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Research Article

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Monitoring of Land Degradation and Desertification in the South of Jabal Al Akhdar Mountain in North East Libya

Ghadah M A Ahweedi

Geography department, Omer El-Mukhtar University, Libya

***Corresponding author**
Ghadah M A Ahweedi, Geography department, Omer El-Mukhtar University, Libya. E-mail: ploto1976@yahoo.com

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Abstract

Over the last few decades, global warming and human activities have led to changes and deterioration in natural vegetation across the world. Land degradation in arid, semi-arid areas led to the emergence of desertification especially areas that are located along the desert margins.

The Al Jabal Al Akhdar Mountains (The green Mountain) in the north east Libya is one of those areas that have experienced changes in vegetation cover. This region has environmental and economic importance in providing habitat for wildlife and services for local communities and cities in the Libyan Desert.

This research will investigate natural vegetation dynamics in the Al Jabal Al Akhdar region using remote sensing techniques in an attempt to monitoring the desertification over the last 42 years to determine the factors that have caused this problem. The overall aim of this paper was to evaluate the factors which have affected vegetation cover change in the Al Jabal Al Akhdar region over the last 42 years.

Keyword: Desertification, Land degradation, Al Jabal Al Akhdar, Climate change, Remote sensing.

Introduction

Vegetation is a key component of ecosystems [1]. It is involved in the regulation of various biogeochemical cycles, for example, water, carbon and nitrogen; affects soil development by increasing productivity; and provides habitat for wildlife [2]. 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 [3]. Changes in these characteristics lead to changes in vegetation phenology, primary productivity, biomass and the distribution of vegetation types [4]. Climate is one of the factors that has a significant effect on the characteristics of vegetation. Recent changes in climate include increases in temperature and changes in precipitation patterns, and these changes have impacted on terrestrial ecosystems [5].

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 [6]. 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 [7].

These changes have caused degradation in soil productivity, soil erosion, desertification and decreases in plant and animal biodiversity [8,9].

The Mediterranean basin is one of the areas likely to be most susceptible to climate change [10]. Evidence indicates that the climate in the region has changed since the beginning of the 20th century, with mean annual temperature increasing by 0.75°C from the mid-20th century [11,12].

Precipitation has decreased in terms of total annual rainfall, and inter annual variance of precipitation across different regions of the Mediterranean has been noted. 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 [13]. 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 [13].

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 [14-16]. Climate change has affected the structure and productivity of vegetation, while human activity in the last few decades has affected some areas in the Mediterranean region [17]. 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 [18]. Natural vegetation in north eastern Libya belongs to the semi-arid/ arid natural vegetation of the Mediterranean [19]. The perennial trees, (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 [20]. 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 [21]. 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).

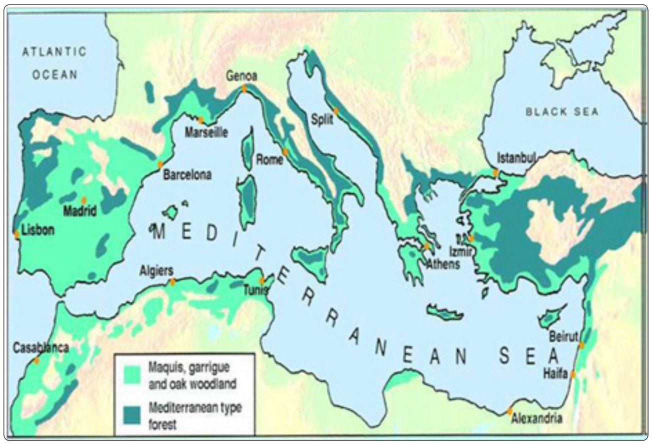

Figure 1.1: The Mediterranean basin and Al Jabal Al Akhdar region in Libya (Source: Google, 2017)

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 (Figure 2.1) [19-21]. 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.

Natural vegetation of the Al Jabal Al Akhdar has a significant impact in the region in terms of providing suitable habitat for wildlife, providing nutrients for the soil, stabilization of the soil and preventing erosion [21]. 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 [19]. 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 [20]. 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. Climate change is potentially an important factor. Therefore, using the available climate data on the stations basis to provide a general picture of climate change in the Al Jabal Al Akhdar.

Figure 2.1: The vegetation on the northern slopes of the Al Jabal Al Akhdar (Source: http://ports.com /libya/port-of-ras-el-hilal/photos)

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, assess the areas of desertification and examine the factors affecting vegetation change and which, was caused the desertification. Overall, this study attempts to decouple the effects of climate change and human activity, in study area by examining the influence of each factor in the spatial distribution of human activities relation to vegetation cover change. This will be achieved by identifying the relationships between the areas that have experienced change in vegetation cover and the in the study area since the 1970s.

Trends of temperature and rainfall at three stations ware examined in order to give insights into the general climate trends in the study area. The climate change may be responsible for vegetation cover change in the areas that no influence from human activity.

Methodology

The first objective aims to assess vegetation cover change that 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 that may affect the reflectance of the vegetation [22].

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, 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 Land Scan 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. 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 1.3). The research specifically used the images that were acquired in the same season to avoid‟ cover changes related to seasonal differences in vegetation growth.

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.

Atmospheric correction

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 [23]. Several proposed methods for removing the influences of atmosphere from satellite images.

LEDAPS

LEDAPS relies on deriving "the aerosol optical thickness from each Landsat acquisition and independently correcting each acquisition assuming a fixed continental aerosol type" [24]. 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 [25]. It also generates cloud masks for images that are covered partially by the clouds.

Empirical line correction

The empirical line method uses the raw digital numbers (DN) in an image together with ground reflectance data from some source [23]. The approach applied the method on 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. The research applied the method on other images that had no atmospheric correction using the available surface reflectance images and generated new images without atmospheric effects.

Table 1. 3: Landsat images used in the study

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			2013-2014

Table 2.3: Methods applied to remove the influence of the atmosphere from the Landsat images selected for this study area

Sensor	Data	Data Surface reflectance	Empirical line corrections applied	Image pair selected	R2 Red waveband	R2 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	🟥				

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.

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 [26]. The topographic effect is the difference in illumination due to the slope direction relative to the elevation and azimuth of the sun. 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 and produced images with more evenly illuminated terrain without topographic effects.

Assessing 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 statistical analysis of regression and the correlations that were applied in this study 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. The results of the analysis of VI using linear regression and correlation analysis (figure 1.4 to 6.4), showed that there was a statistically significant decrease in vegetation cover in some areas over the period of study. 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 thar have positive values saw no significant change in vegetation cover.

The correlation coefficient of the VI showed the pixels that revealed a statistically significant change at a 95% level of confidence in the study area over the 42 years. The results of the VI correlation indicated a statistically significant decrease in the VI in some areas. 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.

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 5.1). 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 5.1). 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 km2. Land cover in the study area has changed as indicated in the previous table. The research illustrated the long-term trends of land cover in graphical form (Figure 5.2). The areal extent (km^2) has decreased for natural vegetation such as the forests and shrubland. Land cover which has been exploited by humans, such as agriculture, urban and quarry, have increased over the 42 years. 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 magnitude and the rates of land use change in the study area exceeded 45 in percentage terms (%), and 400 in terms of spatial extent (km2) in cultivated areas and built-up areas from 1972 to 2014.

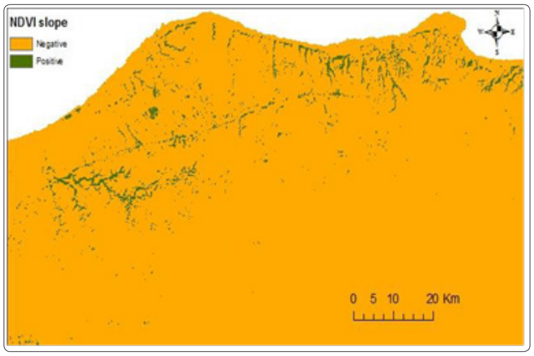

Figure 1.4: The classified NDVI regression slope image

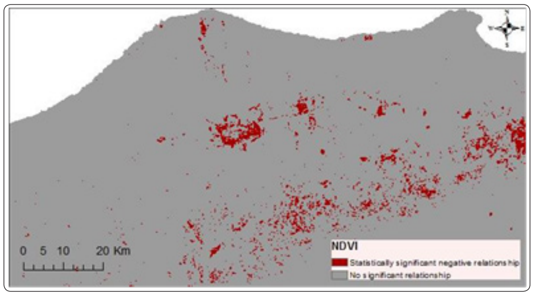

Figure 2.4: The classified NDVI correlation coefficient image

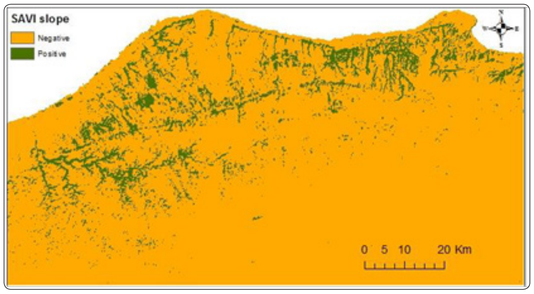

Figure 3.4: The classified SAVI regression slope image

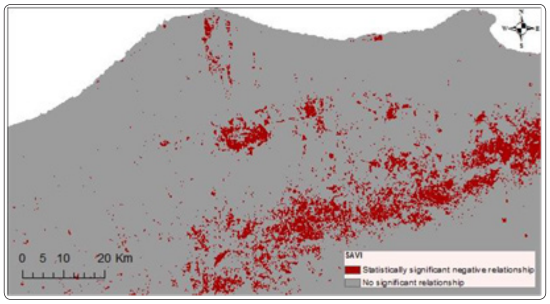

Figure 4.4: The classified NDVI correlation coefficient image

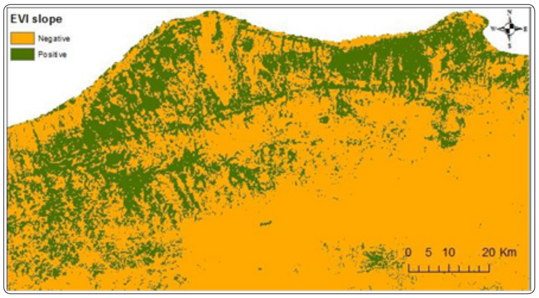

Figure 5.4: The classified EVI regression slope image

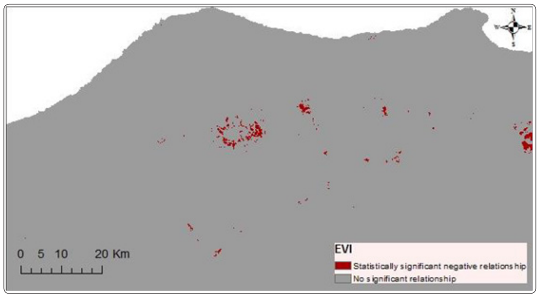

Figure 6.4: The classified NDVI correlation coefficient image

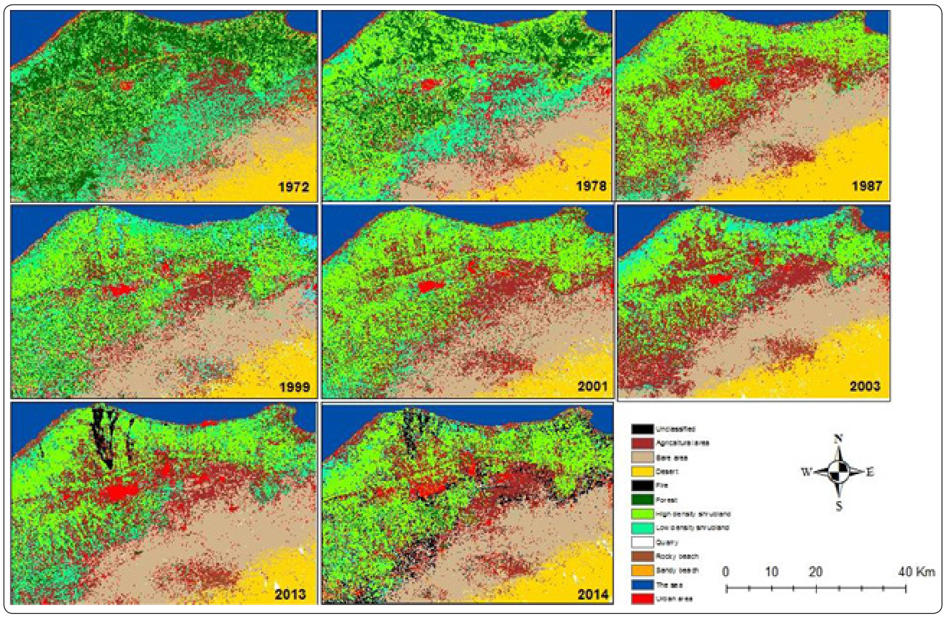

Figure 5.1: Multi-date land cover classification for the study area

Table 5.1: 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**

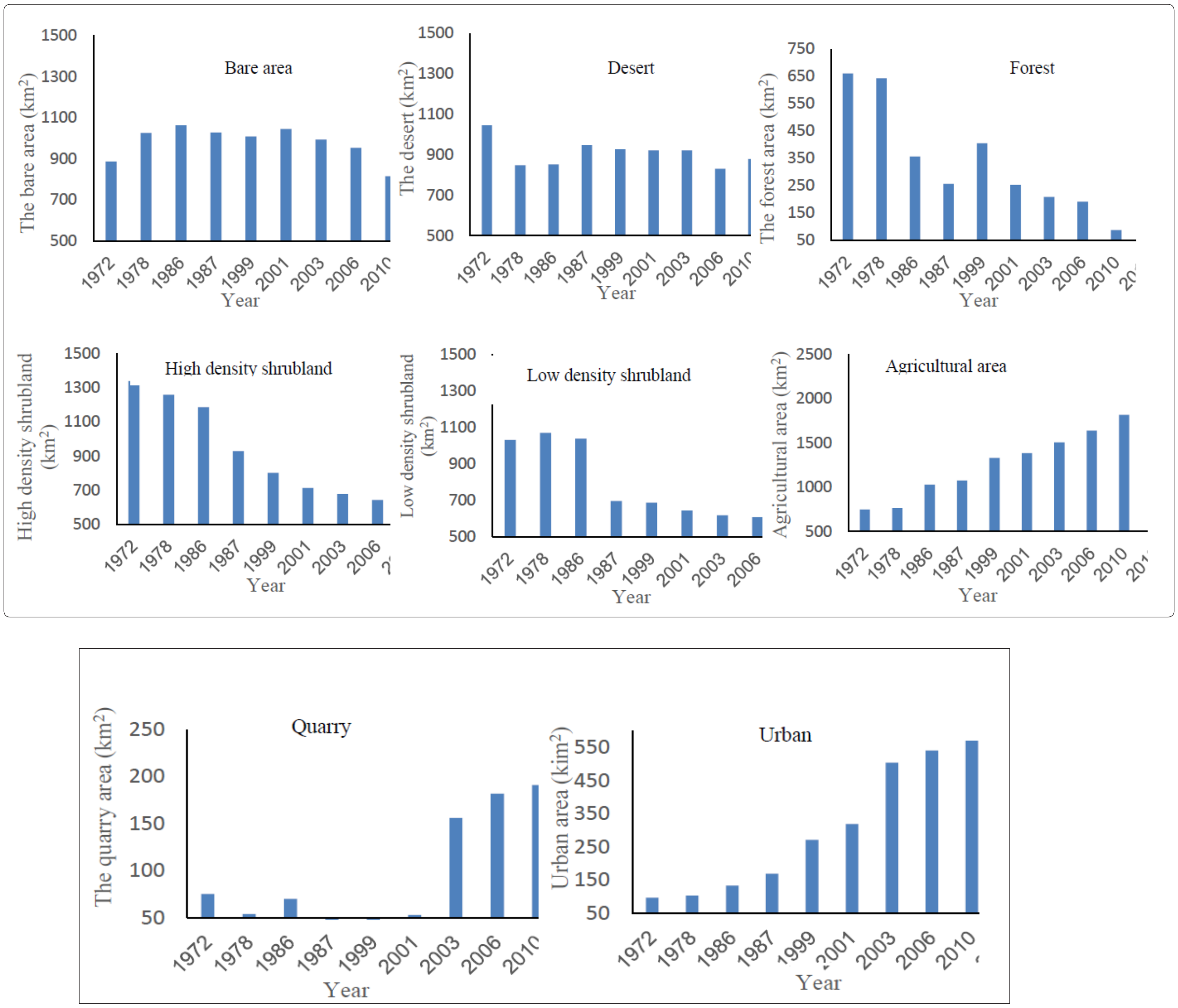

Figure 5.2: Long-term land cover change in the study area

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 [27]. 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 plus some sub-stations (figure 6.1) which provided just one climatic element, such as rainfall or temperature.

Figure 6.1: The locations of climatic stations in the study area (Source: Google Earth, 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 [28]. 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 proximity to the sea and differences in vegetation cover in the region rainfall over the period of study. Pearson"s Correlation Coefficient was used to determine the strength of linear relationships between the to assess the significance of change in temperature and annual rainfall and time (Higgins, 2006), to determine if there was a relationship between them independent (time; x) and dependent (temperature or rainfall; y) variables Pearson"s correlation coefficient provides a measure of the degree of association between X (time) and the Y (temperature or rainfall) climatological time series data [29]. Regression was used to determine the differences between 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).

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. The mean annual temperature in the Mediterranean region has increased by 0.75 °C during the last few decades, with expectations of increases of 1 to 3°C between 2010 and 2039 [11,12]. 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:

1. 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
2. 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.
3. 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) (Figure 1.6, 2.6&3.6). 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.
4. 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).
5. 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.
6. 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.

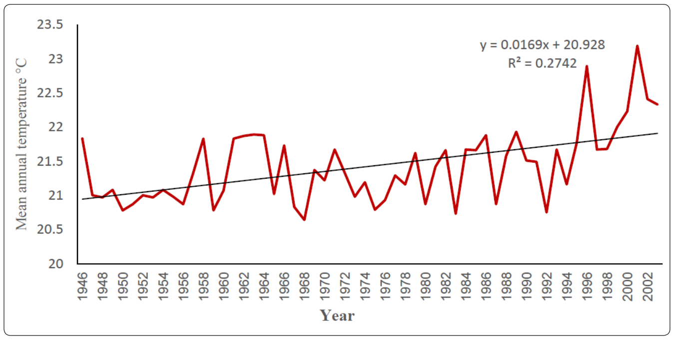

Figure 6.1: The mean annual temperature at Darnah over the period of study

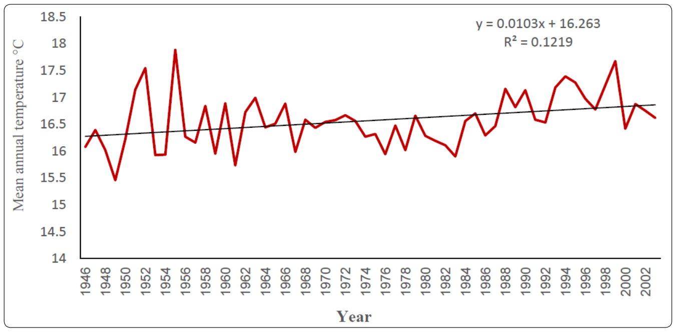

Figure 6.2: The mean annual temperature at Shahat over the period of study.

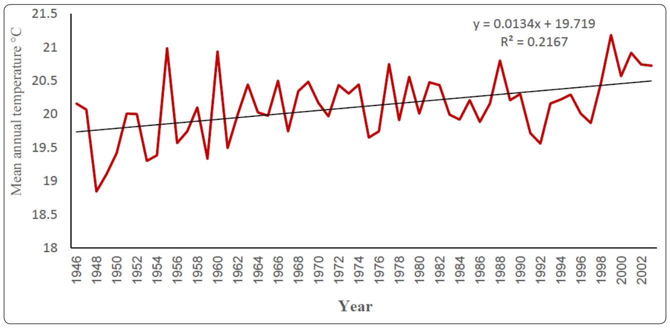

Figure 6.3: The mean annual temperature at Benina over the period of study

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 warming. The key results of this study are as follows:

1. The trends of mean annual rainfall have fluctuated at all stations without clear trends over the periods of study (1946-2003) (Figures 4.6, 5.6&6.6).
2. The period of the 1950s and 1970s witnessed a decline at all stations, whereas the 1990s was characterized by increasing rates of rainfall.
3. 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.
4. 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.

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.

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. 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.

A spatial analysis of factors affecting vegetation change in the study area

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. 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.

The research 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.

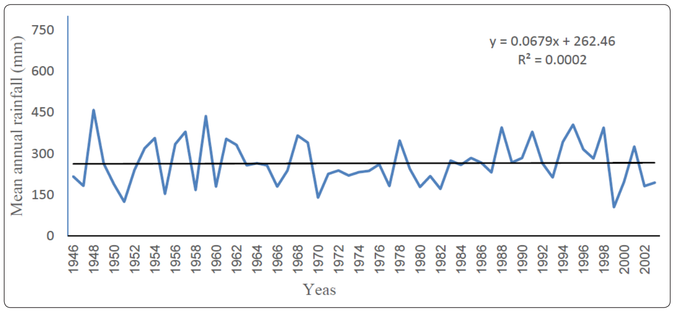

Figure 6.4: The mean annual rainfall at Darnah station over the period of study

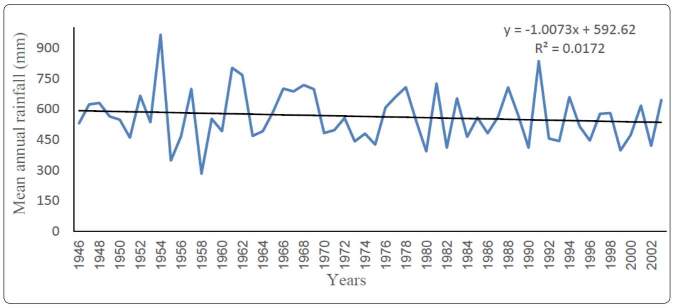

Figure 6.5: The mean annual rainfall at Shahat station over the period of study

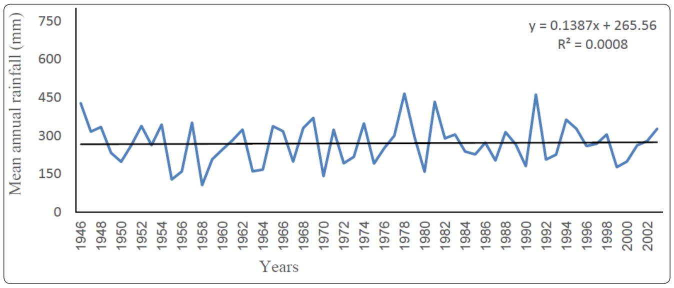

Figure 6.6: The mean annual rainfall at Benina station over the period of study

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 research examines the spatial correlation between areas that exhibited vegetation cover change and the distribution of population. The population data were classified as 1 km resolution population counts for 2013 (Figure 7.1). The three VI correlation images were used in a binary classification with 0 representing no significant VI change and, 1 representing statically significant change ($p< 0.05$). 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 7.2 with the VI change periods coloured by population.

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.

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

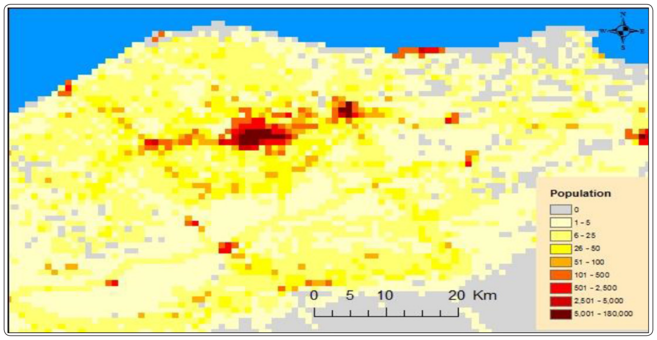

Figure 7.1: The distribution of Libyan population data in the Al Jabal Al Akhdar region in 2012

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 produced 12 binary images, one for each land cover class (figure 7.2), 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. 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 7.3 with the SAVI change coloured by the urban area.

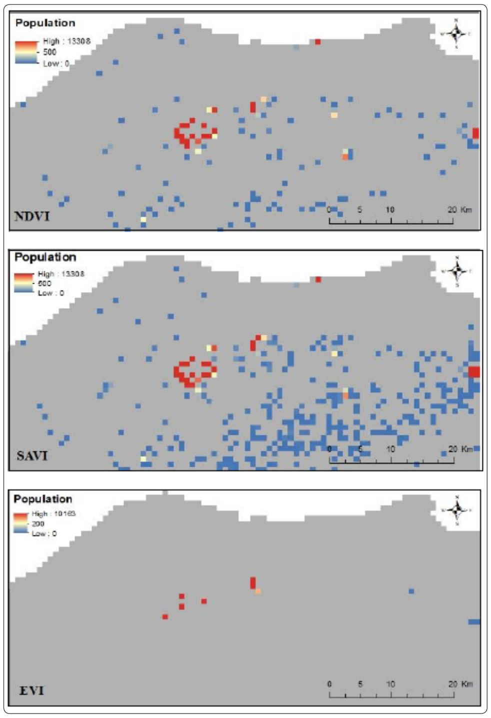

Figure 7.1: The relationship between the population and VI change

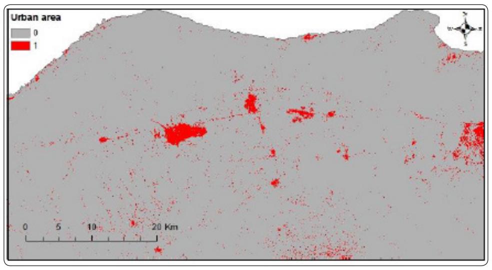

Figure 7.2: The urban area classified image of 2003

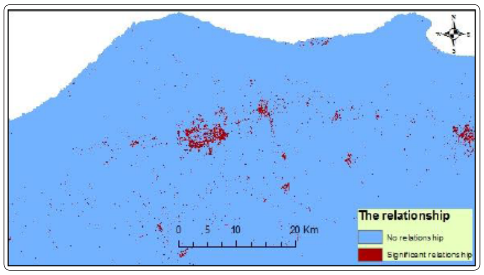

Figure 7.3: The relationship between SAVI and urban area in 2003

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. 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.

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

The climate change may be affecting vegetation cover, especially in the areas that show a change in vegetation cover but low population densities. 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 [19,28]. 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 and detected the desertification in these areas.

Conclusion

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 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 [30].

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