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An evaluation of land degradation and desertification in the Jeffara Plain, Libya.

Shaban Emhamed Abdsmad Mnsur

Thesis submitted in partial fulfilment of requirements of Sheffield Hallam University for the degree of Doctor of Philosophy

Novmber 2014

PREFACE

This report presents work carried out in the Faculty of Development and Society, at Sheffield Hallam University between 2009 and 2014. The submission of this work is in accordance with the requirements for the award of the degree of Doctor of Philosophy (PhD).

ABSTRACT

The research develops the Mediterranean Desertification and Land Use methods and makes then more appropriate for studying land degradation in arid and semi-arid zones. In this research, three approaches were applied to land degradation assessment in the central southern part of the Jeffara Plain in Libya: remote sensing, Mediterranean Desertification and Land Use (MEDALUS) and Universal Soil Loss Equation (USLE).

The Mediterranean Desertification and Land Use Method was used to determine the environmentally sensitive areas (ESAs) in the study area. In addition, this model has been developed by adding two parameters: groundwater management and wind speed. These were not directly applied in the original MEDALUS model and their incorporation makes the method more suitable to the arid and semi-arid zones.

Landsat images were used for the years 1986, 1996 and 2002 and Spot images for the year 2009. The supervised classification (the enhanced maximum likelihood classification) algorithm was applied to generate land cover maps together with the matrix analysis. They were used to analyse and extract land information covering the changes in the study area; they detected and assessed the changes for the period from 1986 to 2009.

In addition to processing the satellite MODIS images, the data were used to identify the relationship between the climate and the vegetation indices (NDVI) for the period from 2001 to 2009.

The Universal Soil Loss Equation (USLE) was used with a Geographic Information System (GIS) to determine quantitatively the average annual soil loss in the study area. A GIS file was created for each factor of the USLE: precipitation, soil type, land cover, and slope, combined with the cell-grid modelling procedures in Arc GIS to predict the soil erosion risk.

The results obtained from remote sensing demonstrated significant decrease in natural vegetation and significant degradation in most of the land in the study area. About 85% of the study area was 'moderate' or 'severe' in terms of degradation, as defined land cover maps and land degradation maps were produced for the study area. Findings from the Mediterranean Desertification and Land Use method showed that almost 75% of the total study area was sensitive to 'critical' desertification. A map for the environmentally sensitive areas vulnerable to desertification was produced for the study area.

In contrast, the results obtained from USLE revealed 'slight' erosion rates in the rangelands and the agricultural lands which together account for 76% of the total land area. A soil erosion map was also produced for the study area.

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LIST OF ABBREVIATIONS

ARC: Agricultural Research Centre

ACSAD: the Arab Centre for the Studies of Arid Zones and Dry Lands, Damascus.

ASSOD: Assessment of the Status of Human-Induced Soil Degradation in South and South East Asia.

ASCII: American Standard Code for Information Interchange

ESAs: environmentally sensitive areas to desertification

FAO: Food and Agriculture Organization

GMRP: Great Man-Made River Project

GIS: Geographic Information System

DEM: Digital Elevation Model xvi

DN: Digital Number

ERDAS: Earth Resources Data Analysis System

GLASOD: Global Assessment of Human-Induced Soil Degradation

GPS: global positioning system

GWA: Water Resources of the Libyan

LADA: Land Degradation and Assessment in Drylands

LY00/004: Mapping of Natural Resources for Agricultural use and Planning Project

MODIS: Moderate Resolution Imaging Spectroradiometer

NDVI: Normalized Difference Vegetation Index

NOAA: National Oceanic and Atmospheric Administration

PACD: Plan of Action to Combat Desertification

PET: Amount of potential evapotranspiration (mm).

RS: Remote Sensing

SOVEUR: Soil degradation assessment in Central and Eastern Europe

SPOT: (Satellite Pour l'Observation de la Terre) (Satellite for the Observation of the Earth)

UTM: Universal Transverse Mercator

UNEP: United Nations Environment Programme

UNCOD: United Nations Conference on Desertification

UTM: Universal Transverse Mercator

WGS84: Word Geodetic System 1984

WB2: Land Degradation Indicators. Scientific report Series No 67.

CHAPTER 1

INTRODUCTION

1.1 Problem Description and Research Rationale

Desertification occurs worldwide and there is currently serious debate about its causes. These are believed to include increases in human activity, population growth and associated numbers of grazing livestock, and changes in temperature and rainfall resulting from climate change. In combination, these lead to the degradation of land in arid, semi-arid, and dry sub-humid areas (UNEP, 1994). The word 'desertification' has been viewed and defined in different context depending on the stakeholder involve (Glantz, 1977). However, the common point on which all the definitions agree is that desertification is viewed as an adverse environmental process. For example, the Convention to Combat Desertification (UNEP, 1994) defines 'desertification' as land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including soil erosion, climatic variation and human activities. Soil erosion itself result from "a complex interaction between natural (e.g. soil properties and climate conditions) and human factors (e.g. over-grazing, over-cultivation and deforestation)" (UNEP, 1997; den Biggelaar et al., 2004; EEA, 2005). In another perspective, Dregne (1982:5) defined desertification as: "the impoverishment of terrestrial ecosystems under the impact of man. It is the process of deterioration in these ecosystems that can be measured by reduced productivity of desirable plants, undesirable alterations in the biomass and the diversity of the micro and macro fauna and flora, accelerated soil deterioration, and increased hazards for human occupancy."

In addition, there is pressure on inherently fragile natural resources in arid and semi-arid areas as population increases and urbanization lead to more pressure of agricultural resources and land degradation (Orhan et al., 2003). According to Brandt et al. (2003), Tanrivermis (2003) and Salvati et al. (2008): "land degradation means reduction or temporary loss of the biological and economic productivity of irrigated and non-irrigated agricultural land, pastures, rangeland, and woodlands". It is believed that land degradation results from various factors, including climatic dryness, poor soil and vegetation quality, and pressure due to agriculture intensification, population growth, urban sprawl, and industrial concentration (Kosmas et al., 2000a; Garcia Latorre et al., 2001; Salvati and Zitti, 2005).

Libya is considered to be an arid country, with an average yearly rainfall of less than 50 mm over 91% of its land surface, the exception is the Mediterranean Coastal Zone (about 7% of the total area of Libya), which receives an average yearly rainfall of 100 to 500 mm/year. More than 90% of the country is desert. Most of the agricultural activities are limited to the long narrow strip along the Mediterranean coast; arable land does not exceed 2% of the total area. Also, the surface water resources are very limited and contribute less than 3% of the current water resources in use.

The cultivated area is estimated at up to 2.2 million ha, or about 1.2% of the total area of the country. The rangeland area is approximately 13.3 million ha (FAO, 2000). The Jeffara Plain, with an estimated total surface area of approximately 18,154 sq. km, i.e. about 1.8 million hectares(Ben Mahmoud, 1995; Selkhozpromexport, 1980), is considered one of the most important coastal plains in Libya. Although the Plain has significant vegetation, soil, water and human resources, it is under threat from land degradation and desertification; this includes human pressure on the inherently fragile natural resources use of marginal lands under irrigation for crops cultivation, overgrazing, deforestation, a significant decline in water level, an increase in the salinity of groundwater, and urban expansion (Al-Idrissi et al., 1996; Ben Mahmoud et al. 2000).

From the above background, it is very important to detect and assess land cover changes and monitor land degradation as well as produce maps of environmentally sensitive areas vulnerable to desertification in the Jeffara Plain, in order to understand the dynamics of land cover changes, and for soil conservation, management and future land use planning. Scholars, such as Ben Mahmoud et al. (2000), Mundia and Aniya (2005) and Yuan et al. (2005), opined that remote sensing and GIS are the main instruments for the spatial study and analysis of natural resources and the production of thematic maps related to vegetation cover. These techniques provide coverage, continuous monitoring, and multiple imaging, and, together with satellite images and field investigations, generate data to help quantify the effects of climate change and human activity that influence vegetation cover, composition, and dynamics. This research approach was applied to detect changes in land cover and to monitor land degradation in the Jeffara Plain over a period of 23 years. The assessment was done using remote sensing and Geographic Information System (GIS) data. This involved the application of the Mediterranean Desertification and Land Use (MEDALUS) Method (Kosmas et al., 1999), and its development to make it more appropriate for mapping the environmentally sensitive areas of arid and semi-arid zone environmental conditions which are vulnerable to desertification.

The MEDALUS method has been selected for modification for many reasons. One of the advantages of this model is that it is simple, highly flexible and allows for the updating of information on local conditions and is capable of identifying areas that are sensitive to desertification risk (see, for example, Kosmas et al. 1999, 2003; Brandt et al., 2003; Contador et al., 2009). This approach developed using MEDALUS has not been previously used in the study area and its application has potential contribution to the development of a land degradation model for the study area. It also provides information which can be beneficially employed in land use planning, particularly in the Jeffara Plain in Libya. In addition, it can be developed by the addition of new factors, such as soil salinity and wind erosion. Salinity is one of the most severe environmental factors limiting the productivity of agricultural crops. Most crops are sensitive to salinity caused by high concentrations of salts in the soil (Ghassemi et al., 1995) (Szabolcs, 1992; Flowers, 1999). In this context, according to ACSAD (2007), in arid and semi-arid areas, land degradation by wind action leads to many problems, such as the transport and deposition of materials which affect vegetation cover and the removal fine-grained and organic matter. Furthermore, this model has not previously for any land degradation study in Libya. In contrast, there is a small amount of water erosion observable in the study area (ARC, 2005). Therefore, it is of interest to see how the model performs. Additionally USLE is a popular model even through it is likely that wind is the more important mechanism for soil erosion.

1.2 Research Objectives and Questions

1.2.1 General aims

The main aim of this research was to apply and develop the method of Mediterranean Desertification and Land Use (MEDALUS) to assess whether it can be made more appropriate for mapping the environmentally sensitive areas vulnerable to desertification in arid and semi-arid zone environmental conditions. It is because the original ESAI model is appropriate for studying land degradation under particular environmental conditions (Kosmas et al., 1999 and 2003 and Brandt et al., 2003). Moreover, there are differences in the condition of the environment between the European Mediterranean and North Africa (Libya). Because the MEDALUS method does not take these differences (e.g. salinity) into account, it was considered that additional factors needed to be included in the model for it to be appropriate to the arid and semi-arid conditions found in the study area.

The research also aimed to detect changes in land cover and to assess land degradation using remote sensing data from 1988 to 2009 and Geographic Information System (GIS) techniques. This was in order to understand the dynamics of land degradation and produce maps of land degradation. This was done by comparing the methods of assessing land degradation (for example, MEDALUS and USLE) and a map of land degradation derived from remote sensing. The resulting map constructed for this research project shows the extent of degradation than would relying on GIS and remote sensing alone.

1.2.2 Specific objectives

In order to achieve the aims identified above, the research is structured around six specific objectives:

1- To identify key information relating to land use and condition changes for the study area.

2- To detect and assess vegetation cover change which has taken place in the study area over a period of time by remote sensing and GIS techniques, and produce thematic maps of land degradation.

3- To identify the factors causing land degradation in the study area and to make recommendations for actions to combat it.

4- To apply two methods, Mediterranean Desertification and Land Use (MEDALUS) and the Universal Soil Loss Equation (USLE), for assessing land degradation.

5- To compare methods of assessing land degradation in arid areas: MEDALUS, USLE, the land degradation map from remote sensing, and a soil erosion map for 1980

6- To develop and test an appropriate modified method for the evaluation and monitoring of desertification of the study area.

1.2.3 Research questions

Primaries research questions:

1- Are there existing appropriate models which can be applied to land degradation in arid environments?

2- Is it possible and appropriate to apply the long-established MEDALUS method to such a situation?

For this study there were seven subsidiary research questions:

1. Does land degradation seem to be a problem in the study area?
2. Are there any discernible changes in the vegetation cover over the last twenty years?
3. Is land in the study area becoming progressively degraded?
4. If this is the case, what are the causes of?
    - a- land degradation affected by human activity
    - b- increased numbers of grazing animals
    - c- farming encroachment on the Plain.
5. What is the best methodology to assess land degradation in Libyan environmental conditions?

6. What factors should be taken into account to develop the original Mediterranean Desertification and Land Use (MEDALUS) method to make it more appropriate for studying land degradation in the arid and semi arid zones?

1.3 Research Methodology

The methodological approach adopted for this research began with an interrogation of key literature and a scoping desktop study of the potential case study location. The potential research questions were identified and the case study location was investigated to evaluate its suitability for this study. The methodology is summarised in Figure 1.2. It has been divided into three sections.

1.3.1 Assessing vegetation cover in the study area was based on Landsat images from 1988, 1996, 2002 and 2009, in order to discover the changes, monitor them, and produce a map of vegetation cover and land degradation using remote sensing and GIS techniques . This stage consists of several steps, mainly:

1. 3.1.1 Image processing: consists of three steps for the main image processing using data of Landsat TM and Spot 4 images.

1.3.1.1.1 Image restoration: is the group of the methods that aim to remove or reduce data errors that have occurred during the scanning recording and playback operation such as, sensor noise, geometric distortions and atmospheric turbulence. This is done through the computer models such as:

- Filtering noise
- Correcting geometric distortions
- Correcting for atmospheric turbulence

1.3.1.1.2 Image enhancement was used to improve the visual interpretation ability of an image by increasing the apparent distinction between the features.

- Contrast enhancement; enhance the perceptibility of objects in the scene by enhancing the brightness difference between objects and their backgrounds.

- Edge enhancement is important in the perception of an image- increasing the prominence of an edge makes the border of an object easier to see, and the image appear clearer.

1.3.1.1.3 Classification techniques were applied to classify the Landsat images of the study. In addition, unsupervised and supervised classifications were carried out for all satellite images to classify land cover and land use type. Maximum likelihood classification (MLC) was implemented to produce land cover and land degradation data in the study area.

1.4 Fieldwork in Libya

The field survey was conducted in the Jeffara Plain in north-western Libya from 20 July 2010 to 12 September 2010. The field survey was organized in co-operation with the Libyan Centre for Remote Sensing and the Agriculture Research Centre (ARC) in Tripoli. Ground truth data were collected to define land cover classes in the study area, from the library of the Agriculture Research Centre (ARC) in Tripoli, the Libyan Centre for Remote Sensing, the Libyan Meteorological Department (climatic data), the General Water Authority, and the libraries of El-Fateh University. The Landsat TM images from 1988, 1996, 2003 and spot image 2009 as well as topographic maps at 1:50 000 were used as a basis for specific feature identification. A total number of one hundred geographic points were visited and recorded by using GPS to provide information on vegetation communities and soil. The information was then imported into GIS for overlaying with the images to provide good information to help understand the spectral signature of the different types of land use and land cover in the study area. Further fieldwork has been undertaken to measure wind erosion and soil salinity. Findings of these measurements are contained in Chapter 7. In addition there were discussions with local experts about the history of agricultural and rangeland in the study area, such as increased in number of animals and changes on vegetation cover and climate change (rainfall, temperature and wind). Increased human pressure through unmanaged agricultural practices such as converting pastoral land to irrigated land was also discussed. In addition the agreement of all local experts that the overgrazing, over-cultivation and climate change are the main causes of land degradation in study area.

1.5 Accuracy Assessment

Accuracy assessment is an essential part of remote sensing. An accuracy assessment should be made for any classification image before it is used. The accuracy of a classification is usually assessed by comparing the final classification with information derived from ground-truthing. Accuracy assessment was applied to all land cover maps produced from remote sensing, by comparisons between the final classification and ground-truthing data (reference data).

1.6 Application and Development of the MEDALUS Method

This method of mapping environmentally sensitive areas at risk from desertification was based on the following data on the physical environment and land management characteristics, which were required for the definition of ESAs vulnerable to desertification: (a) soil data, (b) vegetation data, (c) climate data, (d) land management, and (f) wind erosion data.

a) Soil data were obtained from digital soil map and the associated soil report in 1980.
b) Vegetation data were obtained from several sources, such as satellite image classification and ground truthing, for identification of vegetation cover as well as measuring the proportions of plant cover in the study area and the Agricultural Research Centre report (2002).
c) Climate data were obtained from the Libyan Meteorological Department for the period from 1975 to 2009.
d) Land management data were obtained through ground truthing and previous studies in the study area.
e) Wind erosion and soil salinity data were obtained from field observation.

1.7 Application of the Universal Soil Loss Equation (USLE)

USLE method with Geographic Information System (GIS) data was used for soil erosion risks within the study area. The data used were obtained from weather stations, topographic maps, soil data and vegetation cover data.

1.8 Comparisons Between Methods

This was undertaken between the original MEDALUS, a land degradation map derived from remote sensing, the soil erosion map for 1980, and USLE, to develop the MEDALUS model further by using CROSSTAB model in the Idrisi software.

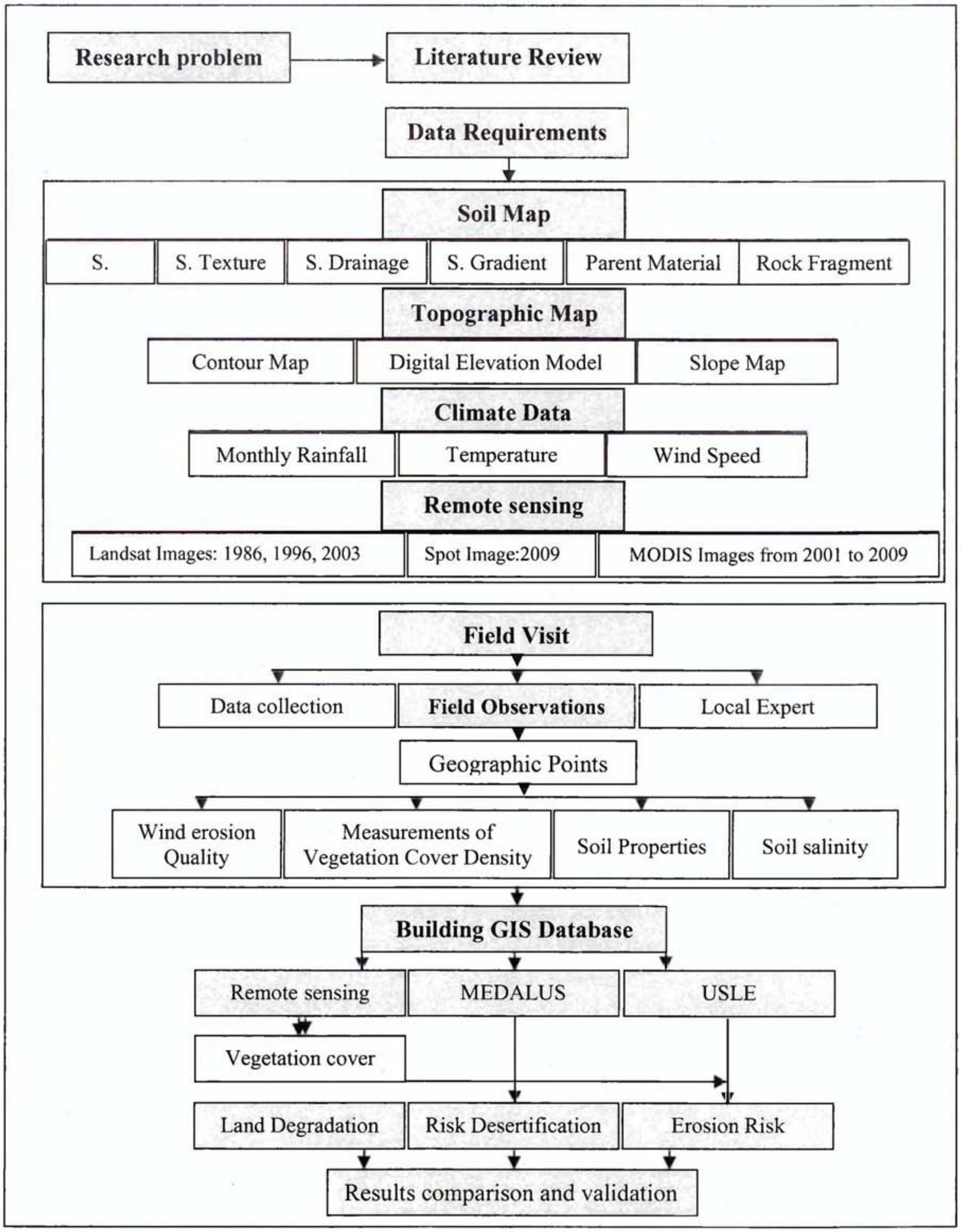


Figure 1.1: Organizational chart explaining the approaches of the methodology and its components.

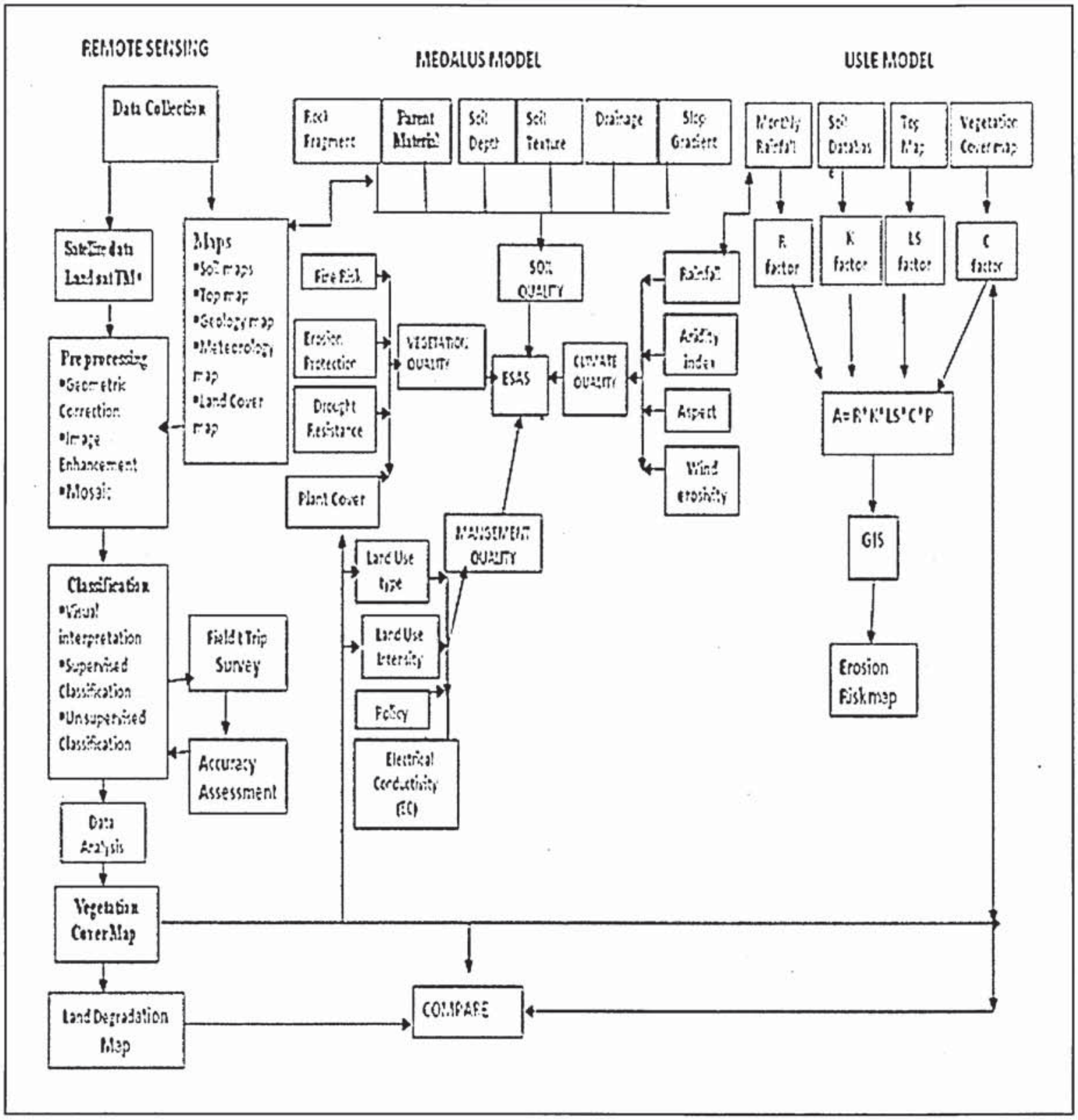


Figure 1.2: Land degradation and desertification models.

This model has been designed to apply three models of land degradation in the study area and provides integration of information between them, and also shows the role of remote sensing to provide data needed for use in MEDALUS and USLE methods, as shown in Figure 1.2.

1.9 Thesis Structure

The thesis is divided into nine chapters and the contents of each chapter is presented below:

Chapter 1 deals with the research problem, research objectives and research questions, and the research methodology.

Chapter 2 describes the general environmental context in Libya.

Chapter 3 deals with the definition of desertification, distribution of dry lands, desertification on a global level in the Arabic region and causes of land degradation in Libya.

Chapter 4 provides an overview of methods of land degradation study.

Chapter 5 examines the capabilities of remote sensing and its applications in monitoring desertification in arid and semi-arid environments.

Chapter 6 shows the results derived through the image processing techniques performed on Landsat TM imagery, spot image and MODS; land cover change maps which have been produced; and the relationship between climate and NDVI, especially rainfall.

Chapter 7 develops the MEDALUS method, and gives the two main results derived through the Mediterranean Desertification and Land Use (MEDALUS) Method and the Universal Soil Loss Equation (USLE), as well as a comparison between the methods.

Chapter 8 discusses the results presented in Chapters 6 and 7.

Chapter 9 provides general conclusions of this study and recommends possible areas for future or further research and policy.

CHAPTER 2

RESEARCH CONTEXT

2.1 Introduction

Libya is in the north of Africa, from 20° to 34° N and 10° to 25°E. It is bordered by Egypt in the east, Tunisia, Algeria and Niger in the west, the Mediterranean Sea in the north and by Chad and Sudan in the south Libya, and covers 1.676 million km^2 of land. Libya includes a very significant area strategically placed at the middle of Africa's northern rim (Figure 2.1). The main fertile lands can be found in the north of Libya in the two main regions of Benghazi and the Jeffara Plain, and these are considered the most important lands in their economy.

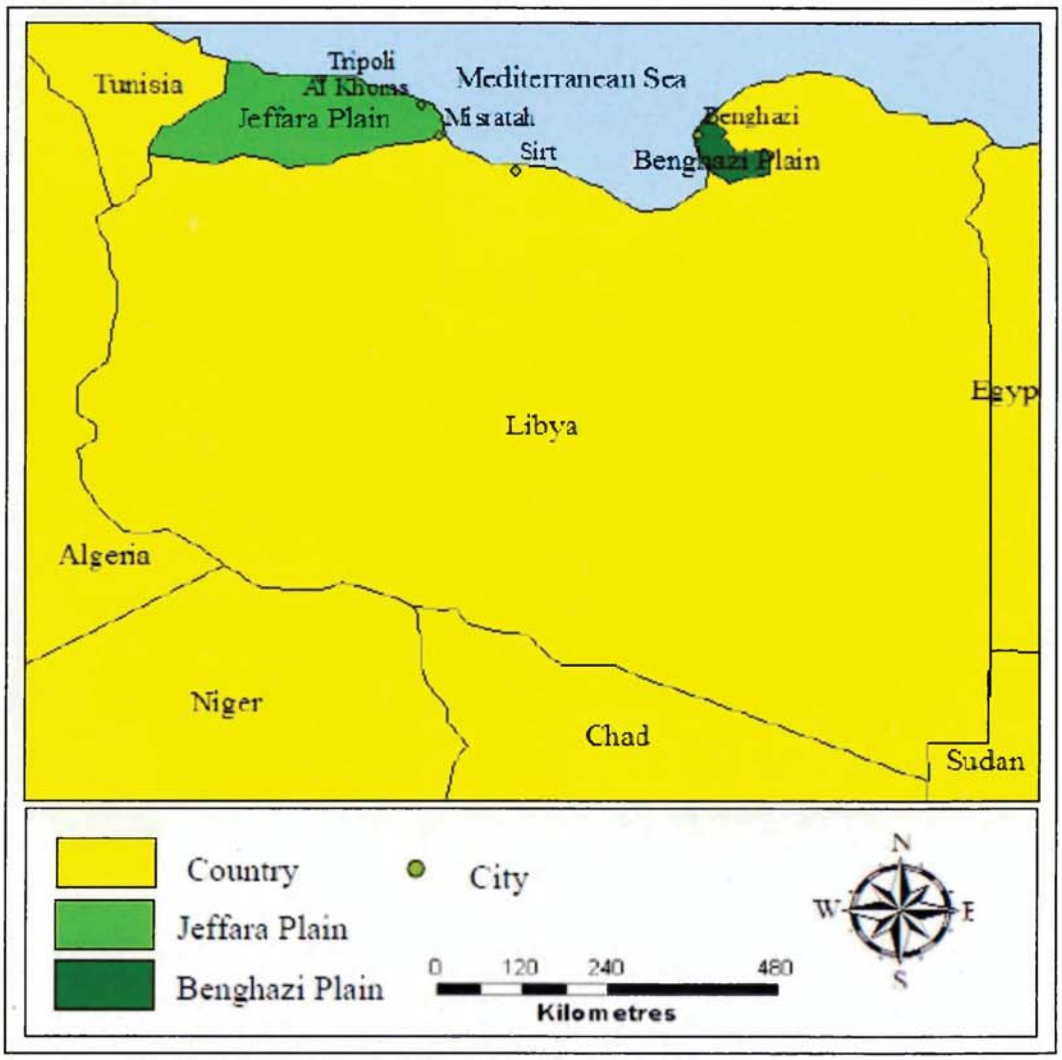


Figure 2.1 Map of Libya.

2.2 Description of Landforms

Libya can be divided into two main land systems based on geographic position and geomorphologic patterns. These two main land systems are the coastal plains which are found in the northern part of the country and the plateaux which are located in the south. The most prevailing natural features are considered to be the Sahara desert in the south, and, for the north, the Mediterranean coastal lands which stretch from west to east (the Tunisian border to the Egyptian border) for about 2,000 km, and which are between 15 and 100 kilometres in width (Ben Mahmoud et al., 2000).

The major parts of the northern region of Libya are the low-lying areas consisting of the coastal lowlands of the Jeffara Plain, the Sirt Plain and the Benghazi Plain, as well as lagoons, salt marshes, swamps and, lastly, the coastal sand dunes. These coastal lowlands are said to be divided from each other by pre-desert areas and backed by plateaus which include steep north-facing scarps.

The topography of the Jeffara Plain area is largely flat and is divided by three main components. These comprise the coastal strip in the north, the central areas, and the foot of Jabal Naffusah Mountain in the south. The northern region is sheltered by deposits coming from the Aziziyah formation. The central areas are enclosed by poorly fused Aelian deposits mixed with brownish silts.

2.3 Population

The total population of Libya was 2.0 million in 1970, 3.2 million in 1984 and 4.4 million in 1995. It had increased to about 5.5 million in 2006 (Figure 2.2). The results of the censuses during the period 1970-2006 show that Libya experienced significant the population growth. The two most densely populated regions of Libya are the Jeffara Plain and the Benghazi Plain. Approximately 58% of Libyan people live in the Jeffara Plain. The main reason why the people live there is the essential resources that can be found in that area, such as soil, water, vegetation and climate. The General Authority for Information census of 2006 suggested that the population of Libya will be more than 10 million by the year 2025. As an effect of this, there is an increased demand for food and other basic necessities, as well as a rapid increase in the percentage of the total population living in urban areas, from 45% in 1970 to 90% in 2006. At the same time, the agricultural population has decreased, with 10% of the population remaining in the rural areas.

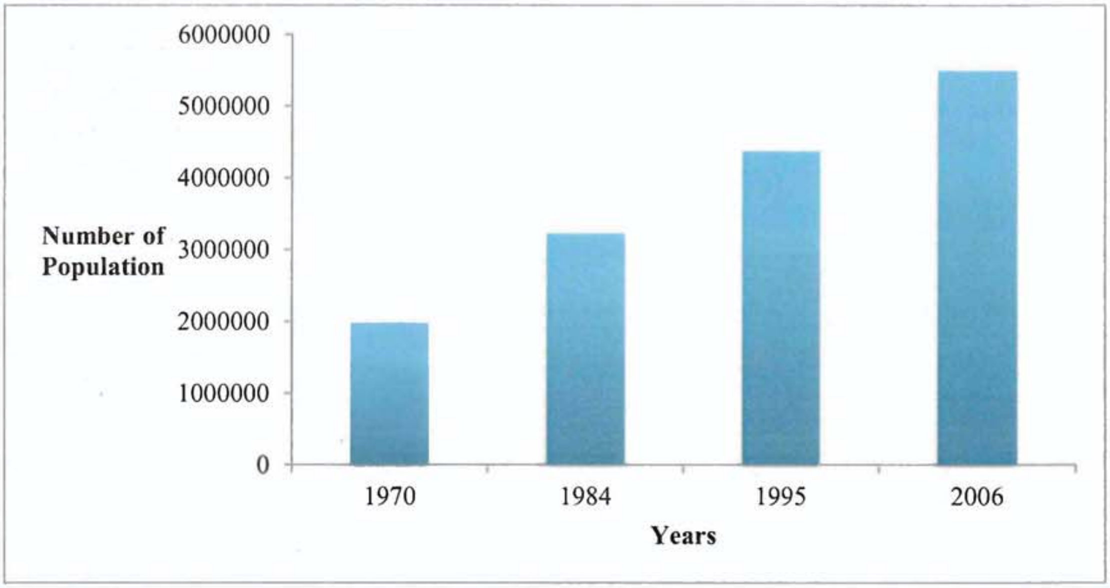


Figure 2.2: The Number of Libyans - Population from the Censuses in 1970, 1984, 1995 and 2006. Source: Libyan Statistics Book, 2007.

2.4 Water Resources

Water resources of Libya are separated into three types: surface water, groundwater, and desalinated and treated water. Libya is an arid country, with an average annual rainfall of less than 100 mm over 91% of its land surface (GWA, 2002). The following are the three types of water resources of Libya:

2.4.1 Surface water.

These resources are very minimal and supply less than 3% of the current water resources being used. The total mean annual runoff measured at the entrance of the wadis in the plains is estimated at 200 million m^3 per year, but part of it either evaporates or contributes to the recharge of the aquifers (Al-Ghariani, 1996). Thus, this type of water resource amounts approximately 100 million m^3 per annum.

2.4.2 Desalinated and treated water

The total amount of desalinated water was about 160 million m^3 in the year 2006; this is due to the establishment of desalination plants near big municipal centres and industrial compounds. A number of sewage treatment water plants are also in use; an example is the El-Khadra water plant which was built in 1971, south of Tripoli City. This was estimated at 91 million m^3 in the year 1990 and increased to 250 million m^3 by 2006 (ARC, 2000).

2.4.3 Groundwater

The last type of water resource, groundwater, is considered the main water resource in Libya, and contributes 97% of the water used. The extraction of groundwater increased rapidly from the early sixties, because of the increasing water demand in the coastal area where the population is high. Aquifers that are being used for these water resources are recharged only from the Jeffara Plain, Jabel Nefusa and Jabel Akhdar. Renewable groundwater resources are presumably 800 to one million m^3 yearly. Not all renewable groundwater can be extracted without doing any harm to the environment. Because of this, the safe yield was projected in this zone as only 500 million m^3 per annum. In addition to the effects of over-extraction and decreasing groundwater levels, saline infiltration from coastal seawater (estimated to be proceeding at a rate of 100 to 250 m yearly southwards from the coast) is reducing the available freshwater for abstraction. It is being predicted that these intrusions will lead to the contamination of all useful aquifers in the near future. If this over-extraction is not stopped or reversed, it is expected that these intrusions will lead to the contamination of all productive aquifers in the near future (Al-Ghariani, 1996). On the other hand, most of the potential groundwater is being found in the desert area (Al-Ghariani, 1996). Because of the Great Man-Made River Project, approximately two cubic kilometres yearly of fossil water is being transferred from the main storage of underground water to the coastal areas where it is utilized particularly for irrigation and moderately for water supply to the major cities.

Table 2.1: Water Balance (values in million m^3)

Year	1995	2000	2005	2010	2015	2020	2025
Supply	3820	3820	3820	3820	3820	3820	3820
Demand	3885	4493	5128	5794	6494	7236	8022
Balance	- 65	- 673	- 1308	- 1974	- 2675	- 3416	- 4202

Source: General Water Authority (2000)

Table 2.1 shows that in Libya the amount of water demand is more than its renewable water resources. And also water needs of Libya are increasing rapidly and water deficit will be more than four billion m^3/year in 2025.

2.5 The Great Man-Made River Project

A fresh underground water resource was revealed in the early 1960 by the penetration of oil drilling inside the Libyan Desert. The most significant rock strata that contain water are said to have been formed in the geological era when the Mediterranean Sea used to flow south until it reached the Tibitsi Mountains. Moreover, the sea water level altered sporadically, leading to the development of sedimentary rocks of different varieties. The geological activities led to the appearance of Nafusah Mountain and Jebal Akhdar and the development of the underground aquifers. The aquifers are made of porous sedimentary rocks into which the water seeps.

Rainwater percolates inside these rocks and is stored there, forming fresh underground water These aquifers are porous sedimentary rocks in which water accumulates and which are surrounded by non-porous rocks. About 14,000 to 38,000 years ago, the climate of North Africa was mild. Libya used to have high precipitation; therefore, rainwater leaked inside the porous rocky strata and was stored there, forming fresh underground water (GMPR, 2008). At the time there are believed to be five main areas of stores of underground water: Al-kufrah, Sirt, Murzuq, Al-Hamadah and Jeffara Plain. These five large reservoirs provide the coastal areas with a great amount of fresh underground water (GMPR, 2008).

2.6 Climate

The climate in Libya is described as the following: cold weather is sparse; summers are hot, with two to three dry months, and the winters are cool and rainy; strong rains come with hurricanes and strong winds. Low total amounts of rainfall and high temperatures in summers are regular (*Tripoli Airport Meteorological Report*, 2009).

The temperature in Libya usually increases gradually from the north to the south of the land in winter and summer. The hottest temperatures in the coastal areas are during August, while the coolest occur during December and January. The mean yearly temperature is lower in the north and higher in the south of the country. The monthly average temperature in the coastal zone is between 23°C and 25°C. In the semi-desert zones the monthly average temperature is between 25°C and 28°C, while the maximum temperature in the desert regions may exceed 30°C (Tripoli Airport Meteorological Report, 2009).

The mean annual rainfall ranges from 0 mm in the south to as much as 500 mm in the north. The rainfall in Libya occurs mostly, during the winter season, particularly in the period between October and March, the heaviest rainfall being in December and January. It is also limited and variable from year to year. Jeffara Plain and Benghazi, the two most important areas of the country for agriculture, receive annual rainfall of 100 to 500 mm, while the rest of the land gets only 50 mm or less. As shown in Table 2, Libya is considered an arid country with an average yearly rainfall of less than 50 mm over 91% of its land surface.

The relative humidity of the air is low in the south in contrast with higher levels in the north. The relative air humidity varies between seasons. In the north, summer values are said to be higher than winter values. However, in the south, winter values are mostly higher. The annual humidity at the coast is between 70% and 80%, while it is 35% or less in the south.

Table 2.2: Aridity zones of Libya

Aridity zones	Average yearly rainfall (mm)	Area (10^3 km^2)	% area
Extremely arid	< 50	1,589	90.8
Arid	50 -200	130	7.4
Semi-arid	200 – 400	26	1.5
Dry sub-humid		5	0.3
Total		1,750	100

Source: Ben Mahmoud (1995).

Prevailing winds in the coastal zone include two types of wind considered to be important in this region. There is a cool wet wind coming from the north and the west as well as the northwest which brings rain to the area and is most common in the wintertime.

The other type is a hot dry wind coming from the south and called Ghibli. The Ghibli (the direction from which the wind blows supplies its name in Arabic) is the hot and dry wind, blowing from the southern deserts, which can raise the maximum temperature and reduce the air humidity to its minimum values. In addition to this, it tends to remove the topsoil and produce sand dunes (for more than 200 days a year the wind velocity on the plain exceeds 3 m/sec, which is critical for sandy and loamy sandy soils) (Zaytseva, 1965; Kalyanov, 1976).

2.7 Soil Information

The Soviet Soil Classification System is the system used in Libya to differentiate the types of soil. The Soviet Soil Pedology System, however, is being used in the north of the country. This investigation was made by the Soil-Ecological Expedition of v/o Selkhozpromexport, the Agricultural Research Centre (ARC), Al Fateh University and the Ministry of Agriculture. The nomenclature of the Soviet Soil Pedology System was implemented for expansion of the soil categorization, and this system has been generally applied to categorize the soil layers of the Mediterranean countries. Classes and subclasses have been singled out on the basis of the classification structure for the tropics and sub-tropics given by Zonn (1974).

In addition to this, non-soil formations such as rocky deserts, Sarir (sandy gravelly deserts), desert pavements (transported or residual), and Sebkhas or saline depressions cover about 98% of the total area of Libya. The remaining area (2%) is the Mediterranean Coastal Zone where the main orders of Libyan soils are Entisols, Aridisols, Mollisols, Alfisols, Vertisols, and Inceptisols (Selkhozpromexport, 1980; Mahmoud, 1995). Generally, most of the soils in the Jeffara Plain (Jabal Nafusah), and some in the Jabal Akhdar, are Entisols and Aridisols characterized by depths ranging between 30 and 150 cm and are often the surface layer of limestone and sand textures (usually) and poor in organic matter and non coherent, may be present from the stones and gravel, limestone, gypsum (Table 2.3).

Table 2.3: The main soil orders in Libya.

Russian Classification	USA Classification	FAO Classification
Reddish Brown Arid	Entisols	Regosols
Serozems, Desert Soils	Aridisols	Luvisols
Red Ferrisiallitic Typical	Alfisols	Chromic Luvisoils Calcic Chromic Luvisols
Rendzinas; Dark and Red	Mollisols	Rendzins Leptosols
Siallitic Cinnamonic	Inceptisols	Cambisols

Source: Selkhozpromexport, 1980; Ben Mahmoud, 1995.

2.8 Natural Vegetation

The natural vegetation of the country of Libya, especially in the north-west, is normally poor and sparse with little variety of species. Those species that have the capacity to thrive and grow in the area are more or less drought-resistant. They have highly developed roots and their foliage is decreased to a minimum. Also, their leaves are characterized generally as filiform, dry and shiny, the epidermis thickened characteristics which are very suitable for existence in such a place. Estimates of forest area and forest loss are difficult to obtain for the Jeffara Plain. One of the few available sources on the region (Selkhozpromexport, 1980) pointed that ancient Libya was covered by forest and has been divided into two general classes, namely woody species and plants. The first and most remarkable of these forests is the Forest Park of *Acacia tortillis* (Talha in Arabic) which is found in the south of the Jeffara Plain. This area has a precipitation of less than 150 mm and the trees seen here are spaced from 50 to 100 m apart.

Tamarix articulate (Etal in Arabic) existed until a few years ago when nomads devastated it completely.

The best known woody species of north-west Libya was found to be the *Zizyphys lotus* (Sedr in Arabic). This species becomes bushy when it is browsed by goats but it may still grow as a tree. Found in abundance are the *Pistacia atlantica* (Batum in Arabic), which can be seen at the foot of Jabal in the south of the Jeffara Plain. Another group of forest in this location grows on fixed sand dunes and deep sandy soil, is located mainly in the middle part of the Jeffara Plain. The following plants are dominant on this soil: a shrub, *Retame reatem* (in Arabic, Rtme); *Rhantherium suaveoles* (in Arabic, Arfaj); and *Aristida pungens* (in Arabic, Asbta).

The second group of forest are located mainly in the southern parts of the Plain on the shallow soil and on rocks with a thin layer of sand. The dominant in the vegetation cover is formed by *Gymnocarpos decander* (in Arabic, Alqgroud) and *Periploca leavigata* (in Arabic, Alhab) (Selkhozpromexport, 1980). Another class is the plants of the steppes. These steppes vary mainly in appearance and features. During the rainy seasons, in areas of stable sands, fine grasses rich in legumes such as perennials cover the soils. The types of perennials which grow on the steppes serve to classify the land structure and vegetation community. These types include *Asphodelus microcarpus* (In Arabic, Belus), which is found in moist, deep and flat sand. Another is, *Imperata cylindrica* (In Arabic, Dis), tends to grow on poor soils but still deep and moist and sometimes slightly salty. This particular plant takes root on sands and is mainly used for dune fixation. Lastly the *Calycotome intermedium* (In Arabic, Gandul) is a small spiny bush which prefers deep stony soil (Selkhozpromexport, 1980).

2.9 Brief History of Agriculture in Libya

The agricultural history of Libya is somehow related, although inversely, to the development of its oil industry. In 1958, prior to the era of oil wealth, agriculture supplied over 26% of Gross Domestic Product and Libya actually exported food. However, although gross levels of agricultural production have remained relatively stable, the increase in oil revenues has resulted in a fall in agriculture's overall share of national income. Agriculture in the 1950s was characterised by low levels of productivity and income. The advent of oil wealth encouraged the people of Libya to leave the rural areas and start inhabiting the urban areas. Because of this the agriculture of Libya began to decline, and so Libya became dependent on imports.

The number of people who left the agriculture industry and opted to work in the oil industry increased dramatically between 1955 and 1962. Another cause of the decline in the agricultural aspect of Libya was that the government started to offer the citizens of Libya long-term loans to purchase land from Italian settlers. Because of this, many citizens started to purchase land for recreational use rather than for farming, thereby inflating land values and contributing to the decrease in agricultural production.

Another cause of agricultural decline was the huge decline in the groundwater level due to the overuse of fresh water which started in the 1970s and at the same time the minimal amount of rainfall. The lack and insufficient distribution of water resulted in the interruption to agricultural production (Allan and Mclachlan, 1976).

So, in the year 1981, the Libyan government started to pay more attention to agricultural development. The government gave inducements to landlords and encouraged them to put their lands in a productive state. The government also funded the Great Man-Made River Project, which is primarily designed to distribute water from the desert wells to the coastal areas like the Jeffara Plain (Allan, 1989). Agricultural production in this region depends mainly on the private sector. The private farms owned by individuals produce the biggest part of the agricultural products. Some of the Libyan farms can be described as rain-fed systems. The main farming systems in the rain-fed areas are cereals in the coastal plains, marginal lands and wadi beds in the rangeland areas receiving less than 250 mm/yr. Barley is the main cereal crop. Olive tree farms are found in the coastal belt and western heights, where annual rainfall is more than 200 mm/yr (Al-Idrissi et al., 1996).

2.10 Summary

Libya is an arid country, with an average annual rainfall of less than 100 mm over 91% of its land surface (GWA, 2003). Also, more than 90% is desert. Most of the agricultural activities are limited to the long narrow strip along the Mediterranean coast; arable land does not exceed 2% of the total area. In addition, the surface water resources are very limited and contribute less than 3% of the current water resources in use. Increase in population has led to increasing need for food, which exacerbated the human pressure on the inherently fragile natural resources, through the use of marginal lands under irrigation for crops, overgrazing, deforestation, a significant decline in water level, an increase in the salinity of groundwater, and urban expansion. To understand the extent of this problem, therefore, requires an extensive but an intense methodological rigour such as the one contained in this research. The next chapter detailed the broader causes and effects of desertification and situating Libya within that context.

CHAPTER 3

CAUSES AND EFFECTS OF DESERTIFICATION

3.1 Introduction

Bai et al. (2008) pointed out that land degradation is increasing in harshness and intensity in many parts of the world, with 30% of forests, 20% of all cultivated areas and 10% of grasslands undergoing degradation. In addition to this, desertification affects about 2.6 billion people, as reported by the United Nations Convention to Combat Desertification (UNCCD), in addition to about a billion people who are placed in danger because of this phenomenon (Lean, 1995). According to FAO (2005), land degradation has affected the whole environment , biodiversity (animals, vegetative cover, and soil), grasslands (rangelands), croplands (rainfed and irrigated), soils, and water resources. Desertification is seen more in dry regions, and is said to result from both climatic and anthropogenic factors. Evidence gathered proves that certain arid, semi-arid and dry sub-humid places have experienced a lessening of rainfall, which affects soil fertility and production in agriculture, livestock forest and rangelands (Mccarthy et al., 2001).

3.2 Desertification: Concepts and Definitions

The word 'desertification' has more than one hundred definitions, testimony of the complexity of the problem (and the variety of stakeholders to whom it is relevant) (Glantz, 1977). In general, the common point on which all the definitions agree is that desertification is viewed as an adverse environmental process.

According to the definition in the Convention to Combat Desertification (UNEP, 1994), 'desertification' means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variation and human activities. In addition, "Soil erosion phenomena are the result of a complex interaction between natural (e.g. soil properties and climate conditions) and human factors (e.g. over-grazing, over-cultivation and deforestation)" (UNEP, 1997; den Biggelaar et al., 2004; EEA, 2005).

Another definition, according to Brandt et al. (2003), Tanrivermis (2003) and Salvati et al. (2008), is that "land degradation means reduction or temporary loss of the biological and economic productivity of irrigated and non-irrigated agricultural land, pastures, rangeland, and woodlands". It is believed that land degradation results from various factors, including climatic dryness, poor soil and vegetation quality, and pressure due to agriculture intensification, population growth, urban sprawl, and industrial concentration (Kosmas et al., 2000a; Garcia Latorre et al., 2001; Salvati and Zitti, 2005).

Dregne (1982) defined desertification as "the impoverishment of terrestrial ecosystems under the impact of man. It is the process of deterioration in these ecosystems that can be measured by reduced productivity of desirable plants, undesirable alterations in the biomass and the diversity of the micro and macro fauna and flora, accelerated soil deterioration, and increased hazards for human occupancy."

3.3 Global Distribution of Drylands

Dry lands cover approximately 5.2 billion hectares, 33.3% of the world's land area, and about 20% of the world's population lives in these areas (UNCED, 1992; UNEP, 2008). Almost all of the northern half of Africa, south-west Africa, the Middle East, some regions in India and Pakistan, parts of Mexico and North America, the west coast and southern tip of South America, and a large part of Australia are dry lands. These regions are located in two belts near the centre of the tropics of Capricorn and Cancer. Almost all of these regions are dry because of the global pattern of atmospheric circulation.

Grainger (1991) pointed out that most of the dry land areas can be found in Africa (37%), Asia (33%) and Australia (13%), while North America and Mexico, South America, and Europe contain 9%, 7% and 1% respectively.

UNEP (2008) pointed out that human activities and climatic variability are the main factors leading to land degradation and desertification in Africa. In this context, because of erosion and/or chemical and physical harm, about 65% of agricultural land in Africa is degraded and 19% of its forests and woodlands are also classified as degraded (UNEP, 2008; FAO, 2005). A major example of this is the loss of vegetation and soil cover and the spread of deserts (Erlich, 1988; Wilson, 1992).

3.4 Desertification in the Arab world

The region of the Arab world is characterized by aridity, with 128 million hectares composed of dry and semi-dry lands. Moreover, about 99 million hectares or 69% of the total Arab world receives an annual rainfall of only 100 mm, making it severely dry. The rest is categorized into two types – those lands which receive 100-400 mm of rainfall annually, called semi-arid lands, and those which receive an annual rainfall of 400 mm and are located outside the arid and semi-arid zones.

Desertification mostly affects the region that extends from the west coast of South Africa, passing through central Africa including Sahel and north Sudan, until it reaches the Arabian Peninsula and Central Asia. Severe penetration of the great African desert affects Arab nations including Egypt, Libya, Algeria, and Morocco. In Sudan, particularly in its savanna region, dune movements, soil erosion and overgrazing have been drying the land, thereby forcing people to move out to lands which can be cultivated.

The Arabian Peninsula countries, including Saudi Arabia, Kuwait, Qatar, Oman, Bahrain, Yemen and the United Arab Emirates, and the Eastern Arab countries, including Iraq, Jordan, Syria, Lebanon, and Palestine, have dry climates, and 72% of the area of these countries receives an annual rainfall measuring less than 100 mm. Environmental degradation in addition to resource depletion, which all together imperil present and future economic status, are affecting this are caused by several sand dunes movements (ACSAD, 2004).

In addition, the results of recent studies carried out by the Arab Center (ACSAD, 2007) show that about 47% of the area of the Arab world is degraded to varying degrees, and that the region most affected is the territory of North Africa; the countries affected by desertification are Egypt, Mauritania, Algeria, Libya, Syria, Morocco and Sudan. The Arab countries least affected during the last 21 years, the period of this study, are Qatar, the UAE, Kuwait and Oman.

3.5 International Perspective of Desertification

In the last four decades, an increasing number of initiatives to understand, adapt, and mitigate the effects of desertification have emerged, led by the international community, as a result of a growing global awareness of this problem. The global community first became concerned with desertification in the 1970s after 200,000 people had perished, in addition to the deaths of animals in Africa which were all caused by severe droughts. Desertification as a global problem was addressed for the first time in 1977, spearheaded by the United Nations Conference on Desertification (UNCOD) held in Kenya. During this conference, a Plan of Action to Combat Desertification (PACD) was implemented.

In 1992, another conference, called the Earth Summit, was organized by the United Nations Conference on Environment and Development (UNCED) and held in Rio de Janeiro, Brazil, and also tackled desertification issues. In addition it addressed the importance of so-called sustainable development and the foundation of an International Negotiating Committee (INCD) that is now required to come up with conventions that are aimed at combating the effects of desertification in affected regions of the world (Lean, 1995).

3.6 Causes of Desertification

Desertification is more frequently in dry regions, and is said to result from both climatic and anthropogenic factors. Evidence gathered proves that certain arid, semi-arid and dry sub-humid places have experienced a lessening of rainfall which badly affects the soil fertility and production in agriculture, livestock forest and rangelands (Mccarthy et al., 2001). Furthermore, humans can also trigger or accelerate desertification. According to the UN (1977) and Goudie (1981), degradation can be slowed down if there is no human disturbance. Problems can be caused by a combination of human and natural activities (Barrow, 1994) but it is also important to consider the fact that there are times when human activities alone trigger the situation, if not aggravate it. As Victor (2004) mentioned, land management practices and land use changes can lead to degradation.

The main activities include overgrazing, inappropriate agricultural practices, deforestation, fire, industrial activities, and urban expansion.

In addition, shortage of water is one of the major concerns for dry lands. The fundamental causes of desertification as well as the degradation of the environment are said to be the insufficiency and wrong use of water (Sharema, 1998: 121).

A major example of this is the loss of vegetation and soil cover and the spread of deserts (Erlich, 1988; Wilson, 1992). In the American West, significant change happened in vegetation cover during the twentieth century (Humphrey, 1958; Branson, 1985; Grover and Musick, 1990; Bahre, 1991; Bahre and Shelton, 1993). In addition, it is believed that the main causes of vegetation decline are climate change and increased overgrazing (Hastings and Turner, 1965; Neilson, 1986; Buffington and Herbel, 1965; Bahre, 1991). Over a 55 year period, the global environment has been changed by human activity beyond the bounds of expected natural variability (Karl and Trenberth, 2003).

Land use change has affected land degradation through an increase in human pressure and land use intensification (Chen and Tang, 2005; Mundia and Aniya, 2006); in this context, it has often led to soil fertility reduction (Guggenberger et al., 1995). Millward and Mersey (1989) pointed out that inappropriate land use and continuous agriculture on steeper land led to soil erosion. In Southern Africa, 25% of soil fertility was lost through desertification with range erosion leading to food insecurity in many areas.

According to Pérez-Trejo (1994), land degradation in arid and semi-arid zones is affected by human activities, and is significantly augmented by other factors such as soil properties, climate, and vegetation cover. In addition, it is believed that the vegetation cover is affected by human activities and unsustainable land-use practices resulting in losses of the top-soil and soil organic matter, as well as mismanagement of irrigation practices causing soil salinity which has led to a rise in soil erosion (Kemp, 1994; Symeonakis and Drake, 2004). Likewise, many studies have reported that human activities play an important role in the desertification process (Thomas et al., 2005; Thomas and Leason, 2005). It is believed that drought conditions in the last 30 years and increased human pressure on the rangelands have caused the destruction of natural vegetation cover. Combinations of damaging factors have resulted in induced windblown loss of topsoil and reactivated sand dune formation (Ben Mahmoud, 2000).

3.6.1 Climate

Climate is one of the natural factors that contribute to the spread of desertification in the arid and semi-arid zones, which are characterized by variability in water resources and the conditions of soil and plants. In the case of disruption of balance, leading to the activation factor in the spread of desertification (ACSAD, 2007). Jacqueline (2000) pointed out the effects of climate change through a decrease in moisture availability expected in arid, semi-arid and dry sub-humid zones, which has led to a rise in the aridity of existing dry lands and has gradually extended the boundaries of areas vulnerable to desertification.

Sivakumar (2006) has argued that there are many climatic factors which have affected the environment although the strongest influences are precipitation and temperature. These factors determine the potential distribution of terrestrial vegetation cover, and there are several studies in China which demonstrate that agriculture and land degradation are affected by climate change (Smit and Cai, 1996; Zhang et al., 2005). According to EEAA (1999: 61) climate change has led to an increase in storms and droughts and to changes in both the amount and the geographical distribution of precipitation which have affected agricultural crops and food security.

Roach (1997) pointed out that climate change leads to a loss of vegetation cover through changing precipitation patterns and increases in temperature which contribute to increased desertification. The African Sahel is considered the zone that has suffered most from climate variability, which has led to hunger, famine and relocation in Africa (Wigley, 1999). Erratic patterns of rainfall for a prolonged period will lead to poor natural vegetation cover as well as affecting crop production and the development of soil salinization (Schafer, 2001).

Stafford Smith et al. (1994) stated that the impacts of climate change affect plant productivity, plant species and land use. Also, Mccarthy et al. (2001) pointed out that climate change could worsen desertification through changes of spatial and temporal patterns in temperature, precipitation, and winds.

3.6.2 Overgrazing

Desertification by humans is primarily caused by overgrazing, according to Goudie (1990). It is also important to consider that 90% of lands that underwent desertification were affected by overgrazing (Alan, 1982).

As Pérez-Trejo (1994) noted, livestock numbers that are ranging normally exceeds the capacity of particular areas, thereby degrading vegetation and compacting and eroding the soil. Plant species which are responsible for upholding the structure of the soil tend to die because of overgrazing since it affects the health of the plant community, even producing a change in species composition. Because there is a rapid growth of population, there is also an increased need for food supply, which in turn calls for the grazing of farm animals to prevent food shortages. This livestock tends to feed on the grass in the rangelands, but mismanagement takes place for the reason that such livestock exceeds the natural capacity of the land. Soil degradation and vegetation cover are affected by overgrazing (Gillson and Hoffman, 2007).

The productivity of forage grasses is decreased by overgrazing (van de Koppel et al., 2002; Darkoh, 1989; De Beer et al., 2005). Many studies have suggested that desertification and overgrazing of rangelands have led to deterioration in the soil physically, biologically and chemically, with consequential sharp changes in land cover (Smoliak et al., 1972; Bauer et al., 1987; Dormaar et al., 1994; Lavado et al., 1996; Chaneton and Lavado, 1996). Moreover, many research studies show that, for example, in the semi-arid steppe of Inner Mongolia, the land has been affected by intensive overgrazing of rangelands (Li et al., 2007; Meyer, 2006; Krümmelbein et al., 2006; Gong et al., 2000; White et al., 2000; Schlesinger et al., 1990). Also, Nahal (1995) pointed out that agricultural development and overgrazing are the main causes of land degradation in Syria. At the same time he noted that the rangelands contain three times the amount of livestock than can be supported by their carrying capacity. Furthermore, in arid and semi-arid regions, land degradation caused by overgrazing has been widely documented (Downing, 1978; Perevolotsky, 1991; Tefera et al., 2007; Abule et al., 2007). Many researchers have pointed out that the overgrazing of rangelands leads to reduced soil quality (physical, chemical and biological), which leads to sharp changes in vegetation cover (Smoliak et al., 1972; Bauer et al., 1987; Dormaar et al., 1994; Lavado et al., 1996; Chaneton and Lavado, 1996).

3.6.3 Over-cultivation

As well as increasing the risk of overgrazing, increased population size can result in over-cultivation of land. Pérez-Trejo (1994) noted that the structure of the soil can be disrupted by over-cropping. It is also important to consider that poor irrigation methods endanger fragile soil structures, thereby eroding the soil. It is even considered by Warren and Agnew (1988) that over-cultivation is a greater danger than overgrazing because cropping tends to rob the land of its fertile topsoil, thereby exposing unfertile subsoil. In addition, unsuitable soil management, absence of grazing management or policies of land use, encroachment on rangelands, and widespread use of fertilizers and pesticides in irrigated areas lead to increased deterioration in soil and water. Cultivation results in the removal of perennial vegetation and leaves the ground barren for several months and sometimes years after harvest, leading to the disintegration of soil structure and the acceleration of the loss of topsoil and the occurrence of dust storms (Ben Mohmemd et al., 2000).

3.6.4 Deforestation

Deforestation is considered one of the most important indicators of desertification. Warford (1986) pointed out that the forests and trees play an important role in environmental conservation by reducing soil erosion, and raise crop yields by protecting crops from aridity, absorbing windblown dust. In addition, they help to absorb carbon dioxide and stabilize sand dunes. On the other hand, deforestation and conversion of land to grazing and cropping as well as the use of wood for construction and fuel leading to an increases in climate change and wind and water erosion (Warford, 1986; Warner, 1992). According to FAO (1997), population growth and increased needs for agricultural land, expansion of economic activities, and forest fires were the main causes of global deforestation, which leads to a high risk of soil erosion and increased flooding, as well as loss of biodiversity.

3.6.5 Effects of ground water table decline on the supply of water for human use.

Ground water table decline has a number of effects on the supply of water for human use. According to Nickson et al (2005), groundwater is a vital natural resource which provides drinking water to one third of the world's population. In the case of the Middle East, several studies (e.g. El -Fadel et al., 2001; Haddad et al., 2001; Lashkaripour et al., 2005) have shown that a substantial population depend on groundwater for domestic use. The Middle East is characterized by water scarcity and a rapidly growing population (Lonergan, 1997). Thus, water is one of the most important constraints for future development in the region. It is also documented by El -Fadel et al. (2001), Haddad et al. (2001) and Lashkaripour et al. (2005) that large drawdowns of the groundwater table or pressure head often results in increased pumping cost. This, in turn may limit water pumping rates for economic reasons. However, Kinzelbach et al (2003) indicates that increased cost is not the only consequence of drawdown. There is also a tendency that pressure reduction may lead to land subsidence in soft strata, as evident in Bangkok and Mexico City.

The dropping of water tables as a result of salt water intrusion has a consequence of declining the water level in coastal regions. It is also important to state that owing to the density difference between the fresh water on the land side and the salt water on the sea side, a salt water wedge could develop. Sometimes, the development of water wedge could progress inland until the pressure equilibrium at the salt-fresh water interface is reached. In some instances, any attempt to perturb the equilibrium by reducing the fresh water flow may lead to a further progression of the salt water wedge inland. As it further progresses inland, it may destroy pumping wells around the region (Saeed et al., 2002; Bower et al., 1999; Wirojanagud et al., 1985). Such occurrences are already documented in academic research. For instance, Kinzelbach et al (2003) reports that sea water intrusion is notorious along the coasts of India, Israel, China, Spain and Portugal.

Kinzelbach et al. (2003) confirmed instances exist where the available water resources are affected by pollution. In their study, they were able to show that sea water intrusion is the most common cause of ground water pollution around the world. Sea water intrusion could lead to diminishing or abandoning of abstractions. But this usually occurs over a period of time, and there is always a possibility of a system returning to the original state in the long-run. However, the length of time it takes for a system to return to normal could be so long that the aquifer cannot be used for drinking water purposes for several generations. Further, Brogaard et al., (1998) observes that water level decline is often associated with increasing groundwater salinity. In Jeffara Plain where the study area is included, according to the GWA (1999-2003), the intensive groundwater extraction from different aquifers caused a significant decline in water levels and an increase in the salinity of groundwater due to seawater intrusion along the coastal belt. Over-pumping from the Mid-Quarternary aquifer along the coastal belt caused the sea water front to move inland along a strip 2 to 10 km. The scenario given above is most likey to confirm Kinzelbach et al. (2003) prediction about the the consequences of sea water intrusion.

3.6.6 The effects of groundwater changes on land cover

Several studies (such as Munoz-Reinoso, 2001; Xu et al., 2007) indicate that in arid and semi-arid regions, groundwater is an important source for the growth of natural vegetation and that changes in the levels of ground water affects productivity and biodiversity. The study of Xu et al. (2007) confirms that the availability of groundwater influences the type of plant growth (e.g. shrubs or trees) as well as species assemblage in a particular region. However, the study did not confirm the effect of the artificial lowering of the water table on plants and vegetation communities; hence deserving further research. The interactions between groundwater and vegetation appear more important than was believed in the past (Le Maitre et al., 1999). For instance, Xu et al. (2007) study on the Tarim River, which flows through the Taklimakan desert, confirmed a positive relationship between the depth of groundwater and natural vegetation. According to Llamas (2004), water table depletion can cause four important effects: 1) a reduction and drying up of springs; 2) it causes low stream flow; 3) it leads to diminution of soil humidity to an extent to which phreatophitic vegetation cannot survive; and 4) it causes changes in microclimate because of a decrease in evapotranspiration (Llamas, 2004). This can result in significant losses of habitat and biodiversity. All these indications are a confirmation of the effects of groundwater changes on vegetation growth and land cover.

3.7 Causes of Desertification in the Jeffara Plain

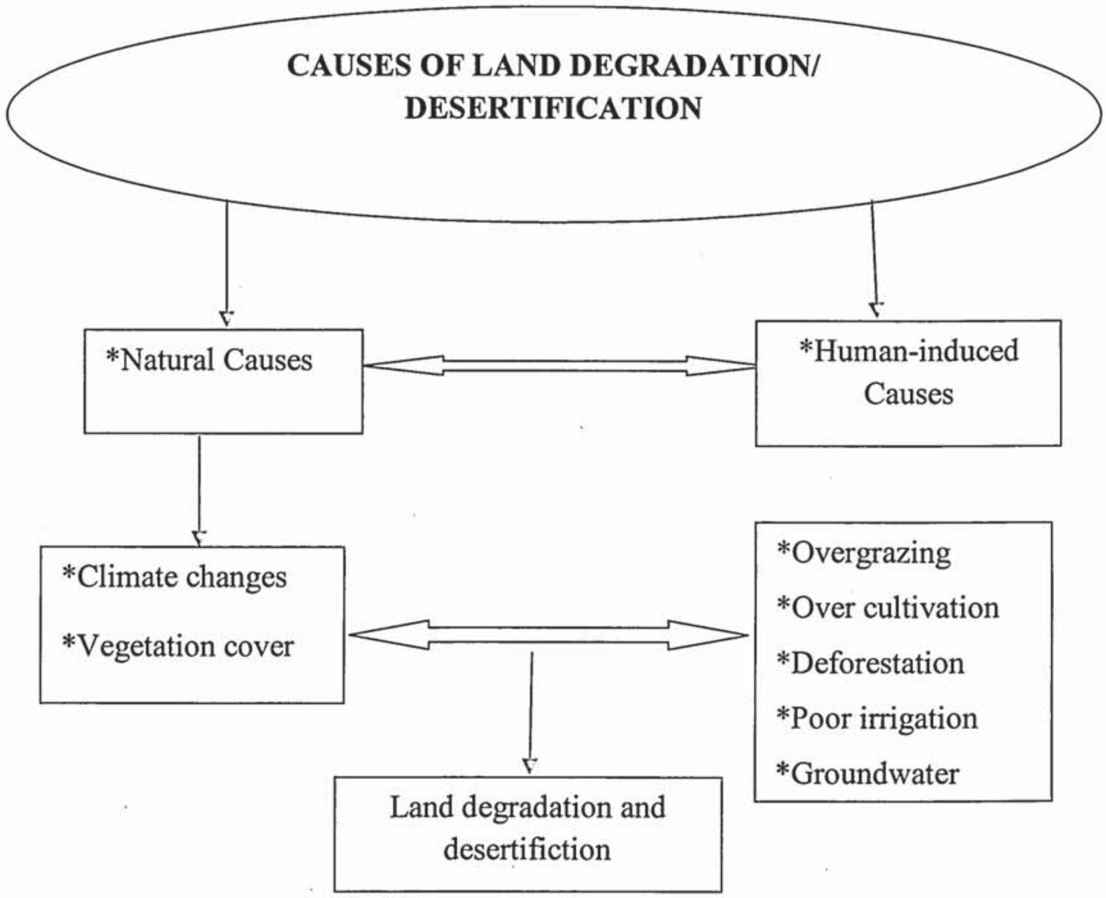


Figure 3.1 Causes of land degradation/desertification processes

3.7.1 Vegetation degradation

It is an established fact that vegetation cover plays an essential role in the protection of soil from erosion; it is also one of the most important factors of soil formation, and plant residues are principally responsible for the content of organic soil. The natural vegetation cover in the study area is poor because of both the low annual precipitation and its erratic distribution, particularly in the areas of rangelands, which receive less than 200 mm rainfall per year. Overgrazing and over-cultivation in the attempts to grow wheat or barley in marginal lands, have led to the clearing of vegetation cover (Ben Mahmoud, 2000).

3.7.2 Poor irrigation management

According to LY 00/004, Mapping of Natural Resources for Agricultural use and Planning Project (2004), the total irrigation area in Libya for growing crops such as vegetables is approximately 470,000 ha. Groundwater is considered the main water resource in Libya and contributes 97% of water used. It appears that the extreme use of underground water is causing a serious problem in decreasing the amounts of water and increasing salinity and sea water intrusion, especially in the last few years, this is made worse because in the coastal area, where there is no legal restriction on digging wells in private farms with poor irrigation practices. An indirect influence of groundwater on the soil processes may be expressed in some causes in the soil salinity with changes in soil structure; permeability and aeration due to irrigation with water from deep aquifers which lead to soil salinization in northwestern Jeffara Plain.

3.7.3 Deforestation

In the Jeffara Plain, the forestation and reforestation started in 1952 with the planting of thousands of hectares of different forest species such as *Encalyptus gomphocephaha, Encalyptus camaldulensis, Acacia cyanophylla, Pinus pinea and Pinus halapensis*. However, since 1986 the forest cover has been decreasing rapidly, mainly through clearing for settlement and crops, mismanagement and exploitation of the land by conversion to irrigated lands, and urban encroachment. Deforestation for agriculture in semi-arid lands around settlement area is the main cause of land degradation in the areas around Tripoli. The destruction of forest around Tripoli city is shown during seven-year period 1986-1993 (Fig. 3.2 and Tab. 3.1).

Table 3.1: Deforestation around Tripoli city in northern Jeffara Plain between 1986 and 1993, (ha)

Area	1986	1993	Deterioration
Ein Zara	5,412.00	3,298	2,114
Elbadaba Elkhadra	4,397	169	4.227.8
Elbasban Elgbarby	2,467.00	1,643	2,823.80
Elnaser	155.6	155.6	0
Elmayah	104.00	104	0
Gouddaen	170	170	0
Total	12,705	5,539.60	4,937.80

Source: Kredegh (2002:47).

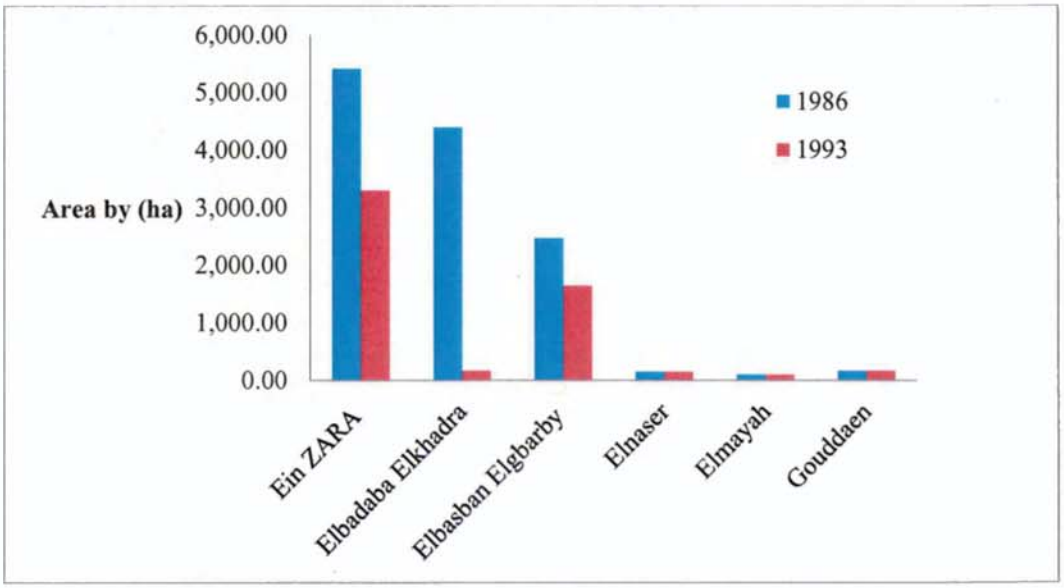


Figure 3.2. Changes in forest area around Tripoli city between 1986 and 1993.
Source: Kredegh, 2002: 47.

3.7.4 Climate

Libya must be considered an arid country, with an average yearly rainfall of less than 50 mm over 91% of its land surface. Dryness in Libya is not solely due to a lack of precipitation, but is influenced by high temperature, low relative humidity, and strong winds (particularly the desert wind which is known as Ghibli) (Ben Mahmoud et al., 2000).

Rain is an important element of the climate in the Jeffara Plain: it is a major factor in the distribution of the population and in determining the types of plants and animals. The rainfall fluctuates either in quantity or in distribution from year to year and from place to place. All this has effects on agricultural production, pasture plants and water resources.

The high temperatures reaching 50°C which lead to physical and chemical weathering of rocks, as well as an increased need for water. The high temperatures also lead to an increase in the amount of evaporation from the soil and transpiration from plants, which has been calculated using the method presented by Thornthwaite (1948), which is common used for estimating potential evapotranspiration. It depends mainly on temperature to calculate evaporation on a monthly basis. The results show that the amount of evaporation (ETP) in the study area is very high, reaching 1200 mm/year, as shown in Table 3.2; which affect the water balance (Pm-ETP) which is always negative, reaching 765 mm in most years, and has also affected vegetation, especially in the areas of rainfed agriculture.

In addition to fluctuations in temperature in summer and winter, this affects the surface layer of the soil and makes it vulnerable to erosion, as well as putting pressure on water resources. All of these factors have led to exposure of the region to drought and desertification.

In the Jeffara Plain, there is a hot dry wind coming from the south, called the Ghibli. The Ghibli (the direction from which the wind blows supplies its name in Arabic) is the hot and dry wind blowing from the southern deserts, which can raise the maximum temperature and reduce the air humidity to minimum values (Arc, 2005).

These violent winds have the effect of drying the soil and parching the vegetation. High Ghibli velocity intensifies the deflation, transportation and redeposition of fine silty and sandy material from the soil surface, the destruction of the most fertile humus horizon, and its burial under the eolian deposits. In addition to this, it tends to remove the topsoil and produce sand dunes with wind conditions on the plain (on more than 200 days a year the wind velocity exceeds 3 m/sec, which is critical for sandy and loamy sandy soils) (Zaytseva, 1965; Kalyanov, 1976).

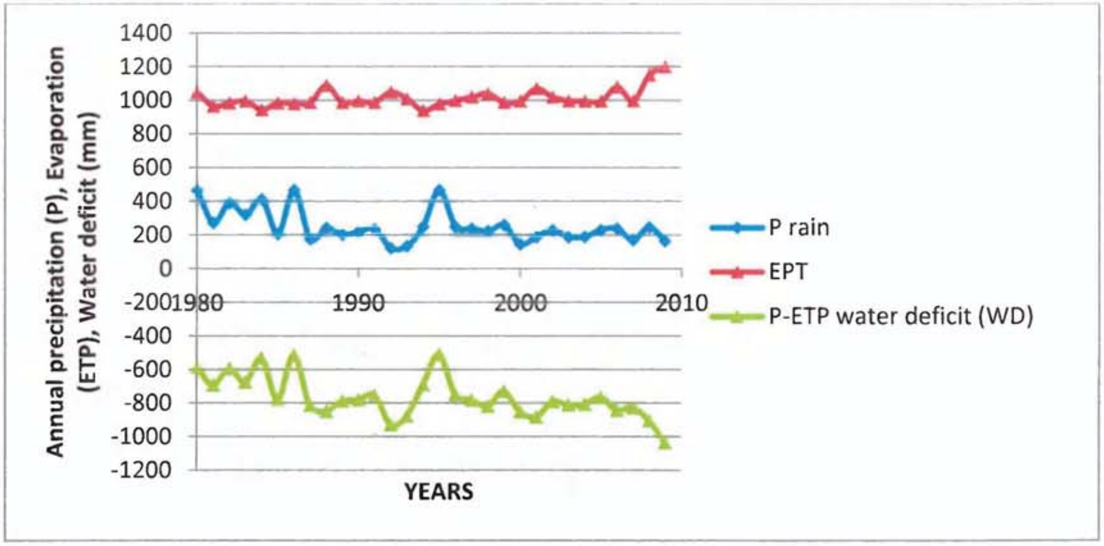


Figure 3.3 Annual precipitation (P), evaporation (ETP) and water deficit (P-ETP) in study area from 1980 to 2009.

Table 3.2: The potential evapotranspiration (ETP) and water deficit (WD) (mm) in the study area during a 30-year period.

Year	P	EPT	P-ETP water deficit (WD)
1980	466	1050	-584
1981	274	966	-692
1982	390	985	-595
1983	320	995	-675
1984	413	945	-532
1985	207	985	-778
1986	467	981	-514
1987	176	988	-812
1988	242	1090	-848
1989	202	989	-787
1990	218	997	-779
1991	236	988	-752
1992	123	1050	-927
1993	134	1010	-876
1994	251	940	-689
1995	468	978	-510
1996	251	999	-748
1997	239	1020	-781
1998	223	1040	-817
1999	259	988	-729
2000	146	996	-850
2001	187	1070	-883
2002	230	1020	-790
2003	188	998	-810
2004	190	996	-806
2005	230	995	-765
2006	238	1080	-842
2007	170	997	-827
2008	247	1150	-903
2009	165	1200	-1035

3.7.5 Overgrazing

In Libya, the area of rangelands is about 11.8 million hectares, mainly in the coastal area between 50-200 mm/yr isohyets, of which 4.8 million hectares are in the western area (Jeffara Plain). The area is under the direct use of herders with sheep, goats and camels and there is no restriction on the use of rangelands with any number of animals, which has led to overgrazing and the presence of large numbers of animals, many more than the grazing capacity of these rangelands (Figure 3.4) (LY 00/004, 2004).

According to ARC (2000), the grazing pressure on the rangelands of the western region is 3.2 times what the rangelands can afford in a sustainable way (Figure 3.5). This shows clearly the poor situation of the rangelands, which has led to land degradation. In addition, Ben Mahmoud et al. (2000) pointed out that the main cause of land degradation and desertification in the Jeffara Plain is overgrazing. Increased human pressure on the rangelands has caused the destruction of the natural vegetation cover (reduction of bio-productivity and invasion of non-palatable species), which has led to amplified soil erosion as well as salinity, which causes an almost permanent loss of land and its production.

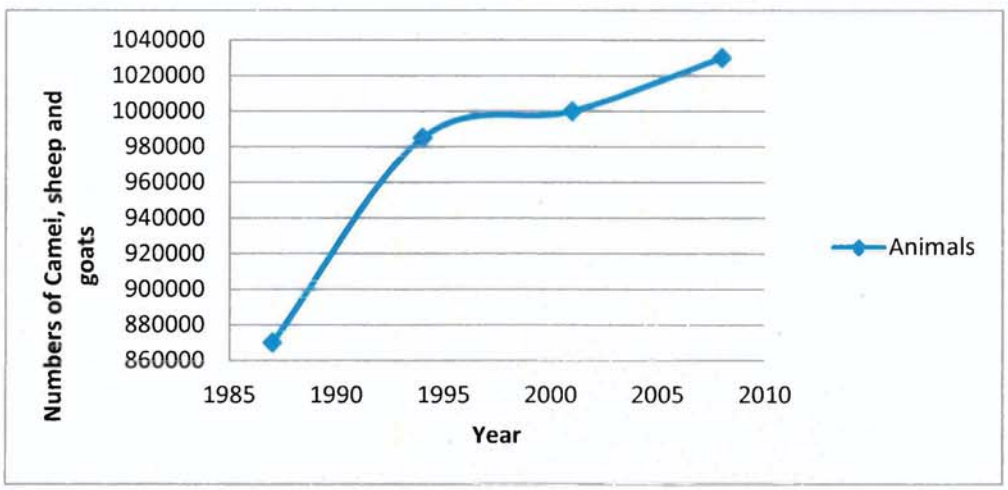


Figure 3.4: The number of animals in the Jeffara Plain (1985–2009).

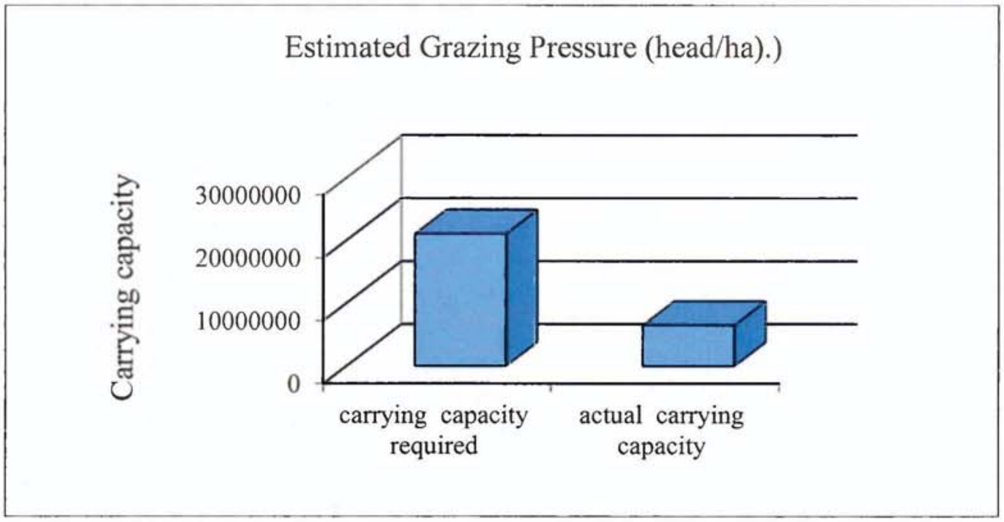


Figure 3.5: Estimated grazing pressure in North West Libya.

Source: Agricultural Research Center.

3.7.6 Over-cultivation

The area of rain-fed land in the Jeffara Plain was 131,764 hectares in 2002; it constitutes 49% of the cultivated area in the Jeffara Plain, and 7% of the rain-fed land in Libya.There has been a decline in the area of rain-fed land, due to the expansion in the area of irrigated agriculture, especially in the southern parts of the region and those which receive less than 200 mm of rain per year.

The area of rain-fed land in the Jeffara Plain in 1974 was estimated at 269,619 hectares, while in 2002 it had decreased to about 131,764 hectares. Furthermore, over 90% has been devoted to the production of barley at the expense of other crops and the neglect of the agricultural cycle, especially in rain-fed agricultural land, which has led to the exhaustion of the soil and made it a source of dust storms after the harvests, which are a catalyst for the spread of desertification. Moreover, the use of marginal lands under irrigation has led to intensively exploited water resources.

3.7.7 Population growth

Desertification is caused by the combination of man's excessive and wrong use of an ecosystem which is inherently susceptible to deterioration (Kassas, 1987: 391). It happens when people enter such an area and act there out of necessity for survival, without knowledge or proper awareness of the environment's boundaries and limitations

(Perez and Thompson, 1995). The Jeffara Plain consists of about 50% of the total irrigated land in Libya, and is inhabited by approximately 58% of the total population of the country, living in an area of less than 1% of the total area of the country, this clearly indicates the population density experienced by this region compared to other regions of the country (Agricultural Research Center, 2000).

The largest and most densely populated cities of the country, including Tripoli, Zawia, Zwara, Swani, and Azizia, are situated in this plain. (Figure 3) (Census, 2006). As a result, there is increased demand for food and other basic necessities. The rapid increase in population in addition to the absence of control and planning policies has produced some serious conflicts in Libya. For example, such conflicts arise from the increase in competition between urbanisation, increasing population, industrial development and the agricultural domains (Libyan Statistics Book, 2007).

3.8 Summary

This chapter has discussed the concept of desertification in general and the distribution of dry lands and desertification in the world, as well as the causes of desertification in general and specifically the Jeffara Plain in Libya. According to FAO and LY004, desertification in the Jeffara Plain is caused mainly by overgrazing of domestic livestock. There is no restriction on the use of rangelands with any number of animals; this has led to overgrazing with large numbers of animals, many more than the carrying capacity of these rangelands. Other factors are over-cultivation during the attempts to grow wheat or barley in marginal lands; deforestation, where approximately 44% of forest areas were cleared during the seven years between 1986 and 1993 around the city of Tripoli; and climate, with the effects of the erratic quantity and distribution of rainfall, high temperature, low relative humidity, and strong winds. All these factors have led to decreased vegetation cover and have affected agricultural production, pasture plants and water resources. This has put the area under severe threat from land degradation and desertification.

The next chapter (4) reports on the various methods used in evaluating land degradation status and the underlying causes. A number of methods have emerged in the last 50 years (excluding the usual land degradation techniques known for centuries), however, each is streamlined to a specific assessment procedure.

CHAPTER 4

A REVIEW OF LAND DEGRADATION ASSESSMENT METHODS

4.1 Introduction

There are many methods that have been used to assess land degradation (water and wind) and most of these methods are experts-based opinion. The main examples of these methods are Global Assessment of Human Induced Soil Degradation (GLASOD), Assessment of the Status of Human-Induced Soil Degradation in South and South-East Asia (ASSOD), Soil Degradation Assessment in Central and Eastern Europe (SOVEUR) and Land Degradation and Assessment in Drylands (LADA). However, over the last 30 years, new methods have been developed that calculate land degradation on the basis of factors such as soil, climate, vegetation, management and topography These include the Mediterranean Desertification and Land Use Method and the Universal Soil Loss Equation (USLE).

The first global source of soil deterioration assessment data, which is presently the only coordinated world-wide source of soil degradation data, is currently referred to as the World Soil Information. According to FAO (2000), it is also referred to as the Global Assessment of Human Induced Soil Degradation (GLASOD) (1990), as classified by the International Soil Reference and Information Centre (ISRIC). Other soil assessments on a regional basis that have been carried out after GLASOD include the Assessment of the Status of Human-induced Soil Degradation in South and South East Asia (ASSOD) (van Lynden and Oldman, 1997) and the Degradation of the Drylands of Asia (Kharin et al., 1999). Other sources of soil degradation information include regional results of GLASOD that have been published. Furthermore, information from the World Atlas of Desertification contains relevant data from various countries on desertification (Middleton and Thomas, 1997). The source of future additional data on soil degradation will be the Land Degradation Assessment in Drylands (LADA) project.

4.2 GLASOD

Originally produced for the United Nations Conference on Environment and Development (UNCED) in 1992, a global map of world soil degradation was developed with an average scale of 1:10M. The next step in this development has been digitisation and storing in GIS format along with related databases and added statistics including the extent of soil degradation. More than 250 experts of varying backgrounds including soil and environmental scientists have contributed to the GLASOD project. According to Oldeman et al. (1991), the aim of the GLASOD project was to characterize the nature of soil degradation by mapping the extent of degradation and the percentage of the mapped area degraded, assessing the apparent rate at which the process advanced over a five- or ten-year period, and attributes related to human intervention and effect.

Those places that were affected by soil degradation due to human action were defined as regions where "the balance between the attacking forces of climate and the natural resistance of the terrain against these forces has been broken by human intervention, resulting in a decreased current and/or future capacity of soil to support life" (Oldeman et al., 1988). GLASOD guidelines, according to Oldeman (1988), suggest that the definition of soil degradation does not include those examples of degradation which have "occurred in the past as a result of geologic events or under past climatic conditions such as the rising of mountain chains, volcanic eruptions, the melting of glaciers such as the rising and subsiding of ocean levels, etc", This means involves degradation as a result of human actions (Oldeman, 1988).

The severity of soil degradation, which can be low, medium, high or very high, can be calculated using GLASOD by adding the degree of degradation, which can be light, moderate, strong or extreme, to the relative extent, which is the percentage of the unit of mapping affected (0–5%, 6–10%, 11–25%, 26–50%, or >50%). Although GLASOD has been widely cited, it does have limitations, given the fact that it is based on a small-scale study. It is limited to soil degradation assessment and does not include degradation of the full land resource in its climate, vegetation, water resources aspects. And also findings mostly based on expert knowledge,which renders it mostly subjective (FAO 2000).

4.3 ASSOD

ISRIC conducted a follow-up study to GLASOD which resulted in the Assessment of the Status of Human-Induced Soil Degradation in South and South East Asia (ASSOD) (1997). This assessment used a refined methodology using a detailed scale of 1:5M for South and South East Asia. It makes available data for seventeen countries that include different degradation types such as erosion due to water and wind.

These forms of erosion have led to the loss of millions of hectares of topsoil, as well as terrain deformation and chemical deterioration, including salinization. ASSOD is more detailed and much more accurate than the GLASOD study, as presented by van Lynden and Oldman (1997). Soil degradation in the ASSOD study is indicated in different subtypes based on qualitative factors such as impact on productivity, expressed in terms such as 'negligible', 'light', 'moderate', 'strong', and 'extreme impact'.

The classification is based on changes in productivity and it also considers the level of management. Relative terms are used to express changes in productivity, which show the current average productivity in comparison to the mean productivity in the non-degraded situation. As with the GLASOD study, only human-induced soil degradation is covered. However, there is a difference between this and the definition used by the UNSD questionnaire, given the fact that experts found difficulties in showing the difference between human-induced and natural degradation. It is difficult to say how much a factor the challenges were in affecting the estimate as well as the added effect of wind and water erosion.

4.4 SOVEUR

Conducted between 1997 and 2000 by ISRIC and FAO, the SOVEUR used a modified GLASOD methodology that focused on diffused pollution in conducting the soil degradation assessment in Central and Eastern Europe. It included information on water and wind erosion as well as salinization.

Degradation in this study was defined in relation to both the type and the intensity of the process in addition to the impact. (The scale used is 'negligible', 'light', 'moderate', 'strong', and 'extreme'.) The degradation impact is measured as a combination of the changes in productivity ("current average productivity compared to the average productivity in the non-degraded or non-improved situation") as well as a measured of the management.This development uses a physiographic map with a scale of 1:2.5M as well as experts' estimates. The study was based on research in thirteen different countries (van Lynden, 2000).

4.5 LADA

Supported by the Global Environment Facility (GEF), United Nations Environment Programme (UNEP), the Secretariat and the FAO as well as the Global Mechanism of the UNCCD, and conducted by the FAO, Land Degradation and Assessment in Drylands (LADA) is an international project started by the UN. This project was initiated in order to make it possible to develop and test a helpful and effective methodology for the assessment of the causes, status and impact of land degradation in drylands based on field observations (recorded and then scored on the field sheets), discussions with farmers and local experts, and questionnaires to the same groups. Several pilot studies have been published among them, as reviewed by van Lynden and Kuhlmann (2002).

4.6 Wind Erosion Equation (WEQ)

The Wind Erosion Equation (WEQ) which uses a relationship between five generalized factors was developed by Woodruff and Siddoway (1965). The five inputs which make the model are as follows:

$$E = f(I', C', K', L', V)$$

Where: I is the soil and knoll erodibility;

Knoll Erodibility is: unsheltered, isolated field with a bare, smooth and crusted surface, which can be obtained from wind tunnel and field measures.

C is the local wind erosion climatic factor;

K is the soil ridge roughness factor;

L is the field length; and

V is the equivalent quantity of vegetation cover.

Woodruff and Siddoway (1965) employed this model to predict annual soil erosion (kg ha–1) from farm fields in the United States. The WEQ was designed for use in the analysis and management of wind erosion. The main aim for developing the WEQ was to apply the model in the determination of the effects of field conditions and erosion mitigation strategies on erosion rates (Woodruff and Siddoway, 1965). The WEQ was developed from empirical relationships which define the effects of environmental controls on soil loss rates. The empirical functions which make up the model were derived from the field and the wind tunnel experiments under a range of soil types and roughness conditions (Chepil and Woodruff, 1954). Further development around the WEQ led to the development of three sub-models of wind erosion: the Wind Erosion Prediction System, WEPS (Hagen, 1991), the Wind Erosion Assessment Model, WEAM (Shao et al., 1996) and the Revised Wind Erosion Equation, RWEQ (Fryrear et al., 1998). Using these sub-models require detailed input data (which are not always available) and depends on field-measured inputs and empirical relationships. Therefore, the choice of any of the above models to produce the desired output is dependent on input data and field data for validation.

Most wind erosion models require field measurement for a long time. In addition, wind erosion needs field equipment and techniques for ascertaining threshold wind velocities amount, and vertical distribution of the eroded soil particles, which are not available at broad spatial scales (Woodruff and Siddoway, 1965; Fryrear et al., 1998). Using this technique requires researchers to conduct field measurement over a long period of time (Woodruff and Siddoway, 1965; Fryrear et al., 1998). Unfortunately, the political instability and conflicts in Libya over the past three years prevented the researcher from undertaking a field measurement over a long period of time as would be required. Therefore, time constraints, the lack of field equipment and techniques, and insecurity were the restrictive factors for not using wind erosion models in the study.

4.7 The Mediterranean Desertification and Land Use Method

Rubio (1995) and Basso et al. (2000) concurred to the concept of Environmental Sensitivity (ES) developed over that last 30 years. This development, according to Rubio (1995) and Basso et al., (2000) occurred in the industrialised countries. As a consequence of desertification and soil degradation, the European Commission – EU funded a project to help deal with the problem in the Mediterranean region. The EU's Mediterranean Desertification and Land Use (MEDALUS) were aimed at investigating the relationship between desertification and land use in the Mediterranean areas in Europe. The technique, MEDALUS a model, invented in this project was based on GIS. MEDALUS models are primarily targeted to and particularly against Mediterranean landscapes for uncultivated conditions in Portugal, Spain, Italy and Greece (Mariota et al., 1998). This method was used in the identification of land that is prone to desertification and degradation (Kirkby et al., 1998; Basso et al., 1999; Kosmas et al., 1999).

The ESAs (Environmental Sensitive Areas) model is based on four considerable groups of indicators, within which the minimum dataset selection, representing soil quality (texture, rock fragments, drainage, parent material, soil depth), climate (rainfall, aridity, aspects), vegetation (plant cover, fire risk, erosion protection, resistance to aridity) and management practices (intensity of land use in rural zones, pastures and forest areas, managerial policies). Desertification indicators are combined into four quality layers, independently of the structure of input layers (number of classes, etc.) as the Soil Quality Index (SQI), the Climate Quality Index (CQI), the Vegetation Quality Index (VQI) and the Management Quality Index (MQI). The values of the quality indices for each elementary unit within a layer are obtained as geometric mean of the scores assigned (following the factorial scaling technique) to each single indicator, namely SQI, CQI, VQI and MQI.

The MEDALUS method for identifying land that is sensitive to desertification and degradation has been used in the arid and semi-arid regions. For example, the method has been used in the Extremadura region of south-west Spain (Lavado Contador et al., 2009), and also in the south-east region of Spain (Hooke et al., 2005). The MEDALUS method has also been used in other regions such as the southern region of Italy (Ladisa et al., 2010), in Apulia region of Basilicata (Basso et al., 2000), in the region of Calabria (Coscarelli et al., 2005), and also in the region of Sicily (Giordano et al., 2002; APAT, CRA, UCEA, 2006). The OOS (2002) also documents the use of the MEDALUS in the North African sub-region, and specifically in five countries namely Algeria, Egypt, Libya, Morocco and Tunisia. These countries were found to be highly vulnerable to risks of desertification up to the scale of 1: 1.000.000. In recent times, the European Environmental Agency has used the bio-physical factors of ESAI to develop the Desertification Sensitivity Index. Following this, a number of studies have been able to use the standard MEDALUS approach in some regions of Egypt (Gad and Lotfy, 2006). It has also been used in the eastern region of Algeria, specifically around the Aures (Benabderrahmane et al., 2010). Kosmas et al. (1999) stated that the vegetation, climate, geology, soil, landforms, and human activity are the main factors considered by the Mediterranean Desertification and Land Use Method (ESAs). All factors in this method are individual to groups of factors. Every part is allotted into different classes with respect to the manner of desertification, and weighting factors are given to each class. Then the following four qualities are evaluated: (a) soil quality, (b) climate quality, (c) vegetation quality, and (d) management quality. After the calculation of four indices for each quality, the ESAs for desertification are defined by combining them. All data collected are entered into a Geographic Information System (GIS).

$$ESAI = (SQI * CQI * VQI * MQI)^{1/4} \quad \text{Equation 2}$$

4.8 The Universal Soil Loss Equation (USLE)

The Universal Soil Loss Equation (USLE) provided by Wischmeier and Smith (1978) is extensively used as an erosion prediction method. It is widely used because of its relative simplicity and sturdiness. The Universal Soil Loss Equation (USLE) is applied using GIS to assess the average annual soil loss in the field. Moreover, the Universal Soil Loss Equation is designed specifically to determine quantitatively the average annual soil loss. To calculate soil erosion, six main factors are used, as in the following equation (Wischmeier and Smith, 1978):

$$A = R \times K \times L \times S \times C \times P \quad \text{Equation 3}$$

where:

A = Annual soil loss in $t\ ha^{-1}\ y^{-1}$

R = Rainfall erosivity factor ($mm/m^{2}\ h^{1}$)

K = Soil erodibility factor ($t\ mm^{-1}$)

L = Slope length factor

S = Slope steepness factor

C = Crop and management factor

P = Conservation-supporting practices factor

4.9 Remote Sensing Method

According to King and Greenstone (1999), during the last thirty years, many Earth observation satellite sensors (e.g. the SPOT, NOAA, and Landsat series) have started to provide images data for global monitoring. In particular, the Landsat-5 Thematic Mapper (TM) provides multispectral data, covering the largest part of the land areas of the world at a spatial resolution of 30m. These techniques provide coverage, continuous monitoring, and multiple imaging, and, together with satellite images, generate data to help quantify the effects of climate change and human activity that influence vegetation cover, composition, and dynamics.

In addition to this, remote sensing and Geographic Information Systems have become the most important tools which aid monitoring and planning processes by providing access to great amounts of relevant information on land resources and their management.

These techniques have helped overcome the limitations of more traditional studies by reducing the intensive field surveys and the expenses which were required by the traditional methods to produce vegetation mapping and to monitor land degradation (Servenay and Prat, 2003; Yang et al., 2007).

Satellite remote sensing and Geographical Information System (GIS) technologies are now widely used for environmental monitoring and mapping the distributions of land surface biophysical parameters (Henderson, 1990). Thus remote sensing techniques offer great potential for monitoring and analysing Land degradation at various spatial and temporal resolutions (Richards, 1993). Remote sensing estimates of vegetation have significantly improved our understanding of intra- and inter-annual variations of vegetation at regional and continental scales (Lillesand et aI, 2004; Okin et aI, 2001).

This method has been used in many countries to study land cover changes and land degradation because of the low cost per surface unit, long term data archive. However, the weakness in this method is its dependence solely on density of vegetation and ground truthing (as mentioned in Chapter 6) in the production of land degradation maps.

4.10 Why was the Mediterranean Desertification and Land Use Method Selected to Study Land Degradation?

The MEDALUS method has been selected as the most suitable and simplified method for modelling land degradation in the study area. This was chosen after meetings and discussions with both the National Committee to Combat Desertification, Libyan Natural Resource Projects (LY00/004), and local experts. This decision was based on the following criteria.

a- This method focuses primarily on Mediterranean environments which are similar to the area of this study and in the same broad climatic region.

b- In this model, different types of ESAs to desertification can be analysed in terms of various parameters such as landforms, soil, geology, vegetation, climate, human activities and management.

c- All of these parameters are grouped into various uniform classes and a weighting factor is assigned to each class; these parameters are considered the most important factors of land degradation in the arid and semi-arid areas.

d- All the data defining the four qualities are presented in a regional geographical information system (GIS), and overlaid in accordance with the developed algorithm and maps of ESAs to desertification are compiled.

e- The key indicators for defining ESAs to desertification, which can be used at regional or national level, can be divided into four broad categories defining the qualities of soil, climate, vegetation, and management (stressor indicators).

f- This method has been used in many areas in the Mediterranean during the execution of the MEDALUS Project: in Greece (the island of Lesvos), Italy (the Agri basin in Basilicata), Portugal (Alentejo region), and other areas such as North Africa and Egypt.

g- Many researchers confirm that the MEDALUS model evaluates the desertification rate accurately with acceptable results (Basso et al., 2000; Rafiei, 2002; Kosmas et al., 2003; Sepehr et al., 2007; Lavado et al., 2009).

4.11 Why was the Method of The Universal Soil Loss Equation (USLE) Selected?

The Universal Soil Loss Equation (USLE), method has been used to determine the quantity of the average annual soil loss. As mentioned earlier due to there was small amount of water erosion observable in the study area (ARC 2005). Therefore, it is of interest to see how the model performs. Additionally USLE is popular model even through it is likely that wind the more important mechanism for soil erosion.

The selection of this method is based on the following:

a. It can be applied in many countries of the world because it contains the same characteristics of the targets to the all areas.

b. It gives a quantitative estimate of erosion rates which can be compared in the long term.

c. This method can be updated at any time when current data are available.

d. It has been widely used at different scales.

e. It is widely used because of its relative simplicity and sturdiness.

f. It has been used in many countries around the world.

4.12 Summary

The methods for the measurement of land degradation provided above vary, as shown by the different examples, such as ASSOD, LADA and GLASOD. As can be seen above, there are many weaknesses in the methods of assessment, and do not take into account the degradation of the full land resource including climate, vegetation and water resources aspects. There is also, the basin of the finding on expert knowledge, which renders it invalid as they are mostly subjective (FAO 2000; Oldeman and Van Lynden 2001, Wood et al. 2000). For example, the GLASOD map was initially manually compiled but later on digitized. As a result, considerable generalizations were made that led to scale reduction, decrease on the number of degradation types, and unclear link between degradation types and their causative factors. On the other hand, the Mediterranean Desertification and Land Use Method depends on many factors such as vegetation, climate, geology, soil, landforms, management and human activity . However, the model does not take into account some factors such as soil salinity management and wind erosion. which are considered an important factors of land degradation in the arid and semi-arid areas. In addition, remote sensing and Geographic Information Systems have become the most important tools aiding monitoring and planning processes, by providing access to great amounts of relevant information on land resources and their management at a relatively low cost and high resolution (see Chapter 5).

CHAPTER 5

REMOTE SENSING AND LAND DEGRADATION

5.1 Introduction

In the last thirty years, remote sensing and Geographic Information Systems (GIS) have become the most important tools which aid monitoring and planning processes by providing access to great amounts of relevant information on land resources and their management. With the help of the readily available remote sensing data, the low data cost and the increased resolution of images from satellite platforms, remote sensing techniques have been become developed and available to the needs of planning agencies and land management. In addition, remote sensing and GIS have provided many applications connected to resources at large spatial scales (Green, 1995; Hinton, 1996). Furthermore, the technology of remote sensing provides a practical and economical tool to study land cover changes, particularly over large areas (Langley et al., 2001; Nordberg et al., 2003).

In such a context, remote sensing and GIS techniques are very important for the study and evaluation of land degradation (De Jong, 1994; Shrestha et al., 2004). According to King and Greenstone (1999), during the last thirty years, many Earth observation satellite sensors (e.g. the SPOT, NOAA, and Landsat series) have started to provide data for global monitoring. In particular, the Landsat-5 Thematic Mapper (TM) provides multispectral data, covering the largest part of the land areas of the world at a spatial resolution of 30m.

Although the full potential use of remote sensing technology has not been completely recognized, the agencies are becoming aware of the need for this technique to help formulate rules and provide insights into patterns and trends of future change. Remote sensing information, together with other technologies like the GPS and GIS, can give good information while remaining cost-effective (Franklin et al., 2000).

5.2 Potential of Remote Sensing for Land Degradation Studies

According to Grainger and Bradley (1998), the observation and monitoring of land degradation at a large scale is very difficult. Nevertheless, Burrough (1986) stressed that, by the combination of image analysis and Geographical Information System (GIS) models that represent both environmental and human impacts, the capacity to observe and examine land degradation will be extended.

Furthermore, remote sensing and GIS are considered the main instruments for the spatial study and analysis of natural resources and the production of thematic maps related to vegetation cover. Satellite images are useful in the study and evaluation of changes in land cover (soil and vegetation), and providing information about land use and urban expansion, over time and spatially, and the monitoring of land degradation (Ben Mahmoud et al., 2000; Mundia and Aniya, 2005; Yuan et al., 2005; Kavzoglu and Colkesen, 2009). Moreover, remote sensing information is helpful in making environmental policy decisions, monitoring and assessing desertification, protected areas, and producing thematic maps (Fassnacht et al., 2006; Sanchez et al., 2007).

In studying agricultural land cover in semi-arid lands, Landsat TM and SPOT HRV (High Resolution Visible) data have proved to be useful. Use of any of these tools requires interpretation techniques that can be visual or assisted by computers.

Weiss et al. (2001) pointed out that some conditions of the vegetation in arid and semi-arid regions have been assessed using MODIS and NOAA AVHRR (Advanced Very High Resolution Radiometer) NDVI (Normalized Difference Vegetation Index) data. Moreover, there are several indicators to evaluate desertification severity; however, the change of vegetation cover is considered the most useful indicator of land degradation, particularly when using remotely sensed images (Zha and Gao, 1997; Yang et al., 2005). It is considered that using satellite imagery is cheaper than other more traditional ways of studying a land area, especially if the land area to be observed is large.

Using multi-temporal Landsat TM/ETM data and converting them into land cover maps employing the change detection technique made it possible for Chen and Rao (2008) to verify the rate and status of grassland degradation in northern China. In the northern province of South Africa, for example, Landsat MSS data provided maps of time-series vegetation index that moreover had revealed land degradation in that area (Botha and Fouche, 2000).

5.3 Multispectral Remote Sensing

Multispectral imagery contains between three and six spectral bands in the visible region of the infrared medium of the electromagnetic spectrum and one or more thermal infrared bands (Smith, 2001a). According to Landgrebe (1999), multispectral and satellite systems have been used for collecting data in the fields of agriculture and food production, geology, geography and urban development.

In determining the ecological status of a particular landscape, Elmore et al. (2000), mentioned that multispectral sensing is applied especially with vegetation indices for the reason that the retrieval of rigorous reflectance proved to be quite challenging. It is important to remember that such vegetation indices tend to determine desert biomass poorly, in addition to being not receptive to vegetation which is not photosynthetic, while being receptive to the colour of soil. Studying vegetation cover in arid lands usually requires a spectral mixture analysis.

5.4 Hyper-spectral Remote Sensing

Data obtained from hyper-spectral sensing are now becoming more available although multispectral data are commonly used in observing and determining the degradation of lands in regions that are arid or semi-arid. The data from hyper-spectral sensing offer a better understanding with regard to the relationship between dry environments and the process of degradation that otherwise endangers such land types. However, there are challenges when it comes to these types of data, and such challenges are also faced by all other means of remote sensing of such dry lands (Smith, 2001b).

5.5 Landsat

The longest-running and oldest enterprise for the acquisition of imagery of the earth from space is said to be the Landsat programme (Lillesand et al., 2004). Its earliest satellite was launched in 1972 and the newest satellite was launched on April 15, 1999.

These satellites are equipped with powerful instruments that have the capability to acquire a million different images. The images, documented in the United States as well as in Landsat stations around the world, are an authentic resource for global change research and applications in agriculture, geology, forestry, regional planning, education and national security.

There are five different sets of sensors that are included in the Landsat missions, which include the Return Beam Vidican (RBV), the Multispectral Scanner (MSS), the Thematic Mapper (TM), the Enhanced Thematic Mapper (ETM) and the Enhanced Thematic Mapper Plus (ETM) (Lillesand et al., 2004). These sensors were launched into repetitive, circular, sun-synchronous and near-polar orbits.

The Landsat TM and Landsat ETM have seven spectral bands which include the visible, near infrared, short-wave infrared and thermal infrared regions of the electromagnetic spectrum, with a pixel size of 28.5 × 28.5 m (Mather, 2004).

The TM sensor is the newly upgraded and improved MSS sub-system: thus the TM instrument is based purely on the same technical principle as MSS but with an improved design and use such as spatial resolution of bands in the visible and reflective infrared regions is 30 m, some 2 .5 times better than the Multispectral Scanner (MSS). while the Landsat 7 ETM sensor gives several improvements over the Landsat 4 and 5 Thematic Mapper sensors, which comprise improved spectral data substance, enhanced geodetic precision, reduced noise, accurate calibration, and the supplementation of a panchromatic band with 15m spatial resolution, and a thermal IR channel with 60m spatial resolution (Masek et al., 2001).

5.6 Classification Techniques

Image classification is considered the most important part of remote sensing and is a means to change spectral raster data into a finite set of classifications that represent the surface types seen in the imagery (Campbell, 2002).

There are two methods of image classification: supervised and unsupervised. Unsupervised classification "is a method which examines a large number of unknown pixels and divides them into a number of classes based on natural groupings present in the image values". Supervised classification "depends on the manual identification of known surface features within the imagery and then uses a statistical package to decide the spectral signature of the identified feature" (Campbell, 2002).

Visual interpretation, supervised classification and a spectral mixture model are techniques which are helpful for understanding data and obtaining more information from satellite images (Vrieling, 2006). Various Earth observation satellites have made available much more information about land cover through optical systems LANDSAT-TM and SPOT-HRV (Hill and Schütt, 2000; King et al., 2005; de Asis and Omasa, 2007).

Visual interpretation using on-screen digitizing depends on image enhancement to improve the visual interpretability of an image by increasing the apparent distinction between the features. There are a number of operations to improve images, such as False Color Composite (FCC) image and histogram equalization, which can be used to obtain clearer images and convert the image to a form better suited for analysis by a human or a machine. After that the process of visual interpretation involves drawing polygons along the boundaries by mouse, then saving them to different polygons and adding attributes (labels) of the polygons to produce the thematic maps (Lilles and Kiefer, 1994).

Supervised classification depends on three phases: the training phase, the classification phase, and the output phase. In the first, the training phase, the analyst classifies representative training areas and makes a numerical description of the spectral attributes of each land cover type of interest in the scene. In the second, the classification phase, each pixel in the image information set is classified into a land cover class which it most closely resembles. It is labeled "unknown" if the pixel is not similar to any training dataset presented.The category assigned to each pixel is then recorded in the corresponding cell of an interpreted data set as an output image. This output image is then categorized and presented in the output phase (Campbell, 2002).

5.6.1 Maximum Likelihood classification

The Gaussian or normal maximum likelihood algorithm is considered to be a supervised classifier, in which the analyst supervises the classification by naming representative areas, called training areas. The areas are then named numerically and presented to the computer algorithm, which classifies the pixels of the entire scene into the respective spectral class that appears to be the same. In a maximum likelihood classification the distribution of the response pattern of each class is assumed to be normal. The training stage is very significant in the sense that its characteristics define the output of the classification. The information should comprise all spectral differences within each class. Statistically based algorithm requires a minimum of n +1 pixels for training in each class, where n is the number of wavelength bands (Lillesand and Kiefer, 1987).

5.7 Mapping and Monitoring Land Degradation

Field observation and evaluation, expert judgment (Sonneveld, 2003), and the use of remote sensing and GIS approaches (Amissah-Arthur et al., 2000; Sujatha et al., 2000; Haboudane et al., 2002; Thiam, 2003; Wessels et al., 2004) are among the methods being employed for studying land degradation.

To gather information about degradation conditions as well as its extent geographically, vital tools are also offered by remote sensing techniques (Eiumnoh, 2001; Symeonakis and Drake, 2004; Wessels et al., 2004). Amissah-Arthur et al. (2000), for example, in assessing the status of land degradation in the African Sahel, used a combination of SPOT data, biophysical data including soil quality, and economic data including intensity of land use, population density, and carrying capacity, among others.

The risks of land degradation can also be assessed, as shown by Thiam (2003), who evaluated the dangers in southern Mauritania, using AVHRR NDVI (Normalized Difference Vegetation Index) images together with other data such as soil types, human impact areas, and rainfall, and a field survey. Mapping of land degradation is usually done using a combination of remotely sensed classification results and associated ancillary data.The accessibility of such ancillary data, in addition to somewhat subsidiary classification results, most of the time reduces its success.

5.8 Land cover Change Detection

Change detection is a process that measures how the attributes of a particular area have changed between two or more time periods. Change detection often involves comparing aerial photographs or satellite images of the area taken at different times. The process is most frequently associated with environmental monitoring, natural resource management, or measuring (Wade and Sommer, 2006).

The remote sensing data can be used to describe and determine changes in land cover and land use properties by a change detection process. The process can discover changes between different times, such as deforestation due to urbanization or natural disasters, agricultural practices and land use changes (Chan et al., 2001; Muchoney and Haack, 1994; Singh, 1989).

Ground observation and remote sensing are among the many ways to study land degradation. It has been considered, however, that ground observations are more costly and more time-consuming than remote sensing – after all, observations and studies can be done by referring only to a remotely sensed image of a vast field measuring hundreds of square kilometres. Such an image, moreover, provides good details that reveal the extent of land degradation in varying degrees (Gao and, 2008).

5.9 Summary

This chapter discussed the capacity of remote sensing to study the land degradation evaluation in drylands. Remote sensing data have provided useful information about land cover change areas. It can help in determining areas of of negative or positive trends of the dynamics of land and the natural resources and risk analysis at different scales. Moreover, this information is helpful in making environmental policy decisions, monitoring and assessing desertification, land degradation and protected areas, and producing thematic maps.

CHAPTER 6

USING SATELLITE IMAGES AND REMOTE SENSING FOR ASSESSMENT AND MONITORING OF LAND DEGRADATION

6.1 Introduction

Satellite images are useful in the study and evaluation of changes in land cover (soil and vegetation) over time and spatially, and the monitoring of land degradation. Therefore, it is suggested that remote sensing and GIS modelling should be widely used to evaluate and understand soil loss and erosion risk (Geerken and Ilawivi, 2004; King et al., 2005; de Asis and Omasa, 2007; Martinez-Carreras et al., 2007; Mathieu et al., 2007; Quincey et al., 2007; Chafer, 2008). In this context, remote sensing and GIS techniques are very important for the study and evaluation of land degradation (De Jong, 1994; Shrestha et al., 2004). In this research three Landsat TM5 satellite images and one spot image were analysed using image-processing software (ERDAS IMAGINE 8.4) and Arc GIS (ESRI 2010). Image enhancement techniques were applied to improve visual interpretation and mapping of land cover and land cover changes in the study area.

This chapter focuses on the use of satellite data in providing the primary basis of information for land cover mapping and monitoring of land cover changes. In this study, supervised classification (enhanced maximum likelihood classification) has been selected, in order to produce land cover maps with acceptable accuracy. The maximum likelihood classification method has been widely used with remote sensing data (Richards, 1995; Campbell, 2002. A land deterioration map was produced using remote sensing and GIS for monitoring of land deterioration.

6.2 Methodology

Remote sensing techniques have provided many applications connected to resources large spatial scales (Green, 1995; Hinton, 1996). In addition, they have the capability to represent land cover classes by several classification processes, and to provide coverage, continuous monitoring, and multiple imaging. This approach uses many satellite images for the monitoring and evaluation of changes in land cover (soil and vegetation), over time and spatially, for the monitoring of land degradation and desertification features. The outputs can be used to find appropriate measures to combat adverse changes and trends in vegetation and land use.

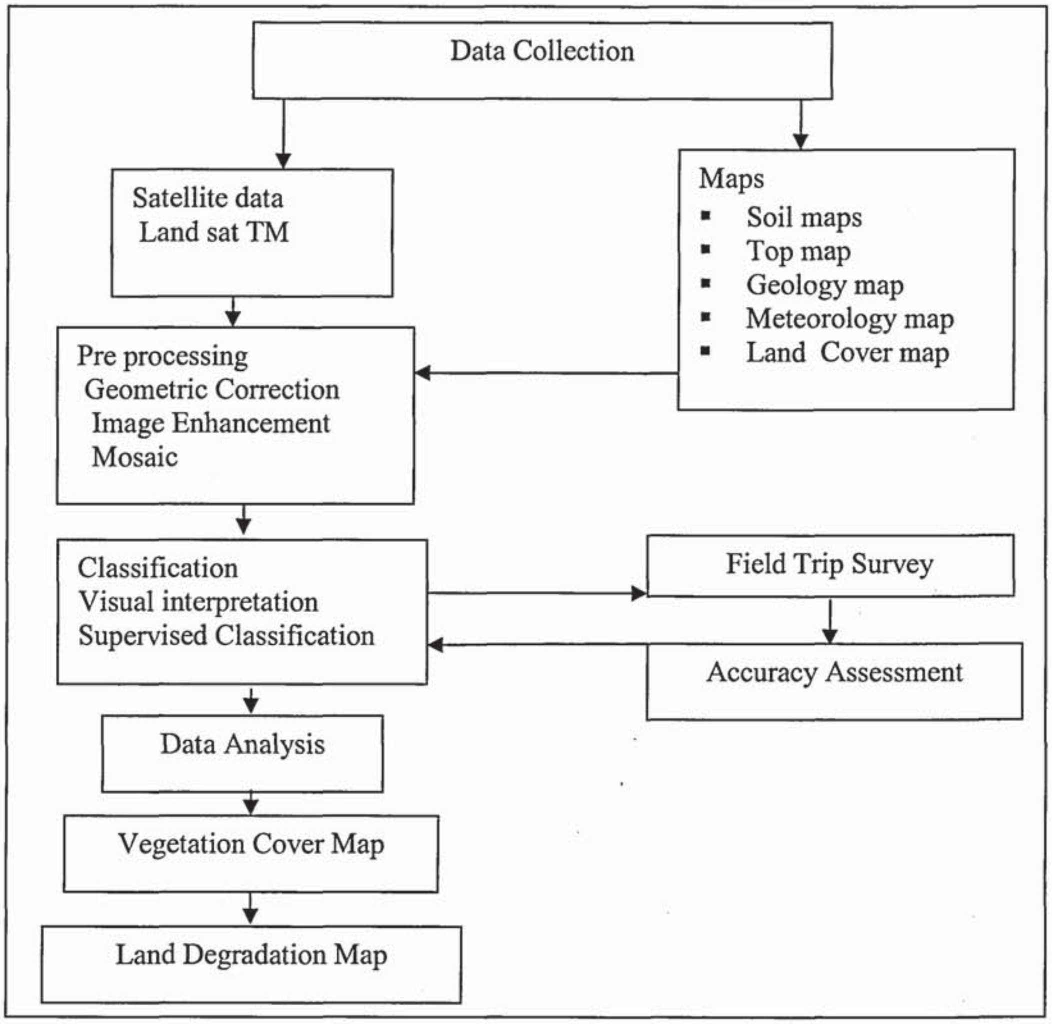


Figure 6.1: Remote sensing model for assessing land degradation in the study area.

6.3 Data Input (Acquisition)

6.3.1 Satellite imagery

Three Landsat images – 5 August 1988, 15 August 1996, and 25 August 2003 – and a Spot Image from 10 September 2009 were used in this study. All satellite images were obtained from the Libyan Centre for Remote Sensing (LCRS), radiometrically and geometrically corrected (level-2A), and free of cloud cover.The scene 189/37 (path/row) has a spatial resolution of 30 metres for Landsat and 10 metres for Spot Image.

6.3.2 Topographic map

A digital topographic map was obtained from the Survey Department of Libya with a scale of 1:50,000. It was projected under the geodetic datum WGS84 and map projection NUTM33, and the unit is in metres.

6.4 Ground Survey

The field survey was conducted in the Jeffara Plain in north-western Libya from 20 July 2010 to 12 September 2010. All reference data were collected from the Libyan Centre for Remote Sensing; the Mapping of Natural Resources for Agricultural Use and Planning Project (FAO, LY00/004); the Agricultural Research Centre; the General Water Resources Authority; the libraries of El-Fateh University, Tripoli; and the Libyan Meteorological Department (Climatic Section).

In the study, the field survey was conducted using several sources including the topographic map, global positioning system (GPS), high-resolution data (SPOT 5), and personal interviews with local experts. Based on the results obtained from the land cover map 2009 and field tested map 2010, a total of 100 geographic points were identified on the grid of soil profiles of Selkhozpromexport (1980), for further observation and study. These sites were visited by the researcher and details were recorded by using the GPS. The information for vegetation cover types, density of vegetation cover and bare land were then imported into GIS for overlaying with the images to provide good information to help understand the spectral signature of the different types of land use and land cover in the study area. The information from the field survey such as types of vegetation cover, rangeland condition, bare land, density of vegetation cover and groundwater were used to determine the accuracy of the assessment of the classified maps and to identify the training areas in the supervised classification analysis (Figure 6.7).

6.4.1 Meeting and discussion with local experts

The local experts were chosen based on their expertise and knowledge on the issue of land degradation and desertification in the study area. In order to avoid bias that may be present when judgement is considered from one expert, a non-probability sampling technique, otherwise known as *referral sampling*, was applied. In this case, experts were identified and the experts in turn recommend potential candidates among their acquaintances. To facilitate the involvement of experts from different backgrounds and reducing individual's subjectivity, the areas of expertise required was clearly adhered to. The local experts were initially chosen by The Director of the Department of Agricultural Research Centre (ARC) and the Head of Soil and Water, Faculty of Agriculture, Tripoli University. They recommended two experts in soil and water, Faculty of Agriculture, Tripoli University; and one other had background in general agriculture and policy. There was also the Agricultural Research Centre (ARC) head of the National Committee to Combat Desertification. Each of the experts had more than 20 years' experience in farming, land degradation and desertification. There were discussions with these local experts about the history of agricultural and rangeland in the study area, such as increases in number of animals and changes in vegetation cover and climate (rainfall, temperature and wind). As well as, increased human pressure on the rangelands by converting pastoral land to irrigated land. In addition the agreement of all local experts that the overgrazing, over-cultivation and climate change are the main causes of land degradation in study area. I did not address the issue of climate because there is only a single climate monitoring station outside the study area and this is potentially a limitation. It must be noted that the 2011 uprising that turned into a civil war in Libya has severely limited my ability to address the aspect of climate.

Over-cultivation refers to unmanaged agricultural practices such as converting pastoral land to irrigated land and encroachment on rangelands for the large-scale cultivation of barley under rain-fed conditions. The areas that still bear vegetation cover are constantly perturbed and removed by expanding farmlands. The real long-term effects of this practice are the eventual removal of the vegetation cover from the land, which leads to land degradation and increased desertification.

6.4.2 Measurements of the density of vegetation cover in study area

Line Intercept Measurements (LIM) method by Canfield 1941, were used to measure the density of vegetation cover in study area. This simple technique to study grass and forbs in forestry and range vegetation requires placing the line at ground level. This method uses visual reading of intercept of the perennial species along a linear transect materialized by a simple rope. The line intercepts are established in homogeneous vegetation replicated and materialized by strings or ropes with a length that varies from a few meters to 100-200 m according to the vegetation structure. As a rule, 3 replicates were conducted, to establish oriented N, E, S, and W radiating from a central peg for each type of vegetation cover. In this method, the belt transect used in density estimates, which has breadth and length, is reduced and regarded as having only one dimension, length. In practice, a tape is laid on the ground between two points and the interception of plants against the side of the tape is recorded in units, usually centimetres.

This method was used to record the percentage contribution of each of the species encountered and to measure the density of vegetation cover for all classes (trees with irrigated area, shrub vegetation with herbaceous vegetation, and sparse vegetation) (Table 6.1). Furthermore, digital photograph was taken of the field-plots and a detailed description and observation for all classes in study area.

Table 6.1 Vegetation cover expressed as percentage from field survey verification.

Classes of vegetation	Percentage of Coverage
Trees with irrigation	70%
Shrub Vegetation	38%
Sparse Vegetation	27%

6.5 Image Processing of Data

6.5.1 Geometric rectification

Raw digital images contain distortions and so cannot be used without correction. The distortions are caused by variations in altitude, latitude and velocity of the sensor platform. In addition, factors such as panoramic distortion, earth curvature, atmospheric refraction, relief displacement, and nonlinearities in the sweep of the sensor's Instantaneous Field of View (IFOV) (Lillesand et al., 2004).

The main purpose of the image correction procedure is to compensate for the distortions caused by these factors so that the corrected and approved image will have the highest geometric integrity. As with geometric correction, the type of radiometric applied to any given digital image data set differs widely among sensors.

The radiance calculated by any given system over an object is influenced by factors such as changes in scene illumination, atmospheric conditions, viewing geometry, and instrument response characteristics (Lillesand et al., 2004). Differences in viewing geometry are less in the case of satellite image acquirement than airborne data collection. It is necessary to produce a set of images taken at different times or to study the changes in reflectance of ground features at varied times and locations. In such, it is recommended to relate a sun elevation and earth-sun distance correction. Geometric correction of satellite images involves modelling the relationship between the image and ground coordinate systems.

There are many methods used for image correction, such as image-to-map rectification or image-to-image registration with the use of ground control points (GCP) and a suitable precision photogrammetric or empirical model based on the positional relationship between points on a satellite image and points on a map or points derived from a GPS (Mather, 1999; Jenson, 1996). In this study, all the processing of image correction procedures, both radiometric and geometric, has been done by the Libyan Centre for Remote Sensing.

6.5.2 Classification

Image classification is considered the most important part of remote sensing and is a means to change spectral raster data into a finite set of classifications that represent the surface types seen in the imagery (Campbell, 2002).

Supervised classification requires the user to identify the cover types of interest sample of pixels than selected based on available ground truth information to represent each cover type. Satellite images were enhanced by using many operations such as histogram equalized stretch, linear contrast stretch to obtain clearer images and convert the image to a form better suited for analysis. And also, visually interpreted, where colour, structure, type, shape and shade, size, pattern, were using these visual elements and an interpretation legend, for attempts to classify features to identify homogeneous groups of pixels which represent various features of land cover classes. Training samples were selected through digital topographic maps, reference data and ground truthing information were used to locate training pixels on the images, and the training samples were then assessed by using class histogram plots. Training samples were refined, renamed, merged, and deleted after the evaluation of class histogram and statistical parameters. A total of 5 classes were determined from Landsat TM 1988 to 2003 and Spot image 2009.

Supervised classification was done using Maximum likelihood classification (MLC) algorithm to each image to produce land cover and land degradation data in the study area. The area was classified into five main classes of land cover: trees with irrigated areas, shrub vegetation with herbaceous vegetation, sparse vegetation, bare land and urban areas. Different maps were prepared and produced after editing of final classification to GIS and conversion of classified data from raster to vector.

6.6 Accuracy Assessment

Accuracy assessment is an essential part of remote sensing. An accuracy assessment should be made for any classified image before it is used. The accuracy of a classification is usually assessed by comparing the final classification with information derived from ground-truthing (Foody, 2002; Stehman, 1997). Data coming from ground verification are required in order to validate the interpretation and analysis of digital images of land cover types. A total of 100 geographic points were selected from the grid of soil profiles documented by Selkhozpromexport (1980). These points were distributed in the land cover map 2009 for comparison with the same pixel locations in either the high spatial resolution imagery (Quick Bird, SPOT 5 and SPOT XS) or with the ground-truthing data. These points (or locations) were visited and described by using GPS in 2010. To assess the accuracy of the 2009 Spot image classification; the result was compared with information derived from ground-truthing carried out in 2010 and checked against the Quick Bird image from the same year. To assess the accuracy of the 1996 Landsat TM5 image classification, the result was compared with the SPOT 5 image from 2002 which was the closest date available. In order to estimate the accuracy of the 2003 Landsat TM5 image classification, it was compared with the classified 1996 Landsat TM5 image, 2002 SPOT 5 image and aerial photography. Finally, the 1988 SPOT XS image, with a spatial resolution of 20 m. Aerial photographs were used to assess the accuracy of the classified 1988 Landsat TM5 image.

An accuracy assessment is done by generating the confusion matrix from image map and field data (Stehman, 1997; Jensen, 1996). It should be noted that Kappa and its variance are employed to determine a coefficient of agreement between the classified image data and ground reference data which summarises the nature of the class allocations made by a classification (Rosenfield et al., 1986; Hudson et al., 1987; Janssen et al., 1994 and Foody, 2002).The confusion matrix (i.e. accuracy measure) for each classified image (Tables 6.2) illustrates the overlap and agreement between the classes (Yuan et al., 2005). An additional accuracy statistic is the Kappa coefficient that summarises the information provided by the confusion matrix (Mather 2004). Kappa values range from -1 to +1, with a value of zero indicating that chance agreement has an equal (uniform) effect on the classifier, a value of +1 indicating a perfectly effective classification with no contribution from chance agreement. Any negative values indicate a very poor classification and still emerge and are expressed as percentages, although they are not considered authentic. Kappa value of 0.75 or greater indicates a very good to excellent classification performance. The overall accuracy, producer's accuracy, user's accuracy and the Kappa statistic are summarised for all images in Table 6.2.

The overall accuracies for 1988, 1996, 2003 and 2009 were, 82%, 80%, 79.5%, 83% respectively, with corresponding Kappa statistics of 0.72, 0.71, 0.7 and 0.72. A uniformly accepted classification accuracy of 81% is often mentioned in the remote sensing literature (Lillesand et al., 2005) and in this case three of the four images met that criterion, whilst the Kappa values were good to very good (Montserud and Leamans, 1992).

Table 6.2: Summary of classification accuracies (%) for 1988, 1996, 2003, and 2009

Land cover	1988		1996		2003		2009	
	Producer accuracy	User accuracy	Producer accuracy	User accuracy	Producer accuracy	User accuracy	Producer accuracy	User accuracy
Sparse Vegetation	90	75	83.3	83	76.9	83	75	75
Shrubs Vegetation	65	87	65	86.5	61.9	88.6	84.6	78.6
Urban Area	100	89.3	100	85.8	85	89	100	100
Irrigated Area	100	70.2	100	69.6	100	66.1	83.3	83.3
Bare Soil	92.9	90.1	91.7	77.1	90.9	70.4	68.7	78.6
Overall accuracy	95.6		94.9		89.7		83.6	
Overall Kappa	0.72		0.71		0.7		0.71	

6.7 Results

Based on the results (Table 6.4 and Figure 6.2), it is suggested that agricultural practices are the main causes of land cover changes. The vegetation cover has changed in the study area between 1988 and 2009. Firstly, the class of shrub vegetation has faced a rapid decrease between 1988 and 1996. In 1988 the total of shrub vegetation covering 39,300 ha has decreased to 23,300 ha in 1996 as shown in point (X, 296000, Y, 3600000) in Figure 6.4. As a result of encroachment on rangelands for the large-scale cultivation of barley under rain-fed conditions, an irrigated area (X, 3020000, Y, 3594000) is degrading into a bare soil. Secondly, the class of irrigated area has faced a rapid increase between 1988 and 1996. In 1988, the total of irrigated area has increased from 9,800 ha in 1996 to 18,300 ha as shown in point (X, 308000, Y, 3605800) and point (X, 314000, Y, 3596000) in Figure 6.4. Between 1996 and 2003, figure 6.5 shows that there are increases in shrub vegetation from the eastern towards the south-western part of the study area (i.e. between point X, 290000, Y, 358800 and point X, 296000, Y, 3582000). As a result of government policy of increasing agriculture between these times, new agricultural projects under irrigation were established. Protected areas typically used for grazing are now extensively used for barley cultivation. As a result of this strategy, the class of protected area showed a rapid decrease between 1996 and 2003. In 1996 the total area under irrigation is 18,300 ha, which decreased in 2003 to 15,120 ha and continued decline until 2009 as shown in point (X, 290000, Y, 3606800) in Figure 6.5. The biggest reduction in the irrigated area was between 1996 and 2009, with a loss of about 8,500 hectares as shown in point (X, 318000, Y, 3606760) in Figure 6.6. This was due to the amount of water that has decreased and with increasing salinity, particularly in the coastal area where there is no legal restriction on digging wells on private farms (Alghraiani, 2003) Appendix B contains detailed information about groundwater level. In addition, the results obtained from the soil salinity map (Figure 7.11) shows that there are high (4-8 dS/m) and very high (8-15 dS/m) soil salinity in irrigated areas in the north east part of the study area. For example, citrus tree and olive tree damage from high salinity was observed in this area, and consequently, impacted on vegetation growth and crop production.

Table 6.3: List of Land Cover classes defined from ground field survey.

Classes		Description
1	Irrigated Tree crop	Areas with fruit trees such as, olive, almond, fig and citrus.
2	Shrub vegetation with herbaceous plants	Areas of natural and semi natural vegetation open area such as, annuals grasses, perennial herbs, shrubs and deciduous perennial shrubs.
3	Sparse vegetation	Sparsely vegetated areas of shrubs with herbs.
4	Bare land	Sand soil and gravel without vegetation
5	Urban Area	Characterized by low intensity residential, these areas mainly usually include single-family housing units and population densities lower intensity residential areas.

Table 6.4: Summary of Landsat classification area statistics for 1988, 1996, 2003 and 2009.

Classes	1988	1996	2003	2009	1988	1996	2003	2009
	Area (ha)	Area (ha)	Area (ha)	Area (ha)	%	%	%	%
Irrigated Area	9.85	18.3	15.15	12.3	9.8	18.3	15.1	12.3
Shrubs Vegetation	39.5	29.2	26.51	26.15	39.5	29.2	26.6	26.1
Sparse Vegetation	27.4	20.9	23.33	26.3	27.4	20.9	23.3	26.3
Bare soil	22.4	30.33	33.46	33.22	22.4	30.3	33.4	33.2
Urban Area	0.94	1.305	1.64	2.1	0.94	1.3	1.6	2.1
Total	100,038	100,038	100,038	100,038	100%	100%	100%	100 %

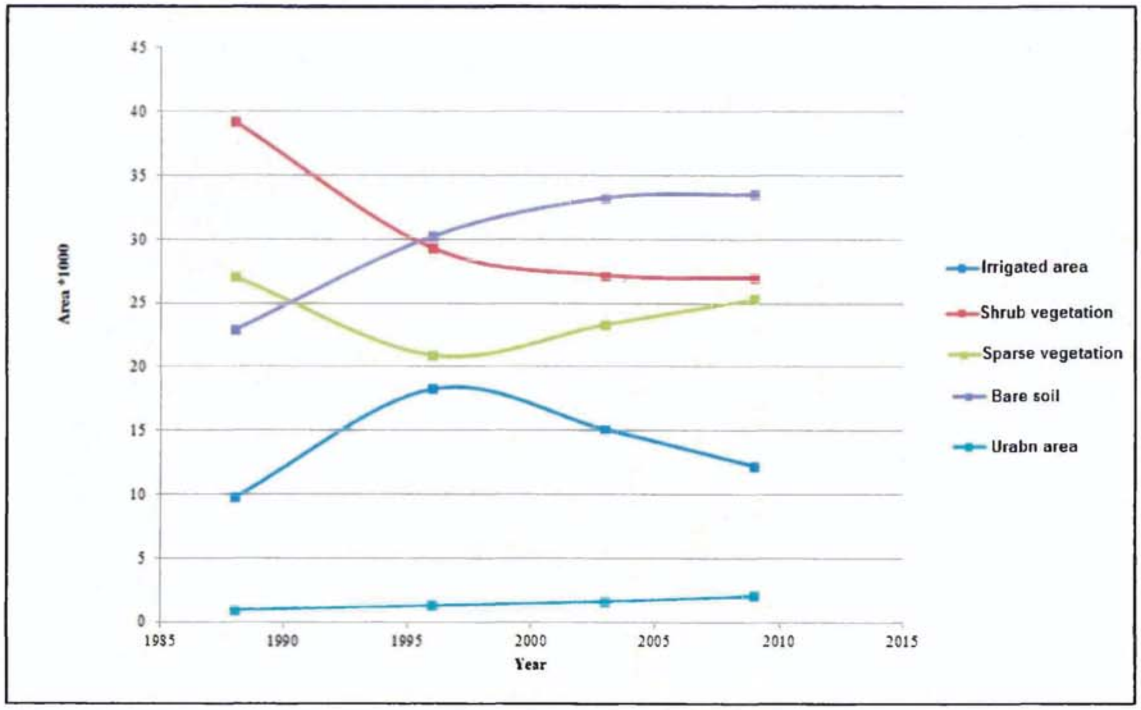


Figure 6.2: Changes in area of land cover classes for 1986,1996,2003 and 2009.

By inspection of the results shown in Table 6.4, the area change (size) for each land cover class in the study area can be easily seen. In addition, to obtain a better understand of the changes, the results have been illustrated in graphs shown in (Figure 6.2). this illustrates the rates of change by increasing or decreasing during the study period.

6.8 Matrix Analysis

In order to understand the mutual conversion rate between the different types of land cover in study area, matrix analysis of land cover change and transfer was used through the ERDAS IMAGINE 8.4 software. The spatial overlay using land-use maps from 1988 to 2009 was put up to obtain the matrix of land use change. According to the original transfer matrix, the mutual conversion rate between the different types of land use between two time periods is obtained (e.g. 1988 and 1996; 1996 and 2003; 2003 and 2009). Tables 6.5, 6.6 and 6.7 shows the tables of land-use conversion matrix achieved.

Table 6.5 Matrix analyses of land cover classes as a percentage between 1988 and 1996

Classes	Bare Soil	Sparse Vegetation	Urban	Irrigated	Shrub Vegetation
bare soil	0.52	0.23	0.0	0.15	0.10
sparse vegetation	0.38	0.35	0.02	0.10	0.15
urban	0.32	0.32	0.14	0.08	0.13
irrigated	0.04	0.22	0.01	0.60	0.13
shrub vegetation	0.16	0.26	0.01	0.12	0.45

Table 6.6: Matrix analyses of land cover classes as a percentage between 1996 and 2003

Classes	Bare Soil	Sparse Vegetation	Urban	Irrigated	Shrub Vegetation
bare soil	0.41	0.27	0.01	0.13	0.18
sparse vegetation	0.20	0.34	0.02	0.24	0.20
urban	0.15	0.11	0.3	0.2	0.24
irrigated	0.18	0.05	0.02	0.4	0.35
shrub vegetation	0.30	0.27	0.01	0.08	0.34

Table 6.7: Matrix analyses of land cover classes as a percentage between 2003 and 2009

Classes	Bare Soil	Sparse Vegetation	Urban	Irrigated	Shrub Vegetation
bare soil	0.42	0.28	0.01	0.08	0.21
sparse vegetation	0.25	0.45	0.065	0.085	0.15
urban	0.23	0.16	0.29	0.10	0.22
irrigated	0.08	0.14	0.01	0.32	0.45
shrub vegetation	0.18	0.19	0.11	0.12	0.40

Tables 6.5, 6.6 and 6.7 reflect the mutual conversion rate between the different types of land cover in study area between two time periods, the Matrix analysis of land cover change and transfer was used through the ERDAS IMAGINE 8.4 software. For example, as shown in Table 6.5, considering the land that was sparse vegetation in 1988, by 1996 38% had changed to bare land, 35% stayed the same class, 2% changed to urban area, 10% became irrigated land and 15% had been converted to Shrub Vegetation. In a similar way, for the land that was classed as shrub vegetation in 1988, by 1996 16% had changed to bare land, 26% to sparse vegetation, 1% to urban area, 12% to irrigated area and 45% remained as Shrub Vegetation. These conversions of land cover from 1988 to 1996 are shown in figures 6.4 and 6.5. For example, in the point (X 296000, Y 3594000), the shrub vegetation displayed in Figure 6.4 were converted to bare land in figure 6.5. Similarly, the bare land in Figure 6.4 in point (X, 308000, Y, 3606000) was converted into irrigated area as shown in Figure 6.5.

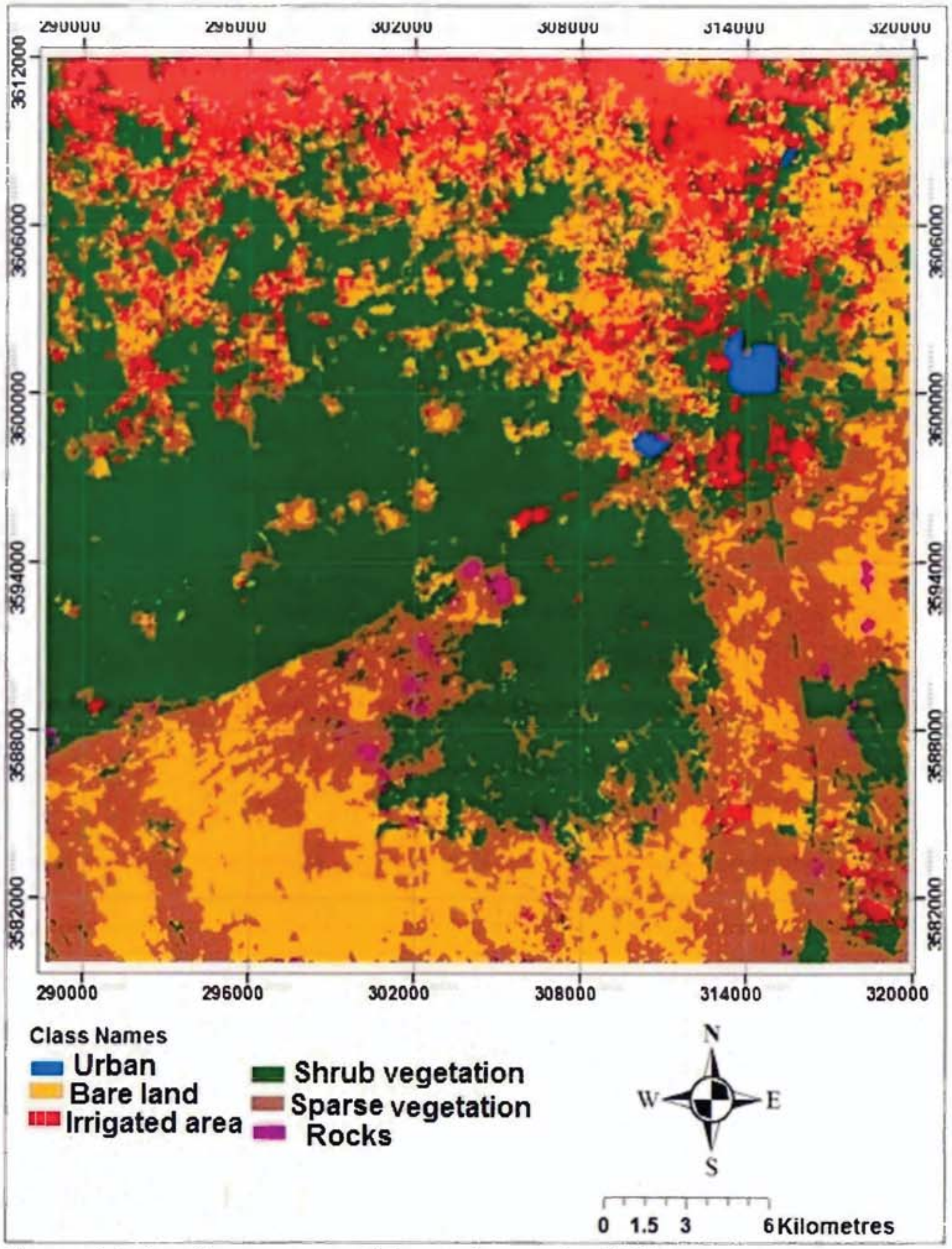


Figure 6.3: Land cover map of the study area in 1988.

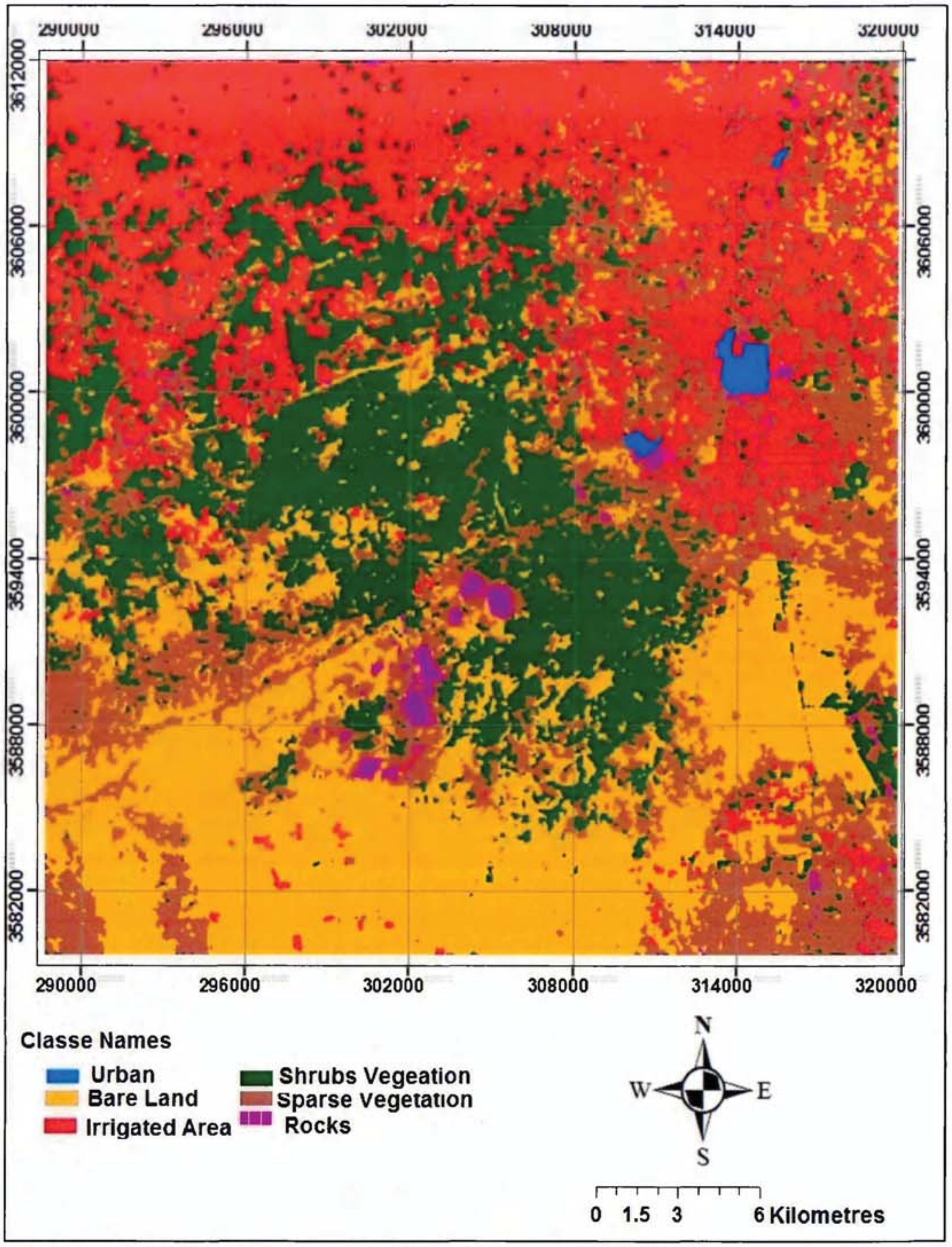


Figure 6.4: Land cover map of the study area in 1996.

When comparing figure 6.4 (land cover map 1996) and the land cover map 1988 (Figure 6.3), within an eight year period, there are increases in the areas of trees with irrigated areas, bare land and urban areas. At the same time, there were decreases in the areas of shrub vegetation with herbaceous vegetation, and sparse vegetation. The proportion of change in terms of size is captured in tables 6.5-6.7.

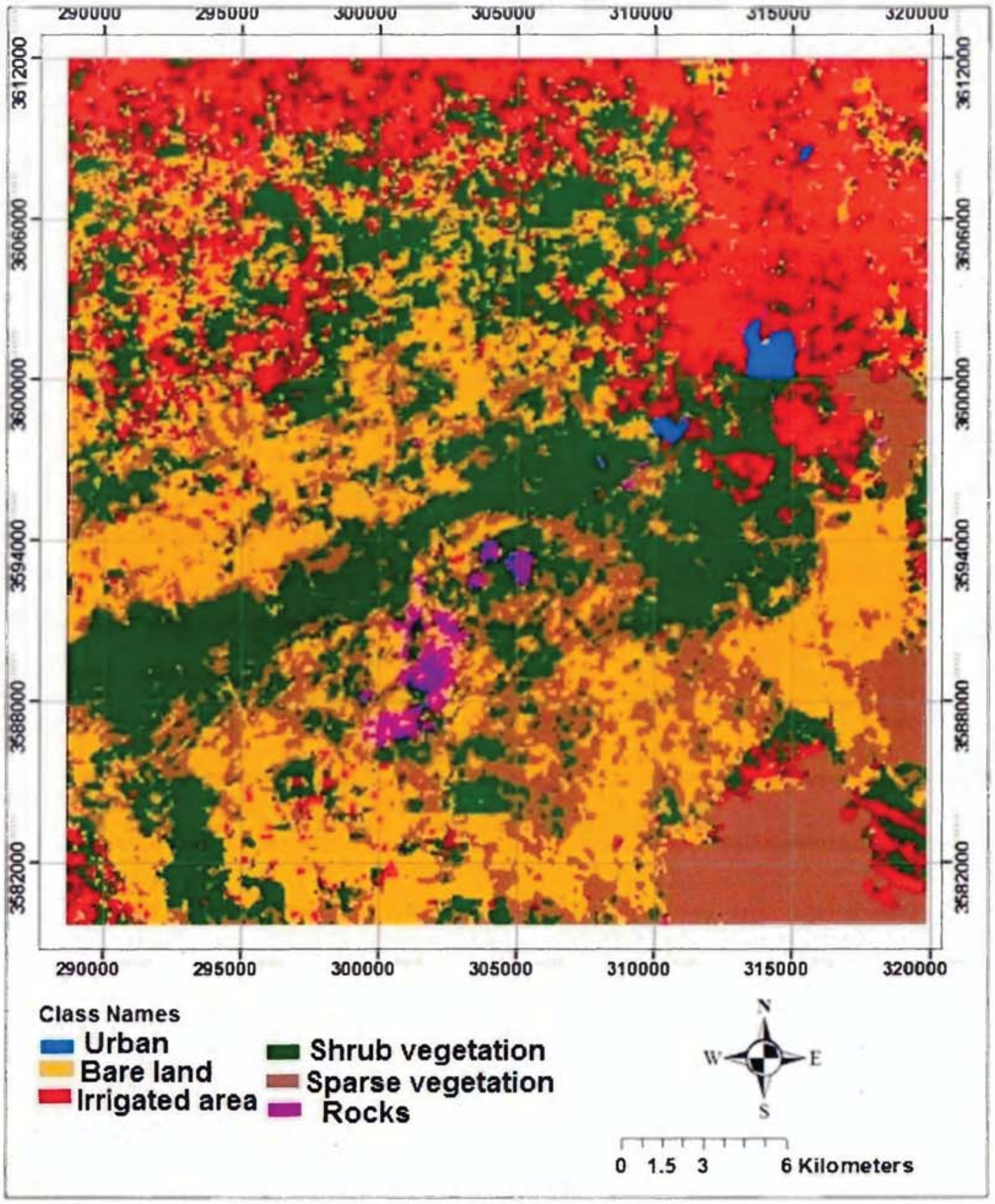


Figure 6.5: Land cover map of the study area in 2003.

Comparison between land cover map 2003 and land cover map 1996, (Figures 6.4 and 6.5) shows that there were decreases in the areas of irrigated areas and shrub vegetation with herbaceous vegetation. At the same time, there were increases in the areas of sparse vegetation, bare land, and urban areas.

There are increases shrub vegetation from the eastern towards the south-western part of the study area (i.e. between point x, 290000, y, 358800 and point x, 296000, y, 3582000 from 1996 to 2003. as a result of government policy of increasing agriculture between these times, new agricultural projects under irrigation were established. Protected areas typically used for grazing are now extensively used for barley cultivation.

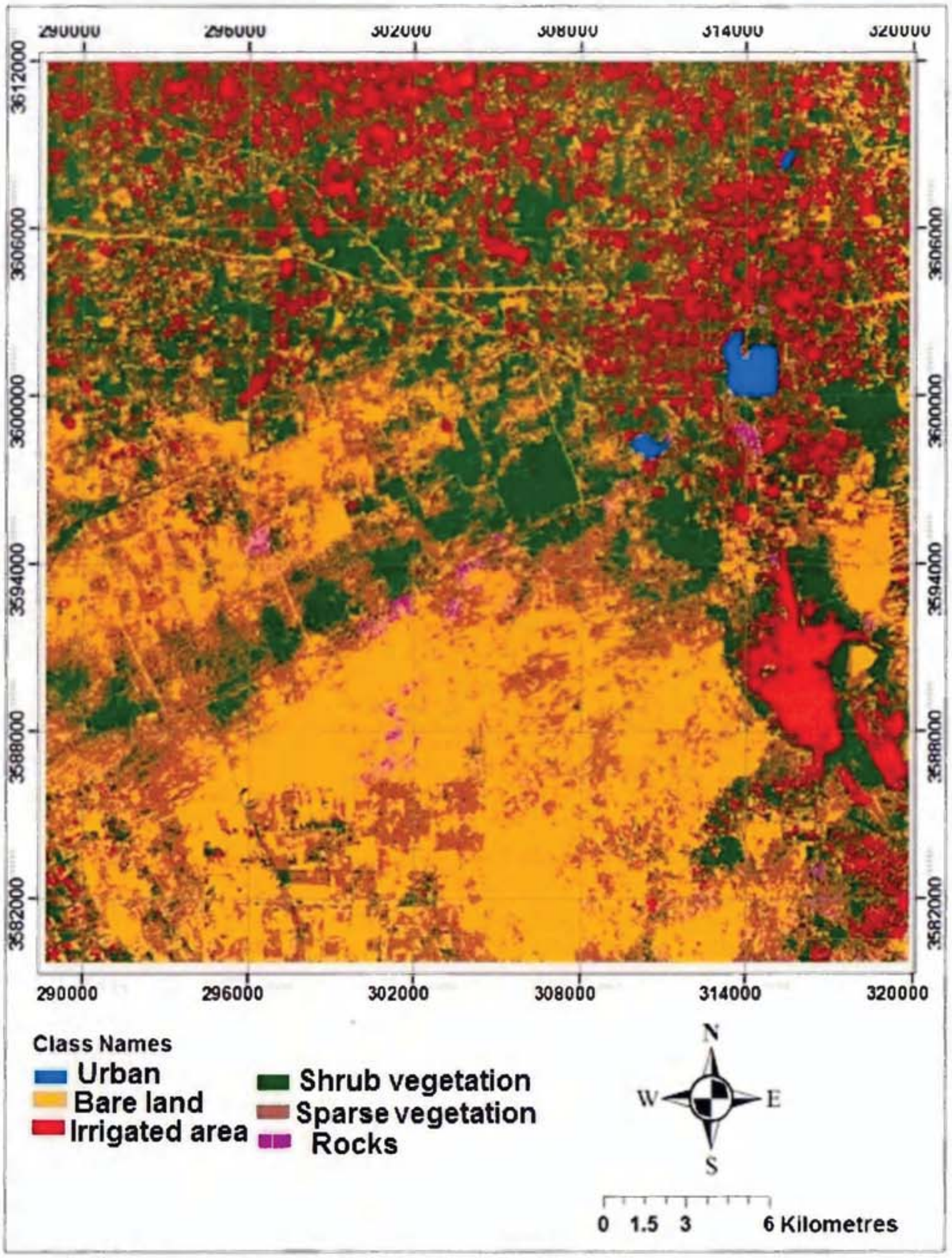


Figure 6.6: Land cover map of the study area in 2009.

Comparison between the land cover map 2009 and land cover map 2003, (Figures 6.5 and 6.6) shows that there were decreases in the areas of shrub vegetation with herbaceous vegetation and irrigated areas. There are increases in the areas of sparse vegetation, bare land, and urban areas. The rock area decreased between 2003 and 2009, due to sand dunes that covered the rock area moving from area to area by wind action.

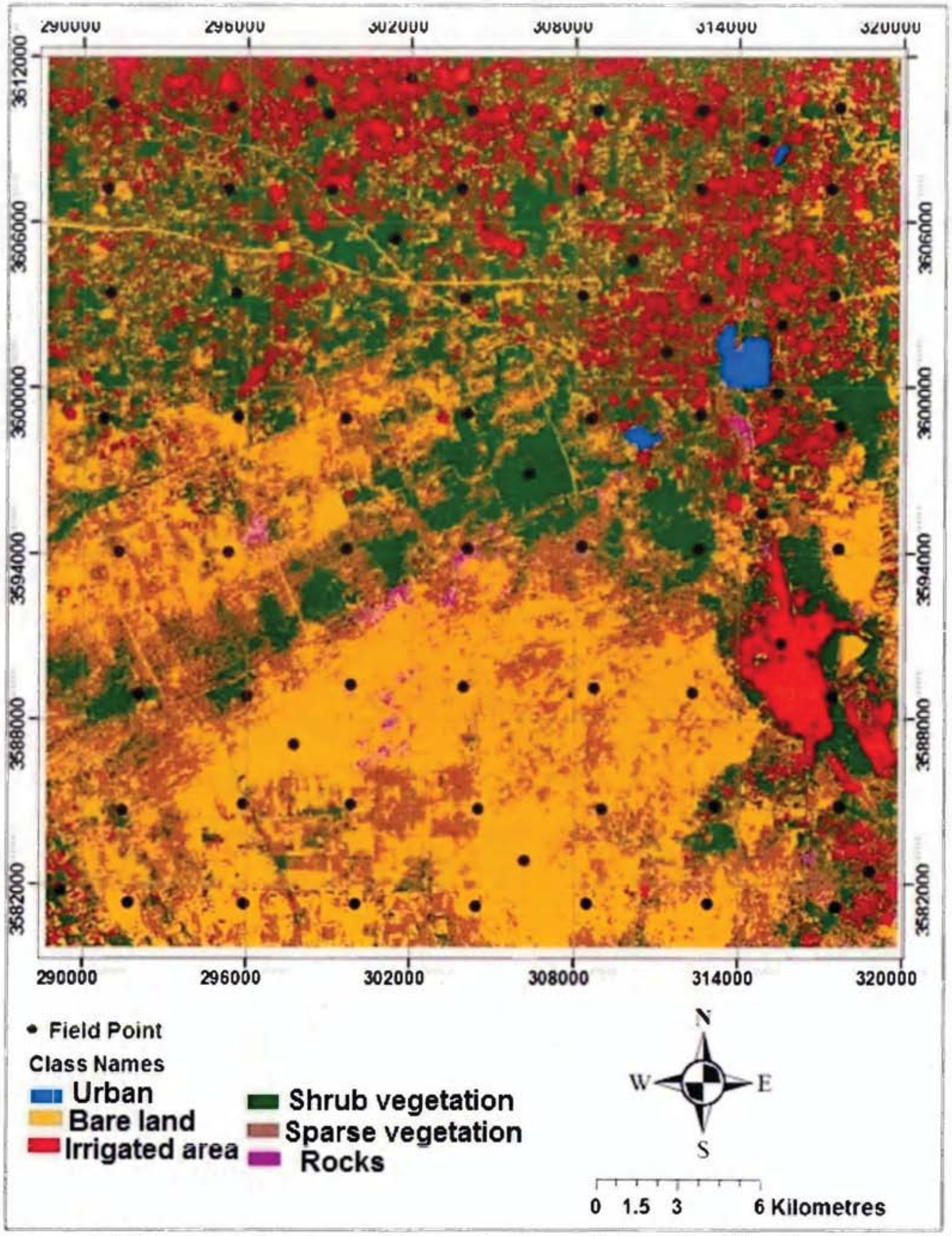


Figure 6.7: Survey reference points overlaying with the classification image 2009.

6.9 Change Detection of Land Cover Area

Post-classification change detection technique was applied. Post classification is the most obvious method of change detection, which requires the comparison of independently produced classified images (Singh, 1989). Post-classification comparison proved to be the most effective technique because data from two dates are separately classified, thereby minimizing the problem of normalizing for atmospheric and sensor differences between two dates (Foody, 2002). Many studies have used a classification comparison approach (e.g. Xu and Young, 1990; Shrivastava and Gebelein, 2007). In the case of Landsat TM, land cover classes in a particular area of study are found through the analysis of images. Different classes are detected a number of times and within a particular time frame. Changes are then distinguished within that time period. Also, in this study, the changes in size in terms of hectares for each class were marked out and this was done from 1988 to 2009 – a total period of over 21 years. It was found that the change between 1988 and 2009 were increases in the areas of trees with irrigated areas, bare land, urban areas and rock outcrop. At the same time, there were decreases in the areas of shrub vegetation with herbaceous, sparse vegetation.

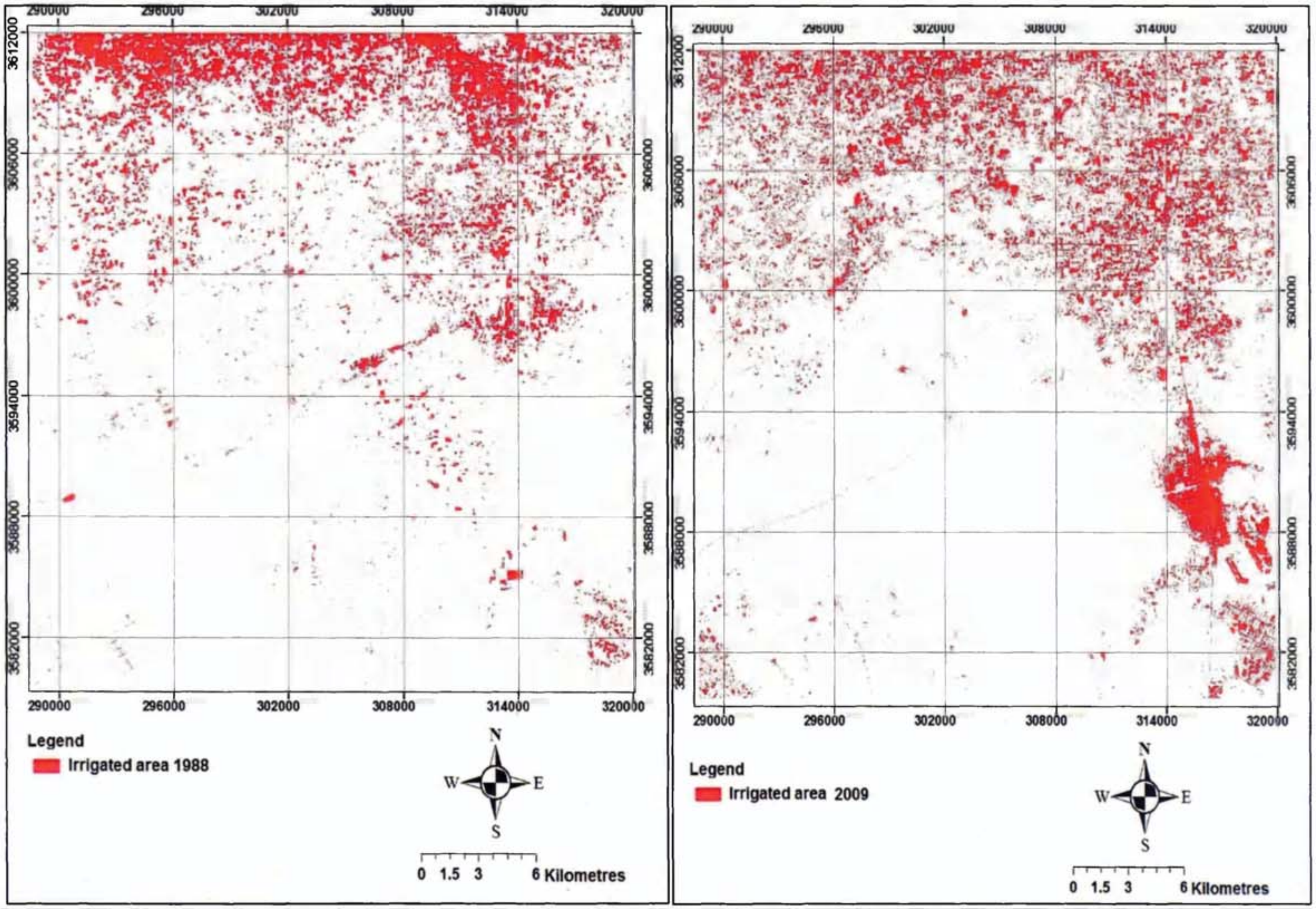
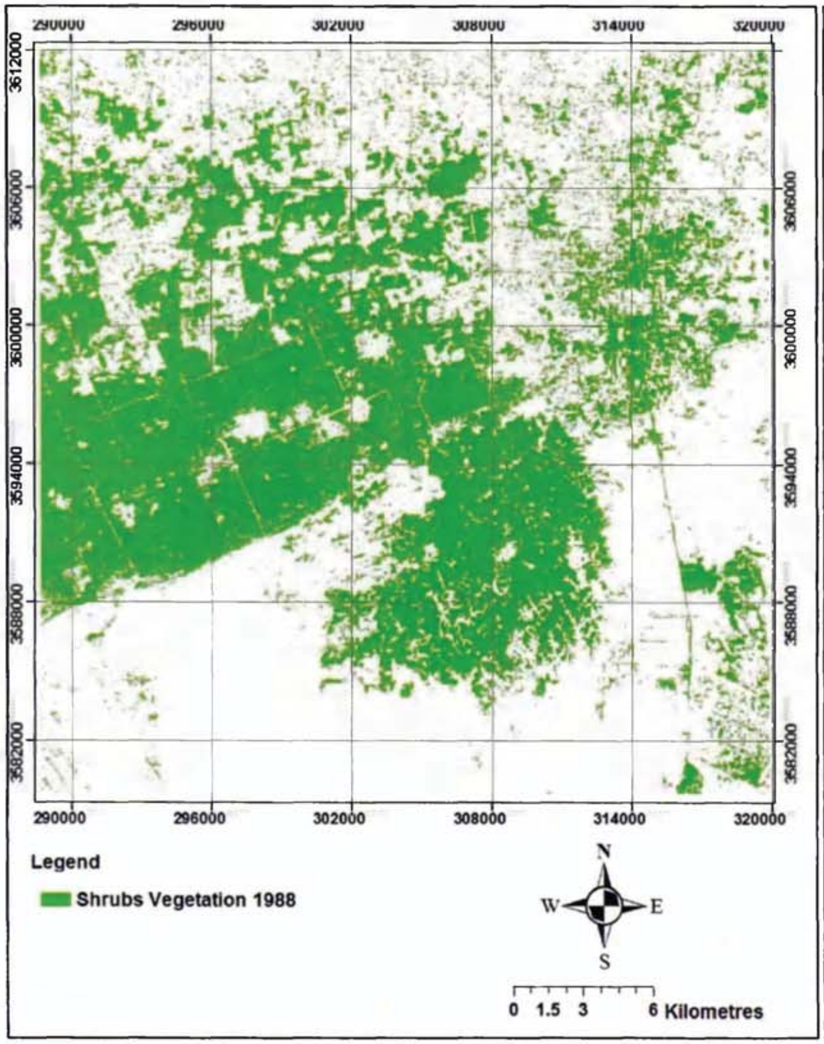


Figure 6.8: Increase areas of Irrigated tree crop class in 2009 compared with the same class in year 1988.



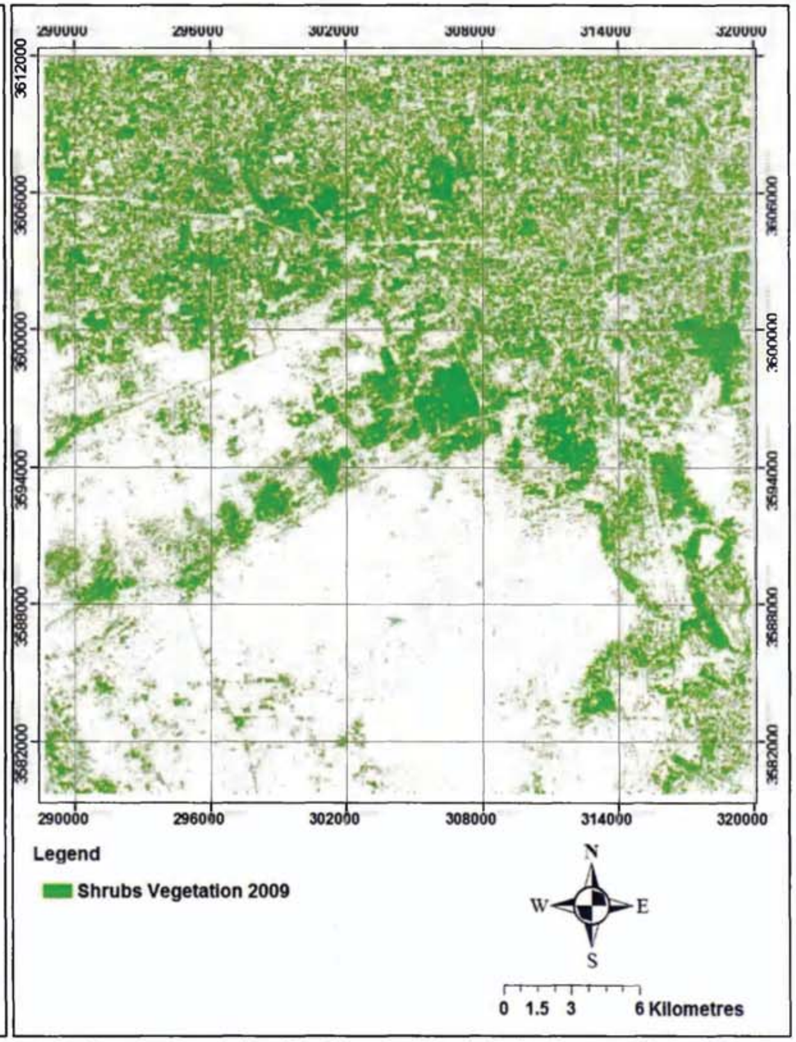


Figure 6.9: Decrease of areas of shrubs vegetation class in 2009 compared with the same class in year 1988.

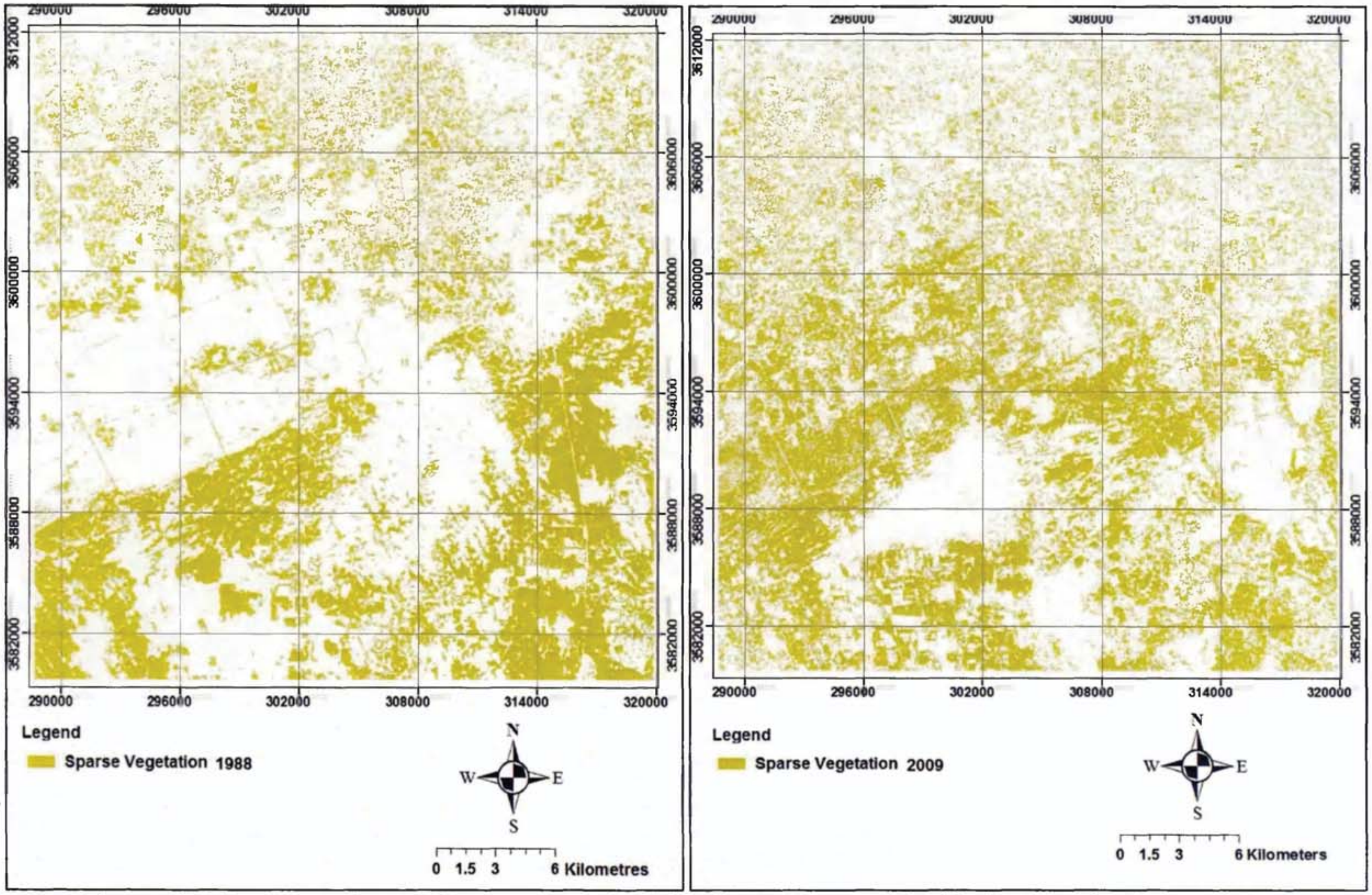


Figure 6.10: Decrease of areas of sparse vegetation class in 2009 compared with the same class in year 1988.

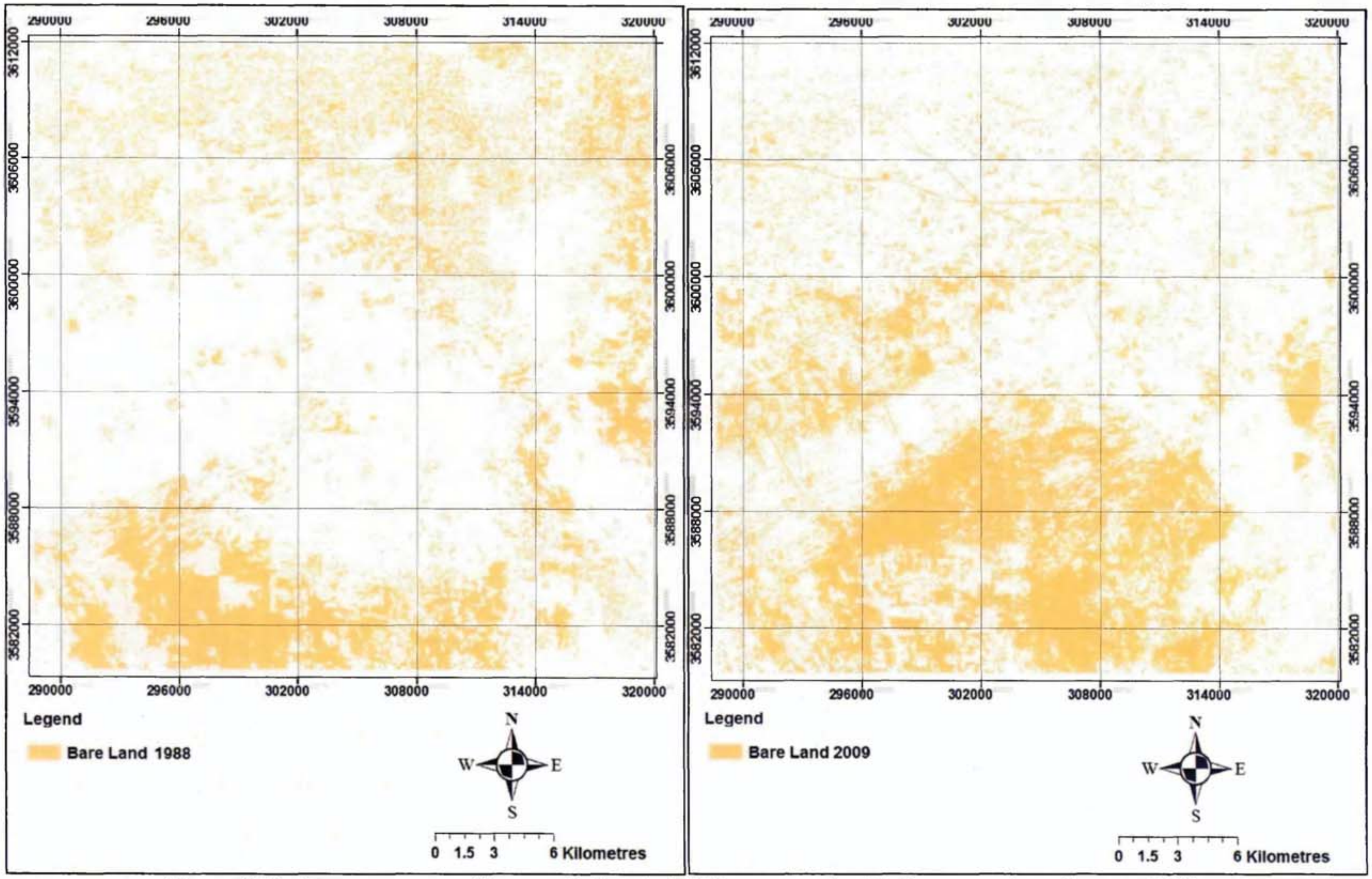


Figure 6.11: Increase areas of bare soil class in 2009 compared with the same class in year 1988.

6.10 Land Degradation

Remote sensing data have been widely used for land degradation in many countries such as Libya, Egypt, Tunisia, Syria and Yemen, South Africa (Botha and Fouche, 2000; Chen and Rao, 2008), and Spain (Haboudane et al., 2002). In addition, many research studies on land degradation have been conducted in semi-arid or arid environments (Hoffman and Todd, 2000; Taddese, 2001; Symeonakis and Drake, 2004). Therefore, this research is an extension of some of the above studies. Based on the remote sensing model (see Figure 6.1), the map of land degradation was produced depending on land cover map in 2009 using the ACSAD methodology for remote sensing and GIS for monitoring of land degradation ACSAD (2000) to produce a desertification severity map (Figure 7.16).

The ACSAD (2000) methodology for remote sensing and GIS for monitoring of land degradation is based on three steps: Firstly, select satellite image for study area and then perform image processing as shown in Section 6.5. Secondly, perform image classification to produce the land cover map as shown in section 6.6. The method was based on intensity of vegetation cover and bare soil, where the areas characterised by low vegetation and bare soil have been exposed to high degree of desertification. The density of vegetation was measured as shown in Section 6.4.2. Visual interpretation on screen digitizing was used for producing the map of land deterioration based on the intensity of vegetation cover and bare land, where the vegetation cover is a primary indicator of land desertification. In addition, the process of visual interpretation involves drawing polygons along the boundaries by mouse, then saving them to different polygons and adding attributes (labels) of the polygons to produce the map, alongside ground observation to gather qualitative information for indicators of land degradation (soil, vegetation cover, water, human activities, rain fed cultivation and overgrazing). This applies several indices for the map based on the ACSAD methodology, such as the description of deterioration factors as heavy grazing (G), deforestation (F), agriculture activity intensification (I) and over-cultivation (O). These factors were based on map land cover classes which presumably are potentially affected by a desertification process (e.g. categories of vegetation, of bare lands) and data collected from ground observation. In this study, data collected from ground observation (information of the type and state of desertification), including a variety of soil properties such as depth, texture and structure were assessed through the agricultural areas where they are increasing in irrigated areas or where crops are encroaching on lands (originally, forest or rangelands). Following this, the data was then brought into GIS for overlaying with the land cover map for producing a land degradation map, based on ACSAD methodology for remote sensing and GIS for monitoring of land deterioration. The degrees of deterioration were described based on the vegetation cover density as, slight (50–100), moderate (30-50), high (15 -30) and very high (0 -15) respectively. The density of vegetation which has been measured by Line Intercept Measurements (LIM) method has been discussed in Chapter Six. From that information a degradation map and table of degradation degrees were produced. The results obtained from the land degradation map (see Figure 6.12) shows three types of land degradation in the study area (Slight, Moderate and High) which represent 27%, 30% and 42% of the total area respectively.

Table 6.8: Classified categories in the study area using the remote sensing method.

Class	Degrees of deterioration	Area (ha)
	Slight	27,200
	Moderate	29,954
	High	41,697
	Urban	1,187

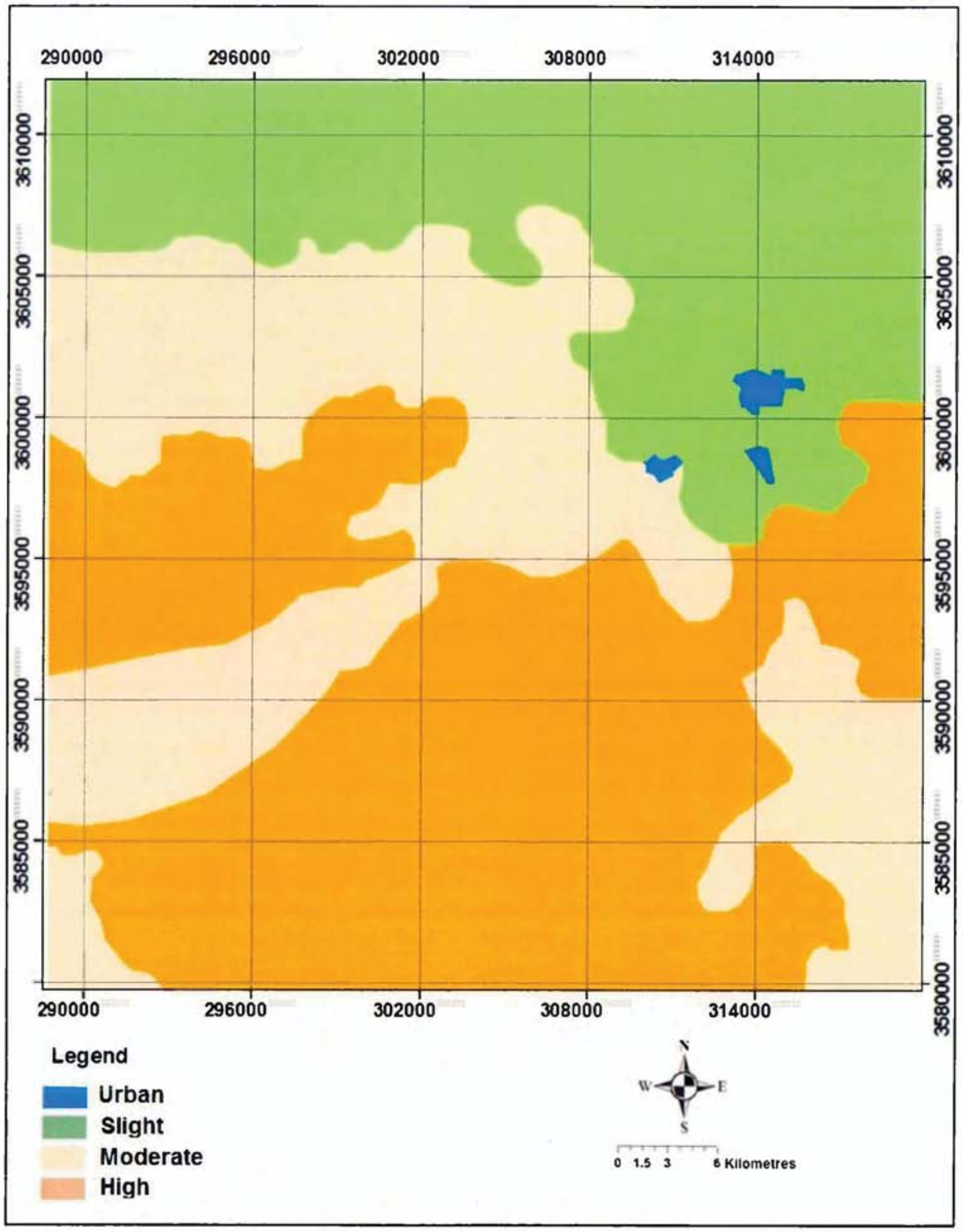


Figure 6.12: Land degradation map based on land cover map in 2009 derived from remote sensing and GIS.

Land degradation in 2009 based on land cover map derived from remote sensing and GIS. The degrees of deterioration based on the vegetation cover density (i.e. 0–15, 15–30, 30-50 and 50–100) range from very low, low, moderate and high. Visual interpretation of screen digitising was used for producing the map of land deterioration based on the intensity of vegetation cover and bare land. As seen in the figure, the southern part of the study area shows high degree of susceptibility to land degradation due to loss in vegetation cover.

6.11 Assessment of Protected Rangeland Production

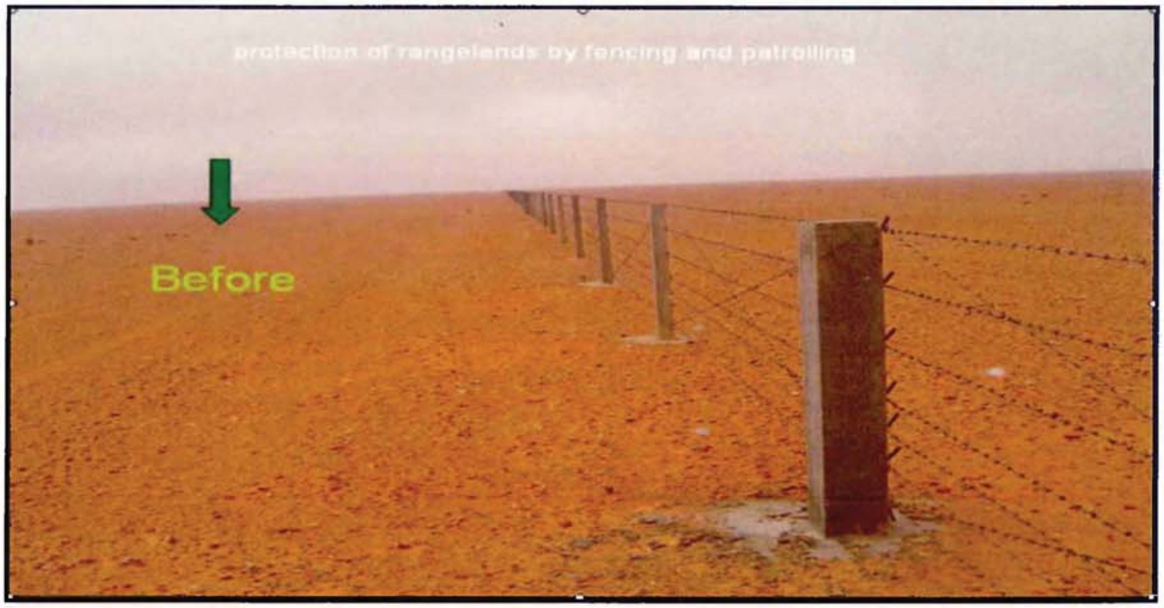
A study was conducted by Agricultural Research Centre (ARC) in 2007 to assess the protection effect on rangelands in a very dry site,which is nearby to the south-western part of the study area, in comparison with the open area around the enclosure. The area within the Protected Pastures Project was subjected to traditional practices of grazing and management over the years. This study shows the role of policy and management in rangeland area protection. The area within the Protected Pastures Project was subjected to traditional practices of grazing and management over the years. The enclosed area, protected by fencing and patrol, covers an area of 7,000 hectares, with a rainfall of 150-180 mm/yr, and has been closed to grazing for five years. The changes recorded between controlled and unprotected areas during a five year period are contained in Table 6.9.

Table 6.9: Changes in vegetation cover in protected area.

Item	Protected Area	Open Area	Increase
Plant Cover (%)	54	23	31
Plant Density (plant/ha)	Increased by 2 plant/m², 20,000 plant/ha		
Productivity (kg/ha)	2,900	1,006	1,900
Grazing Capacity (head /ha)	2	6	4

This research also took measurements in both the enclosed and unprotected area of the rangeland. A total of 160 readings were accomplished as follows:

- Used a measurement tape 100 metres long in eight different spots (locations) both in the protected area and in the open rangeland.
- Readings or measurements were taken from 1 m^2 every 10 metres of the measurement tape.
- Measured the plant cover, plant density and productivity, and then estimated the grazing capacity.
- Took 80 readings from the protected area (8 points x 10 readings (m^2)) and another 80 from the open rangeland.



Photograph 6.1: Protection of rangelands by fencing and patrolling (before). The photograph shows the rangeland area in a very dry site before protection which was subject to traditional practices of grazing and management, South-West of Jeffara Plain (ARC 2002).

Photograph 6.2: Protection of rangelands by fencing and patrolling (after). The photograph shows the rangeland area in a very dry site after the area has been closed to grazing for five years, comparison with the open area around the enclosure in South-West of the Jeffara Plain (ARC 2007).

6.12 Summary

In this chapter, a supervised maximum likelihood classification (MLC) algorithm was applied to generate land cover maps using Landsat TM and Spot image data, and matrix analysis was used to analyse and extract land cover information. This also detected and assessed the land cover changes across the study area during the period from 1986 to 2009. The results show that there was a significant decrease in natural vegetation and degradation of the majority of the land of the study area was affected moderately and severe in terms of up to about 85% of the area studied. In addition, the accuracy of the maps was satisfactory, and the overall accuracy was about 80%. Moreover, from these results, the map of land deterioration was produced, using the remote sensing and GIS.

CHAPTER 7

LAND DEGRADATION MODEL FOR THE STUDY AREA

7.1 Introduction

Desertification occurs worldwide and there is currently serious debate about its causes. These are believed to include increases in human activity, population growth and associated numbers of grazing livestock, and changes in temperature and rainfall resulting from climate change, which lead to the degradation of land in arid, semi-arid, and dry sub-humid areas (UNEP, 1994), as explained in Chapter 3. In addition, there is pressure on inherently fragile natural resources in arid and semi-arid areas, and also population increase and urbanization lead to more pressure on agricultural resources as well as land degradation (Orhan et al., 2003).This chapter shows the methodology followed during the research process. The research methodology has been divided into two sections. The first part deals with the application and development of the Mediterranean Desertification and Land Use (MEDALUS) Method for mapping of environmentally sensitive areas vulnerable to desertification. The second part deals with the Universal Soil Loss Equation (USLE) used with the Geographic Information System (GIS) to assess soil erosion risk.

7.2 Data Requirements for this Research

Monitoring of land degradation requires the availability of suitable data (Tables 7.1 & 7.2).

Table 7.1: Data requirement for the research and sources

Data	**Description**	**Sources**
Topographic Data	Topographic maps available at a scale of 1:50,000	Libyan Centre for Remote Sensing
Soil Data	Soil maps available at a scale of 1:50,000	Libyan Natural Resource Centre (LY/00/004)
	Soil report: physical and chemical soil properties for soil samples	
Soil Erosion Data	Soil erosion maps also available at a scale of 1:50,000	
Infrastructure	Road maps: main roads and tracks	
Climatic data	Rainfall, Temperature and Wind speed	Tripoli Airport Meteorological Station
Field Trip	Visit some geographic points in the study area Visit the Agricultural Research Centre (LARC) library Visit the Meteorological and Climate Department Visit the Libyan Remote Sensing Centre (LRSC)	Local staff (2010) (i.e. discussion with local staff during visits to Tripoli in 2010)

Table 7.2: Satellite image used in the present study

Sensor	Path/Row	Data
Landsat TM	189/37	5-08-1988
Landsat TM	189/37	15-08-1996
Landsat TM	189/37	25-08-2003
SPOT 5	189/37	10-08-2009
MODS	189/37	2001 to 2009

Source: Libyan Centre for Remote Sensing

7.3 The Study Area

7.3.1 Location of Study Area

The Jeffara Plain region covers an area of about 1.8 million hectares, and is located in the north-west of Libya, extending between Al Khoms city in Libya and the Tunisian border (Ben Mahmoud, 1995). The selected study area for this research is the central southern part of the Jeffara Plain, which lies between 32° 18` and 32° 29` N in latitude and 12° 45` and 12° 59` E in longitude. It has an area of about 100,000 hectares (Figure 7.1).

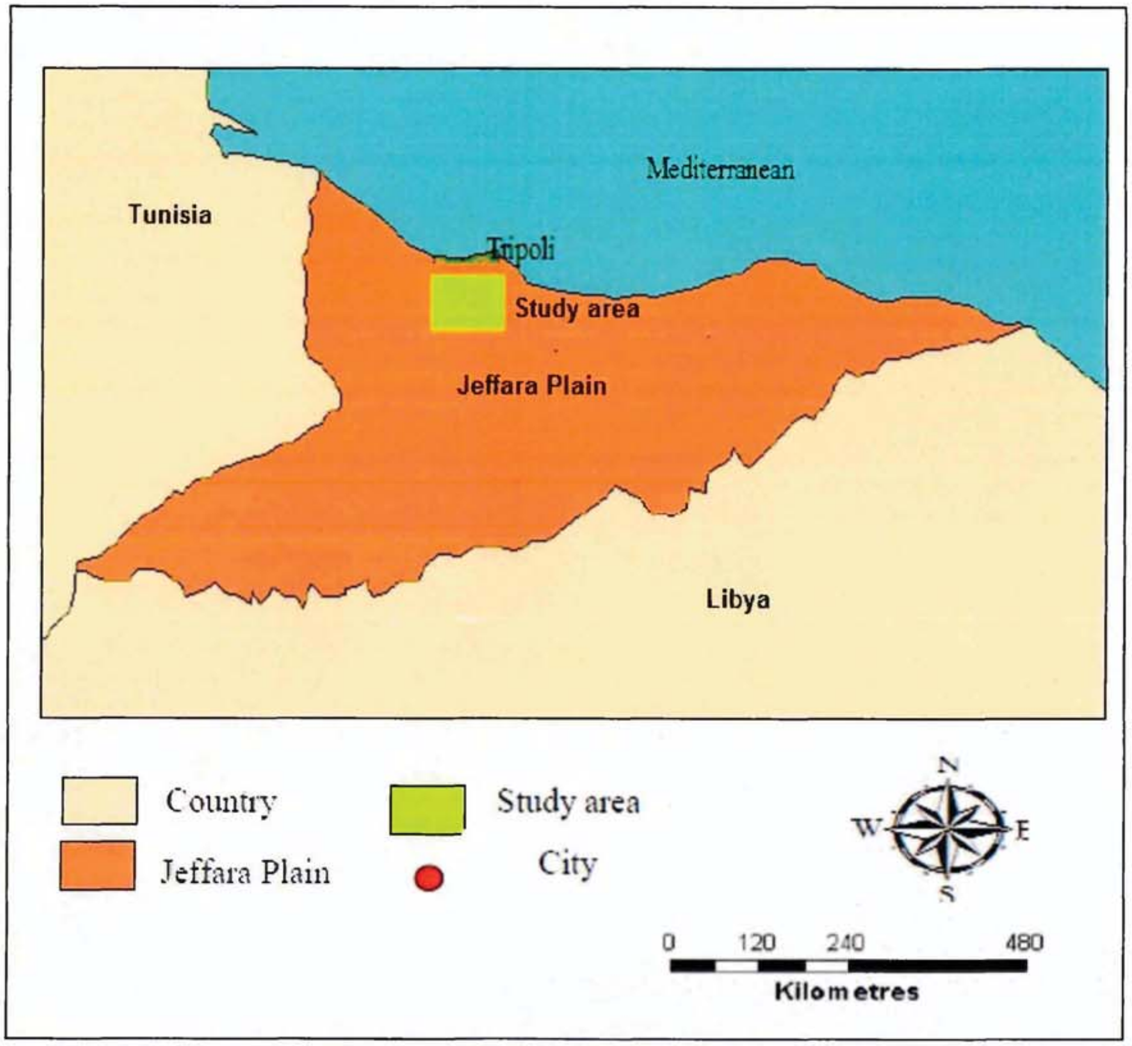


Figure 7.1: Study area location

7.3.2 Climate in the Study Area

The climate in the study area is characterized by Mediterranean conditions: hot and dry in the summer (June, July and August), cold and rainy in the winter. The temperature average is 27°C in summer and 15°C in winter, with a low rainfall of around 180 to 296 mm per year from October to March. The charts in Figures 7.3 and 7.4 demonstrate the averages of temperature (T) and precipitation (P) in the study area for the period 1973-2009.

There was a gradual increase in temperature from the lowest point in January to the peak in August, with about 13°C and 30°C respectively, before it starts to decline dramatically until December with about 15°C (Figure 7.4). However, there were obvious fluctuations in rainfall, from January, with nearly 50 mm, to 0 mm in July and August, in spite of the increase from February to March, with about 25 mm and 35 mm respectively. The sharp increase in rainfall began with nearly 8 mm in September and 40 mm in December. Obviously, the highest temperature points are in the dry season and the lowest ones in the wet period. During the dry season, the rainfall rate is nonexistent, while the wet period represents the whole amount of precipitation.

There are two types of wind that are considered to be important in this region: a cool wet wind coming from the north and the west as well as the northwest, which brings rain to the area and is most common in the wintertime, and a hot dry wind coming from the south in the summertime.

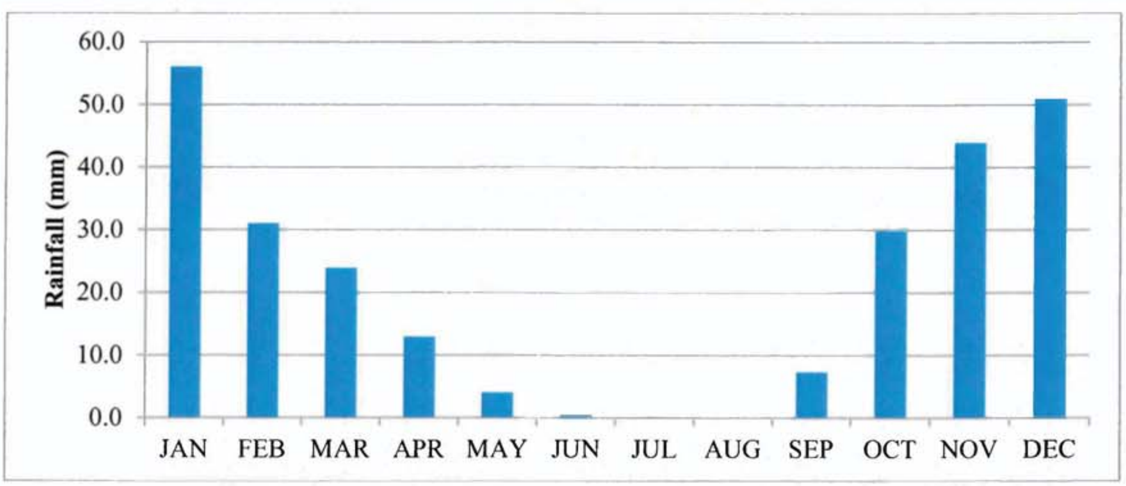


Figure 7.2: Mean monthly precipitation (mm) from Tripoli Airport Meteorological Station (years 1973-2009). Source: Tripoli Airport Meteorological Report, 2009.

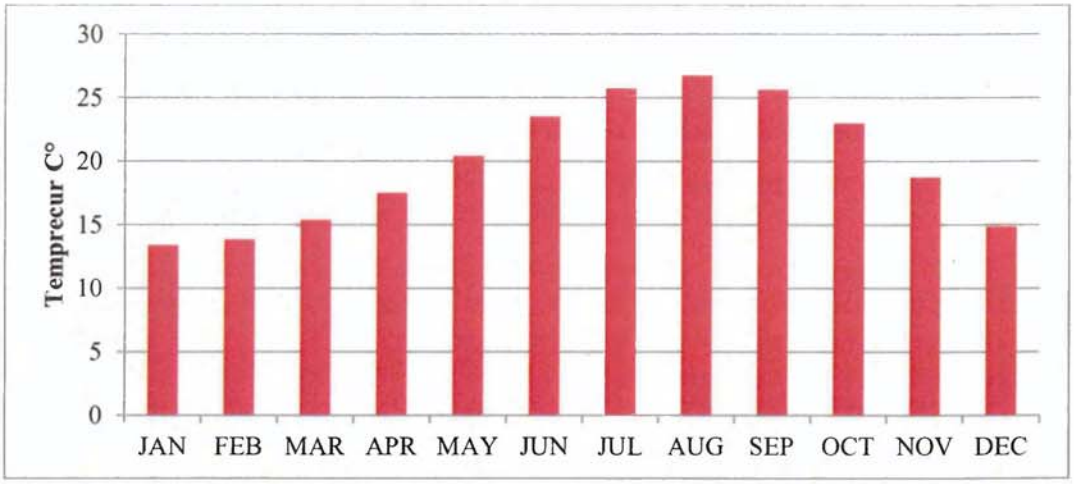


Figure 7.3: Mean monthly temperature (C°) from Tripoli Airport Meteorological Station (Years 1973-2009). Source: Tripoli Airport Meteorological Report, 2009.

7.3.3 Soil in the Study Area

Soil studies in the study area have been carried out by the Soil-Ecological Expedition of Selkhozpromexport, Al-Fateh University, the Ministry of Agriculture and the Agricultural Research Centre (ARC) (Selkhozpromexport,1980), and the soils were classified using Soviet soil taxonomy. The classification system of Soviet soil taxonomy has four categories: soil subclass, soil type, soil subtype and soil genus. The classification is based on soil properties and derived from field observations and laboratory measurements. Soil maps were available for this research at a scale of 1:50,000. Three soil types and nine soil subtypes have been identified in the study area (Table 7.3 and Figure 7.4). The physical and chemical soil properties which are available in the study area are soil texture, soil depth, infiltration rate, soil drainage, percentage of stones at surface, specific density, bulk density, organic matter, electric conductivity, and percentage of soil calcium carbonate.

Table 7.3 Soils in the study area using Russian soil classification.

Russian Classification	USA classification)	FAO Classification
Reddish Brown Arid	Entisols	Regosols
Serozems, Desert Soils	Aridisols	Luvisols
Siallitic Cinnamonic	Inceptisols	Cambisols

Source: Selkhozpromexport, 1980; Ben Mahmoud, 1995.

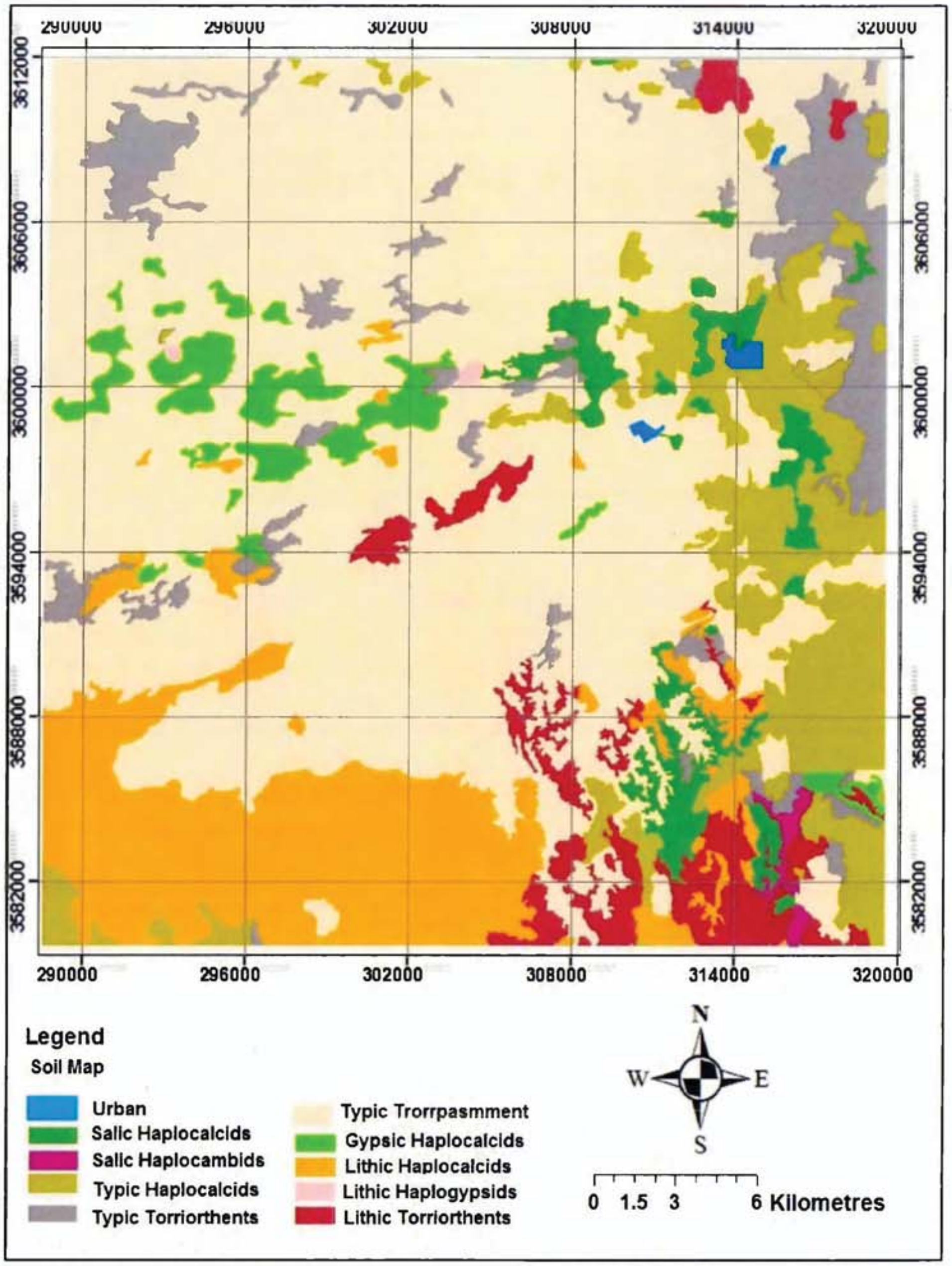


Figure 7.4: Soil map for the study area

Soil map for 1980 has shown the main soil types in study area using the American classification system, include three soil types, and nine subtypes have been identified in the study area. Soil types play an important role in study land degradation. The physical and chemical soil properties which are available from soil report: soil texture, soil depth, infiltration rate, soil drainage, percentage of stones at surface, specific density, bulk density, organic matter, electric conductivity, and percentage of soil calcium carbonate.

7.4 Methodology

7.4.1 The Mediterranean Desertification and Land Use Method

The Mediterranean Desertification and Land Use Method was used to determine the Environmentally Sensitive Areas (ESAs) in the study area. The index is a composite one that uses vegetation, climate, geology, soil, landforms, and human activity as the main factors. Each of these parameters is grouped into various uniform classes together with the effect it produces and the manner of desertification. Weighting factors are also allotted to each class. The following four qualities are evaluated: (a) soil quality, (b) climate quality, (c) vegetation quality, and (d) management quality (Kosmas et al., 1999). After the calculation of the four indices the ESAs for desertification are defined by combining them (Figure 7.5). All data collected are input into a GIS database to evaluate desertification intensity. A quantitative classification system with values ranging from 1 to 2 has been applied in the model for individual indices and also the final classification of Environmentally Sensitive Areas (ESAs). The value "1" was assigned to areas of least sensitivity, and the value "2" was assigned to areas with the most, while values between 1 and 2 reflect relative vulnerability. The individual factors and their indicators are shown in Tables 7.4, 7.5, 7.6, 7.7 and 7.8.

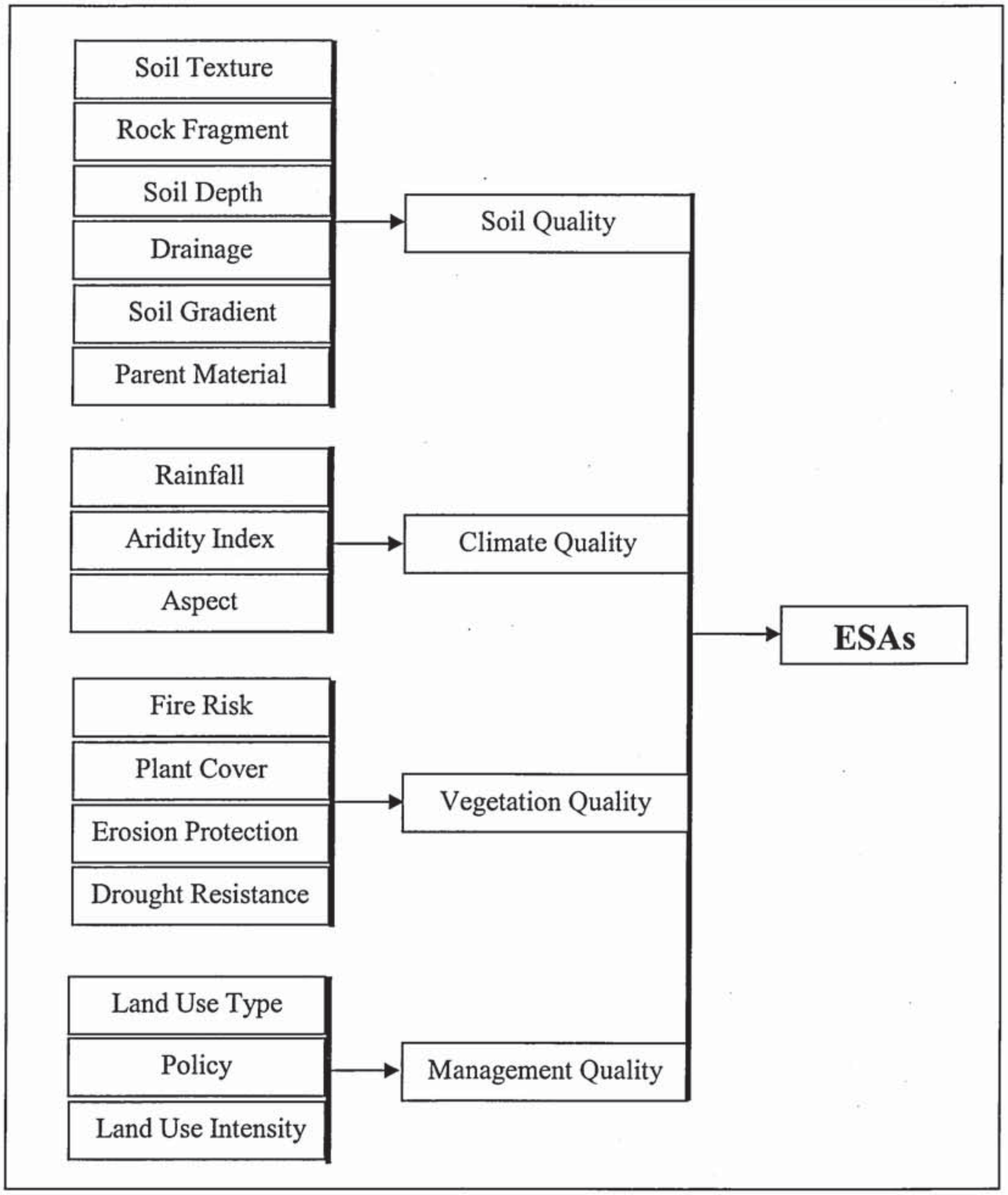


Figure 7.5: Parameters used for the definition and mapping of the ESAs vulnerable to desertification.

The model shows the four qualities (a) soil quality, (b) climate quality, (c) vegetation quality, and (d) management quality, which have been used to evaluated and mapping of the ESAs vulnerable to desertification.

$ESAI = (SQI * CQI * VQI * MQI)^{1/4}$ Original MEDALUS Equation 1

7.4.1.1 Soil quality (SQI)

Soil type and quality is considered the main factor for terrestrial ecosystem function in semi-arid and dry sub-humid zones. "Soil quality indicators for mapping ESAs can be connected to (a) water availability, and (b) erosion resistance. These qualities can be provided from soil survey reports with details of soil depth, slope angle, drainage, stoniness, texture, and parent material" (Kosmas et al., 1999) (Table 7.4). Application of these properties for defining and mapping ESAs requires the description of different classes with respect to the degree to which the land is protected from desertification (Kosmas et al., 1999; Kosmas et al., 2000a; Rubio and Bochet, 1998; Venezian Scarascia et al., 2006; Incerti et al., 2007 ; Gada et al., 2010). In the study area, soil quality plays an important role in land degradation because of sand texture, low moisture capacity, high water permeability and low organic matter, which create a high risk of land degradation.

SQI = (texture * parent material * rock fragment * depth * slope * drainage) $^{1/6}$

Equation **2**

Tables 7.4. Classes and weighting indices for soil quality assessment.

Soil Texture

Class	Description	Texture	Index
1	Good	L, SLC,LS, CL	1
2	Moderate	SC, SiL, SiCL,	1.2
3	Poor	Si,C, SiC	1.6
4	Very Poor	S	2

L: Loamy, S: Sandy, C: Clayey, Si:Silty

Soil Depth

Class	Description	Depth (cm)	Index
1	Good	>75	1
2	Moderate	75-30	1.33
3	Poor	30-15	1.66
4	Very Poor	<15	2

Slope

Class	Description	Depth (cm)	Index
1	Very gentle	<6	1
2	Gentle	6-18	1.2
3	Steep	18-35	1.6
4	Very steep	>35	2

Rock Fragments

Class	Description	RF Cover (%)	Index
1	Very Stoney	> 60	1
2	Stone	20 - 60	1.3
3	Bare of stones / Slightly Stoney	< 20	2

Parent Material

Class	Description	Parent Material	Index
1	Good	Shale, Schist, Ultra basic, Conglomerates, uncolsidated	1
2	Moderate	Limestone, Marble, Granite, Rholite, Ignibrite, Gneiss, Siltstone, Sandstone	1.7
3	Poor	Marl, Pyroclastics	2

Drainage

Class	Description	Index
1	Well drained	1
2	imperfectly drained	1.2
3	Poorly drained	2

Soil Quality

Class	Description	Index
1	High Quality	< 1.13
2	Moderate Quality	1.13- 1.45
3	Low Quality	> 1.45

Source : MEDALUS (Kosmas et al., 1999)

Table 7.5: Soil types in Jeffara Plain and some properties used to calculate soil quality.

Soil Name	Code	Soil texture	Soil depth	Gravel %	Parent Material*
Typic Trorrpsamments	1	S	150	0.5	Eolian deposit
Typic Torriorthents	2	SL	75	24	Eolian deposit
Typic Haplocalcids	3	LS	110	0.6	Jeffara formation
Salic Haplocalcids	4	LS	112	1.5	Jeffara formation
Gypsic Haplocalcids	5	SL	70	5.6	Jeffara formation
Salic Haplocambids	6	SCL	110	0.9	Eolian deposit
Lithic Torriothents	7	SL	40	30	Eolian deposit
Lithic Haplocalcids	8	LS	30	22	Jeffara formation

Parent Material*: Eolian deposit (sand, sand loess); Jeffara formation (silt, sand and conglomerate with gypseous and calcareous crust).

To calculate soil quality, the data mentioned in Table 7.1 (i.e. the digital soil map and the associated soil report) have been applied in Table 7.5, while the slope gradient was calculated by topographic maps and a digital elevation model (DEM) of the study area was created from digital contour lines at a 20-m interval using Arc GIS (ESRI, 2010).

For example, soil quality was calculated based on the soil profile number11 which is located between x 310567, y 3596126 in the soil map. The soil type is psamments and the soil properties for this profile are as follows:

Soil depth = 150 cm, index =1, soil texture = sand, index = 2, rock fragments = 0.5%, index = 2, slope = very gentle to flat < 6, index = 1, drainage = well drained, index = 1 and Parent Material = limestone and sandstone, index = 1.7.

Soil quality (SQI = (texture * parent material * rock fragment * depth * slope *drainage)$^{1/6}$

SQ1 = $(2*1.7*2*1*1*1)^{1/6} = 1.4$

This result indicates that the soil quality is of moderate quality (Table 7.4)

7.4.1.2 Climate quality (CQI)

The assessment of climate quality is based on parameters which influence of the amount of water available for plants to grow. The following data on climate are required for the evaluation of climate quality:

1- temperature - mean monthly air temperature (°C)
2- precipitation - mean monthly precipitation amount (mm)
3- Potential evapotranspiration - mean monthly potential evapotranspiration (mm).
4- Wind velocity (average) km\h.

The concept of the Bagnouls-Gaussen bioclimatic aridity index can be successfully used for determining the aridity index from easily available meteorological data. The Bagnouls-Gaussen aridity index (BGI) is defined as follows:

$$\mathbf{BGI^n} = \sum_{i=1}(2\mathrm{ti} - \mathrm{Pi}).\boldsymbol{k} \qquad \text{Equation 3}$$

where

T is the mean air temperature for month i in °C, Pi is the total precipitation for month i in mm, and k represents the proportion of the month during which $(2\mathrm{ti} - \mathrm{Pi}) > 0$. Slope aspect is considered here for climate quality assessment by distinguishing two classes, class one with Northwest and Northeast aspects and class two with Southeast and Southwest aspects, and assigning them the indices 1 and 2 respectively (Kosmas et al., 1999; Sharma, 1998; Diodato and Ceccarelli, 2004; Incerti et al., 2007; Sivakumar, 2006).

Climate data for the study area were obtained from the Libyan Meteorological Department for the period from 1975 to 2009. These data consist of monthly figures for:

- rainfall
- temperature (maximum and minimum)
- wind speed
- sunshine hours.

These data have been used to calculate the aridity index and annual rainfall, while the slope aspect was calculated by topographic maps and Digital Elevation Model (DEM).

CQI = (rainfall * aridity * aspect) $^{1/3}$ Equation 4

Table 7.6 Classes and weighting indices for climate quality assessment Source.

Rainfall

Class	Rainfall	Index
1	>650	1
2	280-650	1.5
3	<280	2

Aridity

Class	BGI range	Index
1	<50	1
2	50-75	1.1
3	75-100	1.2
4	100-125	1.4
5	125-150	1.8
6	>150	2

Climate Quality

Class	Description	Index
1	High Quality	<1.15
2	Moderate Quality	1.15 - 1.81
3	Low Quality	>1.81

MEDALUS (Kosmas et al., 1999)

7.4.1.3 Vegetation quality (VQI)

vegetation quality was evaluated in terms of (a) plant cover, (b) drought resistance, (c) fire risk and ability to recover, and (d) erosion protection to the soils. Types of vegetation were grouped into three categories according to the plant cover (Table 7.7). Five categories were used for classification of vegetation with respect to drought resistance (Table 7.7). Four categories were used to classify fire risk according to tree types as following (a) bare land, perennial agricultural crops ,annual agricultural crops (maize, tobacco, and sunflower) as 'low' annual agricultural crops (cereals, grasslands) as 'Moderate', (c) deciduous oak, (mixed), mixed Mediterranean, macchia/evergreen forests Mediterranean macchia as 'High', (d) pine forests as 'very high' . Finally, erosion protection of soils is divided into four categories (Kosmas et al., 1999; Loumou et al., 2000; Salvati and Zitti, 2007; Salvati et al., 2008a). In the study area, the vegetation quality is considered to be very important to processes of land degradation. This is because the natural vegetation cover in Libya is very poor, owing to low annual precipitation and its erratic distribution, particularly in the areas of rangelands which receive less than 200 mm of rainfall per year.

For the assessment of vegetation quality in terms of drought resistance, fire risk, ability to recover, and erosion protection to the soils, the data were obtained from several sources, such as satellite image classification and field survey. According to satellite image classification for 2009, the vegetation cover in study area has been classified into four main classes: trees with irrigated areas, shrub vegetation with herbaceous vegetation, sparse vegetation and bare land . Meetings were held with local experts who have experience and knowledge of the vegetation cover, resistance vegetation for drought and environmental conditions of the study area (see Appendix A and the Agricultural Research Centre report, 2002). From all information above the vegetation quality has been assessed according to (Table 7.7)

$$VQI = (\text{fire risk} * \text{erosion protection} * \text{drought resistance} * \text{vegetation cover})^{1/4}$$

Equation 5.

Table 7.7: Classes and weighting indices of parameters used for vegetation quality assessment.

Fire Risk

Class	Description	Type of Vegetation	Index
1	Low	Bare land, perennial agriculyural crops, annual agriculyural crops (maize, tavaco, sunflower	1
2	Moderate	Annual agriculyural crops (cereals,grasslands),deciduous oak, mixed), mixed Mediterranean, macchia/evergreen forests.	1.3
3	High	Mediterranean macchia	1.6
4	Very High	Pine forests	2

Erosion Protection

Clas s	Descripti on	Type of Vegetation	Inde x
1	Very High	Mixed Mediterranean, macchia/evergreen forests.	1
2	High	Mediterranean, macchia, pine forests, perennial grasslands, evergreen perennial crops.	1.3
3	Moderate	Deciduous forests.	1.6
4	Low	Deciduous perennial, agriculyural crops, (almonds, orchards).	1.8
5	Very Low	Annual agriculyural crops (cereals), annual grasslands,vines.	2

Drought Resistance

Class	Description	Type of Vegetation	Index
1	Very High	Mixed Mediterranean, macchia/evergreen forests, Mediterranean, macchia	1
2	High	Conifers, deciduous olives	1.2
3	Moderate	Perennial agricultural tree(vines, almonds, orchards)	1.4
4	Low	Perennial grasslands	1.7
5	Very Low	Annual agriculyural crops, annual grasslands.	2

Plant Cover

Class	Description	Plant Cover (%)	Index
1	High	> 40	1
2	Low	10 - 40	1.8
3	Very Low	< 10	2

Vegetation Quality index

Class	Description	Index
1	High Quality	1 to 1.6
2	Moderate Quality	1.6- 3.7
3	Low Quality	>3.7

Source: MEDALUS (Kosmas et al., 1999).

The table shows classes and weighting indices of parameters used for vegetation quality assessment include fire risk, erosion protection capacity, drought resistance and plant cover (Kosmas et al., 1999).

7.4.1.4 Management quality or degree of human induced stress (MQI)

The land was classified into the following categories according to the main land use for evaluating the management quality or the degree of human induced stress:

Agricultural land (cropland), natural areas (shrubland, bare land), mining areas (quarries, mines, etc.), recreation areas (parks, compact tourism development, tourist areas, etc.), and infrastructure facilities (roads, dams, etc.).

The quality of management of the intensity of land use for cropland is assessed by characterising the frequency of irrigation, degree of mechanisation, the existing of terraces, the use of agrochemicals and fertilisers, the crop varieties used. The quality of management of pasture land can be evaluated by comparing the number of animals grazing the area with the estimated carrying capacity of the area. The sustainable stocking rate (SSR) expressed in animals per hectares can be calculated by the following equation:

$$SSR = X * P * F / R \qquad \text{Equation 6}$$

where:

R is the required annual biomass intake per animal (sheep or goat 187.5 kg animal-1 year-1, FAO 1991);

X is the fraction including grazing efficiency and correction for biomass not produced during the latest growing season (grazed: 0.5, non-grazed 0.25 year-1);

P is the average palatable biomass after the dry season (kg ha^{-1});

F is the average fraction of the soil surface covered with annuals.

To assess the management quality, data was obtained through field survey conducted in the Jeffara Plain, north-western Libya from 20 July 2010 to 12 September 2010. Satellite image classification for 2009 was also obtained to define vegetation cover and land use such as agricultural lands (croplands and rangelands), areas of 'natural' vegetation (woodlands and shrub land) and percentage of plant cover. Previous studies on rangeland and land cover land use from ARC in 2000 and 2002 was also obtained. The intensity of land use for cropland was assessed by characterising the frequency of irrigation, degree of mechanisation, the use of agrochemicals and fertilizers and the crop varieties used. This kind of agriculture that employs the use of improved seed varieties, together with mechanization, fertilizers and disease control was assessed as Medium land use intensity (MLUI) (intensive agriculture) as indicated in Table 7.8. In natural areas, the intensity of use for forests is not required as according to the land cover map in 2009 there is no forest in the study area.

The pasture land was evaluated by comparing the number of animals grazing the area with the estimated carrying capacity of the area. According to ARC (2005) the sustainable stocking rate (SSR) expressed in animals per hectares in the Jeffara Plain included in the study area is 4 animals per hectare. In addition, the General Authority for Information of census (2007) reported that the numbers of animals (sheep and goats) in the study area amounted to about 346,816 head. Moreover, based on the land cover map in 2009 shown in Figure 6.7, the area of rangeland (Shrubs Vegetation with Herbaceous and Sparse Vegetation) amounted to about 53,201 ha. The actual stocking rate (ASR) according to that is about 6.5 (ASR = 346816/53201 = 6.5), which means the number of animals is more than the grazing capacity of rangeland. In addition the policies related to land protection in the study area are limited. The policies for the agricultural land focuses on typical management practices for reducing tillage, for example, no tillage or minimum tillage, tillage of soil in the up-slope direction and the kind of tillage (Ben-Mahmoud 1995; Kosmas et al., 1999). With reference to the kind of tillage or the particular tillage implements tillage where the use of a mouldboard plough and a disk or other implement to pulverize the soil surface. The finely pulverized surface soil is easily detached by wind. Secondly, absence of grazing management such as, lack of restrictions on the number of animals on the rangeland area, encroachment into rangelands by cultivation and tillage where farmers are widely using disc plow which leads to removal of perennial vegetation leaves the ground barren for several months and sometimes years after harvest, leading to the disintegration of soil structure and the acceleration of the loss of topsoil and the occurrence of dust storms (Ben Mahmoud et al., 2000).

Through the field survey as shown the measurements of the density for all classes of vegetation cover in study area. During the field survey it was shown that irrigated tree crops such as, olive, almond, fig and citrus under protection were about 25-40%, whereas in the rangeland areas, annuals grasses, perennial herbs, shrubs and deciduous perennial shrubs, and sparsely vegetated areas of shrubs with herbs as well as bare soil, there is less than 15% of the area under protection. There are no mining activities in the study area.

In the study area, given that the management quality plays an essential role in the protection of natural resources, it must be taken into account when studying land degradation. In developing countries such as Libya there are destructive practices which have worsened the degradation of the vegetation, these practices include uncontrolled and unmanaged agricultural use, absence of grazing management or policies of land use, encroachment into rangelands by cultivation, and the excessive use of groundwater.

MQI = (land use intensity * policy enforcement) $^{1/2}$ Equation 7

Table 7.8 Classes and weighting indices of parameters used for land management quality assessment.

Cropland

Class	Description	Index
1	Low land use intensity (LLUI)	1
2	Medium land use intensity (MLUI)	1.5
3	High land use intensity (HLUI)	2

Pasture

Class	Description	Stocking rate	Index
1	Low	ASR<SSR	1
2	Moderate	ASR = SSR to 1.5*SSR	1.5
3	High	ASR >1.5*SSR	2

Policy

Class	Description	Degree of enforcement	Index
1	High	Complete : >75% of the area under protection	1
2	Moderate	Partial: 25-75% of the area under protection	1.5
3	Low	Incomplete: <25% of the area under protection	2

Management Quality

Class	Description	Index
1	High Quality	1 to 125
2	Moderate Quality	1.25 - 1.50
3	Low Quality	>1.50

Source: MEDALUS (Kosmas et al., 1999)

7.5 Results

7.5.1 Soil quality

Soil quality was computed by Equation 2, and the results obtained from the soil quality map in Figure 7.6 show that there are two soil qualities in the study area, according to Table 7.4. The first level of soil quality classified as 'low soil quality' applies to 6% of the area. The second quality level was classified as 'medium soil quality' and covers

92% of the land. The remaining 2% is indicating the expanding urban use in the study area.

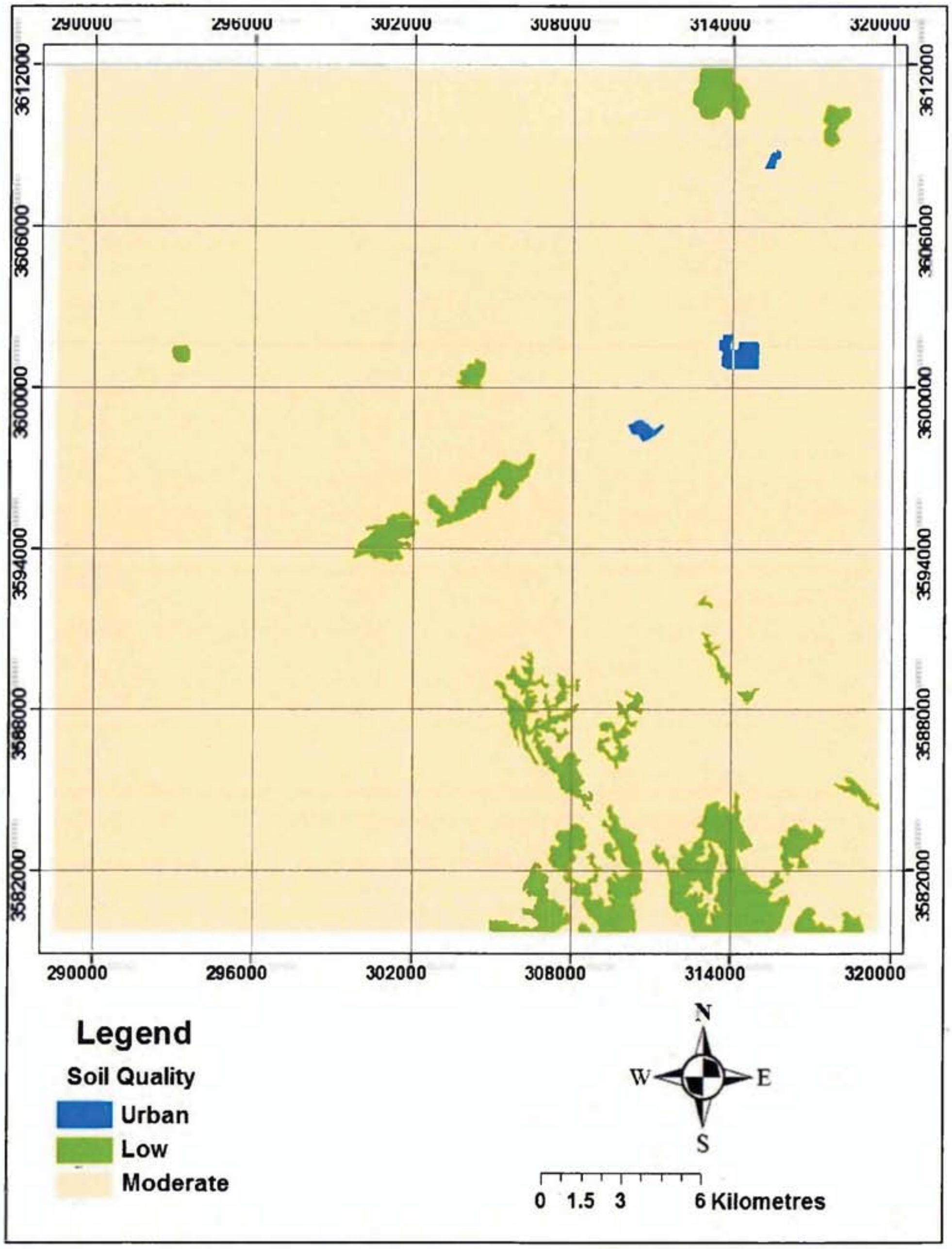


Figure 7.6: Soil quality map of the study area 1980.

7.5.2 Climate quality

Climate quality has been assessed using Equation 4, and the result obtained from the climate quality map (Figure 7.7) demonstrates that there is only one climate quality, 'moderate', in the whole of the study area.

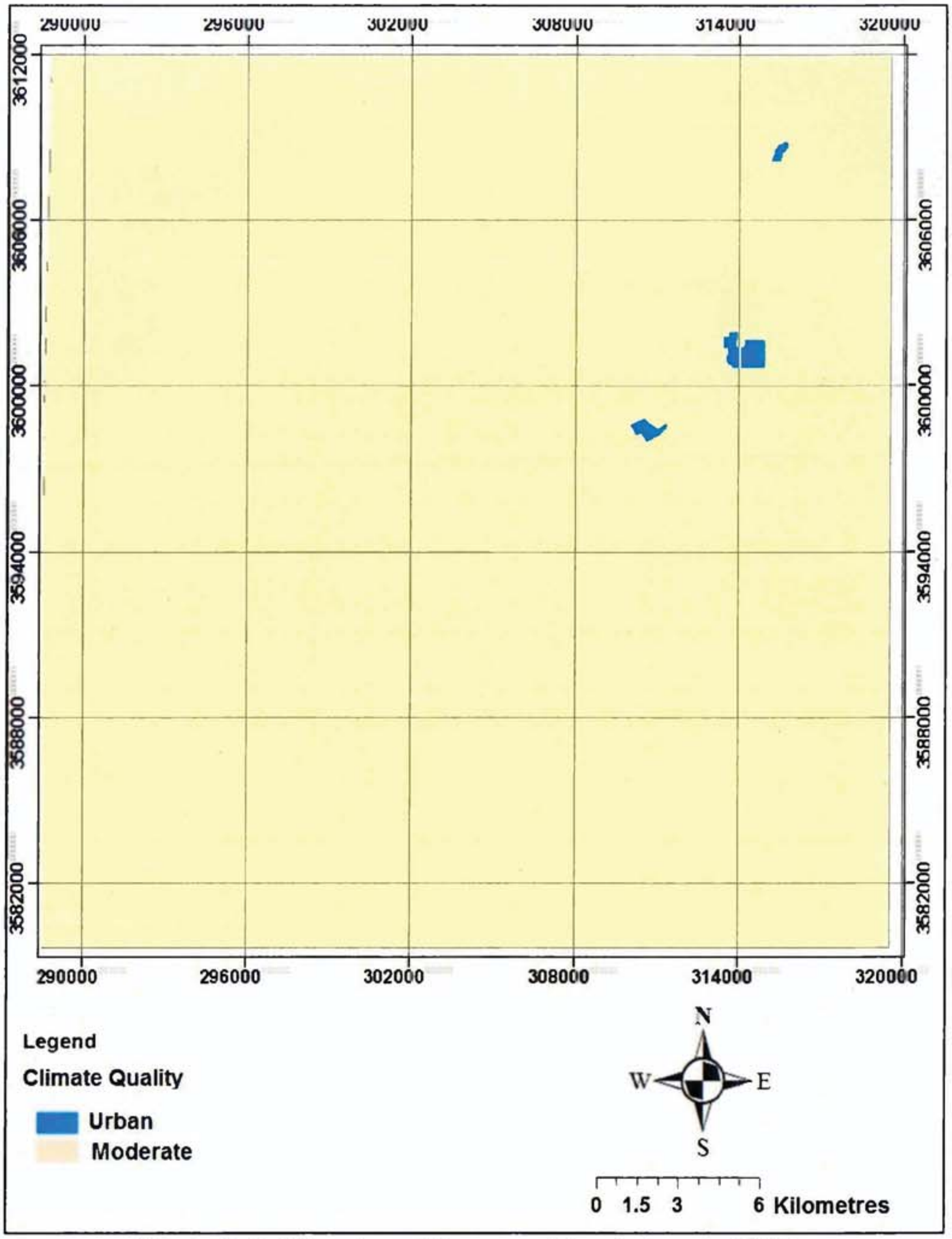


Figure 7.7: Climate quality map of the study area 2009.

7.5.3 Vegetation quality

Vegetation quality has been evaluated by Equation 5, and the results obtained from the vegetation quality map (Figure 7.8) show that there are two vegetation qualities in the study area, according to Table 7.7. The first was classified as moderate vegetation quality and represents 18%, while the second was classified as low vegetation quality and represents 80%.

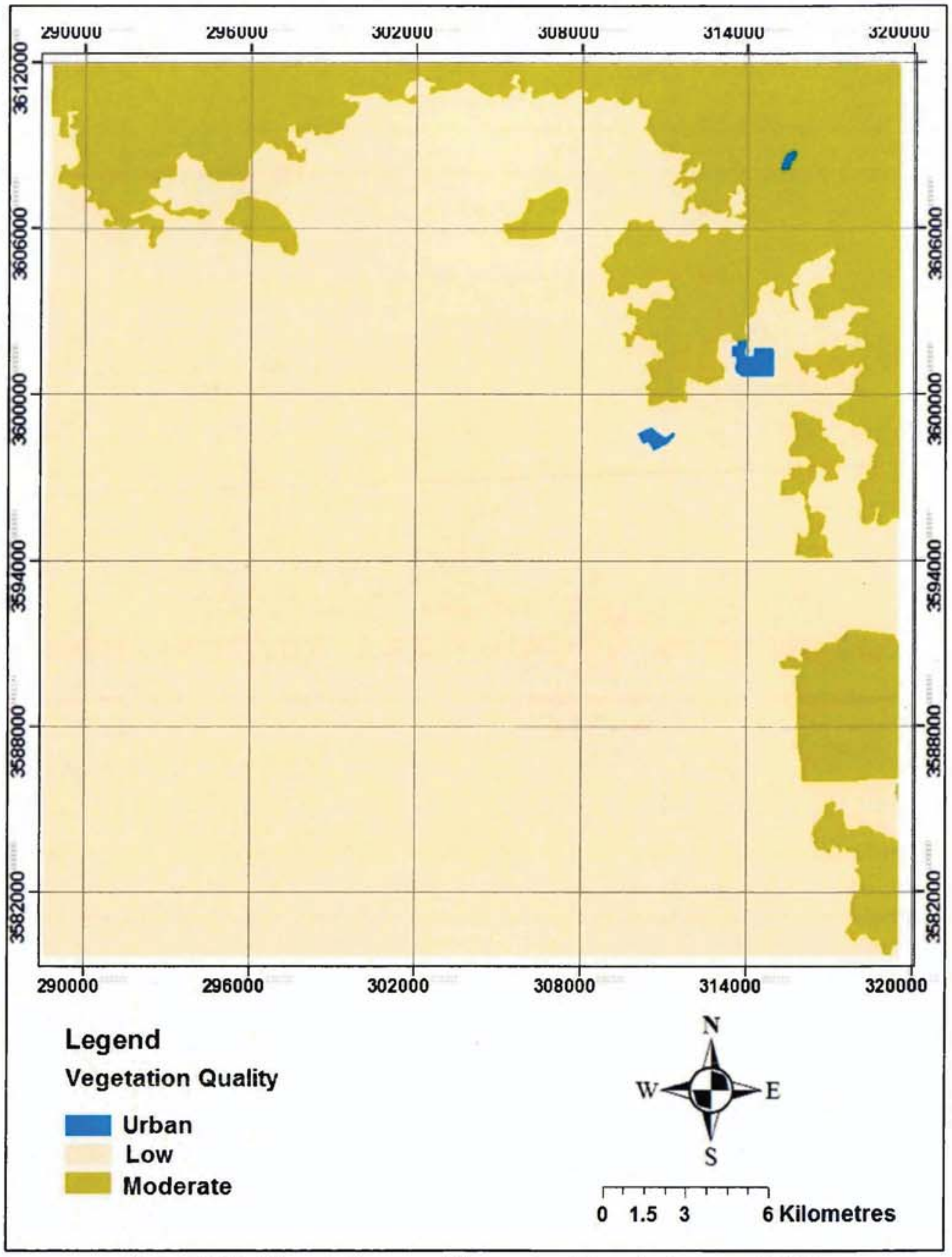


Figure 7.8: Vegetation quality map of the study area 2009.

7.5.4 Management quality

Management quality has been calculated by Equation 7, and the results obtained from the management quality map (Figure 7.8) show that there have been two management qualities in the study area according to Table 6.8: moderate management quality, which represents 18%, and low management quality, which represents 80%, and which is found in rangeland areas.

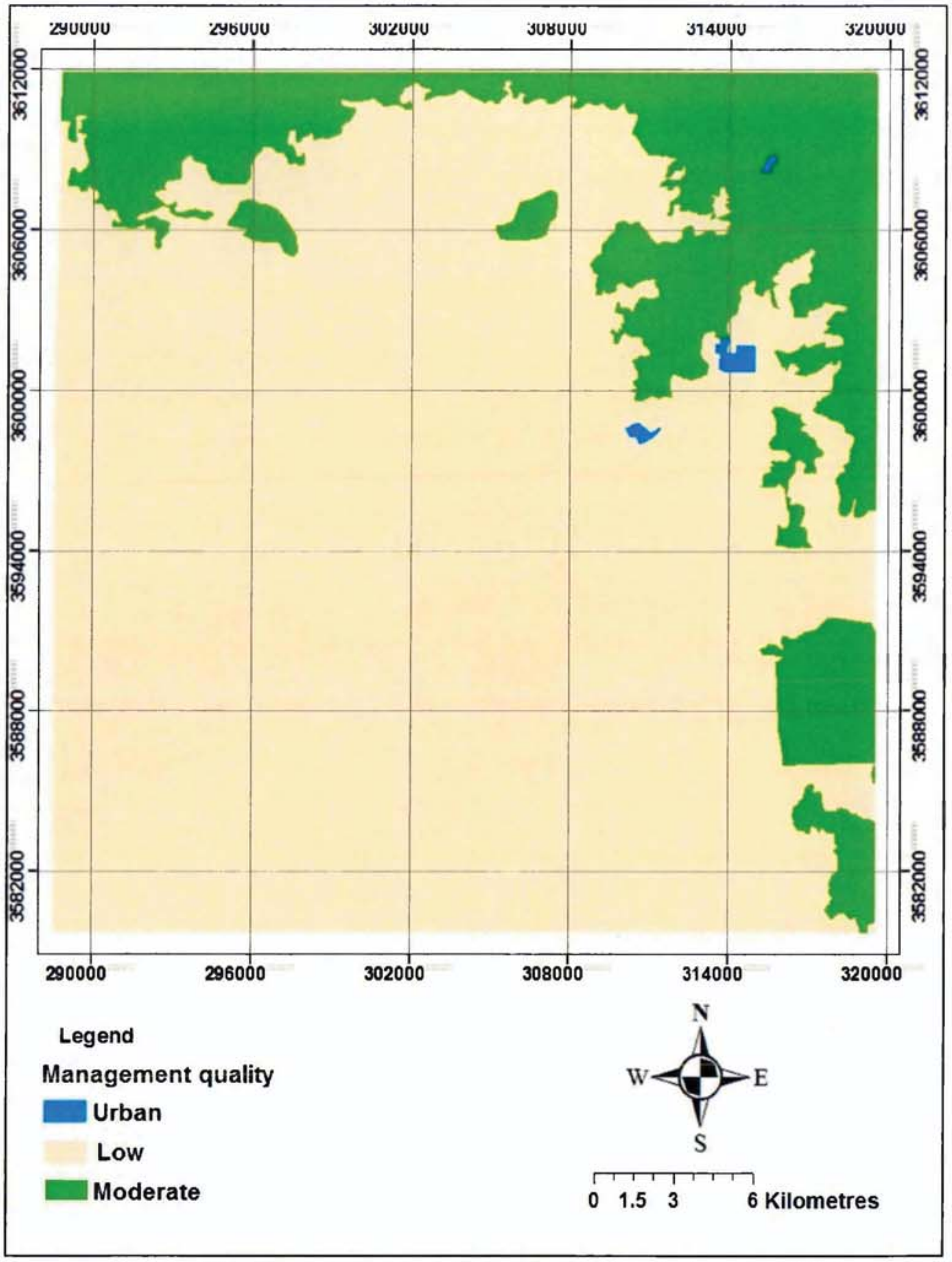


Figure 7.9: Management quality map of the study area 2009

7.5.5 Environmentally Sensitive Areas (ESAI) original MEDALUS

The final stage is the calculation ESAs index (ESAI) by using the four indices as following:

$$ESAI = (SQI * CQI * VQI * MQI)^{1/4} \quad \text{Original MEDALUS} \quad \text{Equation 1}$$

Environmentally Sensitive Areas (ESAs) vulnerable to desertification are classified into three types based on the degree of land degradation (Table 7.9).

Table 7.9 Types of ESAs and corresponding ranges of indices.

Type	Subtype	Range of ESAI
High	C3	1.53 - 2
Moderate	C2	1.38 - 1.53
Slight	C1	1. 27 - 1.37
Very slight	F	1 – 1.26

Source: MEDALUS (Kosmas et al., 1999).

A sensitivity (ESAI) map has been calculated using the original MEDALUS method Equation 1, and the results shown in Table 7.10 reveal that about 76% of the study area has been assigned to the high sensitivity class, while 8% of the study area has been mapped as belonging to the slight sensitivity class, and 15% as moderate. In other words, almost 80 % of the total study area is critically sensitive to desertification.

Table 7.10 the classified categories and the percentages in area using the original MEDALUS method.

Class	Area (ha)	%
Slight sensitivity	7,922.6	7.9
Moderate sensitivity	15,404	15.5
High sensitivity	75,523	75.52
Urban	1187	1.1
Total	100038	100%

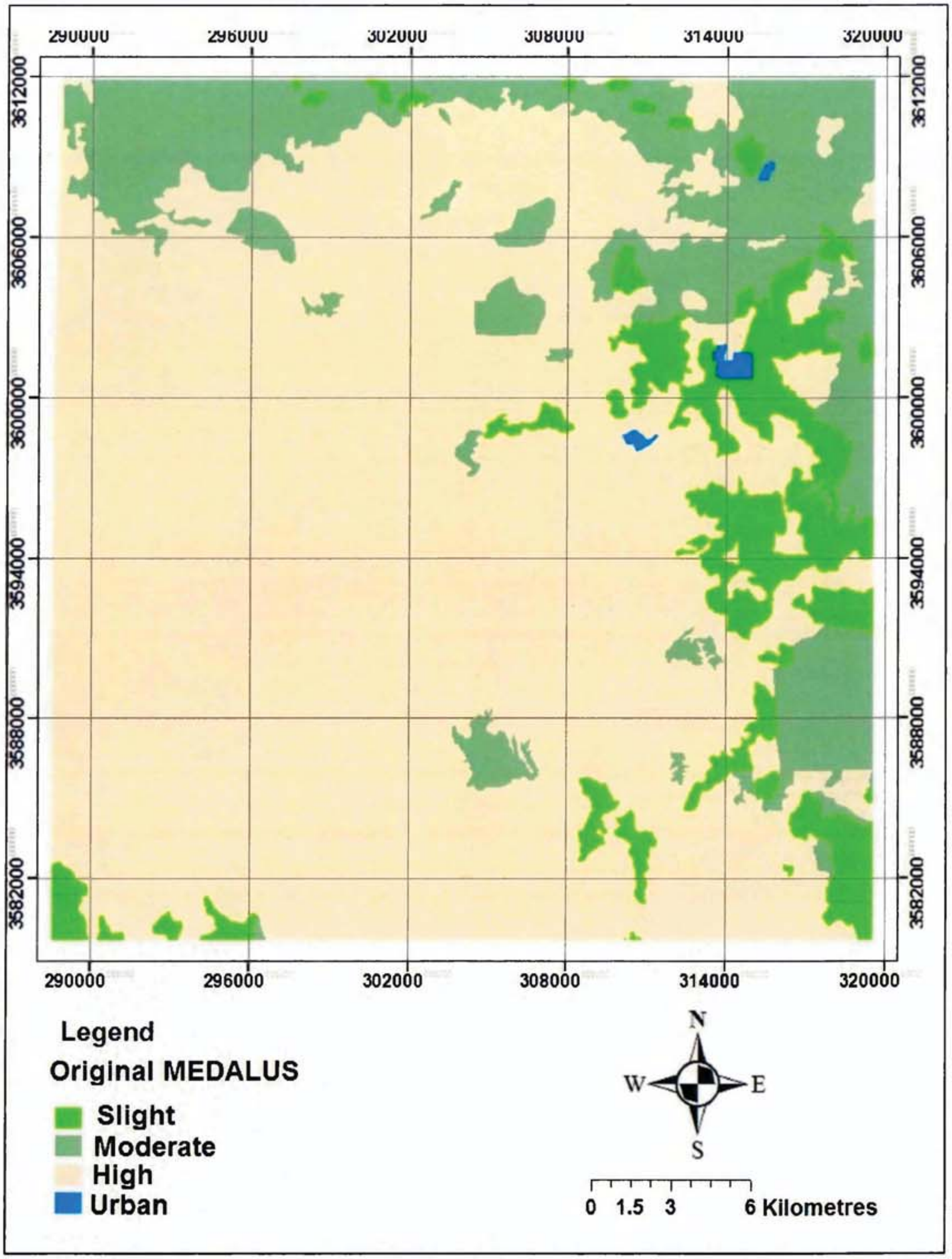


Figure 7.10: Desertification sensitivity map of the study area, using the original MEDALUS method 2009.

7.6. The Limitations of the Original MEDALUS Model of the Study Area

The result from comparing the data from ground truthing and the original MEDALUS map indicates varrrying differentials in high and moderate classes of sensitivity. However, not all the points of the slight class in the original MEDALUS correspond to the class assigned to the points from ground truthing class carried-out in 2010 which was determined by visual assessment of the poor growth of plants especially when compared to nearby rainfall crops. Moreover, all points of the slight classes are located in the irrigated area, and this area used for ground truthing, was affected by the salinity of groundwater used in irrigation. This has impacted on the trees and crops growth and productivity. This is a weakness in the original MEDALUS model because it did not take into consideration soil salinity management as an indicator within management quality. It is therefore necessary to improve the original MEDALUS to accommodate the soil salinity management factor in Libya.

During ground truthing carried out in 2010 which was determined by visual assessment there are many evidences that the study area was affected by wind erosion such as, sand dunes, rocks outside and low vegetation cover. In addition, most of the soil in the study area is Entisols and Aridisols, which are characterised by different depths and are often the surface layer of limestone and sand textures (usually). The soils are poor in organic matter and non-coherent, may be present from the stones and gravel, limestone, which characterises it as being more susceptible to wind erosion (Ben Mahmoud et al., 2000). Furthermore, wind speed plays an important role in wind erosion, where wind is responsible for the most part of wind erosion in the dry lands. This tends to remove the topsoil and produce sand dunes with wind conditions on the plain (see, for example, pictures 7.7-7.10) that consequently affect agricultural and pastoral land. Despite these conditionalities, the original MEDALUS model is unable to take into account wind erosion quality. To test for, perhaps, better results, it is therefore necessary to improve the original MEDALUS by taken into account the wind erosion quality as demonstrated in the previous chapter.

7.7 The Modified MEDALUS Model

According to many studies such as Kosmas et al (1999, 2003), Brandt et al. (2003) and Contador et al. (2009), the original ESAI model is simple, highly flexible and allows for the updating of information on local conditions and capable of generating good result in the identification of areas that are sensitive to desertification risk.

Ladisa et al. (2010) modified the MEDALUS approach in their study of the Apulia region in south-eastern Italy, where new sets of indicators were introduced. The human pressure index (HPI) was introduced as a new quality added to original MEDALUS as separate layer (theme) to initially four layers (i.e., SQI, CQI, VQI and MQI). This new quality Human Pressure Index (HPI) was proposed as

$$HPI = (PD * RP * EA * TPI)^{1/4}$$

where

PD = Population density (PD), RP = Resident population at the end of year, EA= Employment in the agricultural sector (EA) and TPI = Tourism pressure. This index signifies very high and very low population density values as well as excessive increases and decreases in resident population area.

Moreover, the original climate quality was modified by introducing a new indicator or factor which is Rainfall Erosivity index (R), this factor was expressed through factor R of the USLE (Universal Soil Loss Equation) and calculated as proposed by D'Asaro and Santoro (1983) as:

$$R = 0.21q^{-0.096} * p^{2.3} * NRD^{-2}$$

Where q represented the altitude of the meteorological stations (m), P is average annual precipitation (mm) and NRD is the average number rainy days during the year. Accordingly the new climate quality index was calculated and described as:

$$CQI = (BGI * Aspect * P * R)^{1/4}$$

Where BGI is the Bagnouls-Gaussen Aridity index, Aspect represents the direction in which the land faces the cardinal points, P monthly rainfall and R is Rainfall Erosivity index.

The original climate quality was modified by introducing a new indicator or factor which is Rainfall Erosivity index (R) to determine the impact of the energy of a rainstorm and observed maximum rainfall intensities in the Apulia region in south-eastern Italy. Moreover, the human pressure index (HPI) was introduced as a new quality added to original MEDALUS to determine the impact of population density values as well as excessive increases and decreases in resident population on desertification processes. Tourism pressure is an important indicator for the coastal areas of Apulia region, characterised by a significant increase in residents during the summer months. The tourist presence increases the population density by more than two times in the coastal areas (Ladisa et al., 2010).

When evaluating ESAI, any inclusion of further or additional index may not necessarily reduce impact of the other indices. Researchers such as Basso et al. (2000), Ladisa et al. (2010) and Elias et al. (2014) have supported this assertion. When computing the overall environmental sensitivity, Basso et al. (2000) sensitivity analysis of Agri-basin (Italy) municipality confirms that ESAI assigns equal weights to each layer n, within each quality index (QI), as well as equal weights to each QI. This means that each quality index has the same weight in the determination of the final Environmental Sensitive Areas Index (ESAI). The four indicators (soil quality, climate quality, vegetation quality, and management) quality used by was guided by the environmental and socio-economic realities of the study area.

Elias et al. (2014) added that ESAI assumes that all indicators used to define the different degrees of environmental sensitivity are important and hence assigns an equal weight to them all. However, the choice of QI layer is made not only on the basis of importance and by the number of the basic indicators (each of them represents one layer), but also by considering the ability to obtain and update them.

In addition, Ladisa et al. (2010) concluded that the high flexibility of the original MEDALUS approach offers large opportunities for the update of existing climate, soil, land use, vegetation, management quality and anthropogenic factors and the introduction of new ones necessary for the evaluation of complex and case-specific environmental conditions, and it is very simple and easy to implement as a GIS-based method from local to regional or national scale.

As a result of the flexibility of the model and the benefits derivable from its modification, it was considered that additional factors, such as salinity and wind erosion, needed to be included in the model for it to be appropriate to local conditions. The study area is located in the south of Mediterranean and this region is influenced by the arid and desert climate such as high temperatures, strong wind, shortage of rainfall and other elements described in Chapter three. There are many factors that cause wind erosion such as soil, vegetation cover, climate and human activity, and all these factors were included in the original model. However, the model did not take into account wind speed where wind speed plays an important role in wind erosion, and wind is responsible for the most part of wind erosion in the dry lands. This is particularly true in the sandy areas and those sparsely covered by vegetation for most of the year (see chapter 3 and 7). During ground truthing carried-out in 2010 which was determined by visual assessment there are many evidences that the study area suffer by wind erosion such as, sand dunes, rocks at or above ground level, and low vegetation cover. This evidence is particularly useful in the absence of weather monitoring stations.

7.7.1. Soil salinity

Salinity is one of the most severe environmental factors limiting the productivity of agricultural crops. Most crops are sensitive to salinity caused by high concentrations of salts in the soil (Ghassemi et al., 1995; Szabolcs, 1992; Flowers, 1999). Salinisation is the process that leads to an excessive increase in the salinity of the soil due to agricultural practices, such that plant growth is inhibited (Saysel and Barlas, 2001). Soil salinity is a serious problem in arid and semi-arid zones of the world where, often, the only available water for irrigation is poor quality (De Pascale et al., 2005). A high salt content could cause water assimilation problems in plants due to an osmotic pressure increase in the soil solution. Moreover, a high salt content could cause toxicity problems (Bastías et al., 2010; Li et al., 2010). Secondary salinization of agricultural lands is particularly widespread in arid and semiarid environments where crop production requires irrigation schemes. At least 20% of all irrigated lands are salt-affected, with some estimates being as high as 50% (Michael et al., 2000). Moreover, land degradation due to salinity makes the land unsuitable for agriculture or plant growth with the passage of time and out of the scope of agricultural investment and intervention in the list of desertified land (ACSAD, 2010). In Libya, the most productive agricultural fields are in the northern coastal areas of the country where irrigation predominantly relies on groundwater (Rashid, et al. 2010).

The original MEDALUS model is limited in the sense that it did not take into consideration soil salinity management as an indicator for management quality. This study considers soil salinity management as an important indicator and therefore includes it to improve on the MEDALUS model. In this research, therefore, field observation has been selected to assess soil salinity in the study area.

7.7.1.2. Local experts' selection

As part of the strategy for assigning and assessing weight for land degradation due to wind erosion and soil salinity, a number of local experts from the Libyan Agricultural Research Centre (ARC) and Faculty of Agriculture were consulted based on their background in farming, land degradation and desertification. There are criteria set for the selection of local experts:

1. The local experts should be currently working in Libya at the time of conducting the research.
2. The local experts should not only have a good academic background, but also possess years of demonstrated experience in conducting research in soil science, hydrology, agriculture, land management and irrigation.

Whilst it is simple to state the above criteria for selecting local experts, it was a difficult task locating them. This is because: 1) there is no documented and existing database for experts in the above disciplines; 2) no established personal contact; 3) may be working outside Tripoli and 4) may have sought refuge elsewhere due to the 2012 Libyan crisis. To overcome the difficult task of accessing local experts who possess the criteria set for selection, a non-probability sampling technique known as 'referral sampling' or 'respondent-driven sampling', was employed to identify experts through previous acquaintance (see, for example, Morgan, 2008; Heckathorn, 1997). The Director of the Department of Agricultural Research Centre (ARC) and the Head of Soil and Water, Faculty of Agriculture, Tripoli University, were the first subjects identified that referred the researcher to the hidden experts. At least 10 experts were suggested, but only five meet the criteria set for the selection of individual experts. Out of this number, one has background in general agriculture and policy and the rest are: one soil scientist, one hydrologist (water management), one conservationist and a soil scientist (soil physicist). Appendix B contains detailed background of the local experts. It must be noted that the lingering 2012 uprising that turned into civil war in Libya has severely limited access to all the sites to be visited as shown on the outcome of the random sampling techniques. Throughout this period, the sense of insecurity has discouraged farmers to be present on their farms for either the interview or farm work.

7.7.1.3. Soil salinity assessment

Based on the grid of soil profiles of Selkhozpromexport (1980), a GPS was employed to select 125 points that were used to assess soil salinity in the study area. Soil samples were collected from the surface soil by auger at 0–25 cm and 25-50 cm depth for each point as suggested by Ben-Mahmoud (1995) and Selkhozpromexport (1980). Soil salinity was assessed by Electrical Conductivity (EC), that is, the total amount of salt in the soil solution. Having measured soil salinity at all points, the impact of soil salinity on citrus, olive and vegetables crops was assessed visually at all points. The natural growth of the above three crops was carefully examined. For example, a branch and new leaves with bubblegum colour is a sign of growth. If there are no new leaves and branches, it is a sign that about 25% or more parts of the citrus trees are dead (ARC 2007). Information about the production of olive trees and vegetables has been obtained from farmers and the officials of the Agricultural Research Centre. Visual assessment in the field and interviews with farmers has made possible the collection of detailed information about how soil salinity impacts on the growth and development of trees and crops (see Tables 7.11, 7.12).

These tables were confirmed by four local experts, two from the Faculty of Agriculture, Tripoli University and two from the Agricultural Research Centre. After 85 geographic points were selected from the grid of soil profiles all over the study area (irrigated and rain-fed areas), An environmental sensitivity index at each of the 85 locations were selected by the focus group participants and was subsequently used to determine the relationship between soil salinity and the index of environmental damage from salinity (see Table 7.17 and Figure 7.13). each point was assessed individually by a team of five people (including the author) from June to August 2014.

Soil salinity is generally measured on an aqueous extract of a saturated soil-paste by measuring the electrical conductivity (EC). Because the EC and the total salt concentration of an aqueous solution are closely related, EC is commonly used as an expression of the total dissolved salt concentration of an aqueous sample. In order to determine EC, a saturated soil-paste is prepared by adding distilled water to a sample of air-dry soil while stirring and then allowing the mixture to stand overnight to permit the soil to fully imbibe the water and for the readily soluble salts to fully dissolve. A conductivity metre is then used to measure the EC. The analytical procedure for the laboratory determinations of salinity is mentioned in a number of publications (such as Richards 1954 USDA Handbook 60; Rhoades and Clark, 1978; FAO, 1985). The data range was selected according to the soil salinity guidelines provided by Ayers and Westcot (1985), FAO (2006) and WB2 (2010) as indicated in Table 7.11.

For example, in the north-eastern part in the study area, soil salinity was assessed in point x 313804 y 3608884, where the EC value is 8.95 dS/m which has led to death more than 50% of part of citrus trees and decreases in the production of olive trees and vegetable crops, were assessed as very high salinity. Another example can be drawn from the centre part of the study area (point x 295000, y 3694000), where the EC value was less than 2 dS/m, and the majority of the study area was rangeland (not irrigated), hence classified as having 'slight' soil salinity according to Table 7.11.

To use this table, the first process is to measure the soil salinity and then use table 7.11 as classes and weighting of soil salinity assessment. The damage of trees or yield by salinity can then be assessed using table 7.12 if the land use is the same type as those in the table, otherwise use Figure 7.13 for the relationship between soil salinity and the index of environmental damage from salinity. However, if there are other types the land use, the method of assessment can be made robust by visual assessment in the field and interviews with farmers. In other words, the interaction with farmers enables collection of detailed information about salinity impacts on the growth and development of trees and crops. This is very important because the information obtained can be integrated to other methods to obtain a wide variety of different types of data.

Table 7.11 the classes and weighting indices of soil salinity assessment.

Class		EC(ds/m)	Index
1	slight	0 -2	1
2	moderate	2-4	1.25
3	high	4-8	1.5
4	V high	8-15	1.75
5	sever	>15	2

Source: FAO (2006)

Table 7.12: Formula used during field assessment of soil salinity and damage to trees

Class	Slight	Moderate	High	Very high	Severe
Slant/ EC(ds/m)	0 -2 EC(ds/m)	2-4 EC(ds/m)	4-8 EC(ds/m)	8-15 EC(ds/m)	>15 EC(ds/m)
Citrus	The natural growth and with a branch and new leaves with colour of bubblegum.	There are no new leaves and branches	The death of part of some citrus trees, more than 25%	The death of part of some citrus trees, more than 50%	death
Olive	>50 kg/tree	37.5 - 50	38- 26	25 -11	<10
Vegetable crops	>5 ton /ha	5 -2 ton /ha	2-1	<1	zero
MEDALUS value	1	1.25	1.5	1.75	2

The following are examples of the characteristics of land condition from soil salinity, obtained during the fieldwork and used to describe the impact of salinity on the trees and crops.

Pictures 7.1: Affect of soil salinity on the vegetable crops of leaf Chard and Leaf parsley in the irrigated areas in northern parts of study, where the value of the soil salinity (EC) 8.44 in this point, (X: 314148 and Y: 3603996) which led to more than 75% reduction in yield.

Pictures 7.2: Soil salinity on the surface land in the irrigated areas in northern part of the study. The value of the soil salinity (EC) is 9.44 in this point (X: 316159 and Y: 3594017)

Pictures 7.3: The impact of soil salinity on Onion crop in the irrigated areas in northern parts of study, where the value of the soil salinity (EC) is 9.44 in this point (X: 311418 and Y: 3608972), which led to the death of the crop.

Pictures 7.4: Damage to citrus trees by high soil salinity in the irrigated areas in northern parts of study, where the value of the soil salinity (EC) is 8.25 in this point (X: 308996 and Y: 3603776), which led to death of the trees.

Picture 7.5: Damage to citrus trees by soil salinity. It shows the damage and comparison between the trees in terms of the damage where the value of the soil salinity (EC) is 8.2 in this point (X: 308379 and Y: 3606462). It led to the death of more than 50% of the citrus trees (Photograph source = El-Aswed, 2009).

7.7.1.4. Results

The results portrayed on the soil salinity map (Figure 7.11) show that there are four degrees of soil salinity in the study area according to Table 7.12.

Slight soil salinity was found in rangeland (65% of the total area) and the EC value (0-2 dS/m) was observed. This is due to the fact that the majority of the study area was rangeland (not irrigated) and the soil classification according to the soil map is Typic Trorrpsamments, which is characterised by sandy soil texture and non-salinity. Moderate soil salinity was found in agricultural land (8.5% of area), and the EC value of 2-4 dS/m was observed where the groundwater at the first aquifer depth between 100 and 150 m is moderate quality, which is characterised by less salinity. Moreover, most of the farms were located in areas where they are growing cereal crops such as wheat and barley and require much less water than other agricultural activities, such as citrus crop production. High (4-8 dS/m) and very high (8-15 dS/m) soil salinity were found in irrigated areas in the north east part of the study area (15.5 % and 9.8% of the study area respectively), and citrus tree damage from high salinity was observed in this area. In addition, according to information from informal interviews with the farmers the secondary salinity in some of the soil is due to the use of irrigation water qualities, intensive agriculture and several successive years without the application of technical and management programs intact. For example, some of the farmers noted that in some places the groundwater level dropped to between 280 and 350 m, and that the vegetation cover had died, particularly the orange trees. Also, a number of farmers linked the change in water quality (i.e. hot, salty water with sulphurous odour) to the major change in the depth of the groundwater level which has affected on the trees and crops in the area. Due to the prevailing hyper-arid conditions, the soil receives inadequate precipitation to effectively leach salts from the soil profile. Irrigation water is the primary source of salts.

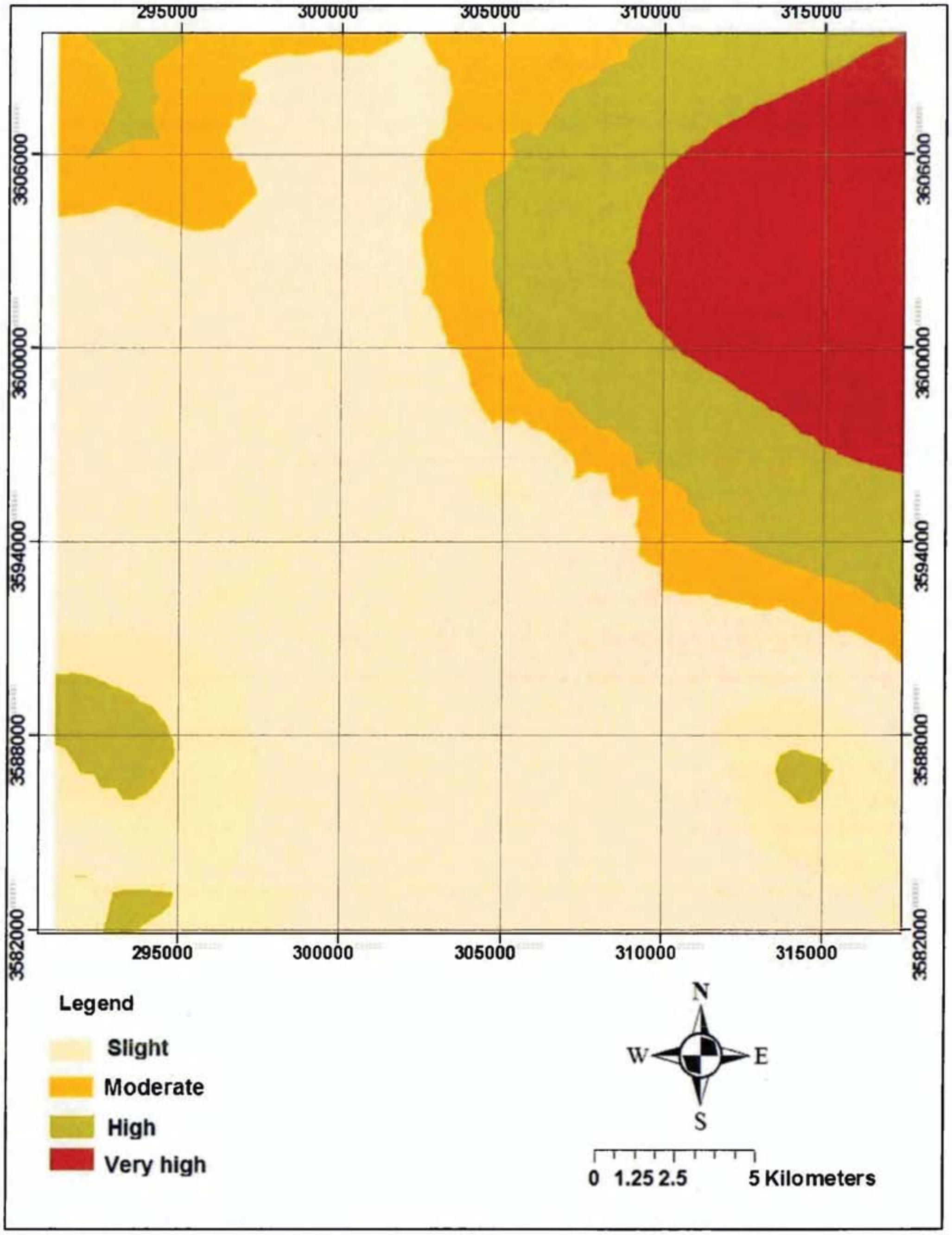


Figure 7.11: Soil salinity map of the study area

The management quality was calculated with the new equation 8, after adding indicator of soil salinity in the study as stated earlier in section 7.7.1.3.

MQI = (land use intensity * soil salinity * policy enforcement) $^{1/3}$ Equation 8

The system of evaluation assigns equal weight to each basic layer in the calculation of the quality indices (i.e. the land use intensity has the same relevance as the soil salinity, and policy enforcement within the management Quality Index). In an irrigated area, the soil salinity may be classified as high, while the intensity of land use is classified as moderate, as well as policies and enforcement. However, in rangeland, the soil salinity is classified as slight, while the intensity of land use is classified as high, as well as policies and enforcement. But the system of MEDALUS model evaluation assigns equal weight to each basic layer in the calculation of the quality indices (i.e. the land use intensity has the same relevance as soil salinity and policy enforcement within the management Quality Index).

7.7.2. Wind erosion

Wind erosion plays an important role in soil erosion, where wind is responsible for the removal, movement, and redeposition of land when soils are exposed to high velocity wind. For much of the dry lands, especially in sandy areas where there is poor soil structure and sparse vegetation cover for most of the year. According to ACSAD (2007), in arid and semi-arid areas, land degradation by wind action leads to many problems such as transport and deposition of materials, which influence vegetation cover and removal of fine grains with organic matter. This may result in decreased crop harvests. These violent winds have the effect of drying the soil and parching the vegetation. High Ghibli velocity intensifies deflation, transportation and redeposition of fine silty and sandy material from the soil surface, destruction of the most fertile humus horizon and its burial under the eolian deposits. In addition to this, it tends to remove the topsoil and produce sand dunes and also affects food crops.

The effect of wind erosion can be on-site as well as off-site. The on-site effects are loss of topsoil and plant nutrients, which have a direct impact on crop growth. Soils become less productive because they contain less nutrients and less capacity to retain water. A field experiment conducted on the effect of wind erosion and sand accumulation in Inner Mongolia shows that long term wind erosion could result in significant soil coarseness, infertility and dryness (Zhao et al., 2006). Abrasion caused by flying soil particles does considerable damage to crops and to young plants in particular. In addition to this, evaporation from plant leaves is accelerated by wind, restricting wheat growth. The off-site effects are due to sand cover on fertile agricultural areas which affects crop growth and eventual decrease of harvest. Wind erosion is an important soil degradation process in arid and semiarid regions of the world (Peterson et al., 2006). Wind erosion in the marginal drylands of the Mediterranean region is a serious problem, through its direct influence on particularly vulnerable land. Drylands are extremely susceptible to wind erosion because soils tend to be dry, poorly structured and sparsely covered by vegetation. Evidence of wind erosion is widespread throughout the dry areas of West Asia and North Africa. A major limitation in these areas is the lack of adequate and reliable rainfall to support a sustainable, protective land cover against the erosive forces of the wind (FAO, 2007).

Despite these conditions, the original MEDALUS model is unable to take account of wind erosion quality. To yield better results, it is therefore necessary to improve the original MEDALUS by taking into account the wind erosion quality in Libya.

7.7.2.1 Assessment of wind erosion

Field observations were made to the assess wind erosion in the study area. This study identified a number of useful criteria (Tables 7.13 and 7.14) from previously published literature (e.g. FAO, 2011; ACAD, 2007) which were combined with MEDALUS degradation criteria. These tables were verified by four local experts (two from the Faculty of Agriculture, Tripoli University and two from the Agricultural Research Centre) by selecting another 100 geographic points distributed all over the study area were selected from the grid. Each point was assessed individually by a team of five people (including the author) from July to August 2014.

Table 7.13: Summary of criteria for field assessment of wind erosion

Observed indicators		Slight	Moderate	High	Very high	Severe
Nebka	high	<25 cm	25 -50	51 – 75	76 -125	>125
	length	30 cm	31 – 60	61 -120	120 180	>180
	Value	0.27	0.34	0.40	0.47	0.54
Sand dunes		< 25cm	26 -50 cm	51-100 cm	101 -150	>150
Value		035	0.44	0.53	0.60	0.70
Out rocks		<15	15-30	30 -50	50 -75	>75
Value		0.2	0.25	0.30	0.35	0.4
Root out		2 cm	2 - 6	6-10	10-15	>15
Value		0.18	0.22	0.27	0.33	0.36
MEDALUS value		1	1.25	1.50	1.75	2

Table 7.14: Classification of wind erosion of the study area based on field evidence

Wind erosion	
None or not apparent	No obvious visual signs of wind erosion but evidence of minor wind erosion may have been masked by, for instance, recent tillage.
Slight	Some visual evidence of the movement of soil particles by wind within individual fields. • No evidence of wind scouring but a few superficial roots exposed. • Deposits of windblown soil at field margins or where the wind progress has been obstructed, less than < 25cm thicknesses. • Nabka: sand arrow Nabka, which are small ovoid dunes (25cm in height, 30cm in length). • Tree root exposure (out root) 2cm • Out rocks: the percentage surface covers <15%Little accumulation of windblown soil in drainage ditches. • Only a light covering of windblown material on roads and minor accumulation in settlement areas
Moderate	Clear signs of the transportation and deposition of soil particles by wind, some scouring but no more than 5cm in depth. • Some tree, shrub, grass and/or crop roots exposed within the topsoil • Deposits of windblown soil at field margins or where the wind progress has been obstructed, between 26-50cm thicknesses. • Nabka: sand arrow Nabka, which are small ovoid dunes (25-50cm in height, 31–60cm in length. • Tree root exposure (out root) 2 – 6cm • Out rocks: the percentage surface covers <15 - 30% • Moderate accumulation of windblown soil in drainage ditches. • Moderate covering of windblown material on roads and accumulation in settlement areas.
High	Clear signs of the transportation and deposition of soil particles by wind, some scouring more than 10cm in depth. • Some tree, shrub, grass and/or crop roots exposed within the topsoil • Deposits of windblown soil at field margins or where the wind progress has been obstructed, between 50-100 cm thicknesses. • Nabka: sand arrow Nabka, which are small ovoid dunes (51–75cm in height, 61-120cm in length. • Tree root exposure (out root) 6–10cm • Out rocks: the percentage surface covers <30-50% • Moderate covering of windblown material on roads and accumulation in settlement areas.
Very High	Clear signs of the transportation and deposition of soil particles by wind, some scouring more than 5cm in depth. • Some tree, shrub, grass and/or crop roots exposed within the topsoil • Deposits of windblown soil at field margins or where the wind progress has been obstructed, between 100-150 cm thicknesses. • Nabka: sand arrow Nabka, which are small ovoid dunes (76 -120cm in height, 120-180 cm in length. • Root exposure (out root) 10 –15cm • Out rocks: the percentage surface covers 50-75% • Moderate covering of windblown material on roads and accumulation in settlement areas.
Severe	Clear evidence of the wholesale transportation and deposition of soil particles by wind. • Deposits of windblown soil at field margins or where the wind progress has been obstructed, >150cm thicknesses. • Extensive exposure of tree, shrub, grass and/or crop roots >15cm • Nabka: sand arrow Nabka, which are small ovoid dunes (>120cm in height, >180cm in length • Root exposure (out root) 10 – 15cm • Out rocks: the percentage surface covers >75% • Subsoil horizons exposed at or close to the soil surface. • Drainage ditches filled with windblown soil. • Windblown material accumulating deep enough on roads and in settlement areas to have a negative impact on transport and living conditions

Field methodological strategy to organise the field observations was to spread the assessment locations evenly across the study area based on the grid of soil profiles of Selkhozpromexport (1980), a GPS was employed to select 125 points to assess wind erosion. The field observations were conducted using several sources including a topographic map, global positioning system (GPS), high-resolution data (SPOT5 image), and current land cover map to make the study easier. To do this, forty blocks were selected using GPS based on the grid of soil profiles cried out by Selkhozpromexport (1980). This was obtained from the UTM grid for the study area, where assessments were carried out for each block in sample plots or transects of 100m x 100m in size within each rectangular block. Four indicators were selected to assess wind erosion features (sand dunes, root out, rocks out and Nebka) in the field for each block.

7.7.2.1.1 Nebka

These accumulations are caused by the presence of a rock, plant or other obstacle in the path of moving sand particles. There are two types of Nebka: sand arrow Nebka, which are small ovoid dunes (50 cm in height, 150 cm in length and 40 cm in breadth) lying in the direction of the prevailing wind; and bushy Nebka, similar to sand arrow Nebka, but capable of reaching a height of 2 m and a length of 3 to 4 m as shown in Photographs 7.7a and 7.8a (ACSAD, 2002; FAO, 1995).

7.7.2.1 .2. Plant / tree root exposure

The removal of soil particles by water or wind can lead to the exposure of the roots of trees, and other plants as erosion lowers the overall soil level (Photograph 7.9b). Close inspection of the lower portion of the tree trunk or plant stem may reveal a mark indicating the level of the original soil surface. By measuring the vertical difference (with a ruler) between this mark and the present soil surface, an estimate can be made as to how much soil has been lost. In the case of lateral roots away from the tree trunk, the upper surface of the most exposed roots is usually taken as the former soil surface (ACSAD 2002; Ben-Mahmoud, 1995).

7.7.2.1.3 Rock outcrops

Rock outcrops should be described in terms of percentage surface cover, together with additional relevant information on the size, spacing and hardness of the individual outcrops (See Picture 7.9b) (Ben-Mahmoud, 1995).

Picture 7.7a. Assessment of high wind erosion by presence of Nebka (ovoid dunes with vegetation). Sand is 51–75cm in height, 60 -120cm in length. Vegetation type is a shrub, *Retame reatem* (in Arabic, Rtme).

Picture 7.7b. Assessment of high wind erosion by presence of sand dunes in Southern part of the study area (X: 311119 and Y: 3596527). Dune height is between 50-100cm. Vegetation type is a shrub, *Aristida pungens* (in Arabic, Asbta).

Picture 7.8a. Assessment of very high wind erosion by presence of Nebka (ovoid dunes with vegetation). Sand is 76 -120cm in height, 120-180cm in length. Vegetation type is a shrub, *Retame reatem* (in Arabic, Rtme).

Picture 7.8b. Assessment of very high wind erosion by presence of sand dunes in Southern part of the study area (X: 311119 and Y: 3596527). Dune height is > 150cm. Vegetation type is a shrub, *Aristida pungens* (in Arabic, Asbta)

Picture 7.9a. Assessment of very high wind erosion by root exposure. Roots are exposed to more than 15cm above the ground level. The vegetation type is a shrub *Gymnocarpos decander* (in Arabic, Alqgroud)

Picture 7.9b. Assessment of very high wind erosion by out rocks. Percentage of surface covered by exposed rocks >75% in the southern part of the study (X: 306274 and Y: 3586382)

Picture 7.10. Assessment of moderate wind erosion features in field. Nebka are 25-50cm in height and 31–60cm in length and sand dunes with a height between 26-50 cm in the middle part of the study area (X: 293804 and Y: 3608840), vegetation type is shrub, *Retame reatem* (in Arabic, Rtme); *Rhantherium suaveoles* (in Arabic, Arfaj); and *Aristida pungens* (in Arabic, Asbta).

7.7.2.2 Results

The results illustrated on the wind erosion assessment map Figure (7.12) show that there are four degrees of wind erosion in the study area, summarised in Table (7.15).

Table 7.15: The classified categories and the percentages in area using field assessment of wind erosion.

Class	Area (ha)	%
Slight	28541	28.5
Moderate	30240	30
High	17485	17
Very High	22585	22.5
Urban	1187	1.1

Slight wind erosion was found in irrigated areas, due to the fact that the majority of the study area was agricultural land characterised by evergreen perennial agricultural trees and the percentage plant cover was 50 -75%, which leads to protection from wind erosion. This means that all indicators were assessed as slight wind erosion. The moderate wind erosion, which was found in the southwest of the study area, was classified as 'moderate Nebka, sand dunes fixed by vegetation, and the plant root and out rock were classified as moderate. This is because the area was considered as having sand deposition. High wind erosion found in the south of the study area was classified as high plant root and out rock while sand dunes and Nebka were classified as moderate. This because the vegetation cover is very poor and the hot dry wind coming from the south, called Ghibli (the direction from which the wind blows supplies its name in Arabic). In addition to this, it tends to remove the topsoil and produce sand dunes. Finally, very high wind erosion was found in the south of the study area and was assessed as very high plant root and out rock while sand dunes and Nebka were assessed as high as well. This area was characterized by low vegetation and bare soil. This area, having a light texture and sparse vegetation cover under intense wind conditions, results in the formation of soil deflated to a different degree.

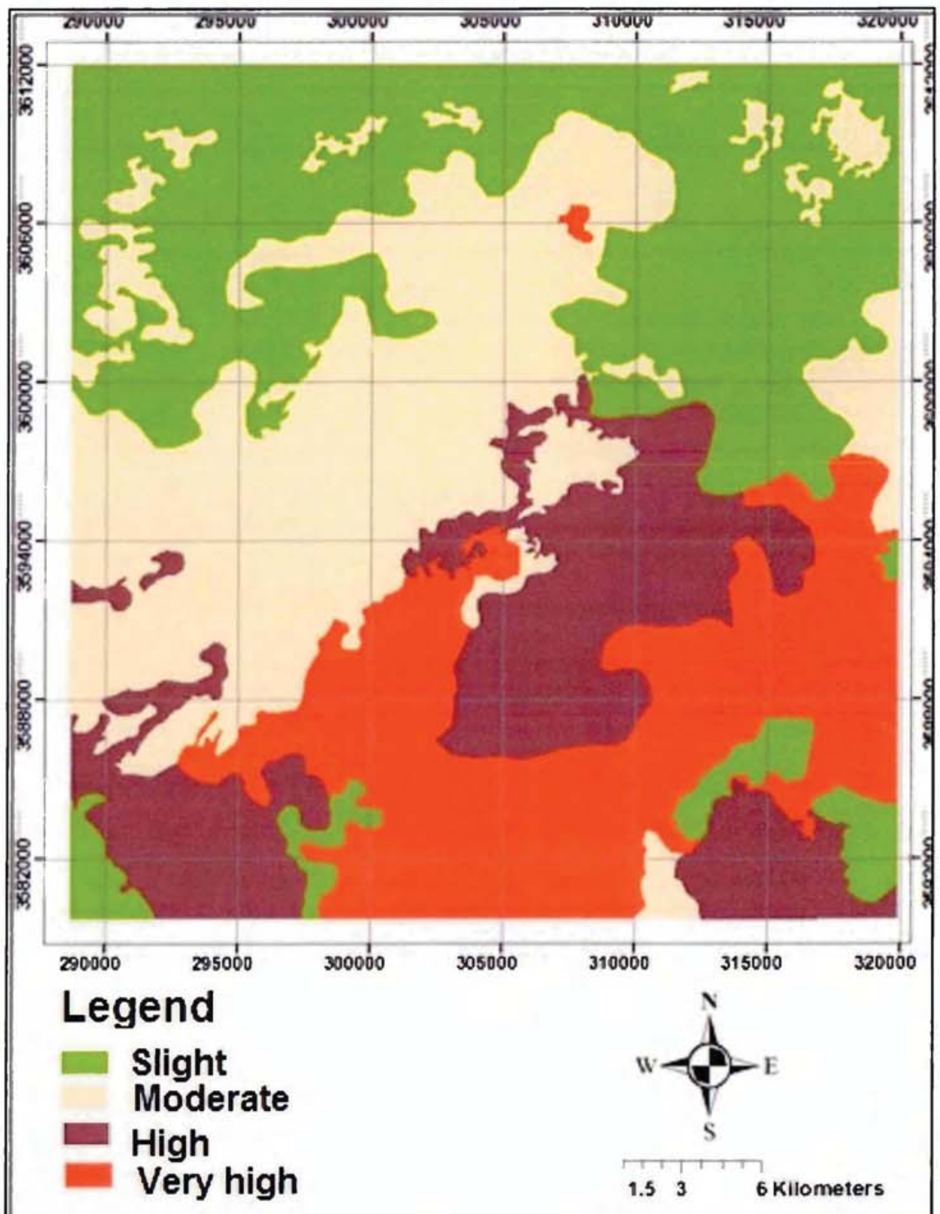


Figure 7.12: Wind erosion quality map of the study area using field assessment.

7.8. Management Quality Index, MQI (Focus group observation of desertification)

A linear relationship between soil salinity and the index of environmental damage from salinity was established at 85 points based on the grid of soil profiles locations. Similarly, to obtain areas that are at the risk of land degradation and desertification due to soil salinity based on the Table 7.12 and Table 7.16, an environmental sensitivity index at each of the 85 locations was also conducted via focus group Figure 7.13 . This group of experts, who visited the field to assess the condition of specific fields/sites, enables gathering of more data in identifying areas vulnerable to land degradation.

Table 7.16: Desertification estimated by focus group

Type	Range
C1	1-1.2
C2	1.4-1.6
C3	1.8-2

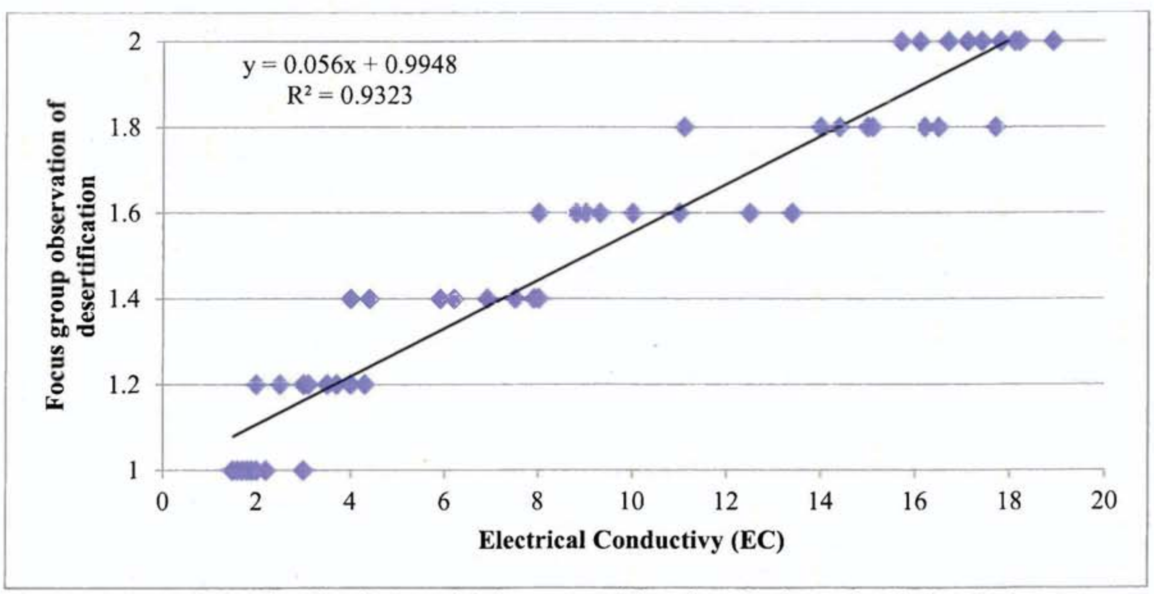


Figure 7.13. Index of soil salinity which assessed by electrical conductivity (EC ds/m)

7.9 Results

7.9.1 Management quality

Management quality was evaluated by Equation 8. The results, shown on the management quality map (Figure 7.14) produced differences from those derived from using equation 7 (Figure 7.9) with 6,750 previously classified as 'moderate' being changed to 'low' in the irrigated area in the north eastern part of the study area. This change was evident when the indicator of soil salinity management to the management of quality equation.

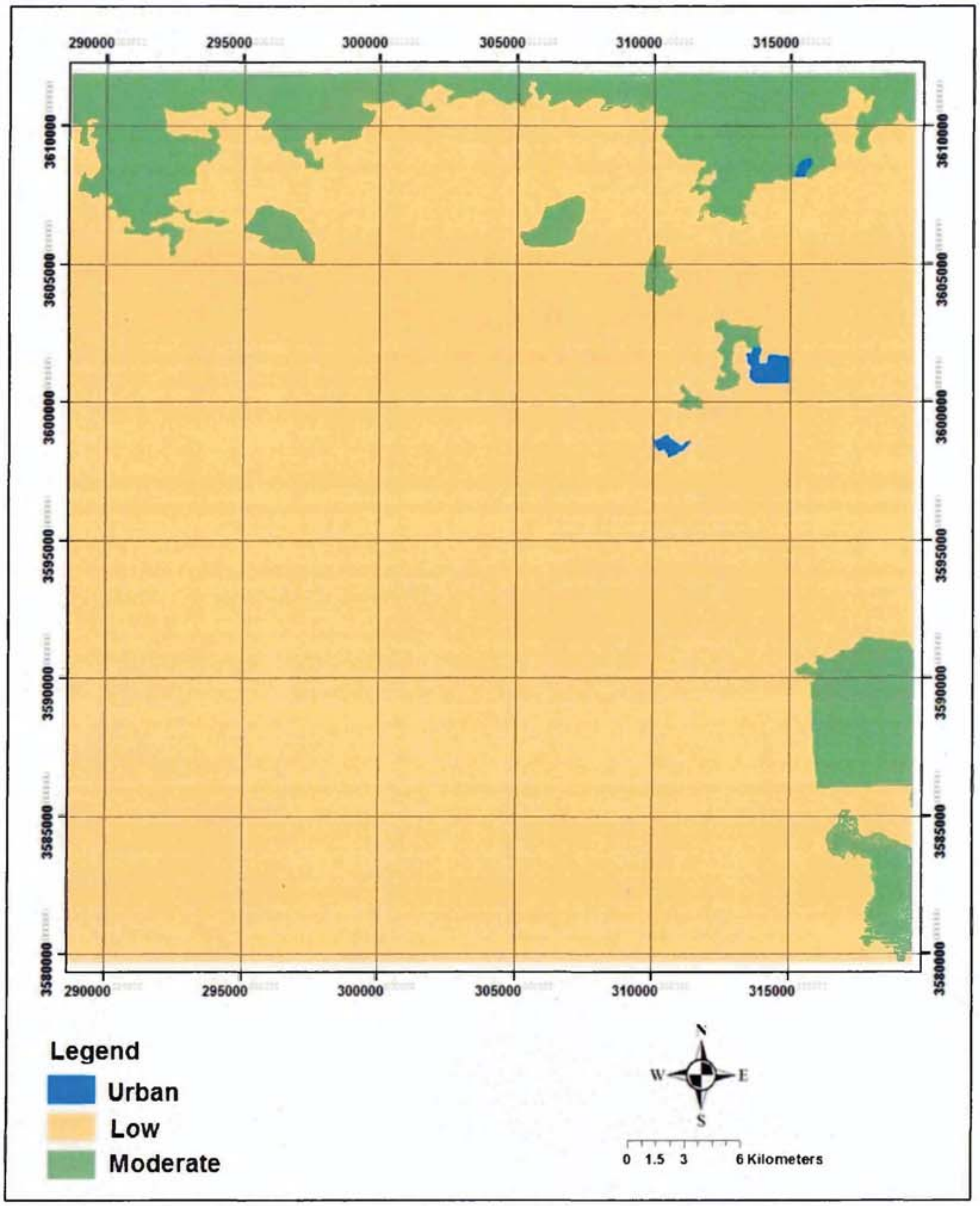


Figure 7.14: Management quality map modified MEDALUS model of the study area

7.9.2 Environmentally Sensitive Areas (ESAI)

It should be noted that the ESAI has been calculated by the new equation 9, after adding wind erosion quality of the study area. The wind erosion quality (WQ) has also been assessed using field observations as stated earlier in section **7.7.2.**

The final stage is the calculation of ESAs after developing the index (ESAI) using the five indices as follows:

$$ESAI\ (developed) = (SQI * CQI * VQI * MQI * WQ)^{1/5} \qquad \textbf{Equation 9}$$

Table 7.17: Types of ESAs and corresponding ranges of indices

Type	**Subtype**	**Range of ESAI**
Very high	C3A	>1.53
High	C3	1.47 -1.53
Moderate	C2	1.38 - 1.47
Slight	C1	1. 27 - 1.37
Very slight	F	1 – 1.26

Source: MEDALUS (Kosmas et al, 1999).

Table 7.18: The classified categories and the percentages in area using the modified MEDALUS method.

Class	**Area (ha)**	**%**
Moderate sensitivity	22.517.5	22.5
High sensitivity	32.950	33
Very high sensitivity	43.382	43.4
Urban	1.187	1.1
Total	100.038	100%

Finally, a sensitivity (ESAI) map was calculated using Equation 9, and the results shown in Table 7.18. In other words, about 75% of the total study area was sensitive to desertification (critical = high + very high classes). Figure 7.15 revealed that majority of the C2 class represents agricultural land characterised by evergreen perennial agricultural trees. Consequently, it was classified as 'moderate'. Most of these lands located in the north and east of the study area were 'moderate' of vegetation quality, climate quality, management quality and soil quality with slight wind erosion. Moreover, the percentage plant cover was measured as 75%. High (C3), located in the centre part of the study area has accrued due to mismanagement, and moderate soil quality and low vegetation quality is caused by the fact that the cover is more than 35% with moderate wind erosion. This result comes as a consequence of the assessment of all the qualities measured above as 'low' or 'moderate'. Very high sensitivity to desertification (C3A) is located in the south part of the study area and accrued due to mismanagement, moderate soil quality and very low vegetation quality caused by the fact that the cover is often less than 30% with high and very high wind erosion. From what has been stated above, it becomes apparent that human activities play the most important role in accelerating the desertification process, through the mismanagement of land resources (water, soil and vegetation) which has led to high sensitivity to desertification in the study area.

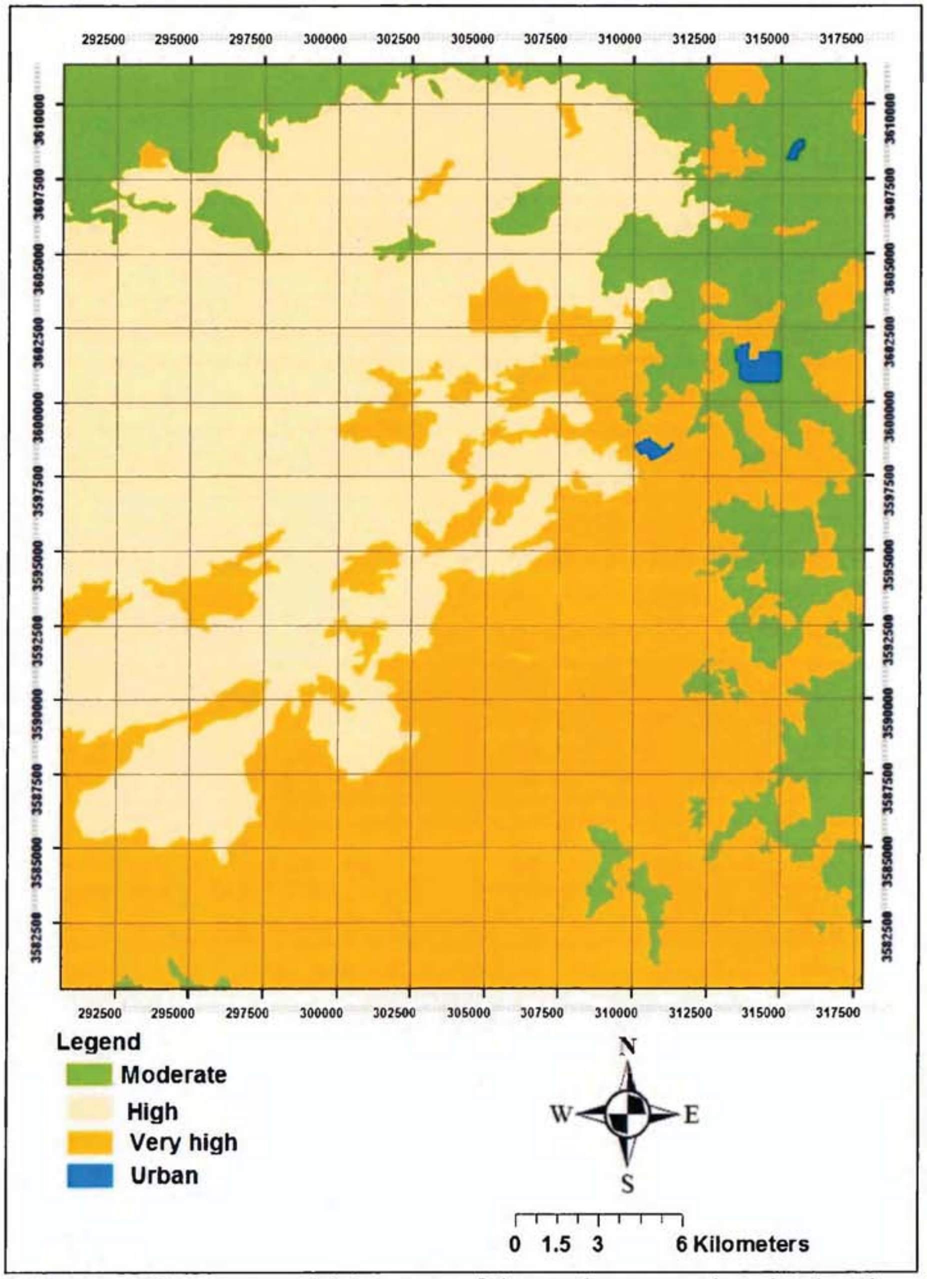


Figure 7.15: Desertification sensitivity map of the study area, using the developed MEDALUS method

7.10 Soil Erosion Map

The soil erosion map was produced by Selkhozpromexport (1980). Classification of soil erosion Figure 7.16 in the Jeffara Plain was worked out from reconnaissance and large-scale soil survey (1:50,000), the generalization of a large number of laboratory analyses, and additional research (Table 7.19). The definition of the degree of soil erosion is made by comparison of the thickness of the A1 and A1+B1 horizons and the chemical composition of an eroded soil with the thickness and chemical composition of the same horizons of standard non-eroded soil. Every type of soil unaffected by the soil erosion process has a definite sequence and thickness of its genetic horizons. On the erosion map the soils are distinguished as slightly, moderately, and severely deflated, according to the degree of deflation (Selkhozpromexport, 1980). It has been used in order to compare the land degradation map and to know which areas have changed between 1980 and 2009 in study area as well as reference data (previous desertification maps) on this study area to validate the final result of this study.

Table 7.19: Classification of soil erosion in the western zone of Libya

Soil erosion class	Type of erosion	Form of erosion
Wind-borne soils	Wind-blowing	Accumulation of sand deposits on soil surface in the form of continuous layer.

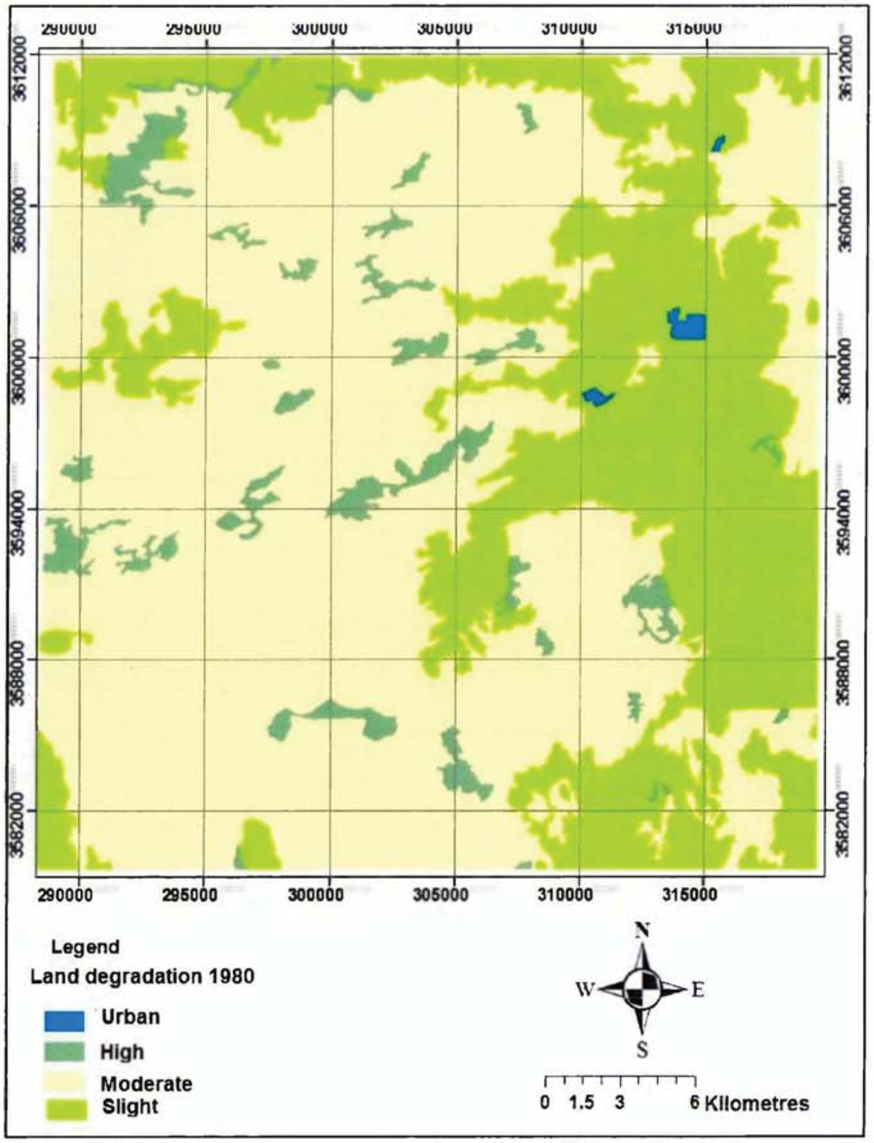


Figure 7.16: Soil erosion map produced in 1980 in the study area (ARC 1980).

7.11 Results Comparison Between Models.

The comparison between years and methods or data was done to identify the changes that have occurred during the period between 1980 and 2014, as well as to detect any change in the original Medalus Model and the developed Medalus model.

The results from the original MEDALUS map, the developed MEDALUS map and the soil erosion map for 1980 (ARC, 1980) were compared on a pixel by pixel basis. Each map was rasterised using ArcGIS software. To perform the comparisons, all the maps were reclassified into four classes corresponding to the four land degradation classes, where U stands for urban H stands for High, M stands for moderate and S is for slight. This procedure was performed to facilitate the comparison between the models by using

CROSSTAB model in the Idrisi software. Moreover, to conduct Kappa statistic and another operation that the CROSSTAB model offers is by cross-classification which results in a new map that shows the locations of all combinations of the categories in the original images. It also shows the correctly classified area between maps and represents the percentage agreement of one map in respect to the other.

7.11.1 Kappa statistic

The Kappa statistic was developed by Cohen (1960) to assess the level of agreement between two maps or models. As a measurement it was originally used to compare two different psychiatric diagnoses and shows how the degree of agreement between two observations is given by chance. Its calculation is based on the difference between observed agreement and expected agreement. The measure of agreement is between 0 and 1. A Kappa value of 0 indicates that there is a poor agreement between the maps and therefore demonstrates no relationship. Any negative value (such as -1) indicates complete disagreement. Meanwhile, a value of 1 indicates an almost perfect agreement (Rossiter, 2004).

7.11.2 Comparison between the original MEDALUS and the developed MEDALUS models 2014

The crosstab tabulation resulting from comparison between the original MEDALUS model and the developed MEDALUS model are shown in Table 7.20 and figure 7.17. The overall accuracy of 0.79 for the total study area was associated with the same classes in both model maps with high overall Kappa statistics value of about 0.68. The results demonstrate that the 60% of the high class in the original MEDALUS map corresponds to the same area in the developed MEDALUS map, while 40% were mapped as very high .In addition, 96% of the moderate class in the original MEDALUS map corresponds to the same area in the developed MEDALUS map, while 5% were mapped as high. Meanwhile, 98% of the slight class in the original MEDALUS map was converted to moderate and 2% was converted to high class in the developed MEDALUS map. The spatial distribution of the agreement and disagreement between the original MEDALUS and a developed MEDALUS class is illustrated by figure 7.17.

Table 7.20: Crosstab tabulation for the original MEDALUS model and the developed MEDALUS model.

MEDALUS (Developed)	MEDALUS (Original)					
		U	H	M	S	
	U	848	0	0	0	848
	H	0	31956	453	125	32534
	M	0	98	10839	5625	16562
	VH	0	21511	0	0	21511
	Column Total	848	53565	11292	5750	71455
	Overall accuracy = 0.79			Overall Kappa = 0.68		

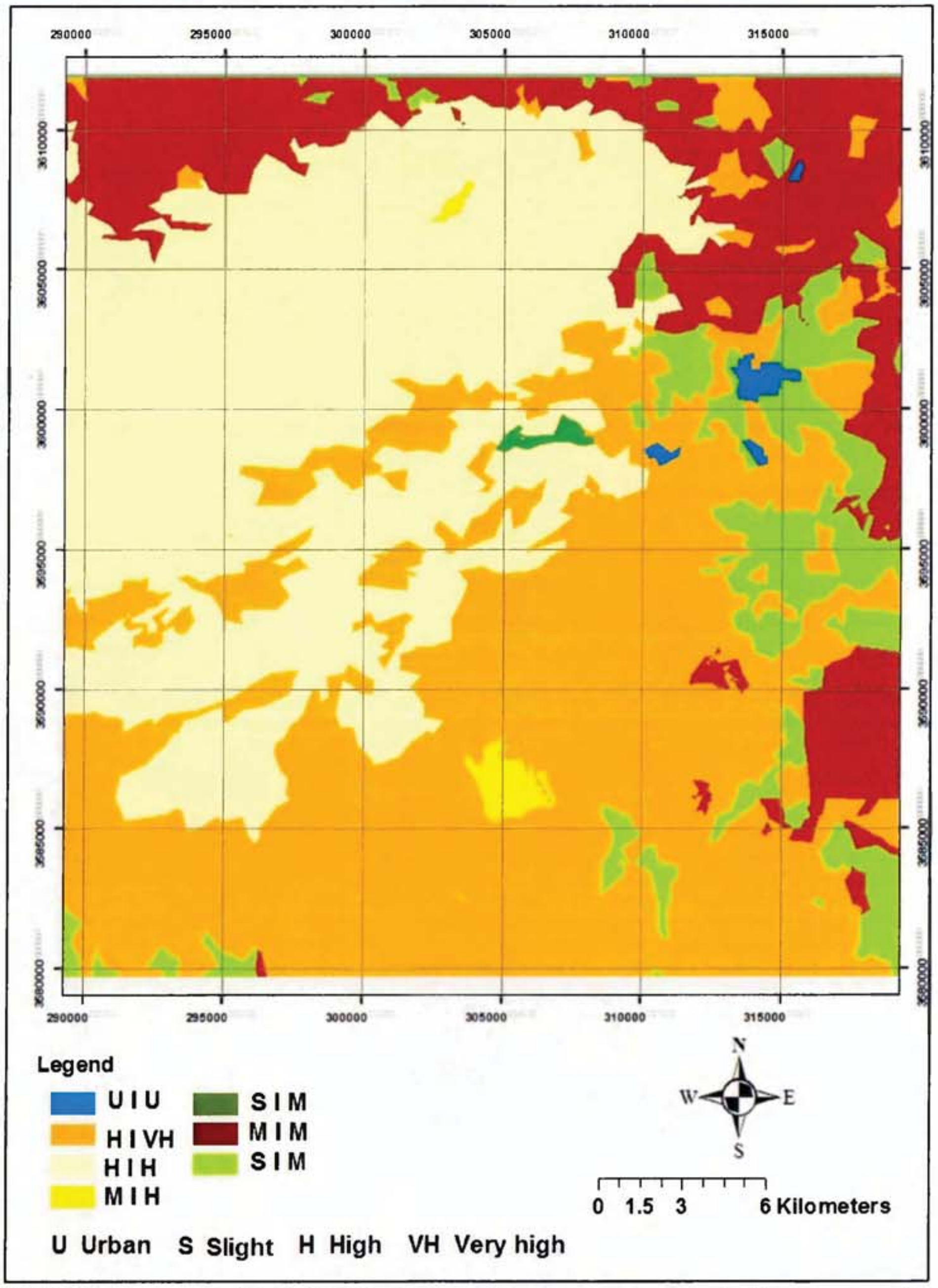


Figure 7.17: The geographical distribution of the agreement and disagreement between the original MEDALUS model and the developed MEDALUS model, (see Table 7.2 for explanation of the key)

To perform the comparisons, all the maps were reclassified into four classes corresponding to four land degradation classes: U stands for urban; H stands for High; M stands for Moderate and S is for Slight. This procedure was performed using CROSSTAB model in the Idrisi software by comparing the models. For example, U I U means the urban area in the map of original Medalus corresponds to urban area in the developed MEDALUS map. Also, M I H means the moderate class in the original MEDALUS map was assessed as high class in the developed MEDALUS map.

7.11.3 Comparison between land soil erosion for 1980 and soil erosion in 2014.

The outcome of the crosstab tabulation from the comparison between the soil erosion map for 1980 and the soil erosion map 2014 are shown in Table 7.21 and Figure 7.18. The overall accuracy of 0.45 in total of the study area was associated with the same classes in both model maps with overall Kappa statistics value of 0.41. The results demonstrate that the 39.6% of the moderate class in the soil erosion map 1980 corresponds to the same area in the soil erosion map 2014, while 22.5% were mapped as slight, 21% as very high and 16.5% as high class. In addition, 43% of the high class in soil erosion map 1980 corresponds to the same area in the soil erosion map 2014, while 54% were mapped as very high. Meanwhile, 51% of the slight class in the soil erosion map 1980 corresponds to the same area in the soil erosion map 2014, 21% was converted to high and 18% indicates very high class in the soil erosion map 2014. The spatial distribution of the agreement and disagreement between the soil erosion map 1980 and soil erosion 2014 classes is illustrated in figure 7.18.

Table 7.21: Crosstab tabulation for wind erosion in 1980 and 2014

Soil erosion by wind 2014	Soil erosion by wind 1980					
		U	**H**	**M**	**S**	
	U	700	0	0	148	848
	H	2	1177	7699	4435	13313
	M	2	100	18387	1674	20163
	S	0	463	10439	10887	21789
	VH		1476	9919	3943	15338
	Column Total	704	3216	46444	21087	71451
	Overall accuracy = 0.45			Overall Kappa = 0.41		

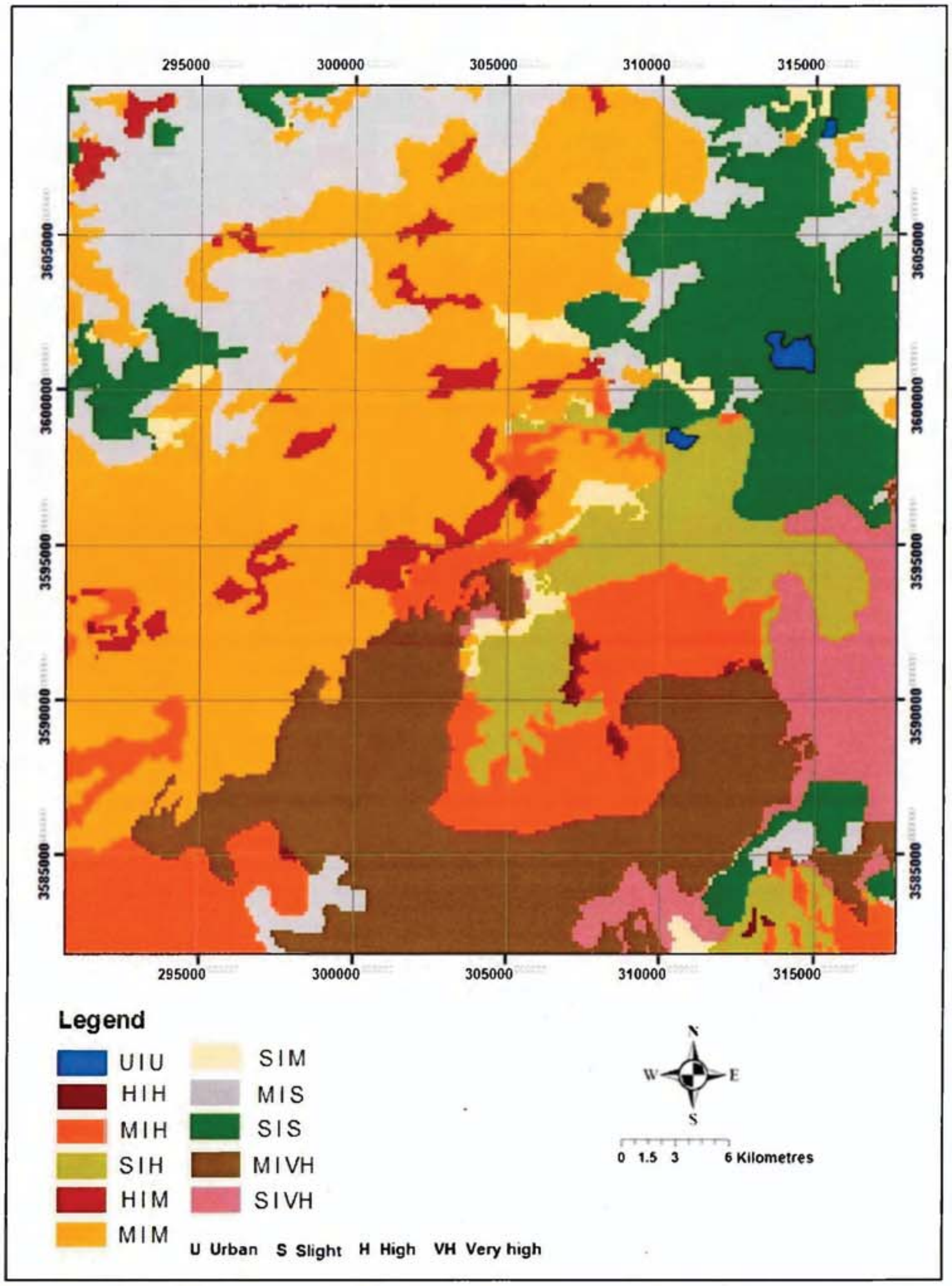


Figure 7.18: The geographical distribution of the agreement and disagreement between the wind erosion for 1980 and 2014 (see Table 7.22 for explanation of the legend)

7.12 Validation

In a similar manner to McCallum et al. (1991) and Scott's (2011) assessment methodology for environmental land use policy and landscape research, the model was validated. The validation was made by comparing ground truthing data to the final ESAI maps. Based on the grid of Selkhozpromexport (1980) soil profile, 125 points were selected and used for the validation. Ground truthing were identified using a Global Positioning System (GPS) and a focus group discussion to assess the degradation and desertification of 125 geographic points within the study area was conducted.

Expertise in soil, topography, climate, vegetation and agricultural policy are required to verify the outcome of the models. The discussion with this group of experts, who visited the field to assess the condition of specific fields/sites, enables gathering of large amount of information in understanding land degradation and irrigation. Each of the experts that form the focus group has approximately 10-20 years of demonstrated experience conducting research and providing field expertise and recommending policies in agricultural related fields. As Collins and Evans (2002) noted, a blend of expertise with relevant skills helps with decision making in policy and research. Further, McCallum et al. (1991) and Scott (2011) opined that environmental land use policy and landscape research use of expert focus group becomes rigorous when expertise is derived from diverse discipline. As stated earlier, the use of local expertise is mainly to gain from their local knowledge and experience in the areas of investigation. They are Libyans, they understand local situations, have wide knowledge and academic background in farming, irrigation and land degradation.

On the conduct of the focus group, the researcher introduced the research by explaining the aim, objectives and usefulness of the research, methodologies employed, expected result and outcome of the discussion. There was also discussion about land degradation and desertification. Substantial part of the presentation dwelled on how discussants will achieve accurate result on the maps presented. The main characteristics for each class in the maps, including keys for each map, were handed out to them to assign weight for each class type in the field (see Tables 7.25; 7.26 A, B).

Table 7.22. Classification of the study area by level of land sensitivity according to the ESA index.

ESAI score		Vulnerability class: Land description (examples)
C1	1. 27 - 1.37	**Low critical sensitivity C1:** moderately fine-textured, stony, moderately deep, well drained, predominantly on limestone, with a high density of evergreen vegetation under high land use intensity and moderate land protection, dwarf shrubs with moderate climate quality, or irrigated and cereals with high land protection and moderate land use intensity. Most areas that have vegetation cover from more than 40%, particularly shrub-land, under moderate climate quality (Basso et al. 2010; Kosmas et al. 1999; Silleos et al. 2008).
C2	1.38 - 1.47	**Moderate critical sensitivity C2:** moderately fine-textured or coarse-textured, stony; the dominant vegetation is mainly shrubs and grasses; the area is under high land use intensity and incomplete enforcement of the existing environmental protection policies. Most areas have less than 40% of vegetation cover, particularly shrub-land, resulting from human activity or seasonal land crops (wheat and barley) under moderate land use intensity and land protection (Gad and Lotfy 2008; Kosmas et al. 1999).
C3	1.47 - 1.53	**High critical sensitivity C3:** shallow, mainly coarse-textured, stony, well-drained, with low vegetation cover (15 -35%) ; highly degraded areas, with incomplete enforcement of the existing environmental protection policy (Ali and El Baroudy 2008; Kosmas et al. 1999).
C3a	>1.53	**Very high critical sensitivity C3a:** shallow, mainly coarse-textured, stony, well-drained, with bare soil, very low vegetation cover (>15%); highly degraded areas, without any environmental protection policy (Ali and El Baroudy 2008; Kosmas et al. 1999). Expansion and spread of desertification, obvious through very low vegetation cover, resulting from over-grazing (Hirche et al. 2011).

The following tables illustrate the classification of the study area by level of land sensitivity according to the ESA index for the vegetated land. For example, in Table 7.23 B the subclass C1 is classified as 1 in vegetation cover, 2 in texture and 2 in Land use intensity which means that this area has a vegetation cover of more than 40% , a soil that is moderately fine-textured and high use intensity, as quantified in Table 7.23 A.

Table 7.23 A. Synthesis of the studies with some environmental problems leading to desertification in natural vegetation land.

	Vegetation cover %	Texture	Depth (cm)	Drained	Rock fragments	Aspect	Wind erosion	Land use intensity
1	>40	fine-textured	>75	well drained	Eolian deposit	N, NW, NE, E, Wand flat	Slight	low
2	30-40	moderately fine-textured	30-75	Well drained	Eolian deposit	S, SW and SE	moderate	moderate
3	15- 30	coarse texture	15-30	Well drained	Jeffara formation		high	high
4	<15		>15	Well drained	Jeffara formation		Very high	

Table 7.23 B. Classification of the study area by level of land sensitivity according to the ESA index for natural vegetation land.

Classes	Vegetation Cover (%)	Texture	Depth(cm)	Drainage	Rock fragments	Aspect	Wind erosion	Land use intensity
C1	1	1	1,2	1	1,2	2	1	2
C1	1	1	1,2	1	1,2	1	2	2
C1	2	1	1,2	1	1,2	1	1	2
C2	1	1	1,2	1	1,2,3	2	2	3
C2	2	1	1,2	1	1,2	2	1,2	2
C2	3	2	2,3	1	2,3	1	2,3	3
C3	3	2	2,3	1	2,3	2	3	3
C3	3	2	3,4	1	2,3	2	3	3
C3	3	2	4	1	2,3	1,2	3	3
C3a	3,4	2,3	2,3	1	2,3	2	3	3
C3a	4	2,3	3,4	1	2,3	2	4	3
C3a	4	2,3	3,4	1	2,3	2	4	3

Table 7.24, comparison of Original MEDALUS land desertification with ground-truth data by local experts 2014.

	Classes	Reference data from focus group C1	C2	C3	C3a	Row Total
Original MEDALUS	C1	0	0	0	0	0
	C2	9	35	12	0	47
	C3	0	4	65	0	78
	C3a	0	0	0	0	0
	Column Total	9	39	77	0	125
	Overall Kappa = 0.69			**Overall accuracy = 0.80**		

The verification process identified some mis-assessment in comparison to FG classification of desertification.

Table 7.25, comparison of developed MEDALUS land desertification with ground-truth data by local experts 2014

	Classes	Reference data from focus group C1	C2	C3	C3a	Row Total
developed MEDALUS	C1	0	0	0	0	0
	C2	0	35	3	0	38
	C3	0	4	38	5	47
	C3a	0	0	0	40	40
	Column Total	0	39	41	45	125
	Overall Kappa = 0.83			**Overall accuracy = 0.90**		

Table 7.25 above shows almost perfect agreement between the developed MEDALUS model and reference data from the focus group experts (Table 7.25). This independent verification of the MEDALUS map confirms its validity. In addition, 86% of the high class agreements correspond to the same point from FG experts, and 10% where FG experts classified them as having medium. 86% of the moderate class (C2) agreements correspond to the same points from FG experts, and 14% is mapped as high class (C3) by FG experts. In addition, these points were located in the overlap area between the moderate class and high class.

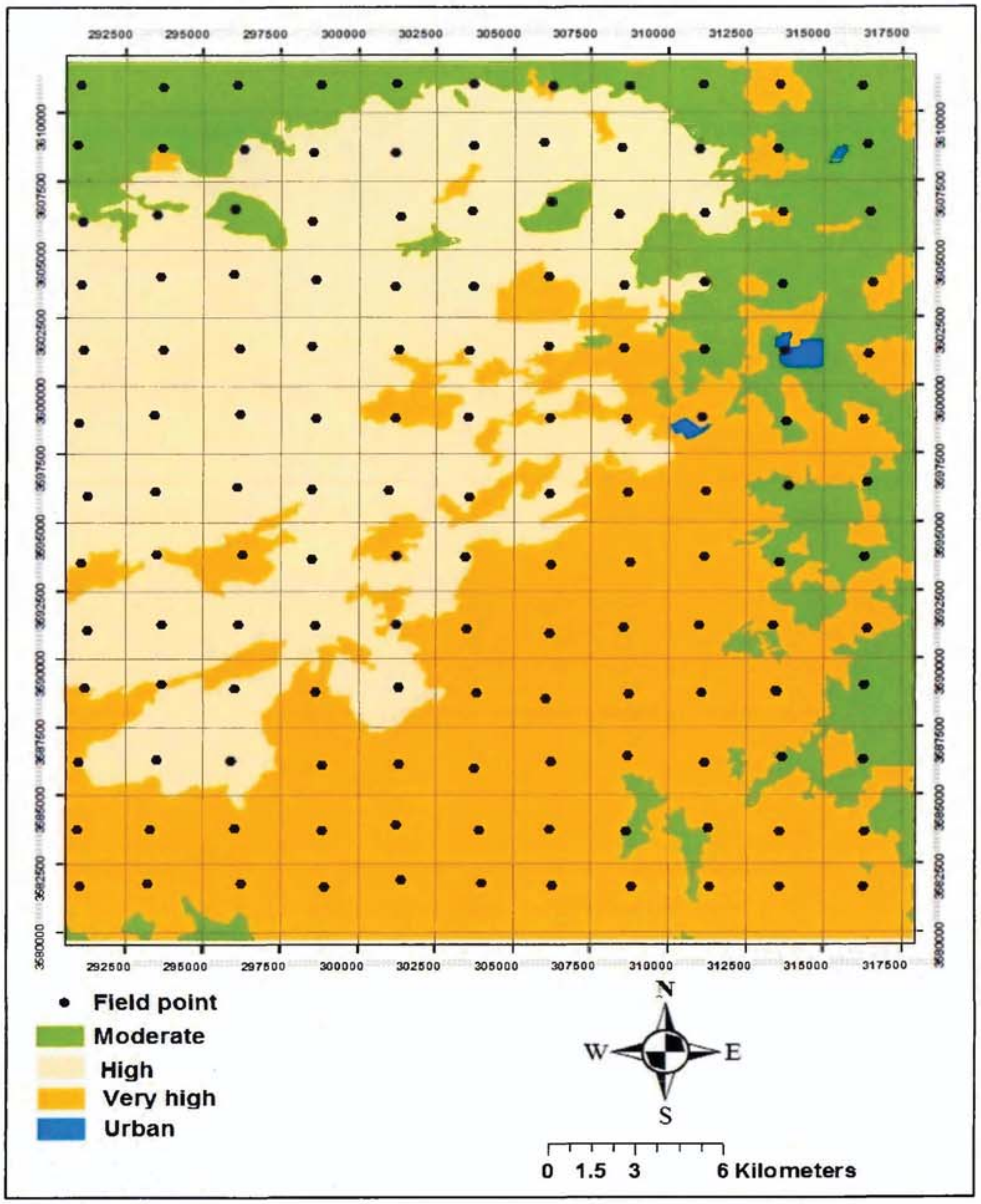


Figure 7.19: survey reference points from field overlaid with the final ESAI map for the validated model.

7.13 Universal Soil Loss Equation (USLE) Model

The Universal Soil Loss Equation (USLE) was developed by Wischmeier and Smith (1978). It is a model that has the ability to predict the long-term average annual soil loss in the field. The model requires data on slope length, slope steepness, precipitation, soil structure, and soil texture, and on erosion control practices and crop management (Adinarayana et al., 1999). Integration between USLE and GIS allows for analysis of soil erosion in more detail by providing the spatial data (Fistikoglu and Harmancioglu, 2002). It has been widely used to provide spatial input data to the model. In the present study the USLE was used with GIS data to determine the average annual soil loss in the study area using five main factors from Equation 12. The data used were obtained from weather stations, topographic maps, soil data and vegetation cover data. A GIS file was created for each factor of the USLE precipitation, soil type, land cover and slope to predict soil erosion risk (Figure 7.21).

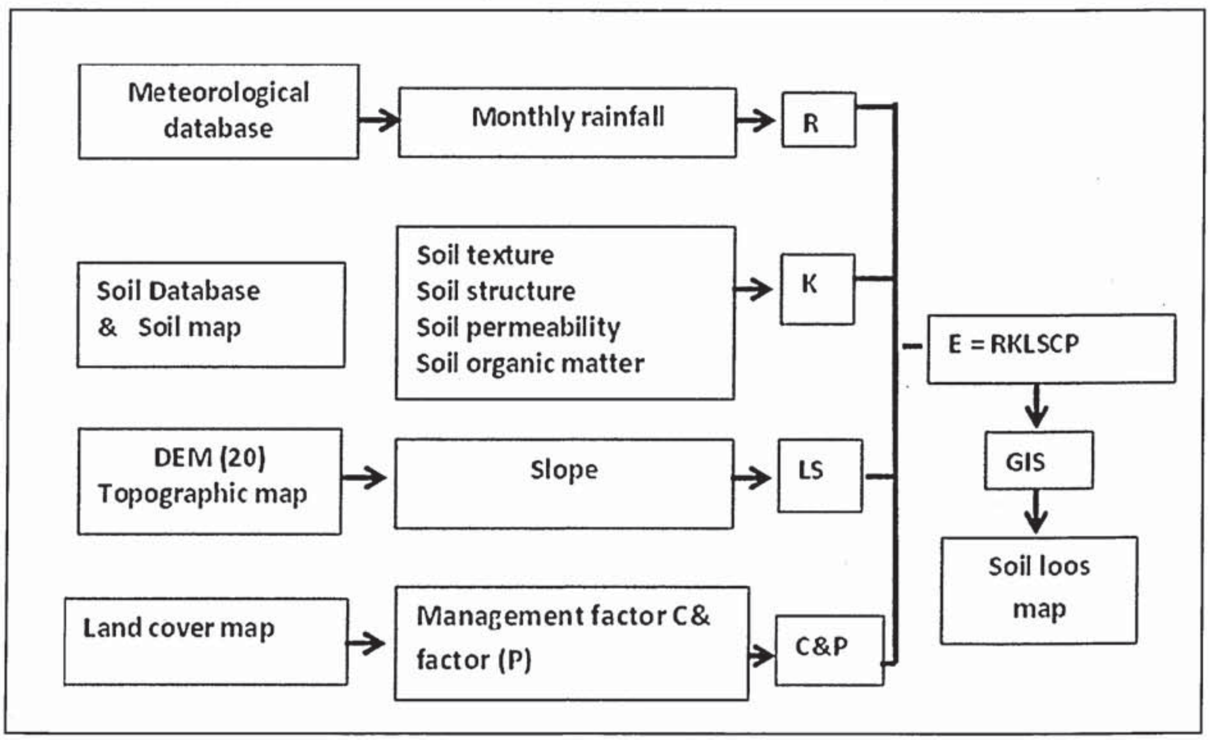


Figure 7.20 : Application of the USLE to determine erosion hazard.

$A = R \times K \times L \times S \times C \times P$ Equation 10

where:

A = Annual soil loss in ($t\ ha^{-1}\ y^{-1}$)

R = Rainfall erosivity factor ($mm.h^{-1}$)

K = Soil erodibility factor ($t\ mm^{-1}$)

L = Slope length factor

S = Slope steepness factor

C = Crop and management factor

P = Conservation-supporting practices factor

7.13.1 Rainfall erosivity factor (R)

The precipitation erosivity factor (R) is considered one of the most important parameters for understanding the geomorphologic processes where the soil loss is directly proportional to this factor (Wischmeier and Smith, 1958). R, the rainfall factor, is calculated from expressions that describe the energy of a rainstorm and observed maximum rainfall intensities. When no record of rainfall intensity exists, alternative equations such as the Fournier index can be used to calculate the R-factor, using monthly and/or annual values of rainfall (Nwer, 2005). In addition to this, the R-value was interpolated using the average annual rainfall data from 1975 to 2009.

The rainfall factor R is calculated from (Equation 11) based on rainfall data.
The Fournier index presented by Ferro et al. (1999) and Renard and Freimund (1994) appears in Equation 11:

$Cc = M^2 x / P$ Equation 11

where: Cc = Fournier index ; M = Monthly value of precipitation (mm) for month x

P = the annual values of precipitation (mm).
In this study, R-value calculated by the Fournier index is based on precipitation data for about thirty four years (1975-2009) the result of rainfall erosivity R = 50.5mm.

7.13.2 Determining soil erodibility (K)

The goal of the soil erodibility evaluation is to determine a factor K for the study area. Soil properties (physical and chemical properties) for each soil unit in the maps (Clay%, Sand%, Silt%, EC, pH, CaCo3%, organic matter, bulk density and permeability) have been used to determine the soil erodibility factor (K) using Equation 12 (Lal and Elliot, 1994). El-Asswad and Abufaied (1994) studied the relation between erodibility and the physical and chemical properties of some Libyan soils which have been used for the calculation of soil loss within the USLE (Figure 7.22). Figure 7.23 shows a map of the K-factor values current in the study area.

$$K = 2.8 \times 10^{-7} \times M^{1.14} \times (12 - \alpha) + 4.3 \times 10^{-3} \times (b - 2) + 3.3 \times (c - 3) \quad \text{Equation 12}$$

where : α is OM = Organic matter content; M is particle size parameter = (%Silt + % Fine sand content) / (100 - % clay); b = Soil structure code (very fine granular = 1, Fine granular = 2, coarse granular = 3, blocky, platy or massive = 4); c = Permeability class (rapid = 1, moderate to rapid = 2, moderate = 3, slow to moderate = 4, slow = 5, very slow = 6).

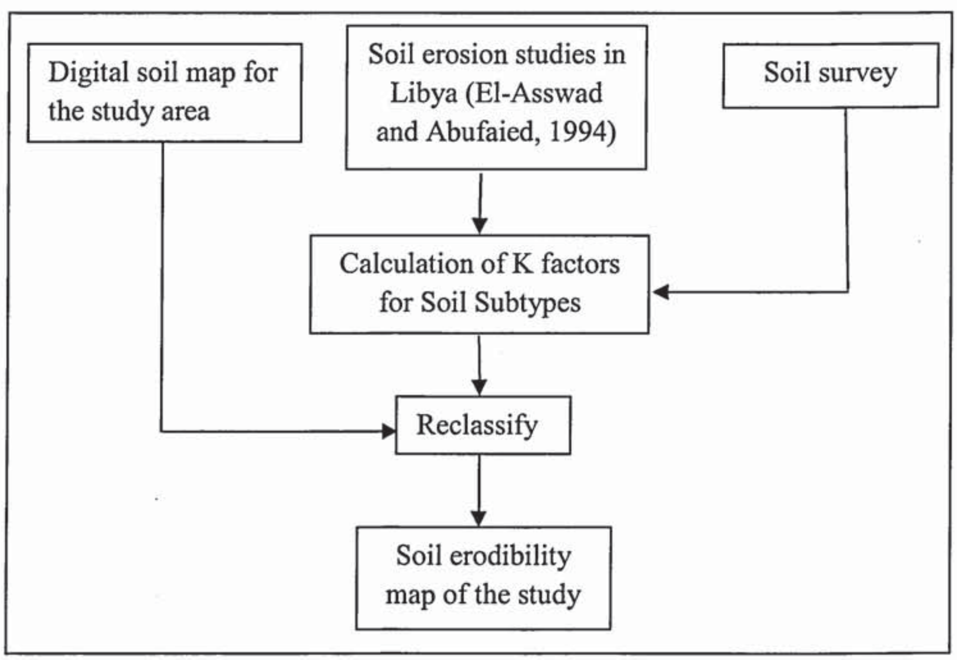


Figure 7.21: Determination of the Erodibility K-factor of the soil in the study.

The flowchart above shows a flow diagram of the steps taken in determining the K-factor of the soil in the study area. It has depended on soil properties (physical and chemical properties) for each soil unit in the maps (Clay%, Sand%, Silt%, EC, pH, CaCo3%, organic matter, bulk density and permeability).

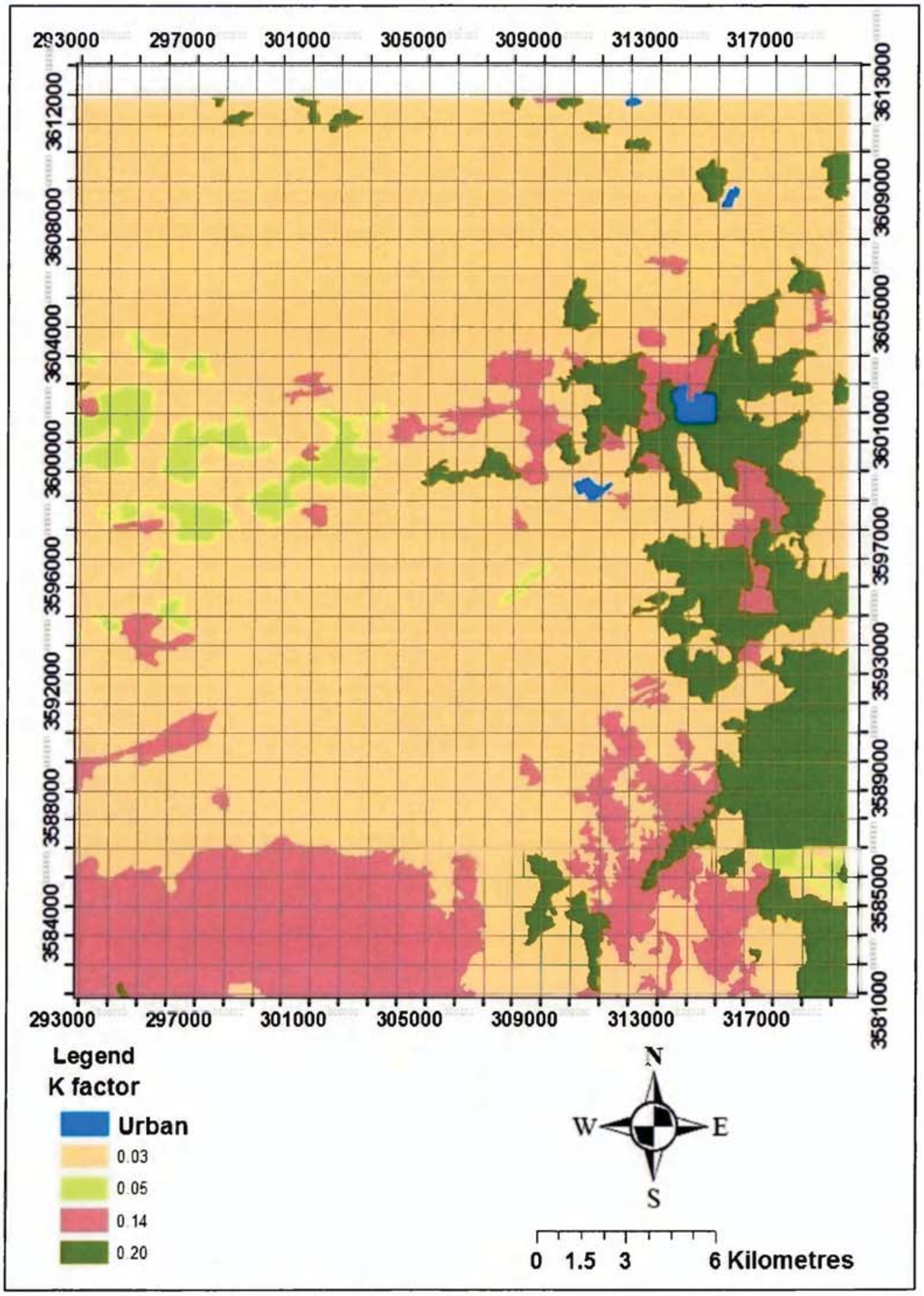


Figure 7.22: Soil erodibility in the study area.

The soil erodibility map above shows a classification for k- factor to give an indication about the k- factor distribution in study area.

7.13.3 Creation of the Digital Elevation Model (DEM)

The Digital Elevation Model (DEM) is spatial fields of terrain elevation values that are usually arranged in a regular square grid or in other arrangements such as a Triangulated Irregular Network (TIN). It should be noted that DEM's are raster files composed of pixels where each pixel has a latitude, longitude and elevation or X, Y and Z reference to location. A TIN is a vector file where points are connected by lines that make up a network of triangles that take on different sizes, slopes, aspects to represent the shape of an object or a surface (Zhang and Montgomery, 1994). There are a number of ways in which DEM can be derived, including digitising contour lines from topographic maps, ground surveys using theodolites of levels, and stereo interpolation of pairs of aerial photographs, all of which contain measurement errors in position and elevation (Blöschl and Grayson, 2001). These various source of data can be stored in one or more of the following formats: as point elevation data on either a regular grid or triangular integrated network or as vectorized contours stored in a digital line graph (Zhang and Montgomery, 1994). In the study area, TIN was created from digital contour lines at a 20-m interval using Arc GIS (ESRI, 2010) (Figure 7.23). It has also been used with a grid element of 250×250 m to derive a slope map of the study area (Figure 7.24).

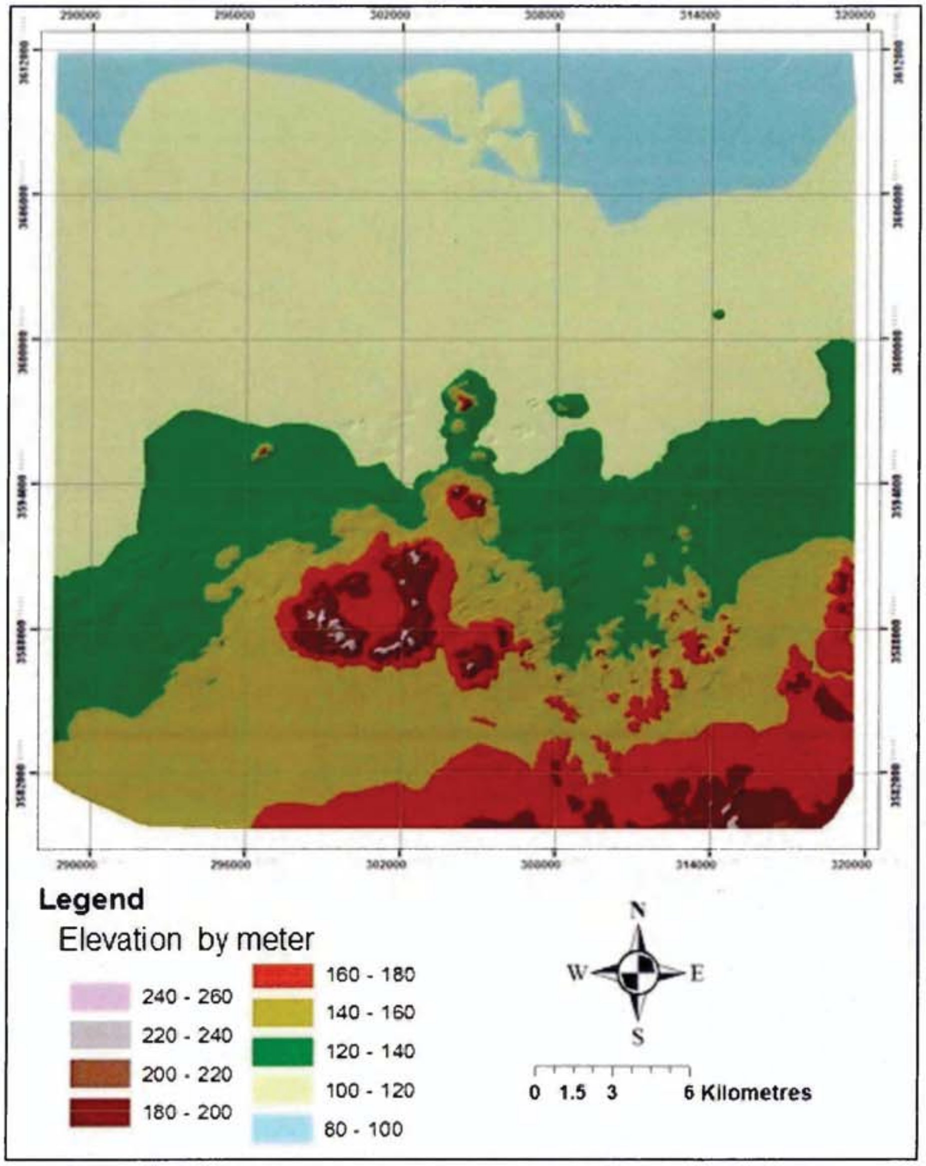


Figure 7.23 : The Digital Elevation Model (DEM) for the study area.

7.13.4 Topographic Factor (LS)

The topographic factor consists of two indices of slope: length (L) and steepness (S). These two indices can be measured separately or combined in a single topographic index termed 'LS factor'. The factor of slope length (L) was calculated based on the relationship developed by McCool et al. (1987):

$$L = (\lambda/22.1)^{m} \qquad \text{Equation 13}$$

Where:

L = slope length factor;

λ = field slope length (m);

m = dimensionless exponent that depends on slope steepness: 0.5 for slopes exceeding 5 per cent, 0.4 for 4 per cent slopes and 0.3 for slopes less than 3 per cent.

The percentage slope was determined from the Digital Elevation Model (DEM) by ArcGIS (ESRI, 2010) (Figure 7.24), while a grid size of 250 m was used as field slope length (λ). A similar supposition of field slope length has been made by several researchers (such as Onyando et al., 2005; Fistikoglu and Harmancioglu, 2002). The slope map (Figure 7.24) was derived from the Digital Elevation using contour maps and shows the classification of slope factor and its distribution in study area.

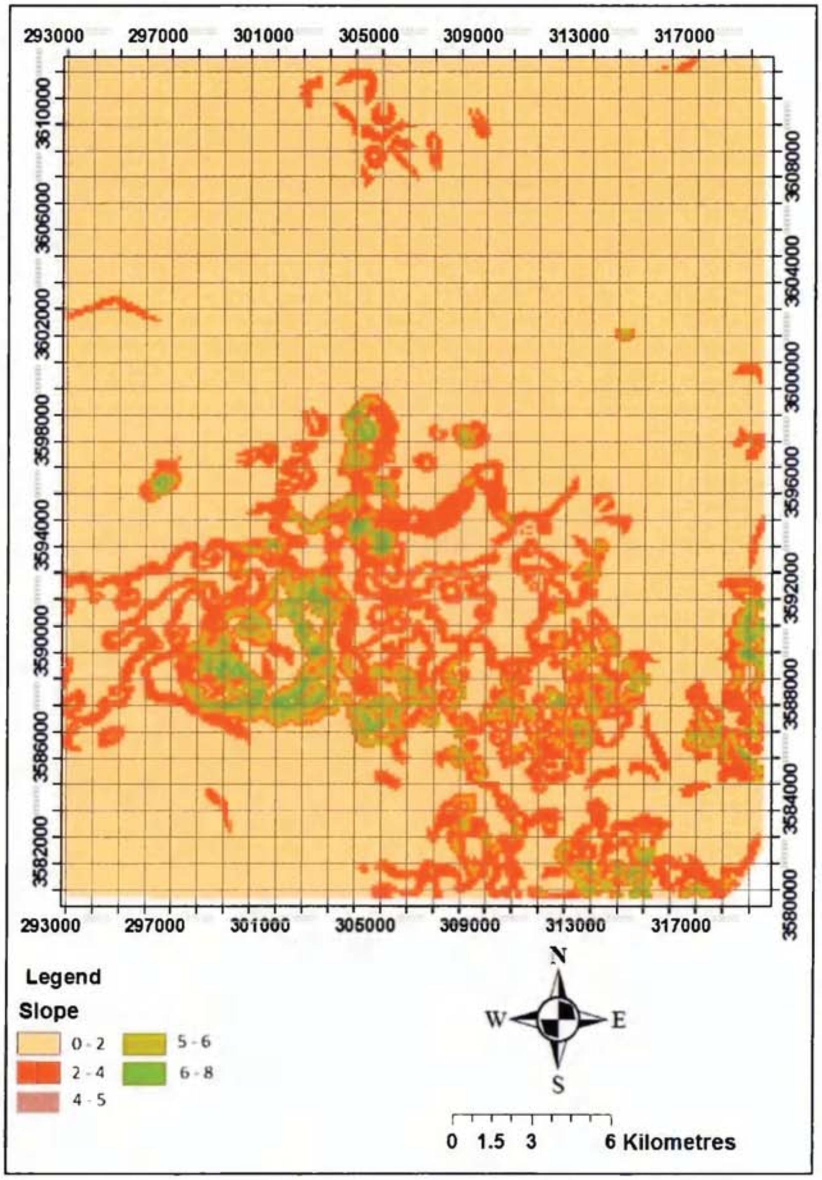


Figure 7.24: Slope map of the study area.

7.13.5 Cover management factor (C)

The cover management factor C expresses the influence of land cover on soil erosion. In addition, the C factor is based on land cover information In the study area. The land cover map derived from the satellite images shown in Chapter 6 was used to allocate C factor to different land cover classes. C-values were assigned as 0.06 for woodland (high vegetative cover), 0.014 for scrub and grass lands, 0.01 for built-up areas, 1 for bare land (low vegetative cover) and 0.377 for agricultural land, as recommended by Morgan (1995) and Htun et al. (2008).

7.13.6 Erosion control practice factor (P)

The P-index is related to control practices which decrease the erosion potential from runoff. "P value was defined according to tillage system, by Htun et al. (2008) for different land use and cultivation practices; i.e. autumn ploughing = 1, spring ploughing = 0.9, mulch tillage = 0.60, zone tillage (no ploughing for three or more years) = 0.25, and no tillage (e.g. natural vegetation or bare soil) 0.25.

7.14 Results

The USLE model was used according to Equation 10 and all factors have been defined. Individual GIS files were built for each factor of the USLE and combined by utilizing the grid cell modelling function in Arc GIS (ESRI, 2010) to predict soil loss in the spatial domain to produce a soil erosion map (Figure 7.25). The average annual soil loss was estimated on the basis of classes according to the guidelines recommended by Pandey et al. (2007): Slight (0–5 t ha^{-1} yr^{-1}), Moderate (5–10 ha^{-1} yr^{-1}), High (10–20 t ha^{-1} yr^{-1}).

Table 7.26: The classified categories and the percentage areas using the Universal Soil Loss Equation (USLE) method.

Class	Area (ha)	%
Slight	75.977	75.9
Moderate	15.890	15.9
High	6.984	6.9
Urban	1.187	1.2
Total	100038	100%

The results shown in Table 7.26 reveal that 76% of the study area was classified as showing 'slight' erosion, while 16% of the study area has been mapped as areas prone to 'moderate' erosion and 7% susceptible to 'high' erosion. In relation to this result, the slope map has shown that there are five classes of slope in the study area as 2.5%, 4%, 5%, 6% and 8%. The result has shown that the most pronounced factors that enhance soil erosion and cause high soil loss potential are the slope length (L) and steepness (S) factors. This is because the ranges of slope from 2.5% to 5% represent about 76% in the study area. These are accompanied with relatively higher soil erodibilty factor (K = 0.2 and 0.14), which resulted in higher soil loss as compared to the surrounding areas.

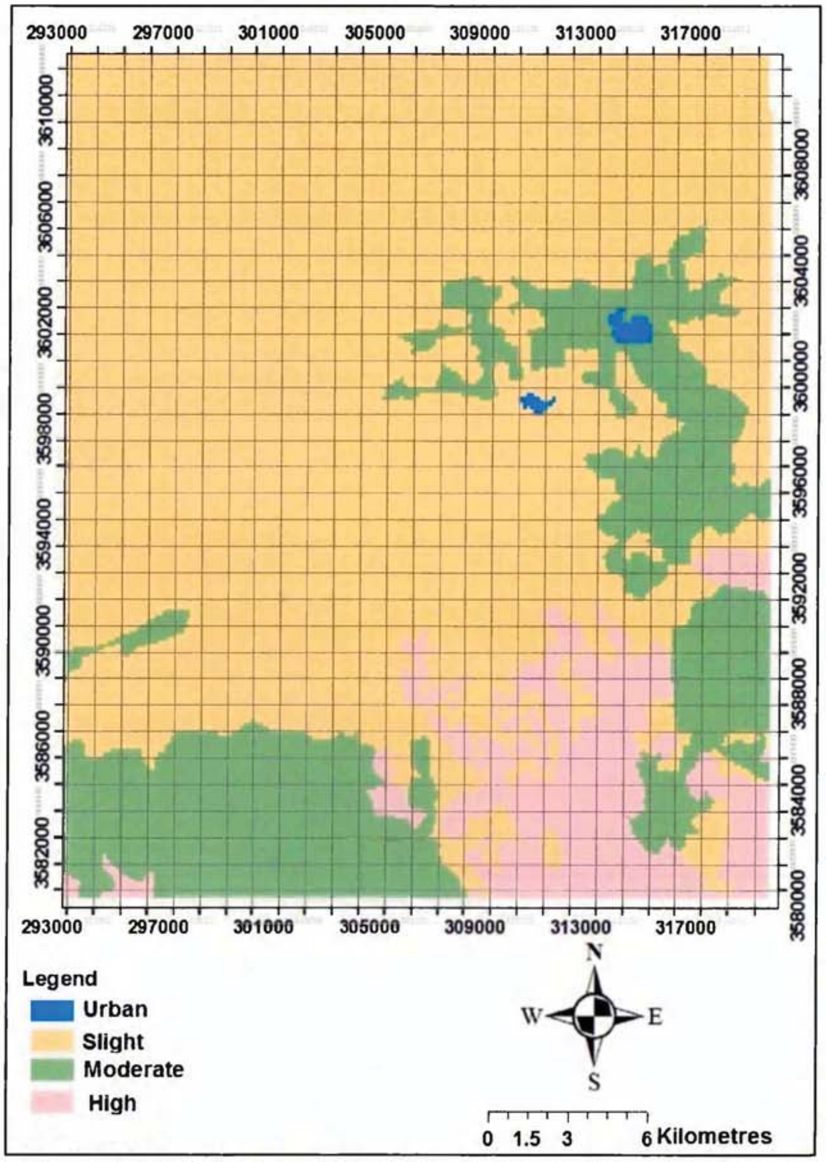


Figure: 7.25: Soil erosion map, using USLE method of the study area.

7.15 Summary

In this chapter, two methods for assessing land degradation were applied. .The first section applied and developed the Mediterranean Desertification and Land Use (MEDALUS) Method to produce mapping of environmentally sensitive areas vulnerable to desertification. The second used the Universal Soil Loss Equation (USLE) with Geographic Information System (GIS) data for the soil erosion risk.

The first method Mediterranean Desertification and Land Use (MEDALUS) assessed four qualities: (a) soil quality, (b) climate quality, (c) vegetation quality, and (d) management quality. The method was developed by adding two parameters, soil salinity indectror and wind erosion quality. The modification of MEDALUS has proven the most significant contributions of this research to knowledge and practice. The second method applied the Universal Soil Loss Equation (USLE) with Geographic Information System (GIS) data. In addition, the maps of land deterioration were produced by using remote sensing and GIS.

The results from the MEDALUS method show that about 33% of the study area was assigned to the 'highly sensitive' class, 43% of the study area was mapped as belonging to the very high sensitivity class, while 22% of the study area was mapped as belonging to the moderate sensitivity class. However, the result from the USLE method shows that 76% of the study area was classified as showing slight erosion, 15% as moderate, and 6.7% as high erosion. For example, the results obtained from the USLE method (Figure 7. 26) shows 'slight risk' of water erosion, while the result from the MEDALUS method shows that the study area is 'highly sensitive' to the risk of desertification caused by wind (Figure 7.15) .

Furthermore, the results obtained from the following methods were compared: the original MEDALUS, the developed MEDALUS, the land degradation map derived from remote sensing, the soil erosion map for 1980, and USLE. The model has been validated by comparing ground truthing data where 125 geographic points were selected from grid distributed all over the study area onto the final ESAI maps. Table 7.28 shows that the overall accuracies of 90% between the points from the focus group and the points from the developed MEDALUS map and the overall Kappa is 83%.

Finally, in this chapter this research has shown that almost 85% of the total study area was sensitive to desertification 'high' (critical), whilst 76% of the total land area was assigned as 'slight' erosion by water. In addition, the MEDALUS method was developed by adding two parameters; soil salinity management and wind erosion quality, and also is becoming more appropriate for studying land degradation in the study area.

CHAPTER 8

DISCUSSION

The results are derived from three land degradation models: remote sensing, Mediterranean Desertification and Land Use (MEDALUS) and the Universal Soil Loss Equation (USLE).

8.1 Discussion of Remote Sensing Results

The results obtained by this method provide good information that helps us understand the dynamics of land degradation over a period of time. Moreover, it helps to provide data needed for use in other methods such as the plant cover, land use intensity; land use type and vegetation cover maps.

As indicated in Chapter 6 (see Table 6.4), the results demonstrate that there was a significant decrease in the natural vegetation and degradation in most of the land in the study area. About 85% of the study area was classified as 'moderately' or 'severely' degraded. This is due to unmanaged agricultural practices such as converting pastoral land to irrigated land. As a consequence, irrigated area has almost doubled from 9.8% of the the study area in 1988 to 18.5% in 1996. The soil properties are also unsuitable for irrigation according to the report of a study of soil by Selkhozpromexport (1980).

Furthermore, the excessive use of the underground water is responsible for causing serious problems. In the last few years, the amount of water has decreased and salinity has increased, especially in the coastal area where there is no legal restriction on digging wells on private farms (Alghraiani, 2003). In addition, the results obtained from the soil salinity map (Figure 7.11) show that there are High (4-8 dS/m) and very high (8-15 dS/m) soil salinity were found in irrigated areas in the north east part of the study area and citrus tree damage from high salinity was observed in this area, as shown in Photograph 8.1. This result corresponds with the findings of Ping et al. (2011), who studied vegetation dynamics induced by groundwater in north-western China. They suggest that the declination in water table, and increase in salinity in the groundwater are the most important factors affecting the vegetation degradation in arid regions (Ping et al., 2011).

Photograph 8.1: Damage to citrus trees by high soil salinity in the irrigated areas in northern parts of study, where the value of the soil salinity (EC) is 8.25 in this point (X: 308996 and Y: 3603776), which led to death of the trees.

At the same time there was a decrease in the natural vegetation from 39% to 27% due to encroachment on rangelands for the large-scale cultivation of barley under rain-fed conditions. The areas that still bear much vegetation are constantly perturbed and removed by expanding farmlands as shown in Photographs 8.2 and 8.3. The real long-term effects of this practice are the eventual removal of the vegetation cover from the land, which leads to land degradation and increased desertification (Ben Mahmoud et al., 2000). This result is in accordance with similar studies by Brogaard et al., (1998) who have used two Landsat MSS scenes from 1975 and 1989 for the land cover change detection in North China and reported that the major changes in land cover in Northern China is due to converting the grassland to cropland, decrease in grassland and increased in bare land.

Photograph 8.2: Encroachment on rangelands through the cultivation of barley in 2014. The area before cultivation of barley showing shrubs and sparse vegetation. In this point (X: 295673 and Y: 3598700).

Photograph 8.3: Encroachment on rangelands through the cultivation of barley in 2014.. In this point (X: 295673 and Y: 3598700) shows the area after harvesting of barley.

With regard to the impacts of heavy grazing pressure, there was an increase in the number of smaller ruminants (sheep and goats) which is more than one and half times of the grazing capacity of rangeland in the study area (described previously in Chapter 7). This led to the destruction of the natural vegetation cover and to the deterioration of the rangelands, which in turn led to an increase in land degradation (see Chapter 6). As a result, the natural vegetation was decreased from 39% in 1988 to 27% in 2009. Bare land has increased simultaneously with land degradation. This result concurs with Dregne (1986), Krümmelbein et al. (2006), Li et al. (2007) and Meyer (2006) who have reported that intensive overgrazing of rangelands are responsible for severe degradation. WRI (1994) states that soil erosion is occurring on more than half of the world's pasture land, and heavy grazing by sheep and goats have led to removing most of the vegetative cover and exposing the soil to erosion in many developing countries.

Additionally, climate has affected the vegetation cover, through reduced rainfall. Data in the study area revealed that about 95% of the annual rainfall occurs from October to March, and also, rainfall is very erratic and limited. Rainfall is an important factor in the determination of the vegetative life cycle and annual vegetative cover, land use and vegetative production in arid and semi-arid regions (Rosenzweig, 1968; Rutherford, 1980) as well as the higher temperatures, lower relative humidity and stronger winds. As a result, the amount of evaporation (ETP) in the study area has increased, reaching 1,200 mm per year, as shown in Table 3.2. This in turn has affected the vegetation, especially in the areas of rain-fed agriculture.

The results discussed above are in agreement with those obtained in Libya by Ben Mahmoud et al. (2000) and Alghraiani (2003), they reported that overgrazing and the change of the rangelands to rain-fed agriculture are the main factors that lead to the destruction of the natural vegetation cover. Moreover, the scarcity of water is responsible for causing a serious problem represented by decreasing amounts of water and increasing soil salinity.

The methods used in the current study are similar to those from many previous studies such as those of Shalaby et al. (2007), Hanafi et al. (2008), Fan et al. (2007), Wang et al. (2008) and Gao et al. (2008), in that they use Landsat images to monitor and assess the desertification processes in different years. In terms of the results obtained these different studies are also similar. All of these authors agreed that land degradation was due to the removal of the vegetation cover, the extraction of water, urban expansion, conversion of grassland for farming, over-cultivation, over-grazing, and deforestation.

8.2 Discussion of the Results from the Mediterranean Desertification and Land Use (MEDALUS) Model

One of the main research aims was to develop the methods of Mediterranean Desertification and Land Use to make them more suitable for studying land degradation in the arid and semi-arid zones where this study area is located.

The soil quality has shown two soil qualities in the study area that are based on Table 7.4. This is because the soil in the study area was divided into two classes based on the soil texture, soil depth, parent material and rock fragment.

The first level of soil quality was classified as 'moderate soil quality'. This is due to the soil depth, which is characterized as 'deep' and less sensitive to desertification. Moreover, the soil texture is characterized as 'sandy silt', which is moderately sensitive to desertification. In addition, the parent material was classified as moderately sensitive to desertification and the areal coverage by rock fragments is less than 20%. The second quality level was classified as 'low soil quality'. It was found that these areas were characterized by soil with a sandy texture, a shallow depth and the areal coverage by rock fragments is more than 20%. These characteristics suggested that the soil was most sensitive to desertification. This result is in agreement with the outcome of Gada et al. (2010). The climate quality in the study area is classified as 'moderate' in all the study area. This is because the amounts of rainfall, aridity and wind erosivity are the same throughout the study area.

The vegetation quality showed that there are two vegetation qualities in the study area according to Table 7.7. The first vegetation quality was classified as 'moderate' for 18% of the study area. This is due to the fact that the majority of the study area was agricultural land characterized by evergreen perennial agricultural trees. Consequently, it was classified as 'moderate' in terms of sensitivity to desertification. In addition, both indicators of drought resistance and fire risk have been classified as 'moderate'. Furthermore, according to Table 6.1, the percentage plant cover was measured as 70%; it was less sensitive to desertification. Moreover, the erosion protection of the soils which depends on the percentage of plant cover and the type of vegetation, such as evergreen perennial trees and deciduous forests, was assessed as moderate. All these indicators contributed to the classification of the vegetation as 'moderate' quality.

The second vegetation quality was classified as 'low' for 80% of the study area. This is because the majority of the study area is rangeland, where the natural vegetation cover is very poor due to overgrazing, rain-fed cultivation and low annual precipitation. This has led to the low vegetation cover with vegetation drought resistance. As indicated in Table 6.1, the percentage plant cover was measured as 38% with a high sensitivity to desertification. Because of the low vegetation cover, the erosion protection to the soil was classified as 'low'. All the indicators stated above were assessed as 'low' and as a consequence the vegetation quality in this area was classified as 'low' quality.

Based on Table 7.8, there are two management qualities in the study area. The first quality is classified as 'moderate' management quality for 15%. It was found in the agricultural land area that was affected by high land use intensity (HLUI) (intensive agriculture).This has led to an increase in the widespread use of chemicals as fertilizers and pesticides. Furthermore, this area was affected by high soil salinity was found in irrigated area in the north and east part in study area, based in Lab analysis of soil salinity by Electrical Conductivity EC value (4-8 dS/m) and (8-15 dS/m). In addition, according to information from informal interviews with the farmers the secondary salinity in some of the soil is due to the use low water qualities for irrigation, intensive agriculture and several successive years without the application of technical and management programs intact. Furthermore, after soil salinity management have been added to the management of quality shows different results, where 6,750 ha from moderate class changed to low quality in the irrigated area in the north study area. This change was evident when the indicator of soil salinity management to the management of quality equation was added. This area was affected by the annual drop in the water level which varies from a few centimetres to more than three metres. At the same time, the water quality in these areas is changing with an increase in salinity due to the dramatic lowering of the water level resulting from pumping deep for the brackish water. Meanwhile, the policies related to land protection covered about 25-40% of the agricultural area, which led to the management quality in the agricultural land being classified as 'moderate' (Table 7.8). The second management quality was found in the rangeland areas, where 80% was classified as 'low'. The quality of management of the rangelands was assessed by comparing the carrying capacity of the area with the actual number of animals grazing the area, where the number of animals is more than one and half times the grazing capacity of rangeland as shown in Chapter 7. Furthermore, the area under protection in the rangeland area is less than 15%.

Finally, a sensitivity (ESAI) map was calculated using Equation 9, and the results shown in Table 7.20 reveal that about 33% of the study area was assigned to the 'highly sensitive' class, 43% of the study area was mapped as belonging to the 'very high sensitivity' class, while 22% of the study area was mapped as belonging to the 'moderate sensitivity' class. In other words, almost 85% of the total study area was sensitive to desertification (critical). Figure 7.15 revealed that 'moderate sensitivity' (C2) represents the fact that the majority of the study area was agricultural land characterised by evergreen perennial agricultural trees. Consequently, it was classified as 'moderate'. Most of these lands located in the north and east of the study area were 'moderate' of vegetation quality, climate quality, management quality and soil quality with slight wind erosion. Moreover, the percentage plant cover was measured as 70%. High (C3), located in the centre part of the study area has accrued due to mismanagement, and moderate soil quality and low vegetation quality is caused by the fact that the cover is more than 35% with moderate wind erosion. This result comes as a consequence of the assessment of all the qualities measured above as 'low' or 'moderate'. Very high sensitivity to desertification (C3A) is located in the south part of the study area and accrued due to mismanagement, moderate soil quality and very low vegetation quality caused by the fact that the cover is often less than 30% with high and very high wind erosion. From what has been stated above, it becomes apparent that human activities play the most important role in accelerating the desertification process, through the mismanagement of land resources (water, soil and vegetation) which has led to high sensitivity to desertification in the study area.

The results discussed above are in agreement with the results found by Lavado et al. (2009), who assessed land degradation by using the Environmentally Sensitive Area index in Spain and has been validated of the ESA maps. They found that the model performed well for environmental sensitivity to land degradation

8.3 Discussion of the Results from the Universal Soil Loss Equation (USLE)

The Universal Soil Loss Equation (USLE) was developed by Wischmeier and Smith (1978) as a mathematical model that describes soil erosion processes. In this research, the USLE is used with the GIS to determine quantitatively the average annual soil loss in the study area. The GIS files were created for each factor of the USLE – precipitation, soil type, land cover, and slope – and combined with the cell-grid modelling procedures in ArcGIS to predict the soil erosion risk (Figure 7.26).

The results obtained from USLE reveal 'slight' erosion rates in the rangelands and agricultural land, which together account for 76% of the total land area. These erosion rates were due, first, to topographic factors, where the area has a very gentle slope, ranging between 2 and 4%, which characterizes it as less susceptible to erosion (Kosmas et al., 1998) and, second, to soil erodibility (K). According to the soil survey reports and the soil map of the study area, the soil is characterized as sand texture, low in organic matter and high in permeability. These factors lead to low soil erodibility (K), factor values 0.03. In addition, the rainfall erosivity (R) has the same value for all the study area.

In contrast, 'moderate' erosion rates were found in rangelands which account for 15% of the total land area. This is due to topographic factor: the area has a gentle slope, ranging between 4 and 6%. This has led to its classification as 'moderately susceptible to erosion' (Kosmas et al., 1998). Besides, the soil texture in this area is characterized as sandy loam. This result has the highest value of soil erodibility (K) factor with a value of 0.14.

Similarly, high erosion was found in rangelands which account for 7% of the total land area. This is due to the topographic factor represented by the slope: the area is characterized with a moderate slope value of 6%. Also, the soil erodibility (K) factor value was 0.2, where the soil texture is sandy clay loam with low vegetation cover. Therefore, both the topographic factor and soil erodibility (K) are considered the main factors that affect soil erosion in the study area.

8.4 Discussion of the Comparative Results

The results from comparison between the original MEDALUS model and the developed MEDALUS model are shown in Table 7.22. The overall accuracy of 79% in total of the study area was associated with the same classes in both model maps with high overall Kappa statistics value of about 68%. Meanwhile, 98% of the slight class in the original MEDALUS map was converted to moderate and 2% was high class in the developed MEDALUS map. The slight class was about 7% of the total area. These changes resulted from developing the model by adding the soil salinity management factor and the wind erosion quality. These were included because they play an important role in land degradation in arid, semi-arid and dry sub-humid areas (e.g. Ayoub, 1998).

The outcome of the crosstab tabulation from the comparison between the soil erosion map for 1980 and the soil erosion map 2014 are shown in Table 7.22 and Figure 7.18. The overall accuracy of 45% in total of the study area was associated with the same classes in both model maps with overall Kappa statistics value of 41%. The results demonstrate that the 39.6% of the moderate class in the soil erosion map 1980 corresponds to the same area in the soil erosion map 2014, while 22.5% were mapped as slight, 21% as very high and 16.5% as high class. In addition, 43% of the high class in soil erosion map 1980 corresponds to the same area in the soil erosion map 2014, while 54% were mapped as very high. Meanwhile, 51% of the slight class in the soil erosion map 1980 corresponds to the same area in the soil erosion map 2014, 21% was converted to high and 18% indicates very high class in the soil erosion map 2014. This is due to the fact that, in the last 34 years, there has been increasing pressure on the existing agricultural lands and rangelands for increased crop production and animal husbandry. Moreover, large areas of less suitable land have been brought under cultivation in many areas in the Jeffara Plain. Ben Mahmoud et al. (2000) viewed this increasing pressures resulting in land degradation and desertification.

During the fieldwork conducted in the study area it was observed that there are large scale features resulting from wind erosion that are are widespread. They include sand dunes, root out, rocks out, Nebka and residual boulders. Small scale features resulting from a small amount of water erosion were also observable. Since the models include variables that are important to wind and water erosion, it is of interest to see how these variables are captured in the USLE model. Additionally, USLE is a popular model even through it is likely that wind is more important mechanism for soil erosion. In the case of this research, the developed MEDALUS method has been used in determining the sensitivity of areas to desertification, as mentioned before. Moreover, this model has been developed and applied in the arid and semi-arid zone. However, as part of the strategy for applying the model in Libyan climatic conditions, the prediction is based on the prevailing physical condition and on the results that emerged from the USLE model. For example, the topography is represented by the slope, however, majority of the study area is flat with a slope of between 1 and 3%, and the soil properties include the sandy textures and the depth, with some sand dunes and low vegetation cover – all these characteristics may lead to the slight risk of water erosion. At the same time, these conditions have contributed to making the majority of the study area highly sensitive to the risk of desertification by wind erosion. A significant amount of the soil is vulnerable soil (see Table 7.3 and Figure 7.4). Vegetation is another variable that influences soil erosion.

The model has been validated by comparing ground truthing data where 125 geographic points were selected from a grid distributed all over the study area onto the final ESAI maps. Table 7.28 shows that the overall accuracies of 90% between the points from the focus group and the points from the developed MEDALUS map and the overall Kappa is 83%.

8.5 Contribution of the thesis to knowledge and understanding

This research made a significant contribution to the development of a land degradation assessment model by expanding the Mediterranean Desertification and Land Use (MEDALUS) model. Libya, where the study area lies, is within the Mediterranean climate but with arid and semi-arid conditions. Therefore, there is greater concern with the effects of wind erosion and salinisation problems. If the land was treated in the same manner as the European Mediterranean environment, then there will be higher risks of exaggerating the model. It is because the original ESAI model as applied above is appropriate for studying land degradation under particular environmental conditions. Moreover, there are differences in the environment condition between the European Mediterranean and North Africa (Libya). The addition of new information has made the MEDALUS applicable in the semi-arid and arid environment. In this context, two parameters were incorporated: soil salinity indicator as a factor in management quality and wind erosion as new quality.

The results were obtained by applying the modified Medalus methodology highlight the extension and the intensity of the threat of degradation in the study area, thus making it an appropriate tool for assessing degradation in arid and semi-arid areas. This standardized model for studying land degradation in north-west Libya has never been used before.

The development and successful widespread application of assessment by focus groups of land degradation, desertification and environmental damage by wind erosion and soil salinity.

This research further makes significant contribution to the growing literature on methodologies for assessing land degradation in arid and semi-arid areas. With the findings of the study based on the modified MEDALUS, it will allow the development of a land degradation assessment model that is transferable to other regions and countries in arid and semi-arid zones, such as Tunisia, Algeria, Morocco and Sudan.

The processing of information using remote sensing and a Geographical Information System (GIS), allows for the handling of considerable amounts of data rapidly and effectively, and for an integration with new information that may derive from the processing of satellite images and from further surveys or research. Findings from remote sensing helps us understand the dynamics of land cover change and degradation over a period of time. This will help the decision makers in improving the management of agricultural land use and planning projects. In addition, the outputs can be used to find appropriate measures to combat adverse changes and trends in vegetation and land use.

Finally, the combination of the above contributions would be useful to policy makers on identifying and understanding issues of past and current land cover changes, risks of land degradation and their consequences.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusion

Through field measurement and environmental modelling, this research has quantified soil degradation in an area of the semi-arid/arid Jeffara Plain, Libya. This study confirms that in natural rangeland, the vegetation cover is subjected to overgrazing by sheep and goats, through traditional nomadic pastoralism with no regional strategic management. It is estimated the grazing intensity is one and a half times the sustainable grazing intensity. Loss of land cover is observed and soil loss is observed to be governed by wind erosion. Rangeland is increasing subjected to encroachment by farming, such as barley production in marginal lands. Unfortunately these activities are often short-lived and the land abandoned. Attempts to increase agricultural productivity through irrigation have also resulted in measureable salinization of the soil. In the extreme, the land is now incapable of supporting plant life.

9.2 General Conclusions Based on Research Questions

The general conclusions in relation to the research questions posed in Chapter 1 are listed below:

Research Question 1: Are there existing appropriate models which can be applied to land degradation in arid environments?

There are many methods that have been used to assess land degradation due to water and wind. The main examples reviewed here are Global Assessment of Human Induced Soil Degradation, Assessment of the Status of Human-Induced Soil Degradation in South and South East Asia, Soil Degradation Assessment in Central and Eastern Europe and Land Degradation and Assessment in Drylands (LADA). To assist in understanding land degradation and desertification the MEDALUS and USLE environmental models were selected from a number of models due to their suitability for application on small-scale and are highly sensitive in indicating ranges in the risk of degradation and desertification. These were applied in a GIS environment.

Research Question 2: Is it possible and appropriate to apply the long-established MEDALUS method to such situations?

Yes, but following field observation of salinity and wind erosion, a novel inclusion of these additional factors improves the accuracy of the land degradation predicted by the MEDALUS model compared to that measured in the field.

Subsidiary Research Questions:

Research Question 1: Does land degradation seem to be a problem in the study area?

Yes, it has been demonstrated that the study area suffers from severe land degradation. There was a significant decrease in natural vegetation due to rapid expansion of farmland in rangeland areas. Consequently, majority of the land of the study area became susceptible to degradation, with about 75% of the area studied being moderately or severely affected.

Research Question 2: Is there any discernible changes in the vegetation cover over the last 20 years?

Yes, it is clear that the vegetation cover has dramatically changed over the last 20 years through the detection and evaluation of changes in land cover and the monitoring of land degradation by remote sensing from 1986 to 2009. Natural vegetation decreased from 39% in 1988 to 27% in 2009, while there was an increase in bare land from 22% to 31% in 2009..

Research Question 3: Is land in the study area becoming progressively degraded?

Yes, it is clear that land degradation is increasing in the study area, where almost 75% of the total study area is sensitive to desertification at a critical point (high risk of desertification). Furthermore, the cover by natural vegetation decreased during the study period. Therefore, the map of environmental sensitivities produced can be used as a very useful tool for making better decisions about soil degradation and desertification encroachment for the future of the region.

Research Question 4: What is the best methodology to assess land degradation in Libyan environmental conditions?

Systematic comparisons have been made between the results obtained from the various methods used in this research. During the fieldwork conducted, it was found that there are large scale features resulting from widespread wind erosion. Small-scale features resulting from a small amount of water erosion were also observed. This means that any developed model should favour wind erosion over and water erosion. The USLE model cannot easily be amended to incorporate soil loss by wind erosion. Therefore in this research, the MEDALUS method has been used in determining the sensitivity of areas to desertification. as it offers the flexibility of including variables that are peculiar to the study area.

9.3 Recommendations for further work

The research has enhanced the development of land degradation assessment models, in particular for the Mediterranean climate. The most important modification that has been made is the introduction of local knowledge from local residents, local experts, and other sources into the model for assessing land cover changes and degradation. The results obtained from these methods have yielded certain recommendations that could be implemented to benefit Libya. With the aims and objectives of the research met and the questions answered, there are, however, further questions identified that would offer an extension to this research project. There are three potential areas this study can be expanded:

First, the proposed methods could be extended to monitor and study land degradation and desertification by selecting experimental locations in different areas in Libya (for example, Sahara region, coastal region, mountainous region etc) with some field measurements for wind factors and salinity of both groundwater and soil. The results could be monitored periodically to establish changes in land degradation in the long-term.

Second, the use of a single climate monitoring station outside the study area is potentially a limitation. It is recommended that more climatic stations should be established to cover the various and distinct climatic conditions in Libya. Therefore, this study can be extended by recording stations located throughout the study area, particularly in the south of the study area, where it is likely to be more arid and have less rainfall than northern Libya.

Third, the use of remotely sensed data with high spatial and spectral resolution can be integrated to more effectively characterise the differences in cropping patterns and land cover change in an increasingly heterogeneous landscape. As the study area is a poor data environment, remote sensing data can also be integrated with local knowledge-based technique to assess and generate sustainable land capability of the region.

Last, with respect to growing environmental and land degradation, coupled with demographic growth and increasing pressure in land use due to urbanisation, the principal mechanism by which an improvement of land quality could be achieved is the development of sustainable land use management. To achieve this requires: 1) quantifying the extent of land degradation by means of identified causative factors; 2) an appropriate methodology that will provide a standardised approach for documentation, monitoring and evaluation; 3) creating a network of local practitioners and expertise for sharing and exchanging knowledge that either benefits people to design appropriate sustainable land use management approaches or to support people in making decisions in the field and at the planning level. This means that the application of sustainable land management requires a holistic approach. This should include the engagement, collaboration and partnership of stakeholders, including land users, technical experts and policy-makers in identifying, understanding and solving land degradation problems whilst increasing productivity. Also, enabling policies and the overall regulatory environment need to be properly developed for the execution of the most appropriate land degradation management measures. Development of this area of work is particularly important in attaining national food security in Libya.

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Appendix A: Field study report

The aims of field study to obtain reference data for image classification and meet some of the authorities responsible for the areas touched on by the research and meeting with soil experts, to have their guidance in designing the model.

1-Meetings with local experts:

1. Professor Khaled Ben Mahmod (the head of the Libyan Natural Resource project)
2. Professor Ezzeddin Alteeb Rhoma (Soil expert in the Faculty of Agriculture, Alfateh University Tripoli)
3. Mr. Khaled Alfathle (The head of the Department of the Geography and Climate the Secretary of Transportation).

- Professor Khaled Ben Mahmod is the member staff in the Al-Fateh University, Faculty of Agriculture, Soil and water Dept. Dr Khaled has shown interest in the research findings and the application of these findings in future land degradation studies. He expressed his willingness to give every possible help to this research. There were discussions about the possibility of output model in the future land degradation. Dr Khaled outlined some important factors to be taken in account when the model of land degradation to be designed. He stated that there are factors should be taken into account when land degradation takes place and these factors are: soil depth, slope angle, drainage, texture, parent material and water availability (drop of groundwater levels and water quality).
- Professor Ezzeddin is a soil expert in Libyan soils and he worked in the Libyan soils area since 1978. The meeting was very useful for these discussions about the contribution to be expected from PhD research.
- Mr. Alfathle is the head of the geography and climate Department in the Transportation Secretary. This department is responsible for managing the climate data. And he provided the all climate data to help with the research.

- Visiting the Agriculture Research Centre (ARC) in Tripoli:

This visit was to the library of the Centre to get some documents, which cannot be borrowed, and take notes from some of these and photocopy others where it was possible. The visit was very useful to answer questions, which have been raised, from the previous reading and writing for the parameters, which would be used to develop the suitability Framework. This involved six working days on to the Arc's library (3th of September to 9th of September) 2010.

Furthermore, a digital camera has been used for the field-plots and a detailed description and observation for all classes in the study area. Examples, tree with Irrigated Area, Shrubs Vegetation with Herbaceous, Sparse Vegetation, Bare Land and Urban Area are shown below:

Photo1: Tree with Irrigated crops: Irrigated vegetable crops and olive trees in the study area.

Photo1: Tree with Irrigated crops in the north part of the study area.

Photo2: Shrubs Vegetation with Herbaceous: Some locations of the study area are being mapped as mixed land cover classes from Shrubs Vegetation with Herbaceous.

Photo2 : Shrubs Vegetation and Herbaceous in the middle part of the study area.

Photo3: Sparse Vegetation in the south west part of the study area.

Photo4: Bare Land in south east of the study area.

Photo 5: Cultivation of fragile soil in south part of the study area.

Appendix B:

Groundwater data were provided by the Libyan General Water Authority (LGWA), collected by measuring the groundwater level from a number of piezometric wells situated in the region.

Piezometer N°:	**1238**		
Location :	Al Aziziyah	Sheet N°:1890 / 2	
Coordinates :	X:30150	Y: 361475	
Elevation (m) :	157.23	Reference point (m) :	0.40
Depth (m) :	80.00	Aquifer : Quaternary	

Data of measurement	Water level from reference point	Data of measurement	Water level from reference point
05/12/1978	-20.74	05/02/1985	-25.49
28/11/1979	-21.83	26/03/1985	-25.82
02/08/1980	-22.65	19/05/1985	-26.00
02/09/1980	-22.77	09/07/1985	-26.35
28/10/1980	-22.83	05/08/1985	-26.38
25/11/1980	-22.74	21/09/1985	-26.23
22/02/1980	-22.67	24/10/1985	-26.33
24/01/1981	-22.54	07/12/1985	-26.29
22/02/1981	-22.47	11/01/1986	-26.09
26/03/1981	-22.63	01/02/1990	-32.10
25/04/1981	-22.89	28/12/1993	-33.16
27/05/1981	-23.06	29/12/1994	-34.30
27/06/1981	-23.17	28/11/1995	-35.13
11/08/1981	-23.37	07/08/1996	-35.70
20/09/1981	-23.34	30/12/1997	-36.53
24/10/1981	-23.41	16/08/1998	-37.16
29/11/1981	-23.30	20/09/1998	-37.20
02/01/1982	-23.38	06/12/1998	-37.32
14/03/1982	-23.26	30/01/1999	-37.24
23/05/1982	-23.54	28/02/1999	-37.26
25/07/1982	-23.91	13/03/1999	-37.29
31/08/1982	-24.07	13/06/1999	-37.53
25/09/1982	-24.14	05/09/1999	-37.98
24/10/1982	-24.15	22/12/1999	-38.16
21/11/1982	-23.90	26/03/2000	-38.25
09/02/1983	-23.72	27/04/2000	-38.41
19/03/1983	-23.92	28/06/2000	-38.67
04/07/1983	-24.45	24/09/2000	-38.49
29/02/1984	-24.79		
06/05/1984	-25.24		
04/08/1984	-25.67		
19/12/1984	-25.62		

Piezometer N°:	**1006**		
Location :	Qasr bin ghashir	Sheet N°: 1990 / 3	
Coordinates :	X: 32955	Y:361850	
Elevation (m) :	69.02	Reference point (m) :	0.70
Depth (m) :	130.00	Aquifer :Plio- Quaternary	

Data of measurement	Water level from reference point	Data of measurement	Water level from reference point
13/12/1978	-58.24	31/12/1985	-73.21
06/03/1979	-58.40	13/02/1986	-72.26
09/10/1979	-64.68	15/07/1986	-89.71
22/01/1980	-61.66	04/08/1986	-90.95
26/05/1980	-65.44	27/08/1986	-91.20
07/07/1980	-69.12	06/01/1988	-74.54
10/09/1980	-72.08	16/04/1989	-77.52
12/11/1980	-68.05	04/06/1989	-85.84
14/12/1980	-63.38	18/11/1989	-87.82
15/02/1981	-60.22	23/01/1990	-76.73
15/03/1981	-60.83	02/01/1993	-86.00
18/04/1981	-63.51	01/01/1994	-93.60
17/05/1981	-64.60	27/11/1994	-101.66
14/06/1981	-68.86	31/10/1995	-101.48
18/07/1981	-72.65	13/06/1996	-101.91
15/09/1981	-74.53	28/12/1997	-94.80
22/11/1981	-70.69	14/06/1998	-96.19
20/12/1981	-66.91	20/08/1998	-96.37
18/05/1982	-67.36	30/09/1998	-96.18
23/06/1982	-72.90	03/12/1998	-96.67
22/08/1982	-77.23	27/01/1999	-95.98
20/09/1982	-77.79	24/02/1999	-93.83
19/10/1982	-77.41	17/03/1999	-93.91
16/11/1982	-71.34	06/06/1999	-95.10
07/02/1983	-63.73	09/09/1999	-96.54
15/03/1983	-64.33	25/12/1999	-97.49
21/06/1983	-75.14	23/03/2000	-97.00
01/02/1984	-65.04	20/06/2000	-97.42
29/04/1984	-70.91	17/09/2000	-97.84
30/07/1984	-79.58	10/12/2000	-97.82
11/09/1984	-81.21	11/03/2001	-97.92
21/01/1985	-66.59	05/06/2001	-97.89
04/03/1985	-67.98	20/10/2001	-97.69
29/04/1985	-71.74	06/12/2001	-97.68
04/07/1985	-80.54	15/06/2002	-96.39
31/07/1985	-81.25	29/09/2002	-94.92
15/09/1985	-82.31		

Piezometer N°:	1178		
Location :	As Swain	Sheet N°: 1990 / 4	
Coordinates :	X:32255	Y:362845	
Elevation (m) :		Reference point (m) :	0.35
Depth (m) :	170.00	Aquifer :Miocene	

Data of measurement	Water level from reference point	Data of measurement	Water level from reference point
16/12/1978	-46.08	16/08/1985	-53.61
03/02/1979	-46.77	07/09/1985	-56.40
26/03/1979	-46.58	12/10/1985	-56.00
09/10/1979	-47.77	26/11/1985	-55.88
16/01/1980	-47.76	25/12/1985	-55.44
08/07/1980	-47.76	28/01/1986	-55.42
18/08/1980	-49.12	23/04/1986	-56.41
06/09/1980	-49.22	07/07/1986	-57.17
04/10/1980	-49.29	02/08/1986	-57.37
04/11/1980	-49.03	22/12/1997	-69.02
07/12/1980	-48.90	11/08/1998	-73.63
05/01/1981	-48.77	27/09/1998	-73.25
04/02/1981	-48.74	13/12/1998	-70.08
03/03/1981	-49.03	01/02/1999	-68.48
11/04/1981	-49.72	28/02/1999	-68.8
05/05/1981	-49.82	14/03/1999	-69.27
03/06/1981	-50.15	09/06/1999	-74.87
05/07/1981	-50.77	11/09/1999	-73.99
12/09/1981	-50.82	26/12/1999	-70.26
18/10/1981	-51.18	28/03/2000	-70.29
14/11/1981	-48.34	30/04/2000	-72.15
08/12/1981	-50.40	21/06/2000	-75.87
11/01/1982	-50.84	19/09/2000	-76.1
20/03/1982	-50.68	13/12/2000	-76.08
02/05/1982	-51.15	13/03/2001	-72.29
01/06/1982	-51.68	07/06/2001	-73.87
01/08/1982	-52.68	20/10/2001	-77.49
04/09/1982	-52.65	13/12/2001	-73.44
04/10/1982	-52.63	09/03/2002	-73.23
01/11/1982	-52.10	12/06/2002	-77.21
01/12/1982	-51.81	22/09/2002	-77.26
22/02/1983	-51.95		
27/03/1983	-52.25		

Piezometer N°:	1327		
Location :	Ain Zarah	Sheet N°:1990 / 4	
Coordinates :	X:33325	Y:363165	
Elevation (m) :	34.43	Reference point (m) :	0.35
Depth (m) :	93.00	Aquifer : Mio-Quaternary	

Data of measurement	Water level from reference point	Data of measurement	Water level from reference point
06/06/1978	-26.59	04/06/1990	-37.47
28/02/1979	-26.80	11/08/1990	-38.9
13/10/1979	-28.73	01/01/1994	-38.53
22/01/1980	-28.21	24/11/1994	-41.04
26/05/1980	-29.68	30/10/1995	-40.42
03/07/1980	-30.33	13/07/1996	-43.04
31/07/1980	-30.76	29/12/1997	-38.31
10/09/1980	-31.14	20/08/1998	-43.45
12/10/1980	-31.12	03/10/1998	-43.35
12/11/1980	-30.50	02/12/1998	-40.24
14/12/1980	-29.85	27/01/1999	-38.23
13/01/1981	-29.22	09/03/1999	-38.12
15/02/1981	-28.84	02/06/1999	-39.22
15/03/1981	-29.15	12/09/1999	-43.8
18/04/1981	-29.92	21/12/1999	-39.44
17/05/1981	-30.58	28/03/2000	-38.19
21/06/1981	-31.64	26/04/2000	-40.16
15/09/1981	-32.34	27/06/2000	-43
22/11/1981	-31.39	21/09/2000	-43.47
20/12/1981	-31.04	18/12/2000	-40.87
18/05/1982	-32.58	15/04/2001	-39.19
23/06/1982	-33.67	14/06/2001	-39.98
22/08/1982	-34.39	19/10/2001	-43.66
20/09/1982	-34.36	11/12/2001	-39.94
19/10/1982	-34.47	10/03/2002	-38.86
16/11/1982	-33.10	29/09/2002	-43.92
07/02/1983	-31.39		
05/03/1983	-32.10		
21/06/1983	-34.72		
01/02/1984	-32.49		
29/04/1984	-34.25		
30/07/1984	-36.01		
11/09/1984	-36.37		
21/01/1985	-33.06		