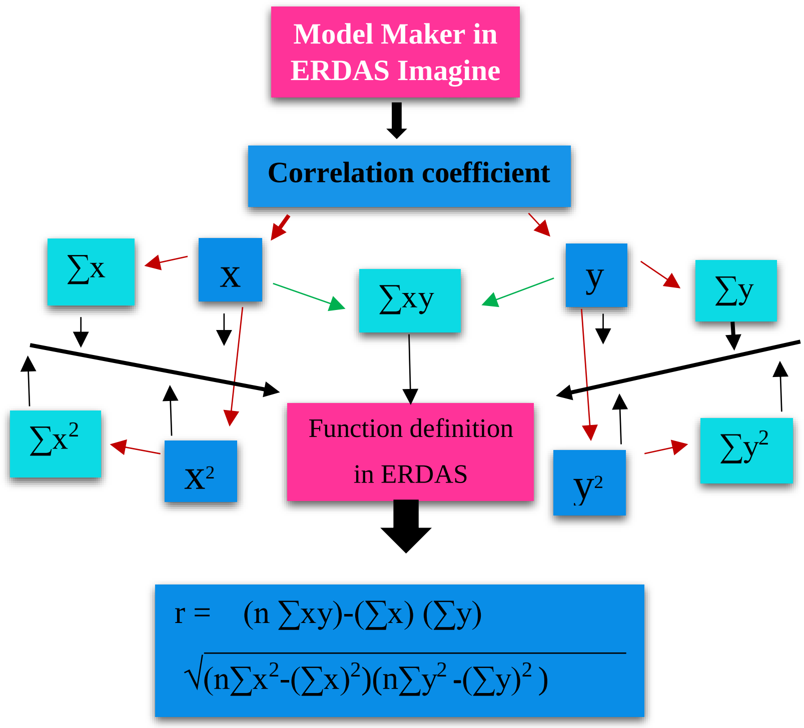


Figure 6.7: The steps of correlation coefficient computation

With a sample size of 11 and at a 95% level of confidence, the critical value for r is 0.553 (n = 11). Thus, if the value is greater than 0.553, it means there is a significant increase in VI, however, if the value is less than -0.553, it signifies a significant negative relationship. The histograms of the correlation coefficient for the NDVI time-series showed the values between 0.33 and -0.87 (Figure 6.9).

The distribution in the histogram shows that most areas in the study area showed a decrease in the NDVI. The values range between a moderate and strong negative linear relationship (-0.553 to -0.87) and indicate a significant decrease in the VI which may be interpreted as a decrease in vegetation cover. In contrast, the positive values indicated no significant linear relationship (values were between 0 and 0.38).

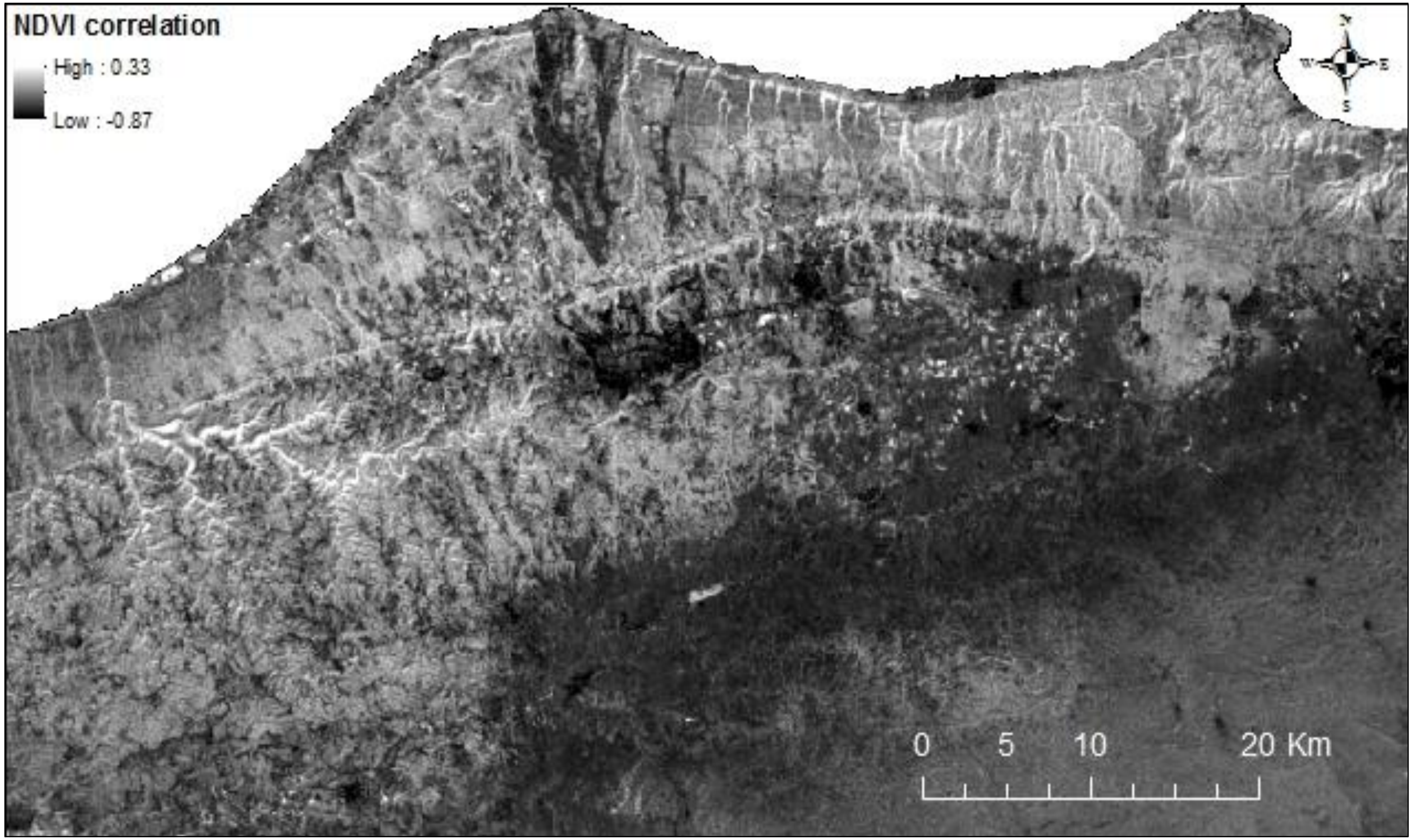


Figure 6.8: The NDVI correlation coefficient image.

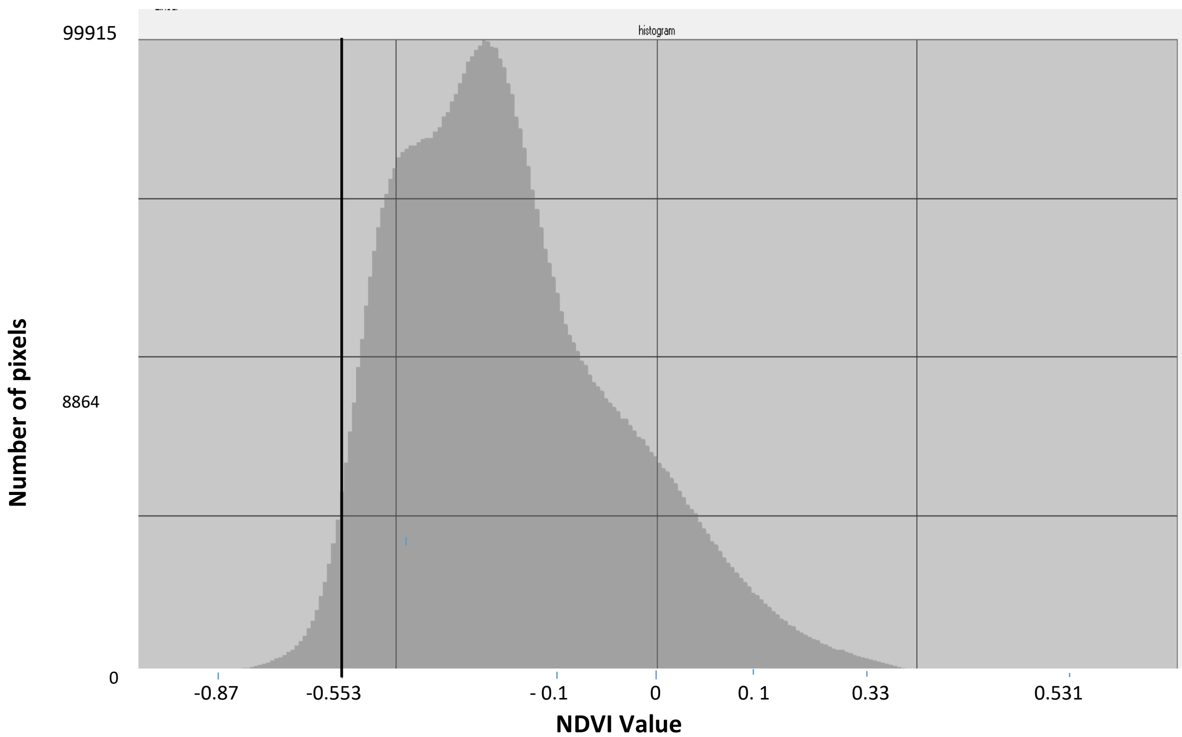


Figure 6.9: The histogram of NDVI correlation coefficients

The research used these values to classify the NDVI correlation image to show the areas that experienced statistically significant change in vegetation cover. By using 'reclassify' in the spatial analysis tools in Arc-GIS, the research chose the number (-0.555) to reclassify the image to two categories; one represents a statistically significant change and the other no significant change. (Figure 6.10).

The results are shown in figure 5.8, where the areas that have a statistically significant change in the NDVI are red in colour while the areas that have no change are coloured by grey.

6.3.2 Soil Adjusted Vegetation Index (SAVI)

The soil-adjusted vegetation index was developed as a modification of the Normalized Difference Vegetation Index (Gilabert et al., 2002), was used to minimize the influence of soil brightness when vegetative cover is low (Huete, 1988). It was deemed suitable for the study area because the vegetation cover in the study area differs in its density from one place to another. The research generated the SAVI images from Landsat images using ERDAS Imagine software (see an example in Figure 6.11).

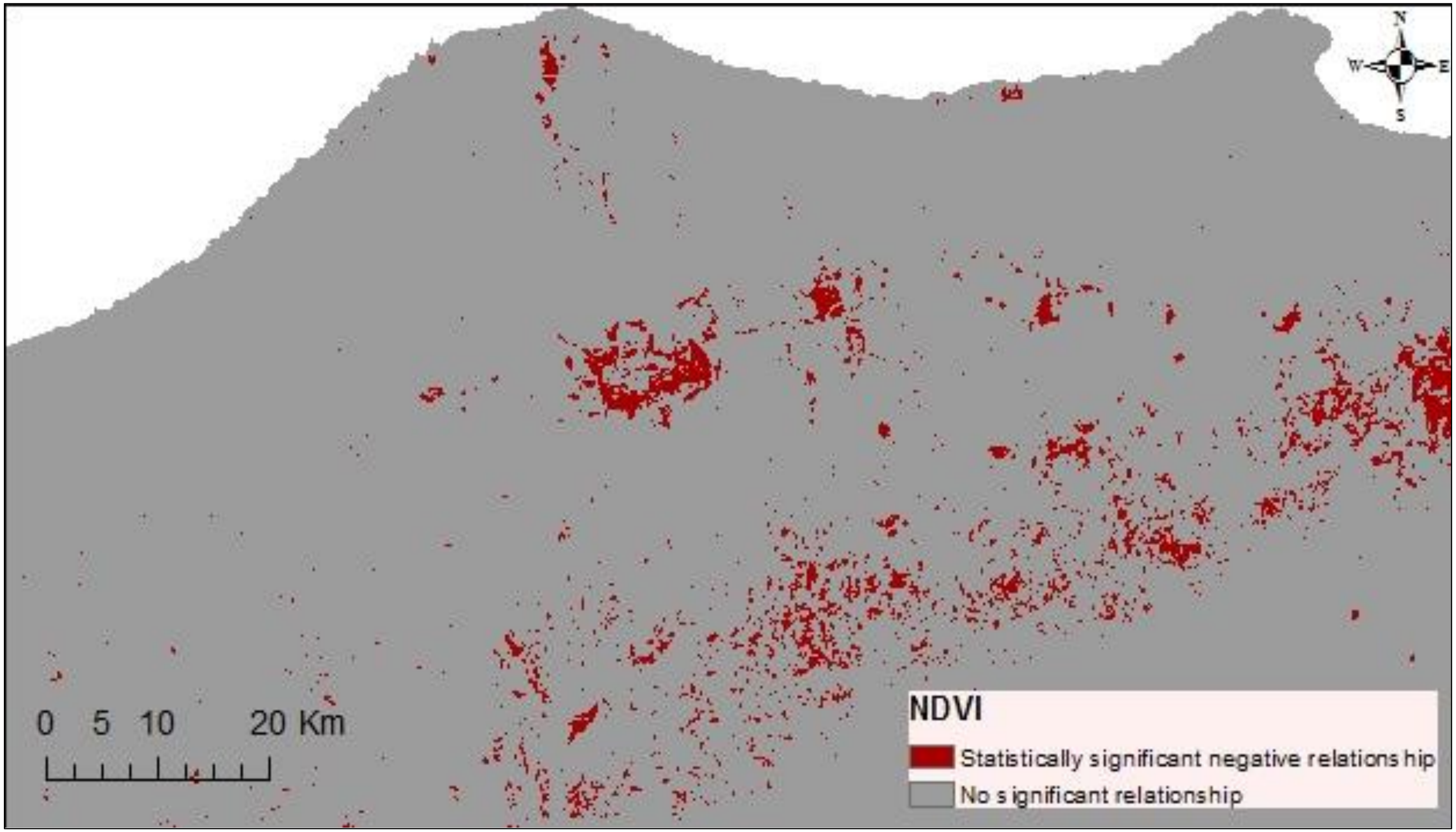


Figure 6.10: The classified NDVI correlation coefficient image.

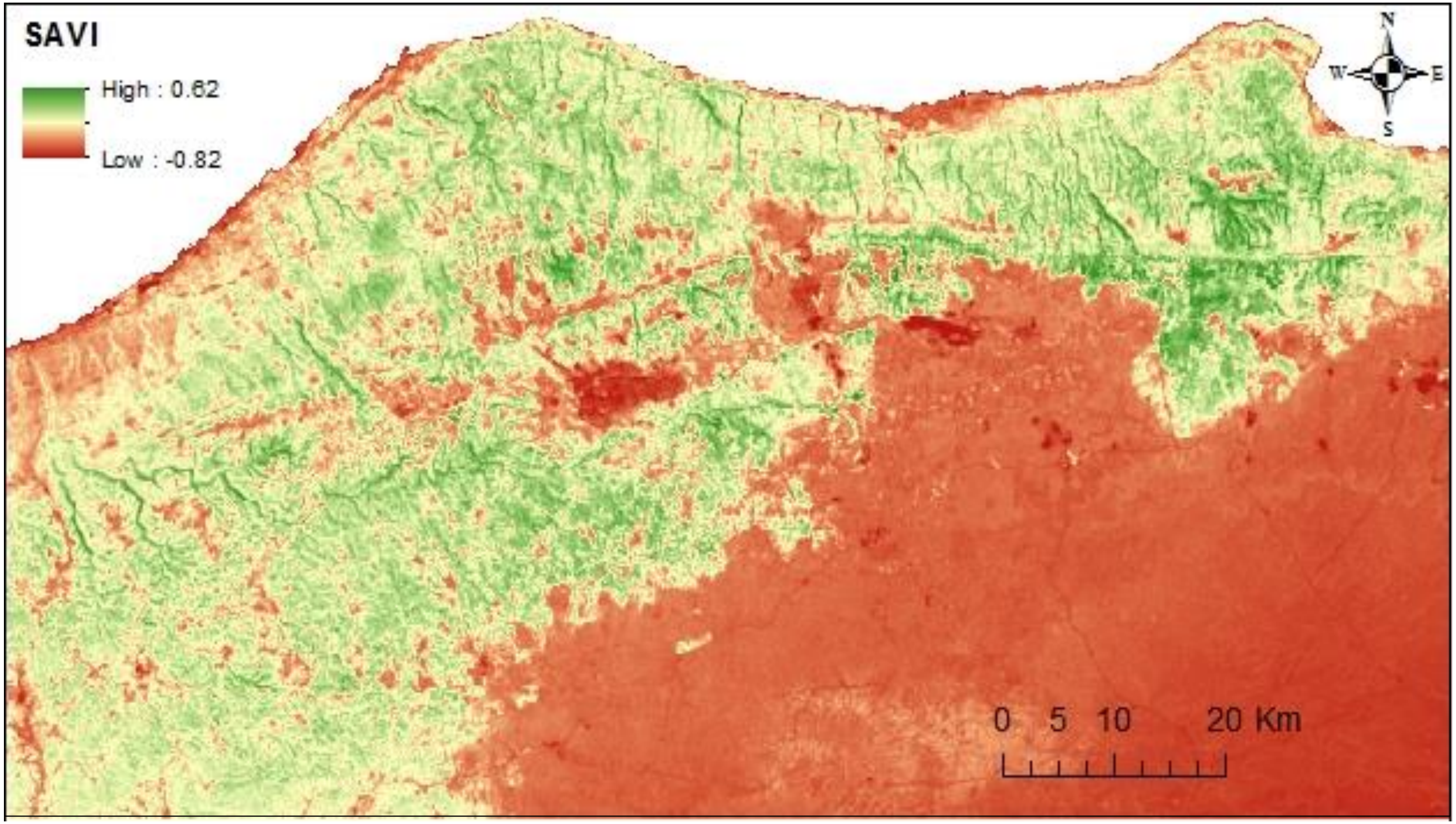


Figure 6.11: The SAVI image generated from Landsat TM image, September 1987.

6.3.2.1 Linear regression of SAVI values per pixel

Soil background exerts considerable influence over partial canopy spectra and the calculation of the vegetation index values, which was noted by way of the slight difference between SAVI and NDVI values. Soil brightness variations are due to factors such as moisture differences, roughness variations, shadow or organic matter differences (Huete, 1988), and this can impact on vegetation index values in the study area. The value in SAVI was slightly higher than the value of the NDVI, because of a reduction in the soil influences from vegetation reflectance. However, the SAVI was similar to the NDVI in the areas that have experienced change over the 42 years. The research generated the SAVI time-series image to determine the trends in SAVI over the 42 years using linear regression slope and correlation coefficient for the SAVI using the previous equations (Figure 6.12). In Figure 6.12, the time-series shows bands 1, 2 and 3 in combination, which represented all the years with 1972 represented by the blue band, 1978 represented by green and 1987 by the red band.

To assess the trend of the vegetation in the study, the research used the linear regression equation generated from the SAVI time-series images to determine the statistical trend in each pixel and identify the variation in the VI over space and time (Figure 6.13).

The SAVI slope image derived from the time-series of SAVI images shows the changing vegetation cover in the region and indicates similar spatial patterns of change in the NDVI slope image. The areas with positive or negative values were similar to those for the NDVI with the study area dominated by the decreasing VI.

The histogram shows the variation in the SAVI and the distribution of regression slope values in the study area (Figure 6.14). The frequency of the negative values of the SAVI increased and the frequency of the positive values decreased in relation to the NDVI.

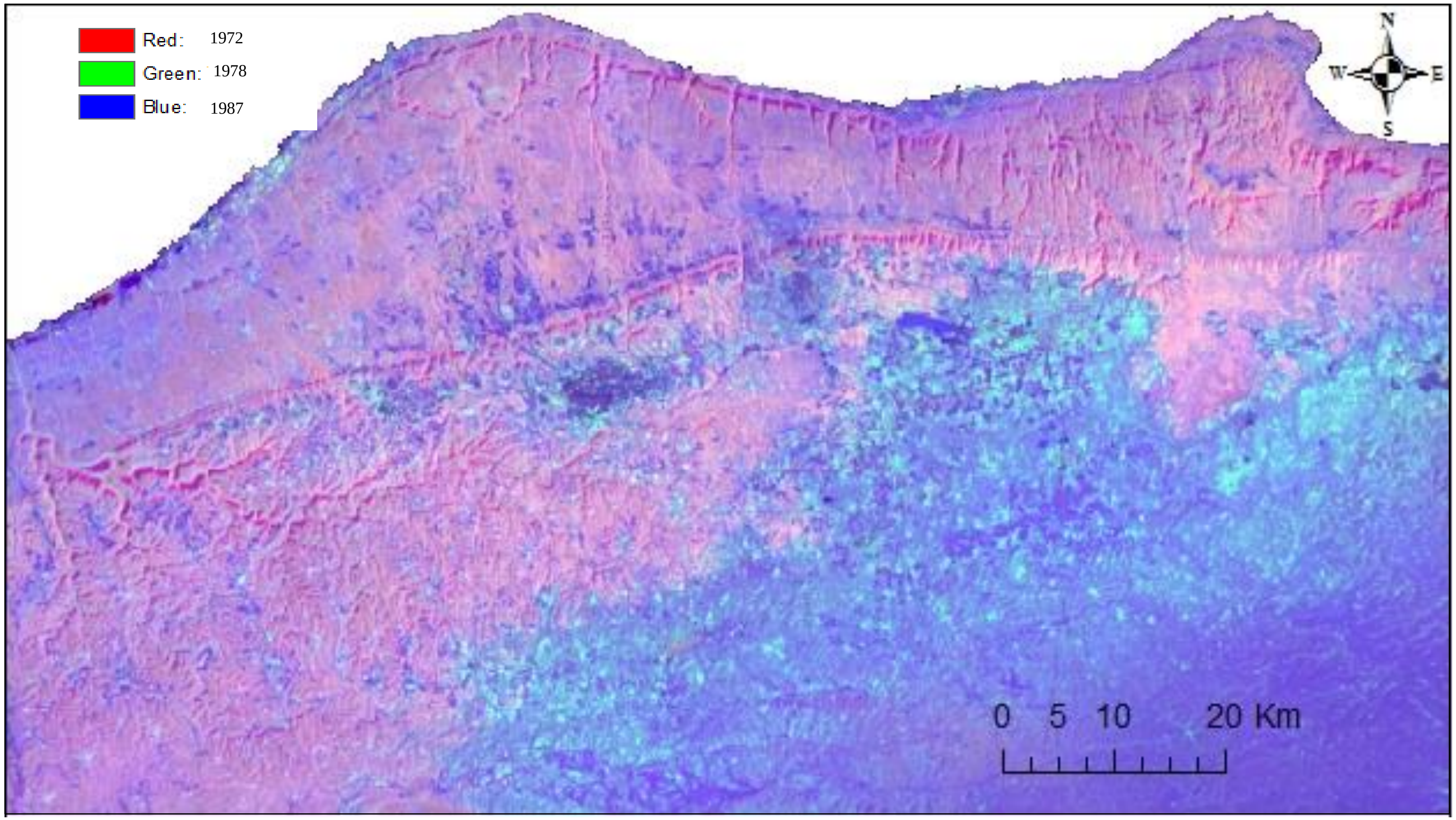


Figure 6.12: Generation of SAVI time-series image

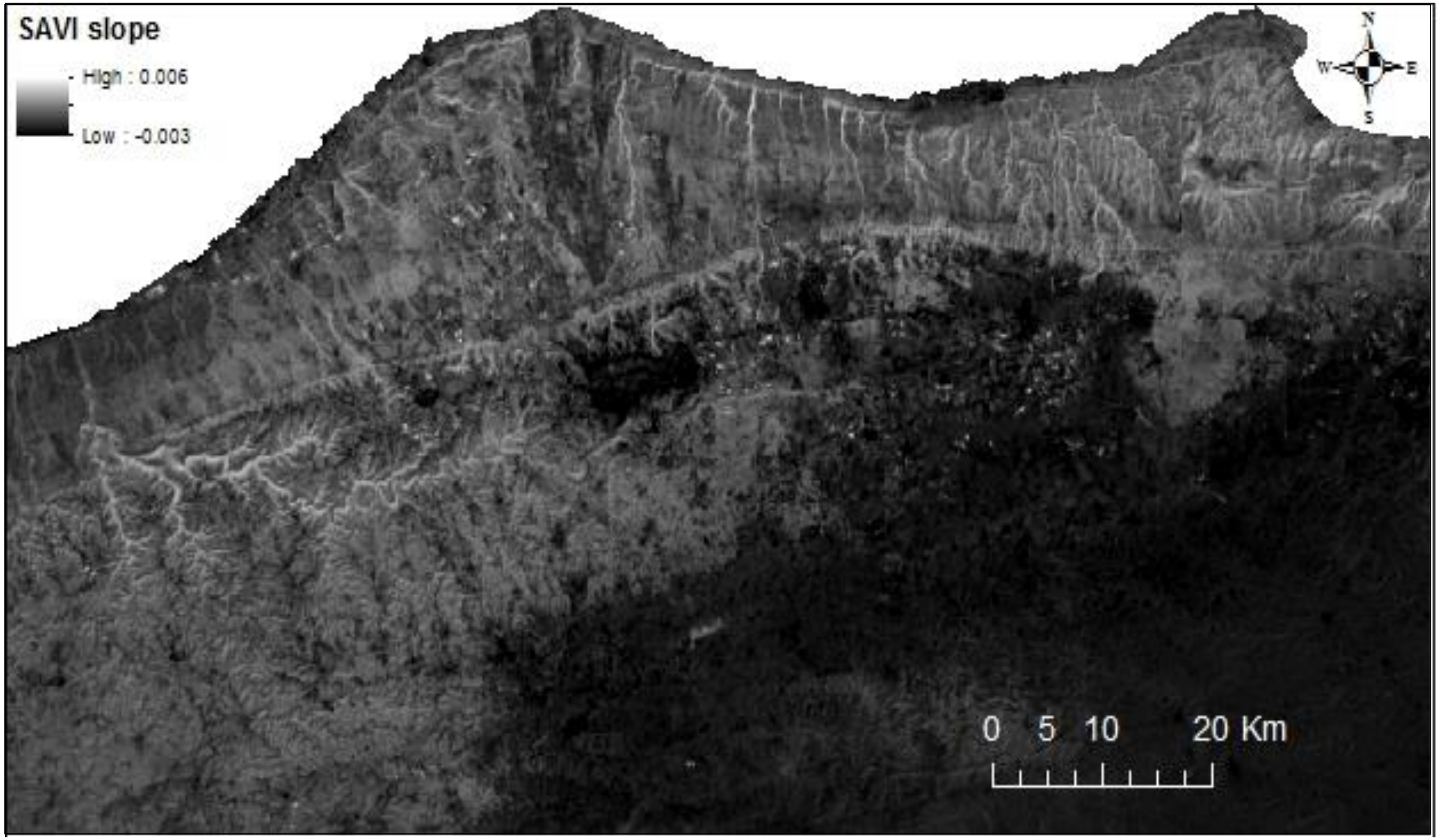


Figure 6.13: The SAVI regression slope image

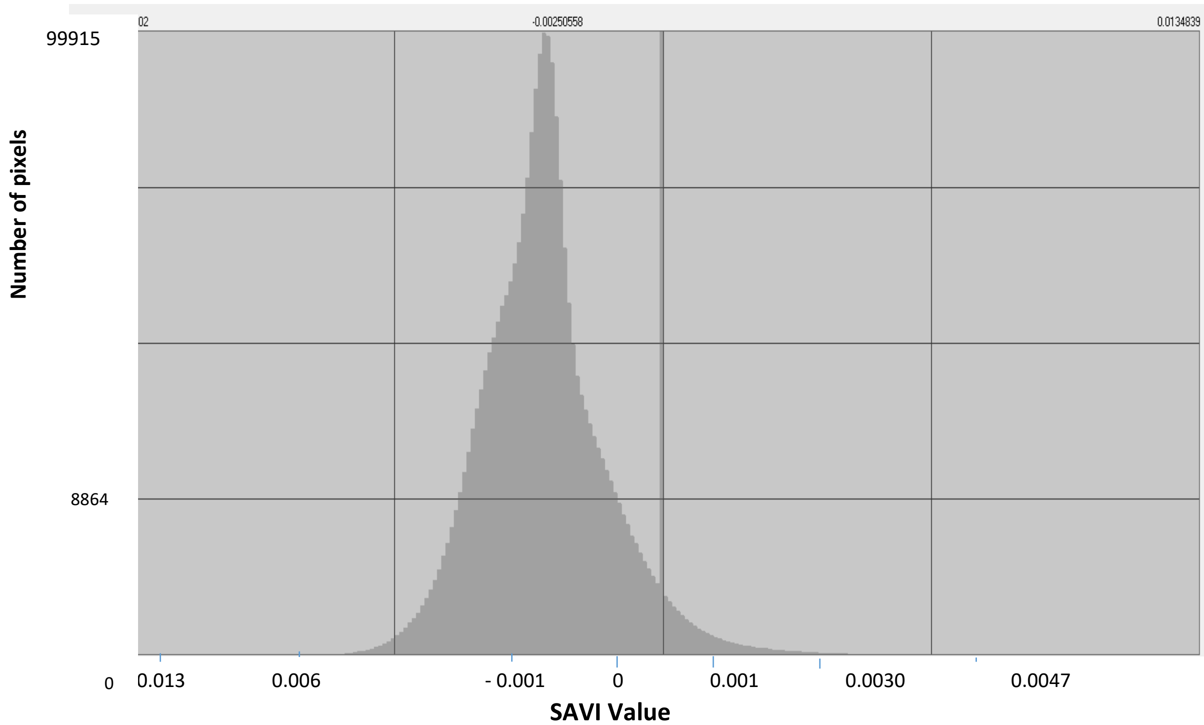


Figure 6.14: The histogram of the SAVI regression slope.

The density sliced image shows the areas that have negative (which indicates a decrease in vegetation cover) and positive slopes (Figure 6.15).

6.3.2.2 The SAVI correlation coefficient image and the histogram

The research calculated the correlation coefficient (r) for the SAVI time-series image using the correlation coefficient equation to assess which pixels showed a statistically significant change in the study area over the 42 years.

With the sample size of 11, the critical value for r = 0.553 (n = 11) at a 95% level of confidence. If the value of SAVI is greater than 0.553 it means there is a significant increase in VI, however if the value is less than -0.553 it indicates a significant decrease.

The histograms of the correlation coefficient SAVI showed the values of the SAVI in the study area and the varied values between 0.51 and -0.87(Figure 6.16).

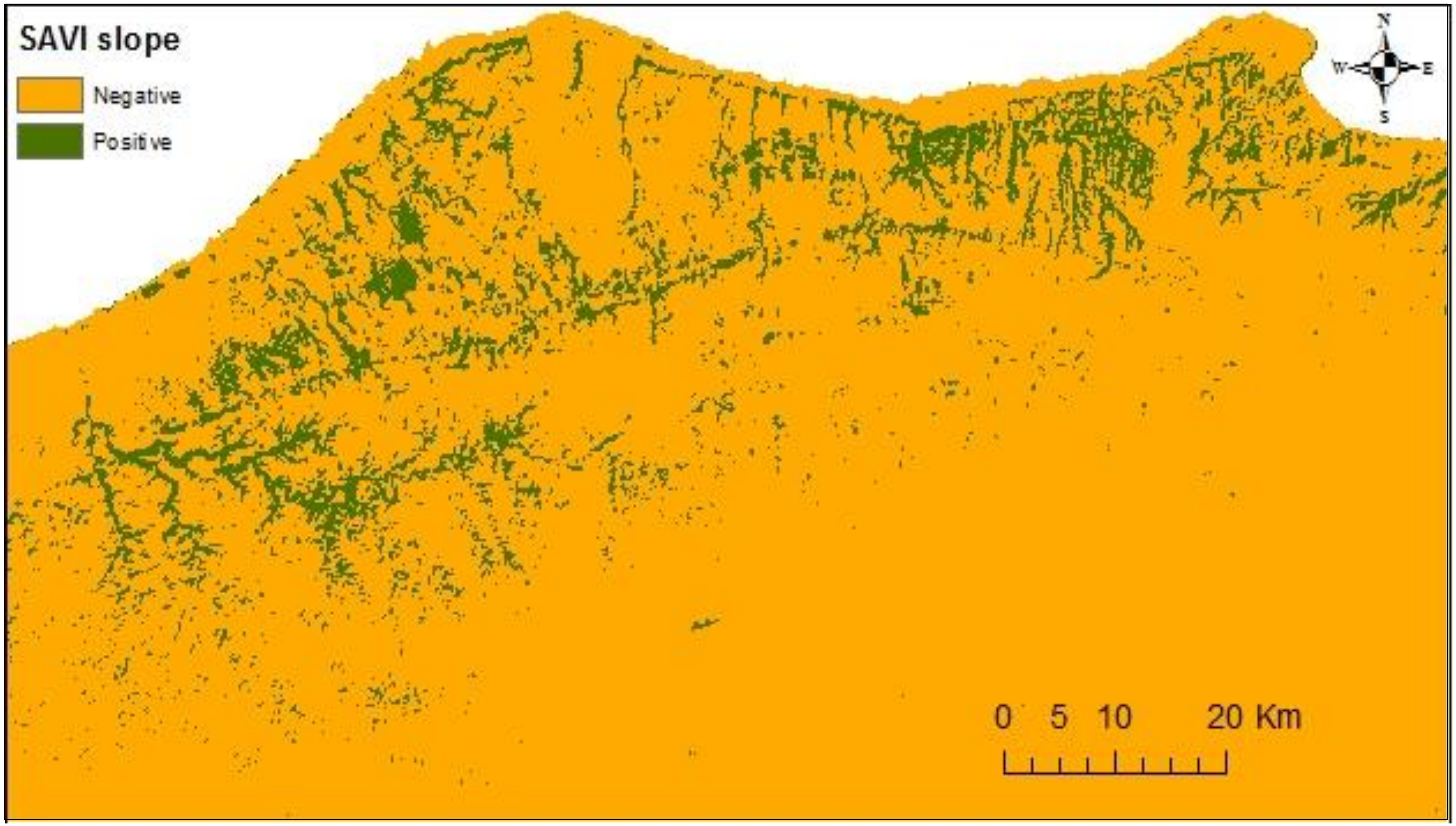


Figure 6.15: The classified SAVI regression slope image

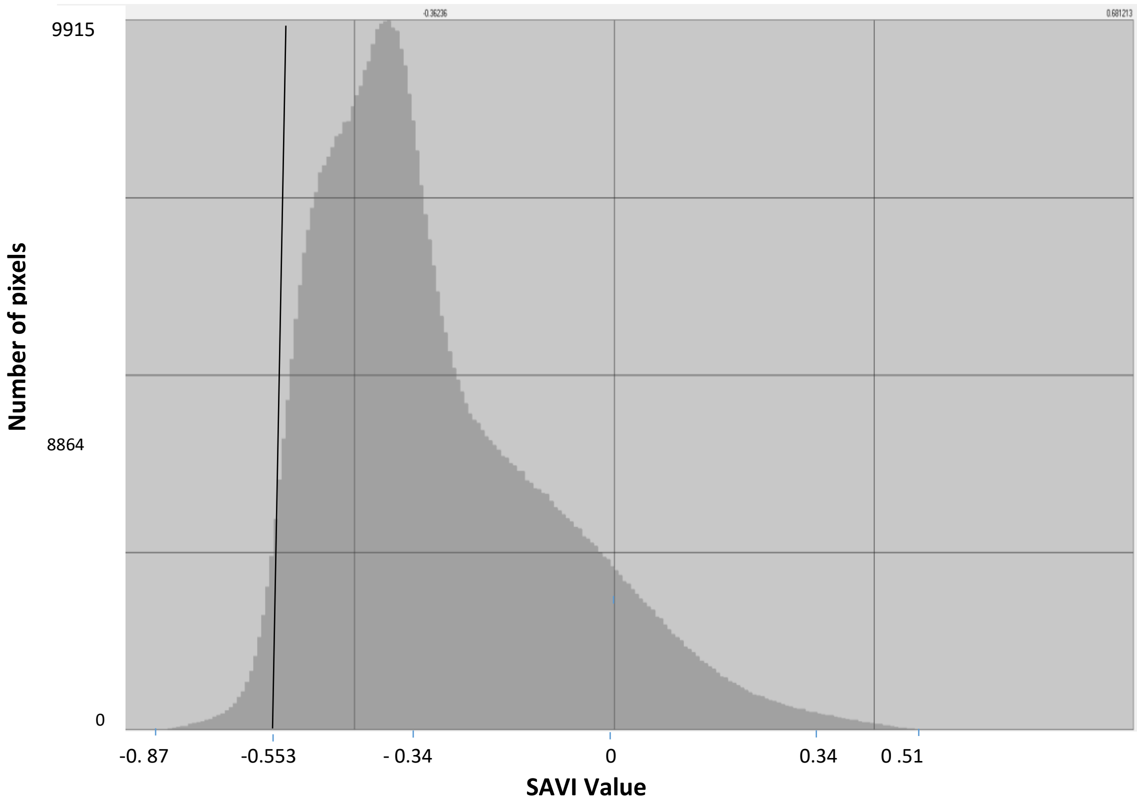


Figure 6.16: The histogram of SAVI correlation coefficient

The values ranged between a moderate and a strong negative linear relationship (-0.553 to -0.87) and indicated a significant decrease in the VI, which may again be interpreted as a decrease in vegetation cover (Figure 6.17).

In contrast, the positive values indicate a non-significant linear relationship in VI (values were between 0 and 0.51), which may mean there were no statistically significant changes in VI in those areas. The histogram shows the distribution of SAVI correlation coefficient values in the study area. The frequency of negative and positive values of the VI increased in relation to the NDVI. The areas with positive or negative values were similar to those for the NDVI, however, the areas dominated by decreasing VI in SAVI were more prevalent than the areas that saw a decrease in the NDVI. The research used these

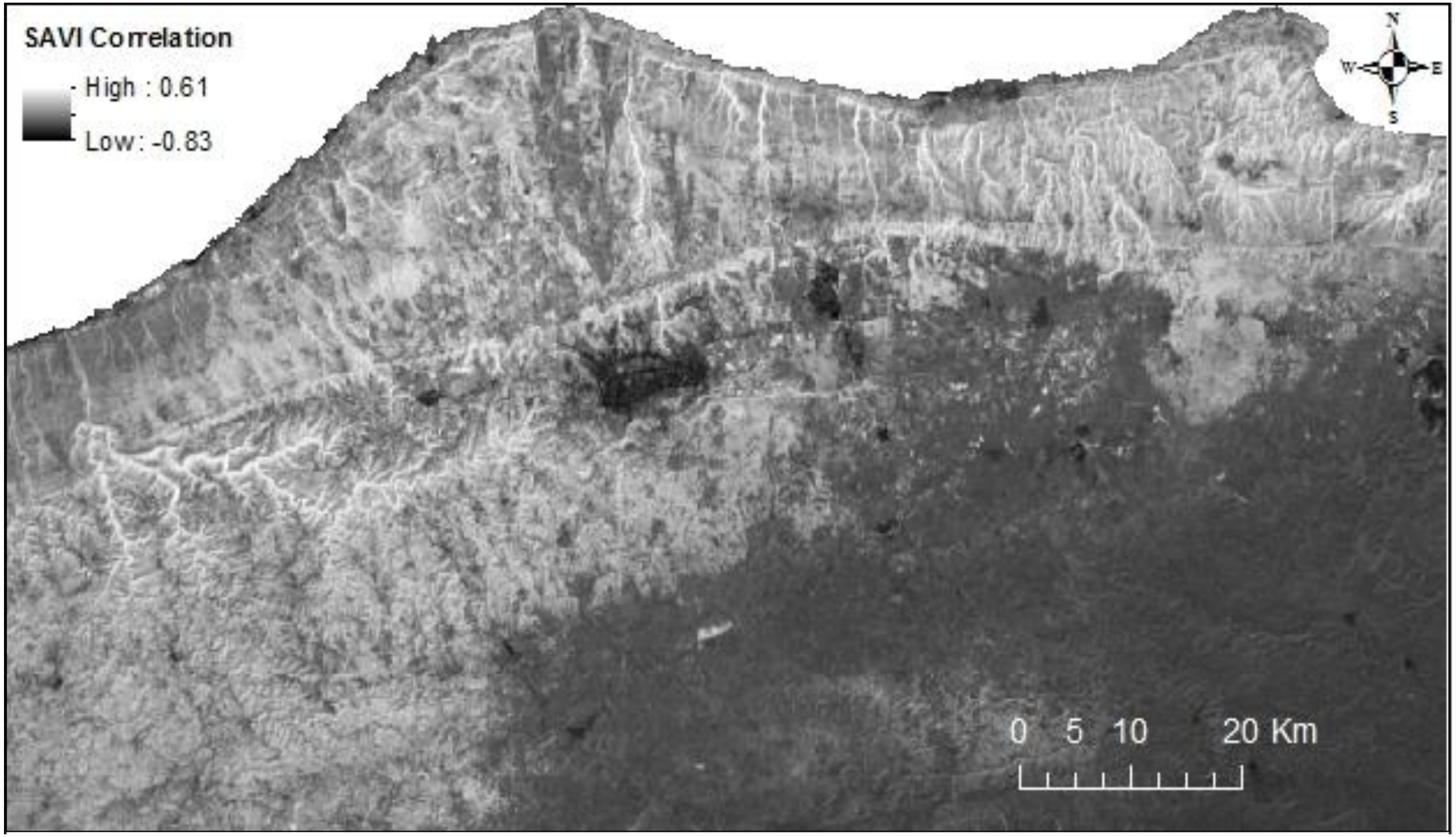


Figure 6.17: The SAVI correlation coefficient image

values to classify the SAVI correlation image to show the areas that experienced significant change in vegetation cover (see Figure 6.18). The results are shown in figure 6.16 where the areas that have statistically significant change in SAVI are red in colour while the areas that have no change are grey in colour.

6.3.3 Enhanced Vegetation Index (EVI)

The Enhanced Vegetation Index (EVI) was proposed by the MODIS Land Discipline Group. It is widely used for monitoring vegetation cover, biophysical derivation of radiometry and structure of vegetation canopies (Matsushita et al., 2007). EVI is used to improve vegetation monitoring through a coupling of the canopy background and minimizing soil and atmospheric influences (Jiang et al., 2008). In this research only seven of the eleven images were used because the Landsat MSS does not have a blue wavelength, so the research used the images of TM, ETM and OLI and generated the EVI images for 1987, 1999, 2001, 2003, 2010, 2013 and 2014 (see Figure 6.19). The research generated the EVI time-series image over a 27 year period (see Figure 6.20). The image shows combinations of bands 1, 2 and 3, which represent three years, namely, 1987 (blue band), 1999 (green band) and 2003 (red band).

6.3.3.1 Linear regression of EVI values per pixel

To assess the trend of the VI in each pixel over the 27 years, the research applied a regression equation to the EVI time-series image using ERDAS Imagine to generate a regression slope image for EVI against time for each pixel in the image (see Figure 6.21). The positive slope value means there is an increase in the VI trend and the negative value indicates a decrease in the VI. The output image of the regression slope EVI analysis indicated the trends of VI over the 27 years and the values of the EVI slope ranged between -0.01 and 0.003. Pixels with negative values (-) experienced a decrease in the VI and positive values (+) had an increase in the VI. The histogram (Figure 6.22) of the EVI slope values shows the distribution of the EVI slope values between -0.002 and 0.003 and most pixels show a negative slope which means there was a decrease in the EVI trend over the period of study.

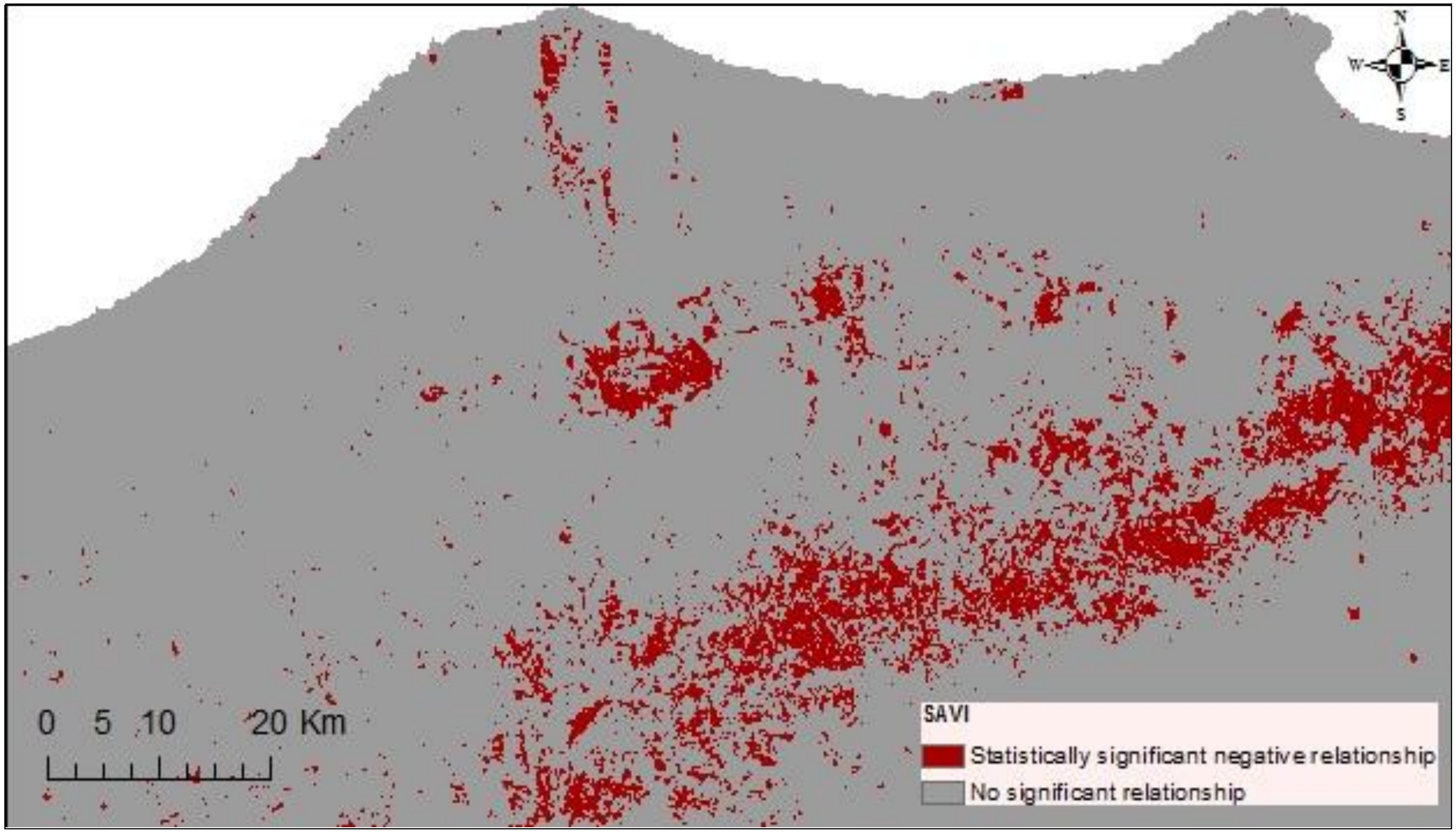


Figure 6.18: The classified SAVI correlation coefficient image.

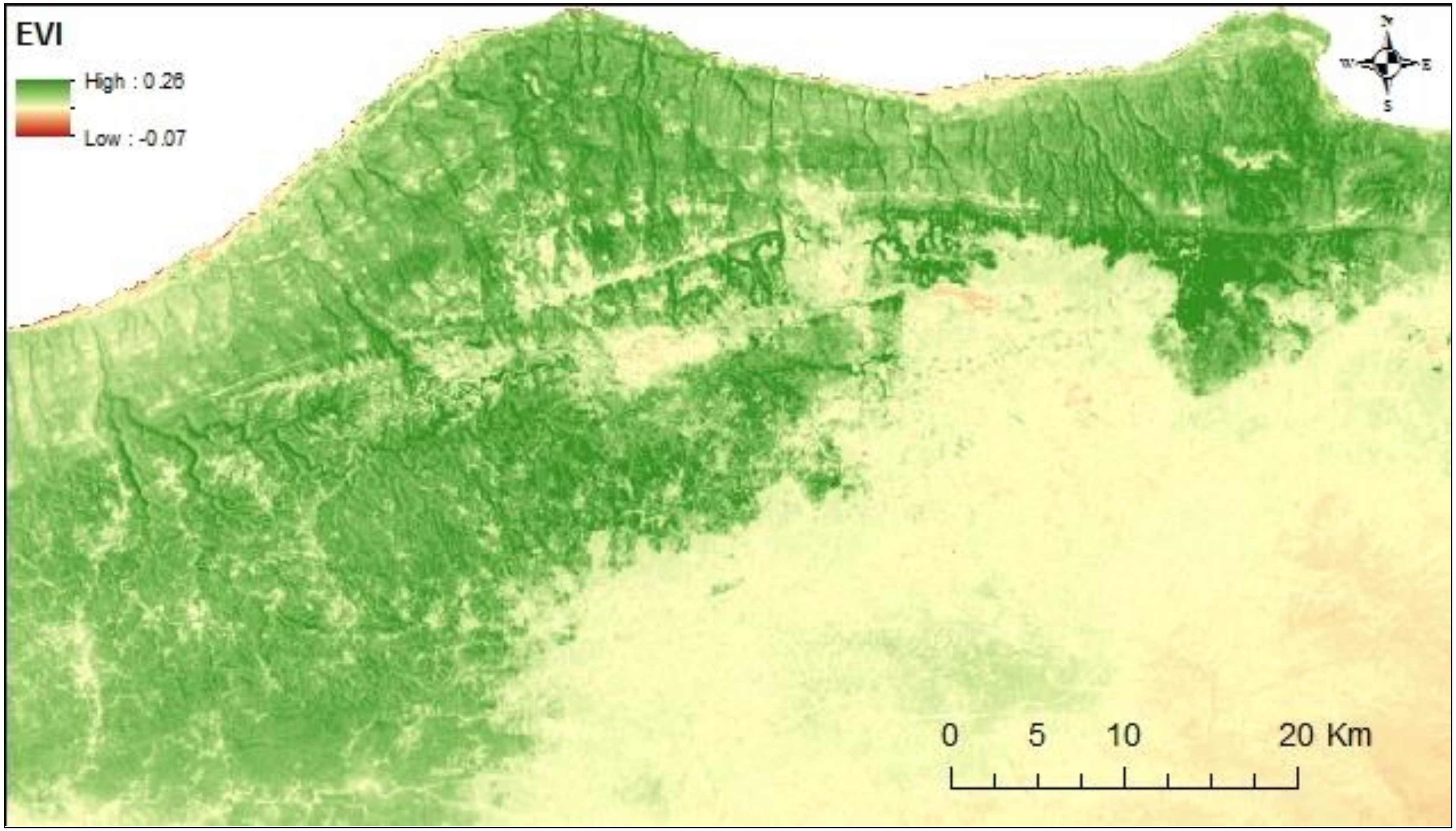


Figure 6.19: EVI image generated from Landsat TM image, September 1987.

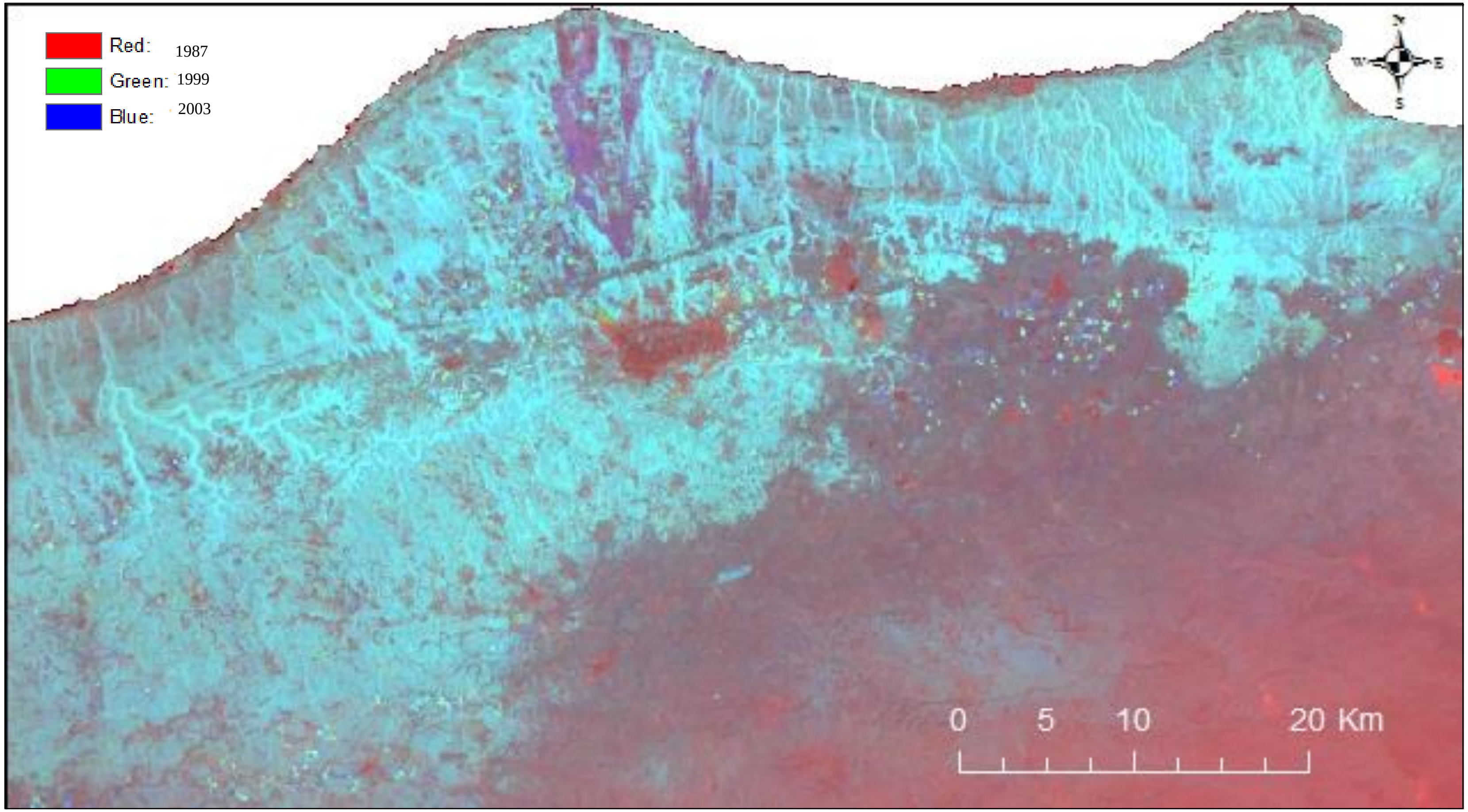


Figure 6.20: Generation of EVI time-series image.

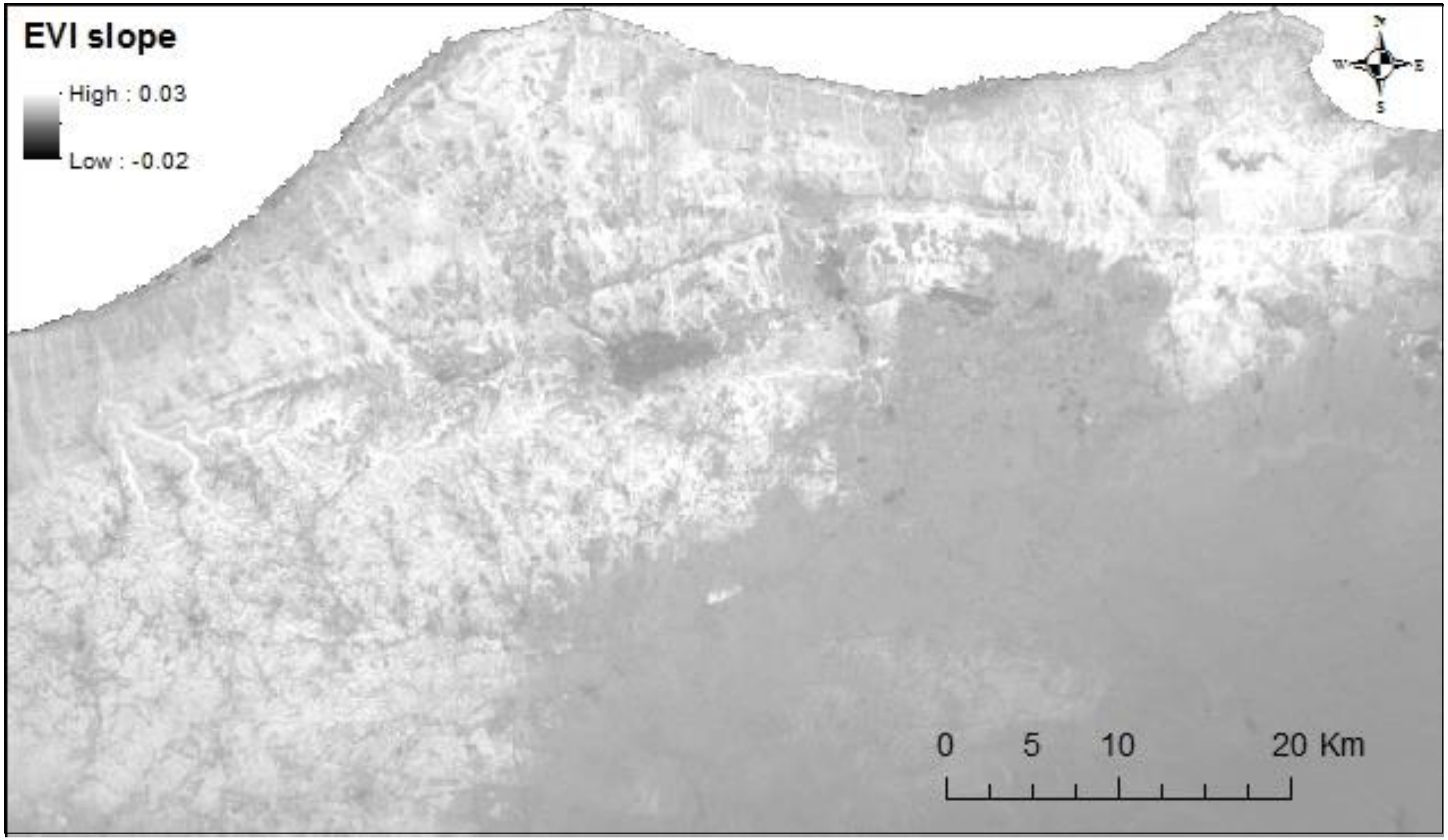


Figure 6.21: The EVI regression slope image.

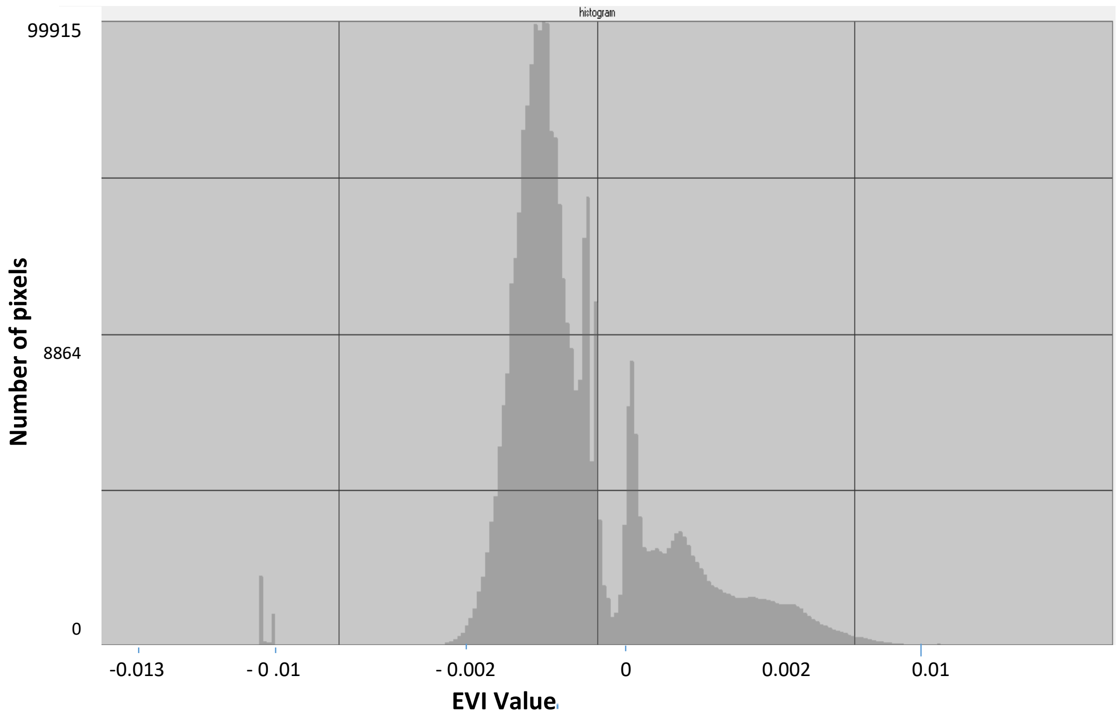


Figure 6.22: The histogram of EVI regression slope

The areas with positive or negative values were similar to those for the NDVI and SAVI, however, the areal extent for the areas that had changed in the EVI was less than that for the NDVI and SAVI, which may be due to change in vegetation cover in the first 15 years (1972- 1987) of satellite images record.

A density sliced image shows areas that have negative (indicating a decrease in vegetation cover) and positive values (indicating an increase or no change in vegetation cover) (Figure 6.23).

6.3.3.2 The EVI Correlation coefficient image

The research calculated the correlation coefficient (r) for the EVI time-series image to determine which pixels shared statistically significant changes in the study area over the 27 years. With a sample size of 7 at a 95% level of confidence, the critical value for r = 0.666. If the value of EVI is greater than 0.666 it means there is a significant increase in VI, however, if the value is less than -0.666 it indicates a significant negative relationship (see Figure 6.24).

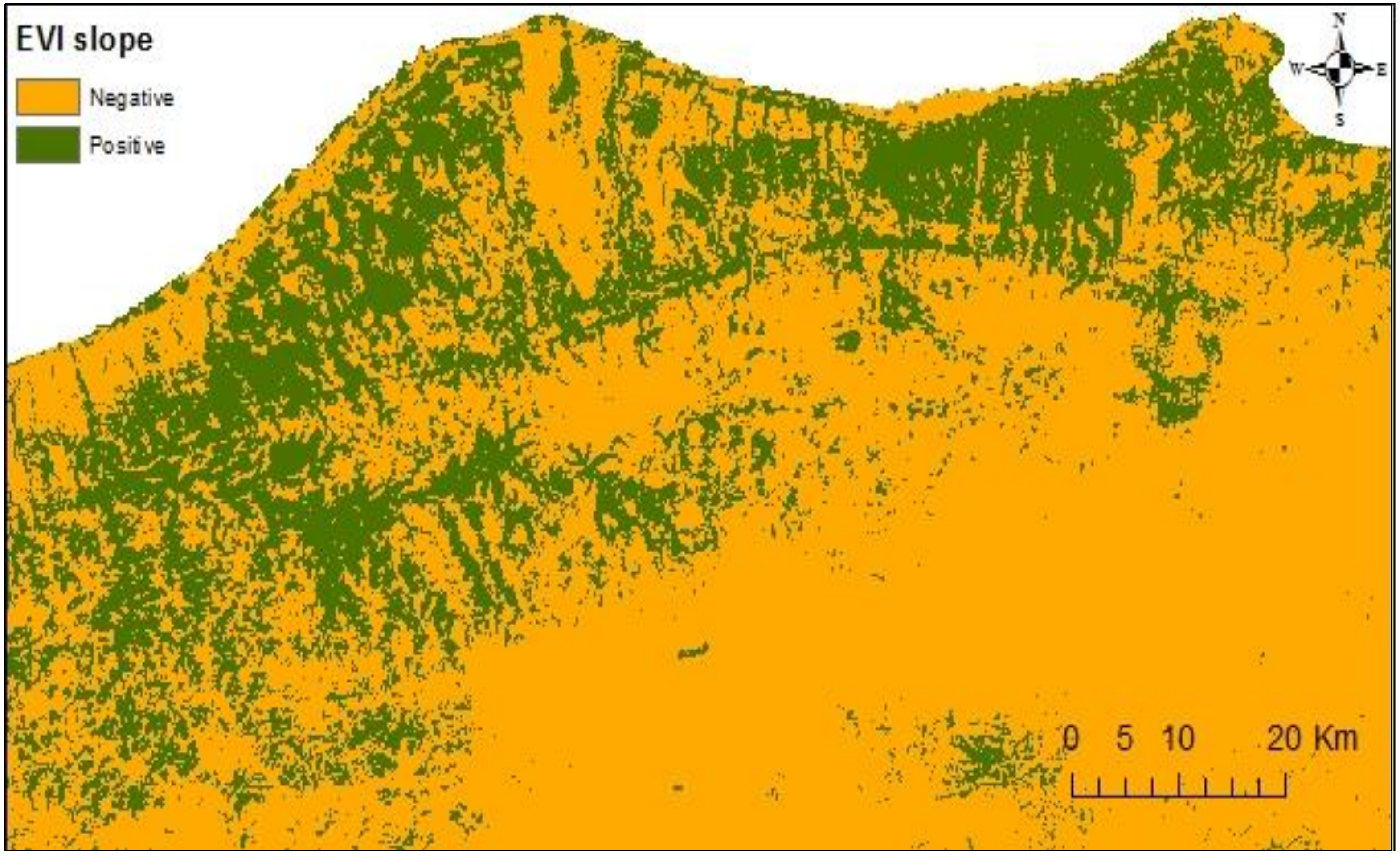


Figure 6.23: The classified EVI regression slope image.

The correlation coefficient values of EVI range between -0.87 and 0.33. The values range between a moderate and a strong negative linear relationship (-0. 666 to -0.87) and indicate a significant decrease in the VI, which may be interpreted as a decrease in vegetation cover. The positive values indicated a non-significant linear relationship in the VI (values were between 0 and 0.33), which may mean there were no detectable changes in vegetation cover in those areas (see Figure 6.25).

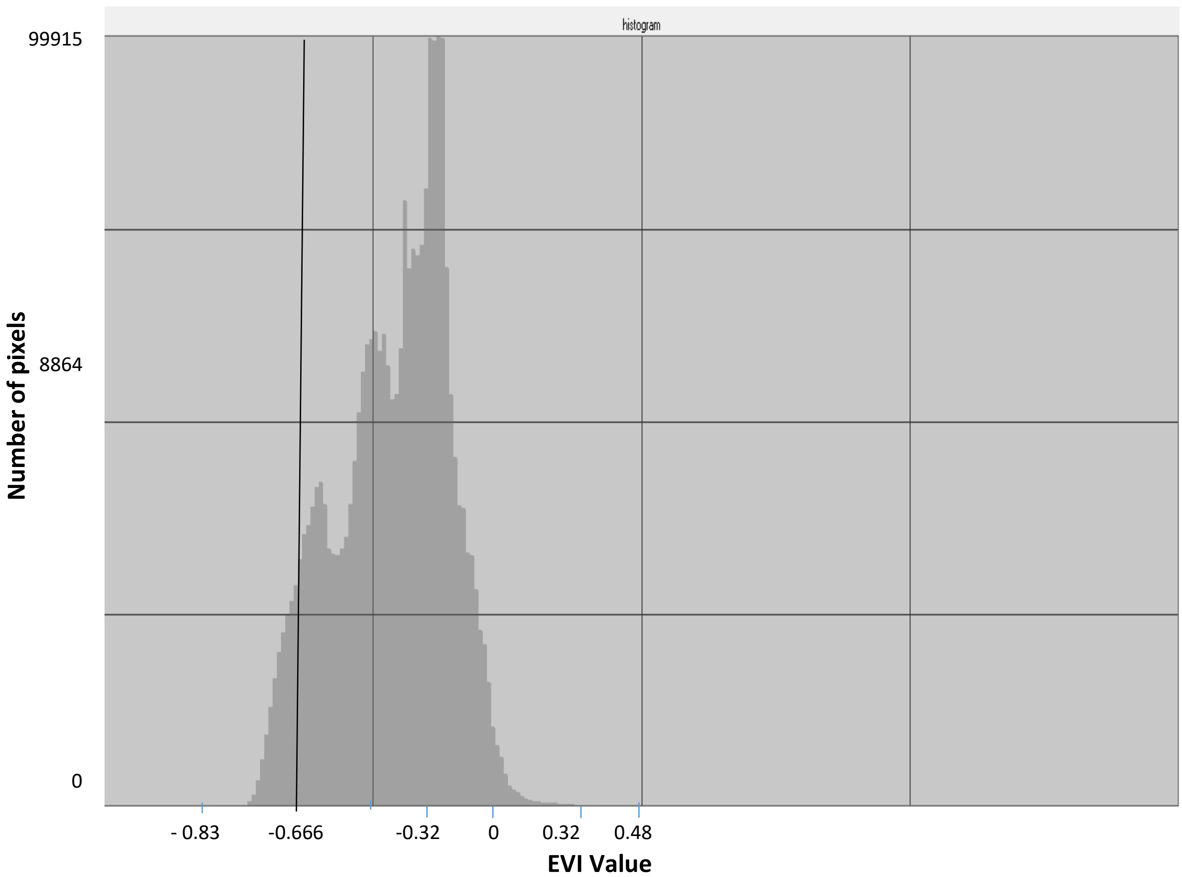


Figure 6.24: The histogram of EVI correlation coefficient

The histograms (Figure 6.24) of the EVI correlation coefficient show the distribution of values in the study area. The frequency of negative and positive values of the VI were different from those of the NDVI and SAVI, however, the areas with negative values were similar. The research used the value -0.666 to classify the EVI correlation image to show the areas that experienced statistically significant change in vegetation cover (see Figure 6.26).

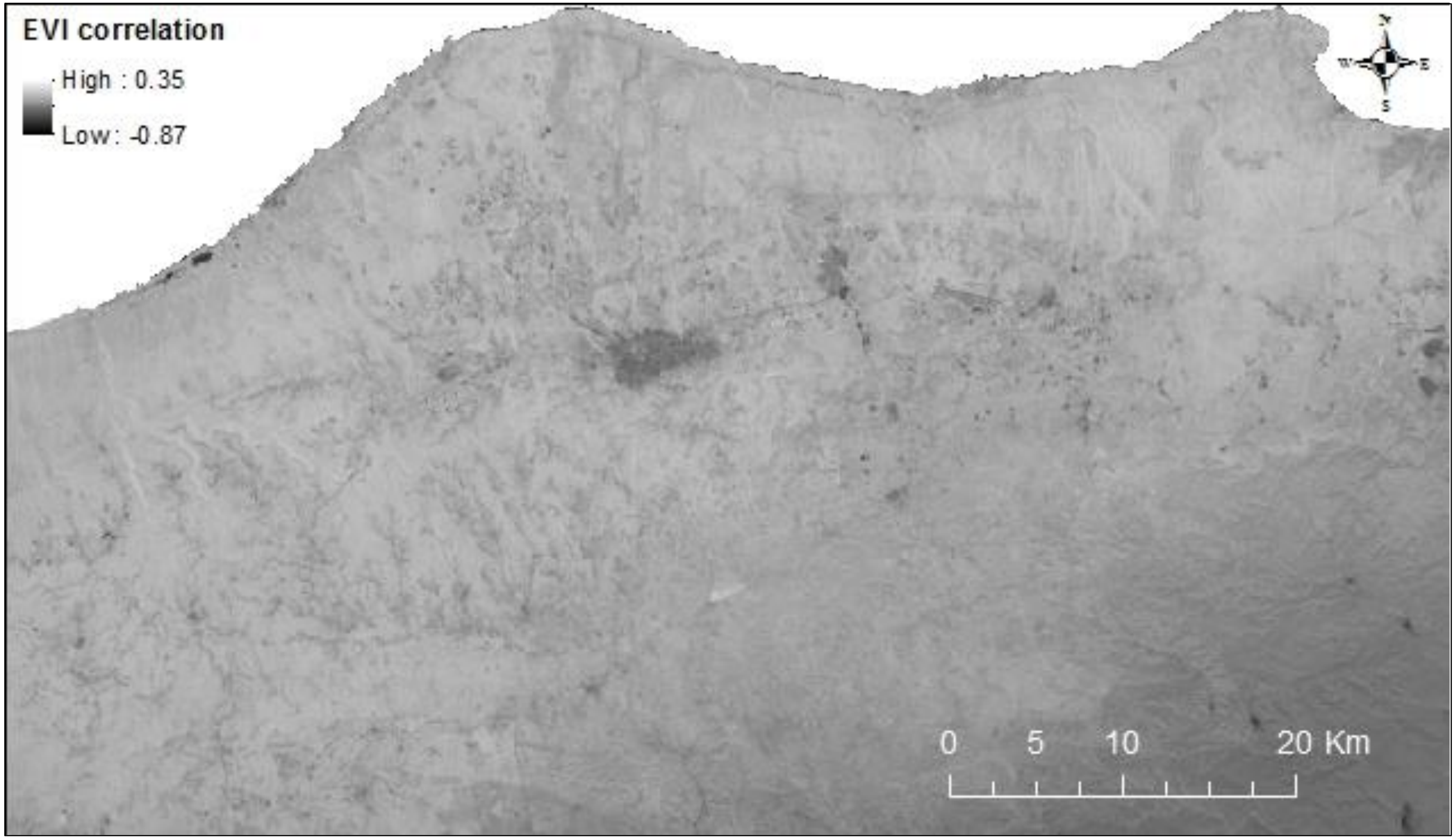


Figure 6.25: The EVI correlation coefficient image

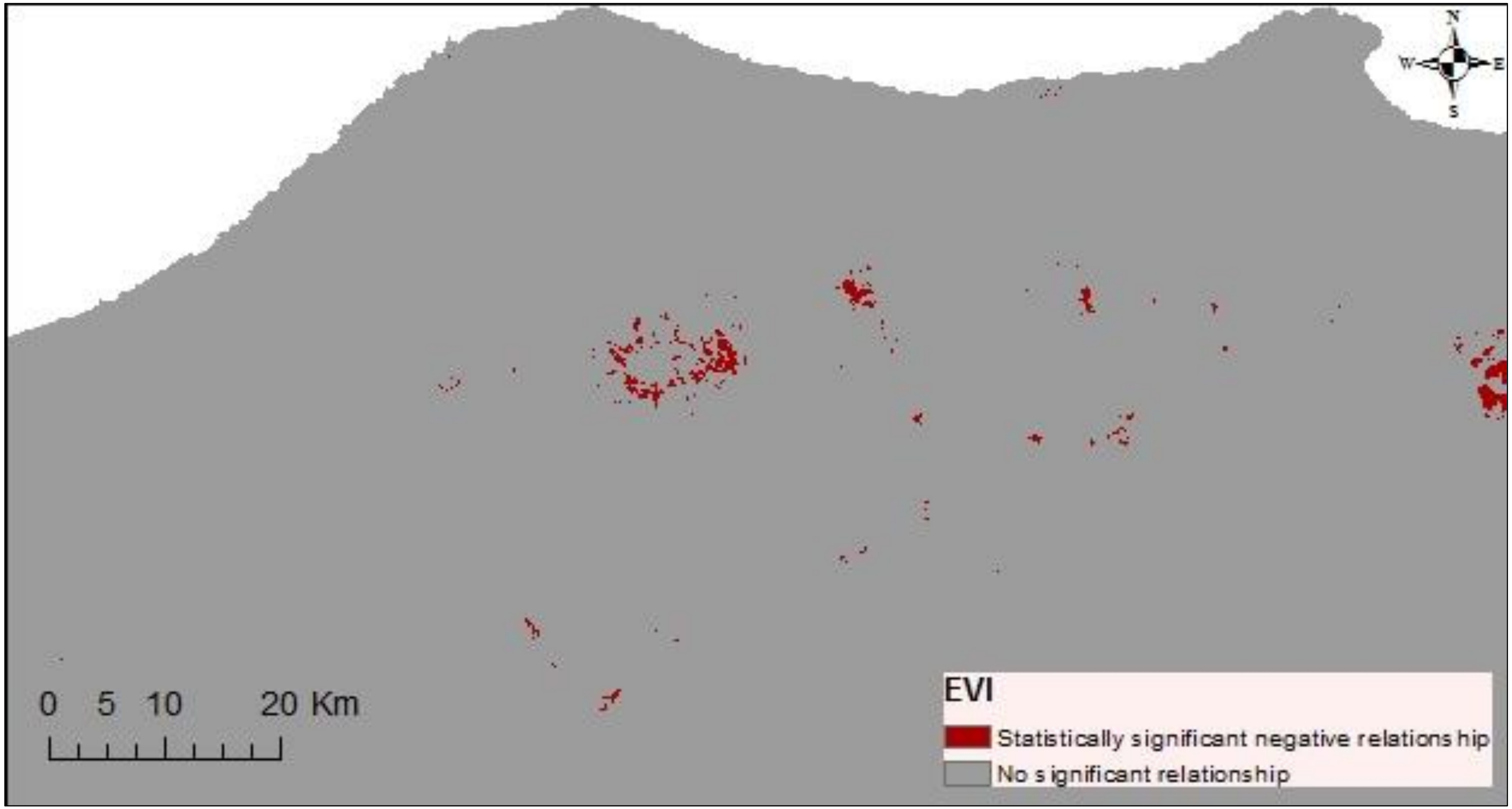


Figure 6.26: The classified EVI correlation coefficient image

6.4 Comparison of the VI changes

Differences and similarities when assessing vegetation cover were compared among various spectral vegetation indices. All VI showed qualitative variations in vegetation cover. However, there were significant differences in the values of the VI over desert, agricultural areas, and forests. The spatial and temporal distribution of the VI produced insights for assessing vegetation cover change in the study area.

To explore these relationships, the research chose the highest negative value in the NDVI correlation image, and collected the values for the same pixel from the NDVI time-series image (11 values), to calculate the linear regression slope and R for this pixel. The research then collected the values of the same pixel from the SAVI and EVI time series images (see Table 6.2).

Table 6.2: Comparison of the highest negative values between the VI

Julian date	Years	NDVI	SAVI	EVI
250	1972	0.163	0.115	-
245	1978	0.15	0.124	-
279	1986	0.106	0.098	-
273	1987	0.125	0.073	0.075
298	1999	0.123	0.051	0.069
209	2001	0.165	0.101	0.081
253	2003	0.042	0.033	0.033
248	2006	0.021	0.03	-
235	2010	0.053	0.053	0.039
251	2013	0.046	0.02	0.018
234	2014	0.044	0.031	0.014

The table shows the value which had the highest negative value in different years in each VI. The Julian date calendar was used to indicate the date of the image within a particular year (collected between July and October) and to avoid seasonal differences in vegetation cover (see Figures 6.27, 28 & 29).

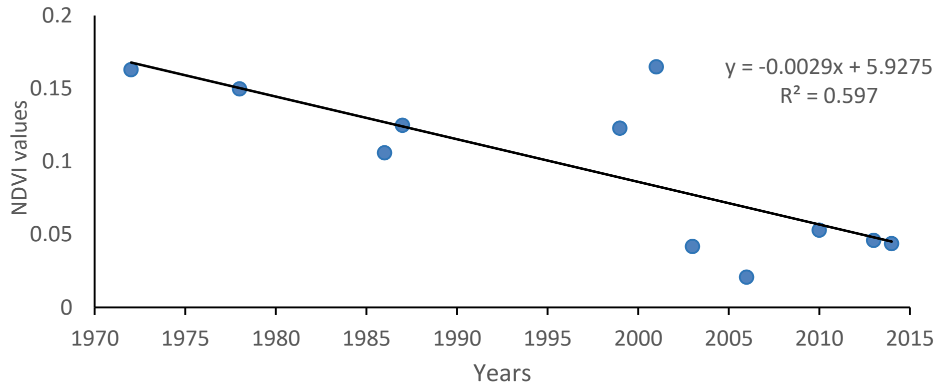


Figure 6.27: The highest negative value in the NDVI time-series image.

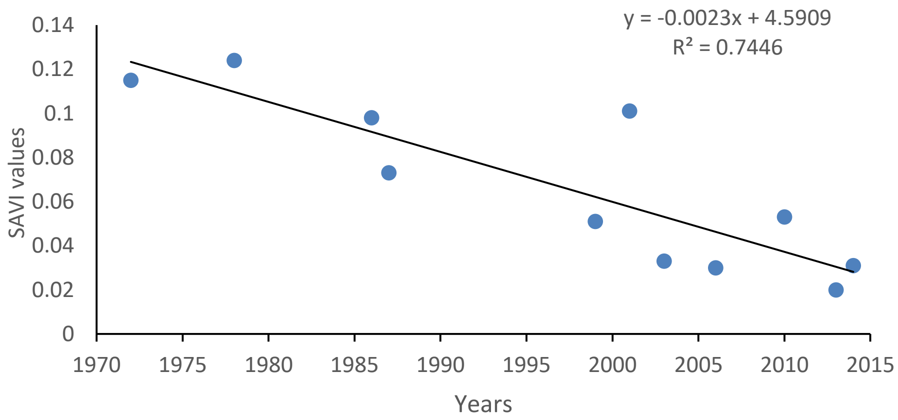


Figure 6.28: The highest negative value in the SAVI time-series image.

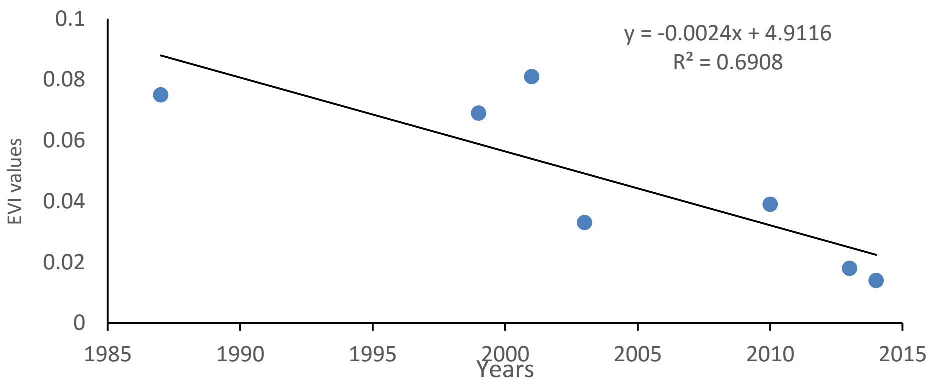


Figure 6.29: The highest negative value in the EVI time-series image.

The results obtained from all the indices are shown in Figure 6.27, depicting the trends for the values in different years and the differences in values among the VI. Although there were differences among the VI in values, all the VI showed areas which saw a decrease in the VI (vegetation cover) over the period of study. It is noted that the largest residual in all three cases was for 2001, on Julian day 209 which was the earliest image used in terms of the vegetation growing season and may represent an early season greening in this area.

6.5 Conclusion

The results obtained from assessing the vegetation cover change were consistent with previous local studies that have examined the natural vegetation in the Al Jabal Al Akhdar region such as Al Mukhtar (2005), Ben Khaial and Bukhechiem (2005), Ibrahim (2006), the Libyan Agriculture Department (2004), and Oune (2006), and confirms that there has been a decrease in the vegetation cover in the region.

The results confirmed that the decrease in the VI may be interpreted as showing a decrease in vegetation cover in the study area over the last 42 years. The spatial and temporal distribution of vegetation cover change across the study area has been examined using time-series spatial resolution satellite imagery and VI. The key results were:

(i) The effectiveness of remote sensing techniques to monitor vegetation change has been demonstrated in the study area, although there were relatively few images covering the study area over the last 42 years.

(ii) The results of the regression analysis of the VI in the Al Jabal Al Akhdar region indicated a change in the VI in some areas over the last 42 years. The negative values of the VI slope showed a decrease in the VI trend and therefore a decrease in vegetation cover in some areas. In contrast, the areas which have positive values saw no significant change in vegetation cover.

(iii) The correlation coefficient of the VI showed the pixels which revealed a statistically significant change at a 95% level of confidence in the study area over the 42 years.

(iv) The results of the VI correlation indicated a statistically significant decrease in the VI in some areas.

(v) Although there were some differences between the NDVI, SAVI and EVI in terms of values, all the VI shared areas which had experienced a decrease in the VI (vegetation cover) over the period of study. The spatial distribution and causes of significant decrease in vegetation cover are explored in the next two chapters.

The aim of this chapter was to assess vegetation cover change in the study area. Vegetation Indices (VI) obtained from Landsat images represent quite a simple and effective technique for quantitative evaluation of vegetation cover for the whole of the study and it can also identify the quantity of vegetation cover in the area. Also, the VI can provide extremely useful insights into vegetation cover change in the study area by examining the time series of VI over a long period.

The statistical analysis of regression and the correlations that were applied in this chapter for the VI index contributed to showing the strength of the linear relationship between the VI and time. It determined which pixels showed a statistically significant relationship, and then determined which pixels had statistically significant trend in the VI over time.

This chapter has provided statistically significant results for the changes in vegetation cover and produced maps for the changes in vegetation cover of the Al Jabal Al Akhdar region over 42 years. These were hitherto not available in Libya because most the studies relied on fieldwork and specific locations. The output of this part of the research will be used to detect the factors which caused these changes.

CHAPTER 7: LAND COVER CHANGE IN THE STUDY AREA

This chapter addresses the third research question and assesses land cover and land use change in the Jabal Al Akhdar over the period from 1972 to 2014.

The chapter uses supervised classification of archived Landsat MSS, ETM+, TM and OLI images for the study area to determine the nature and scale of long-term land cover change that has occurred at this site over a 42 year period. It assesses changes that have occurred within this period and affected the quantity and distribution of vegetation cover in these areas.

7.1 Introduction

Understanding land cover dynamics allows the possibility of predicting the influence of land cover changes on ecosystems in the future (Foody, 2002; Knorn, 2012). Land cover and land use are two separate phenomena. Although land cover and land use are often used interchangeably, their actual meanings are quite distinct (Rawat & Kumar., 2015). Land cover refers to the physical material at the Earth's surface, whether it be vegetation, urban infrastructure, water, bare soil, and so on. Land use refers to human activity on the land, for example, recreation, urban enterprise or agriculture (Rawat & Kumar, 2015; Sohl & Sleeter, 2012). Land cover changes affect land use and land use affects land cover (Knorn, 2012).

Monitoring the dynamics of land cover and land use change in Al Jabal Al Akhdar is important in assessing these changes and the factors that caused them. The research therefore classified the time series of Landsat imagery to detect the changes in land cover and land use in the study area.

7.2 Objective two

The general objective of this chapter is to assess the dynamics of land cover and land use in the study area over the 42 years. This overall objective proposes that land use has changed as a result of an increase in human activity in the region. Initially, land cover change is assessed and then in chapter 8 these changes are used with population distributions to determine the relationship between these changes and vegetation cover change in the study area.

7.3 Detecting land cover change in the study area

Land cover mapping normally requires collecting data from the field to generate the map and test its accuracy, but difficulties resulting from problems of gaining access to the study area made this impossible. Remote sensing provides a long term record of land cover dynamics. It covers a large area and collects data from areas which are difficult to access. To assess the land cover changes, the research relied on Landsat images to create thematic maps for each land cover class and to assess the changes in these classes over the 42 years.

7.3.1 Image classification

The production of thematic maps for land cover and land use, using image classification is one of the most common applications of remote sensing (Foody, 2002). Thematic maps of the study area were based on the supervised classification method; the research used ERDAS software and Arc-GIS to generate the maps from the satellite images by going through several steps, described below.

7.3.1.1 Collect the training areas

In this step the research determines how many land cover categories there are in the study area and allocates a name for each one. . The approach identified 12 categories covering the image of Al Jabal Al Akhdar based on personal knowledge of the study area with the interpretation of imagery from Google Earth. Furthermore, use was made of background information on land cover and a vegetation map of Libya from the report of FAO in 2009 (Figure 7.1) and a classification map of agricultural areas and vegetation in the north east of Libya from the report of the Libyan Agriculture Department in 2004 (Figure 7.2).

Training sites were used as references for each land cover class from the first image of 1972 to generate the training signatures files, which included all the classes of the study area, in ERDAS image software. The approach selected more than 25 training areas for each category of the study area.

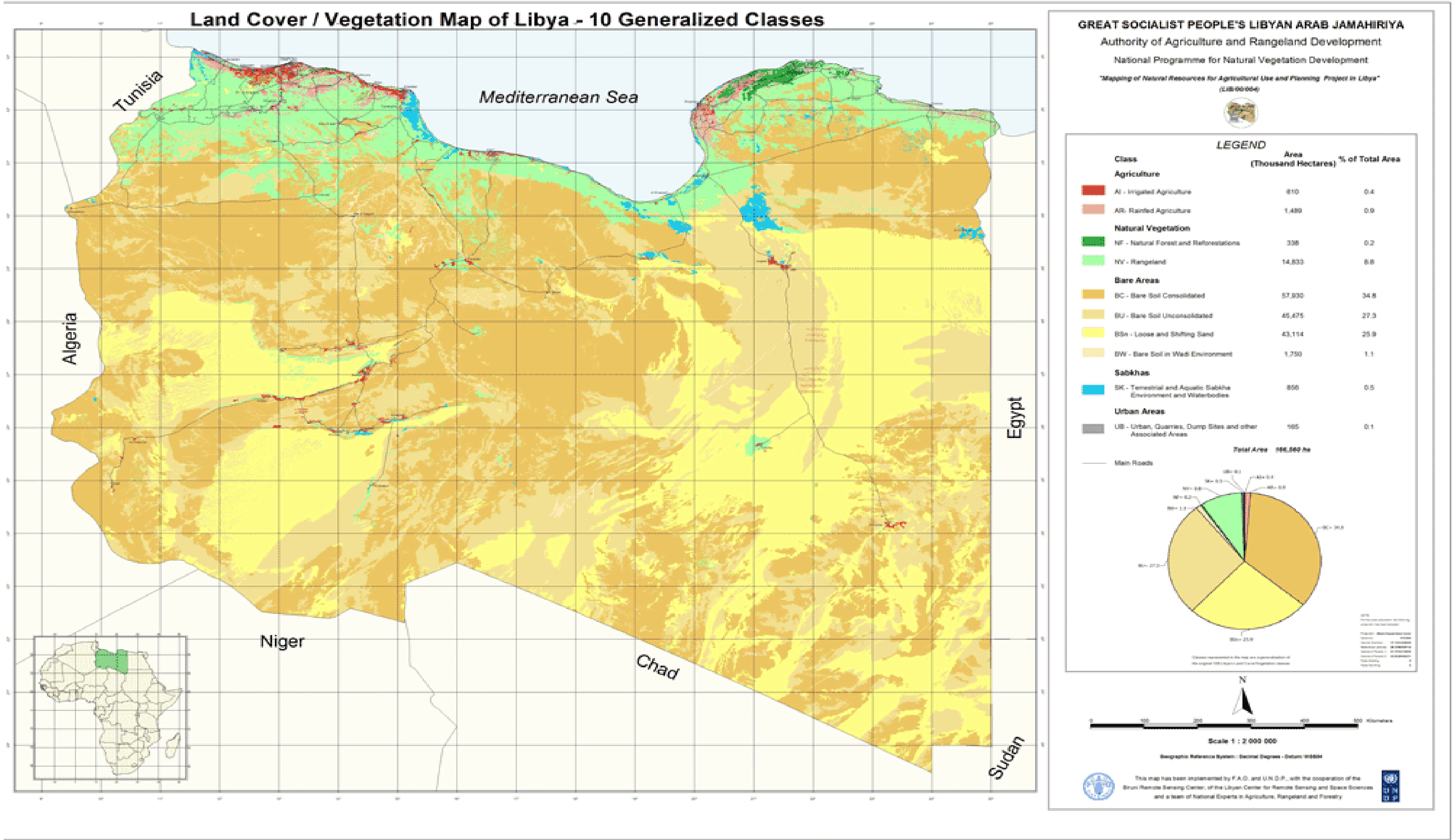


Figure 7.1: Land cover and vegetation map of Libya (Source: FAO, 2009)

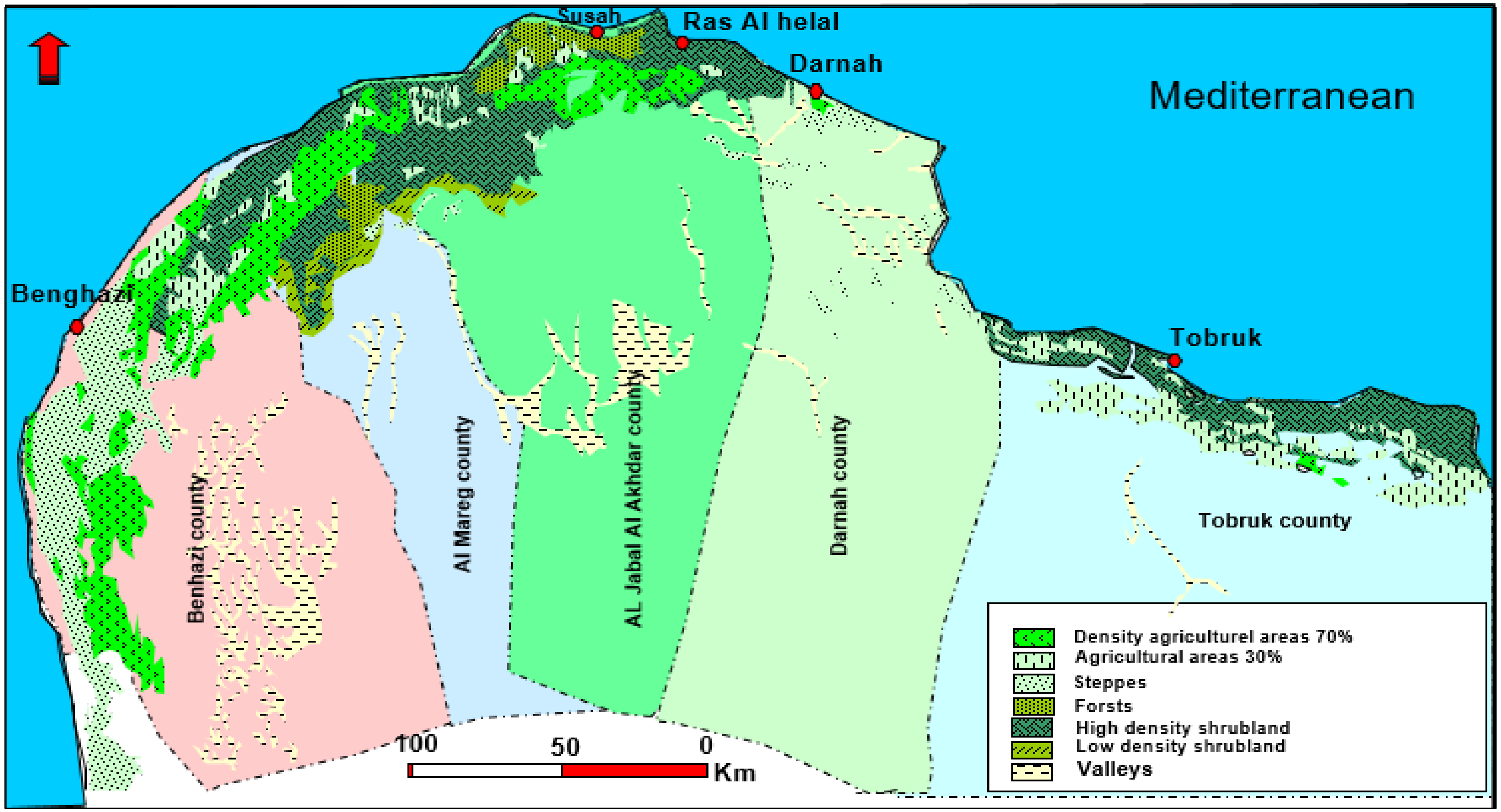


Figure 7.2: The agricultural areas and vegetation cover of north east Libya (source: Libyan Agriculture Department, 2004)

7.3.1.2 Generating the signature files

The approach opened a new signature file from the supervision classification toolbar in ERDAS, and opened the Landsat image in ERDAS viewer and displayed either a true or false colour composite image which was used to draw the training areas. The approach entailed drawing a polygon on each site using the previous information and google earth to represent the class of land cover and save it in a signature file with the name of the class. Some classes were easy to identify such as the sea, sandy beaches, agricultural areas, urban sites and quarries. Other classes were difficult to draw because they were overlaid with other classes or they had the same colour. For example, the forest and high density shrubland have similar colours, so the approach relied on personal knowledge of the sites of the forests which was limited in the study area. In terms of determining high or low shrubland, the researcher chose pixels which identified about 75% or more coverage by shrubs as high density shrubland, and for low density shrubland, the research chose the pixels which showed partial coverage less than 75% with appearing the ground in those pixels. The class of bare area was easy to determine, but the outer limits of this class were overlaid with the beginning of the desert class, so the boundaries of these categories were difficult to define. The approach used the signature files for every image in the supervised classification in ERDAS Imagine and generated classified images which relied on the Maximum Likelihood (ML) classification method (Figure 7.3). The Maximum Likelihood (ML) method is a supervised classification derived from the Bayes theorem (Ahmad, 2012), which uses a discriminant function to assign pixels to the class with the highest likelihood (Dougherty et al., 1992).

7.3.1.3 Accuracy assessment of the classified image

Thematic mapping from remotely sensed data contains innumerable errors for a number of reasons, such as (1) geometric error or incomplete atmospheric correction; (2) clusters incorrectly labelled after unsupervised classification; (3) training sites incorrectly labelled before supervised classification; and (4) indistinguishable classes (Foody, 2002). A classification error constitutes a discrepancy between the situation depicted on the thematic map and reality (Foody, 2002). Therefore, the term accuracy is used to express

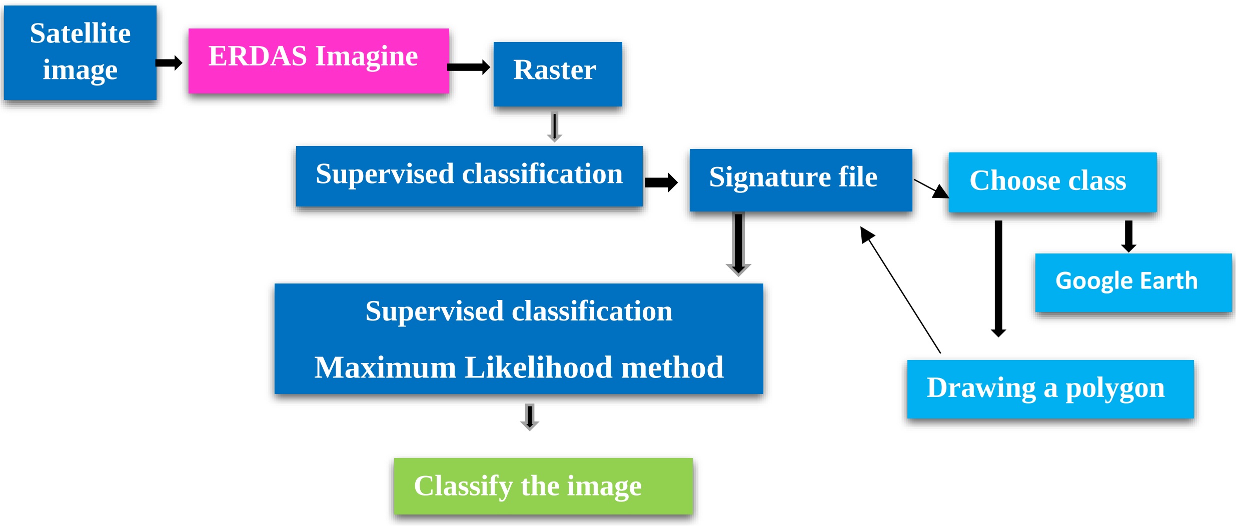


Figure 7.3: Classification process steps.

the degree of correctness of a map or classification. It is one of the most important steps in any classification process because, without an accurate assessment, the output or results are of little value. At this stage, the approach evaluated the classified image file using known ground truth locations and values for assessing the accuracy of the land cover map of the study area.

To evaluate classification images for the study area, the approach collected 1500 randomly selected reference data (ground truth) using Google Earth imagery for 2010, which was clear and free of cloud cover (Figure 7.4), and transferred them into an Excel table. These points encompassed the study area and incorporated a variety of land covers. The research chose the classified image of 2010 for verification of the validity of land cover classification and references on the ground.

To determine land cover in the image, the research identified every type of land cover in each selection point using Google Earth. For example, if a pixel covered an urban area, the coordinates of this pixel were used to validate a category in the classified image.

Accuracy assessment begins with the generation of an error matrix which expresses the number of sample units assigned to each land cover type compared to the reference data. An error matrix is usually used as the quantitative method of characterising image classification accuracy (Congalton, 2007). It is a table that shows correspondence between the classification result and a reference image (Table 7.1).

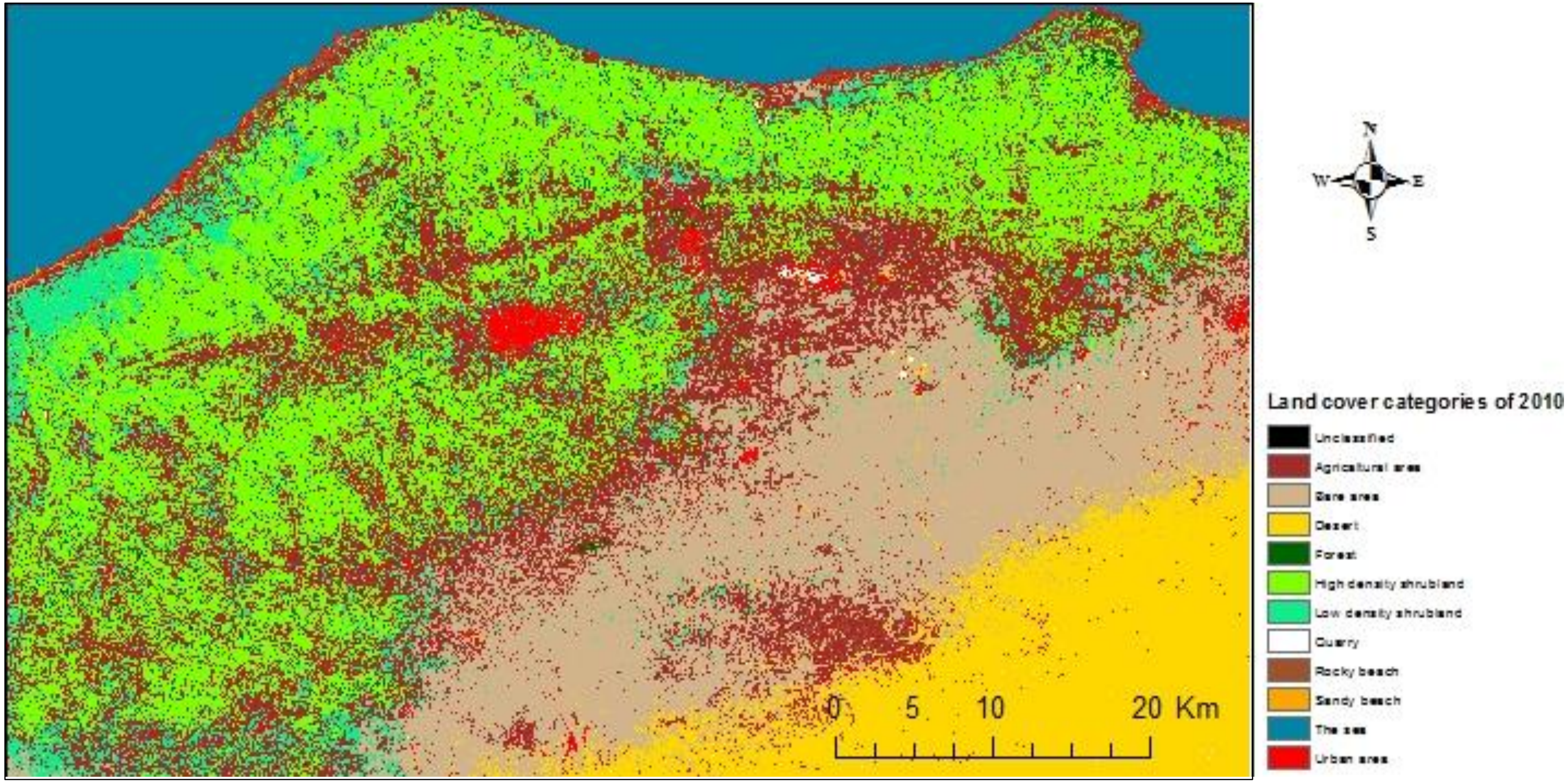


Figure 7.4: Land cover map for 2010.

Table 7.1: Error matrix for the classified image of 2010

Classification image

Category	Reference data												
	Agriculture	**Bare area**	**Desert**	**Forest**	**High density**	**Low-density**	**Quarry**	**Sandy beach**	**Rocky beach**	**The sea**	**urban**	**Total**	**Producer`s accuracy**
Agriculture	184	58	1	0	28	114	2	0	0	1	5	393	79.31%
Bare area	14	115	40	0	1	19	0	0	0	0	2	191	60.20 %
Desert	0	1	145	2	0	0	5	0	0	0	0	153	57.21%
Forest	0	0	0	30	10	0	0	0	0	0	0	40	75 %
High density shrubland	11	5	0	0	66	30	0	0	0	0	1	113	90.91%
Low density shrubland	20	11	0	0	40	81	2	0	0	1	10	165	45.52%
Quarry	0	0	15	1	0	0	77	3	0	0	3	99	32.93%
Sandy beach	0	0	0	0	0	0	0	18	1	0	0	19	89.53%
Rocky beach	2	0	0	0	0	0	0	5	14	3	0	28	66.67%
The sea	0	0	0	0	0	1	0	0	0	122	3	126	93.33%
Urban	1	6	0	0	0	1	0	0	0	1	76	85	95.31%
Total	232	200	201	33	145	246	86	26	15	128	100	1412	71.45% / 72.10%
User`s accuracy	46.82%	60.21%	94.77%	75%	58.41%	49.1%	77.78%	94.74%	50%	96.83%	89.41%		

The columns in the matrix table are reference data (actual land cover), and the rows are the classes of the classified image to be assessed. Cells of the table show the number of pixels for all the possible correlations between the ground truth and the classified image and the major diagonal of the matrix indicates agreement between the reference data and the interpreted land cover types.

The research also described the amount of errors of classification made by the Producer's accuracy indicator. It is the number of correctly identified pixels divided by the total number of pixels in the reference image (Foody, 2002). The table shows the percentage accuracy which should be more than 65% in each class (Congalton, 2007) to render the classification processing a successful reference. The overall accuracy of classification was 71.45% for the producer's accuracy and 72.10% for the user's accuracy. The results recorded in the table indicated accurate scores in some classes such as the desert, forest, sandy beach and quarry area. However, other categories were less than 65% accurate, which was due to the overlapping of some classes, for example, low and high density shrubland overlapping with bare areas and desert on the one hand, and bare areas with agricultural areas without crops on the other hand, because of similarities in their spectral nature.

7.4 Assessing land cover change

The research classified eleven images of the study area and produced eleven thematic maps showing the land cover in the Al Jabal Al Akhdar extracted from Landsat MSS for 1972, 1978 and 1986, and TM for 1987, 2003, 2006 and 2010, and ETM+ for 1999 and 2001, and OLI for 2013 and 2014 (Figure 7.2). A total of 12 land cover types are displayed, namely: agricultural area, bare area, desert, forest, high-density shrubland, low-density shrubland, quarry, rocky beach, sandy beach, the sea and urban area. These maps were used to assess the changes in the land cover and land use over 42 years.

The areal extents were derived from the pixel counts for class in a given land cover map, taking into account the spatial resolution of the imagery. The areal cover of each land cover class was completed and compared between the dates (Table 7.5). For example, the areal extent of 'agriculture' in 1987 was deemed to be of pixels of this class*30*30/1000000 to give the area in km^2.

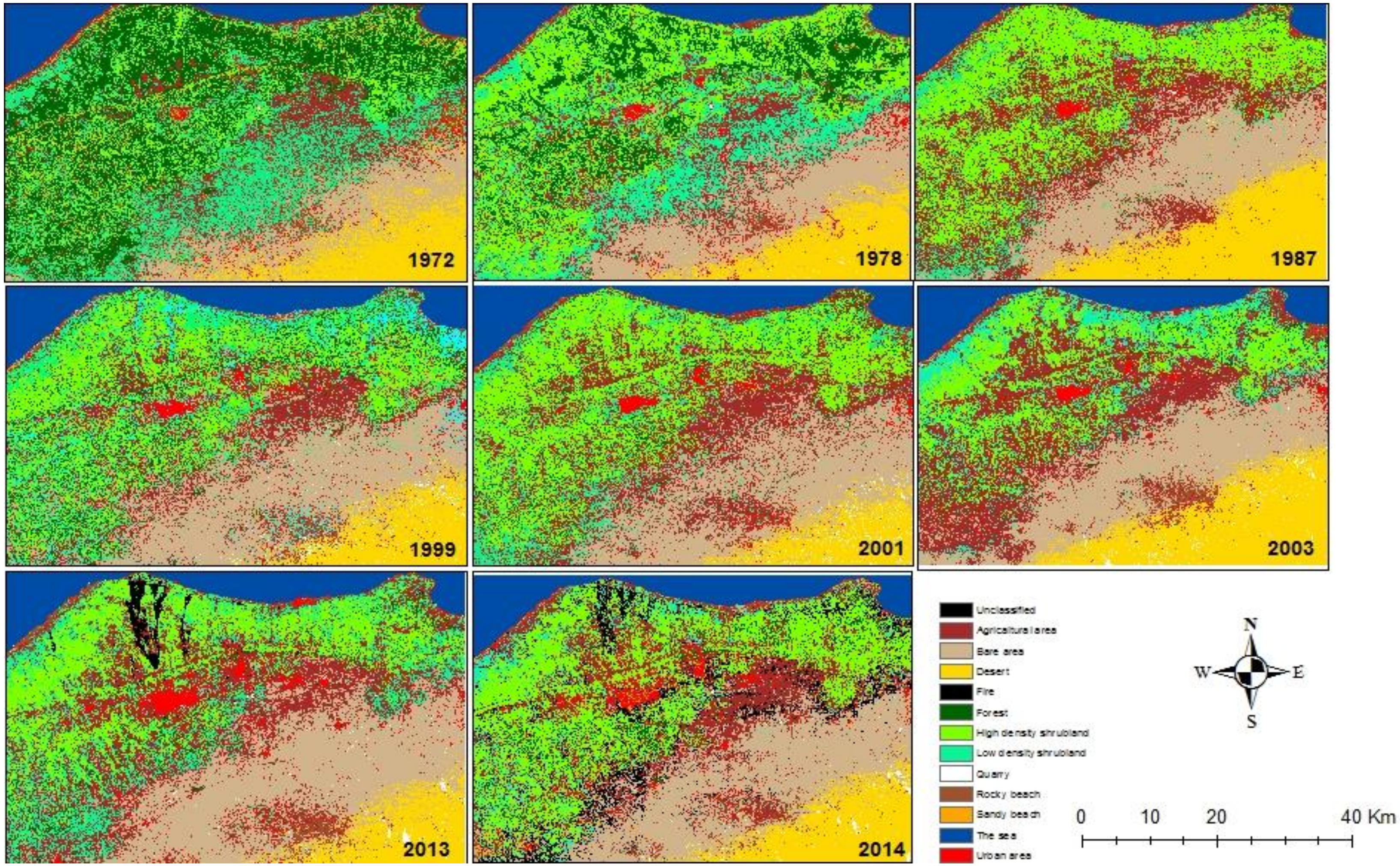


Figure 7.5: Multi-date land cover classification for the study area.

Table 7.2: The areas (km^2) of each land cover over the period of study.

Category/Years	1972 MSS	1978 MSS	1986 MSS	1987 TM	1999 ETM	2001 ETM	2003 TM	2006 TM	2010 TM	2013 OLI	2014 OLI
Unclassified	0.00	0.00	21.80	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture	746.29	763.35	1028.38	1057.18	1230.48	1381.80	1504.00	1635.90	1813.20	2099.00	2088.60
Bare area	886.73	1025.43	1062.80	937.60	1008.46	1045.20	993.40	953.10	815.10	1010.70	904.20
Desert	1045.88	847.46	852.00	946.75	927.04	921.10	921.00	830.10	878.30	858.30	815.50
Forest	661.33	643.48	357.13	256.78	225.29	252.8	208.7	191.4	87.2	79.5	80.9
High density shrubland	1338.76	1258.93	1185.66	928.65	801.69	712.3	676.7	641.3	606.6	578.2	543.5
Low density shrubland	1030.79	1070.32	1037.37	695.95	685.95	642.8	616.7	606.6	661.7	650.3	631
Quarry	75.06	53.63	69.85	37.89	47.59	52.9	155.9	181.7	190.9	191.9	193
Rocky beach	10.24	15.98	24.15	130.61	136.36	171.64	67.58	67	57.19	51.45	453.45
Sandy beach	27.36	5.53	8.68	4.40	3.02	923.79	775	775.05	742.12	317.81	128.93
The sea	508.56	640.67	646.52	1262.75	1090.29	4.25	4.29	3.99	4.13	3.18	2.84
Urban	96.56	102.79	133.23	168.72	271.42	319	504.4	541.4	571	587.3	585.7
Total area	**6427.57**	**6427.57**	**6427.57**	**6427.56**	**6427.56**	**6427.58**	**6427.67**	**6427.54**	**6427.44**	**6427.64**	**6427.62**

In this table, the unclassified pixels for the given years are shown in the first row. The table provides the areal extent (km^2) for all categories and this is then used to derive the magnitude of land cover change over the period of study.

7.4.1 The areal extent of land cover change

Land cover in the study area has changed as indicated in the previous table. The areal extent (km^2) has decreased for natural vegetation such as the forests and shrubland. In contrast, land cover which has been exploited by humans, such as agriculture, urban and quarry, have increased over the 42 years. The research illustrated the long-term trends of land cover in graphical form (Figure 7.6).

The areal extent of bare area and desert has fluctuated at different periods because of the overlaying of the classes during the classification process.

The graph for forests indicated some degradation in the areal extent of forests from 1987 to 2014 in the Al Jabal. However, it should be noted that the forest area in 1999 was higher than in 1987. This may have been due to some error in the ETM image of 1999 which has had wedge-shaped gaps on both sides of each scene, resulting in loss of some data which may have had an effect on the classification process.

The graphs of high and low density shrubland reveal a significantly decreasing trend from 1986 to 2014. The areal extent for high and low density shrubland decreased from 1185 and 1037.4 km^2 to 543.5 and 631 km^2 respectively in 2014.

In contrast, assessment of land cover which related to human activity or land use change is an important component for assessing vegetation cover change, as it can contribute to the current debate on the effects of human activity on land cover change in the Al Jabal Al Akhdar region. The graphs of land use show the changing trends in the study area and increases in the areal extent of agriculture from 746.3 km^2 in 1972 to 2088.6 km^2 in 2014. The areal extent of urban activity increased over the period of study, with a significant increase being noted from 2003 to 2014.

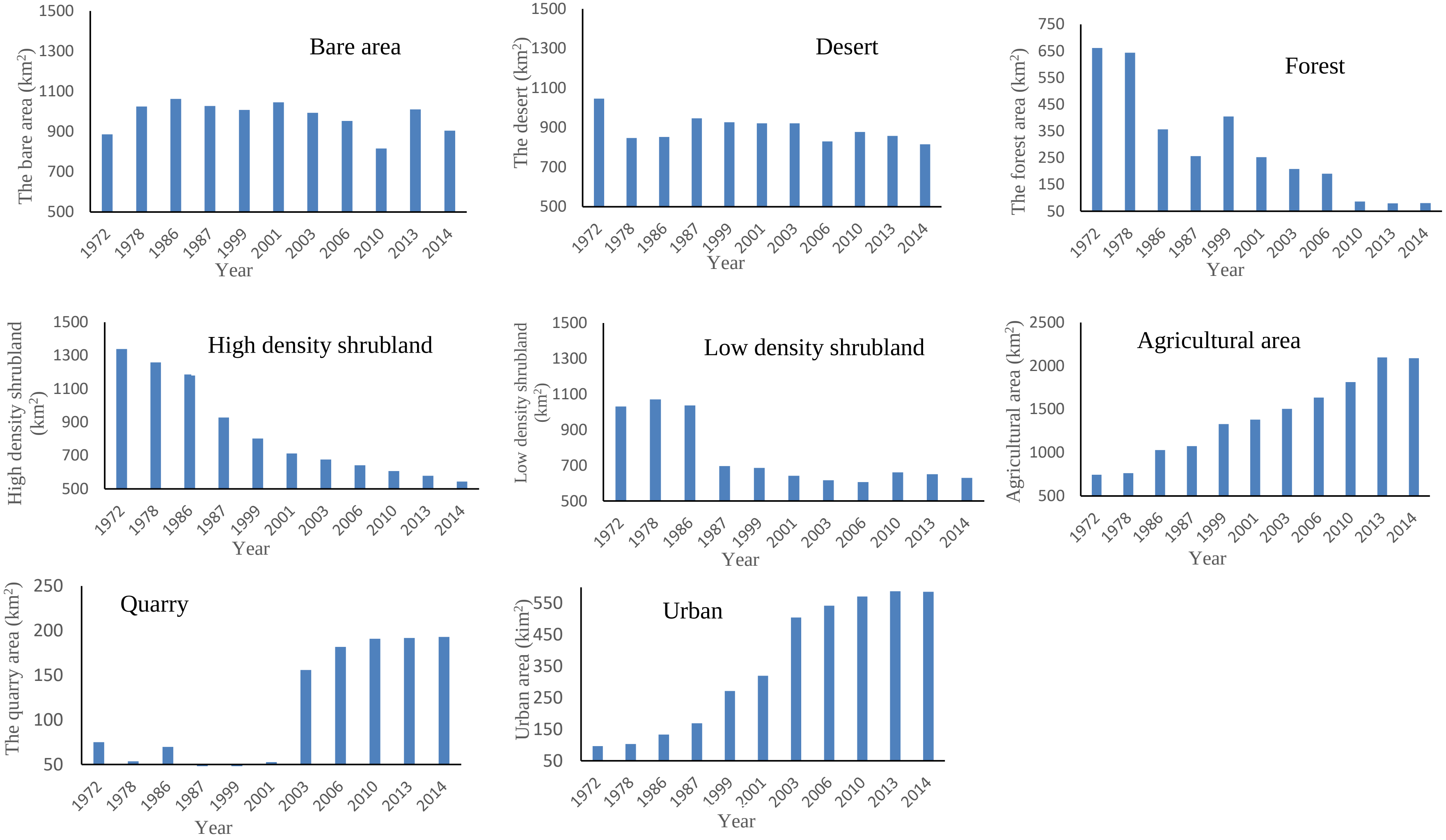


Figure 7.6: Long-term land cover change in the study area

7.4.2 The magnitude of land cover change

To identify the magnitude and rates of land cover change in the study area, the research calculated the rates and percentages of changes from land cover categories over the 42 years. The research divided the period of study into three periods based on 12 year differences. The first period starts from 1972 to 1987 (15 years), the second period is 1987 to 1999 (12 years) and the third period is 2000 to 2014 (14 years). The patterns of transition from one land cover to another which took place in the study area from 1972 to 2014 are presented in Table 6.3.

The table indicates the rates of change in the categories of the study area at different times. The above change rates indicate the changes that have occurred in a given land cover type in relation to the others.

It is quite evident from the negative rates and magnitude of change in the previous table that the forests, and high-density shrubland and low-density shrubland declined between 1972 and 2014 by -580.4, -795.3 & -399.8 km2 respectively. The positive rates have reversed, increasing land use in the area. The agricultural area, quarries and urban area increased significantly by 1342.3, 182.8 and 489.1 km2 respectively.

The influence of land use was evident in the spatial distribution of land cover change, for example forested areas declined steadily from 1972 to 2014 at a rate of -78.2%. In contrast, built up areas had notable increases at a rate of 71.7% from 1972 to 2013 with annual rates surpassing 25%, at least, for one or two dates.

The results in the table indicate that the bare area and desert registered a mix of increases and decreases in their cover proportions. The rates of change -7.2% to -6%, were due to the overlap in the classes in the classification process, so the areal extent for both of them has changed due to the previous process.

The research has chosen different periods for 1972, 1999 and 2013 to show the changes in the percentage of land cover using pie charts in these selected years (Figures 7.7, 7.8 & 7.9).

Table 7.3: The area, magnitude and rates of land cover change in the study area (km^2).

Land cover Categories	Area (km^2)					Change in magnitude (km^2)				Change rate per period (%)			
	1972	1987	1999	2001	2014	1972-1987	1987-1999	2001-2014	1972-2014	1972-1987	1987-1999	2001-2014	1972-2014
Agriculture	746.3	1057.2	1230.5	1382	2089	310	173.3	706.8	1342.31	17.2	7.6	20.4	47.3
Bare area	886.7	937.6	1008.5	1045	904.2	50.9	70.86	-141	-17.5	2.8	3.6	7.2	-1
Desert	1045.9	946.7	927.0	921.1	815.5	-99.1	-19.7	-105.6	-230.4	-5	-1	-6	-12.4
Forests	661.3	256.8	225.3	252.8	80.9	-404.5	-31.49	-171.9	-580.4	-44.1	-6.5	-51.5	-78.2
High-density shrubland	1338.8	928.6	801.7	712.3	543.5	-410.1	-126.96	-168.8	-795.3	-8.1	-7.3	-13.4	- 42.3
Low-density shrubland	1030.8	696.0	686.0	642.8	631	334.8	-10	-11.8	-399.8	-19.4	-0.72	-0.92	-24
Quarry	10.2	37.9	47.6	52.9	193	27	9.7	140.1	182.8	57.5	11	57	89.9
Urban area	96.6	168.7	271.4	319	585.7	72.2	102.7	-266.7	489.1	27.2	23.3	29.5	71.7

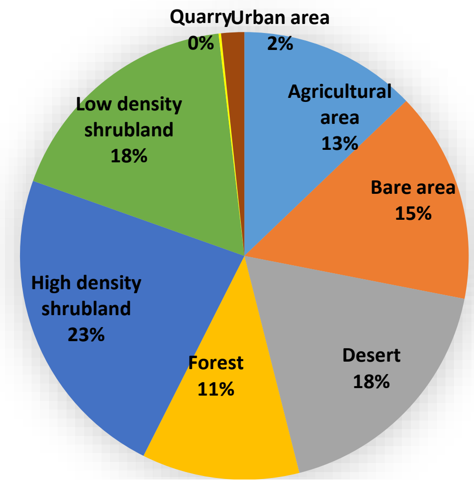


Figure 7.7: The land cover in an image of 1972

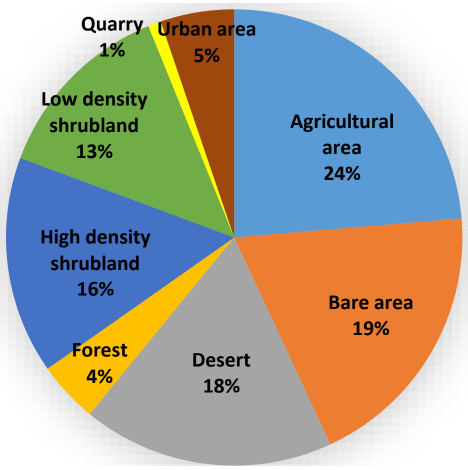


Figure 7.8: The land cover in an image of 1999

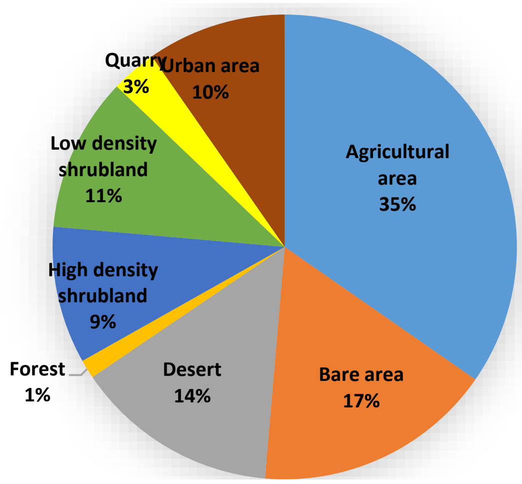


Figure 7. 9: The land cover and land use in an image of 2013

The graphs show the changes in land cover in the study area; for example, the proportion of agricultural land was 13% in 1972, increasing significantly to 24% during the next 27 years and continuing to increase significantly to 35% in 2013.

7.5 Conclusions

This chapter has addressed the second objective which aimed to generate and analyse land cover change for the period of 1972 to 2014 in the Al Jabal Al Akhdar region, using Landsat data. This research demonstrates the ability of GIS and image classification to capture spatial-temporal data and provide thematic maps for the Al Jabal Al Akhdar region, attempting to assess as accurately as possible categories of land cover which have changed over time.

The results confirmed the hypothesis of land cover change. These changes were spread across the Al Jabal Al Akhdar and were not confined to one particular location. Based on the results obtained, the following conclusions can be drawn:

(i) The thematic maps that were extracted from classified Landsat images for the study area proved effective in measuring the areal extent for each land cover. Apart from some problems in accurately calculating some classes due to overlaying, the classes in the classification process could be clearly distinguished for each year.

(ii) The trend in relation to land cover covered by natural vegetation shows a decline. The changes could be clearly seen by way of the decreasing trend in forest and shrubland cover over the 42 years.

(iii) The magnitude and proportions of forest and shrubland cover declined in the study area and were less than zero in terms of both percentage (%) and spatial extent (km^2). The dominant nature of change that has occurred due to the conversion of land cover has led to the increase in the latter.

(iv) Land use change was assessed through evaluating the gains and losses in the study area and the net changes in each land use class. The result indicates a dynamic change in land use, which was expected since most of the changes were caused by human action.

(v) The magnitude and the rates of land use change in the study area exceeded 45 in percentage terms (%), and 400 in terms of spatial extent (km^2) in cultivated areas and built-up areas from 1972 to 2014.

Landsat image classification was an effective procedure and an important method of information extraction for land cover change. It contributed to identifying the land cover of the study area and assessing the changes in each class.

This chapter features thematic maps for land cover from 1972 to 2014, which were not previously available in Libya for this period. These maps are usable and show 12 categories of land cover of the study area and provide information for land cover and land use change. The land use change represents the evidence of human activities in the area and its effect on vegetation cover. This information will be used in the next chapter to detect which factor affected vegetation cover change in the study area. Overall, although using Landsat data to delineate change detection was a valuable method through image classification, it still needs some refinement within individual classes in the classification process such as reclassify some classes which were overlaid with the others in the study area.

CHAPTER 8: A SPATIAL ANALYSIS OF FACTORS AFFECTING VEGETATION CHANGE IN THE STUDY AREA

Overall this chapter addresses the main aim of this study which is to assess the factors affecting vegetation change in the Al Jabal Al Akhdar region. This chapter first assesses the relationship between vegetation cover change and population data, secondly, evaluates the relationship between land cover change and population data and finally, assesses the relationship between vegetation cover change and land cover change in the study area. In addition the results of the analysis of climate change in the study area, which may contribute to vegetation cover change are considered.

8.1 Introduction

The spatial and temporal distribution of vegetation cover change across the Al Jabal Al Akhdar region was examined in chapter 6 using time-series satellite imagery and Vegetation Indices (VI). The key output was new maps of the distribution of statistically significant vegetation index change over the last 42 years and an inference of the areas that experienced changes in vegetation cover.

Land cover of the study area was assessed in chapter 7 using time-series Landsat image classification. The main outputs of this chapter were determination of the magnitude and the rates of land cover change over the period of study, and thematic maps for land cover change categories. These changes are set in the context of increased temperatures at the stations studied in chapter 5, and a further inference that this temperature change may have contributed to decreasing vegetation cover.

Consequently, to investigate the factors affecting vegetation change in the study area, the research used the outputs of previous objectives to identify the relationships between vegetation change and land cover changes, and then the influences of human activity on vegetation cover change.

8.2 Objective three

The proposal related to the third objective is that areas which exhibit statistically significant vegetation cover change over the last 42 years, are the same areas that have dense populations and a variety of human activities, while other areas with significant vegetation change and sparse populations may be responding primarily to climate change. This chapter evaluates the relationship between the areas experiencing vegetation cover change and the main factors that may be causing this change. Population data are used to assess possible relationships between vegetation cover change and the likely distribution of human activity.

8.3 Assessing the relationship between vegetation cover change and population

Population has an influence on vegetation cover by exploitation of land leading to land cover change. The first step was therefore to examine the spatial correlation between areas that exhibited vegetation cover change and the distribution of population. The population data were described in section 4.4 and classified as 1 km resolution population counts for 2013.

The three VI correlation images were used in a binary classification with 0 representing no significant VI change and, 1 representing statically significant change ($p < 0.05$) (Figure 8.1). These data were overlaid on the population data and the two layers multiplied together. The outputs were new data layers showing the population of 1 x 1km pixels where there was a significant change in the VI detected at finer resolution using the Landsat data. The results are shown in figure 8.2 with the VI change periods coloured by population. Histograms of the new images were used to give insights into the counts of population in relation to the areas with significant vegetation cover change (Figure 8.3).

This result provides an ideal panel data set of the relationship between population and vegetation cover. The histograms show the population of the 1 x 1 km areas where one or more statistically significant change in the VI was recorded and the counts of population in the new outputs represent the influences of population on vegetation cover through its activities in these areas.

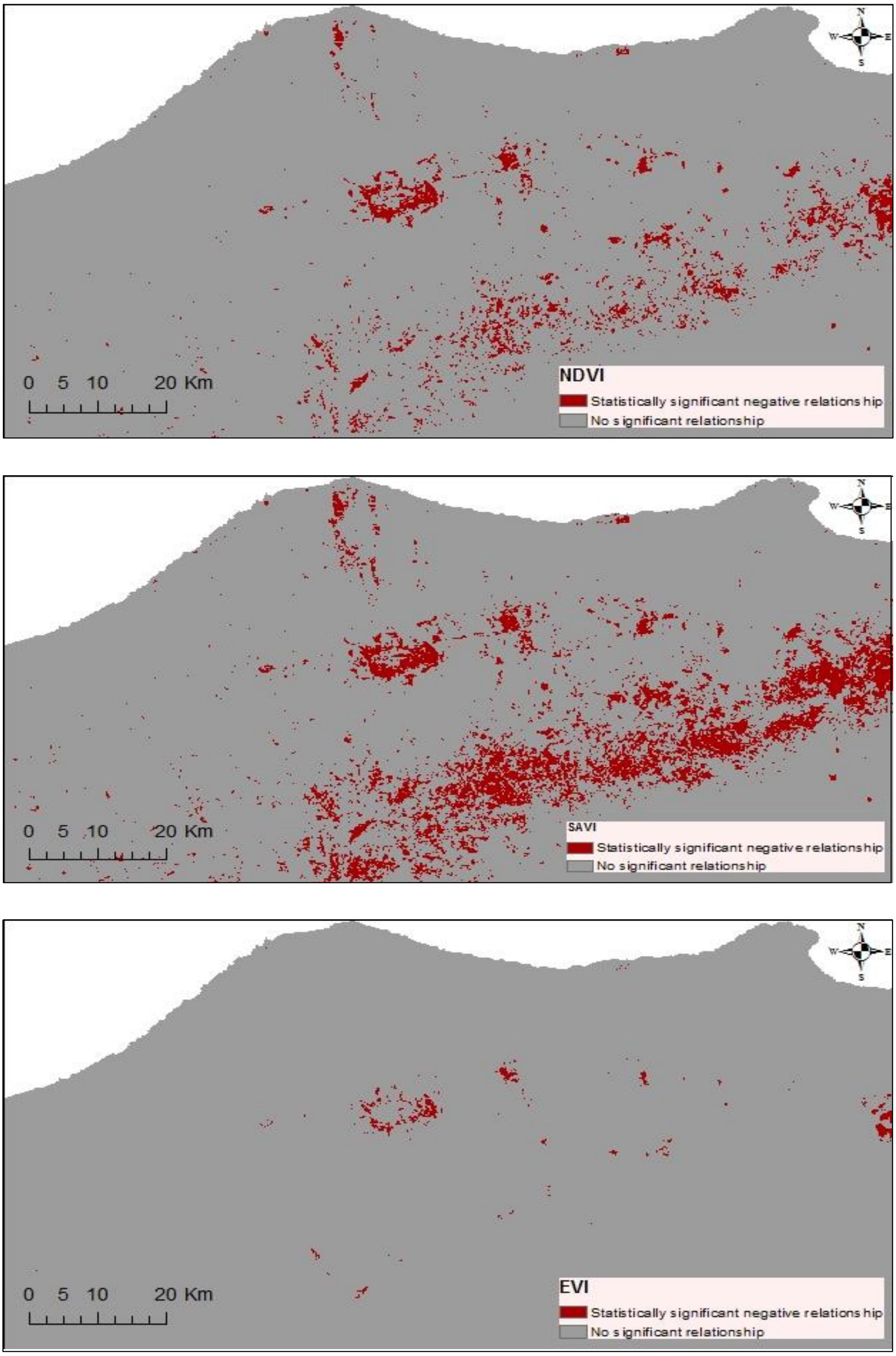


Figure 8.1: The VI classified images

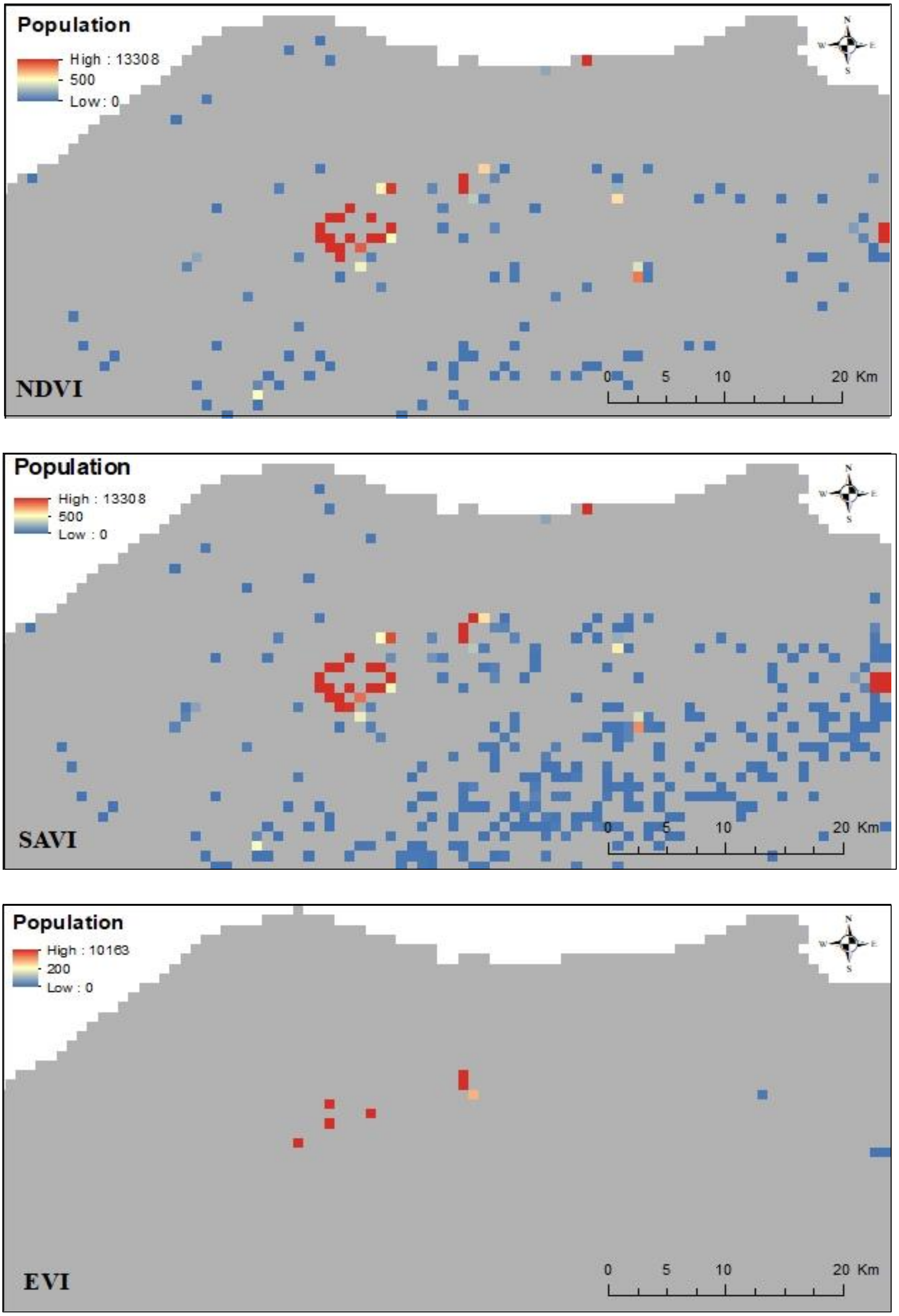


Figure 8.2: The relationship between the population and VI change.

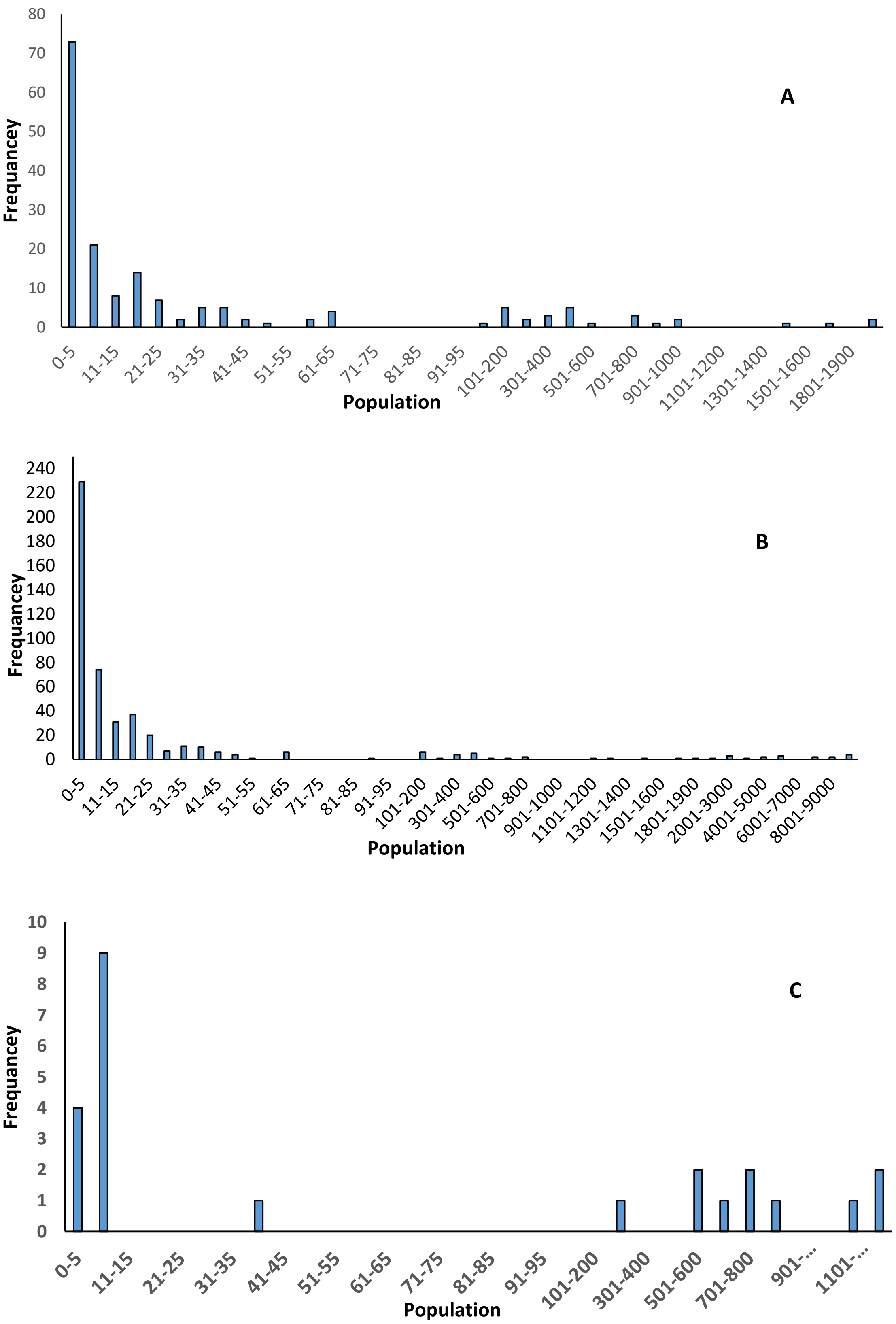


Figure 8.3: The distribution of population on the NDVI (A), SAVI (B) and EVI (C) change.

The main conclusion showed that most of the areas with a statistically significant decrease in VI are low population areas.

8.4 Assessing the relationship between the VI change and land cover change in the study area

Land cover has changed in the study area due to the expansion of human activity during the last 42 years. Land use such as agriculture, quarrying and urbanisation has significantly increased, while the forests and high and low density shrublands have declined as a result of increased human activity which has led to the development of farmland and industrial areas.

The research first produced 12 binary images, one for each land cover class, for each year. Each image represents one type of land cover in which every 30 m pixel has number 1 and all other classes have number 0. An example for the urban class is seen in Figure 8.4.

Each new layer was overlaid on SAVI, which showed the largest area of significant vegetation change compared to the NDVI and EVI due to the removal of the soil's influence and the longer period of study. The two layers were multiplied together and produced new data layers showing land cover in pixels where there was a significant change in the SAVI. The results are show in Figure 8.5 with the SAVI change coloured by the urban area.

The results show pixels classified as Urban in 2003, which also show a long term significant decrease in SAVI. The areas within the urban boundary have seen a reduction in vegetation cover due to urban development. Also, new data layers show a decrease in vegetation cover in some areas as a result of agricultural expansion over the period of study.

The approach assessed all the land cover classes over the period of study with SAVI to assess the land cover in those pixels where there was a significant change in the VI.

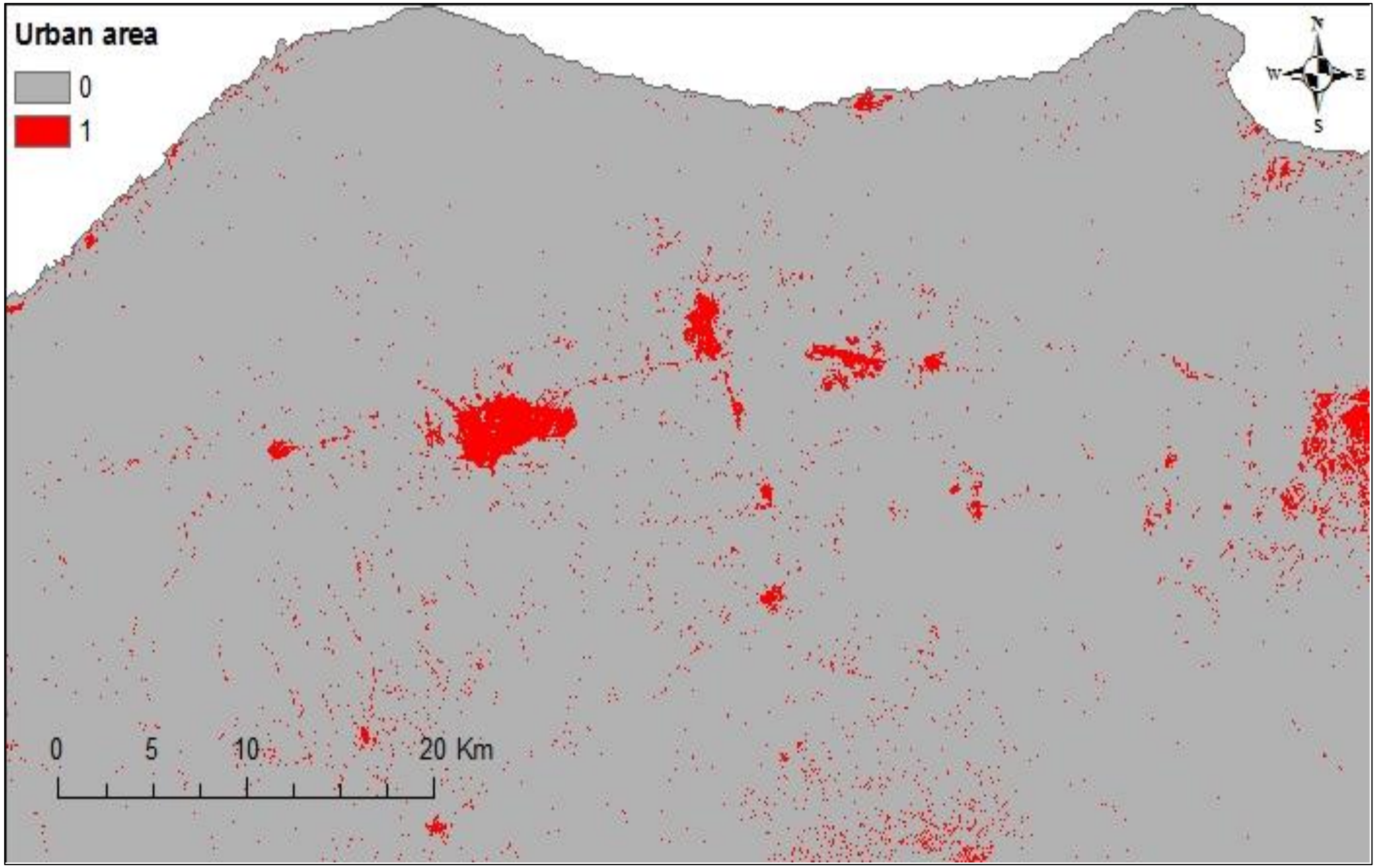


Figure 8.4: The urban area classified image of 2003

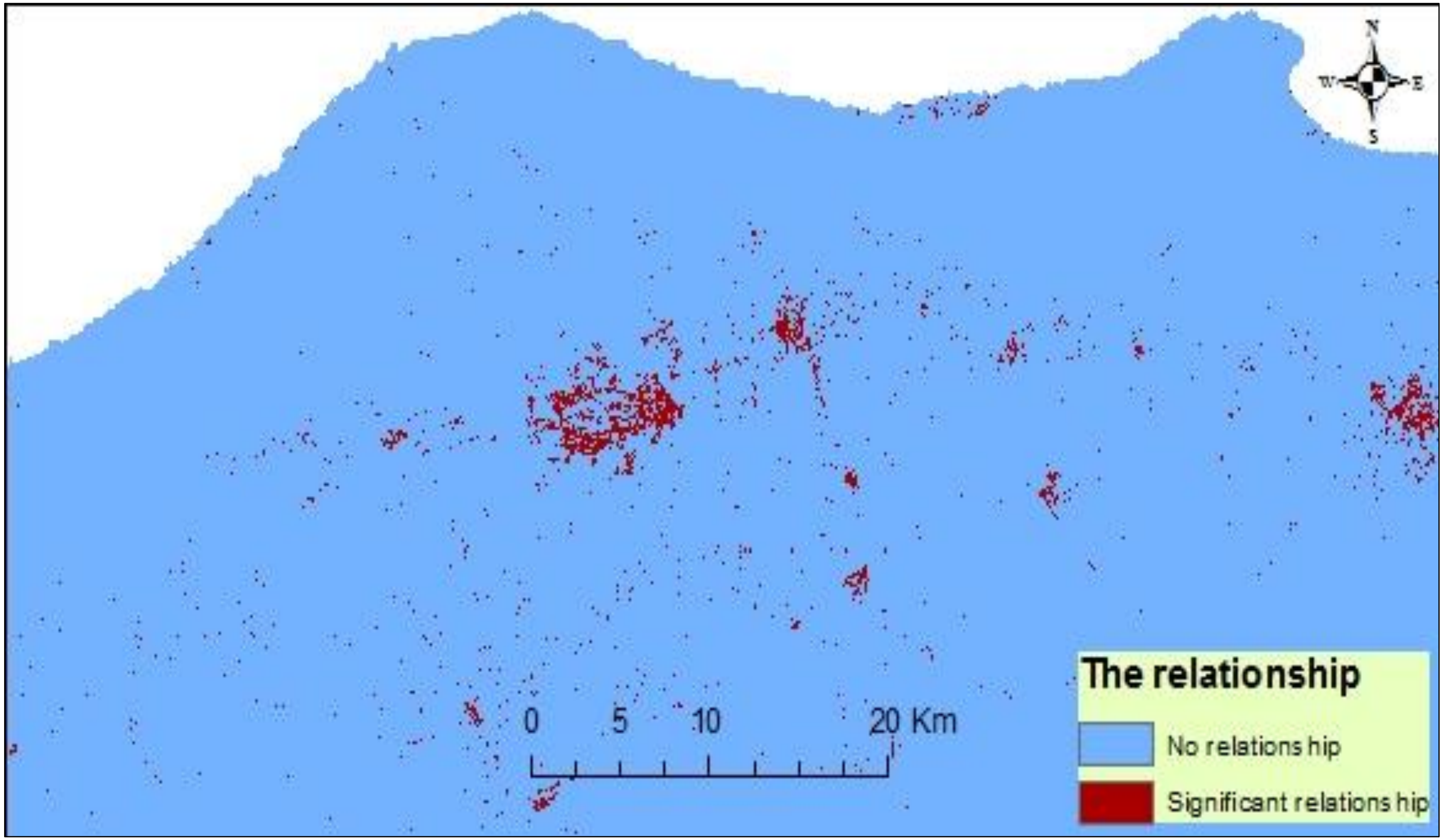


Figure 8.5: The relationship between SAVI and urban area in 2003.

The areal extents of each area of land cover at each date were calculated to assess whether there was a change in the proportions of each class through time (Figure 8.6).

The graphs show several key phenomena. First, the low density shrubland class was consistently the most frequent land cover in pixels showing a significant change in SAVI (except for the most recent image). Second, the agriculture class showed lower frequency of change pixels, but increasing through time. Third, other land cover classes exhibit some changes, although the frequencies for the desert and quarry classes were very low.

Overall, the graphs show that the land cover of pixels showing statistically significant VI change are mostly from the low density shrubland and agriculture classes, although they also occur for other land cover classes. The inference here is that VI change in the agricultural areas are most likely caused by changes in land cover and land use. However, in the areas of low density shrubland, where there is likely to be less human influence, the VI change may be more directly related to climate change.

8.5 Assessing the relationship between land cover change and the population data in the study area

The population of Libya increased from 5,670,688 in 2006 to 6,733,620 in 2012 (General Directorate of Documentation and Information, 2012), which has led to an expansion in human-influenced land cover in the region. The research assessed the relationship between land cover change and the population distribution data for 2013 (since the population data was published in 2012). The aim was to verify the relationship between population and land cover. The approach used the classified land cover images and overlaid them on the population data and the two layers were multiplied together.

The outputs were new data layers showing the population of 1 x 1 km areas where there was land cover change.

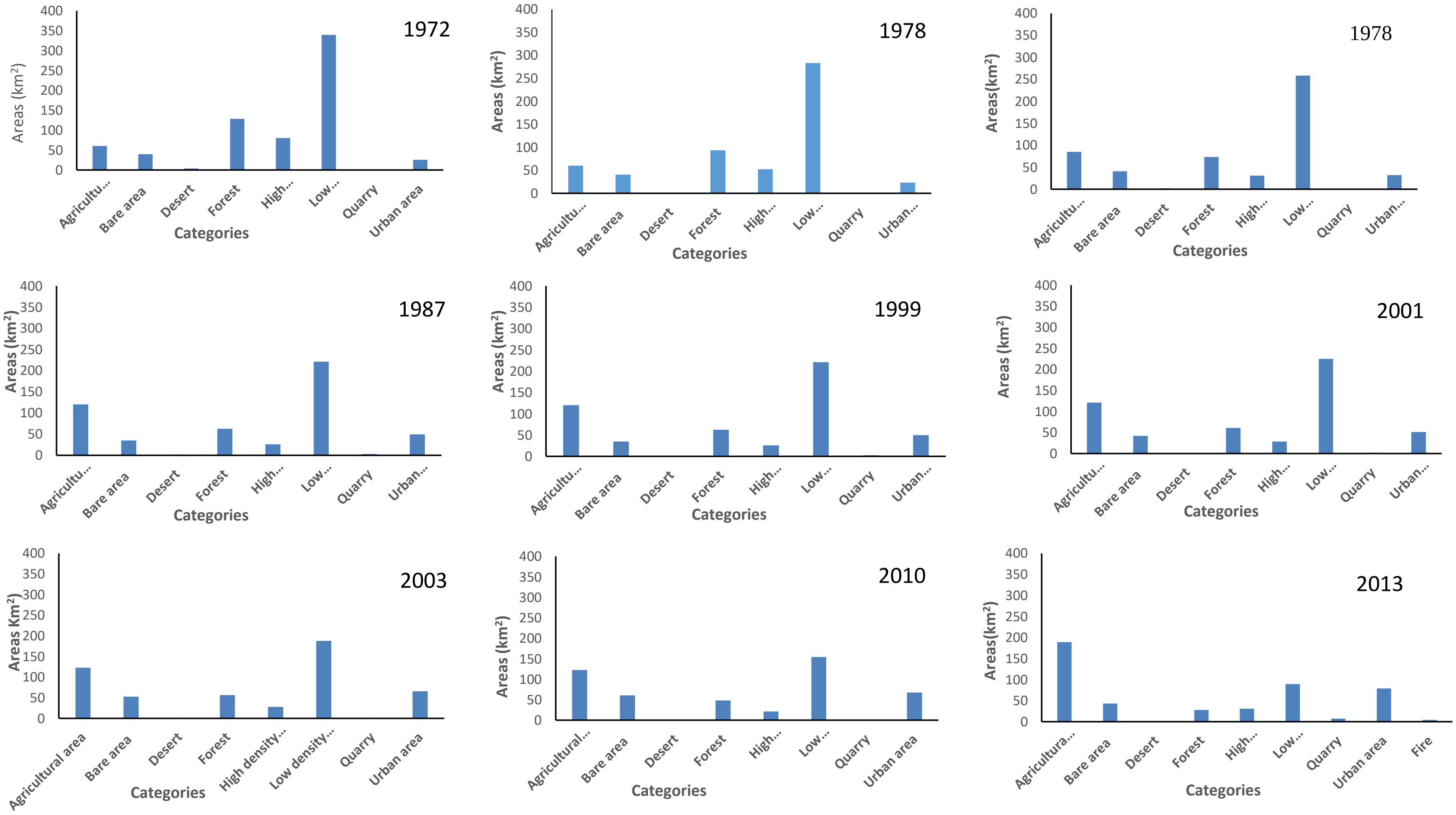


Figure 8.6: The relationship between land cover and significant decrease in SAVI

The images show the concentration of people in the agricultural area and low density shrubland in 2013(Figure 8.7). The approach calculated the population per km^2 on each land cover area, to identify the relationship between cover change and density of population per km^2 (Table 8.1)

Table 8.1: The distribution of population in land cover in the study area in 2013.

Category	area (km^2)	population	population/km^2
Agricultural area	2099	33447	16
Bare area	1010.7	19710	20
Desert	858.3	966	1
Forest	79.5	1254	16
High density shrubland	578.2	17158	30
Low density shrubland	650.3	12979	20
Quarry	191.9	3714	19
Urban area	587.3	259610	442

The table and figure show the distribution of population per km^2 by land cover in 2013. The population was concentrated in small areas in the cities at about 260,000 per 587.31 km^2 or every 442/ km^2, while in the agricultural area, the population was about 33,500 in 2099 km^2 or 16 /km^2 in 2013.

8.6 Assessing the influence of climate change on vegetation cover change in the Al Jabal Al Akhdar

The climate has changed in the study area during the past 57 years, with the mean annual temperature increasing over the 31 years from 1972 to 2003 by 0.2°C at Darnah and Shahat stations and 0.3°C at Benina station in the Al Jabal Al Akhdar region. Furthermore, the results of analysis of the patterns of precipitation indicated no changes in the trends of precipitation in the study area but showed fluctuations in rainfall at all stations over the period of study. Thus, climate change may be affecting vegetation cover, especially in the areas that show a change in vegetation cover but low population densities.

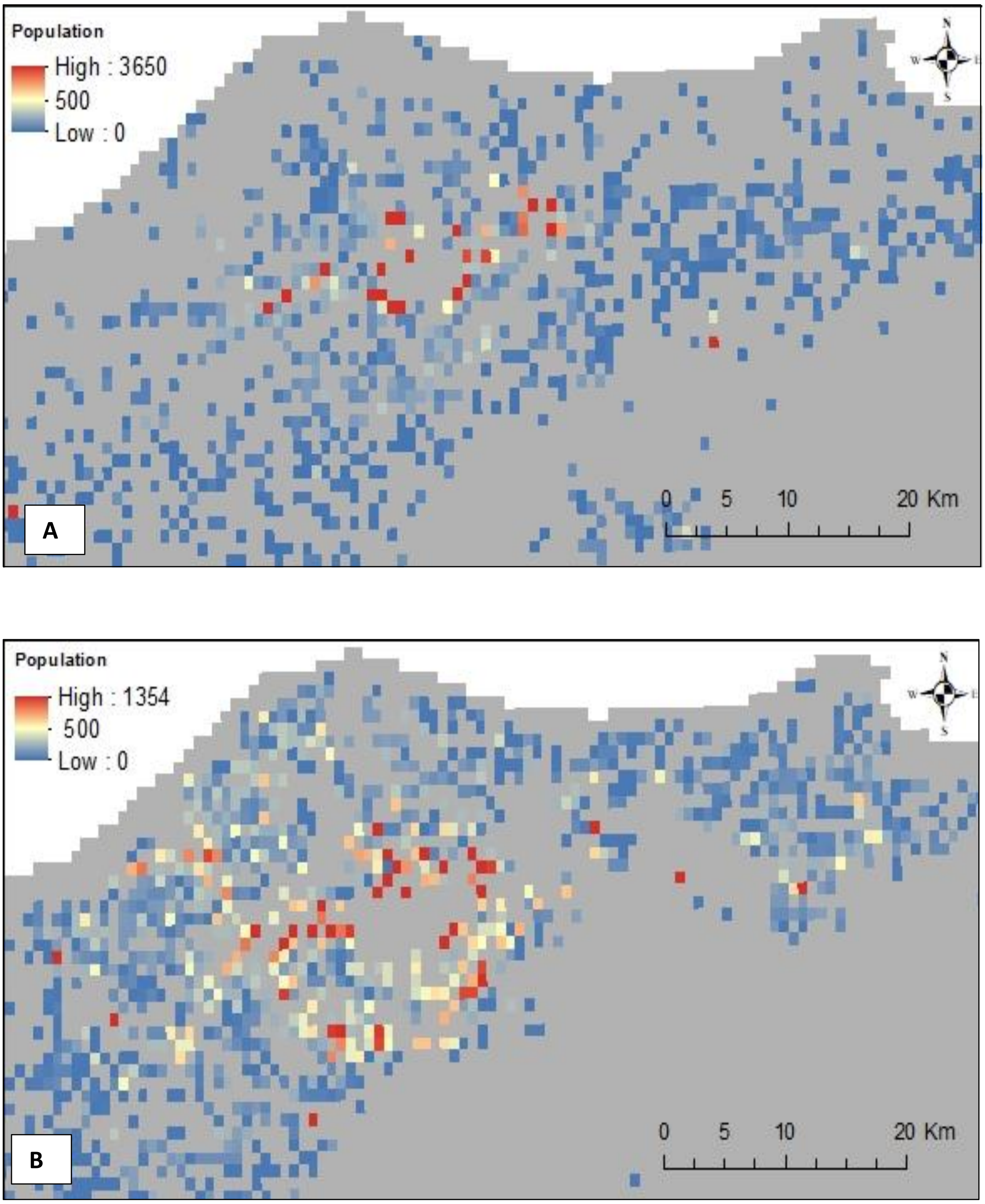


Figure 8.7: The distribution of population in (A) the agricultural area and (B) low density shrubland in 2013.

In the study area, the climate change effect may be most significant on the south-facing slopes of the Al Jabal Al Akhdar region since temperatures are higher than on the north-facing slopes and rainfall is lower (Ageen, 2010: Bukhechiem, 2006). Human activity was shown to be much lower in this area and yet the research showed that there were significant decreases in the SAVI from 1972 to 2014.

8.7 Conclusion

This chapter has presented a range of results aimed at testing the third hypothesis where it was expected that the areas that show vegetation cover change in Al Jabal Al Akhdar were the same areas that have either (i) dense populations and a variety of human activities or (ii) the areas that have vegetation change and low population which may be responding primarily to climate change.

This research demonstrated the relationship between vegetation cover change, land cover change, the population data and climate change in the region to determine whether these factors may be affecting vegetation cover change. Based on the results obtained in chapters 5 (climate change), 7 (vegetation cover change) and 8 (land cover change) in relation to the study area using a remote sensing technique, the research in this chapter synthesized all these results to assess the relationships, and the following conclusions were drawn:

(i) The research evaluated the relationship between vegetation cover change and the population data of the study area to identify the effect of population distribution on vegetation change. The result indicated a large number of areas that experienced change in vegetation cover where population density ranged between medium and high-density.

(ii) The influence was clear in the areas around the cities where population density was highest and vegetation cover decreased over the period of study.

(iii) There was a relationship between the distribution of population and land cover change, where the concentration of population in the urban areas was higher than the population in shrubland, forests, desert and bare areas.

Overall, there are a variety of factors affecting vegetation cover change, however, the effect of human activity on vegetation was clear and rapid through changing land use in the region over the 42 years. The effect of climate change was less clear in other parts of the study area. However, the research suggests that the areas that experienced changes in vegetation cover in shrubland areas with low population density, especially in the areas in the south of the Al Jabal Al Akhdar, responded to increasing temperatures.

The aim of this chapter was to identify the reasons for changes in vegetation cover in the Al Jabal Al Akhdar region over the 42 years. The chapter has used outputs of all the objectives, the VI change maps, land cover change, climate change and population data which were used as a proxy for human activities that cannot be observed on satellite imagery. Use was made of overlay analyses for this aim, and new maps were presented for matching between areas that have significant vegetation cover change and human activity areas showing land use change.

The important conclusion to be drawn from this chapter is that there are areas with low human activity which have experienced significant changes in vegetation cover over the period, therefore, the probability is that climate change may be responsible for this change, or it may be due to desertification, overgrazing, the making of charcoal using the wood of trees or decreasing groundwater. This result needs more investigation for these specific areas by field work and more research needs to be conducted to determine which factors are causing vegetation cover change.

CHAPTER 9: DISCUSSION AND CONCLUSIONS

9.1 Introduction

The Al Jabal Al Akhdar in north east Libya has very significant environmental and economic importance for the local cities, because it is the only region that has natural vegetation with much of the rest of the country being desert. This vegetation belongs to the Mediterranean region and provides many services for the cities which are located north of the Libyan Desert. The main objective of this thesis was to investigate vegetation cover change in the Al Jabal Al Akhdar region over a 42 year period and assess the factors affecting vegetation change in this area.

In recent years, vegetation cover in the study area has been decreasing according to a number of local studies (Al Mukhtar, 2005; Ben Khaial & Bukhechiem, 2005; Ibrahim, 2008). These studies relied on fieldwork to examine the vegetation in a small number of places in the study area and for specific periods of time. The work conducted in this thesis aimed to address some of the shortcomings and gaps in the previous research by introducing a new original research theme. Although the work is intrinsically linked with previous research and is built upon many of its principles, it investigates vegetation cover change over 42 years using remote sensing techniques, and identifies the factors causing this change, which has not previously been explored in this region.

The research presented in this thesis was driven by three main objectives which involved assessing vegetation cover change, human activity, and climate change in the study area, and used the findings to investigate spatial patterns in the factors affecting vegetation change.

To achieve these objectives, the research used time-series Landsat imagery for detecting vegetation cover change, which is one of the most important applications of multi-temporal remote sensing images. In particular, the research used three vegetation indices (VI) to analyse the images and produce maps of vegetation index change. The VI were the Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI) and Enhanced Vegetation Index (EVI). The key points from the research are discussed in the next four sections, followed by a set of final conclusions from the research.

9.2 Climate change

Statistical analysis of climate data from a small number of climate stations in the study area showed that there was an increase in mean annual temperature over the 57 years of available climate records. No statistically significant changes in rainfall were detected. Two key limitations were the small number of stations available and the incomplete record of data, with recent climate records unavailable because of unrest in the area since 2011. This curtailed the number of records available for analysis, and prevented spatial interpretation of the data to a gridded data product. In spite of these limitations the results confirmed those of other studies such as the IPCC Fourth and Fifth Reports (2007, 2014) and Liberato (2011) in the Mediterranean area, and El-Tantawi (2005) and Ageena (2010) in Libya. The remaining work of the thesis builds on this overall observation of increasing temperatures, and an assumption that this increase was present across the study area. In the future, i.e. post-conflict, more data from existing and new meteorological stations may become available, enabling the length of the climate change record to be extended, inspiring more confidence in the climate change observations.

9.3 Vegetation cover change

Vegetation cover change was observed in the Al Jabal Al Akhdar region over the 42 year study period, through a statistical analysis of available long-term Landsat imagery. The results of the analysis of VI using linear regression and correlation analysis showed that there was a statistically significant decrease in vegetation cover in some areas over the period of study.

The main limitation here was the lack of Landsat imagery available to cover the whole of the study area. There were up to 200 images for the study area but just 11 images were usable due to cloud cover, or being in a different season. This led to limitations in the analysis of the spatial and temporal records for vegetation cover.

In spite of this limitation, the results provided maps for vegetation cover change in the study area, and confirmed the local-scale results of vegetation cover change in previous studies such as Fox et al. (2012) and Horion et al. (2013) in the Mediterranean area, and Al Mukhtar (2005) and Ibrahim (2014) in the Al Jabal Al Akhdar region.

The remaining part of the thesis builds on this work to fill some of the gaps in the previous studies in Libya, by introducing new methods to monitor the dynamics of environmental phenomena using long-term remote sensing records. In the future, images from different sensors may become available to use for long-term observation of vegetation change and the time-series can then be extended, promoting more confidence in future assessments of the nature and patterns of vegetation cover change.

9.4 Land cover change

The effect of human activity on vegetation cover was clearly observed in the study area through changes in land cover. The results based on classified time-series Landsat imagery showed an increase in the rates of land use change and in particular decline in the area of forests and shrubland over the 42 years.

There were classification errors in all outputs for the study area and there is a need to improve some accuracies within individual classes in the classification process. This was a key limitation in this objective. The results confirmed the change in land cover with overall classification accuracy of about 72%. The thematic maps for land cover change in the study area over the 42-year period provided approximate rates and magnitudes of change for each land cover. These results confirmed the previous studies which examined land cover change such as, Stefanidis et al.(2016), Al Qurashi & Kumar.(2013) in some areas in the Mediterranean area, and Oune (2006), Ibrahim (2014) in Libya, which used the classification method and showed a decrease of vegetation cover in some areas in the Mediterranean region and Libya and an increase in human land use in those areas.

The remaining work for this objective was based on identifying the negative effect of human activity on land cover change, in an attempt to provide the evidence for environmentalists and decision-makers who are concerned with the effects of human intervention on vegetation cover.

9.5 Exploring the causes of vegetation change

Population expansion and human activities were the main factors causing change in vegetation cover in the study area. The analysis of the statistically significant VI change and the population data showed a strong positive relationship between population and vegetation cover change, through concentration of population in the areas that experienced a change in vegetation cover. Furthermore, there was also a strong relationship between a decrease in the extent of forest and shrubland and an increase in the areas covered by human activity in the study area over the period of study due to an increase in the population. In terms of the effect of climate change, the research assumed that in the areas that had changes in vegetation cover combined with low human population and human activity, climate change may have been responsible for this change.

There were three limitations to achieving this objective: first, non-availability of population data for previous years to determine the relationship between the time-series of population and long-term vegetation cover change; second, the lack of spatial analysis of the relationship between climate change and the areas that have vegetation change due to the small number of climate stations which covered the study area; third, limited background research on the factors affecting vegetation change in the study area, which may help to explain the factors causing vegetation cover change.

In spite of these limitations, the results confirmed other studies such as Estes et al. (2012) and McMichael et al. (2003) which showed the effect of human activity on vegetation cover change in the Mediterranean region, and El-Tantawi (2005) and Oune (2006), who illustrated the effect of human activity on degradation of vegetation cover in west Libya.

9.6 Conclusions

Based on the results obtained from investigating the objectives, the following conclusions are drawn:

(i) The effectiveness of remote sensing techniques to assess vegetation cover change has been demonstrated successfully in the study area.

(ii) The research used three VI indices (NDVI, SAVI and EVI), to examine vegetation cover change, and although the results of the analysis of the VI were slightly different, they confirmed that there was spatial and temporal change in vegetation cover over the 42 years across the Al Jabal Al Akhdar region.

(iii) The results of statistical analysis of the VI correlation coefficient indicated a statistically significant decrease in the trend of vegetation cover in some areas and other areas with no statistically significant change in vegetation cover.

(iv) The thematic maps that were derived from classification Landsat images for the study area proved effective in measuring the areal extent for each land cover.

(v) Land cover has changed across the study area, with results showing a decrease in forest and shrubland cover, with an increase in human activity in terms of conversion to cultivated land or built-up areas.

(vi) There was a positive relationship between the decrease in forest area and shrubland and the increase in human land use in the study area. The area covered by forests in 1972 was about 128.9 km^2 and declined in 2014 to 35 km^2. In contrast, there was an increase in the area of agriculture from 50 km^2 in 1972 to 201 km^2 in 2014 due to an increase in population and increased requirements for food.

The overall conclusion of this work is that vegetation cover in the Al Jabal Al Akhdar has changed over the 42 years and the reasons for this change can be traced to a variety of factors which have affected vegetation cover.

The main aim of this thesis was to assess vegetation cover of the Al Jabal Al Akhdar region and detect any changes over the 42 years, especially during the period of recent unrest in Libya since 2011, using available Landsat images (1972- 2014) , including any negative effects of human activity on vegetation cover. The main finding was that there was a statistically significant change in vegetation cover in many areas across the region, confirming local studies of vegetation cover change in some areas and in specific years. In consequence, the research examined the factors that may have caused these changes, which had not been examined by other local studies, and used a variety of methods to detect these factors.

The influence of human activity on vegetation cover through increased human-related land use in the region during the period of study was clear and rapid through increased agricultural use and urbanisation which were observed from the time series of Landsat image classification. Other areas showing a decline in vegetation cover where there was population but no agricultural activities, quarries or big cities were observed from satellite imagery. leading to the conclusion that there were some illegal activities, such as overgrazing, cutting down trees for fuel, and bush burning for extension of farmland.

However, the research indicated that in the areas that experienced changes in vegetation cover along with low levels of human activity, climate change may be primarily responsible, especially, in the areas in the south of the Al Jabal Al Akhdar region where there were increases in temperature along with low rainfall. Other possible factors might be onset of desertification or lack of groundwater. These areas need more investigation and field work to identify these reasons for these particular changes.

References

Abbott, I., & Le Maitre, D. (2010). Monitoring the impact of climate change on biodiversity: The challenge of megadiverse Mediterranean climate ecosystems. *Austral Ecology, 35*(4), 406-422.

Aggarwal, S. (2004). Principles of remote sensing. Satellite remote sensing and GIS applications in agricultural meteorology. "*In Proceedings of the Training Workshop in Dehradun, India. AGM-8, WMO/TD*, no.1182, 39-65

Aplin, P. (2004). Remote sensing: land cover. Progress in Physical Geography, 28 (2), 283-293.

Ageena, I. (2010). Trends and patterns in the climate of Libya (1945-2010) (Doctoral dissertation, University of Liverpool).

Ageena, I., Macdonald, N., & Morse, A. (2014). Variability of minimum temperature across Libya (1945–2009). *International Journal of Climatology,33* (3), 641-653.

Ahl, D., Gower, S., Burrows, S., Shabanov, N., Myneni, R., & Knyazikhin, Y. (2006). Monitoring spring canopy phenology of a deciduous broadleaf forest using MODIS. *Remote Sensing of Environment, 104*(1), 88-95.

Alhamad, M. (2006). Ecological and species diversity of arid Mediterranean grazing land vegetation. *Journal of Arid Environments, 66*(4), 698-715.

Almukhtar, O. (2005). The natural vegetation of Al Jabal Al Akhdar. Assessment report for the vegetation of the Al Jabal AL Akhdar region, Al Bayda, Libya (3), 1-945.

Alqurashi, A. F., & Kumar, L. (2013). Investigating the use of remote sensing and GIS techniques to detect land use and land cover change*: A review. Advances in Remote Sensing, 2(02), 193*

Andela, N., Liu, Y., van Dijk, M., de Jeu, R. A. M., & McVicar, T. (2013). Global changes in dryland vegetation dynamics (1988-2008) assessed by satellite remote sensing: comparing a new passive microwave vegetation density record with reflective greenness data. *Biogeosciences,* 10(10), 6657.

Bajirao, B. (2015). Importance of vegetation in urban environment. *International Journal of Scientific and Research Publications.* 5(2), 2250-3153.

Bajocco, S., De Angelis, A., Perini, L., Ferrara, A., & Salvati, L. (2012). The impact of land use/land cover changes on land degradation dynamics: a

Mediterranean case study. *Environmental Management*, 49(5), 980-989.

Bannari, A., Morin, D., Bonn, F., & Huete, A. R. (1995). A review of vegetation indices. *Remote Sensing Reviews, 13*(1-2), 95-120.

Barbero, M., Bonin, G., Loisel, R., & Quézel, P. (1990). Changes and disturbances of forest ecosystems caused by human activities in the western part of the Mediterranean basin. *Vegetation*, 87(2), 151-173.

Batllori, E., Parisien, M. A., Krawchuk, M. A., & Moritz, M. A. (2013). Climate change-induced shifts in fire for Mediterranean ecosystems. *Global Ecology and Biogeography, 22*(10), 1118-1129.

Ben Khaial, A., Bukhechiem, A. (2005). Development of agricultural and pastoral in Al Jabal Al Akhdar-Libya. *Annual report of the north east Libya, 2*.

Benediktsson, J. A., Chanussot, J., & Moon, W. M. (2012). Very high-resolution remote sensing: Challenges and opportunities [point of view]. *Proceedings of the IEEE*, *100* (6), 1907-1910.

Berberoglu, S., & Akin, A. (2009). Assessing different remote sensing techniques to detect land use/cover changes in the eastern Mediterranean. *International Journal of Applied Earth Observation and Geoinformation, 11*(1), 46-53.

Berendse, F. (2005). Impacts of global change on plant diversity and vice versa: Old and new challenges for vegetation scientists. *Journal of Vegetation Science, 16*, 613-616.

Beltrán, B. J., Franklin, J., Syphard, A. D., Regan, H. M., Flint, L. E., & Flint, A. L. (2014). Effects of climate change and urban development on the distribution and conservation of vegetation in a Mediterranean type ecosystem. *International Journal of Geographical Information Science*, 28 (8), 1561-1589.

Blondel, J. (2010). The Mediterranean region: biological diversity in space and time. Oxford University Press. Inc., New York.

Bréda, N. (2003). Ground-based measurements of leaf area index: a review of methods, instruments and current controversies. *Journal of Experimental Botany, 54*(392), 2403-2417.

Briales, R., & Ravenel, H. (2013). State of the Mediterranean forest 2013. *Food and Agriculture Organization of the United Nations*. FAO, 2013, New York.

Brovkin, V. (2002). Climate-vegetation interaction. *Journal De Physique Archive, IV* (12), 57-52.

Bukhechiem, A. (2006). The climate of north east of Libya. *Annual report of the north east Libya*, Benghazi, Libya, *2*, (1), 54-203.

Buriánek, V., Novotný, R., Hellebrandová, K., & Šrámek, V. (2013). Ground vegetation as an important factor in the biodiversity of forest ecosystems and its evaluation in regard to nitrogen deposition. *Journal of Forest Science*, *59*(6), 238-252.

Campbell, J. B. (2002). Introduction to remote sensing. CRC Press.

Carlson, T., & Ripley. A. (1997). On the relation between NDVI, fractional vegetation cover, and leaf area index. *Remote Sensing of Environment*, *62*(3), 241-252.

Carlotto, M. J. (1987). Histogram analysis using a scale-space approach. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, (1), 121-129.

Chatterjee, S., & Hadi, A. S. (2015). Regression analysis by example. *John Wiley & Sons.* Inc., Hoboken, New Jersey.

Chatterjee, S., & Hadi, A. S. (2006). Simple linear regression. Regression Analysis by Example, Fourth Edition, 21-51.

Childs, C. (2004). Interpolating surfaces in ArcGIS spatial analyst. ArcUser, July-September, *ESRI Education Service*, Los Angeles. 3235.

Chuvieco, Emilio, and Alfredo Huete. (2009). Fundamentals of satellite remote sensing. CRC Press Inc., London.

Chmura, D., Anderson, P., Howe, G., Harrington, C., Halofsky, J., Peterson, D & Clair, J. (2011). Forest responses to climate change in the northwestern United States: ecophysiological foundations for adaptive management. *Forest Ecology and Management*, *261*(7), 1121-1142.

Colombaroli, D., & Tinner, W. (2013). Determining the long-term changes in biodiversity and provisioning services along transect from Central Europe to the Mediterranean. *The Holocene*, *23*(11), 1625-1634.

Combourieu-Nebout, N., Bertini, A., Russo-Ermolli, E., Peyron, O., Klotz, S., Montade, V & Sadori, L. (2015). Climate changes in the central Mediterranean and Italian vegetation dynamics since the Pliocene. *Review of Palaeobotany and Palynology.*, 218, 127-147.

Congalton, R. (2007).Thematic and positional accuracy assessment of digital remotely sensed data. *In Proceedings of the seventh annual forest inventory and analysis symposium*, Vol. 1,. 1-51.

Cook, B. I., Smerdon, J. E., Seager, R., & Coats, S. (2014). Global warming and 21st century drying. *Climate Dynamics*, 43(9-10), 2607-2627.

Cracknell, A. P. (2007). Introduction to Remote Sensing. CRC press. New York.

Dale, V., Joyce, L., McNulty, S & Neilson, R. (2000). The interplay between climate change, forests, and disturbances. *Science of the Total Environment*, 262(3), 201-204.

Davis, M. A., Pergl, J., Truscott, A. M., Kollmann, J., Bakker, J. P., Domenech, R., & del Moral, R. (2005). Vegetation change: a reunifying concept in plant ecology. *Perspectives in Plant Ecology, Evolution and Systematics*, 7(1), 69-76.

Del Cacho, M., Saura-Mas, S., Estiarte, M., Peñuelas, J., & Lloret, F. (2012). Effect of experimentally induced climate change on the seed bank of a Mediterranean shrubland. *Journal of Vegetation Science*, 23(2), 280-291.

De Dios, V. R., Fischer, C., & Colinas, C. (2007). Climate change effects on Mediterranean forests and preventive measures. *New Forests*, 33(1), 29-40.

Dobson, J., Bright, E., Coleman, P., Durfee, R., & Worley, B. (2000). LandScan: a global population database for estimating populations at risk. *Photogrammetric Engineering and Remote Sensing*, 66(7), 849-857.

El-Tantawi, M. (2005). Climate Change in Libya and Desertification of Jifara Plain Using Geographical Information System and Remote Sensing Techniques. Fachbereich Chemie, Pharmazie, Geowissenschaften der Johannes Gutenberg-Universität, 1- 246. http://d-nb.info/97597503X/34.

Elzinga, C., Salzer, D., & Willoughby, J. (1998). Measuring & Monitering Plant Populations. U.S. Bureau of Land Management, Denver, Colorado.

Estes, A., Kuemmerle, T., Kushnir, H., Radeloff, V & Shugart, H. (2012). Land-cover change and human population trends in the greater Serengeti ecosystem from 1984–2003. *Biological Conservation*, *147*(1), 255-263.

Fan, L., Gao, Y., Brück, H & Bernhofer, C. (2009). Investigating the relationship between NDVI and LAI in semi-arid grassland in Inner Mongolia using in-situ measurements. *Theoretical and Applied Climatology*, *95*(1-2), 151-156.

F.A.O. (2005). Libyan Arab Jamahiriya. *Aquastat*. vol, 29, 1-10.

FAO. (2010). Forest Resource Assessment 2010. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/docrep/013/i1757e/i1757e.pdf http://www.fao.org/forestry/fra2010.

Feng, M., Sexton, J., Huang, C., Masek, J., Vermote, E., Gao, F & Townshend, J. (2013). Global surface reflectance products from Landsat: Assessment using coincident MODIS observations. *Remote Sensing of Environment, 134,* 276-293.

Fensholt, R., & Sandholt, I. (2005). Evaluation of MODIS and NOAA AVHRR vegetation indices with in situ measurements in a semi-arid environment. *International Journal of Remote Sensing*, 26(12), 2561-2594.

Foody, G. M. (2002). Status of land cover classification accuracy assessment. *Remote Sensing of Environment*, 80(1), 185-201.

Fox, D, Witz, E., Blanc, V., Soulié, C., Penalver-Navarro, M., & Dervieux, A. (2012). A case study of land cover change (1950–2003) and runoff in a Mediterranean catchment. *Applied Geography, 32*(2), 810-821.

Foster, D. R. (1992). Land-use history (1730-1990) and vegetation dynamics in central New England, USA. Journal of Ecology, Vol. 80 (4),753-771.

Fuchs, R., Herold, M., Verburg, P., & Clevers, J. (2012). A high-resolution and harmonized model approach for reconstructing and analyzing historic land changes in Europe. *Biogeosciences Discuss*., 9, 14823–14866

Fyllas, N. M., & Troumbis, A. Y. (2009). Simulating vegetation shifts in north-eastern Mediterranean mountain forests under climatic change scenarios. *Global Ecology and Biogeography*, *18*(1), 64-77.

Gallego, F. (2004). Remote sensing and land cover area estimation. *International Journal of Remote Sensing, 25*(15), 3019-3047.

Gandhi, G. M., Parthiban, S., Thummalu, N., & Christy, A. (2015). Ndvi: Vegetation Change Detection Using Remote Sensing and Gis–A Case Study of Vellore District. *Procedia Computer Science*, 57, 1199-1210.

Gerber, S., Joos, F., & Prentice, I. C. (2004). Sensitivity of a dynamic global vegetation model to climate and atmospheric CO^2. *Global Change Biology*,10(8), 1223-1239.

Gilabert, M. A., González-Piqueras, J., Garcıa-Haro, F. J., & Meliá, J. (2002). A generalized soil-adjusted vegetation index. *Remote Sensing of Environment*, 82(2), 303-310

Giorgi, F., & Lionello, P. (2008). Climate change projections for the Mediterranean region. *Global and Planetary Change, 63*(2), 90-104.

Gregory, S., Oetter, D., Ashkenas, L., Minear, P., Wildman, K., & Christy, J. (2002). Natural vegetation. Willamette River Basin planning atlas: trajectories of environmental and ecological change. Oregon State University Press, Corvallis, 96-97.

Haferkamp, M. R. (1988). Environmental factors affecting plant productivity. InAchieving efficient use of rangeland resources. *Fort Keogh Research Symposium,* Miles City (pp. 27-36).

Hall, F. C. (2001). Ground-based photographic monitoring. Portland, OR: US Department of Agriculture, *Forest Service*, Pacific Northwest Research Station. Portland.

Hansen, M. C., & Loveland, T. R. (2012). A review of large area monitoring of land cover change using Landsat data. *Remote sensing of Environment, 122*, 66-74.

Hegazy, A. K., Boulos, L., Kabiel, H. F., & Sharashy, O. S. (2011). Vegetation and species altitudinal distribution in Al-Jabal Al-Akhdar landscape, Libya. *Pakistan Journal of Botany, 43,* 1885-1898.

Higgins, J. (2006). The radical statistician: A beginners guide to unleashing the power of applied Statistics in the Real World. Self-published.

Hill, J., Stellmes, M., Udelhoven, T., Röder, A., & Sommer, S. (2008). Mediterranean desertification and land degradation: mapping related land use change syndromes based on satellite observations. *Global and Planetary Change, 64*(3), 146-157.

Hoffmann, J. (1998). Assessing the effects of environmental changes in a landscape by means of ecological characteristics of plant species. *Landscape and Urban Planning*, 41(3), 239-248.

Horion, S., Cornet, Y., Erpicum, M., & Tychon, B. (2013). Studying interactions between climate variability and vegetation dynamic using a phenology based approach. *International Journal of Applied Earth Observation and Geoinformation*, *20*, 20-32.

Huete, A. R. (1988). A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment*, 25(3), 295-309.

Huete, A. R. (2012). Vegetation indices, remote sensing and forest monitoring. *Geography Compass*, 6(9), 513-532.

Ibrahim, S. M. (2006). The decline of natural vegetation in the south of Al-Jabal Al-

Akhdar Libya. (Unpublished MSc thesis), Omer al Mukhtar university, Darnah, Libya.

Ibrahim, A. A. (2008, November). Using remote sensing technique (NDVI) for monitoring vegetation degradation in semi-arid lands and its relationship to precipitation: Case study from Libya. In The 3rd International Conference on Water Resources and Arid Environments (pp. 16-19).

IPCC (2007). Climate Change 2007: The Physical Science Basis. In: Solomon, S., et al. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (eds). Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC (2013). Climate Change 2013: The Physical Science Basis. Summary for Policymakers. In: Stocker,T., Qin, D., et al. Contribution of Working Group I to the fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds). Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC (2014). Climare Change 2014: Impacts, Adaptation, and Vulnerability, Summary for Policymakers. Working Group II Contribution to the fifth Assessment Report of the Intergovernmental Panel on Climate change (eds). Cambridge University Press, Cambridge, UK.

Ispikoudis, I., Lyrintzis, G., & Kyriakakis, S. (1993). Impact of human activities on Mediterranean landscapes in western Crete. *Landscape and Urban Planning,24* (1), 259-271.

Ivits, E., Horion, S., Fensholt, R., & Cherlet, M. (2014). Drought footprint on European ecosystems between 1999 and 2010 assessed by remotely sensed vegetation phenology and productivity. *Global Change Biology, 20*(2), 581-593.

Jackson, R. D., & Huete, A. R. (1991). Interpreting vegetation indices. *Preventive Veterinary Medicine*, 11(3-4), 185-200.

Jiang, Z., Huete, A. R., Didan, K., & Miura, T. (2008). Development of a two-band enhanced vegetation index without a blue band. *Remote Sensing of Environment*, 112(10), 3833-3845.

Jin, X. M., Zhang, Y. K., Schaepman, M. E., Clevers, J. G. P. W., & Su, Z. (2008). Impact of elevation and aspect on the spatial distribution of vegetation in the Qilian mountain area with remote sensing data. *The*

International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 37, 1385-1390.

Jing- Yun, F., Yong-chang, S., Yan-chong, L., Shi-long, P. (2002). Vegetation-climate relationship and its application in the division of vegetation zone in China. *Acta Botanica Sinica, 44*(9).

Jiguet, F., Brotons, L., & Devictor, V. (2011). Community responses to extreme climatic conditions. *Current Zoology, 57*(3), 406-413.

Jiménez, M., & Díaz-Delgado, R. (2015). Towards a standard plant species spectral library protocol for vegetation mapping: A case study in the shrubland of Doñana National Park. *ISPRS International Journal of Geo- information,* 4(4), 2472-2495.

Joannin, S., Lebretona, V., Magri, D., Martinetto, E., Orain, R & Sadori, Laura. (2015). Climate changes in the central Mediterranean and Italian vegetation dynamics since the Pliocene. *Review of Palaeobotany and Palynology,*218, 127–147.

Jonckheere, I., Fleck, S., Nackaerts, K., Muys, B., Coppin, P., Weiss, M., & Baret, F. (2004). Methods for leaf area index determination. Part I: Theories, techniques and instruments. *Agric. For. Meteorol, 121*, 19-35.

Ju, J., Roy, D., Vermote, E., Masek, J& Kovalsky, V. (2012). Continental-scale validation of MODIS-based and LEDAPS Landsat ETM+ atmospheric correction methods. *Remote Sensing of Environment,* (122), 175–184.

Karas, J. (1997). Climate change and the Mediterranean region. Report prepared for Greenpeace. *Greenpeace International,* Amsterdam, 34.

Karmeshu, N. (2012). Trend Detection in Annual Temperature & Precipitation using the Mann Kendall Test–A Case Study to Assess Climate Change on Select States in the Northeastern United States. Science, University of Pennsylvania Scholarly Commons, 1-27.

Kasturirangan, K. (1996). Ground based measurements for interpretation of vegetation indices over developing countries. *Advances in Space Research, 17*(8), 31-40.

Kawada, K., Suzuki, K., Suganuma, H., Smaoui, A., & Isoda, H. (2012). Plant biodiversity in the semi-arid zone of Tunisia. *Journal of Arid Land Studies*. 22(1), 83-86.

Keeley, J. E. (1986). Resilience of Mediterranean shrub communities to fires.

Resilience in Mediterranean-type ecosystems (pp. 95-112).

Kharuk, V. I., Alshansky, A. M., & Yegorov, V. (1992). Spectral characteristics of vegetation cover: factors of variability. *International Journal of Remote Sensing*, 13(17), 3263-3272.

Knorn, J. (2012). Studying land-use and land-cover change with high resolution data (Doctoral dissertation, Humboldt-Universität zu Berlin, Mathematisch-Naturwissenschaftliche Fakultät II).

Krishnaswamy, J., John, R., & Joseph, S. (2014). Consistent response of vegetation dynamics to recent climate change in tropical mountain regions. *Global Change Biology, 20*(1), 203-215.

La Mela Veca, D. S., Cullotta, S., Sferlazza, S., & Maetzke, F. G. (2016). Anthropogenic influences in land use/land cover changes in Mediterranean forest landscapes in Sicily. *Land*, 5(1), 3.

Lanfredi, M., & Liberti, M. (2005). Long-time vegetation dynamics inferred from satellite: evaluation of characteristic time scales of photosyntetic activity trends. *Geophysical Research Abstracts* (Vol. 7, p. 09679).

Langgut, D., Almogi-Labin, A., Bar-Matthews, M., & Weinstein-Evron, M. (2011). Vegetation and climate changes in the South Eastern Mediterranean during the Last Glacial-Interglacial cycle (86 ka): new marine pollen record. *Quaternary Science Reviews, 30*(27), 3960-3972.

Lasanta, T., & Vicente-Serrano, S. M. (2012). Complex land cover change processes in semiarid Mediterranean regions: An approach using Landsat images in northeast Spain. *Remote Sensing of Environment, 124*, 1-14.

Lasanta, T., Vicente-Serrano, S., Henne, M., Che´ Elkin, P & Colombaroli , D. (2013) Impacts of changing climate and land use on vegetation dynamics in a Mediterranean ecosystem: insights from paleoecology and dynamic modelling. *Landscape Ecol* (28), 819–833

Lavorel, S., Canadell, J., Rambal, S., & Terradas, J. (1998). Mediterranean terrestrial ecosystems: research priorities on global change effects. *Global Ecology & Biogeography Letters, 7*(3), 157-166.

Lelieveld, J., Hadjinicolaou, P., Kostopoulou, E., Chenoweth, J., El Maayar, M. Giannakopoulos, C., Hannides, C., Lange, M., Tanarhte, M., Tyrlis, E., and Xoplaki ,E.(2012). Climate change and impacts in the Eastern Mediterranean and the Middle East. *Climate Change*, 114(3-4), 667–

687.

Lepart, J., & Debussche, M. (1992). Human impact on landscape patterning: Mediterranean examples. *In Landscape Boundaries* (pp. 76-106).

Lei, H., Yang, D., & Huang, M. (2014). Impacts of climate change and vegetation dynamics on runoff in the mountainous region of the Haihe River basin in the past five decades. *Journal of Hydrology*, *511*, 786-799.

Lhag, M., & Boteva, S. (2016, October). Mediterranean Land Use and Land Cover Classification Assessment Using High Spatial Resolution Data. In IOP Conference Series: *Earth and Environmental Science* (Vol. 44, No. 4, p. 042032). *IOP Publishing.*

Li, H. J., Zheng, L., Lei, Y. P., Li, C. Q., & Zhou, K. (2007). Comparison of NDVI and EVI based on EOS/MODIS data. *Progress in Geography*, Beijing, 26(1), 26-32.

Li, X., Wang, H., Long, H., Wei, D., & Bao, Y. (2012). A model for the estimation of fractional vegetation cover based on the relationship between vegetation and soil moisture. *International Journal of Remote Sensing*, *33*(11), 3580-3595.

Li, Y., Wang, H., & Li, X. B. (2015). Fractional Vegetation Cover Estimation Based on an Improved Selective Endmember Spectral Mixture Model. *PLOS one*, 10(4), e0124608.

Liberato, M. L., Paoletti, E., & DaCamara, C. (2011). Climate Changes and Forests. *Forest Ecology and Management*, *262*(10), 7-9.

Libyan Agriculture Department (2004). The forests of Al Jabal Al Akhdar. *The Annual Report of Vegetation, Benghazi, 4.*

Lillesand, T., Kiefer, R. W., & Chipman, J. (2014). Remote sensing and image interpretation. *John Wiley & Sons.* New York

Liu, X. (2005). Supervised Classification and Unsupervised Classification.

Lelieveld, J., Hadjinicolaou, P., Kostopoulou, E., Chenoweth, J., El Maayar, M., Giannakopoulos, C. & Xoplaki, E. (2012). Climate change and impacts in the Eastern Mediterranean and the Middle East. *Climatic Change*, 114(3-4), 667-687.

Mansour, K., Mutanga, O., & Everson, T. (2012). Remote sensing based indicators of vegetation species for assessing rangeland degradation: Opportunities and challenges. *Afr. J. Agric. Res*, *7*(22), 3261-3270..

Maiersperger, T., Scaramuzza, P., Leigh, L., Shrestha, S., Gallo, K., Jenkerson, B., & Dwyer, J. (2013). Characterizing LEDAPS surface reflectance products by comparisons with AERONET, field spectrometer, and MODIS data. *Remote Sensing of Environment, 136*, 1-13.

Matsushita, B., Yang, W., Chen, J., Onda, Y., & Qiu, G. (2007). Sensitivity of the enhanced vegetation index (EVI) and normalized difference vegetation index (NDVI) to topographic effects: a case study in high-density cypress forest. *Sensors*, 7(11), 2636-2651.

Martinez-Fernandez, J., Ruiz-Benito, P., & Zavala, M. A. (2015). Recent land cover changes in Spain across biogeographical regions and protection levels: Implications for conservation policies. *Land Use Policy,* 44, 62-75.

McMichael, A. (2003). Climate change and human health: risks and responses. *World Health Organization.* Geneva, Switzerland.

Melia, J., Younis, M., Gilabert, M., (1998). The use of remote sensing data in the study of the desertification process in Medalus project. *International Symposium, Satellite-based Observation*: A tool for the study of the Mediterranean basin. Tunis, 23-27, November 1998.

Michaelowa, A. (2006). Climate Change in the Mediterranean. *Climatic Change,75* (4), 513-515.

Morales, P., Hickler, Th., Rowellw, D., Smith, B., & Sykes, M. (2007). Changes in European ecosystem productivity and carbon balance driven by regional climate model output. *Global Change Biology, 13*, 108–122.

Mamtimin, B., EL-Tantawi, A. M. M., Schaefer, D., Meixner, F. X., & Domroes, M. (2011). Recent trends of temperature change under hot and cold desert climates: Comparing the Sahara (Libya) and Central Asia (Xinjiang, China). *Journal of Arid Environments, 75*(11), 1105-1113.

Muller, R. A., Curry, J., Groom, D., Jacobsen, R., Perlmutter, S., Rohde, R. & Wurtele, J. (2013). Decadal variations in the global atmospheric land temperatures. *Journal of Geophysical Research: Atmospheres, 118* (11), 5280-5286.

Muñoz-Rojas, M., De la Rosa, D., Zavala, L. M., Jordán, A., & Anaya-Romero, M. (2011). Changes in land cover and vegetation carbon stocks in Andalusia, Southern Spain (1956–2007). *Science of The Total Environment, 409* (14), (2011) 2796–2806.

Nazeer, M., Nichol, J. E., & Yung, Y. K. (2014). Evaluation of atmospheric correction models and Landsat surface reflectance product in an urban coastal environment. *International Journal of Remote Sensing*, *35*(16), 6271-6291.

Naveh, Z. (1975). The evolutionary significance of fire in the Mediterranean region. *Vegetation*, *29*(3), 199-208.

Oune, O. (2006). Monitoring desertification in south west Tripoli using multi-temporal remotely sensing data and GIS. PhD thesis University of Dundee, UK.

Osborne, C & Woodward, F. (2001). Biological mechanisms underlying recent increases in the NDVI of Mediterranean shrublands.int. *Remote Sensing*, *22*(10), 1895–1907.

Osborne, C., Mitchell. P., Sheehy, J & Woodward, F. (2000). Modelling the recent historical impacts of atmospheric CO_2 and climate change on Mediterranean vegetation. *Global Change Biology*, (6), 445-458.

Osborne, C., Mitchell, P., Sheehy, J., & Woodward, F. (2000). Modelling the recent historical impacts of atmospheric CO_2 and climate change on Mediterranean vegetation. *Global Change Biology*, *6*(4), 445-458.

Pears, N. (1990). Basic biogeography. Second edition. *Longman Scientific & Technical*, London UK.

Pérez-Hugalde, C., Romero-Calcerrada, R., Delgado-Pérez, P., & Novillo, C. (2011). Understanding land cover change in a Special Protection Area in Central Spain through the enhanced land cover transition matrix and a related new approach. *Journal of Environmental Management*, *92*(4), 1128-1137.

Philandras, C., Nastos, P., Kapsomenakis, J., Douvis, K., Tselioudis, G& Zerefos, C. (2011). Long term precipitation trends and variability within the Mediterranean region. *Natural Hazards and Earth System Science*, *11*(12), 3235-3250.

Pohlert, T. (2015). Non-Parametric Trend Tests and Change-Point Detection. *Technical Report*, January (2015).

Podleśny, J., & Podleśna, A. (2013). Effect of High Temperature in the Flowering Period on Growth, Development and Yielding of Faba Bean (Vicia faba L. spp. Minor). *Ecological Chemistry and Engineering. A*, *20*(1), 71-76.

Prentice, I. C. (1986). Vegetation responses to past climatic variation. *Vegetation*, 67(2), 131-141.

Qi, J., Chehbouni, A., Huete, A. R., Kerr, Y. H., & Sorooshian, S. (1994). A modified soil adjusted vegetation index. *Remote Sensing of Environment,*48 (2), 119-126.

Raich, J & Tufekcloglu,A. (2000). Vegetation and soil respiration: Correlations and controls. *Biogeochemistry* 48: 71–90.

Rawat, J. S., & Kumar, M. (2015). Monitoring land use/cover change using remote sensing and GIS techniques: A case study of Hawalbagh block, district Almora, Uttarakhand, India. *The Egyptian Journal of Remote Sensing and Space Science,* 18(1), 77-84.

Richter, R., Kellenberger, T., & Kaufmann, H. (2009). Comparison of topographic correction methods. *Remote Sensing, 1*(3), 184-196.

Rivaes, R., Rodríguez-González, P., Albuquerque, A., Pinheiro, A., Egger, G& Ferreira, M. (2013). Riparian vegetation responses to altered flow regimes driven by climate change in Mediterranean rivers. *Ecohydrology, 6*(3), 413-424.

Roerink, G. J., Menenti, M., Soepboer, W., & Su, Z. (2003). Assessment of climate impact on vegetation dynamics by using remote sensing. *Physics and Chemistry of the Earth, Parts A/B/C,* 28(1), 103-109

Rondeaux, G., Steven, M., & Baret, F. (1996). Optimization of soil-adjusted vegetation indices. *Remote Sensing of Environment*, 55(2), 95-107.

Roush, W., Munroe, J. S., & Fagre, D. (2007). Development of a spatial analysis method using ground-based repeat photography to detect changes in the alpine treeline ecotone, Glacier National Park, Montana, USA. *Arctic, Antarctic, and Alpine* Research*, 39*(2), 297-308.

Sedgwick, P. (2012). Pearson's correlation coefficient. *British Medical Journal (BMJ*), 345, e4483

Sesnie, S. E., Dickson, B. G., Rosenstock, S. S., & Rundall, J. M. (2012). A comparison of Landsat TM and MODIS vegetation indices for estimating forage phenology in desert bighorn sheep (Ovis canadensis nelsoni) habitat in the Sonoran Desert, USA. *International Journal of Remote Sensing*, 33(1), 276-286.

Seefeldt, S. S., & Booth, D. T. (2006). Measuring plant cover in sagebrush steppe rangelands: a comparison of methods. *Environmental Management*, 37(5), 703-711.

Sexton, J., Urban, D., Donohue, M & Song, C. (2013). Long-term land cover dynamics by multi-temporal classification across the Landsat-5 record. *Remote Sensing of Environment,* (128) 246–258.

Shalaby, A., & Gad, A. (2010, June). Urban sprawl impact assessment on the fertile agricultural land of Egypt using remote sensing and digital soil database, case study: Qalubiya Governorate. In US Egypt Workshop on Space Technology and Geoinformation for Sustainable Development, Cairo, Egypt (Vol. 1417).

Shaw, G., & Burke, H. (2003). Spectral imaging for remote sensing. *Lincoln Laboratory Journal*, 14(1), 3-28.

Shoshany, M. (2000). Satellite remote sensing of natural Mediterranean vegetation: a review within an ecological context. *Progress in Physical Geography, 24* (2) (2000), 153–178.

Silleos, N. G., Alexandridis, T. K., Gitas, I. Z., & Perakis, K. (2006). Vegetation indices: advances made in biomass estimation and vegetation monitoring in the last 30 years. *Geocarto International*, 21(4), 21-28.

Sivakumar, M. V. K., P. S. Roy, K. Harmsen, and S. K. Saha. (2004). "Satellite remote sensing and GIS applications in agricultural meteorology." In *Proceedings of the Training Workshop in Dehradun, India. AGM-8, WMO/TD*, no. 1182..

Sluiter, R. (2005). Mediterranean land cover change: modelling and monitoring natural vegetation using GIS and remote sensing. Utrecht University. Netherlands.

Sneyers, R. (1999). On the statistical analysis of series of observations, *Technical Note 143, WMO*-No, 415, 192-194.

Sohl, T., & Sleeter, B. (2012). Role of remote sensing for land-use and land-cover change modeling. 225-239

Solaimani, K., Arekhi, M., Tamartash, R., & Miryaghobzadeh, M. (2010). Land use/cover change detection based on remote sensing data (A case study; Neka Basin). *Agriculture and Biology Journal of North America (Agric. Biol. JN Amer),* 1, 1148-1157.

Soleimani, K., Kordsavadkooh, T and Muosavi, S. (2008). Effect of environmental factors on vegetation changes using GIS (Case Study: Cherat Catchment, Iran). *World Applied Sciences Journal, 3*, 95-100.

Song, C., Woodcock, C. E., Seto, K. C., Lenney, M. P., & Macomber, S. (2001).

Classification and change detection using Landsat TM data: when and how to correct atmospheric effects?. *Remote Sensing of Environment, 75* (2), 230-244.

Stefanidis, K., Kostara, A., & Papastergiadou, E. (2016). Implications of human activities, land use changes and climate variability in Mediterranean lakes of Greece. *Water*, 8(11), 483.

Suwanprasit, C., & Srichai, N. (2012). Impacts of spatial resolution on land cover classification. *Proceedings of the Asia-Pacific Advanced Network*, 33, 39-47.

Svoray, T & Carmel, Y. (2005). Empirical Method for Topographic Correction in Aerial photographs. *IEEE Geoscience and Remote Sensing Letters, 2* (2), 211-214.

Symeonakis, E., Koukoulas, S., Calvo-Cases, A., Arnau-Rosalen, E., & Makris, I. (2004, July). A land use change and land degradation study in Spain and Greece using remote sensing and GIS. In Proceedings of XXth ISPRS Congress, Istanbul, Turkey, http://www. isprs. org/istanbul2004/comm7/papers/110. pdf,(15 January, 2006).

Symeonakisab, E., Caccettab, P. A., Wallaceb, J. F., & Koukoulasa, S. (2006). Multi-temporal land use/cover change detection in the Spanish Mediterranean coast. The International Archives of the Photogrammetry*, Remote Sensing and Spatial Information Sciences,* Vol. 34, Part XXX.

Sykes, M., Hickler, T., Rowell, D., Smith, B., & Morales, P. (2007). Changes in European ecosystem productivity and carbon balance driven by regional climate model output. *Global Change Biology*, *13*(1), 108-122.

Tivy, J. (1993). Biogeography: a study of plants in the ecosphere (No. Ed. 3). Longman Group Limited, *Longman Scientific & Technical*.

Trodd, N., & Dougill, A. (1998). Monitoring vegetation dynamics in semi-arid African rangelands: Use and limitations of Earth observation data to characterize vegetation structure. *Applied Geography*, *18*(4), 315-330.

Tuominen, J., & Lipping, T. (2011, April). Atmospheric correction of hyperspectral data using combined empirical and model based method. In Proceedings of the 7th European Association of Remote Sensing Laboratories SIG-Imaging Spectroscopy Workshop, Edinburgh, Scotland, UK (Vol. 1113).

Yin, H., Udelhoven, T., Fensholt, R., Pflugmacher, D., & Hostert, P. (2012). How normalized difference vegetation index (ndvi) trends from advanced very high resolution radiometer (AVHRR) and system probationer observation de la terre vegetation (spot vgt) time series differ in agricultural areas: An inner Mongolian case study. *Remote Sensing,* 4(11), 3364-3389.

Virginia H. Dalea,U, Linda A. Joyceb, Steve McNultyc, Ronald P. Neilson. (2000). The interplay between climate change, forests, and disturbances. *Science of the Total Environment* (262). 201-204

Wang, G., Gertner, G., Fang, S., & Anderson, A. (2004). Mapping vegetation cover change using geostatistical methods and bitemporal Landsat TM images.Geoscience and Remote Sensing, *IEEE Transactions,* on 42(3), 632-643.

Warmink, J. (2007). Vegetation Density Measurements using Parallel Photography and Terrestrial Laser Scanning (Doctoral dissertation, MSc Thesis, Utrecht University).

Weiss, M., Baret, F., Smith, G. J., Jonckheere, I., & Coppin, P. (2004). Review of methods for in situ leaf area index (LAI) determination: Part II. Estimation of LAI, errors and sampling. *Agricultural and Forest Meteorology, 121*(1), 37-53.

Wilson, M. (2007). How to measure: Measuring vegetation characteristics per area. Oregon State University.

Wilson, J. (2011). Cover plus: ways of measuring plant canopies and the terms used for them. *Journal of Vegetation Science,* 22(2), 197-206.

Ying, F., Lei, J. Q., Xu, X. W., & Pan, B. (2013). Composition and characteristics of Libyan flora. *Archives of Biological Sciences, 65*(2), 651-657.

Zalidis, G., Stamatiadis, S., Takavakoglou, V., Eskridge, K., Misopolinosa, N. (2002). Impacts of agricultural practices on soil and water quality in the Mediterranean region and proposed assessment methodology. *Agriculture, Ecosystems & Environment, 88*(2), 137-146.

Zhang, Y & Li1, X. (2011). Topographic Normalization of Landsat TM Images in Rugged Terrain Based on the High-resolution DEM Derived from ASTER. Progress *In Electromagnetics Research Symposium* (PIERS) Proceedings, Suzhou, China, September, 12–16.

Reports:

General Directorate of Documentation and Information. (2010). The population of

Libya, Tripoli, sheet (24), 25.
General Directorate of Documentation and Information. (2012). The population of Libya, Tripoli, sheet (62), 21.

Web sites:

http://glcfapp.glcf.umd.edu:8080/esdi/

http://gsp.humboldt.edu/OLM/Courses/GSP_216_Online/lesson2-1/vegetation.html)

http://earthobservatory.nasa.gov/Features/MeasuringVegetation.

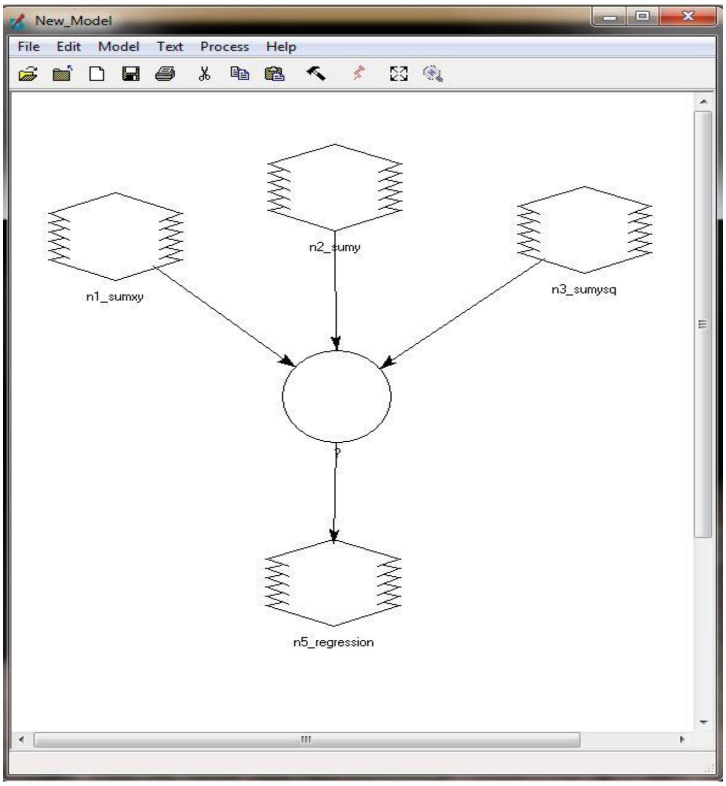
http://landsat.usgs.gov/band_designations_landsat_satellites.php

http://web.ornl.gov/sci/landscan/landscan_popden_ArcMap10x.shtml

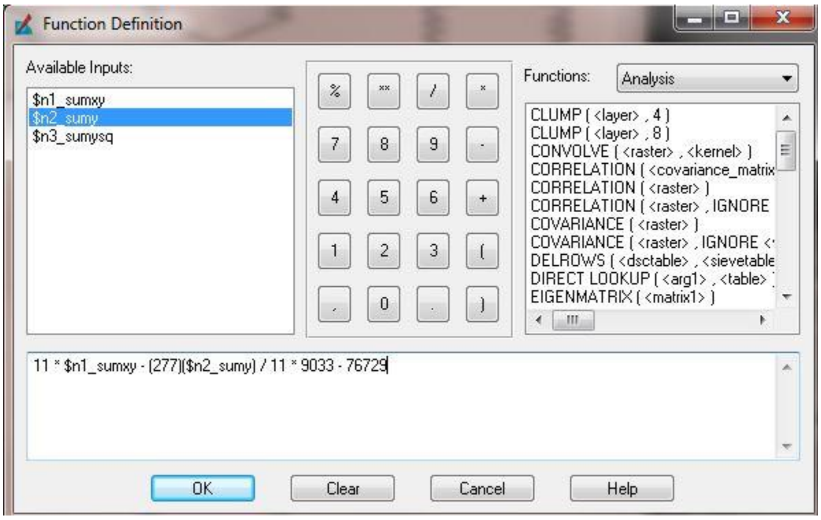
Appendices

1. Regression model

1.1



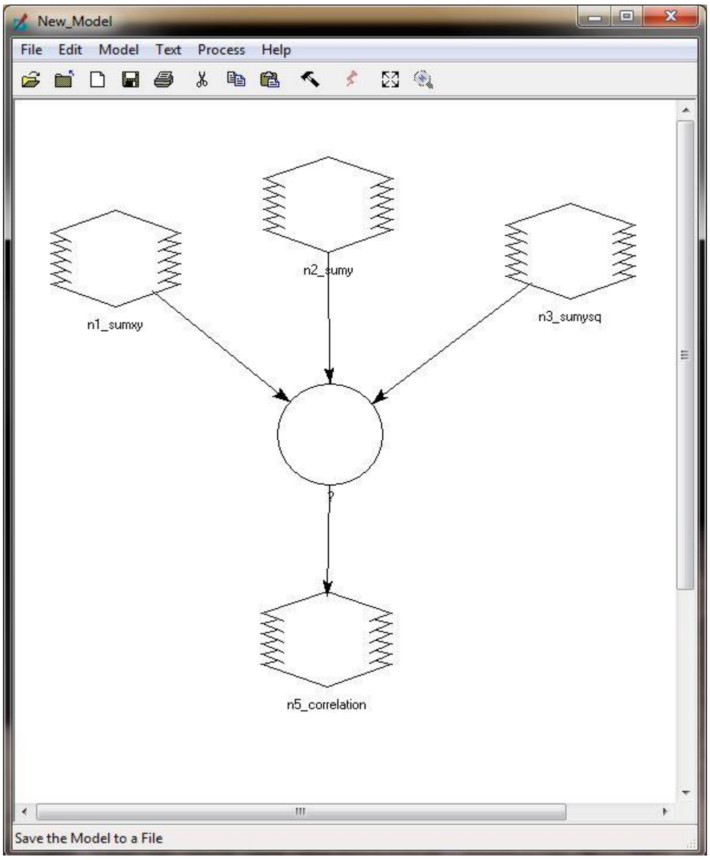
1.2



Appendix 2

2. Correlation coefficient model

2.1



2.2