Assessing land degradation and land use in the Libyan Al-jabal Alakhdar region

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

December 2013

PREFACE

This report presents work carried out in the Faculty of Development and Society, at Sheffield Hallam University between 2009 and 2013. The submission of this work is in accordance with the requirements for the award of the degree of Doctor of Philosophy (PhD).

ABSTRACT

This research examines and identifies the causes of land degradation in a semi-arid area in eastern Libya subject to soil loss through water erosion.

Temporal changes in landscape cover are detected between 1984 and 2008 using satellite imagery: a 26% decrease in dense vegetation and shrubs, a 100% increase in agricultural land and an increase of 5% in both irrigated crops and bare soil occurred.

Soils and climate information was used to apply a theoretical model of desertification (MEDALUS) within GIS to the study area. Statistical verification of the model employed extensive data from a comprehensive assessment of the study area by a focus group of experts assembled for this research. Theoretical relationships to significantly improve the model were developed using new field data, including actual stocking rates, dry biomass and plant palatability, to describe grazing intensity. The environmental impact of these human activities in natural areas can now be applied.

Spatial changes were explored using a further model with the universal soil loss equation (USLE), which was independently verified in both 1984 and 2008 to easily allow mapping of the changes extent and assessment in those 24 years. A new soil conservation practice factor is introduced for natural areas based on grazing intensity. The model results indicate that in 1984, the natural land had only a slight risk of land degradation due to the protection provided by the high density of cover and sustainable grazing intensities, unless the land slope is very steep.

By 2008, an additional 26% of the study area suffered from different degradation levels, caused by land use change. Only 20% of the study area remains dense, natural vegetation under sustainable grazing intensity but a further 5% of land is grazed and converted to sparser vegetation cover. Agriculture and overgrazing are the main drivers of unnatural soil erosion, indicating that some farming practices are unsustainable.

This work has comprehensively quantified the rate extent and causes of land degradation in the north-east of Libya. This knowledge can be used to organise more sustainable land management to avoid further land degradation and to mitigate that already observed.

TABLE OF CONTENTS

PREFACE... I

ABSTRACT... II

TABLE OF CONTENTS... III

LIST OF FIGURES... VII

LIST OF TABLES... X

ACKNOWLEDGEMENTS... XIV

CHAPTER 1... 1

1.1 Introduction... 2

1.2 Research aims and objectives... 5

1.3 Overview of the research strategy and methodological approaches......... 6

CHAPTER 2: Environmental conditions of Al-jabal Alakhdar region........... 7

2.1 Vegetation cover in the study area... 8

2.2 Climate information in the study area... 9

2.3 Soil information in the study area... 13

2.4 Land management in the study area... 15

2.5 Conclusion... 19

CHAPTER 3: Definition of land degradation... 20

3.1 Land degradation and desertification: definition... 21

3.2 Processes and causes of land degradation and desertification................. 21

3.2.1 Processes of land degradation and desertification... 21

3.2.2 Causes of land degradation and desertification... 23

3. 3 Assessment of land degradation and desertification... 26

3.3.1 Universal Soil Loss Equation (USLE) methodology... 31

3.3.2 Mediterranean Desertification and Land Use (MEDALUS) methodology... 33

3.4 Conclusion... 37

CHAPTER 4: Land cover changes... 39

4.1 Introduction... 40

4.2 Change detection methodology... 40

4.2.1 Satellite digital image processing.. 41

4.2.2 Image classification.. 44

4.2.3 Comparison of four independent land cover classifications................ 48

4.3 The Land use map.. 50

4.4 Conclusion.. 52

CHAPTER 5: Land degradation model (USLE).................................... 53

5.1 Introduction... 54

5.2 Land degradation model (USLE)... 54

5.3 Conclusion.. 60

CHAPTER 6: Land desertification model (MEDALUS).......................... 62

6.1 Introduction... 63

6.2 Establishing areas environmentally sensitive to desertification.............. 63

6.2.1 Soil quality... 64

6.2.2 Climate quality.. 70

6.2.3 Vegetation quality.. 72

6.2.4 Management quality... 76

6.2.5 Index of Environmentally Sensitive Areas.................................. 90

6.3 Conclusion.. 93

CHAPTER 7: Verification of MEDALUS and USLE maps.......................... 94

7.1 Introduction... 95

7.2 Degree of degradation in the various types of ESAs........................... 95

7.3 Verification of USLE and MEDALUS maps..................................... 96

7.3.1 Verification of USLE map... 96

7.3.2 Verification of MEDALUS map... 101

7.3.3 Discussion... 107

7.4 Conclusion.. 110

CHAPTER 8: Improvement of the management quality index for natural land within the model MEDALUS.. 112

8.1 Introduction... 113

8.2 Land use intensity from grazing animals.. 114

8.2.1 Method to calculate Actual Stocking Rate.. 114

8.2.2 Method to determine the sustainable stocking rate.. 116

8.2.3 Analysis and results for actual and sustainable stocking rates.. 119

8.2.3.1 Actual stocking rate.. 119

8.2.3.2 Adjusted actual stocking rate.. 121

8.2.3.3 Sustainable stocking rate.. 123

8.3 Management Quality Index, MQI (Focus group observation of desertification & MEDALUS data).. 134

8.4 Verification of improved MEDALUS model including new MQI.. 138

8.5 Conclusions.. 139

CHAPTER 9: Improvement to conservation practice and cover management in the model USLE and exploring temporal changes in land degradation....... 141

9.1 Introduction.. 142

9.2 Improvement of the USLE model for the Al-jabal Alakhdar region.......... 143

9.2.1 The cover management factor C.. 143

9.2.2 Conservation practice factor P on agricultural land.. 145

9.2.3 Conservation practice factor P in natural areas.. 146

9.3 Verification of new USLE model.. 148

9.4 Using USLE to investigate temporal changes in land degradation.. 152

9.4.1 Temporal changes in land degradation for Al Awylia region.. 153

9.4.2 Temporal changes in land degradation for the Taknis region.. 154

9.4.3 Temporal changes in land degradation for Al Bayyadah region.. 154

9.4.4 Temporal changes in land degradation for the Wadi Az Zaghtun region... 155

9.4.5 Temporal changes in land degradation for the Marawah region.. 155

9.4.6 Temporal changes in land degradation for the Gandolla region.. 156

9.4.7 Temporal changes in land degradation for the Wadi Al-Hmarh region..... 157

9.4.8 Temporal changes in land degradation for the Omar Al-Mukhtar region.. 157

9.4.9 Summary of temporal changes in land degradation for the study area...... 158

9.5 Conclusions.. 160

CHAPTER 10: Conclusion and recommendation for further work................ 162
10.1 Conclusions... 163
10.2 Contribution to science.. 165
10.3 Recommendations for Further work... 166
11 References.. 169
12 Appendix.. 189
12.1 Field work... 189
12.2 General description of vegetation in the study area.............................. 192
12.3 Penalty costs for actual plants, forest, shrubs and pasture grass............ 207

LIST OF FIGURES

Figure 1.1. Map of Libya, with study area... 4

Figure 1.2. Schematic diagram showing application of methodologies &models for the land cover changes, MEDALUS and USLE..................... 6

Figure 2.1. Map of average annual rainfall for the Al-jabal Alakhdar region including the study area.. 10

Figure 2.2. Average monthly temperature (°C) and precipitation (mm) in the study area 1956-1972.. 11

Figure 2.3. Average monthly precipitation (mm) and temperature (°C) in the study area 1978-2010 12

Figure 2.4. Average monthly precipitation and temperature in the study area, 1978- 2010.. 13

Figure 2.5. Soil classification.. 15

Figure 2.6. Number of goats and sheep in the study area between 1984 and 2008.. 18

Figure 3.1. Main desertification and land degradation processes.................. 22

Figure 3.2. Main causes of desertification and land degradation.................. 24

Figure 3.3. Schematic diagram showing the integrated application of methodologies & models for the classification of land cover, desertification (MEDALUS) and degradation (USLE).. 37

Figure 4.1. Methodology for detection of land cover change..................... 41

Figure 4.2. Satellite image and enhancement procedure.......................... 44

Figure 4.3. (A, B, C and D). Classification of land cover for each time step.... 47

Figure 4.4. Land cover in 1984, 1992, 2000 and 2008........................... 49

Figure 4.5 Land use map of the study area... 51

Figure 5.1. USLE methodology to determine erosion hazard..................... 55

Figure 5.2. Spatial distribution of USLE topographic factor LS.................. 57

Figure 5.3. Determination of the erodibility factor K of the soil in the study area.. 57

Figure 5.4. Variation of USLE soil erodibility factor K in the study area........ 58

Figure 5.5. Spatial distribution of cover management factor C in 2008.......... 59

Figure 5.6. Spatial distribution of conservation practice factor P in 2008....... 59

Figure 5.7. USLE land degradation map for study area in 2008................. 60

Figure 6.1. Framework to show the parameters used for the definition and mapping of the ESAs vulnerable to desertification................................ 64

Figure 6.2. Digital Elevation Modelling of land in the study area................ 68

Figure 6.3. Slope (%) of land in the study area.................................... 68

Figure 6.4. Wadi drainage systems in the study area.............................. 69

Figure 6.5. Map of soil quality index.. 70

Figure 6.6. Aspect of slope in the study area....................................... 72

Figure 6.7. Variation of vegetation quality index in the study area.............. 76

Figure 6.8. Locations of assessments of land use intensity by expert panel to determine the management quality index (MQI).................................. 77

Figure 6.9. Management quality index in the study area.......................... 89

Figure 6.10. Map of study area showing sensitivity to desertification........... 91

Figure 8.1. Regional average head of sheep and goats per hectare from Government records for 2008.. 115

Figure 8.2. Grid cell division of the study area to measure actual stocking rates.. 115

Figure 8.3. Actual stocking rate of sheep and goats from survey of shepherds.. 119

Figure 8.4. Comparison of the actual stocking rates in different land cover classes... 120

Figure 8.5. Variation of adjusted actual stocking rate with land cover class.... 122

Figure 8.6. Land cover classes related to product of the average edible biomass (P) and fraction of the soil surface covered (F).......................... 126

Figure 8.7. Comparison of sustainable stocking rates using three scenarios of grazing efficiency: SSR1, X=0.5; SSR2, grass X = 0.5 & woody plant + shrub X = 1; SSR3, grass X = 0.5 & woody plant + shrub X = 1 with plant palatability.. 129

Figure 8.8. Comparison of the ratios of adjusted actual to sustainable stocking rates with forage supplement in different land cover classes based three scenarios.. 131

Figure 8.9. Index of grazing damage and grazing intensity: grazing efficiency SSR1; X=0.5... 132

Figure 8.10. Index of grazing damage and grazing intensity: grazing efficiency SSR2; grass X = 0.5 & woody plant + shrub X = 1.................... 132

Figure 8.11. Index of grazing damage and grazing intensity: grazing efficiency SSR3; grass X = 0.5 & woody plant + shrub X = 1 * plant palatability.......... 133

Figure 8.12. Variation of grazing intensity using grazing efficiency scenario 3 for different land cover classes.......... 134

Figure 8.13. Management quality index (MQI) and grazing intensity for the study area.......... 136

Figure 8.14. Index of grazing intensity and Management quality index (MQI). 137

Figure 8.15. Management quality index in the study area in 2008.......... 137

Figure 8.16. Map of the study area showing sensitivity to desertification....... 139

Figure 9.1a. Spatial distribution of cover management C factor in 1984......... 144

Figure 9.1b. Spatial distribution of cover management C factor in 2008......... 144

Figure 9.2a. Spatial distribution of improved conservation practice factor P for cultivated agricultural areas in 1984.......... 145

Figure 9.2b. Spatial distribution of improved conservation practice factor P for cultivated agricultural areas in 2008.......... 146

Figure 9.3. Relationship between Conservation Practice factor P and grazing intensity for different land cover classes in rangeland.......... 147

Figure 9.4. Geographical location of randomly selected sample points for statistical comparisons overlaid on 1980 water erosion map.......... 149

Figure 9.5. USLE land degradation map for study area in 1984.......... 149

Figure 9.6. USLE land degradation map in 2008, after improvements to C and P factors.......... 150

Figure 9.7. Illustration of examples of different levels of land degradation classification.......... 151

Figure 9.8. Sub-regions in the study area based on observed land degradation.......... 152

LIST OF TABLES

Table 2.1. Soil taxonomy classifications to the subgroup level for the study area........ 14

Table 2.2. Agricultural laws........ 16

Table 4.1. Interpretation of Kappa........ 46

Table 4.2. Accuracy assessment of the 2008 land cover map........ 48

Table 4.3. Land cover in 1984, 1992, 2000 and 2008........ 49

Table 6.1. MEDALUS Description of soil texture........ 65

Table 6.2. Soil texture class for 0-0.3m soil depth........ 65

Table 6.3. MEDALUS classification of parent material of soil........ 65

Table 6.4. Underlying geology in the study area........ 66

Table 6.5. MEDALUS classification of the variable "rock fragments", based on the % cover of the ground by stones........ 66

Table 6.6. MEDALUS classification of soil depth........ 67

Table 6.7. MEDALUS classification of slope %........ 67

Table 6.8. MEDALUS classification of drainage in the study area........ 69

Table 6.9. Classification of soil quality index........ 69

Table 6.10. Description of rainfall classes........ 71

Table 6.11. MEDALUS classification of Bagnouls-Gaussen classes........ 71

Table 6.12. Description of climate quality index........ 72

Table 6.13. MEDALUS classification of Vegetation type in relation to its fire risk and ability to recover........ 73

Table 6.14. MEDALUS classification of vegetation type in relation to ability to protect against soil erosion........ 74

Table 6.15. MEDALUS classification of vegetation type and resistance to drought........ 74

Table 6.16. MEDALUS classification of plant cover and its impact on water erosion........ 75

Table 6.17. MEDALUS classification of vegetation quality index........ 75

Table 6.18. Description and degree of enforcement of policy for environmental protection........ 77

Table 6.19. Management Policy index for agricultural areas........ 79

Table 6.20. Classification of enforcement policy for charcoal making in the natural area based field evidence.. 80

Table 6.21. Types of land use intensity in agricultural land........................ 81

Table 6.22. Land use intensity in agricultural land..................................... 81

Table 6.23. Types of land use intensity in natural areas.............................. 83

Table 6.24. Land use intensity in natural areas... 84

Table 6.25. Formula used during field assessment of grazing damage.......... 85

Table 6.26. Classification of grazing intensity of the natural area based on field evidence.. 86

Table 6.27. Types of ESAI and corresponding ranges of indices.................. 90

Table 7.1. Comparison of classifications from desertification (MEDALUS) and degradation (USLE) models.. 95

Table 7.2. Skills of focus group experts and relationship to degradation methodology... 97

Table 7.3. Classification of the study area by level of land degradation......... 98

Table 7.4 A. Synthesis of the case studies with some environmental problems leading to land degradation in land with varying vegetation cover............... 99

Table 7.4 B. Classification of the study area according to the degree of land degradation in the natural vegetation land 99

Table 7.5 A. Synthesis of the case studies with some environmental problems leading to land degradation in agricultural land 100

Table 7.5 B. Classification of the study area according to the degree of land degradation in agricultural land... 100

Table 7.6. Comparison of USLE 2008 land degradation map with field classifications of land.. 101

Table 7.7. Classification of the study area by level of land sensitivity according to the ESA index... 102

Table 7.8 A. Synthesis of the case studies with some environmental problems leading to desertification in natural vegetation land............................ 103

Table 7.8 B. Classification of the study area by level of land sensitivity according to the ESA index for natural vegetation land......................... 103

Table 7.9 A. Synthesis of the case studies with some environmental problems leading to land degradation.. 104

Table 7.9 B. Classification of the study area by level of land sensitivity according to the ESA index for agricultural land.................................. 104

Table 7.10. Evaluation of MEDALUS map and field classifications of land.. 104

Table 8.1. Typical Livestock feed requirements, forage supplement and required natural biomass... 122

Table 8.2. Number and location of biomass sample plots with areal extent of each land cover class in each geographical region. The superscript denotes the number of biomass plots.. 123

Table 8.3i. Average available edible biomass per hectare for land cover class B.. 123

Table 8.3ii. Average available edible biomass per hectare for land cover class C... 124

Table 8.3iii. Average available edible biomass and per hectare in land cover class D.. 124

Table 8.3iv. Average available edible biomass per hectare for land cover class E.. 124

Table 8.3v. Average available edible biomass per hectare for land cover class F.. 124

Table 8.3vi. Average available edible biomass per hectare for land cover class G.. 125

Table 8.3vii. Average available edible biomass per hectare for land cover class H.. 125

Table 8.3viii. Average available edible biomass per hectare for land cover class I... 125

Table 8.3ix. Average available edible biomass per hectare for land cover class J.. 125

Table 8.3x. Average available edible biomass per hectare for land cover class K.. 126

Table 8.4. Available plants in the study area and their degree of palatability to sheep and goats.. 128

Table 8.5. Average palatable biomass available in land cover class B........... 129

Table 8.6. Comparison of sustainable stocking rates using three scenarios for the study area... 129

Table 8.7. Evaluation of improved MEDALUS map and field classifications of land.. 139

Table 9.1. Cover management factor C for different vegetation cover classes.. 144

Table 9.2. Cover management factor C for different land use classes............ 144

Table 9.3. Comparison of USLE 1984 land degradation map with 1980 water erosion map... 150

Table 9.4. Comparison of USLE 2008 map (improved P and C factors) and field classification of water erosion... 151

Table 9.5. Change in USLE land classification from 1984 to 2008.............. 158

Table 12.3.1. Percentage that added to actual plants cost........................ 207

Table 12. 3. 2. Penalty costs for forest and shrubs................................ 208

Table 12. 3. 3. Penalty costs for pasture grass...................................... 208

ACKNOWLEDGEMENT

First and foremost, I thank ALLAH for giving me the strength to be able to finish this thesis. I would like to express my profound gratitude and indebtedness to the people who have helped me in the completion of this work for their constant motivation, valuable suggestions and timely inspirations while I have been working on the thesis: the thesis guides and supervisors Dr Kevin Spence and Professor Ian Rotherham.

I am sincerely thankful to them for their valued guidance and for their efforts in improving my understanding on the topic; and for their constructive criticism, their advice to change my way of approaching the problem wherever necessary, and for their constant inspiration.

I sincerely thank Sheffield Hallam University for giving me the opportunity to study for a PhD. Sheffield Hallam University has been a great source of inspiration.

I am also very grateful to Omar Al-Mukhtar University, the Libyan local experts, the agricultural engineers in the Secretariat of Agriculture in Al-jabal Alakhdar and the agriculture project in Al-jabal Alakhdar for their help in the successful completion of my thesis work: I thank them from the bottom of my heart.

Thanks to all my family, who have always encouraged me and given me a helping hand whenever it was required. I am grateful to my wife, my sons Mohamed and Bilal, my daughter Fatima and my brother Abdalhamed.

Finally, I would like to thank Professor Yagoub, Professor Assaadi and Professor Al-Hendawi for their comments and Mr Jebreel and Mr Anees for their encouragement. Professor Yagoub has been the main local staff member who has provided me with his experience in this field of study; therefore, he deserves special thanks.

CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

There are many definitions of 'land degradation'; the expression being used to explain the processes of deterioration of soil and vegetation (Mainguet 1991; Wang et al. 2012c). Degradation can also be defined as the loss of potential utility or the diminution or change of natural features that are difficult to replace (Barrow 1991). Many descriptions of land degradation suggest that deterioration results from irreversible changes that have an adverse impact on the ecosystem and which have led to loss of ecosystem utility (Koohafkan and Ponce-Hernandez 2004). According to information from the International Desertification Convention (FAO 2005), land degradation in arid, semi-arid and sub-humid areas is the result of various factors, including climatic variations and human activities. Land degradation results in accelerated physical, chemical and biological deterioration of the soil, undesirable alterations to ecosystems and increased hazards for human occupancy (Koohafkan and Ponce-Hernandez 2004). It includes soil erosion by water and wind, and the long-term continuous loss of natural vegetation cover (Chabrillat et al. 2003). Because of the influence of climate changes, land use changes (which may also be described as land cover changes) and soil deterioration, the risk of land degradation has become the main ecological issue globally (Bajocco et al. 2012). Approximately 20% of the human population live in arid and semi-arid climate zones, such as Libya, which cover about 40% of the Earth (Satterfield et al. 1998; White et al. 2000). The sustainability of land cover and habitation in these arid and semi-arid areas is threatened by desertification. This is a serious issue and leads to degradation of vegetation and soils (Hellden and Tottrup 2008; Prince et al. 2009). Human pressure has been recognized in recent years as a major factor in shaping the biosphere (Meyer and Turner 1994). To improve understanding of the reasons behind land cover changes and desertification, the effect of human pressure on land cover also needs to be considered (Zhang et al. 2012). Irresponsible human actions such as deforestation, over-grazing, growing cash crops and fire can easily trigger desertification in the arid and semi-arid zones (Koohafkan and Ponce-Hernandez 2004). This transformation of the land can be divided into two components: those relating to land use change and those relating to land cover change. Land use change at any location may involve either a shift to a different use or an intensification of the existing one. Land cover changes fall into two ideal types: conversion and modification. The former is a change from one type or class of land cover to another; for example, from grassland to cropland. There may also be a change of condition within a land cover category, such as the thinning of a forest or a change in its composition (Meyer and Turner 1994). The evaluation of the degradation caused by human activity is a challenge in arid and semi-arid lands. Land degradation can be detected by comparing land cover data from different periods of time (Graetz 1996; Lal et al. 1998). Although they are not all considered in detail in this research, there are many manifestations of land degradation which can be measured on many specific scales, such as reduced productivity of the plants that form the source of livelihood and income, and undesirable alterations in the biomass and the diversity of micro- and macro-flora and fauna (soil biodiversity). The causes of degradation in arid and semi-arid lands are linked to inappropriate or over-intensive land use and land management practices (White et al. 2002).

This research is concerned with degradation and desertification in a particular area of Libya, where it is believed that the vegetation cover is threatened with serious degradation and land mismanagement (Rotherham 2010). This stress originated in 1988 from global political pressure on Libya, with a consequential restriction in trade and requirement for improved food security of staple foodstuffs. As a result, land formerly managed by low impact and traditional farming techniques has been converted to more intensive and mechanised agricultural production. One of the two regions that were the focus of this change has been selected for further study in this research and is located in Al-jabal Alakhdar (Arabic for "the Green Mountain"), a mountainous area on the east side of Libya (North Africa). It is bordered by the Mediterranean Sea to the north and west, by the Albutnan Plateau to the east, and by the Great Desert to the south. It represents about 1% of the total area of Libya (Figure 1.1). The study area extends between longitudes 21° 13′ and 21° 40′ E, and between latitudes 32° 38′ and 32° 29′ N. The total area is about 95,000 hectares and contains the small agriculturally based towns of Marawah, Gandolla, Omar Al-Mukhtar, Al Bayyadah, Al Awylia and Taknis.

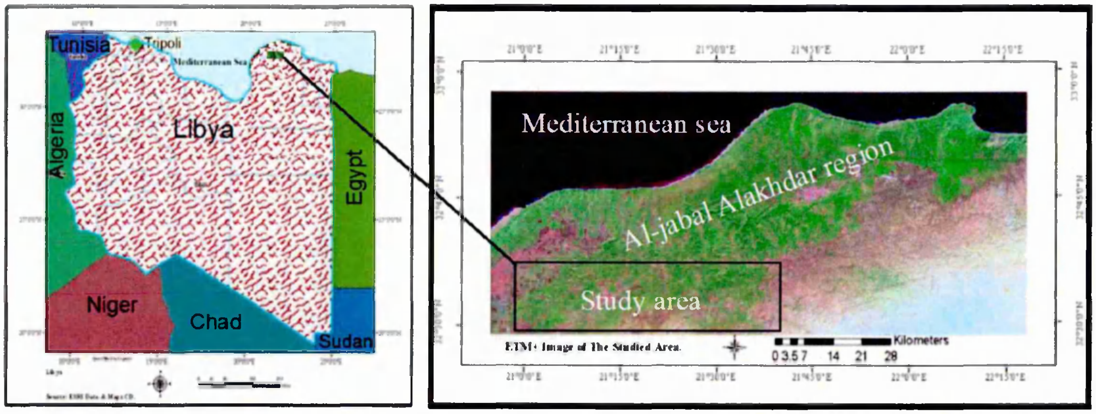


Figure 1.1. Map of Libya, with study area.

The land area selected for examination is believed to be under the threat of serious and continuous damage, but this threat has not been quantified thoroughly or addressed in any coherent way. There have been a number of local studies in the Al-jabal Alakhdar region that have aimed to describe soil degradation and land cover. The most important study was that by Zaed et al. (2005). It gives general ideas about the Al-jabal Alakhdar region in terms of its location, vegetation cover, soil types, water resources and geology. However, this study lacks depth and has no rigorous and comprehensive survey; its general information does not specify and describe the degradation problem in adequate detail. In addition, the study did not cover all forms of degradation, no maps were produced that locate and specify the areas in Al-jabal Alakhdar that have suffered from degradation. It did not investigate the reasons for degradation in the region or their relative importance.

The extent and severity of desertification on national and global scales can be shown on maps, which are important for the assessment of desertification trends and for understanding the environmental changes that are occurring in dry lands, as well as for the development of effective policies to combat land degradation (Liu et al. 2004). For sustainable management of the land, effective policies, regulation, laws and plans are required. This requires the availability of sufficient and accurate spatial information. Remote sensing (RS) and Geographic Information Systems (GIS) provide new tools for advanced ecosystem management by offering effective tools for capturing and processing the required data. Remote sensing can be the basis of fast data collection and GIS techniques can aid manipulation of data, especially for the rates of change at specific locations. The use of these technologies helps to generate land cover maps, and provides many benefits in tracking land cover changes, such as giving a complete, permanent and continuous coverage of degraded lands. This makes it possible to study any region when necessary and for the required time period, to monitor the remote and rugged inaccessible areas, and to record the current status of a certain region at a certain time; this record represents a documentary reference for this region (Bharti et al. 2011; Raj and Kumar 2012). Consequently, this study is concerned with land degradation and desertification in a particular area, to identify its extent, the rate of change and the underlying causes. This research will be the first applied to this area which has employed RS data and GIS. Finally, and importantly, the research highlights the benefits and opportunities of using these techniques.

1.2 Research aims and objectives

1.2.1 Research aims

The primary aims of this research are to quantify and understand the spatial and temporal change in land degradation within the Al-jabal Alakhdar region.

The secondary aim is establish whether theoretical models can be successfully applied to aid interpretation of the various variables that cause or resist change, establishing any the limitations and improvements required of any such model.

1.2.2 Research objectives

- To determine and evaluate temporal changes in land cover from 1984 to 2008 using remote sensing and GIS mapping, to produce a current land use map that is accurately assessed via field survey.
- To apply theoretical models to the 2008 land cover whose results can be verified by assessment in the field of observed land degradation and desertification.
- To interpret and evaluate the different land degradation and desertification that occurs, developing and improving the theoretical models where necessary. Any improved model should be verified by independent study.
- To review and summarise the causes of spatial and temporal changes in the study area.

1.3 Overview of the research strategy and methodological approaches

Remote sensing (RS) in combination with a Geographic Information System (GIS) can be used to collect and present information on land use and land cover. Techniques such as satellite imagery were used here in the documentation of the natural vegetation cover of a specific piece of land during a specific historical period to follow up the changes in extent or condition and to identify reasons for changes. In this study, a remote sensing technique was used to classify four satellite images data (Landsat) that were taken at different times: 1984, 1992, 2000 and 2008. The satellite images demonstrate where temporal changes have occurred and highlight that change detection approaches can be highly beneficial for gaining insights about land use patterns at both small and larger scales. In order to understand the degradation and desertification and subsequently promote better land management, two theoretical models were applied to the study area: the MEDALUS method (Mediterranean Desertification and Land Use) and the USLE (Universal Soil Loss Equation) to investigate land desertification in study area. In GIS land cover 2008 map was used to generate a land use map to be used as base data map for MEDALUS and USLE. Kosmas et al. (1999) reported that the MEDALUS method identifies areas that are threatened by desertification. This was based on four indicators, which are soil quality, vegetation quality, climate quality and land management quality. The land degradation can also be evaluated through prediction of the amount of soil erosion, derived from USLE. This was based on five major factors (rainfall pattern, soil type, topography, crop system, and management practices) which were computed from the databases in GIS. MEDALUS and USLE required improvement to increase accuracy during their application.

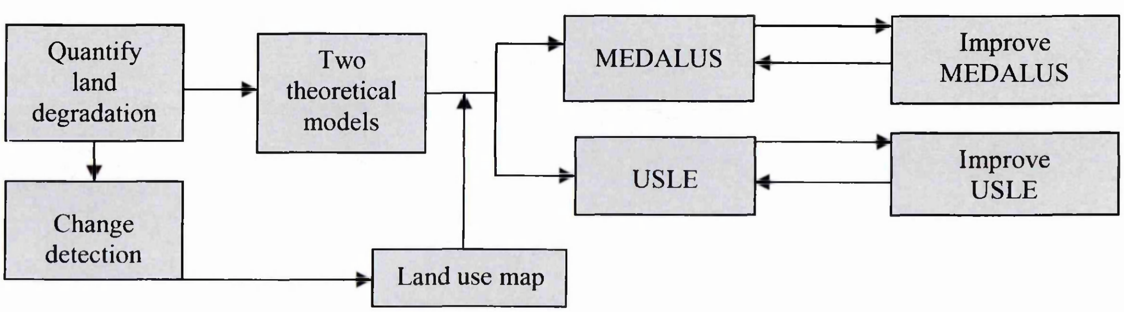


Figure 1.2. Schematic diagram showing application of methodologies &models for the land cover changes, MEDALUS and USLE.

CHAPTER 2

ENVIRONMENTAL CONDITIONS OF AL-JABAL ALAKHDAR REGION

2.1 Vegetation cover in the study area

Vegetation cover In Libya is restricted to the coastal the regions and is concentrated in Tripoli and Benghazi and their surrounded regions. Near Benghazi, Al-jabal Alakhdar is regarded as an island of vegetation, which begins at the coast and continues up to the highest areas (ACSAD 1984; Zohary 1973). In 1978, the area of forest in Libya was estimated to be around 6,680,000 hectares (Alzegt 1978). The current area of forest has not been measured, but it is believed that it has been subjected to destruction and as a result has shrunk in size over a very short period of time (Al-Zani 2002). The area is dominated by Mediterranean-type vegetation, with the environment and associated plant and animal ecology being very similar to areas such as Syria, Italy, the Greek islands and Turkey. Al-jabal Alakhdar represents about 1% of the country's total area but it contains about 50% of its total plant species: 1,100 out of the 2,000 species found in Libya (Zaed et al. 2005).

Many plant species are present in the study area, including trees, shrubs, grass and crops. Some are annual and others are perennial or evergreen. The vegetation cover is exposed to degradation and some species have become almost non-existent because of human activities. The trees can be considered as either regional or imported plants. The majority of regional trees fall under the heading of Mediterranean vegetation. The majority of imported trees come from Australia and cover less than 1% of the study area. All the vegetation cover in the study area can be considered drought-resistant and gives a high level of protection to the soil from water erosion; however, the majority of such cover is not fire-resistant (Zaed et al. 2005).

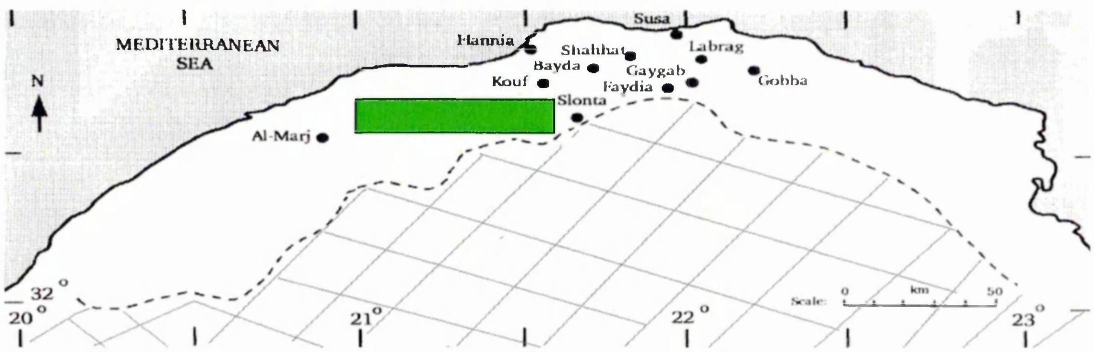
There are a number of different types of trees in the study area, such as Phoenician Juniper (*Juniperus phoenicea*) and Stinking Juniper (*Juniperus foetidissima*) These two species are about 4 to 6 metres tall, are considered to be Mediterranean evergreen vegetation, and cover about 70% of the study area. The distribution of these types differs from one sub-region to another, because in Gandolla they are widespread and cover more than 80% of the land area whereas in Almishal they coverless than 10%. Some plant species are absent from well managed land or where there is soil of good quality, but are commonly found when desertification has occurred, such as Pyrenean Thistle and Musk Thistle (*Carduus nutans*), so their presence can be used as indicator species to identify the existence of desertification (Al-Zani 1996; Zaed et al. 2005).

The absence of some types of plants and the presence of others indicate some level of degradation in these areas. Many types of plants are threatened with extinction or disappearance from the study area, as they are very rare or are subjected to destructive human activities (Al-Zani 1996). For example, only very small amounts of large berried Juniper still exist in Al Bayyadah. Only a few Desert Pistachio trees are still present, very close to Taknis. Gum Sandarac might have been already exterminated. The Three-lobed Sage (*Salvia triloba*) is threatened as it is being extensively harvested and consumed as a flavouring for tea and as an alternative medicine by the local population. Trees such as the Kermes Oak are being extensively felled owing to the high quality of the charcoal that can be produced. Buckthorn is under grazing pressure because it is palatable to livestock and Thyme is subject to uncontrolled overgrazing and harvesting by the local population. The spread of some invasive plants such as Lotus and Burnet, Pyrenean Thistle and Santonica Wormseed that grow rapidly in a place that is not considered to be their usual environment is an indication of major ecosystem stress. The above activities indicate there is evidence of poor management of the land which may lead to a decline in soil condition and a reduction in the amount of vegetation cover provided by trees and shrubs.

The natural vegetation in the south-east of the study area is of low quality owing to intensive human activities. The area has witnessed the extinction of a number of annual plants and evergreen bushes. Indications of deterioration include different forms such as the reduction in the growth rate of plants. The role of land use in causing vegetation decline in the study area is strongly indicated. Intensive overgrazing is considered a clear cause of the deterioration in the natural cover. Destruction of the natural vegetation cover and the start of crop cultivation can also lead to desertification because growing crops year after year in the same piece of land leads to soil erosion (Ali 1995).

2.2 Climate information

Rainfall varies across the geographical region of Al-jabal Alakhdar. The Al-jabal Alakhdar region has more rainfall than other regions in Libya, with an average annual rainfall of 400 mm $yr^{-1}$and a maximum of 650 mm yr^{-1}. The maximum average annual rainfall is 560 mm in the city of Shahhat, and levels fall gradually east, west, north and south of this region, with less than 350 mm in Faydia. There is much less rainfall in the south of the region (Figure 2.1). The following data represent a summary of the climatic elements in the Al-jabal Alakhdar region. The region is characterised by a moderate-to-warm climate, varying by month and geographic location, with average temperatures between 10 and 30 degrees Celsius, and an average minimum temperature of 1.5 degrees Celsius. Moreover, the climate is cold in the winter and warm in the summer. The average relative humidity is about 60% from April until the end of September, and reaches 90% in December and January. The majority of the prevailing winds are westerly in winter and north easterly in the summer. Southerly winds also blow in the region. The average wind speed ranges between 8 km hr^{-1} and 12 km hr^{-1}, sometimes reaching 45 km hr^{-1}, especially in south Al-jabal Alakhdar.



Key:
Precipitation>350 mm/year — Precipitation<350 mm/year — Location of study area

Figure 2.1. Map of average annual rainfall for the Al-jabal Alakhdar region including the study area.

Figure 2.2 shows a comparison of the two periods in terms of the annual rainfall (mm) coloured green and average monthly temperature (°C) coloured yellow in the study area, between 1956 and 1972. In general, the amount of precipitation is variable; in 1961 the amount was 639 mm, which represents the highest amount during this period. In both 1970 and 1963, the amount was about 470 mm, which represents the lowest amount. The annual average amount of rainfall in this period was about 525 mm yr^{-1}. The line graph of temperature was variable; in 1956 the average temperature for the year was 12.3°, which represents the lowest in this period. In 1972, it reached the highest level of 17.2°C. The average monthly temperature was 15.7°C.

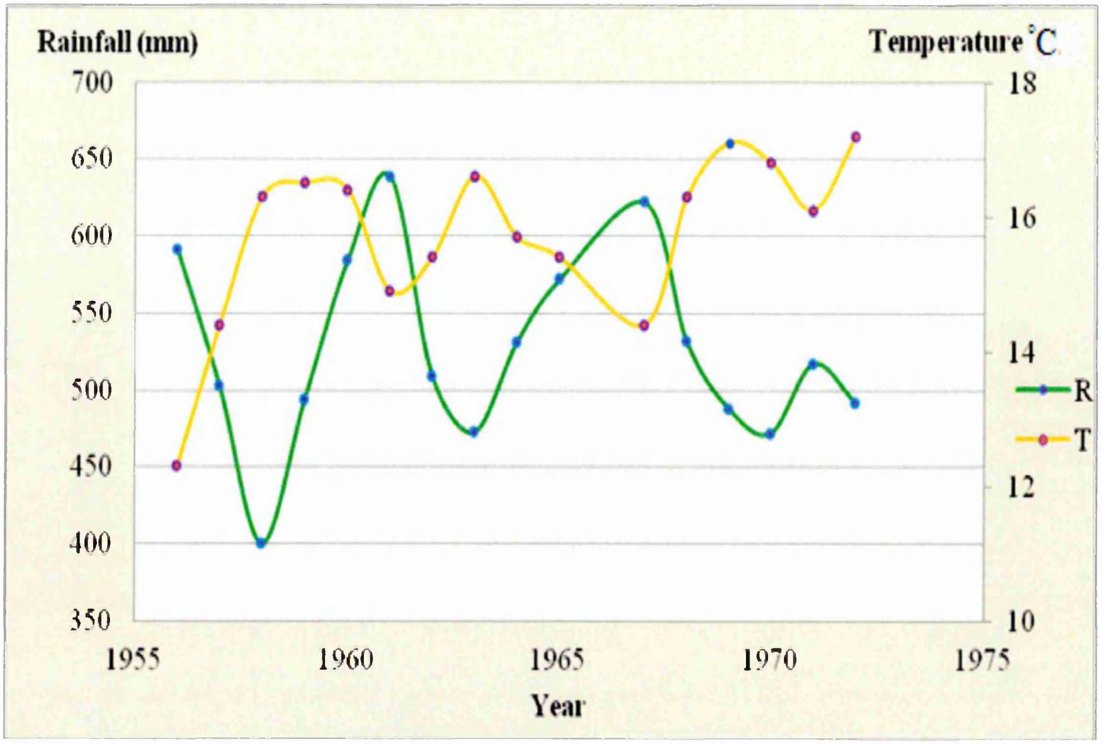


Figure 2.2. Average monthly temperature (°C) and precipitation (mm) in the study area, 1956-1972 (Libyan Meteorological Department 2011).

Figure 2.3 shows rates of precipitation and temperature in the study area from 1978 to 2010. The average rainfall is about 450 mm yr^{-1}. The line graphs compare two period of time in terms of average monthly temperature (°C) and annual precipitation (mm) in the study area between 1978 and 2010. It is clear that precipitation was greatest in 1979, 1982, and 1991. The most dramatic decreases were seen from 1985 to1990, and from 1993 to 1997. The period from 2000 to 2010 showed fluctuation. The temperature line graph shows the average highest and lowest temperatures for the study area. The highest temperatures were in 1993, 1998 and 2010. The lowest temperatures were from 1978 to 1987, and in 1992, 2000 and 2008. Highest and lowest temperatures ranged between 16 degrees C and 18.5 degrees C.

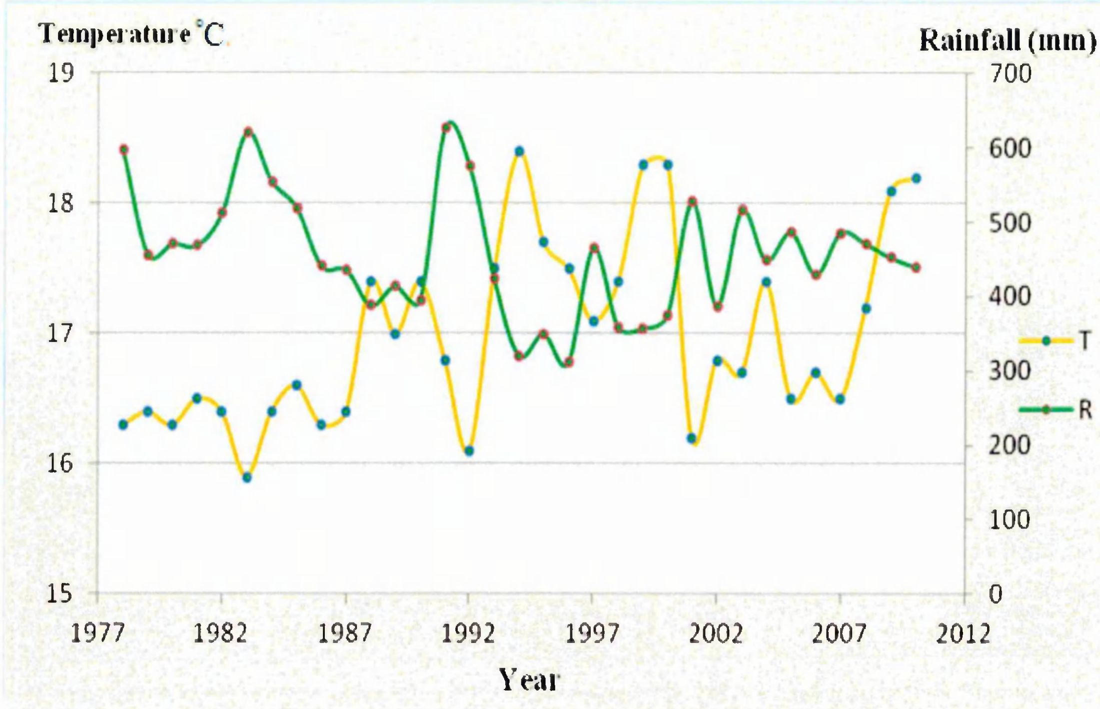


Figure 2.3. Average monthly precipitation (mm) and temperature (°C) in the study area, 1978-2010 (Libyan Meteorological Department 2011).

There were significant variations in rainfall and fluctuations in temperature in the study area in the two periods, from 1956 to 1963, and 1978 to 2010, as illustrated by Figures 2.2 and 2.3 respectively. It is clear that the temperature and precipitation are almost inversely proportional, except for some anomalous points. Figures 2.2 and 2.3, show that there was a considerable difference in the rate of rainfall between 1956 and 1972, and 1978 and 2010. The average rate was about 525 mm yr^{-1} in the first period (1956 to 1972), and about 450 mm yr^{-1} in the second period. In terms of temperature, there was a slight increase between 1956-1972 and 1978-2010; average temperature in the first period was 15.7°C and in the second period 17°C.

The average monthly temperature and rainfall are shown in Figure 2.4. The two variables are generally inversely proportional. During the summer season (June, July and August), the temperature is about 25°C and precipitation is less than five mm. Drought during summer affects all vegetation cover and leads to a complete death of the annual grass. However, the remaining seasons have low temperatures and higher precipitation, particularly between November and March. However, large amounts of precipitation can cause soil erosion, particularly if there is no land cover and the soil is bare.

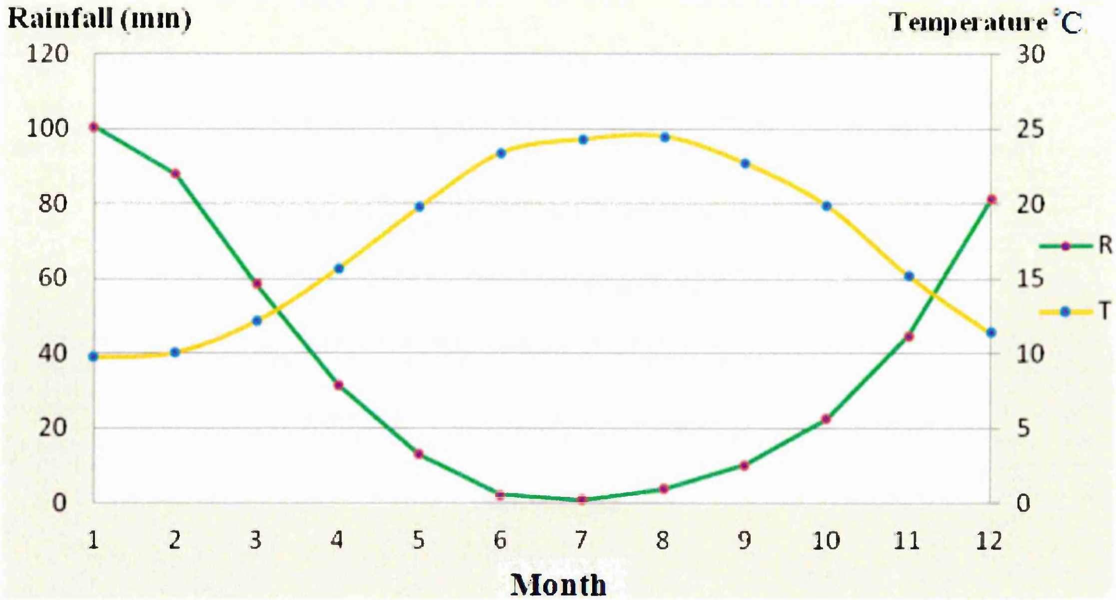


Figure 2.4. Average monthly precipitation and temperature in the study area, 1978- 2010 (Libyan Meteorological Department 2011).

2.3 Soil information in the study area

The soils in the Al-jabal Alakhdar region have been studied extensively (Selkhozpromexport1980) and exhaustive reports have been published (Ben-Mahmoud 1995; Selkhozpromexport 1980; Zaed et al. 2005). The information that has been gathered includes soil organic matter (SOM), $CaCO_3$ percentage, pH, cation exchange capacity (CEC), major soil nutrients, electrical conductivity of soil (EC) and soil depth.

Since the early seventies, numerous soil surveys and classification studies have been carried out in different parts of Libya. These were conducted by various foreign agencies. The most important soil classification was done by Selkhozpromexport (1980), and a 1:50,000 soil map covering all Al-jabal Alakhdar was produced. The soil classification systems used in these reports are the USA soil taxonomy, the modern soil classification of Russia and the FAO/UNESCO system (Table 2.1). The soil subgroups in the study area are Calcic Rodoxeralfs, Gleyic Rodoxeralfs, Typic Rodoxeralfs, Lithic Sombric Rendolls, Lithic Rhodic Rendolls, Typic Xeropsamments, Lithic Xeropsamments and Calcic Xerochrepts.

Soil subgroup American classification	Russian classification	FAO& UNESCO classification
1- Calcic Rodoxeralfs	Red ferrisiallitic Typical Carbonate Soils (Ft)	Calcic Chromic Luvisols
2- Gleyic Rodoxeralfs	Red ferrisiallitic Hydromorphic Soils (Fhd)	Gleyic Chromic Luvisols
3- Topic Rodoxeralfs	Red ferrisiallitic Typical Leached Soil (Fi)	Chromic Luvisols
4- Lithic Sombric Rendolls	Rendzina Dark (RZ)	Rendzic Leptosols
5- Lithic Rhodic Rendolls	Rendzina Red (RZr)	Rendzic Leptosols
6- Topic Xeropsamments	Reddish Brown Arid Brown Arid Soils (FBd)	Regosols Xerosols
7- Lithic Xeropsamments	Reddish Brown Arid Crust Brown Arid Crust (Lfb)	Regosols Lithosols
8- Calcic Xerochrepts	Siallitic Cinnamonic Carbonate Soils (CSt)	Calcic Cambisols

Table 2.1. Soil taxonomy classifications to the subgroup level for the study area (Ben-Mahmoud 1995; Selkhozpromexport 1980).

In this research, the original soil data gathered by Selkhozpromexport (1980) were reclassified using the USA soil taxonomy system (Table 2.1), and digitised to generate soil classification map (Figure 2.5). The forest soil represents about 30% of the study area and includes Calcic Rodoxeralfs (Ft), Gleyic Rodoxeralfs (Fhd) and Typic Rodoxeralfs (Fi). Grass and savannah soil represents about 60% of the area and includes Lithic Sombric Rendolls (RZ), Lithic Rhodic Rendolls (RZr). Undeveloped soils (10% of area) are identified as Typic Xeropsamments (FBd), Lithic Xeropsamments (Lfb) and Calcic Xerochrepts (CSt). This map is an essential step in identifying soil quality and is used in later modelling of the study area. The depth of soils are classified as deep (>75cm), moderate (30-75cm), shallow (15-30cm), or very shallow (<15cm), and they are all well drained. All soils are alkaline with pH values between 7.2 and 8.5, but the soil texture varies depending on location. The majority of soils have a moderately fine texture, including sandy loam, loam, sandy clay loam, salty clay loam, clay loam and clay.

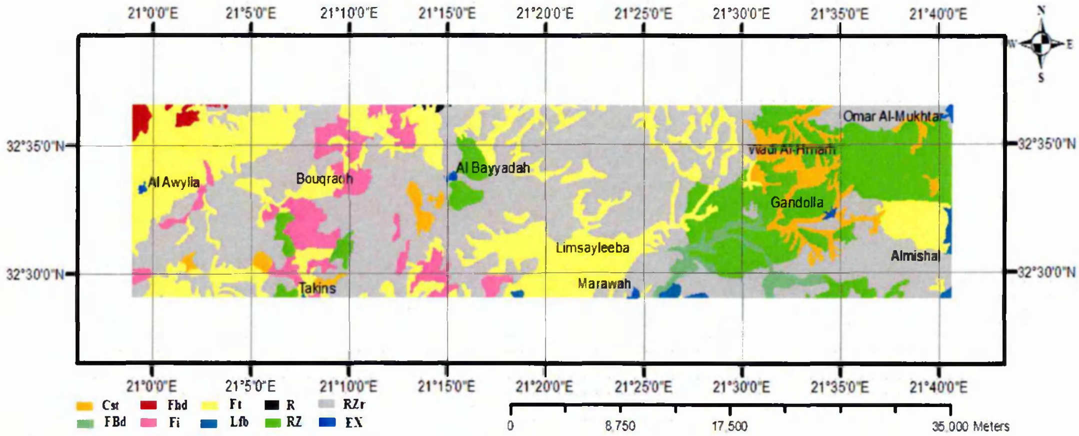


Figure 2.5. Soil classification by Selkhozpromexport (1980).

Original soil profile information was established from boreholes drilled on a grid of 700m by 700m (Selkhozpromexport 1980). Transfer of this information from the paper archives to GIS databases was performed specifically for this study and was necessary to undertake modelling. The data include information on land texture, parent material, rock fragments, depth, slope and drainage, all of which is necessary for evaluation of the overall quality of the soil. Information on each of these contributing variables to the soil quality is now discussed.

2.4 Land management in the study area

Many measures have been applied to fight against desertification in the study area in the last four decades. These have formed a part of the broad National Agricultural Development Plans, which were regarded as highly important by the government. The severe conditions, to which the study area is exposed, such as dry climate, scarcity of water, limited land area and human activity, were taken into account. Some of these attempts succeeded and others met less success. If degradation is to be prevented, the natural vegetation has to be managed in a manner that increases the awareness of its value and of the hazards of its deterioration. Degradation of vegetation cover and the lack of good management are intimately connected to the change in vegetation cover and acceleration of soil erosion (Anjum et al. 2010). The following are some of the policies, actions and measures initiated to conserve land resources and to combat desertification and land degradation:

Year	Law
1966	to conserve and protect plants from deterioration
1971	to establish centres for agricultural research
1975	to protect sparse lands from cultivation
1980	to establish a National Authority for Scientific Research
1982	to protect forests from deforestation, and sparse natural vegetation
1982	to conserve the environment by protecting it from rubbish and garbage
1982	to limit drill water wells and to maintain water sources
1983	protection from urban expansion
1983	to embark on huge and costly investment projects aimed at economic development
1984	to protect trees from illegal charcoal making
1988	to establish an Arab Centre for Desert Research and to develop desert communities
1992	to protect farm lands and to utilize alternative sources of irrigation water such as treated sewage water and spring water
1998	to create financial penalties for illegal deforestation, based on the tree type and age
2000	Supported projects for vegetation cover development, reforestation, watershed management of water resources and soil conservation
2000	Banned the cultivation of hilly areas
2001	Organized ploughing time and depth for each soil type
2000	Banned the cultivation of barley and wheat in areas more sensitive to desertification
1983	Regulated irrigation in relation to the time and type of plants

Table 2.2. Agricultural laws (Agricultural Research Centre 2010).

In the study area, policies are currently insufficient to protect the land from degradation. This is due to the limited nature of some of the policies and the fact that even good policies may be only weakly enforced. A review of the application of policies in several other countries found that policies varied because of environmental and ethnic differences, and were implemented to varying degrees.

The existence of land use policies at a national level (Table 2.2) was explored through a long search of the Tripoli agricultural library in Libya where the relevant legal documentation is routinely archived. This search was supported by thematic expert interviews. This investigation suggests that land use policies in the study area are complex; land use policies can be argued to exist but their transparency and implementation is weak because of strong and extensive administration and bureaucracy. Planning for land use is embedded under the issues and procedures of land policy. This means that land use is mostly determined by the prevailing structures and systems of landownership. Land use planning and policy issued by the government and ministerial operators; therefore land use policies cannot be said with certainty at the moment to properly protect the land from desertification or degradation. In the study area the need of integrated coordinated land use policy can be strongly argued, improvements in land policy could be achieved by a new environmental policy approach. In the absence of presidential circular the responsibilities of the different ministries cannot be presented in detail. The administrative system of land use policy is not based on the regional ministerial offices because they have no responsibility for the regional implementation of the national programs and plans. Land use policy has not been taken very seriously in the study area, as a clear national coordination of the land use affairs has been missing. The various and multiple laws for the land and environment do not provide proper guidance for the regulation of land and its use. The field of land use policy is quite confusing and hidden behind the shadows of laws, administrations, bureaucracy and conceptual complexity. The governing of land use has no sufficient knowledge on land use environmental policy and has been carried out through bureaucracy rather than policy making. In the study area, enforcement of government policies or even their development may be perceived to be in conflict with local personal interests and as a constraint on local income generation, even though activities may not be giving proper consideration to degradation. The protection policies indicator should be improved to include information on the effective implementation of policies, but is outside the scope of this research. There are some policies that regulate the impact of human activities on desertification; however, some important policies, such as reducing overgrazing, have not been published or considered.

According to Cao et al. (2011), policies and laws that protect and conserve land cover, such as the prohibition of logging and grazing, reductions in the areas of cultivated land and the maintenance of natural vegetation cover, should be prioritized because they are more important than environmental restoration and re-growth programmes.

There are many options for sustainable land management techniques, which must be suitable, applicable, and adaptable to the environment in the local conditions. They must be assessed and negotiated prior to implementation, with the integration of land users and local knowledge (Gabathuler et al. 2011; Kapalanga 2008). Increasing awareness of degradation amongst scientists and policy makers is now an urgent requirement (Duncan et al. 2010; Schwilch et al. 2012). Researchers in natural sciences should be enabled and encouraged to apply a holistic approach and tackle a complex problem together; this will contribute to more sustainable management (Schwilch et al. 2012).

In the study area, the number of sheep and goats has increased rapidly by 238,872 animals from 124,275 in 1984 to 363,148 animals in 2008, as can also be seen by the average stocking rates for each region in the study area (Figure 2.6). There is an absence of strong regulations and laws to control grazing and livestock populations.

The intensity of grazing in the study area depends on:

- type, weight and age of animals
- number of grazing hours per day and year
- type and density of pasture, which depend on the annual rainfall (Albargathy 2010).

The number of animals in the study area has increased beyond the normal pasture capacity level, which Albargathy (2010) estimates is about 2-3 animals per hectare with less than 15 hours of grazing a day in the whole year.

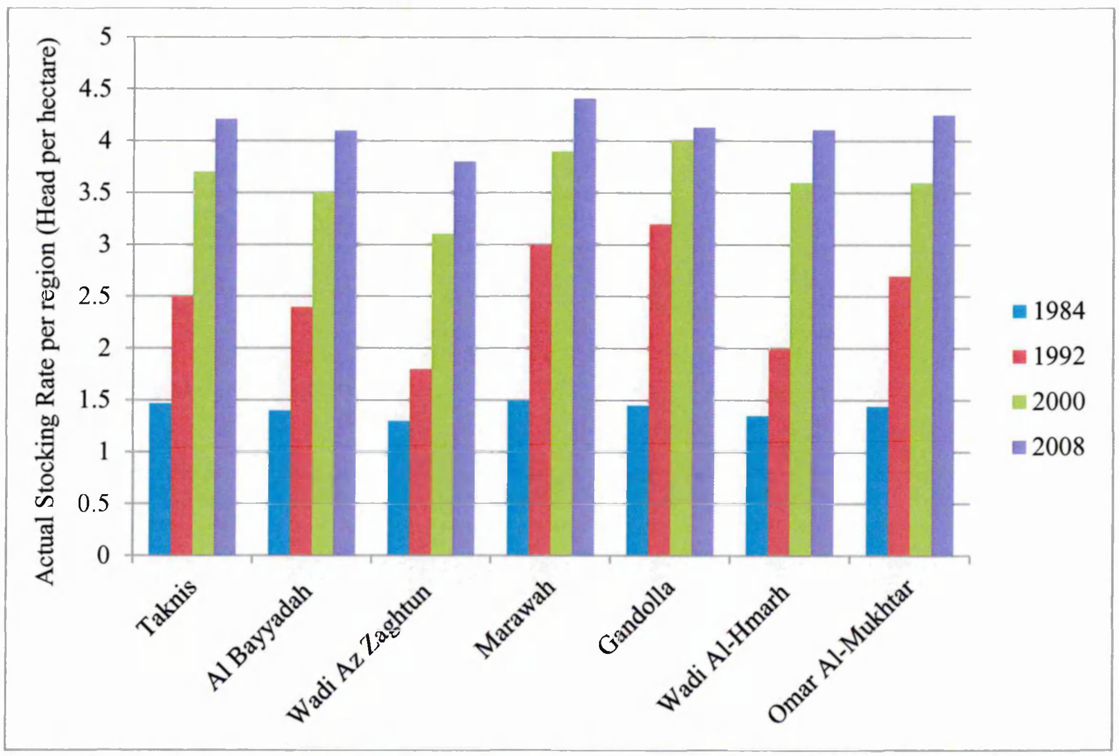


Figure 2.6. Number of goats and sheep in the study area between 1984 and 2008 (Agricultural Research Center 2011).

2.5 Conclusion

Degradation of vegetation cover and lack of good management are intimately connected to accelerated soil erosion. One of the main aspects of mismanagement is weak local government policies and lack of enforcement for protection and conservation of the land cover. Policies are either improperly applied or not applied at all.

CHAPTER 3

DEFINITION OF LAND DEGRADATION

3.1 Land degradation and desertification: definition

Land degradation in arid, semi-arid, and dry sub-humid lands (dry lands), resulting from various factors including climate variation and human activities, leads eventually to desertification. In addition to this, irresponsible human action can easily trigger desertification in the semi-arid and dry sub-humid zones of the Mediterranean region. Degradation has occurred as a result of various types of poor management, including unwise strategies of cultivation implemented by farm owners such as clearing of vegetation and harvesting activity (Pinto-Correia and Mascarenhas 1999). The true value of any land cannot be measured or fully appreciated without taking into account the significance of human activities. Since mechanization arrived in the 1950s in Mediterranean regions, on mountains and steep hill slopes, many changes have occurred to the traditional farming systems that depend on annual or permanent crops (Caraveli 2000). These changes are leading to rapid and irreparable environmental degradation through their effect on vegetation and management systems (Clarke and Rendell 2000; Garcia-Ruiz et al. 1996). Policies and strategies which are designed to support sustainable use and systems management are required (Andersen et al. 2007; Onate and Peco 2005; Rasul et al. 2004; Thapa and Rasul 2005; Van Wesemael et al. 2006).

3.2 Processes and causes of land degradation and desertification

Land and people are two essential and complementary parts of any culture and they have a profound impact on its aspects; these two elements affect the development and productivity of any district and its relationship with other regions. Human activities at any location may involve a shift to a different, inappropriate, land use or an increase in the pressure on the land due to mismanagement.

3.2.1 Processes of land degradation and desertification

Desertification sets in when humans disturb natural equilibria by over-exploiting natural resources. Human actions are largely intentional and, though often based on ignorance, are mostly driven by rising need and/or greed. Overexploitation of natural resources such as inappropriate agricultural practices and overgrazing are seen to spur degradation of land that relates to degeneration of soil and vegetation cover (Rapp 1974). There are many processes of land degradation: according to FAO (1984), the main processes are soil degradation, soil erosion and vegetation cover degradation (Figure 3.1).

This typically increases soil erosion, soil depth reduction, impaired fertility of the soil, and loss of organic matter (Hogan 2009), and encourages diminished land productivity and biodiversity and increased desertification. The soil erosion processes are a major global environmental problem and are responsible for land degradation (Ten Caten et al. 2012; Tosic et al. 2012; Wu and Chen 2012). In semi-humid and semi-arid areas, water erosion and the related loss of soil nutrients are the main problems (Kosmas et al. 1999). In dry lands (semi-arid and arid areas), wind, erosion and salinization are the dominant problems. In the Mediterranean regions, water erosion and agricultural mismanagement are the major causes of land degradation (Benmansour et al. 2013; Blanco-Moure et al. 2012; Martinez et al. 2012). Water erosion is directly controlled by a number of factors that interact with one another: climate, vegetation, soil properties and topography (Haboudane et al. 2002; Kirkby and Cox 1995). In semi-arid lands, water erosion is a major source of soil degradation; combined with vegetation cover destruction, it contributes to an increase in land degradation risks (Haboudane et al. 2002). According to Koohafkan and Ponce-Hernandez (2004), the processes are complicated and including those arising from human activities, soil erosion, deterioration of the physical, chemical and biological and long-term loss of natural vegetation. These conditions occur in combination with social, political, economic, and cultural factors to affect land in a negative way.

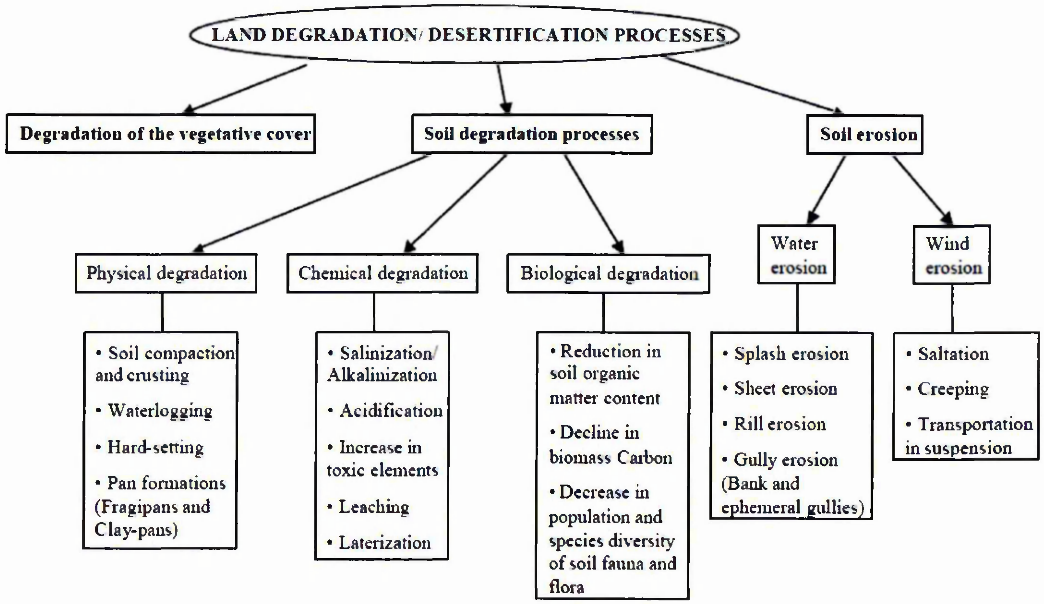


Figure 3.1. Main desertification and land degradation processes (Denti 2004).

3.2.2 Causes of land degradation and desertification

In the Mediterranean Basin, wild fires burnt 200,000 hectares in the 1960s and about 600,000 hectares in the 1980s (Lehouerou 1993). The unrestrained expansion of cities and their suburbs into rural areas causes urban sprawl, leading to many drastic consequences, with farmlands converted to roads and houses to accommodate the growing population. Industrial development has also taken place at the expense of natural lands (Kong et al. 2012; Paulsen 2012; Wang et al. 2012b). In the early years of the twenty-first century, attempts to improve EU agricultural policy led to increases in forest and shrub-land areas while farmland shrank by about 1% (Lehouerou 1993). So management of livestock grazing and sustainable agriculture are the first step and the foundation of mitigating the effects of degradation (Hardin 1968; Rayburn 2000). Many practices have been applied to manage grazing distribution; for example, distributing grazing pressure evenly and avoiding localised overgrazing, fencing to control movement of stock, development of water resources, application of fertilizer, salt placement and supplements, and planting special types of forage that can be used for grazing enhancement in under-utilized areas. Grazing management offers a further advantage for the grassland: it is possible for the farmer to allocate relatively small areas of grass for conservation, which helps the pasture to re-grow (Czegledi and Radacsi 2005).

Overgrazing occurs when the vegetation cover faces intensive grazing for an extensive period, if there is not enough recovery time. Overgrazing can mean the almost total elimination of vegetation cover through grazing and trampling effects of high densities of herbivores (Henry and Gunn 1991). The reasons for its occurrence are livestock in weakly controlled agricultural applications and overpopulation by wild animals, whether native or not; the grazing effects depend on the time, intensity and frequency of grazing, and the chance for the plants to re-grow (Czegledi and Radacsi 2005). Overgrazing can cause many problems, such as diminishing the productivity of the land and its biodiversity, and desertification. It is also responsible for spreading invasive species of weeds. Intensive pressure of grazing reduces the density of the plants, which causes many changes in the pasture's botanical composition, as well as leading to a decrease in the productivity of the forage grasses (O'Farrell et al. 2007). Typically, overgrazing increases and causes soil erosion, soil depth reduction, impaired fertility of the soil, and loss of the soil's organic matter (Hogan 2009). To mitigate the loss of soil fertility, appropriate organic fertilizers and soil treatments may be applied. According to Hardin (1968) and Rayburn (2000), management of grassland, management of livestock grazing, and sustainable agricultural practices are the first step towards mitigating the effects of overgrazing and keeps pastures healthy and productive. The grazing can be controlled within the pasture's capacity to ensure adequate soil quality and vegetation (Petean et al. 2010).

Denti (2004) stated that there are many global causes of degradation, which are divided into two main categories: indirect and direct (Figure 3.2).

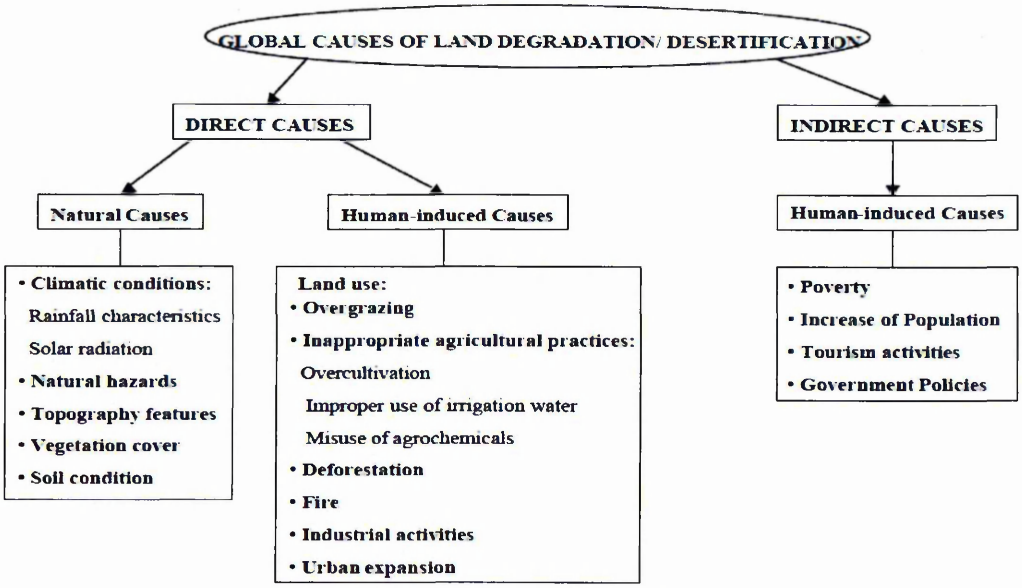


Figure 3.2. Main causes of desertification and land degradation (Denti 2004).

Pressure to convert from natural vegetation to crops has arisen from a drive to improve food security (Beddington et al. 2012; Dulal et al. 2012) at both national and individual levels.

Locally, increased land terracing has been widespread, but is often poorly considered, as the natural and chemical land characteristics, such as soil depth and parent material, may not have been taken into account. For example, orchard planting has often been unsuccessful as the majority of the soils in the region are insufficiently deep and have a high pH (Ben-Mahmoud 1995; Selkhozpromexport 1980).

Lack of income and increase of family size to 6-10 persons supported by just one salary which is not enough to meet family requirements has resulted in unprecedented efforts, such as cultivation for food, feed, or hay production, overgrazing and cutting of trees for charcoal, to provide the requirements of living, increase crop yields and maximize profit (Yagoub and Assaadi 2007). Agricultural practices introduced on sloping land under cultivation in the eighties and early nineties have been identified as a major contributor to soil degradation (Zaed et al. 2005). Farmers' training and farming efficiency have lagged behind, owing to the government's negligence as well as its failure to build the skills of land users. There are not enough agricultural education institutions and they have not implemented new approaches in their curriculum, such as sustainable land use management (SLM) and interactions between SLM planning, socioeconomic status, and the education and behaviour of residents.

However, agricultural education institutions must improve quite rapidly, and should modernise their curricula, since education is the key component in maintaining viable land cover to promote SLM.

Increase in goat, sheep and camel livestock populations has resulted in overgrazing, in the absence of strong laws and regulations (Zaed et al. 2005). Farming at the expense of natural cover, over-grazing and fuel fetching were identified as the most effective causes of natural cover degradation (Abu Hammad and Tumeizi 2012; Meshesha et al. 2012; Mwalyosi 1992; Yiran et al. 2012). Intensive pressure from grazing reduces the density of the plants, which causes many changes in the pasture's botanical composition, as well as leading to a decrease in the productivity of the forage grasses (O'Farrell et al. 2007).

There have been a number of local studies in the study area that have aimed to describe soil and vegetation degradation, soil classification and soil erosion, at a scale of 1:50,000 (e.g. Selkhozpromexport1980; Zaed et al. 2005). However, the results of these studies are not integrated in a theoretical framework, which does not assist in understanding whether observed land degradation is a recent or a historical issue, or allow identification of its causes.

3.3 Assessment of land degradation and desertification

There are many different approaches for assessing land degradation and desertification but there is no single best global method because they are mainly based on expert opinion. Nevertheless, field observations and measurements, productivity reductions, estimations of land users, remote sensing and modelling are essential approaches for assessing of land degradation. Land degradation assessment is complex as many types of degradation can occur in one place; consequently, using the same methods, tools and approaches for assessing different types of degradation in one place is difficult. Several methods have been developed and justified to gather as much useful data as possible based on its study area and data availability.

Monitoring the locations and distributions of land-cover changes is important for assessment of degradation and establishing linkages between policy decisions, regulatory actions and subsequent land-use activities. Using satellite data in change detection provides an appropriate and consistent estimate of changes in land-use trends over different size scales (Prakash and Gupta 1998). A unified land cover classification scheme has been established for classification of images (Zhou et al. 2008), and some studies have used Thematic Mapper (TM) to classify data (Li et al. 2004; Xiuwan 2002). A spatial resolution (Landsat-TM) at a scale of 20 to 30 m will be acceptable for land use classification (Lilles and Kiefer 1994). This study applies techniques to the study area using Landsat TM and Enhanced Thematic Mapper Plus (ETM+) satellite data to identify and classify land cover (i.e. vegetation, urban areas, shrubs, bare soil, rain-fed and irrigated land) over a 24-year period at 8-year intervals, from 1984 to 2008. This enables changes in land cover to be detected and the compiling of long-term land cover histories (Duncan et al. 2010). Supervised classification and post-classification detection techniques applied to Landsat images with visual interpretation give a general idea about the forms of land cover changes (Shalaby and Tateishi 2007). Because of limitations such as the temporal resolution of the Landsat TM image and image classification techniques, visual interpretation is an efficient method for classifying complex and heterogeneous landscapes. Kappa statistical analysis and error matrices can be used to test the accuracy of the classification of the land cover map with ground truth data (Guler et al. 2007; Jensen 1996).

The use of remote sensing can generate a land cover map which provides many benefits for tracking land cover changes (Guler et al. 2007; Koruyan et al. 2012; Wu and Zhang 2012). These allow any region to be studied at different periods of time, making it possible to monitor and record the past or current status of a certain region (Bharti et al. 2011; Ediriwickrema and Khorram 1997; Peng et al. 2011; Raj and Kumar 2012). Special attention has been paid to change detection for understanding the causes for positive and negative impacts on land cover (Pungetti 1995). Change detection is the most commonly used quantitative method to identify land cover and land use changes in a study area (Guler et al. 2007; Wu and Zhang 2012). Remote sensing can map directly many areas under some specific desertification process; assessment and monitoring of vegetation degradation and erosion (Ostir et al. 2003). It was shown that in certain cases, land cover analysis allows identification of specific features of desertification, (FAO 2005). Remote sensing is the most effective and efficient tool to assess temporal changes even in small scales, however it will never allow observation of or identify the causes, levels and types of degradation (Lantieri 2003).

In the 1980s, GIS started to be introduced in land use planning departments (Eastman 1999). When using GIS, a researcher generally gathers a variety of information on separate subjects such as vegetation, soils, climate, topography and geology that is organised in individual layers. Detailed knowledge of the landscape is required when classifying such natural aspects. These separate layers of information can then be laid over one another at any single position or area that is of interest. GIS is therefore used for storing and retrieving the existing database information, analysing and integrating it and then generating interpretative maps based on data attributes (Burrough 1991).

The data manipulation and analysis function determines the information that can be generated by the GIS (Aronoff 1991). Manipulation and analysis refer to the retrieval of data from the geographical database and the creation of new information by combining these data; the analysis and manipulation are done through GIS commands and functions (Tomlin and Johnston 1988). Cartographic modelling has been successfully applied in fields such as environmental planning, land evaluation, and forest management (Burrough and McDonnell 1998).

Generally, the land cover and land use maps that are part of the GIS database are the result of a supervised classification of remotely sensed data and accuracy assessment, making use of GIS maps.

GIS is the most effective tool for managing this complex phenomenon as it is a mapping system with the capability to digitise maps, overlay spatial data and display the outcomes as maps. Within GIS, viewing and managing land cover components such as natural vegetation and soil types as well as climate and topography data is possible and all of such data can be analysed within one framework.

Application of an appropriate theoretical model may help identify the causes of land degradation, which is the first step towards its reduction. Land degradation has been assessed using a number of different methodologies, such as the basic principle of Global Assessment of Soil Degradation (GLASOD), which provides information about soil and land degradation and increases awareness for the need of soil and vegetation maintenance (Bridges and Oldeman 1999). GLASOD has been applied on a worldwide scale and its appraisal provides data on erosion intensity and distribution over the world as well as the types and degree of degradation (Bridges and Oldeman 1999). The maps of Oldeman et al. (1990) identified areas with a particular severity of erosion risk, irrespective of the causes that led to such erosion. Nonetheless, no remote sensing or field measurements have been included; it was based on expert opinions (Jones et al. 2003) and on responses to a questionnaire sent to recognized experts around the world. Some of the recognized experts did not answer the questionnaires at all and some answered few parts only, consequently, results produced from such types of models are not accurate, complex and hard to use for regional comparison (Jones et al. 2003).

Land Degradation Assessment in Dry lands (LADA) methodology considers biophysical factors and socio-economic driving forces. It is based on the DPSIR framework where D indicates the driving forces, P the pressures, S the condition of land and its resilience, I the impacts of the increased or reduced pressures, and R the responses by the land users to release or reduce the pressures on the land. The project is intended to make an innovative generic contribution to methodologies and monitoring systems for land degradation in Argentina, China, Cuba, Senegal, South Africa and Tunisia (Kapalanga 2008). Because LADA is concerned with soils for agricultural purposes it integrates land user opinion, field criteria, field monitoring and productivity changes (FAO 2005). In contrast, remote sensing techniques should be used to observe indicators such as land cover and land use change, vegetation clearing and fragmentation (Burning and Lane 2003).

To estimate soil erosion and to develop optimal soil erosion management plans, many erosion models, such as Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), Water Erosion Prediction Project (WEPP) (Flanagan and Nearing, 1995), Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998), and European Soil Erosion Model (EUROSEM) (Morgan et al., 1998), have been developed. Among these models, the USLE has remained the most practical method of estimating soil erosion potential in fields and to estimate the effects of different control management practices on soil erosion for nearly 40 years (Dennis and Rorke, 1999; Kinnell, 2000) while other process-based erosion models have intensive data and computation requirements. Although originally developed as an empirical model, revisions of the USLE could lead to a conceptual model that provides a capacity to extend well beyond the conditions experienced in the associated data set (Kinnell 2007).

Many refinements and revisions have been made to produce the Revised Universal Soil Loss Equation (RUSLE), but it overestimates soil erosion if the surface of soil has a high capacity to infiltrate rainfall; this is due to the lack of a runoff factor in the RUSLE (Risse et al. 1993). The degree of overestimation falls as the ability of the soil to produce surface runoff increases. A number of models have been developed to attempt to overcome inaccuracy in estimation of soil erosion by considering short time periods rather than over a year (Foster et al. (1982), Yu et al. (2001), Kinnell (2003), etc.) such as the Modified Universal Soil Loss Equation MUSLE (Williams 1976) which performed better than the Universal Soil Loss Equation (USLE) in estimation and prediction of soil loss (Arnold and Allen 1996). However, MUSLE estimates the overall loss of soil during a single rainfall event and so would require rainfall intensities from a number of gauges spread over the study area, which are not available here and so MUSLE is not appropriate for this study. Land degradation can also be evaluated through prediction of the amount of soil erosion using USLE methodology (e.g. McCool et al. 1987; Onyando et al. 2005; Pandey et al. 2007; Htun et al. 2008). Appropriate and consistent quantitative techniques for soil erosion estimation and prediction can be provided by USLE (Wang et al. 2009). USLE is particularly appropriate because it may enable a linkage to be established between land cover, topography, soil characteristics and farming practice and soil loss, particularly through water erosion (Lee 1994). USLE has been widely used to provide a quantitative and consistent approach for estimating soil loss in hilly areas (e.g. Wischmeier and Smith 1978; Wang et al., 2009). USLE has had an extremely profound influence on how research on the conservation of soil is conducted over the whole world. It is able to forecast the distribution of soil erosion spatial patterns and evaluate its causes (Wang et al. 2012a). The USLE holds many benefits because of a perceived ease of parameterization use and leads to a more conceptual approach that gives a flexible capacity beyond the experienced conditions in the related data set (Kinnell 2007). Although USLE has met with practical success as support for the reduction of soil erosion, it cannot simulate soil erosion as this is a dynamic process scattered through watersheds and time changing.

Land desertification can also be evaluated using the Mediterranean Desertification and Land Use (MEDALUS) method, which identifies areas that are threatened by desertification. MEDALUS has been used in Greece (Giordano et al. 2002), Italy (Basso et al. 2012), Portugal (Roxo et al. 1997), and many other countries such as Egypt (Ali and El Baroudy 2008; Gad 2010; Gad and Lotfy 2008) and Algeria (Benabderrahmane and Chenchouni 2010). MEDALUS has been used to assess and study the causes and responses that contribute to sensitivity to desertification of each fundamental land unit illustrating an Environmental Sensitive Area (ESA) and the interrelationship between land uses, land cover change and land degradation. In the context of the MEDALUS, a distinction is made between the processes of desertification in European Mediterranean environments and those which occur in some much dryer regions. Although both models have been used in the Northern Mediterranean area, neither has previously been applied in any region of Libya.

3.3.1 Universal Soil Loss Equation (USLE) methodology

According to Lal et al. (1998), there have been many research studies on specific areas to assess the impact of soil erosion on land degradation using USLE (Universal Soil Loss Equation), in particular erosion by water. The National Runoff and Soil Loss Data Centre in cooperation with Purdue University developed USLE. During the 1960s in the US Midwest, USLE was applied in the field, and subsequently this method has been widely used in many parts of the United States and has been used extensively for predicting soil loss in hilly areas (Wischmeier and Smith 1978). The development by Wischmeier and Smith (1978) of a system of equations for calculation was helpful for ecologists in developing conservation reserves and agricultural land guidance. USLE has been used extensively because of its ease of application. It has been designed to forecast long-term soil losses where there are also effects of short-term fluctuations. The FAO (1996) published the work by Wischmeier and Smith (1978) which developed the equation using data from 1958 to 1978 to estimate soil erosion in ten states in the USA. In addition, Htun et al. (2008) developed the Universal Soil Loss Equation (USLE) and applied it in Central Myanmar using GIS and remote sensing in an integrated database to illustrate all factors relevant to soil erosion. A GIS database includes all the USLE factors: soil quality will produce the soil erodibility factor (K); the topographic factors (LS) are generated from the topographic maps; the rainfall erosivity factor (R) is based on climate quality; and vegetation quality together with land management quality generates the crop management factor (C) and the erosion control practice factor (P). Then, a map is produced to demonstrate soil erosion that is called a land degradation map, which is particularly important. USLE has been widely used to provide a quantitative and consistent approach for estimating soil loss in hilly areas (e.g. Wischmeier and Smith 1978; Wang et al. 2009) and it is able to forecast the distribution of spatial patterns of soil loss and evaluate its causes (Wang et al. 2012a). There are some distinguishing features of USLE that are important for degradation assessment such as: it has made many positive impacts in several countries, and has been applied around the world, it can estimate the quantity of soil that will be affected by water erosion. It has been designed to predict soil degradation that will occur in the future and give an opportunity to maintain the agricultural land to avoid this risk. Its globally applicable equations have been developed to be suitable for some different environments and it has been developed and approved by many scientists (e.g. McCool et al. 1987; Harmancioglu 2002; Onyando et al. 2005; Pandey et al. 2007; Htun et al. 2008).

USLE was firstly developed to estimate water erosion in agricultural land, to identify the suitable crop for agricultural lands and to establish an empirical model for predicting erosion on a cultivated field. Erosion control specialists could then choose the kind of measures needed in order to keep erosion within acceptable limits given the climate, slope and production factors. However, researchers improved USLE to include degradation assessment in different environments based on each researcher or developer study area. R factor; Wischmeier and Smith (1978) stated that R can be calculated from expressions that describe the energy of a rainstorm and observed maximum rainfall intensities. The rainfall factor, R is calculated from the total energy E from the potential of falling rain drops and flowing water in a particular area to produce erosion (defined as the EI30 index where E is the total storm kinetic energy from maximum 30-min storm duration). This is extensively used in the USLE erosivity factor in many pieces in the world. This equation has been developed in Zimbabwe by Hudson (1971) and adds a new idea of $E > 25$ (total energy for intensities greater than 25 mm h^{-1}). According to (Elwell, 1977) in Southern Africa seasonal kinetic energy was used as the erosivity index. Lal (1976) believes that the EI30 is the best index in Western Nigeria and later applied to case studies in two areas of the USA and Brazil by Foster et al. (1982). Toy et al. (2002), Htun et al. (2008), Euimnoh et al. (2000) said that if E and EI30 are not available then an alternative could be used by calculating mean annual precipitation. C factor; Roose (1977), Singh et al. (1981), Hurni (1987), Hashim and Wong (1988) have set a range for determining values of C factor, which based on types of land cover. As the USLE has been used in a very wide range of different areas and as the protection provided by cover may vary, the C factor has been altered to suit individual study areas, as performed for example by Morgan (1995) and Htun et al. (2008). For the P factor, Wischmeier and Smith

(1978) stated that P value ranges between 0.2 to 1.0 where there are no erosion control practices; there are different ways to determine the value of P factor based on the requirements for a specific area such as Htun et al. (2008) calculated P by considering cultivation practices (ploughing time) and Lufafa et al. (2003); Fu et al. (2006); Terranova et al. (2009); Roose (1977); Chan (1981) used slope tillage in order to determine the value for the P factor. Factors C and P vary widely in many studies according to the land cover and type of human practice therefore each study or research has to adapt C and P to meet its requirements.

3.3.2 Mediterranean Desertification and Land Use (MEDALUS) methodology

This method lays emphasis on the choice of suitable indicators at regional and European level. Areas that are sensitive to desertification are identified by the combination of four quality parameters: a vegetation index, a land management index, a soil index and a climate index. For each of these, a GIS database is interrogated to produce separate digital map layers (Kosmas et al. 1999). The land use map provides an accurate interpretation of the vegetation cover features (e.g. establishing the erosion resistance or fire risk) and a calculation of the resultant vegetation quality index. The management quality index evaluates land use type, land use intensity and current agricultural policy. The soil quality index is very important and helps explain land cover. This index comes from the soil and topographic maps. The topographic map can also be used to produce an aspect map that can be combined with climate data to produce the climate quality index (Riesterer 2008). The distinguishing features of Mediterranean Desertification and Land Use (MEDALUS) methodology are various such as; it has been developed to be suitable for small scales such as 1:50,000, with resolution down to an area of 20m x 30m. It combines detailed data into four indexes to help explain problems of specific or general regions, and it is sufficiently sensitive to indicate the risk of desertification while there is potentially time and opportunity to address these risks.

However, MQI in MEDALUS is calculated based on intensity of land use and agricultural policies, where lands grouped into four categories: agricultural and pasture lands, natural areas (forests, shrubs and bare land), mining areas and recreation and park areas.

In this study, mining areas, recreation and park areas are less important as there are no such lands in the study area. In addition, there is no guide to show how to calculate MQI in agricultural areas in relation to mechanisation and application of fertilizers. There is no sufficient description for classification of mechanisation degree and fertilizers amount, time or type. In forests land, ratio of actual production to sustainable production is used to determine MQI; this way is only suitable for managed forests but not for the study area that is subjected more to overgrazing rather than deforestation. In relation to natural area there is no sufficient description; forests are not managed in the same way as in other Mediterranean regions. Pasture rarely appears as separate fields but is integrated with shrubs in the form of an open rangeland with no physical division between areas that have different owners. It is culturally acceptable for shepherds to graze their animals freely over different areas, without the permission or knowledge of the owners of the land. A major distinction must be made between natural forests and managed forest in the study area. In the case of natural forests the quality of management is considered as high. In the case of managed forests, the intensity of use is determined by the demand for forest products. The grazing intensity of land use in natural areas has not been assessed because grazing in these areas is limited due to laws that prevent such activity; however, in the study area grazing in natural areas is not controlled or prevented. There is no description or guide for land use intensity or how to obtain MQI in shrubs lands, as well as agricultural policies are different from region to region and from country to country, it is very different in developed countries compared with developing countries. Therefore, MEDALUS cannot be generalized on every study so adjustments or adaptations are required in order to obtain MQI.

Most existing degradation and desertification studies lack appropriate method of verification and present model results without any validation (Kok et al. 2001; Xu et al. 2011). However, model validation can be achieved through statistical comparisons with independent expert observations, which would provide a more rigorous model (Johnson 2007). The validation approach employed here uses ancillary (statistical) resources and field measures to assess the accuracy of the model outputs. The process of validation should confirm whether the applied methodologies give sound estimates of the degradation and desertification when compared with field data. There are many studies that use different validation approaches; for example, visual comparison between field ground data and a theoretically produced map is commonly used to identify areas at risk of degradation (Ceccarelli et al. 2006; Salvati and Carlucci 2010). Advisory groups of experts have also played an invaluable role in supporting, inspiring and steering many research projects. Using expert knowledge has many potential uses in the assessment and measurement of environmental aspects (Ooshaksaraie et al. 2009). Employing experts in environmental issues should help in the efficient assessment of degradation and desertification maps, and could then offer appropriate clarification and assessment of the accuracy of a particular method of mapping land degradation features. Focus group (FG) technique has become the subject of important methodological debates and is considered as an innovative technique. In FG the informative source is a group that focuses on and investigates a specific phenomenon (Acocella 2012). It has the potential to produce preliminary outputs and disseminate knowledge efficiently, whereas one person often faces a situation with too much information for effective comprehension and judgment. The experts' decisions are appropriate for particular concepts because they are reached by a group through participation and contribution of views and usually provide immediate ideas for the improvement of particular concepts to help reach desired goals. Firebaugh (1988) used data from aerial photography to validate a land degradation map at a number of randomly selected reference points. Salvati and Carlucci (2010) improved on this visual comparison approach by supplementing the aerial photography with photographs of the landscape, site notes that described the appearance of the landscape and discussions of all this data with local experts. This procedure allowed an improved evaluation of the accuracy of the degradation map classification. However, this approach used random sampling, which is not as effective as stratified sampling. The latter generates better results with higher accuracy and lower error outcomes (Wu et al. 2012). In addition, Salvati and Carlucci (2010) did not use statistical analysis for the evaluation and accuracy assessment of the results, and did not require experts to visit locations in the field to have a dialogue with them at each location; instead, satellite and photographic images of a number of locations were presented to them. A group of experts can provide rich data through direct interaction with the researcher; the interaction can be flexible in terms of format, types of questions and desired outcomes. The focus group combines discussion and consensus-based decision making where participants both generate and evaluate their ideas. It allows the collection of many opinions from a knowledgeable group rather than one decision maker. The exchange of views among participants and their contributions in a focus group give the ability to produce accurate outcomes (Fern 1982; Morgan and Spanish 1984; Stewart and Shamdasani 1990). Another study assessed, monitored and mapped the areas that were most sensitive to desertification by comparing Environmentally Sensitive Areas Indexes (ESAI) maps using areas in square kilometres and the percentage of the area included in each class, based on the application of standard and adjusted MEDALUS approaches (Bakr et al. 2012). In another study, sensitive areas (ESAs) and SALUS (the system approach to land use sustainability), were compared in a study to identify factors and their impact on land degradation processes. It used a layering approach in GIS to compare the maps pixel by pixel, where each pixel is 30 x 30 metres, to identify areas at risk of degradation (Basso et al. 2012; Basso et al. 2010). However, the verification approaches mentioned are limited because no statistical analysis to test the obtained outputs has been used. Furthermore, there is no fieldwork to assess the truth of the degradation maps.

Therefore both USLE and MEDALUS are potentially appropriate techniques to assess damage to an environment, but it is possible that one of both of the methods may require improvement if their verification shows less accuracy. It is useful to compare the two models schematically, to help visualise what data are entered into each of the models, and what the outputs are, especially the descriptions of any resultant land degradation and desertification (Figure 3.3).

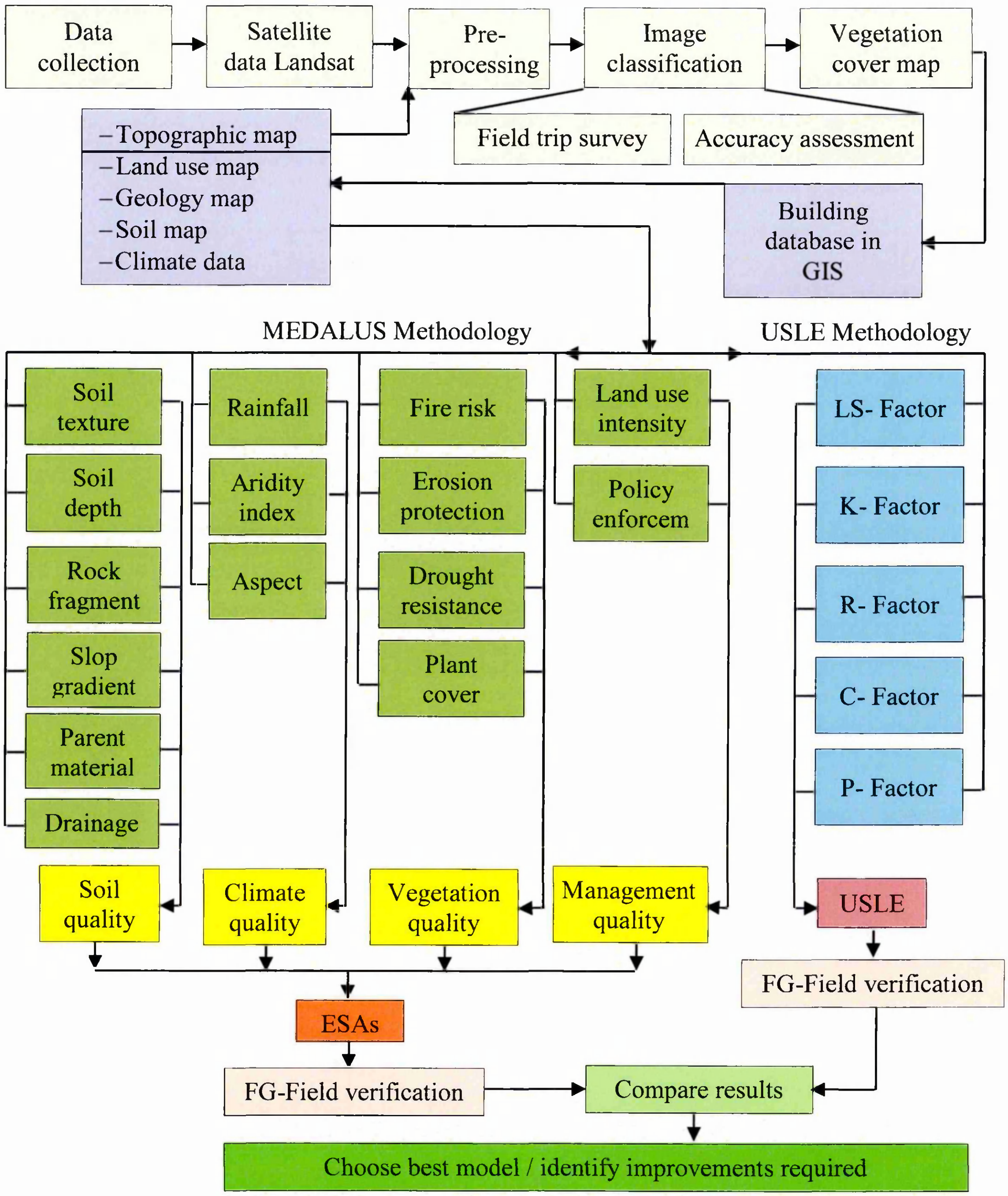


Figure 3.3. Schematic diagram showing the integrated application of methodologies & models for the classification of land cover, desertification (MEDALUS) and degradation (USLE).

3.4 Conclusion

In this chapter it has been shown that land degradation occurs in all kinds of landscapes over the world. Desertification can be seen as a specific type of land degradation, occurring mainly, but not exclusively, in dry-land regions. The degradation of the natural resource base and environment started with various human activities, before adequate mitigation measures were considered an integral part of the development process. Despite extensive research, it appears there is a lack of good information on extent and severity of land degradation in dry-lands, which still hampers attempts to determine its significance. The major causes of land degradation include, land clearance poor farming practices, overgrazing, inappropriate irrigation, urban sprawl and industrial activities. Assessing the effects of land degradation in the study area is not an easy task, and a wide range of methods have been used in other studies. Utilization of the USLE and MEDALUS methodologies for this study area should help to identify the cause and effect of severity degradation and desertification respectively. There have been no previous studies to assess the comparative performance of these two models in one particular extensive study area. The results should be useful to help to plan prevention, mitigation and remediation actions and obtain a restored landscape. The overall reliability of the models is based on validation and verification by the assessments of local experts, which rely on an accumulated understanding of the relevant processes. The relative performance of the models should allow a judgement of which model should be selected and improved as required.

4.1 Introduction

It is an established fact that there are a number of measurements used to evaluate and assess the condition of the natural or modified vegetation cover in a specific area including ground-layer, trees and shrubs. Some of these measurements were suggested by important international agencies such as the FAO (2010).

The major points which can be determined using biophysical aspects and which can help the understanding of potential land use are soil erosion susceptibility and land capability. Here, satellite imagery is used in the documentation of the natural vegetation cover of a specific piece of land during a specific historical period to investigate the changes in its size or condition and to identify the reasons behind the changes. Previously, methods to calculate and show changes that have occurred include methods that only describe the change in the area of land cover (such as subtraction and division methods) and those that describe the area, amount and type of the changes such as comparison after classification (Htun et al. 2008).

4.2 Change detection methodology

Change detection procedures can be grouped under three broad headings characterized by the data transformation procedures and the analysis techniques used to delimit areas of significant changes: satellite digital image processing, land cover classification and comparison of four independent land cover classifications (Figure 4.1). The primary data that are available for this part of the study are satellite image data (Landsat). These were taken at different times: 13 August 1984, 15 August 1992, 30 July 2000 and 5 August 2008. These are the most recent images and the eight-year gaps between the images are enough to illustrate obvious changes in land cover. Capturing the images in July and August is useful because they are normally drought months. At other times of the year, it is difficult to differentiate between the colour of large plants and grass, but in dry conditions the grass has died and appears as a distinct grey colour, which assists its correct identification.

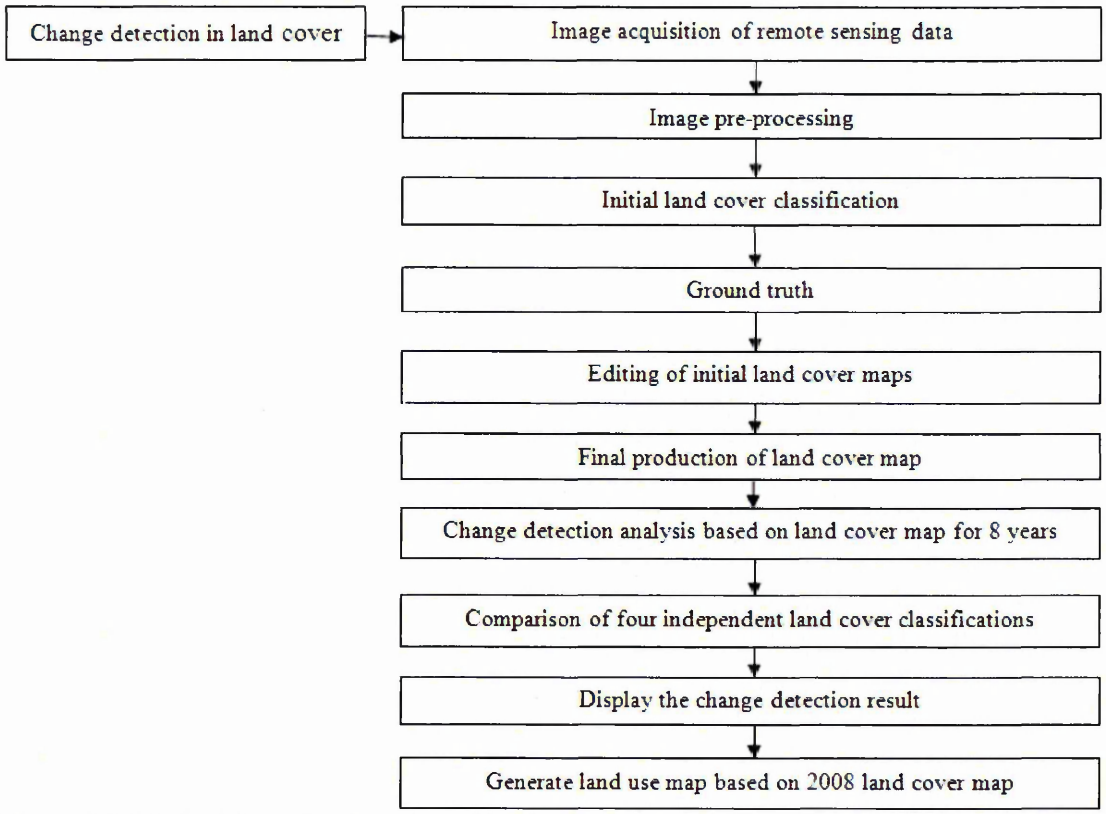


Figure 4.1. Methodology for detection of land cover change.

4.2.1 Satellite digital image processing

Remotely sensed data generally contain flaws and deficiencies when acquired from imaging sensors mounted on satellite platforms. The correction of these flaws and deficiencies can be described as pre-processing. Generally, pre-processing activities are user defined based on the objectives pursued. The most difficult issue in all change detection procedures is managing the sources of uncertainty in mapping the changes. Measurements of change over time using multi-temporal image data sets will, in the case of optical imagery, require atmospheric correction or normalization, image registration, geometric, radiometric correction, and masking (e.g. for clouds, water, irrelevant features) (Coppin and Bauer 1996). In the pre-processing stage, it is vital to eliminate any kind of atmospheric effects before any image analysis or information extraction are carried out (Chavez 1988). This becomes especially important when scene to scene comparisons of two or several images in applications, such as change detection, are being sought (Heard et al. 1992). If multi-temporal image data are being processed then they must be corrected for atmospheric effects to ensure that they are comparable.

Registration phase: is the process of transforming different sets of data into one coordinate system. Data may be multiple photographs, data from different sensors, from different times, or from different viewpoints. Measurements of change over time using multi-temporal image data sets will, in the case of optical imagery, require the correction of atmospheric variability, and registration of the images forming the multi-temporal sequence to common geographic coordinates. Accurate registration of multi-temporal imagery is a critical prerequisite of accurate change detection. In this case, the four images were registered by means of a topographic map. The topographic map scale is 1:5,000 published by the Libyan Surveying Department (LSD) (1980). Updated images with accurate geo-references were then used.

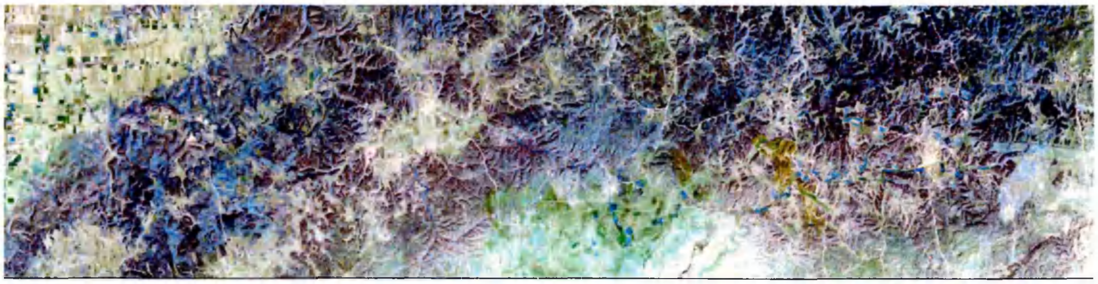
Radiometric corrections: two main factors seriously affect the radiometric quality of digital satellite data: atmospheric attenuation and topographic distortion (sensor variation). Other factors like illumination angle and soil moisture also affect radiance values and consequently classification results and change information. These factors need to be either corrected or taken into consideration. Radiometric correction improves the fidelity of the digital number for each pixel that constitutes an image. The purpose of radiometric correction is to reduce the errors that may confound scientific use of the digital numbers (Larsson 2002). Some form of image matching or radiometric calibration is thus needed to eliminate exogenous differences. In this case, radiometric correction of the images had already been carried out in Libyan Centre of Remote Sensing 2009, so it was not applied.

Geometric corrections: these are required in order to pre-process the remotely sensed data and to eliminate geometric distortion. Thus the elements (pixels) of each individual image are accurate in their (x, y) position, as described by Baboo and Devi (2011). Remotely sensed images are not maps so they need to be transformed in order that they have the scale and projection of geographical maps in a process referred to as geometric correction. This technique should not be confounded with registration, which is the fitting of the coordinate system of one image to that of a second image of the same area. The sources of geometric error in digital satellite imagery are: instrument error, finite scan rate of some sensors, the wide field of view of some sensors, the curvature of the earth, sensor non–idealities, panoramic distortion, earth rotation and platform instability. The root mean square error (RMSE) method was used to analyse the deviation among the values of checkpoints and selected ground control points (located using topographic maps at a scale of 1:5,000 and GPS during the field study), and was compared with the data obtained from the Earth Resources Data Analysis System (ERDAS). The root mean square error (RMSE) was calculated between the two images. If the RMSE between the two images was less than 0.4 then the image was accepted (Shalaby and Tateishi 2007). A topographic map that was generated in 1980 has been used to correct the 1984 image by using 20 control points, and the RMSE was 0.31 pixels. The geometrically corrected 1984 image has been used to check the remaining 1992, 2000 and 2008 using 18, 19 and 19 control points respectively, and the RMSEs were 0.34 pixels, 0.33 pixels and 0.35 pixels respectively.

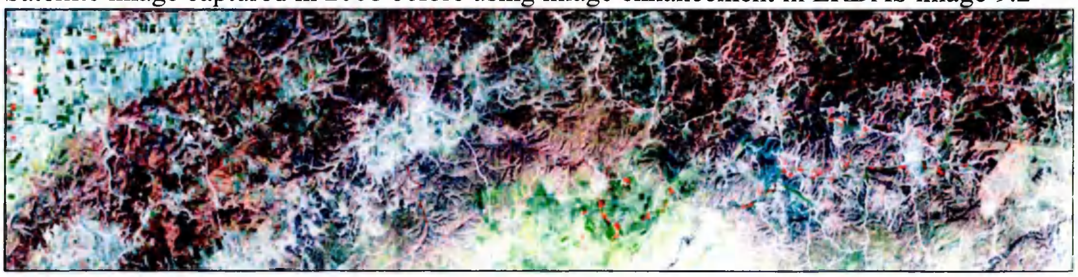
Image enhancement and visual interpretation:

Image enhancement techniques improve the quality of an image, this technique is used as an alternative to classification techniques to extract features, locate objects on the ground and gain helpful information from images (Faust 1989). It is helpful because many satellite images when examined on a colour display give inadequate information for image interpretation. The goal of image enhancement is to improve the visual interpretability of an image by increasing the apparent distinction between the features. The process of visually interpreting digitally enhanced imagery attempts to optimize the complementary abilities of the human mind and the computer (Lilles and Kiefer 1994). Image enhancement is attempted after the image is corrected for geometric and radiometric distortions.

An example of an enhancement procedure is shown in Figure 4.2.



Satellite image captured in 2008 before using image enhancement in ERDAS image 9.2



Same satellite image captured in 2008 after image enhancement using ERDAS image 9.2

Figure 4.2. Satellite image and enhancement procedure.

4.2.2 Image classification

The intent of classification process is to categorize all pixels in a digital image into one of several land cover classes or themes. This classified data is used to produce thematic maps of the land cover present in an image.

Unsupervised classification: The software assigns each pixel within an image to a class, depending on its colour, but the interpreter gives no a priori information about the objects to be determined, only the total number of classes required, e.g. 6 or 12. This generally results in too many classes of land cover; for example, bare soil in sunshine and bare soil in shade, whereas really we are only interested in bare soil as a land cover type. A number of classes therefore need to be combined to generate a map that is meaningful, but unsupervised classification is useful to begin with to identify how many classes there are and to help understand the areas within an image.

Supervised classification: this process gives a statistical description for land cover that depends on the structure of a class that is given by the analyst (e.g. a red colour is defined as irrigated land). This procedure begins with the definition of information for each class, and afterwards each pixel is assigned to a class. The classification method is most often used to assess the likelihood that every pixel belongs to a specific class, according to its spectral and statistical characteristics. The supervised pixel-based classification using Maximum Likelihood Classifier (MLC) and the Nearest

Neighbour (NN) object-based classification were implemented to the map. In this case, Landsat data of four dates were independently classified using the supervised classification method of maximum likelihood algorithm. Spectral signature files for all classes were subsequently created and used by maximum likelihood robust classifier to categorize the continuum of spectral data in the entire image (Ediriwic-krema and Khorram 1997; McGwire et al. 1996).

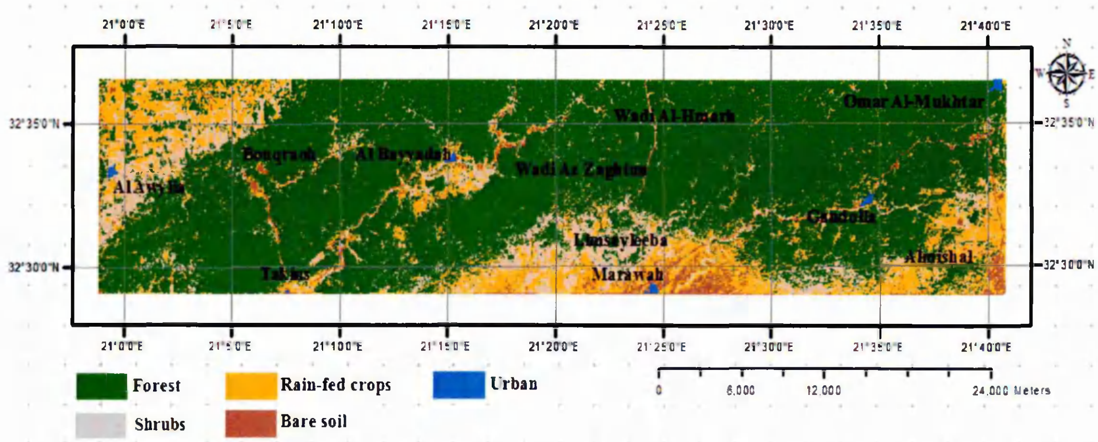
Accuracy assessment is an integral component of any classification (Muller et al. 1998; Richards 1996; Stehman and Czaplewski 1998). The detection of thematic map errors depends on both the accuracy of the classification and the number and type of validation data (San Miguel-Ayanz and Biging 1997). The standard for reporting accuracy in most published work includes a contingency matrix (or error matrix) from which values for overall accuracy are taken by Kappa statistical analysis (Congalton 1991). Kappa coefficient is a statistical measure of inter-rater agreement or inter-annotator agreement for qualitative (categorical) items (Carletta 1996). It is a more robust measure than simple percent agreement calculation and the main advantage of Kappa is that it offers more information than any simple calculation of the agreement of raw proportion (Viera and Garrett 2005). The number of reference pixels is the main factor in determining accuracy of classification (Guler et al. 2007). It is revealed that 250 reference pixels or more are required for estimating the mean accuracy of a class within plus or minus 5 percent (Congalton 1991). The Kappa analysis and the overall accuracy have been applied to assess the accuracy of the classification derived from error matrix analysis. The technique of simple descriptive statistics was used and overall accuracy was computed by the total number of pixels inside the error matrix. Actually, the Kappa analysis is a technique of discrete multivariate analysis used for assessments of accuracy (Hammen 1997). Kappa analysis was used to obtain and measure the agreement or accuracy assessment. There are many methods to assess inter-observer agreement; however, the most generally reported method is Kappa analysis. There are different Kappa values, which indicate different levels of agreement (Table 4.1).

Kappa		Agreement
Poor	< 0	Less than chance agreement
Slight	0.01–0.20	Slight agreement
Fair	0.21– 0.40	Fair agreement
Moderate	0.41–0.60	Moderate agreement
Substantial	0.61–0.80	Substantial agreement
Almost perfect	0.81–0.99	Almost perfect agreement

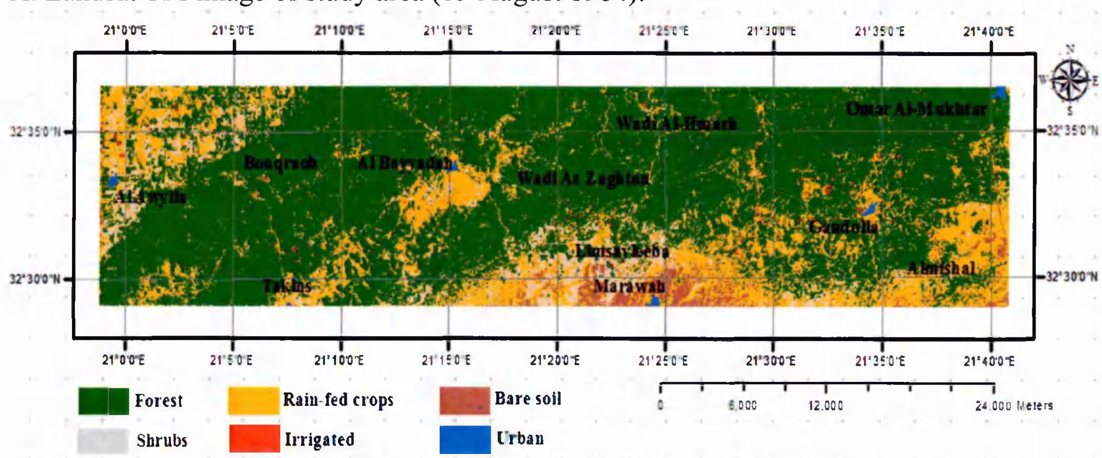
Table 4.1. Interpretation of Kappa (based on Viera and Garrett 2005).

Classification of images for the study area

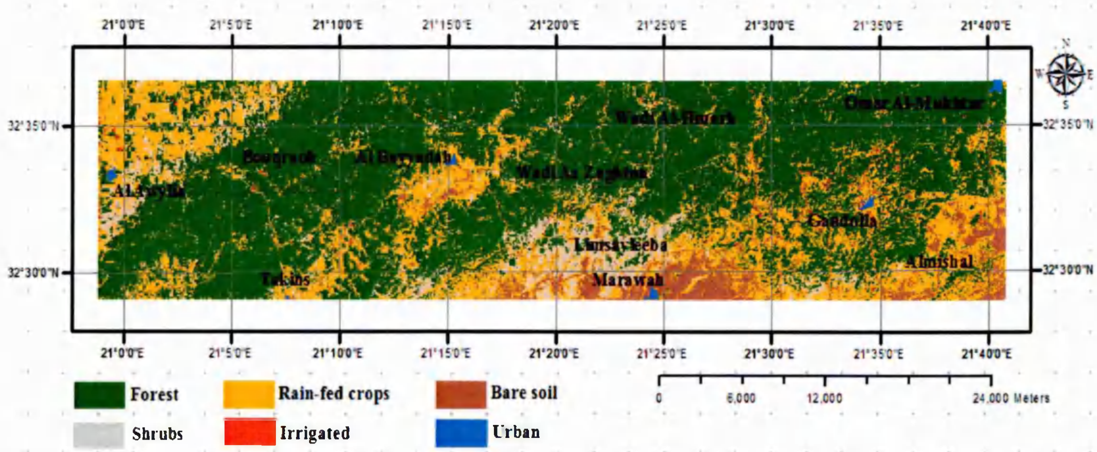
Interpretation of remote sensing was used in the study area to obtain appropriate classification schemes. An unsupervised classification method was used initially, followed by a supervised classification to give a land cover map that was divided into six classes: forest, rain-fed crops, wild shrub lands, irrigated land, bare soil and urban areas (Figure 4.3).



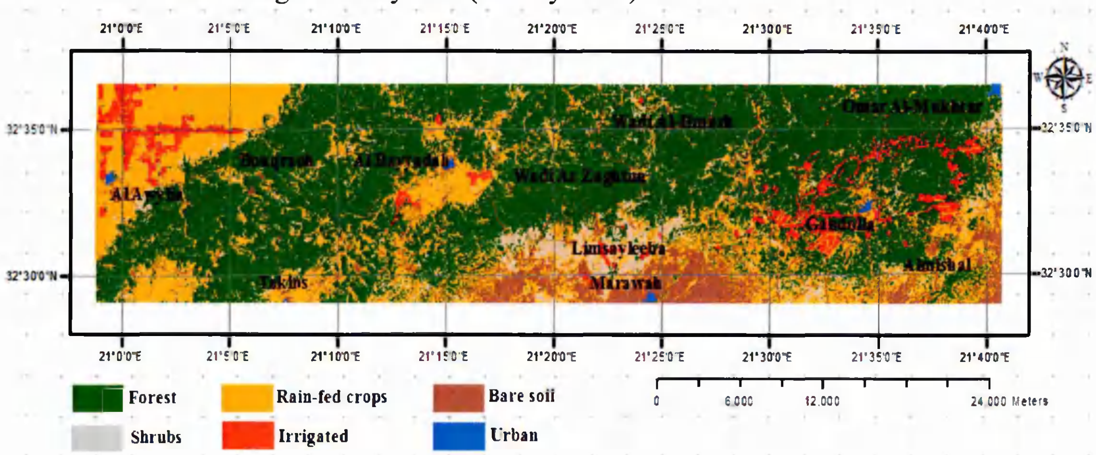
A. Landsat TM image of study area (13 August 1984).



B. Landsat TM image of study area (15 August 1992).



C. Landsat ETM+ image of study area (30 July 2000).



D. Landsat ETM+ image of study area (5 August 2008).

Figure 4.3. (A, B, C and D). Classification of land cover for each time step.

Comparative analysis between spectral classifications carried out at two different times is the best method of detecting change between one class and another for an image. Cross-tabulation and Kappa analysis index technique (i.e. error matrix analysis) were used to compare the model outputs (Singh 1989).

Accuracy assessment was performed for 2008 land cover map; a random sampling design was adopted in the accuracy assessment. A total of 298 pixels were selected for the 2008 land cover map.

Reference data								
Classified data	Bare soil	Farmland	Shrubs	Forest	Irrigated	Row total	User accuracy (%)	Kappa*
Bare soil	**69**	4	0	0	0	73	94.5	0.91
Farmland	1	**68**	2	3	0	74	91.9	0.89
Shrubs	1	1	**16**	1	1	20	80.0	0.80
Forest	0	1	1	**93**	4	99	94.0	0.91
Irrigated	1	0	2	0	**29**	32	90.3	0.89
Column total	72	74	21	97	34	**298**		
Accuracy (%)	94.4	91.9	76.2	95.9	85.3			

Note: Number of pixels correctly classified: 275; overall classification accuracy: 91.6%. *Overall Kappa index of agreement: 0.90.

Table 4.2. Accuracy assessment of the 2008 land cover map.

The result pointed to an overall classification accuracy of around 91.6 per cent and agreement of a Kappa index is about 0.90 (Table 4.2). The accuracy of this process was checked by field visits. This revealed that all classes of land cover were accurately classified, confirmed by the Kappa conditional statistics for each class of land (Table 4.1; Guler, Yomralıoglu and Reis 2007). Slightly poorer agreement was obtained for shrubs. This may be due to difficulty in differentiating between small trees and large shrubs, for example.

4.2.3 Comparison of four independent land cover classifications

Changes in land cover and land degradation risks have become significant issues at the global level. Two systems are responsible for vegetation degradation: the natural system and the socio-economic system (Bajocco et al. 2012). In areas around rural villages, desertification markedly prevails over land vegetation cover. Mismanagement and land use changes are the most important driving factors affecting vegetation degradation (Dawelbait and Morari 2012). There are many threats to vegetation cover, such as fire, deforestation, and cultivation to convert vegetated land to other types of land (Chabrillat et al. 2003; Dulal et al. 2012). In addition, decline in vegetation cover, and increased farming, are alarming findings leading to barren lands (Meshesha et al. 2012).

The following table illustrates the recent changes to the land in the study area:

Year	1984		1992		1984-1992	2000		2008		2000-2008	1984-2008
Class name	Land cover		Land cover		Area changed	Land cover		Land cover		Area changed	Area changed
	(ha)	(%)	(ha)	(%)	(ha)	(ha)	(%)	(ha)	(%)	(ha)	(ha)
Forest	68230	71.6	61690	65	-6540	51600	54.3	43500	46	-8100	-24730
Rain-fed	15795	17	20000	21	4205	27700	29.2	31230	32.8	3530	15435
Shrubs	7395	7.8	6890	7.3	-505	6600	7	5270	5.5	-1330	-2125
Irrigated	0	0	300	0.3	300	500	0.5	5000	5.3	4500	5000
Bare soil	3000	3	5500	5.7	2500	7900	8.3	9000	9.4	1100	6000
Urban	580	0.6	620	0.7	40	700	0.7	1000	1	300	420

Table 4.3. Land cover in 1984, 1992, 2000 and 2008.

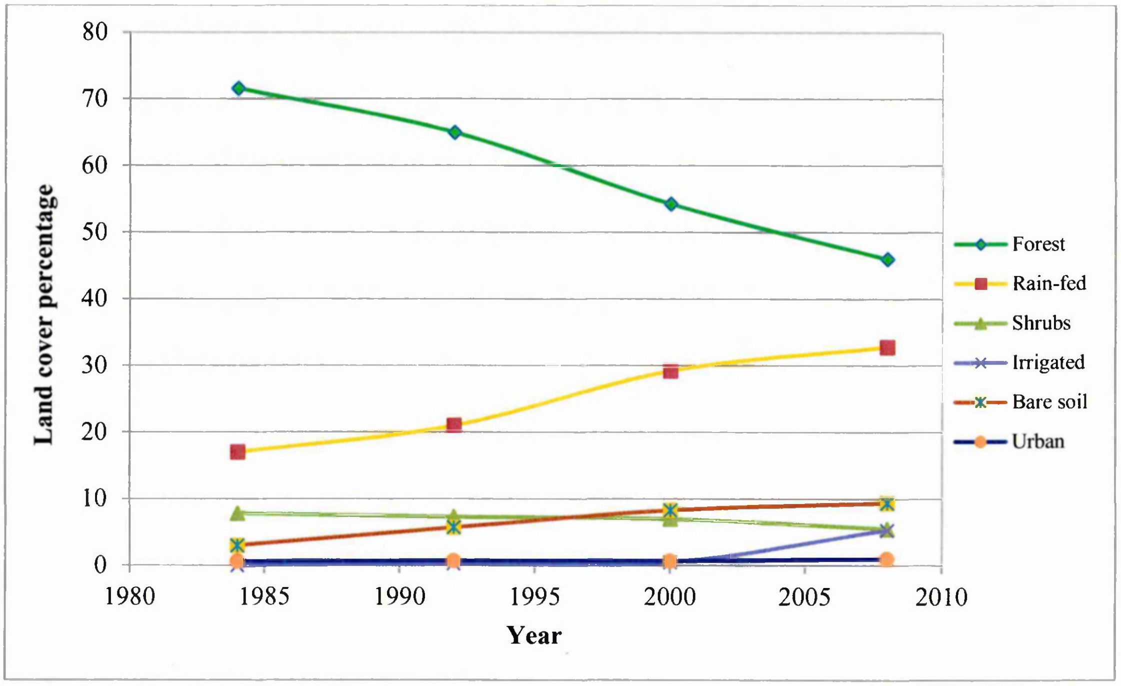


Figure 4.4. Land cover in 1984, 1992, 2000 and 2008.

Based on the results, (Table 4.3 and Figure 4.4), it is suggested that agricultural practices are the main cause of land cover changes, through removal of forest or conversion to farmland. Furthermore, it seems that the lack of planning in the exploitation of forests and other natural vegetation and increasing human pressures are the main factors behind forest depletion. The vegetation cover has changed in the study area between 1984 and 2008. Firstly, the forestlands have faced a rapid decrease throughout the study period. In 1984, the total vegetation cover was 75,625 hectares, which decreased in 1992 and continued its decline until 2008; the overall reduction is more than 26,850 hectares. The biggest reduction in the vegetation cover was between 2000 and 2008, with a loss of about 9,500 hectares; it is facing extreme destruction and exploitation. The clearance of vegetation creates adverse impacts in a similar manner to that observed by Meshesha et al. (2012). On the other hand, the rain-fed crops increased gradually during the study period to twice what they were at the start. Therefore, human impacts are clearly the main reasons for those changes and can devastate the vegetation cover. The cause of this land degradation might therefore be considered to be inappropriate land use and mismanagement, as observed by de Waroux and Lambin (2012); Dulal et al. (2012). However, this is not always the case, indicating that other variables may be playing a part, such as the variation in soil properties and topography (Nunes et al. 2010).

4.3 The Land use map

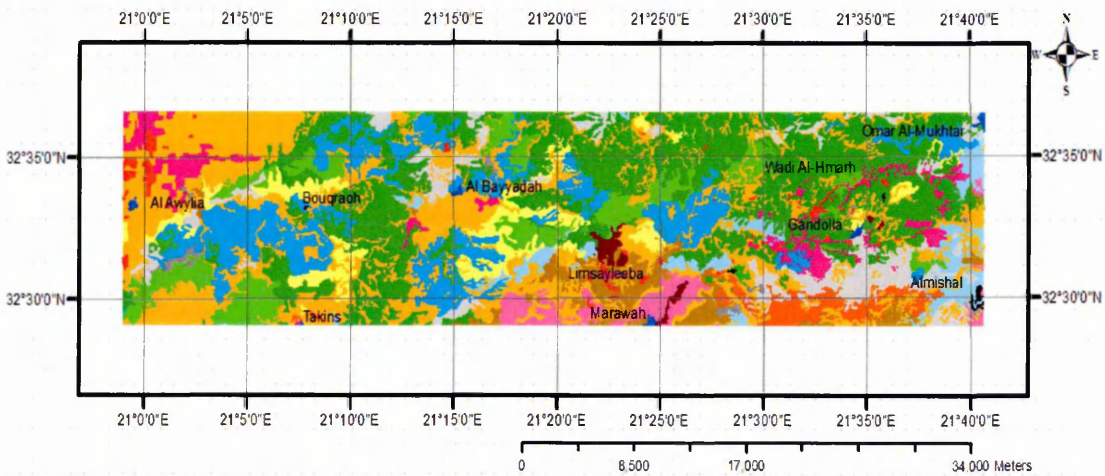
The land use map was derived from the ERDAS 9.2 land cover map of 2008 using digital image processing software. The land cover map is composed of six classes: vegetation, shrubs, bare soil, and urban, rain-fed and irrigated land. Instead of these six main landscape classes, consideration of the requirements of both the MEDALUS and USLE models means a more detailed understanding of the land cover is required. For example, a single vegetation class in the land cover map is divided into eleven classes in the land use map, such as closed (densely planted) woody vegetation with shrubs or open woody vegetation with dwarf shrubs. Sixteen land classes were eventually used.

It was necessary to visit the study area, first to confirm the accuracy of the land cover map, and then to identify these new land use classes. A total of 850 locations were selected by stratified random sampling for quality control purposes (Congalton 1991). These were found in the field by using a hand-held GPS. The type, height and density of vegetation cover were established according to the relative percentage of woody component cover in rectangular sample plots or transects of 100m x 100m in size (Agricultural Research Centre 2008) and two duplicates were taken for each location.

A list of each vegetation species was compiled, scoring the relative cover percentage of each species; for example, Juniper comprises 70% of the natural vegetation in the study area. Information on vegetation health was collected only for woody species.

During the field visit, the dead remains of herbaceous plants were identified as types that die completely or leave no persistent woody stem above the soil surface at the end of the wet season. This is particularly the case between the end of April and the middle of May. These plants then grow again at the start of the next wet season between the beginning of October and the middle of November from natural seeding or from roots and tubers that have survived below the soil surface. The identification of the membership of these plants to particular vegetation classes was established either through personal identification or through verbal confirmation with landowner or tenant farmer. The vast majority of those plants are annual species; for example, ragwort, peony, artichoke thistle and most grass types. In the case of agricultural fields, a short description of the agricultural activities, cultivated crops and land management system was recorded, including, for example, whether the crops were irrigated or rain-fed. Further general information and other details about the description and classification of the vegetation are given in appendix.

All the data collected during the field survey were then combined with the existing land cover database to produce the land use map (Figure 4.5).



Land use classes	Description of land use	Land use classes	Description of land use
A	*Mixture of rainfed fruit trees and Crops (density of cover > 50%)*	I	*Open (30- 40 %) Woody Vegetation with Dwarf Shrubs*
B	*Closed (50-60 %) Shrubs (h = 3 - 0.5 m) with Herbaceous*	J	*Sparse (1- 10 %) Woody Vegetation with Dwarf Shrubs*
C	*Open (10- 20 %) Woody Vegetation with Dwarf Shrubs*	K	*Open (20- 30 %) Woody Vegetation with Dwarf Shrubs*
D	*Sparse (1-10 %) Dwarf Shrubs with Herbaceous*	L	*Closed (> 50 %) Pinus Plantation*
E	*Closed (60-100 %) Woody Vegetation with Shrubs*	M	*Herbaceous Rainfed Crop (density of cover > 50%)*
F	*Very Open (10- 20 %) Dwarf Shrubs with Herbaceous*	N	*Herbaceous Irrigated Crop (density of cover > 50%)*
G	*Closed (50- 60%) Woody Vegetation with Shrubs*	O	*Quarry*
H	*Close to Open (40- 50 %) Woody Vegetation with Shrubs*	P	*Urban Area*

Figure 4.5. Land use map of the study area.

4.4 Conclusion

In forest, or dense vegetation cover, the primary cause of change in cover is inappropriate agricultural practice. Deforestation largely occurred between 2000 and 2008, as land was cleared for farmland (irrigated land and rain-fed barley and wheat crops). Some of this newly cleared area then degraded to bare soil, in a similar manner to that observed by Chabrillat et al. (2003). On land with a low density of vegetation cover (e.g. shrubs), over-grazing is the main cause of the reduction in agricultural productivity and eventual change in cover to bare soil, as observed in other dry lands (Meshesha et al. 2012). However, this is not always the case, which indicates that other variables may be playing a part, such as the variation in soil properties and topography.

There may be many different causes or combinations of causes that result in land degradation; however, the complexity and substantial nature of the information that could define the degradation requires the application of a suitable theoretical model to enable identification and interpretation of the causes of the land degradation. If this can be achieved, it would be the first step in stopping the damage.

CHAPTER 5

LAND DEGRADATION MODEL

(USLE)

5.1 Introduction

The amount of soil erosion can be predicted from the Universal Soil Loss Equation (USLE methodology), which is based on five major factors (rainfall pattern, soil type, topography, crop system, and management practices). This model enables the calculation of an average annual rate of soil erosion for a location for any number of erosion control practices, management techniques, and scenarios involving cropping systems (Kouli et al. 2009). The estimation of soil loss in the application of USLE with GIS within the raster/grid and the raster models, are cell-based representations of map features. These offer analytical capabilities for continuous data and allow fast processing of map layer overlay operations, for computing the expected average annual erosion (Fernandez et al. 2003). Normally the mapping of the spatial dimension (geographical distribution) is the foundation for the monitoring of temporal variations (Onyando et al. 2005; Wu et al. 2005). The type, intensity, extent and spatial degree of land degradation are all important parts of information for the formulation of priorities, action plans and policies to reverse it and if possible to prevent it. Severity refers to the intensity of the degradation process and suggests the definition of a scale of intensity, whether categorical or numerical, continuous or discrete. Extent indicates distribution in both, spatial and temporal dimensions of the different types and degrees of intensity of the process. In this chapter, the purpose of environmental hazard assessment and monitoring is to identify particular part of land under a given land use regimes is threatened by water erosion and divide the land under consideration into areas that have a similar degree and type of erosion hazard as a basis for a plan for soil conservation.

5.2 Land degradation model (USLE)

The USLE theoretical model is applied to the study area to assess whether the land cover changes result in land degradation, taken here as soil erosion. The elements involved in the determination of soil loss and hence erosion of land quality is shown in Figure 5.1. The model is applied within GIS on a 200 × 200m cell basis and incorporates the diverse factors that have an impact (equation 5.1):

$E = R*K*C*P*LS$ **(Equation 5.1)**

where E is the average annual soil loss rate (t $ha^{-1}yr^{-1}$), R is a rainfall erosivity factor, K is a soil erodibility factor, LS is a topographic factor, C is the land cover management factor and P is a factor that defines soil conservation practice (Jayasinghe et al. 2010). Each factor can be defined in a number of ways. Here the equations most applicable to the semi-arid Mediterranean climate of the study area were selected.

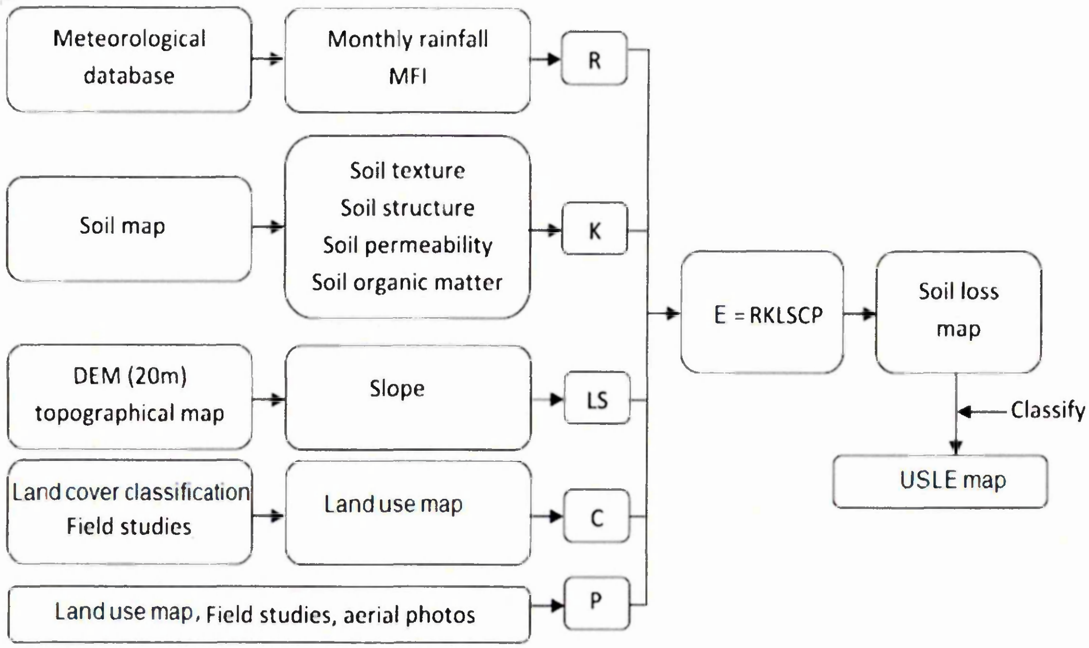


Figure 5.1. USLE methodology to determine erosion hazard.

Rainfall erosivity R: Wischmeier and Smith (1978) stated that R, the rainfall factor, is calculated from expressions that describe the energy of a rainstorm and observed maximum rainfall intensities. In the absence of such detailed information, an alternative equation in terms of the mean annual precipitation could be used (Euimnoh et al. 2000). This procedure has also been used by a number of investigators (e.g. Htun et al. 2008). According to Wischmeier and Smith (1978), there is a relationship between rainfall and soil erosion which is directly proportional. The rainfall factor R is calculated from two equations based on rainfall data. The first equation (5.2) was derived by Htun et al. (2008) and Eiumnoh et al. (2000) and gives satisfactory results for erosivity.

$R = 38.5 + 0.35\ P$ **(Equation 5.2)**

where P = mean annual precipitation.

The second equation (5.3) has been tested in a number of countries, for example in Morocco by Renard and Freimund (1994) and in Greece by Kouli et al. (2009).

$R = 0.264\ MFI^{1.50}$ **(Equation 5.3)** where

$$\text{MFI} = \frac{\sum_{1978}^{2010} \frac{\sum Monthly\ rain\ fall^2}{Annual\ rain\ fall}}{31}$$

In this study, R-value calculated by the two equations is based on precipitation data for about thirty years (1980-2010). Equations 5.2 and 5.3 give the same result of rainfall erosivity R = 152.5mm.

Slope length factor L is calculated following the method suggested by McCool et al. (1987):

$L = (\lambda/22.1)^m$ **(Equation 5.4)**

where λ is the slope length in the field, and m is a dimensionless exponent based on slope steepness, s(0.5 for slopes exceeding 5%, 0.4 for 4% slopes and 0.3 for slopes less than 3%) (Dabral et al. 2008; Pandey et al. 2007). There are many scientists who have used and recommended Equation 5.4, including Renschler et al. (1999), Jain et al. (2001), Fistikoglu and Harmancioglu (2002), Onyando et al. (2005), Pandeye al. (2007), and Dabral et al. (2008). A digital elevation model (DEM) determined the slope percentage, while a 200 m x 200m grid was used to establish the slope length. The Slope Steepness Factor, s (McCool et al. 1987), is computed using:

$S = 10.8 \sin\theta + 0.03,\ s < 9\%$ **(Equation 5.5a)**

$S = 16.8 \sin\theta - 0.05,\ s \geq 9\%$ **(Equation 5.5b)**

where the slope angle, θ, is measured in degrees. The topographic factor is defined by the product of L and S, and large spatial variations in its magnitude (Figure 5.2) are observed.

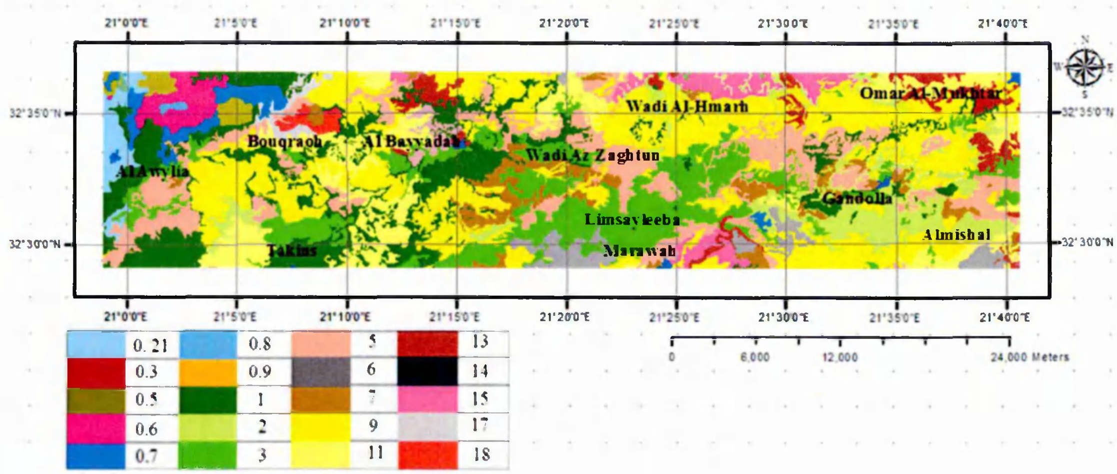


Figure 5.2. Spatial distribution of USLE topographic factor LS.

According to Figure 5.2, most of the north-west of the study area has LS between 0.21 and 0.9, indicating semi-flat terrain or plains with an absence of complex topography. This area is lower than the surrounding land. Areas where LS is >6 are steep and the potential for soil erosion is high.

The soil erodibility factor K represents the long-term average response of the soil to the erosive power related to precipitation and runoff (Figure 5.3). It is determined using nomographs derived by Wischmeier and Smith (1978), after the percentages of silt, fine sand and organic matter and the soil structure and permeability in the study area have been established (Selkhozpromexport 1980). The process identified in Figure 5.3 was used to determine the erodibility factor K.

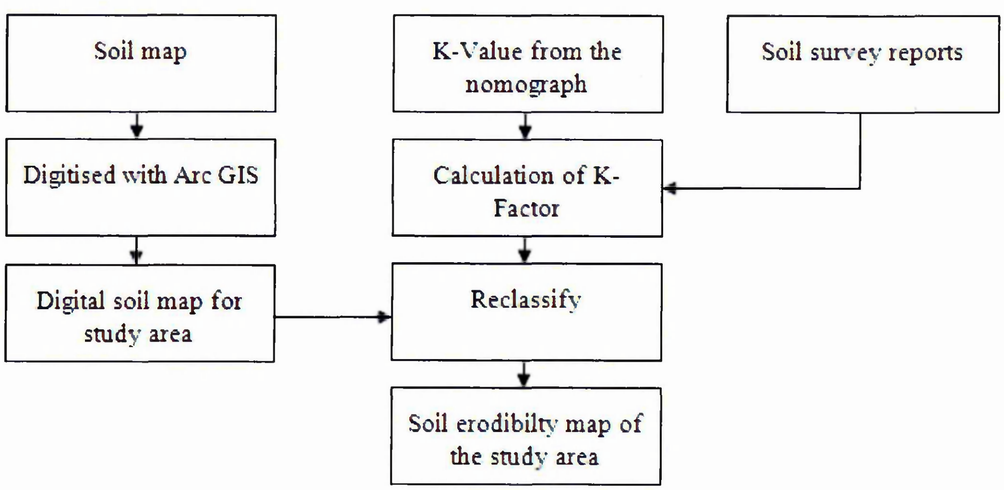


Figure 5.3. Determination of the erodibility factor K of the soil in the study area.

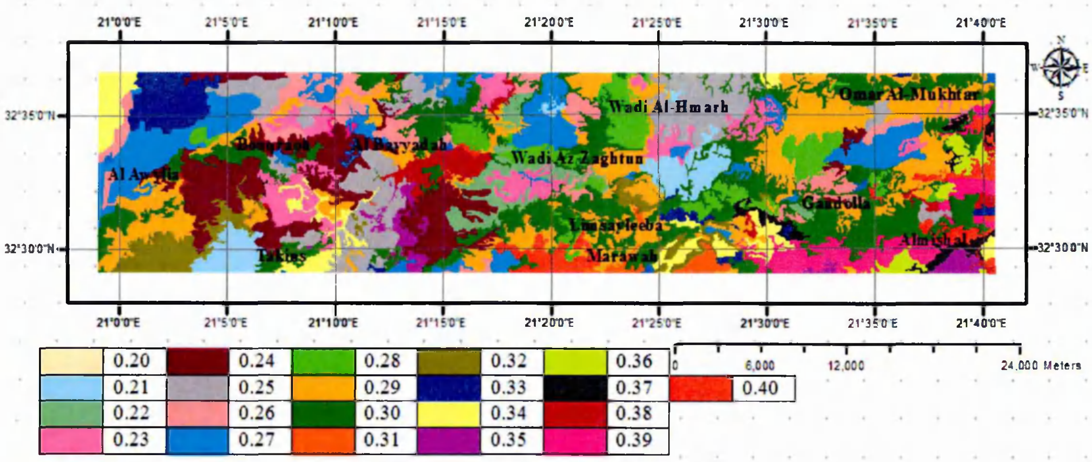


Figure 5.4. Variation of USLE soil erodibility factor K in the study area.

K ranges between 0.20 and 0.40. Moderate-textured soils such as silty clay loam are prevalent and have values of about 0.22 to 0.27, as they are moderately susceptible to detachment. Most farmland is characterized by a high value of K (up to 0.30). Land cover has a long-term impact on soil erodibility; for example, land with dense natural vegetation (forest) has low erodibility, as it contains a high percentage of organic matter and a granular structure, which reduce runoff at the soil surface.

The cover management factor C expresses the influence of land cover upon soil erosion. Many studies have determined values of the C factor based on land cover type, such as Roose (1977), Singh et al. (1981), El-Swaify et al. (1982), Hurni (1987), Hashim and Wong (1988), which require specification of land cover and land use (Htun et al. 2008; Morgan 1995; Wu et al. 2005). Other authors have modified the C factor that is based on cover type by additionally considering the quality of the vegetation (Morgan 1995; Htun et al. 2008). The C factor used for the study area (Figure 5.5) is determined using the procedure adopted by Morgan (1995); Htun et al. (2008), and depends on the land cover and land use classes identified from the Landsat image data imported into GIS; for natural woodland (heavy vegetative cover) C = 0.06, for bare land (low vegetative cover) C = 1, for agricultural land C = 0.377, and for urban areas C = 0.01.

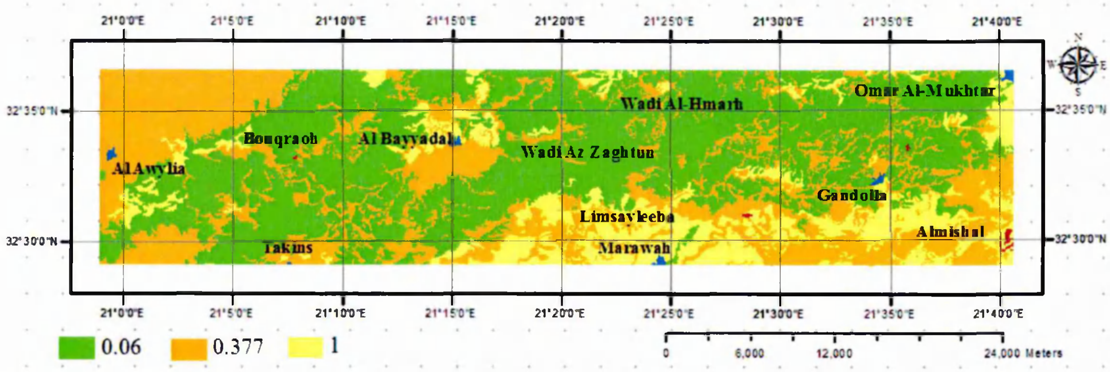


Figure 5.5. Spatial distribution of cover management factor C in 2008.

The conservation practice factor (P), the P factor has been determined with different methods based on the requirements for a specific area, Wischmeier and Smith (1978) stated that P value range between 0.2 and 1.0. For example Htun et al. (2008) calculated P by considering cultivation practices (ploughing time). Lufafa et al. (2003); Fu et al. (2006); Terranova et al. (2009); Roose (1977); Chan (1981) considered the slope of the ground under tillage. Values used here are those defined 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. In the study area (Figures 5.6), the conservation practice factor is generally 0.25 because of the presence of natural woodland and shrubs with grassland or bare land where no tillage occurs. Areas where P = 1 are associated with wheat and barley crops, sown after autumn ploughing. Lands where P = 0.6 are fruit orchards or irrigated cropland where stubble mulch farming is undertaken, which provides a certain level of protection for the soil.

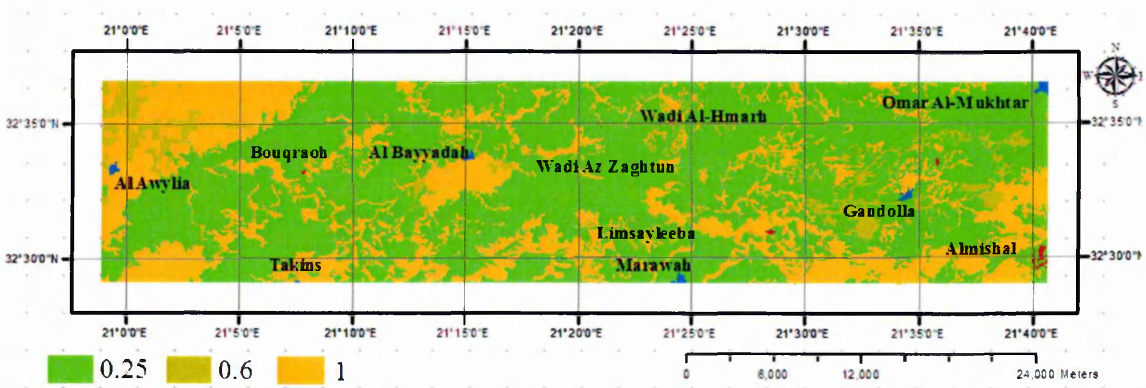


Figure 5.6. Spatial distribution of conservation practice factor P in 2008.

The spatial variation of average annual soil loss (Figure 5.7) can now be determined (equation 5.1). The average annual soil loss was estimated on the basis of classes according to the guidelines recommended by Pandey et al. (2007), Veljko et al. (2013): Slight (0–5 t $ha^{-1}yr^{-1}$), Moderate (5–10 t $ha^{-1}yr^{-1}$), High (10–20 t $ha^{-1}yr^{-1}$), Very High (20–40 t $ha^{-1}yr^{-1}$), Severe (40–80 t $ha^{-1}yr^{-1}$) and Very Severe (>80 t $ha^{-1}yr^{-1}$).

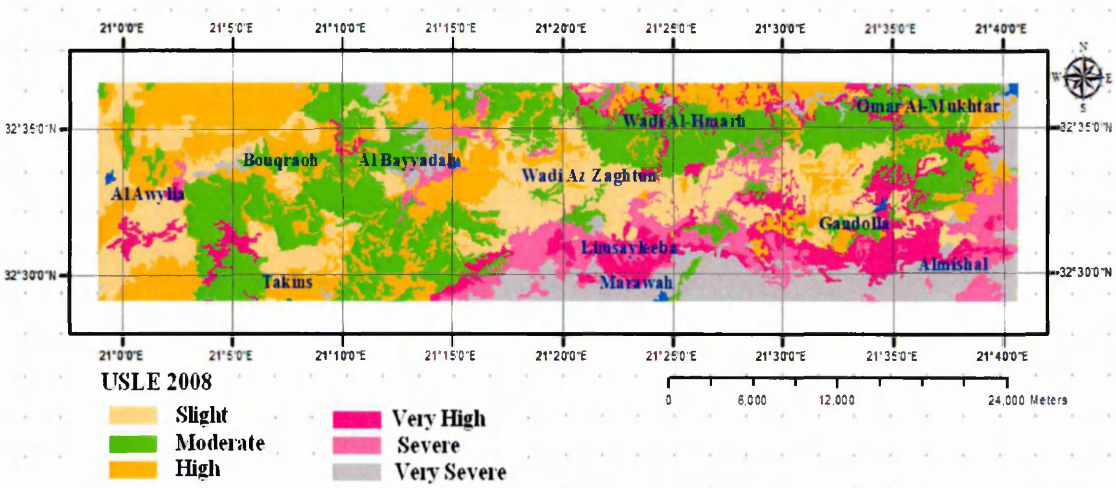


Figure 5.7. USLE land degradation map for study area in 2008.

Slight and Moderate soil erosion occurs in areas that contain low LS factors or intensive vegetation cover (classes B, E and G in Figure 4.5). In the developing countries, soil erosion is a serious environmental problem, and the most important factors for soil erosion are topography and scarcity of vegetation (Kefi et al. 2011). Soil loss is mainly affected by LS factor that has higher impacts on accelerating the erosion followed by C, P and then K factors, as suggested by Miguel et al. (2011). C, P and LS are considered as the most important factors affecting soil erosion and leading to surface runoff especially in hilly zones (Zhou et al. 2008).

5.3 Conclusion

The decline in forested area is primarily due to an increase in the area of rain-fed crops, which unfortunately changes in time to bare soil. The degradation of the natural resource base in the study area started with various agricultural development activities, before adequate mitigation measures were considered as an integral part of the development process. This happened because of a lack of three factors: appropriate sector policies, awareness among the residents, and integration of environment and development into conventional development strategies. Development cannot be achieved without real conservation of the vegetation cover. The study area has shown need for concern regarding degradation issues.

Slight and Moderate erosion areas have a low LS factor or intensive vegetation cover that protects the land from erosion. Maximum sediment loss appears in the areas that have a LS-value higher than 5, particularly in areas of farmland. High or greater erosion rates occur in about 50% of the study area because of faulty cultivation practices and undulating topography. K factor is more significant in areas that do not contain plant cover or has only a few plants.

CHAPTER 6

LAND DESERTIFICATION MODEL

(MEDALUS)

6.1 Introduction

The key indicators for defining environmentally sensitive areas in the MEDALUS model are divided into four broad categories: Soil, Climate, Vegetation and Management Quality, as shown in Figure 6.1. In the standard MEDALUS approach (Kosmas et al. 1999), a score is allocated to each parameter in each quality index. The scores ranged from "1 = best" (for the areas least sensitive to desertification) to "2 = worst" (for the area most sensitive to desertification).

In some research, additional categories have been incorporated which are judged to be of particular importance to certain environments. For instance, the model has been applied with the addition of two more factors to account for erosion and groundwater in southern Iran (Sepehr et al. 2007). Furthermore, two different factors were incorporated to allow for erosion and soil water-logging when the original MEDALUS model was modified for other areas of Iran (Honardoust et al. 2011). Incorporation of additional factors does not seem appropriate here, for example, there are no problems with groundwater quality as the sodium adsorption ratio (SAR), chloride (Cl) and electrical conductivity (EC) levels are all acceptable. Land and particularly the irrigated land in the study area do not suffer from water logging, as the water table level is more than 300m below ground level (GPCALW 2006).

The main goal of this chapter is to investigate land desertification in the Al-jabal Alakhdar region by applying the MEDALUS model to the study area. Extensive amounts of data are processed to produce maps that describe the physical characteristics of the study area. In particular, these maps are verified by verification in the field; a number of previous studies have been produced without field checks (e.g. Bakr et al. 2012 Fern 1982; Morgan and Spanish 1984; Stewart and Shamdasani 1990).

6.2 Establishing areas environmentally sensitive to desertification

The environmentally sensitive areas to desertification (ESAs) are established using the MEDALUS methodology, whose structure is shown in Figure 6.1.

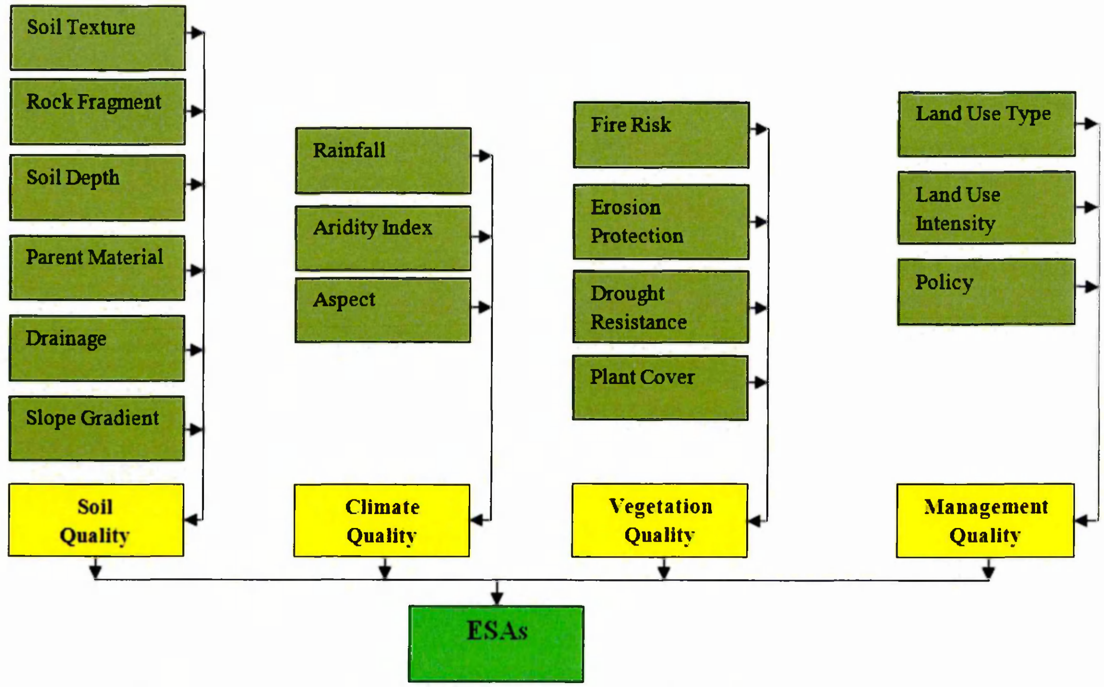


Figure 6.1. Framework to show the parameters used for the definition and mapping of the ESAs vulnerable to desertification.

How each part of the MEDALUS structure contributes to the overall classification of the land is now described.

6.2.1 Soil quality index (SQI)

The overall soil quality for any area is described by a soil quality index (SQI), and is calculated using the following equation:

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

(Equation 6.1)

The texture of the soil is related to its capacity for water retention, crusting, stability of aggregate and erodibility. The soil structure and texture are related to the availability of water. A high amount of silt in soils increases the water-holding capacity of the soils. However, sandy soils are more drought-prone than clayey soil because of their non-cohesive nature, which retains less water (Basso et al. 2010). The soil texture for each location within the study area can be described by four classes (Table 6.1), although only classes 1 to 3 are present here.

Class	Description	Texture	Texture Index
1	good	loam, sandy clay loam, sandy loam, clay loam	1
2	moderate	sandy clay, silty loam, silty clay loam	1.2
3	poor	silt, clay, silty clay	1.6
4	very poor	sand	2

Table 6.1. MEDALUS Description of soil texture (Kosmas et al. 1999).

Number of samples (Selkhozpromexport1980)	Soil texture class (Selkhozpromexport1980)	MEDALUS Description	Area (%)
360	clay	poor	9
150	sandy clay	moderate	3.5
750	sandy clay loam	good	18.5
1950	clay loam	good	49
270	silty loam	moderate	7
480	loam	good	12
25	silty clay loam	moderate	0.6
15	sandy loam	good	0.4
4000	Total		100

Table 6.2. Soil texture class for 0-0.3m soil depth.

The summary of the soil texture description for the study area from the GIS database is given in Table 6.2. It is important to recognise that 80% of the study area has soil with a good texture and 11% has a moderate texture. Whilst sensitivity to desertification is dependent on the product of a number of factors, the 9% of the study area that is clay and has a poor texture is potentially a problem.

Different parent materials make each soil react differently to erosion, desertification and vegetation. For instance, shallow soils with a relatively dry moisture system are produced from limestone (Basso et al. 2010). In some regions of the Mediterranean, parent materials with a limestone structure have been desertified previously when the soil mantle has been eroded. Likewise, pyroclastic that fall under the heading of acid igneous parent materials generate shallow soils, with a high risk of desertification and erodibility (Benet et al. 2010; Kosmas et al. 2000). As Table 6.3 illustrates, the different types of parent materials can be grouped into three classes in relation to their sensitivity to desertification:

Class	Description	Type of parent material	Parent material index
1	good	shale, schist, basic, ultra basic, conglomerates, unconsolidated, clays	1
2	moderate	limestone, marble, granite, siltstone, sandstone, dolomite	1.7
3	poor	marl, pyroclastics	2

Table 6.3. MEDALUS classification of parent material of soil (Kosmas et al. 1999).

Parent material	Area (%)
limestone	90
dolomite	4
clays	6

Table 6.4. Underlying geology in the study area (Libyan Surveying Department 1980).

As shown in Table 6.4, the prevailing parent materials of the study area are sedimentary rocks such as limestone, so 94% of the material can be described as moderate. There is about 6% of good parent material.

In the Mediterranean region, there are rock fragments present on the surface of soils, which, according to Danalatos et al. (1995), can have a great effect on soil erosion and runoff. Biomass production and the conservation of soil moisture are also positively related to the presence of rock fragments (Moustakas et al. 1995; Wesemael et al. 1995). Rock fragments present on the surface of the soil are grouped into three classes in relation to their capacity to protect soils from erosion and to allow soil water conservation (Table 6.5). In the study area, about 75% of the soil surface is classed as stony while 20% is very stony and 5% is bare to slightly stony.

Class	Description	Cover (%)	Index
1	very stony	>60	1
2	stony	20-60	1.3
3	bare to slightly stony	<20	2

Table 6.5. MEDALUS classification of the variable "rock fragments", based on the % cover of the ground by stones (Kosmas et al. 1999).

The soil within hilly regions is derived from weathered parent material; the primary parent materials of the study area in the mountains, plains and plateaus are limestone and can be exposed and broken down to form soil. Whilst there are a number of methods to describe accurately the depth of various soil horizons, in the MEDALUS methodology, the soil depth is defined as the depth to the parent material or rock. It is observed in the field that this depth can vary rapidly, even over short distances. The soil is generally shallow because of the existence of bedrock close to the surface. This restricts the capability for supporting a considerable vegetation cover under Mediterranean climatic conditions. If a critical depth based on the parent material is not achieved, most species of woody plants disappear (Kosmas et al. 2000) and just a few annual plants are able to survive. The soil depth is grouped into four classes

(Table 6.6): deep, moderate, shallow and very shallow, which cover 80%, 10%, 5% and 5% of the study area respectively.

Class	Description	Depth (cm)	Index
1	deep	>75	1
2	moderate	30-75	2
3	shallow	15-30	3
4	very shallow	<15	4

Table 6.6. MEDALUS classification of soil depth (Kosmas et al. 1999).

The depth of soil is recognized as one of the most significant soil parameters seriously affecting desertification, and consequently a higher weighting factor is assigned to this parameter, reflected in the larger magnitudes of the soil depth indexes (Basso et al. 2010).

According to Basso (2010), the angle of slope and topographic features are certainly considered as one of the strongest determinants for the erosion of soil. Erosion will be acute if the angle of the slope exceeds a critical value, and erosion processes affect a great portion of the territory, especially the hilly and agricultural areas (Roxo et al. 1997). Using a topographic map to identify the average of a hill slope is quite simple; the average slope can be determined in two different ways, which are the angle and the percentage gradient of the slope. The latter technique was used here. The contour lines from a topographic map (scale 1:50,000) are imported into Arc GIS in shapefile format. An interpolation module is used to create a digital elevation model (DEM) (Riesterer 2008). This is then exported to Arc GIS as a raster file, and then read by the spatial analyst extension (Figure 6.2) for further processing to generate the slope percentage (Figure 6.3). The grade of the slope was assigned to one of four classes according to its impact on soil erosion (Table 6.7).

Class	Description	Slope %	Index
1	very gentle to flat	<6	1
2	gentle	6-18	1.2
3	steep	18-35	1.5
4	very steep	>35	2

Table 6.7. MEDALUS classification of slope % (Kosmas et al. 1999).

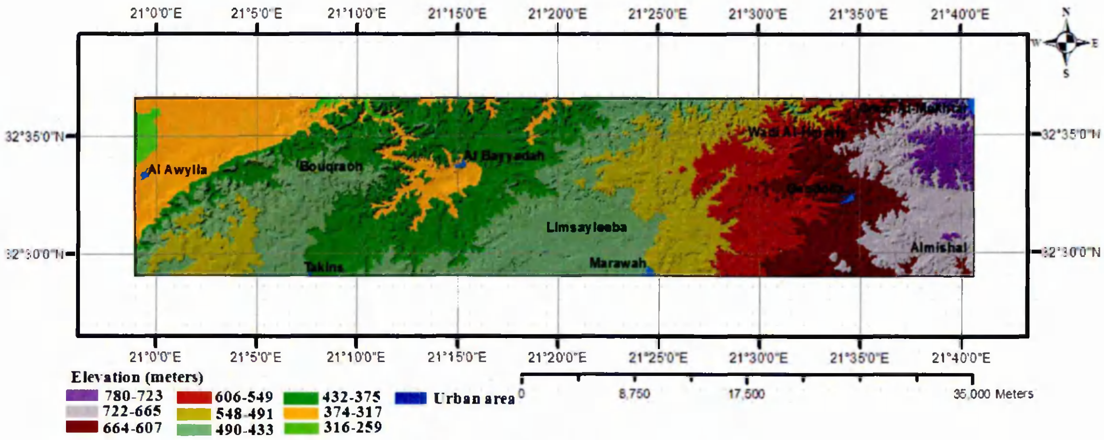


Figure 6.2. Digital Elevation Modelling of land in the study area.

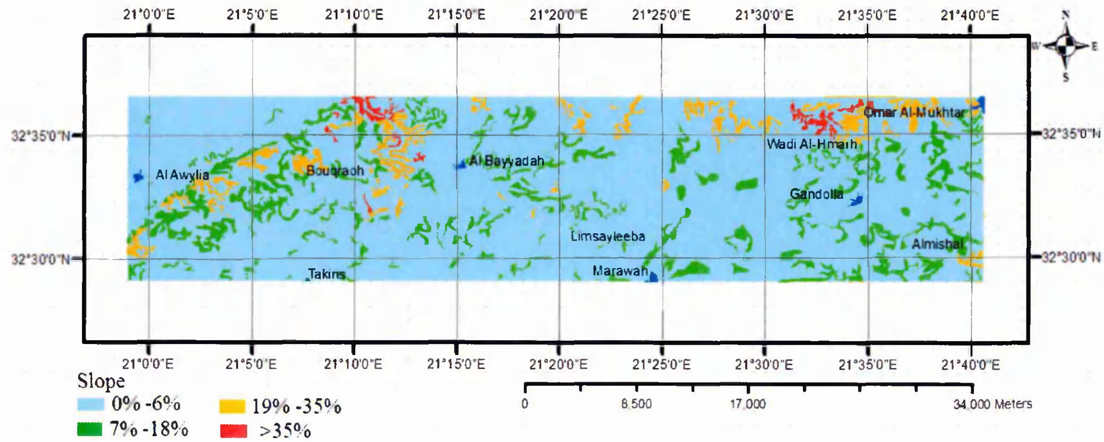


Figure 6.3. Slope (%) of land in the study area.

The majority of the study area (about 80%) falls in Class 1 as a very gentle to flat slope. A gentle slope is found in about 15% of the land. Steep and very steep levels of slope are found in about 5% of the land area.

Evaluation of soil drainage is generally included when measuring the risk of desertification because of the potential of salinization of flat regions (Basso et al. 2010). The Digital Elevation model, DEM, indicates that the land elevation decreases gradually from the east to the west (Figure 6.2). In general, the land at lower elevations will not be as well drained as the higher land. The land is also drained by a number of wadis (Figure 6.4) and a dense network of much smaller tributaries, which do not follow this general direction of elevation change. For example, in the eastern half of the study area, the northern part drains to the north, via streams such as Wadi Bu Zahair, and in the southern part it drains to the south west, e.g. via Wadi Al Halq and Wadi Al Masid. In the western half of the study area, the land generally drains to the north-east, e.g. via Wadi Sadar Al Mrah, and the west, e.g. via Wadi Al Qambu.

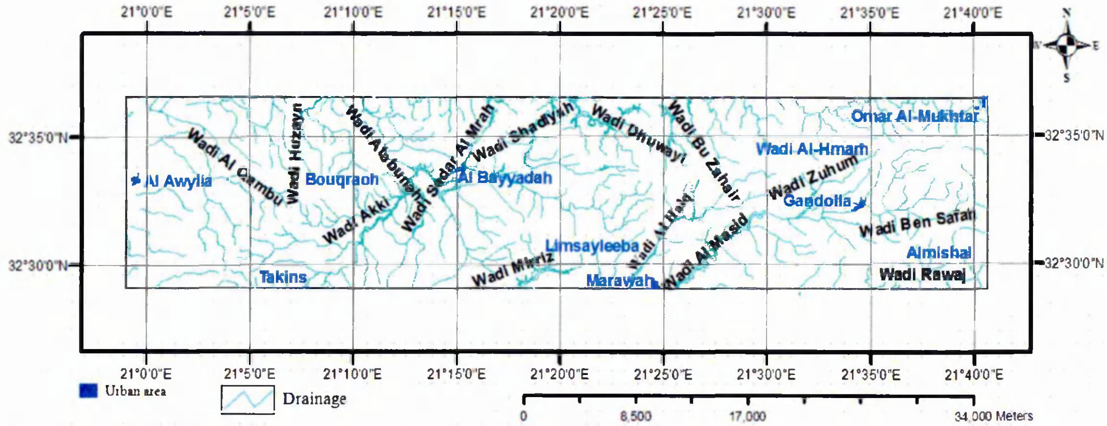


Figure 6.4. Wadi drainage systems in the study area.

The vast majority of the study area was assigned to drainage Class 1 (Table 6.8). This decision was based on the density of the drainage network. A small area to the west of Al Awylia in the north-west of the study area was assigned to Class 3. This is because the soil is darkly discoloured (visual evidence of water logging) and low-lying, with elevations between 259m and 316m (Figure 6.2). Discussion with local farmers revealed that the land was flooded each winter by a large 700-hectare lake.

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

Table 6.8. MEDALUS classification of drainage in the study area.

Using GIS, the MEDALUS Equation 6.1 is applied to generate resultant values of soil quality. These are assigned a class value based on Table 6.9. The soil is generally of moderate quality, with some areas of low quality (Figure 6.5).

Class	Description	Range
1	high quality	<1.13
2	moderate quality	1.13-1.46
3	low quality	>1.46

Table 6.9. Classification of soil quality index (Kosmas et al. 1999).

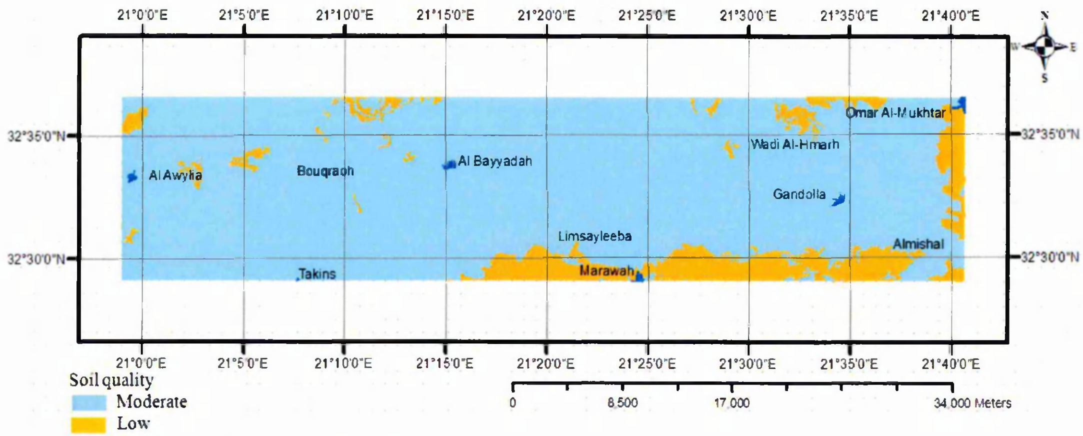


Figure 6.5. Map of soil quality index.

Soil quality defines a highly significant factor, particularly in regard to the capacity for sustaining the maintenance and growth of vegetation (Basso et al. 2010). According to Figure 6.5, areas surrounding Gandolla, Al Bayyadah, Wadi Al-Hmarh, Limsayleeba and Taknis have soil of moderate quality. The low quality found to the south of Omar Al-Mukhtar, south and west of Almishal, and west and east of Marawah is because the soil is lithic. To the north of Bouqraoh, the low quality is caused by the slope being greater than 35%. To the north-west of Al Awylia, the low soil quality of the land is due to poor texture and poor drainage.

6.2.2 Climate quality

Plant growth, availability of water, water demand, and land degradation are affected by important environmental factors such as climate (Abu-Zakham and Khoury 2000). Climate has been recognized as an important factor affecting land cover. The uneven annual distribution of rainfall, the magnitude of its extreme events and the fact that at the start of the rainy season there is little ground cover from annual grasses result in degradation of land in the semi-arid and arid zones of the Mediterranean Arid, semi-arid, and dry areas with climate changes can increasingly become degraded (Benet et al. 2010; Quezel 1977). The climate quality is assessed by using the amount of precipitation, air temperature and aspect, which affect the availability of water for plants. The impact of climate is described in MEDALUS by a climate quality index (CQI), as follows:

$$CQI = (rainfall*aridity*aspect)^{1/3} \qquad \textbf{(Equation 6.2)}$$

The individual variables are now discussed. The annual precipitation is grouped into three classes, which takes into consideration that an annual rainfall of 280 mm is a critical threshold value for soil erosion and plant growth (Kosmas et al. 1997). From 1980 to 2009, the average annual precipitation has been measured as 450mm, meaning that the rainfall in the study area is described as class 2 (Table 6.10). A limitation of this description is that it is derived from a single rain gauge just outside the study area, north of Omar Al-Mukhtar.

Class	Rainfall (mm)	Index
1	>650	1
2	280-650	2
3	<280	4

Table 6.10. Description of rainfall classes (Kosmas et al. 1999).

The main way to calculate the availability of water in the soil is precipitation minus evapotranspiration and runoff. Nevertheless, such a calculation needs relatively large amounts of data, for example on soil moisture retention and vegetation growth, which are not available. Therefore, the simple Bagnouls-Gaussen aridity index (BGI) described by Kosmas et al. (1999) is applied here to determine the aridity of the land:

$$BGI=\sum_{i=1}^{n}(2t_i-p_i)k_i \quad \textbf{(Equation 6.3)}$$

where

t_i=mean air temperature (°C) for month i

p_i= total precipitation (mm) for month i

k_i = monthly proportion during which 2ti – Pi > 0.

n = 12 months, from January to December.

According to Table 6.11, the aridity index is divided into six classes. The aridity index for the study area is equal to 2 because the BGI range > 150.

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

Table 6.11. MEDALUS classification of Bagnouls-Gaussen classes (Kosmas et al. 1999).

The aspect of sloping land is also considered as affecting microclimatic conditions, and is defined by Kosmas et al. (1999) who divided it into two aspect classes: land facing the north, north-west, north-east, east and west and flat land is assigned an index of 1, and land facing the south, south-west and south-east is assigned an index of 2. This is for several reasons, including vegetation growth characteristics and soil moisture retention characteristics. The DEM is used to calculate the slope aspect in the study area. Figure 6.6 shows the prevailing aspect index of the land. The slopes facing north, north-east and north-west and the flat land represent more than 80% of the study area, while south, south-east and south-west slopes represent less than 20%.

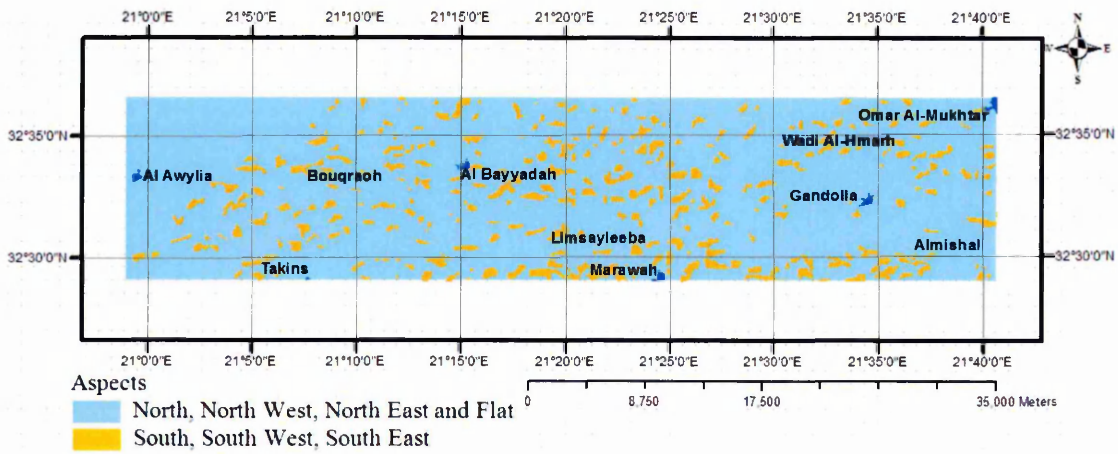


Figure 6.6. Aspect of slope in the study area.

Climate quality index	Description	Range
1	high quality	<1.15
2	moderate quality	1.15-1.81
3	low quality	>1.81

Table 6.12. Description of climate quality index (Kosmas et al. 1999).

Using Equation 6.2 and Table 6.12 indicate that the climate quality index for most of the study area is moderate, except for the 20% of the study area where the slope has a south, south-east or south-west aspect.

6.2.3 Vegetation quality

In Mediterranean regions, the following are considered the most important: fire risk and the ability to recover from fire damage, protection given to the soil from erosion, resistance to drought, and the extent of plant cover over the soil which both protects the soil from erosion and encourages soil moisture retention, texture and fertility for example (Kosmas et al. 1999). The impact of vegetation is described in MEDALUS by a vegetation quality index (VQI), as follows:

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

(Equation 6.4)

According to Basso (2010) and Al-Zani (2002), in the Mediterranean region, an important cause of land degradation is forest fire, which has become extremely frequent, particularly in the pine forests, with dramatic consequences in the rates of soil erosion and loss of biodiversity. The natural or accidental occurrence of fire is lower in grasslands and evergreen forests although the pastures of the Mediterranean region are often deliberately subjected to fires by farmers to obtain a higher annual production of grass. Vegetation types dominant in the Mediterranean are divided into four classes, in relation to their fire risk (Table 6.13).

Class	Description	Type of vegetation	Index
1	low	almonds, orchards, vines, olives and irrigated annual crops	1
2	moderate	perennial grasslands, pastures, cereals, annual grasslands, deciduous forests (oak, mixed),evergreen forests, sparse vegetation, shrublands	1.3
3	high	Mediterranean macchia	1.6
4	very high	pines and other conifer forests	2

Table 6.13. MEDALUS classification of vegetation type in relation to its fire risk and ability to recover (Kosmas et al. 1999).

Most woodland in the study area contain Phoenician juniper, *Pistaicia atlantica* and *Pistaicia lentiscusphoenicea*, being represented in the key to Figure 4.5 by cover class B, E, G, H and I. These areas are therefore classed as being moderately flammable; although these species have a high content of resins and essential oils, they do have a good capacity for recovery after a fire, which occurs gradually over a few years (Assaadi et al. 1999; Zaed et al. 2005). Land which is very sparsely vegetated, containing a mixture of shrubs within grasslands, and annual crops (cereals) are classified as moderate and represented in the key to the land use map by K, C, F, J, D, and M (Fig 4.5). Orchards and irrigated annual crops which are represented in the key to Figure 4.5 by N and A have a low sensitivity for fire risk.

Vegetation cover plays a significant role in protecting the soil surface from water erosion by reducing surface water runoff and raindrop splashing. Plants also help soil conservation and development, for example by increasing soil organic matter, soil aggregate stability, water-holding capacity and hydraulic conductivity (Kosmas 2011). Vegetation and land use are two significant features that control aspects such as the rate of overland flow and the intensity of soil erosion (Bryan and Campbell 1986; Mitchell 1990). Extensive cultivated areas for agriculture based on rain-fed crops, such as orchards and cereals, are extremely sensitive to erosion when located in hilly areas with shallow soils (Grove 1996). In fact, such cultivated soils could remain bare of cover for a large proportion of the year. The different vegetation types are classified as follows with respect to their ability to protect soils from erosion (Table 6.14):

Class	Description	Type of vegetation	Index
1	very high	evergreen forests; mixed Mediterranean macchia-evergreen forests and bedrocks	1
2	high	Mediterranean macchia; conifer forests; perennial grasslands; pastures; olives; shrublands	1.3
3	moderate	deciduous forests (oak, mixed)	1.6
4	low	deciduous perennial agricultural crops (almonds, orchards)	1.8
5	very low	annual agricultural crops (cereals); annual grasslands; very sparse vegetation	2

Table 6.14. MEDALUS classification of vegetation type in relation to ability to protect against soil erosion (Kosmas et al. 1999).

The variety of ecosystems in the Mediterranean presents an enormous resistance to aridity. Most natural or naturalised species that exist under the climatic conditions of the Mediterranean region have to resist droughts and soil moisture contents below the point of theoretical wilting for several months of the year (Al-Zani 2002; Alzegt 1978; Kosmas et al. 1999; Walter 1979). These different prevailing types of vegetation are placed in four classes according to their resistance to drought (Table 6.15).

Class	Description	Type of vegetation	Index
1	very high	evergreen forest; Mediterranean macchia; mixed Mediterranean macchia - evergreen forests and bedrocks	1
2	high	conifer forests, deciduous forests, olives	1.2
3	moderate	perennial agricultural trees (vines, almonds, orchards)	1.4
4	low	perennial grasslands, pastures, shrublands	1.7
5	very low	annual crops (annual grassland, cereals, maize, tobacco, sunflowers, etc.); horticulture; very sparse vegetation.	2

Table 6.15. MEDALUS classification of vegetation type and resistance to drought (Kosmas et al. 1999).

The main response of plants to increased aridity is a reduction in the leaf area index (Walter 1979). The majority of plants in the study area have high and very high drought resistance due to their small, hard, leathery, evergreen foliage (e.g. on pine trees or juniper bushes) that is specially adapted to prevent moisture loss. Moreover, some soil wetness may be kept in the rocks' cracks and plants such as *Juniperus macrocarpa* and Phoenician juniper are able to extract and benefit from it (Al-Zani 2002; Kosmas et al. 1999).

In a large range of environments, the runoff and loss of sediment reduce exponentially as the vegetation cover percentage increases (Elwell and Stocking 1976; Francis and Thornes 1990; Lee and Skogerboe 1985). The land use map (Figure 4.5) is used to define the spatial variation of vegetation cover. A vegetation cover value of 40% is considered significant. Below that, accelerated erosion dominates in sloping areas (Thornes 1988). Vegetation cover decreases the effect of rainfall strength at the soil surface (Faulkner 1990). When vegetative cover declines from 43% to 15% on a 10% slope, the rate of sediment rises rapidly. However, when vegetative cover is less than 15%, the rate of sediment increases markedly and these results indicate that less than 15% vegetative cover is ineffective in retarding erosion (Rogers and Schumm 1991). This impact on soil erosion by the different amount of vegetation cover is grouped into three classes (Table 6.16).

Class	Description	Plant cover (%)	Index
1	high	>40	1
2	low	10-40	1.8
3	very low	<10	2

Table 6.16. MEDALUS classification of plant cover and its impact on water erosion (Kosmas et al. 1999).

The vegetation quality index (VQI) is calculated using equation 6.4 and the values obtained are assigned to a class, as defined by Table 6.17. Figure 6.7 shows the resulting spatial variation in the classes of the vegetation quality index for the study area.

Class	Description	Vegetation quality index
1	high quality	1 to 1.12
2	moderate quality	1.13 to 1.38
3	low quality	>1.38

Table 6.17. MEDALUS classification of vegetation quality index (Kosmas et al. 1999).

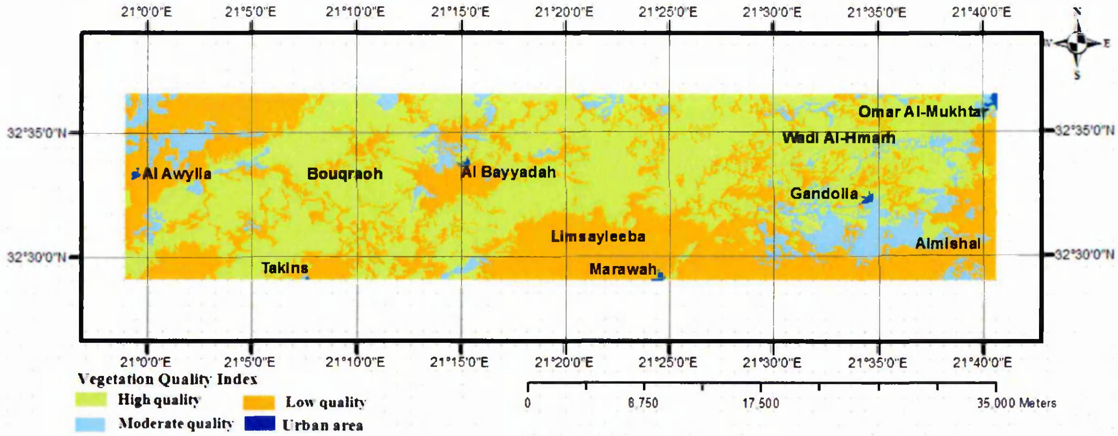


Figure 6.7. Variation of vegetation quality index in the study area.

There is about 48% high quality land, 17% moderate quality land and 35% low quality land in the study area. The high vegetation quality index applies to land that is covered by woody vegetation with shrubs or reforested land and has vegetation cover of 40% or more, indicated by B, E, G, H, and L in the key for Figure 4.5. The moderate quality occurs in orchards and areas covered by woody vegetation with shrubs where the range of vegetation cover lies between 30% and 40%; these lands are symbolized by A and I in Figure 4.5. Most areas that do not have a low percentage of vegetation cover, particularly shrub-lands or seasonal land crops such as N, C, D, F, J and M cover classes in Figure 4.5, are characterized by low vegetation quality.

6.2.4 Management quality

The management quality index (MQI) is governed by human-induced stress on the environment, which is dictated by the pressure from social, environmental and economic activities. Management quality can be evaluated for the five broad land types that have been defined by Kosmas et al. (1999): agricultural land, natural areas (subdivided into forests, shrub-land and bare land), pasture, tourism, and mining. The last two are minimal in the study area at the present time and so are currently not considered further. Kosmas et al. (1999) stated that the Management Quality Index can be calculated using the following equation:

$$MQI = (\text{policy enforcement} * \text{land use intensity})^{1/2} \qquad \textbf{(Equation 6.5)}$$

Therefore, evaluation of the management quality for each type of land requires assessment of two factors from field observations.

The methodological strategy to organise the field observations was to spread the assessment locations evenly across the study area. To do this, the study area was divided into one hundred and five blocks, each block being 9 km^2 in extent. Two or three assessments in sample plots or transects of 100m x 100m in size within each rectangular block were carried out, with the locations being selected randomly (Figure 6.8). This meant 250 assessments occurred in total. The small size of these blocks and the rate of spatial variation of the land cover meant that all land cover/use occurring in each block was assessed. If a land use type was assessed more than once in a block, then these results were averaged. To avoid bias, each point was assessed individually by a team of four people (including the author); during the period from July to September 2010 (see Appendix for the identities of the expert panel). Discussion of the individual assessments at a particular location ensued until a consensus was reached.

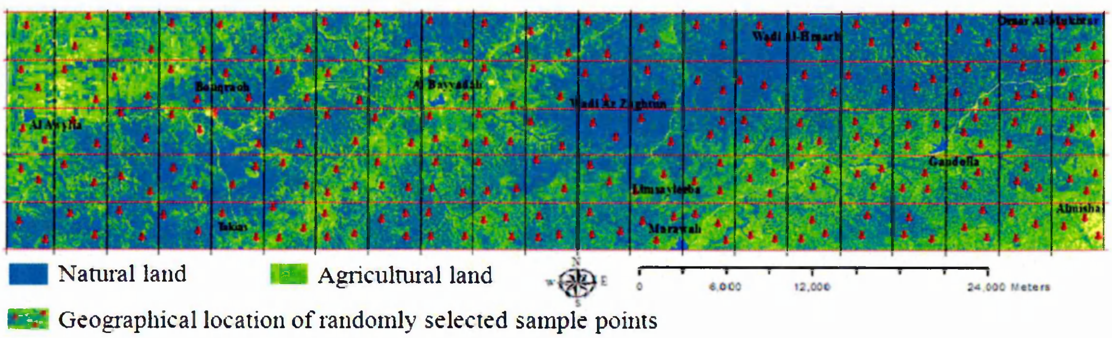


Figure 6.8. Locations of assessments of land use intensity by expert panel to determine the management quality index (MQI).

The assessment method and any development that was required beyond the established MEDALUS methodology and the results obtained for each land use type are now discussed.

6.2.4.1 Policy enforcement

It has been recommended that the magnitude of the index for policy enforcement for use in Equation 6.5 can be determined using Table 6.18 (Kosmas et al. 1999).

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

Table 6.18. Description and degree of enforcement of policy for environmental protection (Kosmas et al. 1999).

The information must be collected on the existing policies and their implementation and enforcement. The government's department of agriculture should have a policy to promote better regulation of the development of agricultural and natural lands and need to issue laws and regulations based on the problems that affect each region. To establish what laws have been passed to protect the environment, two visits were made to the Agricultural Research Centre 2010, to research their records of legislation that had been passed. Interviews of officials were also undertaken to confirm the data collected. This information is organised in terms of land cover class/use. The year in which the legislation was passed is also given for information (Table 2.2).

It is suggested that there should be different policies for different land use types (Kosmas et al. 1999). The land cover classes for agricultural land range for example from fields of rain-fed wheat and barley, to orchards with an understory crop, to irrigated vegetable crops of tomatoes and onions. The policies for the agricultural land focus on typical management practices for reducing tillage and water erosion, for example, no tillage or minimum tillage, tillage of soil in the up-slope direction and the kind of tillage (Ben-Mahmoud 1995; Ben-Mahmoud 2013; Kosmas et al. 1999). With reference to the kind of tillage or the particular tillage implements being used, most will agree that "conventional" tillage is the use of a mouldboard plough and a disk or other implement to pulverize the soil surface. This system effectively reduces surface mulch to zero. The finely pulverized surface soil is easily detached by raindrops and becomes suspended in water.

At the same time, soil pores become clogged with the suspended soil particles. The result is more soil-laden water moving off the land. Soil, water and fertility are lost from the land and streams are polluted. This kind of tillage is seldom justified on sloping land susceptible to erosion. However, there are situations where no-till should not be used either. When special weed problems, certain soil conditions or farmer preference rule out no-till, there are reduced-tillage systems that can be used. Certain tillage implements such as rippers and chisel ploughs break up the soil but leave most of the residue on the surface. This combined with less disking or other types of soil mixing, can reduce erosion rates by 50% (Ben-Mahmoud 2000; Ben-Mahmoud 2013). The most effective tillage system for controlling soil erosion, while producing grain crops on sloping land is no-tillage. Soil disturbance is limited to a narrow slit which serves as the seedbed when the crop is planted. In flat or semi-flat land used a mouldboard plough and a disk or other implement to pulverize the soil surface. In the hilly area, the direction of tillage operations in relation to slope is critical in limiting soil erosion. The erosion potential associated with any type of tillage system can be significantly decreased by working across the slope rather than up and down the slope. In many cases, this is simply a matter of planning ahead. Contour tillage and strip cropping systems are more involved, but many farmers in the region use them to effectively reduce soil erosion.

Kosmas et al. (1999) described various agricultural land management activities which should be regulated by policy (Table 6.19). These descriptions are supplemented by quantities to define each description, as proposed by Ben-Mahmoud (2000, 2013) and shown in Table 6.19. Of course the effectiveness of policies depends on the degree to which they are enforced (Kosmas et al. 1999). Whilst Komas et al. (1999, 2010) defined the magnitude of the index applied to each area in terms of the percentage of area over which a policy was applied, it is inferred that this procedure is more appropriate for large land areas, rather than the 9 km^2 blocks into which the study area was divided for this assessment. Here, an index is assigned to each block, depending on the policy adopted in the three sample plots for each block. If a different degree of use is observed for the plots within each block, taking a mean value is proposed though in reality, the same behaviour was observed was each block.

Degree of use	Description	Index
Adequate	In flat or semi-flat land using certain tillage implements such as rippers and chisel ploughs break up the soil but leave most of the residue on the surface and the depth of ploughing < 20cm.	1
Moderate	Use rippers and chisel ploughs, across the slope in the hilly area. The depth of ploughing =20-40cm.	1.5
Low	Use mouldboard plough and a disk or other implement to pulverize the soil surface. up and down with direction of tillage. The depth of ploughing >40cm.	2

Table 6.19. Management Policy index for agricultural areas.

For natural land, there are no policies currently in place to regulate the use of this land for grazing. As there is no policy it cannot be enforced. This might suggest that an index of 2 should be applied for the natural area. However, field visits to verify the land cover included visits to natural lands, some of which had suffered from over grazing, but other areas had not suffered environmental damage. Thus widespread application of a single high index does not seem appropriate.

Policies do exist to regulate the gathering of wood for domestic purposes and charcoal making, the latter being observed in a small area of Gandolla. To identify the level of policy enforcement against illegal tree cutting, the following table was developed (Table 6.20). Fully grown Juniper trees are generally the target for illegal harvesting, rather than shrubs. This was based on the potential impact of chopping trees down on the cover class magnitude, which varies for each land cover class.

Overall vegetation cover (tree & shrubs)	Class	Protection given by policy	Juniper trees lost (%)	Index	Area affected (ha)
>60%	1	High	<10	1	
	2	Moderate	10-20	1.5	-
	3	Low	>20	2	-
50-60%	1	High	<10	1	
	2	Moderate	10-17	1.5	-
	3	Low	>17	2	-
40-50%	1	High	<10	1	
	2	Moderate	11-20	1.5	350
	3	Low	>20	2	10
30-40%	1	High	>20	1	
	2	Moderate	21-40	1.5	-
	3	Low	>40	2	-

Table 6.20. Classification of enforcement policy for charcoal making in the natural area based field evidence.

It is not clear how to proceed if an area is affected by the enforcement or lack of enforcement of more than one policy. It is proposed here to focus on the primary activity in the natural land, which in the majority of the natural area is grazing of sheep and goats. As no policies exist to control this, for these land classes, the policy index is ignored and the management quality index is dependent entirely on land use intensity.

6.2.4.2 Land use intensity

The definition of the intensity of land use is dependent on land cover and land use, which is initially divided into the two broad groups of agricultural and natural land. The land use map (Figure 4.5) helps identify the activity in any particular location, together with descriptive supporting notes taken in the field trip for each land use type.

Agricultural land

Agricultural land is divided into three classes as illustrated in Table 6.21.

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

Table 6.21. Types of land use intensity in agricultural land (Kosmas et al. 1999).

A more detailed description for each class of agricultural land in the Mediterranean region has also been published (Table 6.22).

Class		Description	Index
1	Low land use intensity (LLUI)	Local plant varieties are used, fertilisers and pesticides are not applied, and yields depend primarily on fertility of soils and environmental conditions. Mechanisation is limited. In case of seasonal crops, one crop is cultivated per year or the land remains fallow.	1
2	Medium land use intensity (MLUI)	Improved varieties are used, insufficient fertilisers are applied and inadequate disease control is undertaken. Mechanisation is restricted to the most important activities such as sowing and fertiliser application. Pesticides applied 2-3 times per year	1.5
3	High land use intensity (HLUI)	Improved plant varieties are used. Application of fertilisers and control of diseases are adequate. Pesticides applied 4 or more times per year. Cultivation is highly mechanised.	2

Table 6.22. Land use intensity in agricultural land (developed from Kosmas et al. 1999).

This information can only be obtained by questioning the fruit grower. It can be seen from the above table that the difference between the classes of land use intensity depends primarily on the number of fertiliser and pesticide applications. According to Etbaile (2000), applying 0.1-0.15 kg year^{-1} of ammonium sulphate or ammonium nitrate or 0.1 kg year^{-1} of composite fertiliser that contains nitrogen, phosphorus and potassium in a single application falls under low land use intensity. If such amounts of fertiliser are repeated two or three times each year then it considered as medium land use intensity, and if higher, it falls under the heading of high land use intensity.

In relation to method of pesticides application, the manual backpack-type sprayer is used in low land use intensity one or two times a year; more than this amount is considered to be medium land use intensity. The use of large self-propelled agricultural floater sprayers in pre- and post-emergent pesticide application is considered to be high land use intensity. Based on such information, fieldtrips and additional surveys conducted during the ground truthing of the land use map, it was found that most orchard farming applied pesticides and fertilisers in the low and medium land use categories. An insufficient application of pesticides may occur due to lack of finance and lack of agricultural education. In relation to mechanisation, the degree of mechanisation was between 'limited' and 'restricted'. Little mechanisation occurs in orchard work compared to European farming; for example, crops are picked by hand, fertilisers and pesticides are applied by hand, and utility vehicles are used to transport fruit. Mechanisation consists of ploughing in the grass two or three times per year to control growth between rows of trees and for mulch tillage. Grass growth under trees is controlled using hand tools (e.g. sickle, hoe).

Personal communication with Kosmas (2010) confirmed that the following proposals were appropriate for the study area.

A- Rain-fed area (barley and wheat)

Locally, according to Ben Mahmoud et al. (2000), all areas cultivated with wheat and barley are considered to be in medium or high land use intensity. Fertilisers are applied once a year in the medium land use class and more than once a year in high land use intensity. Pesticides are not applied in the medium land use class and used in high land use intensity (Etbaile 2000). Machines are used once during the year in the medium land use class for autumn ploughing, sowing and harvesting. Further activity means the intensity of land use is considered being high.

B- Irrigated area

Irrigated land requires soil nutrients and water for satisfactory growth. Nitrogen is the major nutrient and occupies an important position in the fertiliser programme. The other major nutrients are phosphorus and potassium. The micronutrients iron, boron, copper, zinc, magnesium and manganese are required in very small amounts (Ben Mahmoud 1995). In relation to land use classification, medium land use intensity occurs when the fertilisers are applied once every 3-4 weeks at the beginning or end of the day to avoid the heat, and must not applied during the hot months (July and August). If the fertilisers applied less than such amount it counts as low land use intensity, otherwise land falls under the heading of high land use intensity if fertilisers are applied more than once every 3-4 weeks. Levels of pesticide application vary but it always depends on the insect pests observed in the field. Precautionary preventative spraying is also undertaken; generally, pesticides are used two to three times during the crop period in the medium land use class. High land use intensity occurs when pesticides are used more than two to three times during the crop season however, applying pesticides less than twice during the crop period considered to be low land use intensity (Etbaile 2000).

Mechanisation in medium land use intensity is used only for waterways to divert water for the purpose of irrigation, or to remove the remnants of the previous crop, and the occasional use of utility vehicles or small open-backed trucks for harvesting. In low land use intensity no mechanisation is used: most irrigated work is done using hand tools. However, in high land use intensity, mechanisation is used to till the ground more than three times per year, or an agricultural 'floater' sprayer is engaged in pre- and post-emergent pesticide application.

Natural areas

Within MEDALUS, a land cover classification of forests, shrubs or bare soil is defined as a natural area. In the natural forests, the quality of management is considered as high, and therefore the intensity of land use is low; the intensity of use is based on the demand for forest products. To assess the quality of forest management, an assessment of the sustainable yield of a forest (S) and the actual yield (A) is performed by calculating the ratio of actual to sustainable rate A/S (Kosmas et al. 1999).

Kosmas et al. (1999) describe the intensity of use of natural areas and the index value that should be assigned as follows, in terms of actual and sustainable yield:

Class	Description	Management characteristics	Index
1	Low	A/S = 0	1
2	Moderate	A/S < 1	1.2
3	High	A/S = 1 or greater	2

Table 6.23. Types of land use intensity in natural land (Kosmas et al. 1999).

In the study area, two small areas are assigned to land use class L (Fig 4.5) which may be considered as managed forests as they consist of pine trees specifically planted to reduce soil erosion. There is no demand for the wood from such trees, so the ratio of actual to sustainable yield here is zero.

Natural areas consist of woody plants, shrubs and grassland mixed together in various proportions, and each is therefore allocated to a different land cover class, e.g. B to K (Figure 4.5). Observation in the field suggests that these lands may be subjected to multiple land uses, e.g. timber harvesting for domestic uses, charcoal production, and animal grazing, where the presence or predominance of any activity may depend on the land use/cover classification, the composition of plants and trees, regional location, and proximity to roads, as discussed previously.

One of the important key indicators for assessing the land's capability to withstand further degradation is damage from grazing. Overgrazing removes the protective vegetation cover and causes weed invasion while livestock trampling exposed soils. Soils are then vulnerable to wind and water erosion, which removes the nutritionally rich upper layers of the soil (Daryanto and Eldridge 2010). Selective grazing or browsing resulted in a loss of palatable forage species and an increase in less palatable plants (Vallentine 2000). From observations in preliminary field work, it seemed the most widespread damage in the natural areas was a result of grazing pressures, rather than other uses such as timber harvesting for charcoal production.

Guidance on how to assess the intensity of land use by MEDALUS model when the land is subjected to multiple uses is not clear and published advice is not explicit (Kosmas et al. 1999). Currently, MEDALUS does not consider livestock grazing in the assessment of land use intensity in natural areas. As mentioned previously (Chapter 2), livestock in natural areas can range freely with their shepherds over a wide area, irrespective of land ownership, making it very difficult to track down shepherds and their flocks, although visible damage from overgrazing is observed in the study area. Therefore, the principal author of the MEDALUS project was contacted for guidance on how to establish an index for natural land in this situation (Kosmas, pers. comm. 2012). A rather general table of descriptive information was given in reply (Table 6.24), but with no information on how to identify land that belonged to a particular class.

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

Table 6.24. Land use intensity in natural areas (Kosmas, pers. comm. 2010).

Therefore, a method needed to be developed for assessment of the intensity of overgrazing in the natural area. In the natural areas, the various land use types have been suitably grouped as homogeneously as possible into the three classes of high, medium and low for the intensity of land use.

The result of overgrazing is that in some parts of the study area, tall-growing species die and short-growing species that are more subject to drought injury dominate the pasture. A proper approach to assess grazing intensity is to consider important aspects such as the size of grazing patches (Kosmas et al. 2011), and damage to vegetation cover (Noah et al. 2009). Overgrazing is also seen as a cause of the spread of invasive species of non-native plants and of weeds, bare spots created by overgrazing and the spread of undesirable grass cover (Alsady 1998). To assess the pressure due to grazing, this study identified a number of useful criteria from previously published literature (e.g. Arnalds et al. 1997). Information on land use was inferred from visual assessment in the field and standardized interviews with livestock breeders containing detailed information on management practices. The following categories (Table 6.25) are used to express levels of exploitation by grazing and have been verified by personal communication (Yagoub, pers. comm. 2010; Ben-Mahmood, pers. comm. 2010). It can be seen that the left hand column of highlighted figures adds up to one and the right hand column adds up to two. These are the two extremes of the MEDALUS intensity of land use indicator.

Observed indicators	**Case**				
Field evidence of level of exploitation for grazing (%)	≤20	21-40	41-60	61-80	>80
Value	0.4	0.5	0.6	0.7	0.8
Bare soil (%)	≤10	11-20	21-30	31-40	>40
Value	0.2	0.25	0.3	0.35	0.4
Shrub/tree cover (%)	>50	50-41	31-40	21-30	≤20
Value	0.2	0.25	0.3	0.35	0.4
Undesirable grass cover (%)	≤10	11-15	16-20	21 - 25	>25
Value	0.1	0.125	0.15	0.175	0.2
Damage to vegetation (%)	≤10	11-20	21-30	31-40	>40
Value	0.1	0.125	0.15	0.175	0.2

Table 6.25. Formula used during field assessment of grazing damage (developed by researcher).

Bare soil, spread of undesirable grass cover and damage to vegetation were measured through visual assessment in the fields in the sample plots for each block. The percentage of shrubs and tree cover was determined using a land use / cover map. The level of exploitation for grazing is measured in the field using the classification of grazing intensity (Table 6.26).

Utilization	Key species degree of use	Plant description
Light to non-use	≤20	In annual plants: little or no use of the grazing species. Grazing is not apparent from a distance. With close inspection, a few plants of the key species show evidence of light use. Grazing species are more than 15 cm tall and grazed patches are small or not present. In shrubs, little or no use of grazing species; with close inspection, a few plants show evidence of light use (grazed heights less than15cm).
Conservative	21-40	In annual plants: varying degrees of grazing and grazed patches 10 to 50 cm in diameter. In shrubs: grazing evidence is not seen from a distance, grazed height 5 to 15cm, no use of less preferred species, and no trampling damage or bare ground.
moderate	41-60	In annual plants: varying degrees of grazing and grazed patches 50 to 100 cm in diameter. In shrubs: grazing evidence is not seen from a distance, grazed heights 16 to 25cm, light use of less preferred species, and light trampling damage and some bare ground.
Heavy	61-80	Nearly all primary plants show grazing, palatable species show hedging. Less preferred species have received some use. No ungrazed patches and plants show some graying. Grazed patches 100 to 200 cm in diameter. Some trampling damage and bare ground.
Severe	>80	In annual plants and shrubs: no ungrazed patches, heavy use of less preferred species. Shrub is hedged and enclosed. Grazing is noticeable from a distance. There is evidence of livestock trailing and trampling effects.

Table 6.26. Classification of grazing intensity of the natural area based on field evidence.

The following are examples of characters of land condition suffered from overgrazing, obtained during the fieldwork and used to describe the intensity of land use in the classification.

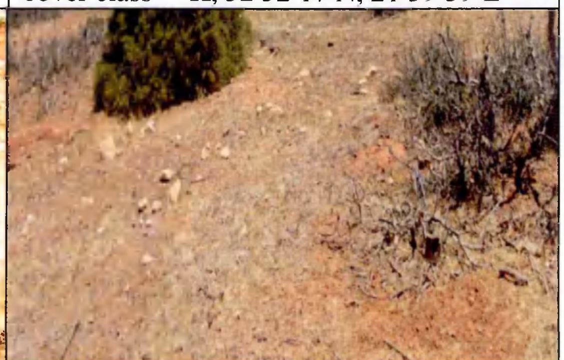
Pictures 6.1. Visual assessment of a small Mastic tree for grazing damage (high land use intensity. Land cover class = H, 32° 34' 1" N, 21° 18' 23" E

Picture 6.2. Animal paths indicating high land use intensity. Land cover class = B, 32° 31' 42" N, 21° 30' 29" E

Picture 6.3. High land use intensity: complete denudation of small Mastic tree (<0.4m) through over grazing. Land cover class = F, 32°30' 41" N, 21°24' 56" E.

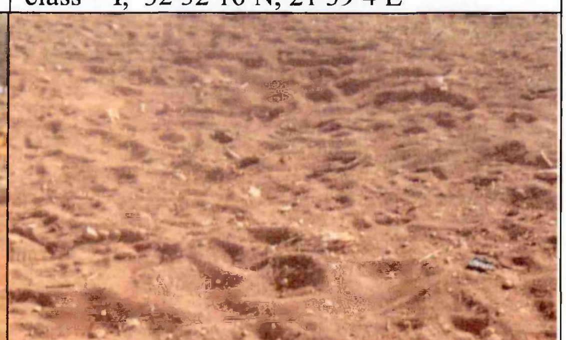
Picture 6.4. High land use intensity: extensive consumption of lower levels (<0.2m) of highly palatable *Santonica Wormseed* shrub from over grazing. Land cover class = K, 32°32' 17" N, 21°39' 39" E

Picture 6.4. High land use intensity: consumption of 70% of *Santonica* Wormseed shrub of low height from overgrazing (<0.25m). Unpalatable Caper shrub to the left. Land cover class = D, 32°33' 57" N, 21°43' 24" E



Picture 6.4. High land use intensity: dead Mastic tree to the right from overgrazing (<0.5m), with unpalatable Juniper shrub to the upper left. Trampling of ground and sheep excrement also present. Land cover class = I, 32°32' 16" N, 21°39' 4" E

Picture 6.4. Removal of grass and bare soil remaining (high land use intensity). Land cover class = C, 32°31' 39" N, 21°40' 41" E



Picture 6.5. Intensive hoof prints resulted in bare soil (high land use intensity). Land cover class = F, 32°30' 8" N, 21°23' 49" E

Picture 6.5. Spread of poisonous weed because of over grazing high land use intensity. Land cover class = I, 32°32' 5"N, 21°32' 31"E

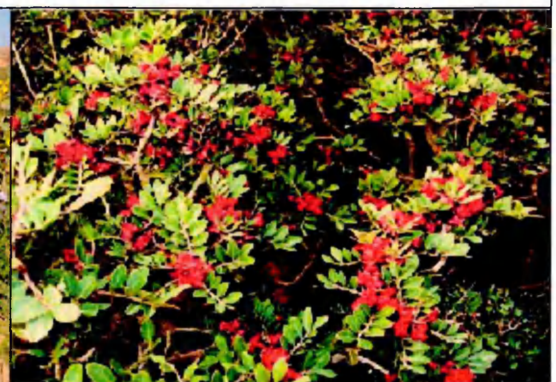
Picture 6.7. Spread of undesirable weeds because of high land use intensity. Land cover class = H, 32° 33' 42" N, 21°28' 24"E

Picture 6.8. Medium grazing effects on grass only and has no effect on shrubs. Land cover class = H, 32°36' 3"N, 21°24' 48"E

Picture 6.9. Medium grazing effects on grass only and has no effect on vegetation. Land cover class = G, 32°33' 21"N, 21°22' 51"E

Picture 6.10. Low grazing effects; soil Covered with herbs and grasses. Land cover class= H, 32° 34' 57" N, 21° 19' 4" E

Picture 6.11. No grazing effects; soil covered with herbs because it is lithic resulted in bare soil. Land cover class= K, X: 32° 30' 43" N, 21° 23' 7" E



Picture 6.12. No grazing effects on Mastic trees. Land cover class= E, 32° 36' 21" N, 21° 18' 2" E

6.2.4.3 Spatial distribution of Management Quality index

The resulting spatial variation in the classes of the management quality index for the study area is shown (Figure 6.9).

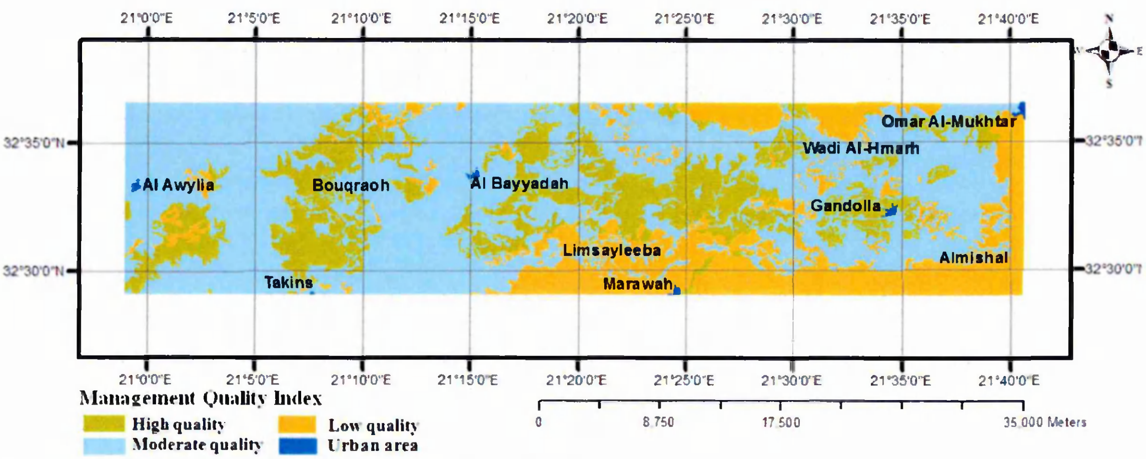


Figure 6.9. Management quality index in the study area.

According to the land use map (Figure 4.5) and fieldwork, the intensity of land use in woodlands with shrubs is low because there is dense plant cover and little human involvement. This is symbolized by B, E, G, H and L in the key to Figure 4.5. In addition, some of the classes mentioned are located in areas of medium-intensity and others in areas of high-intensity because of human activities. The rest of the natural areas are classified as showing high-intensity land use (C, D, F, J and K in Figure 4.5); these areas have a low vegetation cover and a high human impact, primarily from livestock grazing. In the orchards, woody vegetation with dwarf shrubs cover from 30% to 40% of the land, annual crops (cereals), and irrigated lands, are symbolized by A, I, M and N in the key to Figure 4.5, and classified under medium land use intensity. Some of the areas under plantation plan (symbolized by L in Figure 4.5) are assigned to areas under high protection because they are fenced off from the public and guarded by the landowner/tenant and the government.

6.2.5 Index of Environmentally Sensitive Areas

The environmental sensitivity area (ESA) using the MEDALUS method is shown in the framework in Figure 6.1. The final ESA index (ESAI) is calculated using equation 6.6:

$$ESAI = (SQI*CQI*VQI*MQI)^{1/4} \qquad \textbf{Equation6.6}$$

The result is classified as critical, fragile, potential or non-affected, according to Table 6.27. The first two types are divided into three subclasses, ranging from 3 (high sensitivity) to 1 (lower sensitivity).

	Type	Subtype	Range of ESAI	Sensitivity Index (% of critical factors)
	Critical	C3	>1.530	> 47.19
	Critical	C2	1.416-1.530	> 36.95 <= 47.19
	Critical	C1	1.376-1.415	> 33.39 <= 36.95
	Fragile	F3	1.326-1.375	> 28.94<= 33.39
	Fragile	F2	1.266-1.325	> 23.60<= 28.94
	Fragile	F1	1.226-1.265	> 20.04 <= 23.60
	Potential	P	1.170-1.225	>15.14 <=20.04
	Non affected	N	<1.170	>=0 <15.14

Table 6.27. Types of ESAI and corresponding ranges of indices (Kosmas et al. 1999).

After a detailed survey has been conducted of all the required land parameters and management characteristics mentioned, there are some different types of the environment that are sensitive to desertification in the study area.

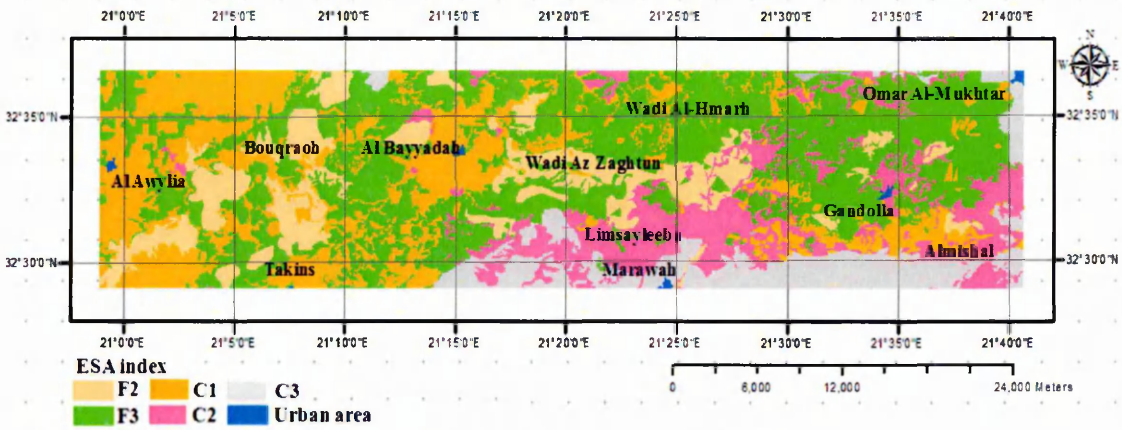


Figure 6.10. Map of study area showing sensitivity to desertification.

Comparing Figure 4.5 and Figure 6.10, revealed that F2 represents most of land that is characterized as dense natural woody vegetation with shrubs or as forest, which are well managed. Most of these lands located in the centre of the study area, between Gandolla and Al Bayyadah, north and south of Bayyadah, north-west and south-west of Bouqraoh and south-east of Al Awylia consist of dense vegetation (i.e. B and L in Figure 4.5) and represent 21% of the land. Land that has dense natural woody vegetation with shrubs is considered as F3 in the case of low climate quality with high management quality or moderate quality of climate and management, and as C1 in the case of low climate quality and moderate quality of management or low quality of management. In the case of low climate and management quality these lands are considered as C2. Woody vegetation with dwarf shrubs that cover from 30% to 40% of the land is considered as C1 in the case of moderate climate quality and as C2 in the case of low climate quality. Orchard land is considered as F3 because it has moderate climate, soil, vegetation and management quality. Irrigated land is considered as C1 because it has moderate climate, soil and management quality with low vegetation quality. Lands with less than 30% vegetation cover are considered as C2 in the case of moderate climate and soil quality and as C3 in the case of low climate or soil quality. Land cultivated annually for cereals is considered as C1 in the case of high land protection and as C2 in the case of moderate land protection. C2 and C3 accrue to mismanagement, low soil quality and low vegetation quality caused by the fact that the cover is often less than 30%. Most of the medium sensitivity (C2) is located around

Limsayleeba and around Almishal. High sensitivity to desertification (C3) is located in small areas in different parts to the south of Omar Al-Mukhtar, south and west of Almishal towards Marawah and also for a further 10km west of Marawah, most of this area is farmland and its forest exposed to severe degradation. C2 and C3 classifications apply to 12% and 10% of the land area and are natural lands with either sparse vegetation cover or a complete elimination of vegetation because of the absence of good quality management.

Gad (2010) and Gad and Lotfy (2008) noted land with a high and very high sensitivity to desertification (C2 and C3) due to a lack of vegetation cover in Egypt. In the study area, lower sensitivity (C1) applies to 28% of the land and is important because it is includes the major croplands for wheat and barley. Most C1 areas have suffered from mismanagement where the vegetation cover is not dense enough. Ali and El Baroudy (2008) found that, at Wadi El Natrun in Egypt, land was highly sensitive to desertification, due in part to the absence of enforcement of management policies where there is a low density of natural vegetation cover. Desertification has also been observed because of mismanagement in rain-fed croplands (Gad 2010).

In the study area, there are a number of local laws which give regulations for land management that control the misuse of vegetation and soil resources. These regulations are perceived as a restraint on national development and sometimes as being in conflict with the national interest. Therefore, the application of agricultural policies is not enough for environment protection. For example, a law was passed in 1998 to create financial penalties for illegal deforestation, based on tree type and age. The Ministry of Agriculture (1998) also issued penalties in relation to compensation for forest and pastures that suffer damage or complete removal (see the appendix). Currently the lack of proper implementation of the existing controls is not enough to preserve the environment (Briassoulis 2003; Rubio 2003; Thornes and Burke 1999). In addition, the protection policies are not sufficiently comprehensive; some local experts believe that there are no regulations or laws to protect the natural land and the soil from livestock over-population and the pressure of intensive overgrazing. Furthermore, the government has not passed laws for grazing management, such as controls on the grazing season or the duration of grazing and numbers of livestock for the land. In the MEDALUS model, the nature of the existing policies is not considered, only the level of enforcement of such policies. This is potentially a shortcoming of the model. There is also a need for appropriate policies at different spatial scales, based on the different requirements of specific areas. However, definition of the impact of existing or newly implemented policies is still limited, owing to the lack of sufficient documentation and the absence of data (Briassoulis 2003; Rubio 2003; Thornes and Burke 1999; Van-Camp et al. 2004).

6.3 Conclusion

In the classification of environmentally sensitive areas to desertification (MEDALUS), C1 refers to land which is mostly farmland and forest and which is exposed to human pressure. The C2 class includes lands that have a sparse natural vegetation cover or where a complete elimination of natural vegetation has occurred because of overgrazing in the absence of good quality management. A C3 classification is given to land for the same conditions as those described for C2 lands, but where the soil is lithic. F2 and F3 land classifications have a high density of vegetation and good management. Information gained during fieldtrips and from interviewing local experts confirmed that F2 and F3 lands are less sensitive to desertification.

CHAPTER 7

VERIFICATION OF MEDALUS AND USLE MAPS

7.1 Introduction

The last maps of land degradation (USLE) and desertification (MEDALUS) created for the year 2008, were compared and their accuracy assessed. The maps were compared through the layering of grids in GIS. The accuracy of the maps was assessed by verification of the results against field data. To gain these data, a focus group consisting of 10 local experts (including the author) was assembled to undertake field observation of degradation and desertification at random points within the study area. This assessment methodology is commonly used in environmental land use policy and landscape research (McCallum et al. 1991; Scott 2011).

7.2 Degree of degradation in the various types of ESAs as a percentage of the study area, measured by using the layering and squares approach

The objective of this section is to establish the degree of agreement between definition of land degradation (USLE model) and desertification (MEDALUS model). This agreement is expressed as a percentage of the total area in the study area. It was measured using 10,000 grid squares each of 10 hectares after layering the maps in GIS. One problem is that are 6 USLE classifications but only 5 MEDALUS classifications. Therefore, some scatter within the table is inevitable, irrespective of the accuracy of the classification. It is encouraging that the relative degree of damage defined by each model compares reasonable well (Table 7.1). However, it seems each of the desertification classes F2, F3 and C1 are spread over two degradation classes, whereas C2 and C3 largely correspond to severe and very severe respectively.

		Land degradation classification (USLE) →						Total area (%)
		Slight	**Moderate**	**High**	**Very High**	**Severe**	**Very Severe**	
MEDALUS sub classification ↓	**F2**	10.8	8.6	1.1	0.4	0	0	20.9
	F3	9.8	13.6	3.3	1.1	0.9	0.8	29.5
	C1	1.7	2.2	10.8	11.1	1.7	0.4	27.9
	C2	0	0.1	0.7	1.6	7.2	1.9	11.5
	C3	0	0	0.1	0.3	1.2	8.6	10.2
Total area (%)		22.3	24.5	16	14.5	11	11.7	100

Table 7.1. Comparison of classifications from desertification (MEDALUS) and degradation (USLE) models.

7.3 Verification of USLE and MEDALUS maps

7.3.1 Verification of USLE map

The experts assessed the risk of soil erosion in the field at the sampled locations in 2010. When variation in individual assessment according to USLE reference documentation occurred, particularly when a Very High or Severe classification was proposed, the members of the focus group assembled on site and discussed the results. Negotiations ensued until a consensus was reached. The verification was conducted using a focus group comprising a number of experts in the study area, who visited the field to assess the condition of specific sites. There were two experts in soil and water, four experts in natural resources and environmental science, three employees in the Libyan Natural Resource Project, each of whom has more than twenty years' experience in natural resources, and the Secretary of the People's Committee for Agriculture and Livestock in the Al-jabal Alakhdar region (see Appendix for the identities of the focus group).

This research requires specialized expertise in various fields such as soil type, slope range, climate, vegetation type, management of vegetation and enforcement of agricultural policies and laws. A combination of people with relevant skills for a particular domain helps with decision making (Collins and Evans 2002). Therefore, the application of the expert focus group commonly used in environmental land use policy and landscape research is more effective when it is a combination of different specialists in vastly diverse subject areas (McCallum et al. 1991; Scott 2011). The reason for choosing local experts is that they are considered locally as a dedicated team with scientific expertise and local knowledge. They are Libyan agricultural specialists and have a background in farming and land degradation. They are renowned for their knowledge and concern about the degradation process. The skills of the focus group experts and their relationship to the content of the USLE map are shown in Table 7.2. This highly professional team gave this research informed advice, expertise and specialist support.

	Skills	Relationship to methodology	Number of people
1	Soil& water; soil type, soil conservation, land management, erosion, natural resources conservation, aridity, environmental pollution treatment, water analysis (pollution, quality & classification), soil degradation, desert environment, statistical studies in multiple fields, agricultural lands, soil, soil fertility, chemical, physical, and biological characteristics of the soil, relationship of soil with water and plants, runoff, rainfall, land evaluation, organic material, hydrology, saline and alkaline soils, land reclamation, water resources in Libya, drainage, soil minerals, geology, soil genesis and classification, soil microbiology, design of irrigation methods, experimental designs, remote sensing, GIS applications, land map science and agricultural mapping	(soil texture, soil depth, parent material, drainage, slope, water erosion, soil erodibility, aridity)	2
2	Natural resources conservation and environmental ecology, plant nutrition, role of forests in domestic tourism and entertainment, impact of grazing on the characteristics of perennial vegetation and soil, grassland and plant types, ecological condition of forest lands, causes of reduction in vegetation cover, improved and developed management of vegetation cover, classification of vegetation, GIS applications, geology, marine plants, birds and marine mammals, fish farming, fungi science, plant genetics, plant physiology	Vegetation (fire risk, erosion protection, drought resistance, plant cover, vegetation management, natural vegetation cover conservation, land use intensity, forestation, vegetation degradation problems, aridity, etc.)	4
3	Development of the vegetation cover, afforestation, vegetation and management quality, plant types, agricultural policies and land protection, development of land management, and sustainability of afforestation.	Land management locally (land management, enforcement of agricultural policy, afforestation, vegetation degradation problems, inappropriate human activity, etc.)	3
4	Agricultural laws and regulations, agricultural areas, types of crops irrigated and rain-fed, agricultural production, numbers of animals, types of animal feed, prices of agricultural products, forested area, etc	Land management, farming practice, agricultural laws and regulations, etc.	1

Table 7.2. Skills of focus group experts and relationship to degradation methodology.

At the beginning and before the field preview, the methodologies were presented, defined and described to the members of the focus group experts. In this presentation, all indicators and factors of the methodologies were explained; the members were also shown how to achieve accurate results in both maps. There was a discussion during the presentation about land degradation and desertification in the study area. Keys for each map which explain the main characteristics for each class in the maps were handed out (Tables 7.3; 7.4 A, B; 7.5 A, B; 7.7; 7.8 A, B; 7.9 A, B). These documents would make it easy for the experts to identify each class type in the field. During the presentation, several geographical locations were used as examples and explained to the experts. The following is the description of the two maps that was given to the experts as documents.

Description of USLE scores and classes of vulnerability to degradation

Table 7.3 below is the description of the USLE classes and sub classes, with their scores from Slight to Very Severe, which was given to the experts.

USLE score		Vulnerability classes and land descriptions
Light	(0 to 5 t $ha^{-1}yr^{-1}$)	Heavy natural vegetative cover, that covers more than 50% help to decrease in the deposit to about 30% (ACSAD 1984; ACSAD 2002). Slope lengths and steepness are very low. No traces of water flow can be seen anywhere even on the long slope of certain perimeters (Battah). There are no rills on the slope or traces of erosion at the base where the streams should normally leave a trace of their passage (ACSAD 2002).
Moderate	(5–10 t $ha^{-1}yr^{-1}$)	Natural woodland, scrub, grasslands (Pandey et al. 2007), irrigated land and orchards, are grow in soil with depth of 70 cm or more; some parts of the soil surface layer have been removed, and there appear to be small tables or shallow rills (indicating the existence of shallow channels) with 20-50m distance between them. In shallow soils, the distance between the shallow rills ranges from 50 to100 metres (ACSAD 2002).
High	(10–20 t $ha^{-1}yr^{-1}$)	Located in agricultural land under cultivation of wheat and barley. The slope length and slope steepness are semi-flat (Pandey et al. 2007). Gullies and rills appear in lands that have 30-50% vegetative cover; the depth of the rills and gullies ranges from 25 to 50cm and the distance between them ranges from 20 – 50m (ACSAD 2002).
Very High	(20–40 t $ha^{-1}yr^{-1}$)	Located in bare land (low vegetative cover) with evidence of human activities and agricultural land under cultivation of wheat and barley where slope lengths are very long (Pandey et al. 2007; ACSAD 2002), sometimes reaching 400 metres, with an average slope of 2 to 5 percent. Gullies and rills appear with a width of about 150cm and depth from 50to 100cm (ACSAD 2002).
Severe	(40–80 t $ha^{-1}yr^{-1}$)	Territories without dense vegetation cover or with bare soil and areas with undulating topography that have faulty methods of cultivation where there is human activity. There is a decrease of the vegetation cover and a loss of the soil due to human activity through overgrazing or the removal of vegetation for domestic use or for agricultural purposes (Ben-Mahmoud 1995; Pandey et al. 2007). Large valleys have been forming and contain gullies and rills which are 100-200cm wide and 100-150cm deep. The terrain is non-reclaimable at farm level (ACSAD 2002).
Very severe	(>80 t $ha^{-1}yr^{-1}$)	The soil is bare, and overgrazing characteristics are discernible (Ben-Mahmoud 1995); sediment rate is maximum in areas that have sharp steep slope and long slope length (Pandey et al. 2007). There are large valleys containing gullies and rills which are up to about 250cm wide and more than 150cm deep. The terrain is irreclaimable and beyond restoration. Original biotic functions are completely destroyed (ACSAD 1984; ACSAD 2002).

Table 7.3. Classification of the study area by level of land degradation.

The following tables illustrate the classification of the study area according to USLE land degradation classes in relation to the vegetation cover. For example, in Table 7.4 B, the class 'Slight' is classified as 1 in vegetation cover and 1 in soil depth, which means this area has natural vegetation cover of more than 50% and soil depth of more than 75 cm, as illustrated in Table 7.4 A.

	Vegetation cover (%)	Depth (cm)	Gullies and rills	CaCO3 (%)	Slope	Grazing
1	natural vegetation >50%	>75	no obvious characters	low	flat or semi-flat	light
2	natural vegetation 40-50%	30-75	depth 10-25cm	moderate	very gentle to flat	moderate
3	natural vegetation 30-40%	15-30	depth 25-50cm	high	gentle	heavy
4	natural vegetation 10-30%	<15	depth 50-100cm		steep	
5	natural vegetation 0-10%, Bare land		depth 100-150cm, width 100-200cm		very steep	
6			depth>150cm, width ≅250cm			

Table 7.4 A. Synthesis of the case studies with some environmental problems leading to land degradation in land with varying vegetation cover.

	Vegetation cover (%)	Depth (cm)	Gullies and rills	$CaCO_3$ (%)	Slope	Grazing
S	1	1	1	1	1	1
M	2	1,2	2	1	1,2	1,2
H	2,3	1,2	3	1,2	2	2
V.H	2,3,4	2	4	2,3	2	2,3
S.V	2,3,4,5	2,3	5	2,3	3,4	2,3
V.S.V	4,5	4	6	3	4,5	3

Table 7.4 B. Classification of the study area according to the degree of land degradation in the natural vegetation land.

The following tables, (7.5 A and 7.5 B), illustrate the classification of the study area according to the USLE measurement of land degradation in agricultural land. For example, in Table 7.5 B, the class Slight is classified as either 1or 2 in land cover, which means this area is classed as perennial agricultural crops or irrigated land, as illustrated in Table 7.5 A.

	Land cover	Erosion control practice	Soil depth (cm)	Gullies and rills	$CaCO_3$ (%)	Soil texture	Slope (%)	Grazing
1	perennial agriculture crop	mulch tillage	>75	no obvious characters	low	moderate or fin-texture	flat or semi–flat	no grazing
2	irrigated	spring ploughing	30-75	depth 10-25cm	moderate	coarse texture	very gentle to flat	light
3	cereals	autumn ploughing	15-30	depth 25 - 50cm	high		gentle	moderate
4				depth 50-100cm			steep	heavy
5				depth 100-150cm, width 100-200cm			very steep	

Table 7.5 A. Synthesis of the case studies with some environmental problems leading to land degradation in agricultural land.

	Land cover	Erosion control practice	Soil depth (cm)	Gullies and rills	CaCO3 (%)	Soil texture	Slope	Grazing
S	1,2	1,2	1	1	1	1	1	1
M	1,2	1,2	1,2	2	1	1	1,2	1
H	3	3	1,2	3	1,2	1	2,3	2
V.H	3	3	2	4	2	1,2	3	3
S.V	3	3	2,3	5	3	2	4,5	4

Table 7.5 B. Classification of the study area according to the degree of land degradation in agricultural land.

It is more appropriate to use an error matrix when comparing the computed USLE 2008 map with an assessment of land degradation in the field Card (1982); Congalton (1991); Congalton et al. (1983), it is a particularly effective accuracy examination tool (Stehman and Wickham 2006). Kappa analysis was used with the error matrix to determine the extent of conformity of the USLE map to reality; this was done previously when assessing agreement between land cover and reference data (Congalton 1991; Congalton et al. 1983; Stehman 1997; Stehman and Wickham 2006). The Kappa is computed by:

$$\kappa = \frac{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}$$

where N is the total number of sites in the matrix, r is the number of rows in the matrix, x_{ii} is the number in row i and column i, x_{+i} is the total for row i, and x_{i+} is the total for column I (Hammen 1997).

The following table is the comparison of USLE 2008 land degradation with ground-truth data by local experts 2010.

Classified data		Reference data from focus group								
		S	M	H	V.H	SV	V.SV	Row total	User accuracy (%)	Kappa*
USLE 2008 Map data	S	60	8	2	0	0	0	70	85.7	0.8544
	M	9	66	3	2	1	0	81	81.5	0.8495
	H	0	12	46	5	1	0	64	71.9	0.7003
	V.H	0	0	7	38	4	1	50	76.0	0.7302
	SV	0	0	2	13	37	4	56	66.1	0.6191
	V.SV	0	0	0	3	12	34	49	69.4	0.6841
Column total		69	86	60	61	55	39	370		
Producer's accuracy (%)		86.1	76.7	76.6	62.3	67.3	87.2			

Note: Number of pixels correctly classified: 281; overall classification accuracy: 75.6%. *Overall Kappa index of agreement: 0.7421.

Table 7.6. Comparison of USLE 2008 land degradation map with field classifications of land.

According to Viera and Garrett (2005), when overall classification accuracy and the Kappa index of agreement are used, there is a substantial agreement between the USLE 2008 model and 2010 reference data from the focus group experts (Table 7.6).

7.3.2 Verification of MEDALUS map

Description of ESAI scores and classes of vulnerability to desertification, Table (7.7) contains the description of the ESA classes relevant to the study area that correspond to the Fragile and Critical scores, and their subclasses, This description has been given to the experts as documents.

<table>
<tr><th colspan="2">ESAI score</th><th>Vulnerability class: Land description (examples)</th></tr>
<tr><td rowspan="2">Fragile</td><td>1.266 - 1.325</td><td>Moderate fragile sensitivityF2: Areas with mainly steep to gentle slopes, moderately fine-textured, stony, moderately deep to deep and well drained. These areas are mainly found on north-facing slopes or flat ground. These areas have a high density of vegetation cover; they are under low land use intensity and moderate land protection (Kosmas et al. 1999).</td></tr>
<tr><td>1.326 - 1.375</td><td>High fragile sensitivity F3: Area with very steep to steep slopes, moderately fine-textured, stony to slightly stony, moderately deep to deep, well drained. Vegetation is evergreen, with a high fire risk; it has a good resistance to drought and can protect the soil from erosion. In addition, orchards and areas covered by woody vegetation with shrubs with vegetation cover of more than 40% are under moderate land use intensity, land protection quality and climate quality (Kosmas et al. 1999; Silleos et al. 2008).</td></tr>
<tr><td rowspan="3">Critical</td><td>1.376 - 1.415</td><td>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 30 to 40%, particularly shrub-land, under moderate climate quality (Basso et al. 2010; Kosmas et al. 1999; Silleos et al. 2008).</td></tr>
<tr><td>1.416 - 1.530</td><td>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 30% 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).</td></tr>
<tr><td>>1.53</td><td>High critical sensitivity C3: shallow, mainly coarse-textured, stony, well-drained, with low vegetation cover; highly degraded areas, with incomplete enforcement of the existing 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).</td></tr>
</table>

Table 7.7. Classification of the study area by level of land sensitivity according to the ESA index.

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 7.8 B the subclass F2 is classified as 1 in vegetation cover and 1 in texture, which means that this area has a vegetation cover of more than 40% and a soil that is moderately fine-textured, as described in Table 7.8 A.

	Vegetation cover (%)	Texture	Depth (cm)	Drainage	$CaCO_3$ (%)	Rock fragments	Slope (%)	Aspect	Land use intensity
1	>40	moderately fine-textured	>75	well drained	low	very stony	very gentle to flat	N, NW, NE, E, Wand flat	low
2	30-40	coarse texture	30-75	poorly drained	moderate	stony	gentle	S, SW and SE	moderate
3	0-30		15-30		high	bare to slightly stony	steep		high
4			<15				very steep		

Table 7.8 A. Synthesis of the case studies with some environmental problems leading to desertification in natural vegetation land.

	Vegetation cover (%)	Texture	Depth	Drainage	$CaCO_3$ (%)	Rock fragments	Slope (%)	Aspect	Land use intensity
F2	1	1	1,2	1	1,2	1,2	1	1	1
F3	1	1	1,2	1	1,2	1,2	1,2	2	1
F3	1	1	1,2	1	1,2	1,2	1,2	1	2
C1	1	1	1,2	1	1,2	1,2	1,2	2	2
C1	1	1	1,2	1	1,2	1,2	1,2	1	3
C1	2	1	1,2	1	1,2	1,2	1,2,3	1	2
C2	1	1	1,2	1	2,3	1,2,3	2,3	2	3
C2	2	1	1,2	1	1,2	1,2	1,2,3	2	2
C2	3	2	2,3	1	2,3	2,3	3,4	1	3
C3	3	2	2,3	1	2,3	2,3	3,4	2	3
C3	3	2	3,4	1	2,3	2,3	3,4	2	3
C3	3	2	4	1	2,3	2,3	1,2,3,4	1,2	3

Table 7.8 B. Classification of the study area by level of land sensitivity according to the ESA index for natural vegetation land.

Tables 7.9 A and 7.9 B, below, illustrate the classification of the study area by level of land sensitivity according to the ESA index for agricultural land. For example, in Table 7.9 B, the subclass F3 is classified as 1in land cover and 1 in fire risk, which means that this area has a perennial agricultural crop as described in Table 7.9 A.

	Land cover	Fire risk	Protection of soil	Resistance to drought	Depth (cm)	Texture	Under protection	Land use intensity
1	orchards	low	very high	very high	>75	moderately fine-textured	complete	low
2	irrigated	moderate	high	high	30-75	coarse-textured	partial	moderate
3	cereals	high	moderate	moderate	15-30		incomplete	high
4		very high	low	low				
5			very low	very low				

Table 7.9 A. Synthesis of the case studies with some environmental problems leading to land degradation.

	Land cover	Fire risk	Protection of soil	Resistance to drought	Depth(cm)	Texture	Under protection	Land use intensity
F3	1	1	4	3	1	1	2	2
C1	2	1	5	5	1,2	1	2	2
C1	3	2	5	5	1	1	1	2
C2	3	2	5	5	1,2	1,2	2	2
C3	3	2	5	5	3	2	3	3

Table 7.9 B. Classification of the study area by level of land sensitivity according to the ESA index for agricultural land.

Table 7.10, below, is the comparison of MEDALUS 2008 land desertification with ground-truth data by local experts 2010.

Classified data		**Reference data from focus group 2010**							
		F2	**F3**	**C1**	**C2**	**C3**	Row total	User accuracy (%)	Kappa *
MEDALUS 2008 map data	**F2**	**64**	9	4	0	0	77	83.1	0.8267
	F3	12	**89**	6	1	0	108	82.4	0.8197
	C1	0	6	**70**	9	2	87	80.4	0.7983
	C2	0	0	3	**44**	7	54	81. 5	0.8041
	C3	0	0	1	6	**37**	44	84.1	0.8356
Column total		76	104	84	60	46	370		
Producer's accuracy (%)		84.2	85.6	83.3	73.3	80.4			

Note: Number of pixels correctly classified: 304; overall classification accuracy: 81.84%. *Overall Kappa index of agreement: 0.8168.

Table 7.10. Evaluation of MEDALUS map and field classifications of land.

The above table shows almost perfect agreement between the MEDALUS 2008 model and 2010 reference data from the focus group experts (Table 7.10). This independent verification of the MEDALUS map confirms its validity. However, in natural areas some points in B, E, G, H and I have been classified as having high quality management by MEDALUS where FG experts classified them as having medium quality management, which reflected on the accuracy of MEDALUS classification. The less accuracy of MEDALUS classification is because the management assessment is insufficient for the study area. In natural areas such as forests and shrubs, the intensity of land use is defined by assessing the ratio of actual to sustainable yield, and relates to forest products such as charcoal or the harvesting of trees. However, in the study area there is no managed lands for forest and shrubs products and the main cause to adequately assess land use management is overgrazing.

Distinguishing features of the methods of comparison

The two models were verified by two different methods. It is useful to compare the two models schematically, to help visualise the data input for each of the models, and the outputs, and especially how any resultant land degradation and desertification is described.

This method has compared two maps that are completely different, which is a unique achievement. The first model (USLE) is based on five factors (rainfall pattern, soil type, topography, crop system, and management practices) and has a unit of measurement of t $ha^{-1}yr^{-1}$. The second model (MEDALUS) is divided into four broad categories soil, climate, vegetation and management quality and estimates different levels of sensitivity in a defined area.

First, USLE and MEDALUS models are compared through layering and grid squares. Interpreting land shapes on a map by a square grid is a helpful method that allows the categorizing of spatial patterns inside every square with its counterpart. The purpose of the comparison between the two methodologies in this way is to find out the extent of the relationship between factors and indicators of degradation and desertification. Such verification shows a significant relationship between the two methodologies and proves their suitability for the study area. In the study area, the outcomes reveal that there is a relationship between the classes in the degradation map and their counterparts in the desertification map; for instance, the Very Severe class in the degradation map is compatible with C3 in the desertification map. Numbers of statistical analyses have been performed for more assessments of the methodologies during this verification.

Secondly, the verification of the MEDALUS and USLE maps is performed by a focus group containing local specialists, who estimate and assess model results and their own field observations. Once this has been done, statistical analysis is applied to give more accuracy to the achieved results. The achieved results of the maps reveals that the two methodologies were sound and reasonable; the MEDALUS methodology was closer to reality because of its dependence on the most important indicators of vegetation degradation: land use and management, soil quality and climate variation.

After the various indicators and factors of land degradation and desertification have been presented and reviewed, it is time to visit each geographical location individually and classify it. For example, the condition at the geographic location south-east of Al Bayyadah that is located at X: 525154 and Y: 3602751is discussed for illustrative purposes. At this location, there is a moderate soil depth of between 50 and 70 cm and the parent material is limestone. The soil is well drained and has a moderately fine texture. The woody vegetation and shrubs cover from 30% to 40% of the land, and human practices such as removal of some of the vegetation cover and overgrazing are obvious. The removal of the vegetation encourages the appearance of rills and gullies, and large valleys have been forming, containing gullies and rills which are 100-200cm wide and 100-150cm deep. After the members of the focus group experts had completed their forms, each individual reached a conclusion regarding the classification of the site in terms of USLE and MEDALUS. There was some variation in the conclusions of group members. The members of the focus group experts then assembled on site and began a discussion of the results and the factors that were important or where variation had occurred. Long debate ensued with negotiations to reach a more precise and accurate classification through exchanges of views and use of the reference documents, which included the description of the classes for each methodology. There was some disagreement in the use of the MEDALUS classification system because some of the experts stated that this location has soil that can be described as moderately fine-textured, stony to slightly stony, moderately deep and well drained, with moderate land use intensity: these are C1 characteristics. However, other experts stated that the slope faces the south so it counts as C2 (Tables

7.9 A and B). With respect to the USLE classification system, there was a slight disagreement between experts as to whether the classification should be Very High or Severe (Table 7.4 A and B). Consequently, after the discussions, the entire group agreed and reported that this land is classified as showing moderately critical sensitivity (C2) in MEDALUS and as Severe in USLE because the slope is steep.

To take another example, the condition at the geographic location south of Gondola that is located at X: 553774 and Y: 3601932 are discussed for illustrative purposes. At this location, wheat and barley are cultivated, there is a moderate soil depth of between 40 and 75 cm, and the parent material is limestone. The ploughing is done only in autumn; there are gullies and rills which are 100-200cm wide and there is a moderate percentage of $CaCO_3$. The soil is well drained and has a moderately fine texture. The mismanagement is obvious because some parts of the natural vegetation cover have been removed for cultivation of wheat and barley under moderate land use intensity. The intensity of land use for cropland is measured by many aspects such as the frequency of irrigation, the existence of terraces, the frequent use of agrochemicals and fertilisers, varieties of the crops used, and the degree of mechanisation. Mechanisation is classified as the most important aspect, and includes ploughing, sowing, and fertiliser application. This location falls under moderate land protection; environmental protection of land is measured by many aspects which are classified according to the degree in which they are enforced for each case of land use. The information on the existing policies is collected and then the degree of implementation/enforcement is evaluated. When all these aspects are considered, the result will be either C1 or C2 but this area is under moderate land protection, which means it has to be classified as moderate critical sensitivity C2 (Tables 7.9 A and B), and with respect to the USLE classification it is Severe because the slope is steep (Tables 7.5 A and B).

7.3.3 Discussion

A quantitative assessment of soil loss on a grid basis was made using the USLE methodology and a map was drawn for the study area. The degree of erosion was classified and lands that suffer from high erosion were identified on the basis of land cover data. The USLE (Universal Soil Loss Equation) is performed by assessing five factors: soil, topography, vegetation management, erosion control practice and climate. The results show that the study area has six classes (slight, moderate, high, very high, severe and very severe). Assessment of desertification is performed by the standard MEDALUS method (Mediterranean Desertification and Land Use) with four indicators: soil quality, vegetation quality, management quality and climate quality. As a consequence, the MEDALUS has five classes showing the intensity of desertification, which are described as fragile (F) or critical (C): medium sensitivity (F2), high sensitivity (F3), low sensitivity (C1), medium sensitivity (C2) and high sensitivity (C3). To evaluate the degradation and desertification hazards, reference has to be made to the natural susceptibility of land to degradation and desertification by comparing USLE and MEDALUS outputs by overlaying the two maps and comparing the classifications in a grid of 10,000 squares, each having an area of 10hectares. After layering and using the squares approach for assessing desertification, the results show that some classes in USLE are compatible with some in MEDALUS, because the two methodologies agree that the vegetation cover is the most important factor when degradation and desertification occur. According to Table 7.1 and Figure 7.1, the results show that some classes in USLE are compatible with some in MEDALUS medium sensitivity (C2) with Severe and high sensitivity (C3) with very severe for two reasons. Most of the C2 and severe lands fall in agricultural land that has an LS ranging from 3 to 5 or in areas with no dense vegetation cover where the LS ranges from 5 to 7. The most obvious cause is the mismanagement that leads to vegetation cover depletion and accelerates the water erosion process. Most of the high sensitivity (C3) areas are compatible with very severe because they fall in lands with no dense vegetation cover that have an LS of more than 7, and in agricultural lands where the LS is more than 7, which have low soil quality and where mismanagement is noticeable and most effective. C1 is compatible with the high and very high classifications because the majority of C1 areas fall in agricultural lands with LS ranging from 1 to 3, and in lands with natural woody vegetation and shrubs under low-quality management and land with vegetation cover ranging from 30% to 40%. The majority of the high class is located in lands with cover ranging from 30% to 40% and LS from 1 to 2, and in agricultural lands with LS from 0.7 to 1. The very high class is located in lands with 30% to 40% cover and in agricultural lands with LS ranging from 1 to 3. The F2 class area is compatible with the slight and moderate classes, with about 50% and 40% respectively of the area in each class. This is because the F2 classification occurs in lands with a vegetation cover of more than 40% under good management that faces north, north-west, north-east, east, or west, or is flat, whereas the slight class occurs in areas with more than 40% vegetation cover and LS less than 7, and also in agricultural lands with LS less than 0.3. The F3 class is compatible with the slight and moderate classes in woody vegetation with shrubs, for three reasons: firstly, F3 falls in lands with vegetation cover facing the south, south-west and south-east; secondly, F3 is located in lands that have more than 40% vegetation cover; thirdly, F3 is located in orchard lands with LS less than 3. The Moderate class occurs in land with more than 40% vegetation cover and LS from 7 to 9. This also occurs in agricultural lands with LS ranging from 0.3 to 0.7. The nature of the fragile and critical classes in the current study area is similar to observations in Italy by Madrau and Zucca (2008). Their results show that the fragile classes are located in areas in which any changes in the delicate balance of natural and human practices are likely to bring about land degradation.

The impact of human pressure might affect the vegetation cover, intensify the rate of soil erosion, and finally increase the level of vulnerability of the land. A land use pressure such as overgrazing and cereal cultivation on sensitive soils produces an immediate increase in runoff and soil erosion. Critical classes are located in areas that are already degraded through past mismanagement, severe runoff and sediment loss; such badly eroded lands are susceptible to certain desertification and would produce many threats to the environment of the surrounding land (Madrau and Zucca 2008). The visual comparison of the contribution of all the USLE factors and the resultant map of land degradation indicates that the topographic factor (LS) is the main cause of the soil erosion. Topography is important in the process of soil erosion; the most dominant effect is the loss of topsoil, which is often not conspicuous but nevertheless potentially very damaging (van der Knijff et al. 2000). But with an increase in vegetation cover density reducing the severity of soil erosion. The second most important factor is faulty cultivation practices. This supports the findings of other work (e.g. Bryan and Campbell 1986; Mitchell 1990) where vegetation cover and land use were considered to be the main factors controlling the intensity of soil erosion. In the MEDALUS methodology, the fragile and moderate are compatible with Slight and Medium in the USLE land degradation map; however, there is some overlap with different classes because some agricultural lands have an insignificant risk of erosion because they are flat although the land is threatened by desertification from poor management such as overgrazing that is not taken into consideration.

Overall classification accuracy and Kappa agreement index were computed as illustrated in Tables 7.6 and 7.10, and Kappa indices were calculated which incorporate the chance allocation of class labels (Stehman 2006). The overall accuracy of MEDALUS and USLE maps data when compared with reference data from the focus group experts was determined to be 81.8 percent and 75.6 percent respectively. The Kappa indices for the MEDALUS and USLE maps were 0.8168 and 0.7421 respectively (Tables 7.6 and 7.10). There is an "almost perfect" agreement of 82% between the MEDALUS map of environmentally sensitive areas and the reference data, and a "substantial" agreement of 76% between the USLE map of land degradation assessment and the reference data (Table 4.1).

However, MEDALUS and USLE assessments are not sufficient for the study area, as the latter has no productive forest and suffered from absence of management; misuse of rangelands and heavy grazing rates in some places, which contains water resources, troughs, palatable plants leaves or places near to shepherd home. Encroachment of the lands and cutting of shrubs with no execution of laws, environmental constrains with low rainfall amounts and long dry seasons. Roads construction to remote areas of rangelands permits more use for grazing with big numbers of flocks. Absence of grazing managements or policies of land use where the animal are grazed in the natural area (shrubs and wood land) which led to a competition for the land use on a tribal traditional means (Yagoub pers. comm. 2010).

Others studies such as Giordano et al. (2002) assessed land use intensity in woodlands, semi-natural areas by land principally occupied by agriculture with significant areas of natural vegetation, non-irrigated arable land using a land cover map. Contador et al. (2009) assessed livestock grazing intensity by registering indicators of livestock activity like excrements and animal tracks density and qualitatively on a scale from very intense to non-affected. Such studies give no comprehensive description and assessment for the intensity of land use. In USLE, the description of C and P factors is not enough for the study area and USLE equation lacks the overgrazing factor.

7.4 Conclusion

The Kappa index was used to measure the level of agreement between field classifications of the environment by the focus group and the results of the models applied to the study area, with an almost perfect agreement being obtained for the

MEDALUS model and a substantial agreement being reached for the USLE model. . The agreement when the results of the two models are compared to each other is good, and either model could be used to identify degraded land.

For the MEDALUS model, the difference in classification is primarily caused because the assessment of the quality of management in the study area is not sufficiently precise in natural areas not subjected to agricultural crop production. Improvement of this process is therefore required to take into account the impact of grazing by sheep and goats. This is also true for the USLE model, which governed here by the land conservation practice factor, P. In addition, it is apparent from the focus group assessment at some locations that the magnitude of the factor C for the management of land cover identified from other research may not be appropriate and requires improvement.

CHAPTER 8

IMPROVEMENT OF THE MANAGEMENT QUALITY INDEX FOR NATURAL LAND WITHIN THE MEDALUS MODEL

8.1 Introduction

It was established in the previous chapter during comparison of the MEDALUS modelling results with the focus group's field assessment of desertification, that whilst the MEDALUS model performs well over a large range of vegetation and soil types, the level of desertification under natural cover is underestimated, particularly when the land is grazed intensively by flocks of sheep and goats.

This impact of human activity on the landscape is evaluated using the management quality index and therefore requires improvement. The management quality index consists of two variables: intensity of land use and enforcement of policy for environmental protection. It is proposed here to simplify this index by considering intensity of land use only, and setting aside enforcement of policy. This is because of two reasons: firstly it is believed that the enforcement of policy is conceptually not very well developed, as discussed previously, and secondly how environmentally damaging any activity undertaken on the land is of most importance, and it is believed that this can be assessed in the natural areas by considering how intensively the land is being used.

Currently, in natural areas such as forests and shrub-land, the intensity of land use is defined by assessing the ratio of actual to sustainable yield, and relates to forest products such as charcoal or the harvesting of trees, as in studies by Zehabian et al. (2005), Parvari et al. (2011), and Bakr et al. (2012). As grazing is the primary land use, it is appropriate however to consider the natural areas as pasture land. The intensity of land use (in the study area grazing intensity), was determined by evaluating the ratio of the actual stocking rate (ASR) (number of animals grazed within a particular area over a year), to the sustainable stocking rate (SSR) (number of animals that can be supported by the biomass produced on an area of land during a year).

The carrying capacity is the number of animals that can be placed on a pasture or rangeland for an entire season without harming it (Papanastasis 1998; Evlagon et al. 2012), i.e. when ASR/SSR <1. However in previous studies, there is little mention of how to quantify environmental impact and its relation to carrying capacity (Mysterud 2006); Pietikainen (2006); Nilsson (2001); Doran et al. (1997); Oba and Kaitira.

(2006). Whilst Kosmas et al. (1999) provide categories of management quality index for three bands of grazing intensity, the data on which this is based had not been identified. Consequently, the relationship between carrying capacity of the land or grazing pressure and desertification needs to be quantified. This is of particular importance in this study.

The aim of this chapter is therefore to investigate whether the quality of management in the natural areas can be defined by intensity of grazing. This will be achieved by meeting the following objectives. Firstly, the intensity of land use from grazing animals will be determined for the land cover classes of natural land in the study area by establishing the actual and sustainable stocking rates. Secondly, this intensity of land use will be compared against the environmental damage observed in the field from both grazing pressure and also compared against the management quality index obtained through the manipulation of MEDALUS modelling data and field observations of desertification described previously.

8.2 Land use intensity from grazing animals

8.2.1 Method to calculate Actual Stocking Rate

There are three variables important to evaluation of the actual stocking rates: the number of livestock, the area over which livestock are spread and finally the elevation of the number of livestock caused by importing forage to an area by shepherds, which means numbers are above those that might be supported by the natural vegetation (Papanastasis 1990; Seligman and Perevolotsky 1994).

Regional Governments of Libya keep records of the total number of animals in a region from the sum of animals from smaller geographical districts (Agricultural Research Centre 2010). In the study area, there are annual records for seven districts (e.g. Gandolla, Marawah and Taknis) as shown in Figure 8.1, although these are spatial averages over a wide area for each district.

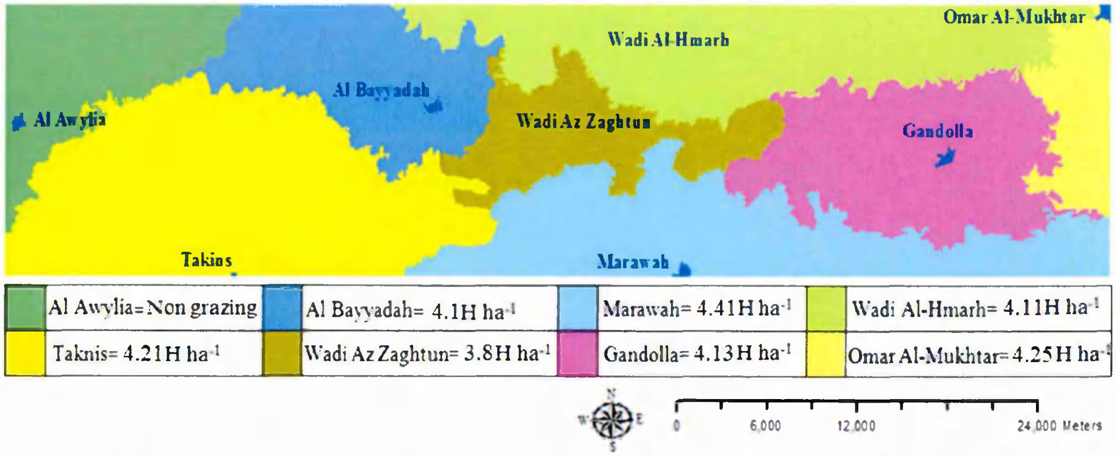


Figure 8.1. Regional average head of sheep and goats per hectare from Government records for 2008.

The livestock rates vary geographically, but the spatial resolution is coarse. To calculate a more spatially accurate ASR begins by dividing the regional area using a raster grid that covers the whole study area as shown in Figure 8.2.

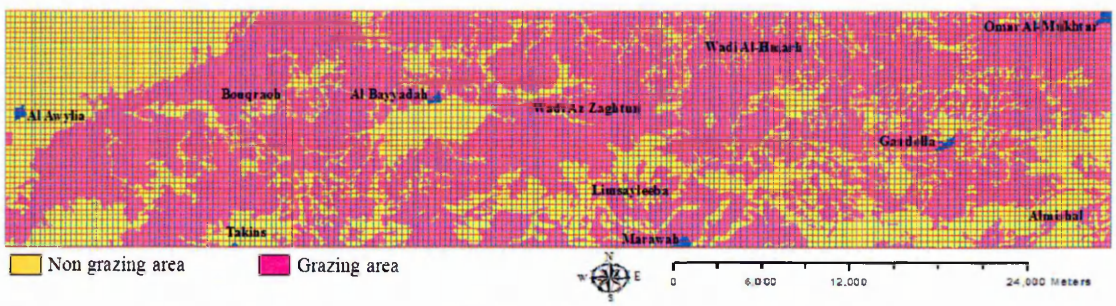


Figure 8.2. Grid cell division of the study area to measure actual stocking rates.

The total grid of 9,270 "squares" including natural and agricultural lands and the first one is used to identify 6,490 units of grazing land (each square = 10.2 ha). This size was selected to balance the volume of fieldwork, time, financial resources, and the fact that the average area grazed by a flock controlled by a single shepherd or family is 6-9 ha. Whilst it was quite time consuming, each grid square (grazing area) was visited and the shepherd or shepherds were located and questioned personally about the number of animals in the grid square and the grazing area for 2008. If the range grazed by a particular flock extended over part or more than one grid square, then this area was recorded and used to give the correct stocking rates for the grid squares concerned. If more than one shepherd grazed his flock in a grid square, then a total was calculated for the combined flock.

During calculation of stocking rates, it is important to determine forage supplements levels in terms of quantity and duration per head to obtain the most accurate results (Agricultural Research Centre 2006; Agricultural Research Centre 2010). In the Al-jabal Alakhdar region for a three month period over autumn/winter, it is common that shepherds and breeders start to use other sources of concentrated feeds and external feed supplements. This data was obtained via questionnaire presented to the shepherds. A yearly average value was recorded, as the amount of supplement forage will depend on the health of the animals and mass of palatable vegetation available on the natural land for a particular year. This depends on such natural variables as rainfall or pests and diseases. These data were verified against agro-pastoral systems data.

8.2.2 Method to determine the sustainable stocking rate

The sustainable stocking rate (SSR) in a particular pasture depends on the total palatable biomass produced. This is the yield available for grazing and is crucial to meeting the needs of the grazing animals and is often evaluated in developed countries for stock management (Abouguendia 1990; Romo 2004; Papanastasis pers. comm. 2013). For MEDALUS, Kosmas et al. (1999) present this in the form of the following equation:

$$SSR = X * P * F / R \qquad \textbf{(Equation 8.1)}$$

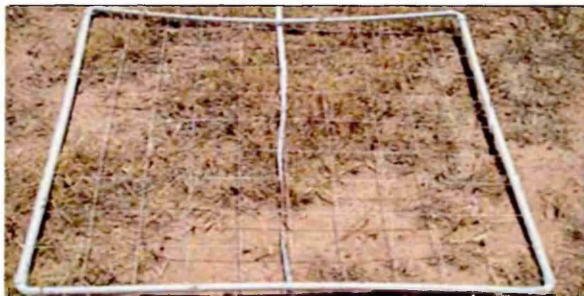
where R is the required annual biomass intake per animal (kg $animal^{-1}$ yr^{-1}), F is the average fraction of the soil surface covered with annual plant species and edible shrubs, and P is the averaged palatable biomass after a dry season (kg). Kosmas et al. (1999) do not give guidance on its application over a wide geographical area, and there is little previous published information on its implementation over such areas, and detailed descriptions of methodological approaches used are absent, for example Bakr et al. (2012); Basso et al. (2010); Ali and El baroudy (2008); Benabderrahmane et al. (2010). The techniques used here are now defined.

The majority of livestock in the study area are sheep and goats; therefore R is taken as 187.5 kg $animal^{-1}$ yr^{-1} (FAO 1991). The animal feed requirements in terms of dry matter (R) is a minimum of 2.0 percent of its body weight daily, where the average mass of a sheep or goat is 25.7 kg (Agricultural Research Center 2008). This basic requirement may not be met throughout the year under conditions of subsistence grazing, and in certain seasons low feed intake results in weight loss, to compensate for which, weight must be gained during the rest of the year. Sheep and goats are treated as similar creatures and numbers within a flock are not reported or considered separately according to type. Therefore, a constant value for all animals is considered appropriate.

The value of F, the average fraction of the soil surface covered with annual plant species and edible shrubs, is a summation of the cover provided by each of these plants. This detailed information was determined from a total of 850 ha over all the land cover classes during field verification of the land cover map (Figure 4.5). For any area of land of a particular land cover class, the magnitude of F is the mean value from all field measurements for that land cover class.

The averaged palatable biomass after a dry season, P, refers to the dry weight of standing vegetation per m^2 (Mulonda 2011; Cook and Stubbendieck 1986) at the end of August or September. There are many ways to evaluate biomass, based on research objectives, the structure and variety of vegetation e.g. grass or shrubs, research funding, time availability and the researcher's skills (Mulonda 2011). Traditionally, hand or mechanical clipping and harvesting in a plot fenced off from grazing animals have been the most widely used method to determine biomass. Harvesting and then weighing is an accurate measure on individual plots but it is time and labour intensive and it requires numerous samples (Cook and Stubbendieck 1986; Catchpole and Wheeler 1992). The biomass sample plots were allocated across all cover types and across all regions as far as possible, and in approximate proportion to the fraction that each class occupies in the study area.

Each plot was fenced off between October and November 2009, prior to the start of the growing season. This protected it from grazing. The available biomass was assessed separately by the author with the assistance of a further three researchers at fifty-two plots during August 2010. Usually, each plot is 1 m^2 (Mulonda 2011; Cook and Stubbendieck 1986), however here each plot is 2 m x 5 m to increase accuracy, enabling a more accurate average biomass for each plant type to be calculated per 1 m^2. A portable 1 m x 1 m frame divided into a 0.1 m grid squares was placed over each part of the plot area to calculate the fraction of ground covered by each plant species. Equipment for harvesting plants for aboveground biomass measurements vary based cover type; a scythe is used for harvesting annual grass, with a serrated knife and hand shears being used for herbaceous plants. A shrub requires hedge shears. All annual grass and herbaceous plants from the plots were harvested at ground level as close to the soil surface as possible, and the shrubs were clipped from 1.5-2.5 cm above ground level to the height observed to be affected by grazing i.e. $\leq$ 1.5 m. After clipping and harvesting, the dry biomass from each fenced plot was sorted and then weighed by plant species individually. Knowing the area covered by each plant type in the plot allows a biomass per m^2 to be calculated for each species.



Picture 8.1a. Use of grid to measure fraction of cover by plant species; visualisation square indicates a 35% cover of annual grasses in Marawah (08/2010). (32° 29' 21" N, 21° 28' 41" E)

Picture 8.1b. Use of grid to measure fraction of cover by a (shrub) in, visualisation square indicates a 20% cover of dwarf shrubs in Marawah (08/2010). (32° 28' 58" N, 21° 28' 43" E)

Picture 8.2. Harvesting and collecting annual grass.

Kosmas et al. (1999) state that X (equation 8.1), is a variable that considers both grazing efficiency, as animals do not eat 100% of plants in an area, and a correction for biomass not produced during the latest growing season, suggesting values of 0.5 for grazed land. This is similar to the common rule for planning an appropriate level of pasture utilization, which is "take half, leave half", or a 50 per cent use of annual available forage production (Mark and Matthew 2007). This degree of forage utilization includes not only herbage actually consumed by the animal but also damage to the plants caused by trampling and losses owing to other non-livestock factors such as loss to insect or wildlife damage (Papanastasis, pers. comm. 2013).

Finally, different plants are appear to be defoliated to different levels in the same patch when grazed, as sheep and goats seem to prefer certain plants e.g. Mastic trees compared to juniper bushes, as has been mentioned generally in other research (Marriott et al. 1997; Senft et al. 1987). The palatability of some plants can be determined from published literature, for example it is known that Mastic tree is readily eaten by sheep (Zaed et al 2005: Assadi et al 1999; Assaadi and Bayoumi 1995). However, a complete list is not currently available for the study area; therefore it is necessary to research plant palatability through personal field experience in Libya, consultation with scientific experts and interview of 200 shepherds, randomly sampled from throughout the study area. Of particular importance, shepherds are likely to have experience of sheep plant preference watching their flocks over many generations in the same geographical area.

8.2.3 Analysis and results for actual and sustainable stocking rates

8.2.3.1 Actual stocking rate

The total number of animals within the study area compared well with Government records. The regional differences illustrated earlier (Figure 8.1) are thought to be caused by regional differences in vegetation cover (Figure 4.5), therefore the actual stocking rate (ASR) is organised and presented in terms of frequency distributions for each cover class (Figure 8.3).

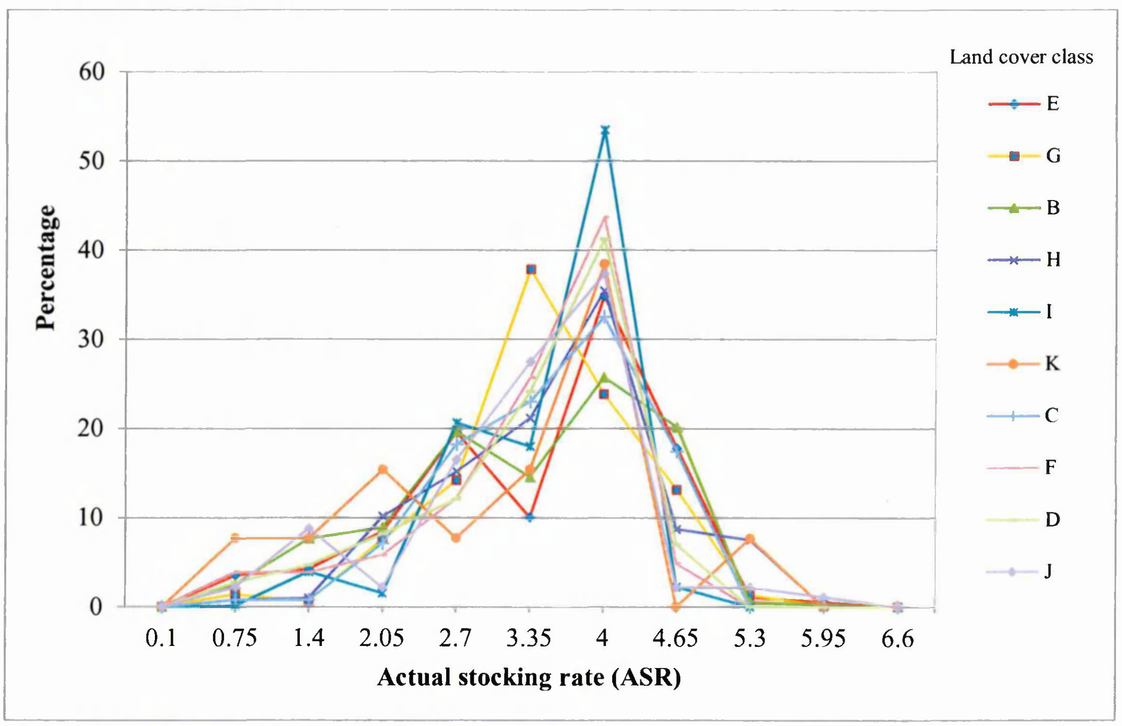
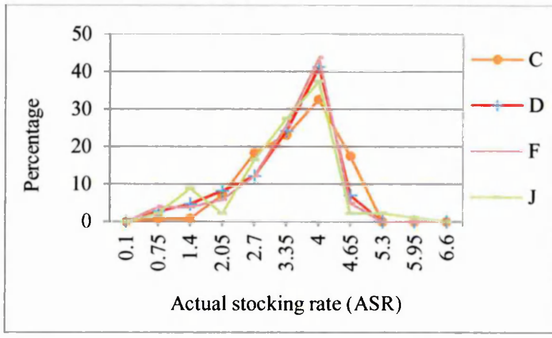
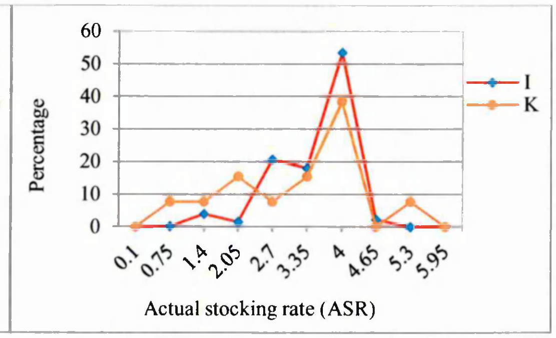


Figure 8.3. Actual stocking rate of sheep and goats from survey of shepherds.

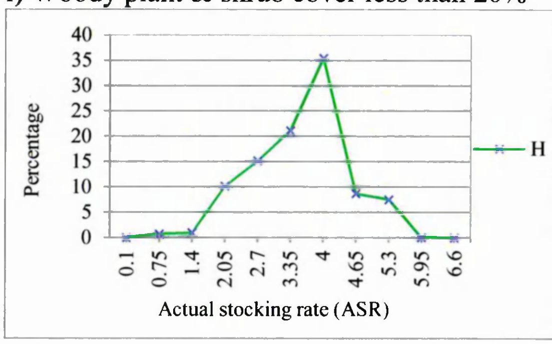
From Figure 8.3, it can be seen that about 20% of the land has less than 2.7H ha^{-1}, the vast majority of land has 2.7- 4.6H ha^{-1} and less than 10% of the land has more than 5H ha^{-1}. The majority of the land cover classes have similar animal frequency distributions.



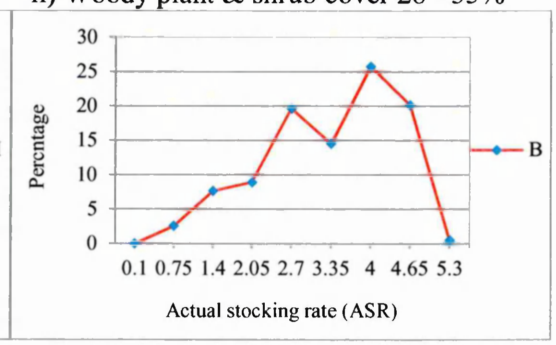
i) Woody plant & shrub cover less than 20%



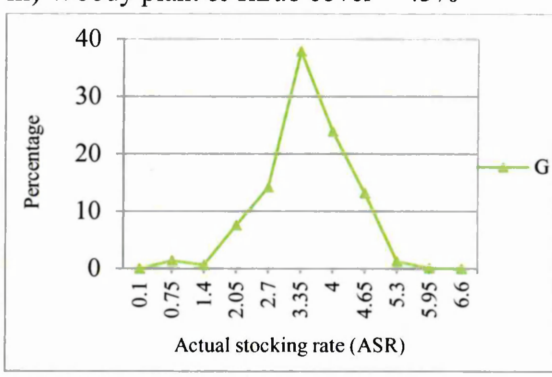
ii) Woody plant & shrub cover 28 - 35%



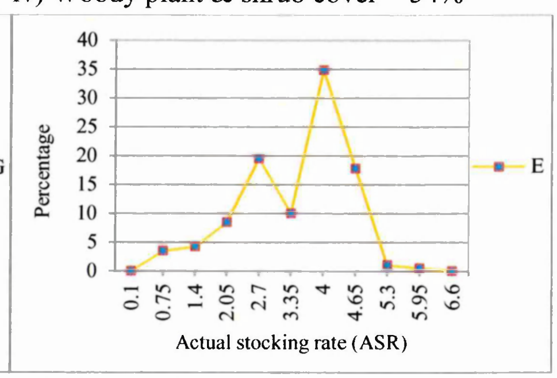
iii) Woody plant & shrub cover = 45%



iv) Woody plant & shrub cover = 54%



v) Woody plant & shrub cover = 57%



vi) Woody plant & shrub cover = 68%

Figure 8.4. Comparison of the actual stocking rates in different land cover classes.

The Figure 8.3 has been divided into six sub graphs in Figure 8.4 to depict and illustrate the classes. The frequency distributions may be influenced by a number of different socio-economic factors such as wealth and interest in sheep farming, proximity to markets for disposal of stock and the purchase of supplemental forage, the desire to employ foreign nationals as shepherds or to keep livestock husbandry as a family business. However, the sample size of 6,240 shepherds is large and so it is expected that any personal influence on the data by individual shepherds will not dominate the data. Land cover classes C, D, F and J can only be found in Marawah and have very similar distributions of actual stocking rates. They have quite similar percentage cover of vegetation cover of less than 20% and quite similar percentage cover of annual grass and these lands treated as marginal land either surrounded by more intensively used agricultural land or near to agricultural land (Figure 8.4i).

Land cover classes K and I (Figure 8.4ii) have similar modal stocking rates owing to the similar percentage cover of both vegetation and annual grass. Although there is a larger tail to the left for class K. Class K also only appears in Marawah and also has a similar shaped distribution to classes J, D and F. Land cover class H appears over the whole of the study area and it is the largest class and has similar stocking rates to G. The difference in the distributions for G and H is caused by the greater availability of palatable biomass in H (Figure 8.4iii & v). The narrower distribution for class G is probably caused by the presence of Phoenician juniper and the limited availability of water resources (Figure 8.4v). Land cover class B has a similar percentage cover as land cover class G, however the different distribution of stocking rate for B is probably caused by an abundance of small roads, water resources and widespread low density housing (Figure 8.4iv & v). Land cover class E (Figure 8.4vi) has quite different distribution of stocking rates to other land classes. It has the highest percentage of vegetation cover and is characterized by unpalatable and tall Phoenician juniper and Mediterranean cypress (*Cupressus sempervirens)* whose presence may explain the long tail towards lower stocking rates.

8.2.3.2 Adjusted actual stocking rate

The required biomass per animal per year, R, is 187.5 kg H^{-1} yr^{-1} (FAO 1991). This requirement from each area of land will be reduced by the mass of any supplemental forage imported by a shepherd for his animals. This is generally about 50 kg 100 H^{-1} day^{-1} over a three-month period in the winter. This information was collected from each shepherd when he was interviewed. For one animal, the required natural biomass, rnb, is therefore

rnb = R - forage supplement **(Equation 8.2)**

To identify how much pressure the animals are exerting on the land, the stocking rate that the natural land has to support is therefore adjusted using equation 8.2 to account for this additional forage provided by the shepherds, with typical values used for an example calculation given in Table 8.1.

Adjusted actual stocking rate (AASR) = ASR * rnb/R **(Equation 8.3)**

Supplemental forage mass	0.5 kg $Head^{-1}$ day^{-1}
Time	90 days yr^{-1}
Forage supplement	45 Kg H^{-1} yr^{-1}
Required biomass	187.5 Kg H^{-1} yr^{-1}
Required natural biomass (rnb)	142.5 Kg H^{-1} yr^{-1}
Division factor to alter existing ASR calculation	1.32

Table 8.1. Typical Livestock feed requirements, forage supplement and required natural biomass.

It was found that about 87% of shepherds provided supplemental forage for their animals. No obvious variation with land cover class was noted. The impact of adjusting ASR is an overall reduction in the actual grazing pressure on the land (Figure 8.5), as livestock consumes fewer plants. The vast majority of the lands have an adjusted ASR of 2.5-3.5H ha^{-1}, with about 20% of land having less than 2H $ha^{-1}$and less than 10% of land having more than 3.5H ha^{-1}.

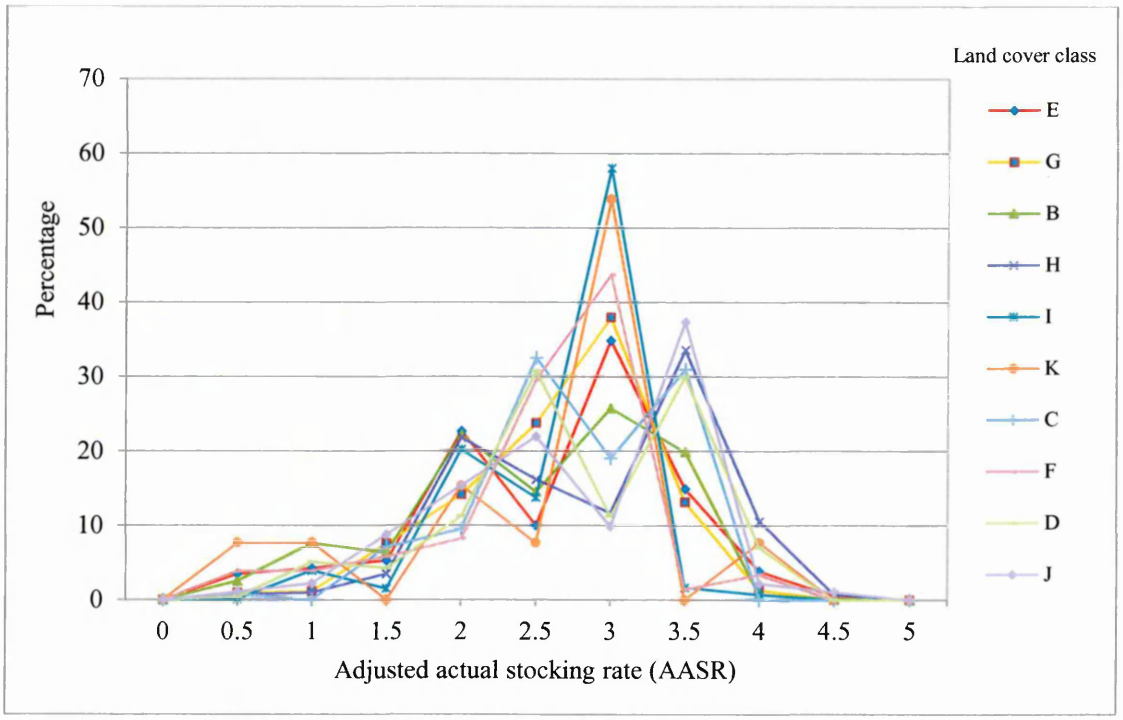


Figure 8.5. Variation of adjusted actual stocking rate with land cover class.

8.2.3.3 Sustainable stocking rate

The most important factor in calculation of the sustainable stocking rate is the available biomass, P. In this study, a number of biomass sample plots that were representative of each land cover class were located and distributed across the study area (Table 8.2).

Region		Taknis	Al Bayyadah	Wadi Az Zaghtun	Marawah	Gandolla	Wadi Al-Hmarh	Omar Al-Mukhtar	
No. of sample plots	Cover class	Area (ha)	Area (ha)	Area (ha)	Area (ha)	Area (ha)	Area (ha)	Area (ha)	Total area (ha)
4	B	1990^{1}	0	1510^{1}	0	210^{1}	160^{1}	50	3920
2	C	40	180	10	510^{1}	0	20	500^{1}	1260
2	D	10	0	0	2510^{1}	0	0	50^{1}	2570
4	E	1280^{1}	980^{1}	2300^{1}	0	580^{1}	540	0	5680
2	F	0	0	0	2050^{2}	0	0	10	2060
10	G	6500^{2}	1790^{2}	1690^{2}	0	140^{2}	360^{1}	250^{1}	10730
19	H	4660^{4}	2840^{4}	900^{2}	160^{1}	5700^{2}	8650^{4}	490^{2}	23400
5	I	940^{1}	1150^{1}	0	1110^{1}	2770^{1}	950^{1}	200	7120
2	J	50	40	0	640^{2}	60	0	120	910
2	K	0	0	0	130^{2}	0	0	0	130

Table 8.2. Number and location of biomass sample plots with areal extent of each land cover class in each geographical region. The superscript denotes the number of biomass plots.

The values of P and F for each plant type within a particular land cover class are averaged from all plots in that land cover class. The results for all land classes are shown in Table 8.3.

Plant type	Fraction of surface covered F	Average biomass P (kg ha^{-1})	F * P (kg ha^{-1})
Mastic tree	0.22	850	187
Phoenician juniper	0.20	500	100
Strawberry Tree	0.07	300	21
Burnet	0.01	10	0.1
Jerusalem Sage, Phlomis	0.01	10	0.1
Common Horehound	0.01	10	0.1
Other mixed plants	0.02	10	0.2
Annual grass	0.40	1240	496
Total			805

Table 8.3i. Average available edible biomass per hectare for land cover class B.

Plant type	Fraction of land covered F	Average biomass P (kg ha^{-1})	F * P (kg ha^{-1})
Pitturanthus tortosus	0.01	40	0.4
Thyme	0.09	595	53.6
Santonica Wormseed	0.03	260	7.8
Mastic tree	0.02	335	6.7
Burnet	0.015	10	0.15
Jerusalem Sage, *Phlomis*	0.01	10	0.1
Common Horehound	0.015	10	0.15
Annual grass	0.69	1080	745.2
Total			814

Table 8.3ii. Average available edible biomass per hectare for land cover class C.

Plant type	Fraction of land covered F	Average biomass P (kg ha^{-1})	F * P (kg ha^{-1})
Pitturanthus tortosus	0.005	25	0.125
Thyme	0.005	470	2.35
Santonica Wormseed	0.06	300	18
Common Horehound	0.005	5	0.025
Burnet	0.006	10	0.06
Jerusalem Sage, *Phlomis*	0.009	10	0.09
Annual grass	0.78	1000	780
Total			801

Table 8.3iii. Average available edible biomass and per hectare in land cover class D.

Plant type	Fraction of surface covered F	Average biomass P (kg ha^{-1})	F * P (kg ha^{-1})
Mastic tree	0.34	880	299.2
Phoenician juniper	0.3	500	150
Strawberry Tree	0.01	300	3
Common Horehound	0.005	10	0.05
Other mixed plants	0.02	10	0.2
Annual grass	0.28	1250	350
Total			802.5

Table 8.3iv. Average available edible biomass per hectare for land cover class E.

Plant type	Fraction of land covered F	Average biomass P (kg ha^{-1})	F * P (kg ha^{-1})
Pitturanthus tortosus	0.01	35	0.35
Thyme	0.01	580	5.8
Santonica Wormseed	0.1	250	25
Mastic tree	0.03	300	9
Annual grass	0.72	1070	770.4
Total			811

Table 8.3v. Average available edible biomass per hectare for land cover class F.

Plant type	Fraction of surface covered F	Average biomass P (kg ha^{-1})	F * P (kg ha^{-1})
Mastic tree	0.23	850	195.5
Phoenician juniper	0.28	500	140
Strawberry Tree	0.03	300	9
Jerusalem Sage, *Phlomis*	0.005	10	0.05
Common Horehound	0.005	10	0.05
Other mixed plants	0.02	10	0.2
Annual grass	0.39	1260	491.4
Total			847.2

Table 8.3vi. Average available edible biomass per hectare for land cover class G.

Plant type	Fraction of surface covered F	Average biomass P (kg ha^{-1})	F * P (kg ha^{-1})
Mastic tree	0.22	850	187
Phoenician juniper	0.18	500	90
Strawberry Tree	0.01	300	3
Burnet	0.01	10	0.1
Jerusalem Sage, *Phlomis*	0.01	10	0.1
Common Horehound	0.01	10	0.1
Other mixed plants	0.01	10	0.1
Annual grass	0.48	1210	580.8
Total			861.2

Table 8.3vii. Average available edible biomass per hectare for land cover class H.

Plant type	Fraction of land covered F	Average biomass P (kg ha^{-1})	F * P (kg ha^{-1})
Thyme	0.12	590	70.8
Santonica Wormseed	0.1	290	29
Mastic tree	0.11	390	42.9
Burnet	0.01	15	0.15
Jerusalem Sage, *Phlomis*	0.001	4	0.004
Common Horehound	0.01	2	0.02
Annual grass	0.6	1100	660
Total			802.87

Table 8.3viii. Average available edible biomass per hectare for land cover class I.

Plant type	Fraction of land covered F	Average biomass P (kg ha^{-1})	F * P (kg ha^{-1})
Pitturanthus tortosus	0.01	30	0.3
Thyme	0.01	480	4.8
Santonica Wormseed	0.01	240	2.4
Common Horehound	0.001	10	0.01
Mastic tree	0.03	235	7.05
Burnet	0.001	10	0.01
Jerusalem Sage, *Phlomis*	0.001	10	0.01
Annual grass	0.78	1020	795.6
Total			810.18

Table 8.3ix. Average available edible biomass per hectare for land cover class J.

Plant type	Fraction of land covered F	Average biomass P (kg ha^{-1})	F * P (kg ha^{-1})
Pitturanthus tortosus	0.01	37.5	0.375
Thyme	0.12	592.5	71.1
Santonica Wormseed	0.05	300	15
Common Horehound	0.01	5	0.05
Mastic tree	0.03	380	11.4
Burnet	0.05	6	0.3
Jerusalem Sage, *Phlomis*	0.01	5	0.05
Annual grass	0.64	1120	716.8
Total			815.075

Table 8.3x. Average available edible biomass per hectare for land cover class K.

The product of average edible biomass (P) and fraction of the soil surface covered (F) by shrubs and by grass separately varies with change in land cover (Figure 8.6). This is a new outcome from this research for the study area and has not been attempted elsewhere over such a wide area and over different cover types. The biomass from grass decreases as that from shrubs increases as the percentage of cover increases. When both forms of biomass are added together, the total biomass is approximately constant at about 815 kg ha^{-1}.

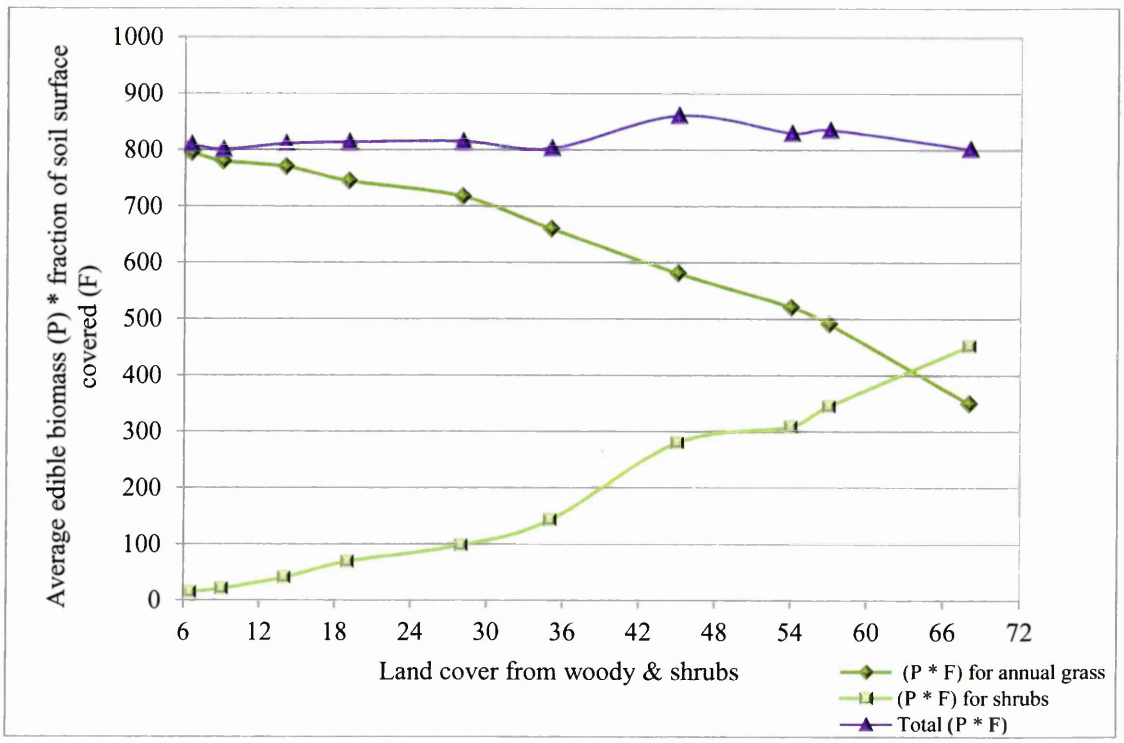


Figure 8.6. Land cover classes related to product of the average edible biomass (P) and fraction of the soil surface covered (F).

Three different scenarios were applied to evaluate the grazing efficiency factor X required to calculate sustainable stocking rate. In the first proposal for X factor, the "take half, and leave half" rule for the amount of useable dry forage per hectare is used. Therefore the total edible biomass from the sample plots is multiplied by 0.5. Part of this 50% reduction in biomass is a result of damage by trampling and pests (FAO 1991; Kosmas pers. comm. 2010). In the natural areas of Libya, such activity is noticeable on grass but is not discernable on shrubs. Consequently, in the second scenario for grazing efficiency, X = 0.5 for the annual grass and X = 1 for the shrubs, remembering that only the biomass that would be consumed by animals was removed from the woody plants and shrubs in calculation of available biomass, rather than all biomass from the plant. In the third scenario, the value of X is adjusted to consider the potential impact of the palatability of plants on the grazing. Consideration of the popularity of plants in biomass calculations is new concept, largely because in previous studies (e.g. Ohlenbusch et al. 1994; Willms et al. 1986; Natural Resources Conservation Service 2008; Bruynooghe and Macdonald 2008; Willms et al. 1985; Schneiderat et al. 2005) the edible biomass is from pastures where different grasses have nearly the same palatability, rather than from rangeland which is composed of grass, shrubs and trees. For example, in mixed stands of annual grasses and perennial plants or shrubs, livestock prefer grass as it is more palatable, as observed by Jeffrey and Roselle (2006). As grazing animals can be selective in their grazing (Ohlenbusch et al. 1994), the grazing pressure will be focused on areas that have more palatable plants, thus highly palatable plants will be more adversely affected by intensive grazing than less preferred plants (Schacht et al. 2011). A clear understanding of the palatability and susceptibility of all plants is required in the calculations of grazing intensity and to design a sustainable strategy, as also advocated by Daines (2006). Higher stocking rates would bring about higher levels of utilization of the less palatable species, but such stocking rates may exceed the acceptable level of utilization of the palatable species. However, variable levels of palatability for a particular plant are not considered here and it is assumed to be constant for each plant species.

A list of available plants in the study area was prepared and classified on a scale of zero to one in terms of their palatability to sheep and goats (Table 8.4). This was based on personal field experience in Libya, data from the Libyan Agricultural Research Center (2008), consultation with scientific experts (Assaadi, Yagoub and Baboo pers.

comm. 2010) and verbal circulation of the list to a sample of 200 shepherds throughout the study area.

Name of plant	Palatability	Name of plant	Palatability
Trees		Levant Horehound	0
Carob	0.2	*Plantago major*	0
Phoenician juniper	0.01	*Rhus tripartita*	0
Mediterranean cypress	0	*Phyllarea angustifolia*	0
Wild Olive tree	0	*Vibrnum tinus*	0
Canary Islands Pine (*Pinus halepensis*)	0	**Annual grass**	
Shrubs		*Matthiola longipetala*	1
Mastic tree	0.65	*Cynosurus coloratus*	1
Santonica Wormseed	0.6	*Echinochloa colona*	1
Three-lobed sage	0.6	*Hordium marinum*	1
Thyme	0.5	*Lamarckia aurea*	1
Strawberry Tree	0.3	*Lolium loliaceum*	1
Pitturanthus tortosus	0.1	*Lolium rigidum*	1
Solanum nigrum	0.1	*Stipa capensis*	1
Ouercus coccifera	0.015	*Bromus rubens*	1
Lotos (*Ziziphus*)	0.01	*Bromus madritensis Lioyd*	1
Lonicera etrusa	0.01	*Cynara cornigera Lindely*	0.8
Burnet	0.01	*thistle (thorny plants)*	0.8
Common Horehound	0.01	Thistle (*Carduus carlinoides)*	0.8
Peganum harmala	0.01	*Carduus nutans*	0.8
Ephedra alata	0	*Thapsia garganica*	0.7
Globularia alypum	0	*Chamomilla aurea*	0.7
Jerusalem Sage, Phlomis	0	*Asphodelus microcarpus*	0.6
Rhamnus lyciodes	0	*Malva sylvestris*	0.6
Phyllarea latifolia	0	*Cuscuta planifolia*	0.6
Cistus parviflorus	0	*Urginea maritima*	0
Caper (*Capparis spinosa*)	0	*Paronychia arabica*	0

Table 8.4. Available plants in the study area and their degree of palatability to sheep and goats.

The information from Table 8.4 can be used with that from the biomass field plots (Table 8.3) to calculate the available palatable biomass per plant species. This information is combined with the fraction of ground that each plant species covers to give the total biomass for any ground cover class. An example of this process is shown for land cover class B (Table 8.5). The overall impact on the sustainable stocking rates by the three scenarios is shown (Table 8.6 and Figure 8.7).

Plant type	Palatability	Fraction of land covered F	Average biomass P (kg ha^{-1})	Palatability*F*P (kg ha^{-1})
Mastic tree	0.65	0.22	850	122
Phoenician juniper	0.01	0.20	500	1
Strawberry Tree	0.3	0.07	300	6.3
Burnet	0.01	0.01	10	0.04
Jerusalem Sage, *Phlomis*	0.01	0.01	10	0.001
Common Horehound	0.01	0.01	10	0.001
Other mixed plants	0.01	0.02	10	0.001
Annual grass	1	0.40	1240	496
Total				625.4

Table 8.5. Average palatable biomass available in land cover class B.

	B	C	D	E	F	G	H	I	J	K
SSR1	2.21	2.17	2.13	2.14	2.16	2.2	2.29	2.14	2.16	2.17
SSR2	3.03	2.35	2.19	3.34	2.27	3.15	3	2.52	2.2	2.4
SSR3	2.07	2.17	2.14	1.98	2.18	2.01	2.21	2.19	2.16	2.19

Table 8.6. Comparison of sustainable stocking rates using three scenarios for the study area. SSR1: X=0.5, SSR2: grass X = 0.5 & woody plant + shrub X = 1, SSR3: grass X = 0.5 & woody plant + shrub X = 1, with plant palatability.

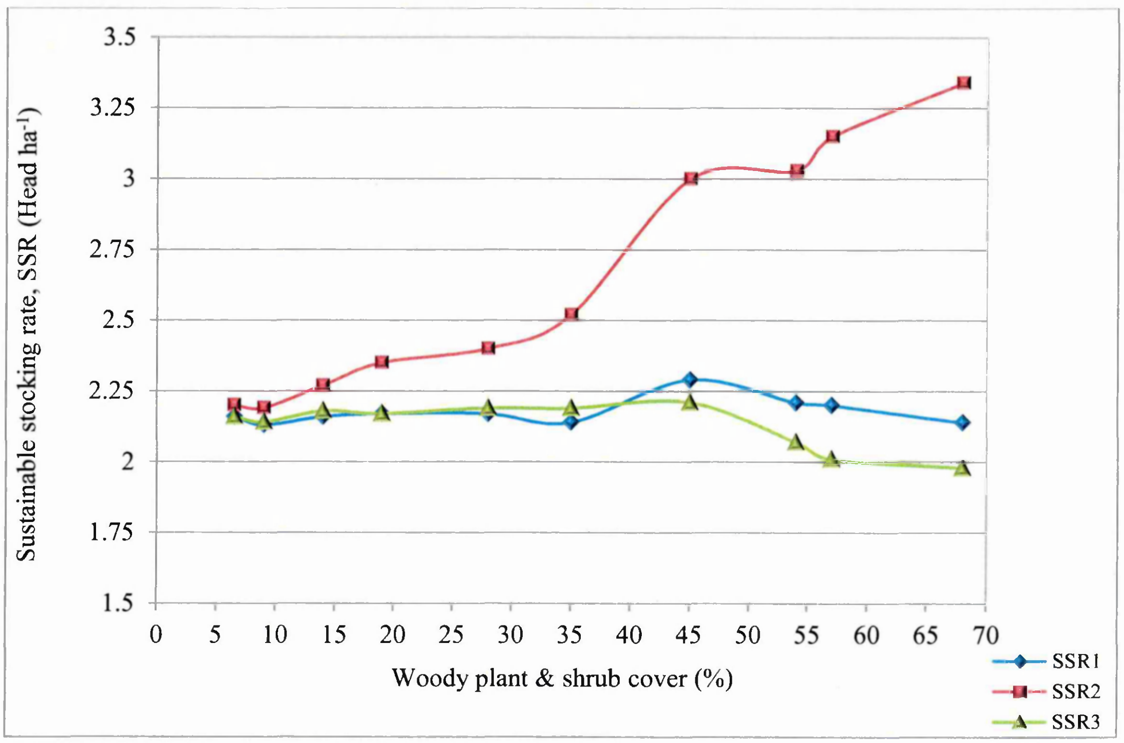
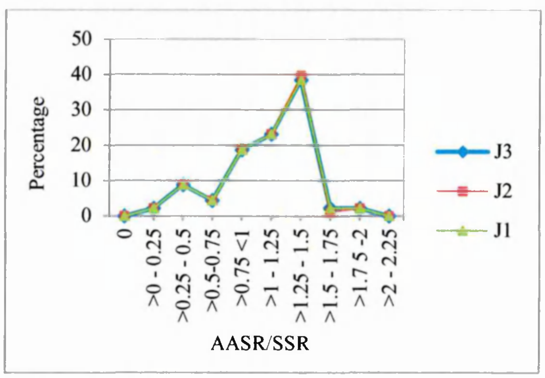
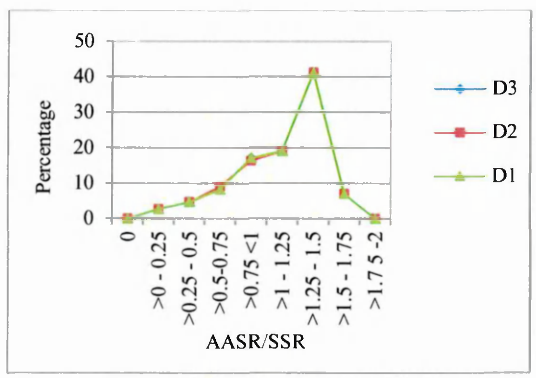


Figure 8.7. Comparison of sustainable stocking rates using three scenarios of grazing efficiency: SSR1, X=0.5; SSR2, grass X = 0.5 & woody plant + shrub X = 1; SSR3, grass X = 0.5 & woody plant + shrub X = 1 with plant palatability.

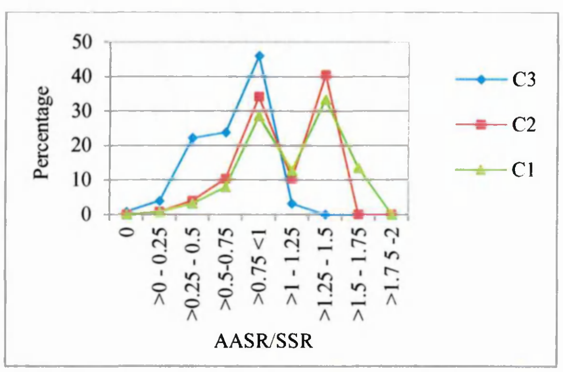
The ratios of adjusted actual stocking rate to the sustainable stocking rate using each of the three scenarios are shown for each land class (Figure 8.8). The distributions of grazing intensity are almost identical when the land cover is less than 10% (class J), as the land is nearly all covered in annual grass (Figure 8.8i). Here, the value of X is the same for all scenarios and palatability is the same for these plants. Very similar distributions of grazing intensities are also obtained for all classes (D, C and F) when the land cover is less than 20% (Figure 8.8ii-iv). Land cover class C appears to have a bimodal distribution of actual to sustainable stocking rate, but this is a function of class size when evaluating frequency distributions (Figure 8.8iii). As the percentage of permanent cover increases, the impact of the supposed increase in biomass from the increased cover from shrubs (Figure 8.7) is apparent in the distributions for SSR2 (Figure 8.8v-x) as the grazing intensity increases. Although there in an increase in available biomass and no trampling in the third scenario, there is also an amount of less palatable species such as Phoenician juniper and an abundance of unpalatable species such as *Globularia alypum* and *Cistus parviflorus* which reduces the sustainable stocking rate for cover classes B, G and E (Figure 8.7). This causes a reduction of the sustainable stocking rate for these classes compared to the first scenario, which is apparent in higher grazing intensities (Figure 8.7 viii-x).



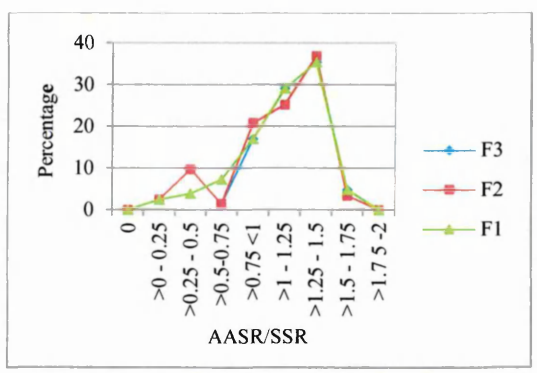
i) Woody plant & shrub cover = 6.5%



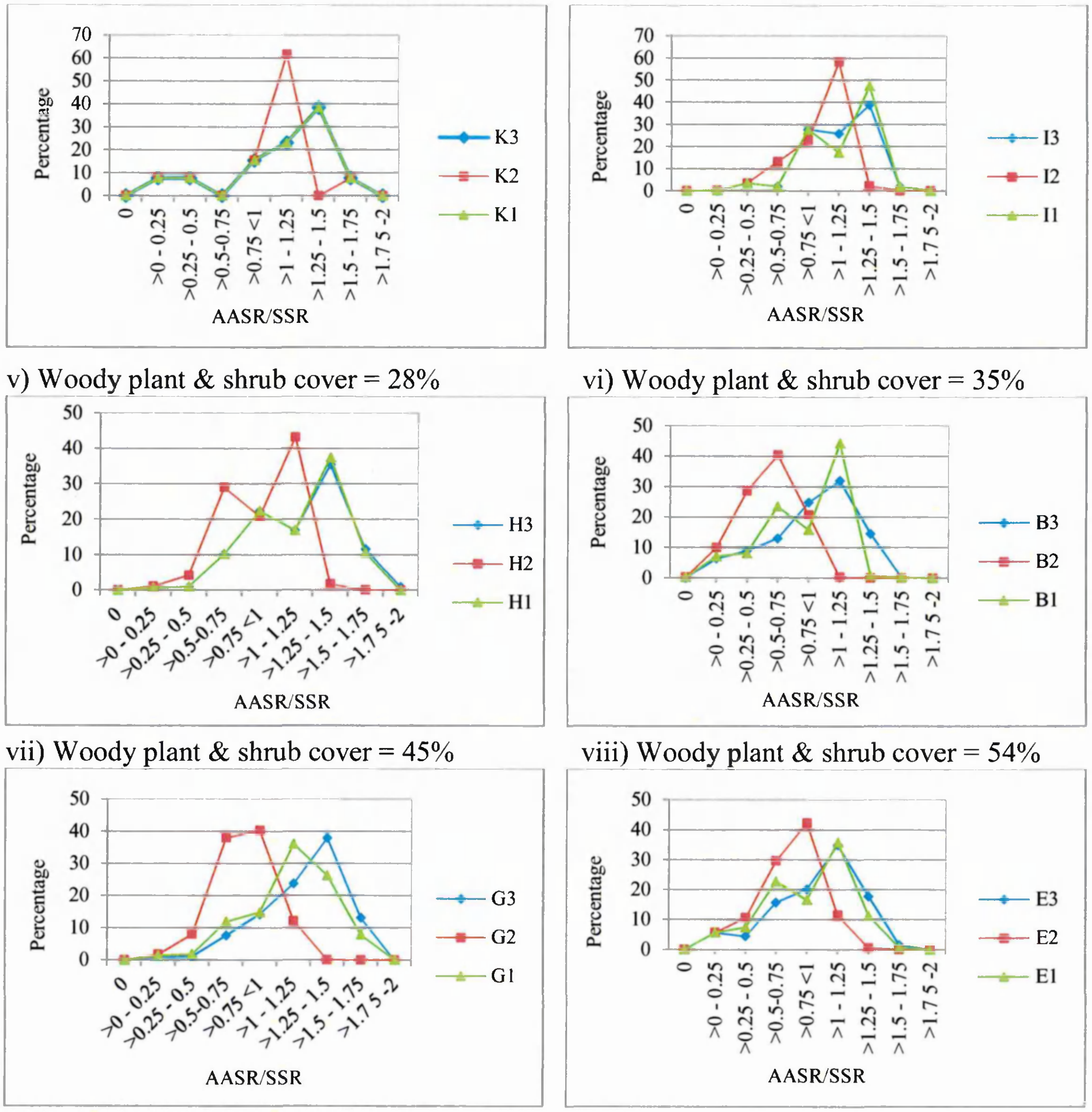
ii) Woody plant & shrub cover = 9%



iii) Woody plant & shrub cover = 19%



iv) Woody plant & shrub cover = 14%



v) Woody plant & shrub cover = 28%

vi) Woody plant & shrub cover = 35%

vii) Woody plant & shrub cover = 45%

viii) Woody plant & shrub cover = 54%

ix) Woody plant & shrub cover 57%

x) Woody plant & shrub cover = 68%

Figure 8.8. Comparison of the ratios of adjusted actual to sustainable stocking rates with forage supplement in different land cover classes based three scenarios.

An appropriate way to assess the accuracy of any of these scenarios for the intensity of land use is to compare how these grazing intensities have affected the land. This is achieved by measuring the pressure imposed on the vegetation cover and the land by the grazing animals. How this was measured using a focus group has been described in chapter 6. The original continuous scale calculated with field data derived using Tables 6.25 and 6.26, which are a various classes of the legend have been suitably grouped into just 3 classes, as homogeneous as possible with regard to the intensity of land use that was used in chapter 6. Tables 6.25 and 6.26 are used here for the 90 locations visited and the results obtained were assigned from values of each observed indicators. The following graphs (Figures 8.9 - 8.11) show the results for the three scenarios of grazing efficiency:

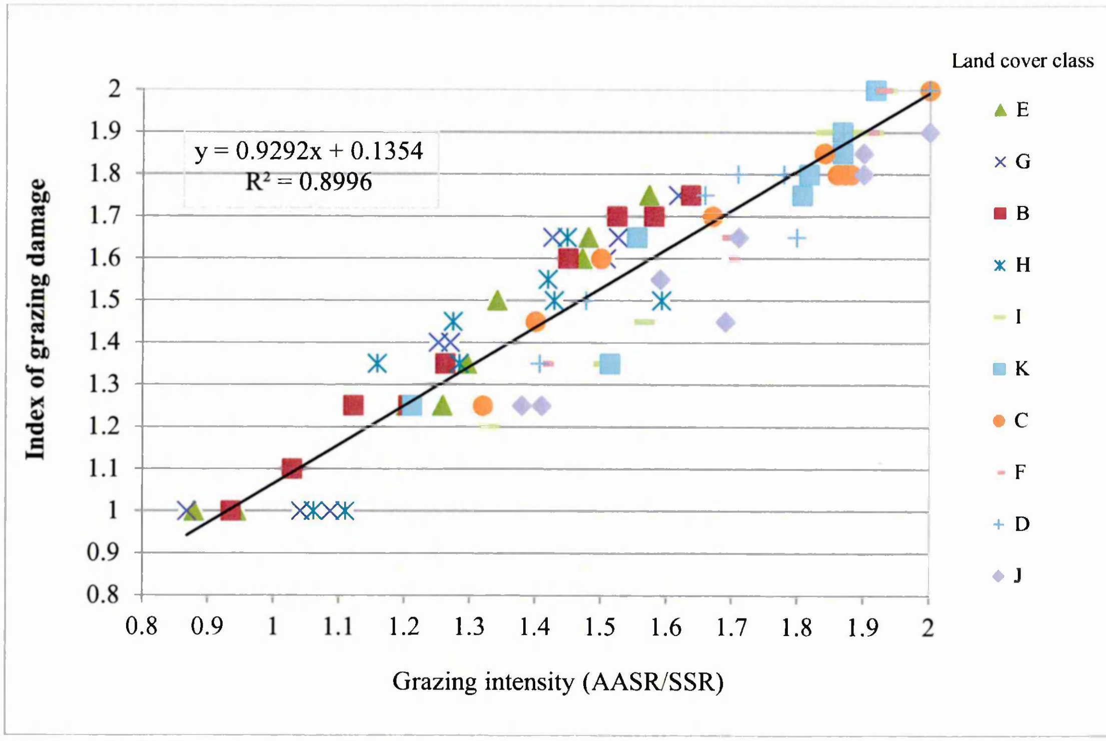


Figure 8.9. Index of grazing damage and grazing intensity: grazing efficiency SSR1; X=0.5.

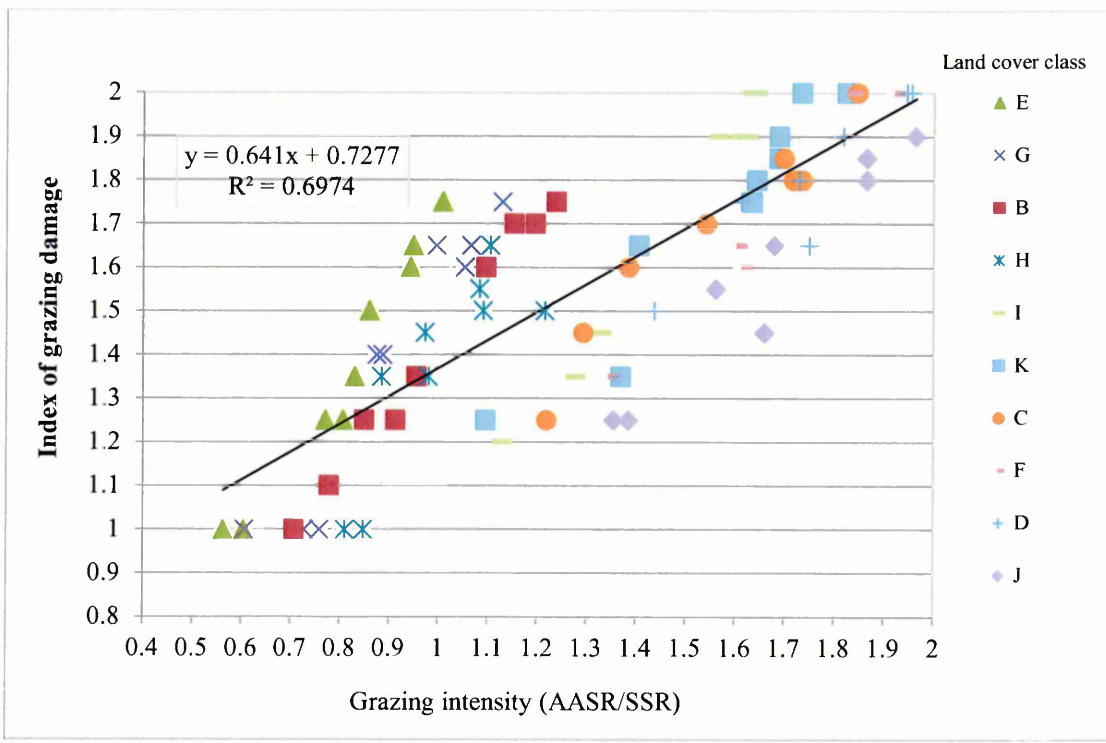


Figure 8.10. Index of grazing damage and grazing intensity: grazing efficiency SSR2; grass X = 0.5 & woody plant + shrub X = 1.

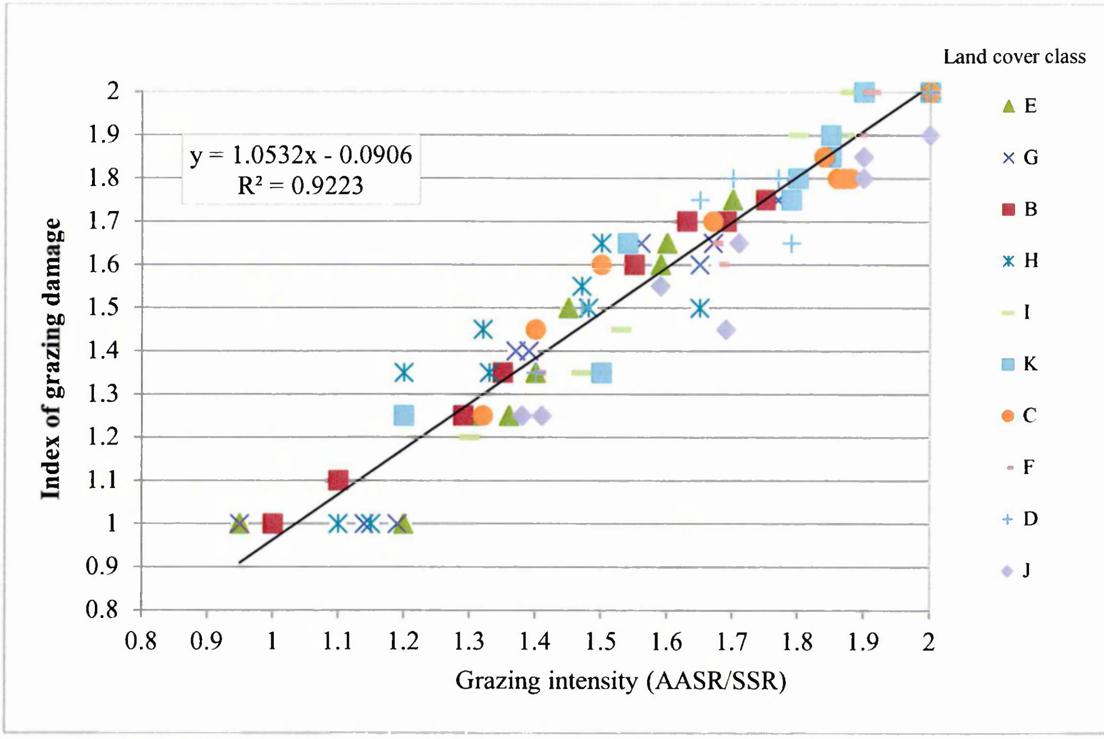


Figure 8.11. Index of grazing damage and grazing intensity: grazing efficiency SSR3; grass X = 0.5 & woody plant + shrub X = 1 * plant palatability.

The results clearly show that the second assumption produces much worse correlation between grazing intensity and grazing damage from field observation of the damage caused to the land by grazing animals. Scenarios 1 and 3 are similar, but scenario 3 has the best correlation co-efficient. In addition for Scenario 1, land with the greater shrub cover tends to appear above the linear regression line, such as classes B and E, whilst land with sparse shrub cover appears below it, such as classes J and K (Figure 8.9). In the third scenario, the data are mixed together. There are no previously published data on the relationship between grazing damage and grazing intensity, and so this is an important contribution of this research. The form of the relationship was not known, and the closeness of the data to a straight line confirms it is a linear relationship. It can also be inferred that inclusion of policy enforcement for calculation of management quality index is not necessary to evaluate the impact of the intensity of land use in natural areas subject to grazing pressure as a good linear relationship has been obtained.

As the third scenario of grazing efficiency gives the best correlation with observed grazing damage, the distributions of grazing intensities for all land cover classes are compared (Figure 8.12):

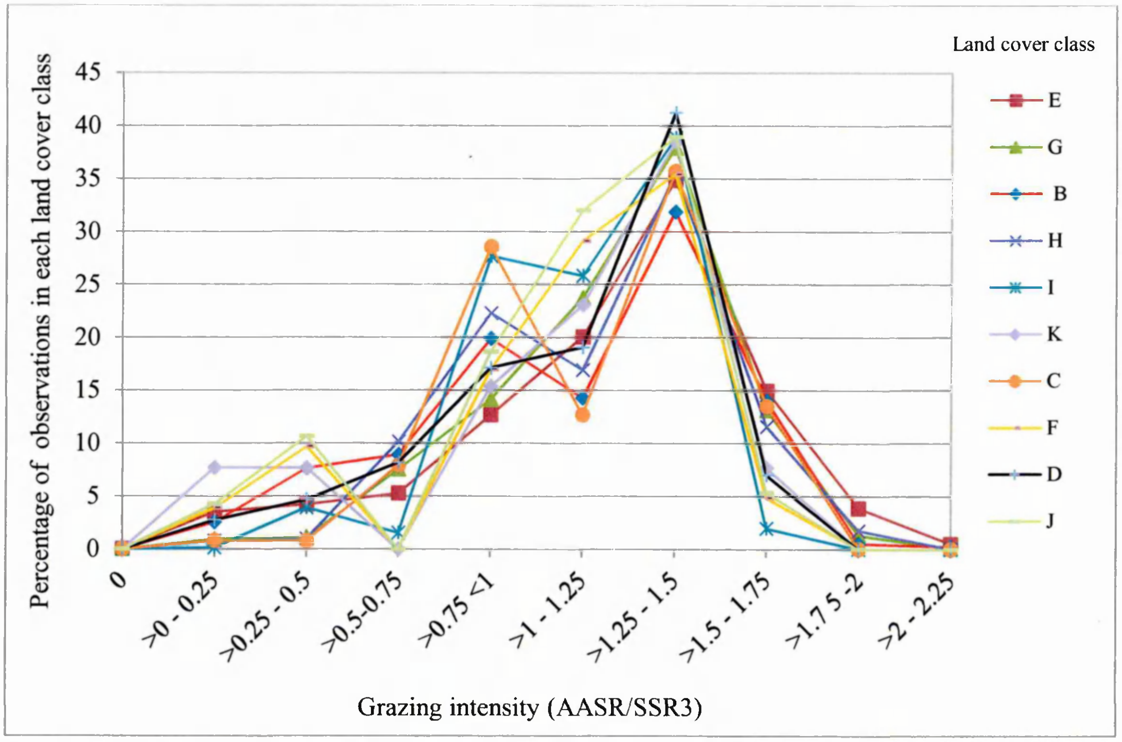


Figure 8.12. Variation of grazing intensity using grazing efficiency scenario 3 for different land cover classes.

When the ratio of AASR/SSR is less than 1, there is likely to be no long-term damage from this grazing pressure. The peak grazing pressure for all land cover types is the same and given by an AASR/SSR of between 1.25 and 1.5. The shape of the distribution is now similar for each land cover class; compared to the greater variability in the actual stocking rates recorded (Figure 8.3).

8.3 Management Quality Index, MQI (Focus group observation of desertification & MEDALUS data)

A linear relationship has been found between grazing intensity in each land class and the index of environmental damage from grazing at 90 randomly stratified locations. However an index for an Environmentally Sensitive Area to desertification at each of the 90 locations was also obtained via the focus group ($ESAI_{FG}$). It was proposed in Chapter 7 that the definition of desertification by the focus group should be the same as that derived from the MEDALUS model. Therefore, as

$$ESAI_{FG} = (SQI*VQI*CQI*MQI)^{1/4}$$ **(Equation 8.3)**

And rearranging gives

$$MQI = \frac{(ESAI_{FG})^4}{(SQI*VQI*CQI)}$$ **(Equation 8.4)**

The denominator is based on soil map, land use/land cover map and climatic data respectively. For example, the point in land cover class B for a grazing intensity of 1 in Figure 8.13 is obtained as follows:

The classification of this point based on the Focus Group was F2 and was equal to a value of 1.27, and its climate is classified as moderate so CQI = 1.58. The calculation of its soil index is based on the following equation:

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

(Equation 6.1)

The soil texture is silty clay loam, there are stony fragments in the soil surface, the soil depth is shallow, the parent material is limestone, the slope is 7% (which is assigned to the gentle class), and the soil is well drained. Therefore

$$SQI = (1.2 * 3 * 1.3 *1.7 *1.2* 1)^{1/6} = 1.456$$

In relation to the vegetation quality index (VQI), the calculation is based on the following equation:

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

(Equation 6.4)

The indicators are classified as moderate for fire risk and very high for protection against soil erosion and resistance to drought, and the plant cover percentage is more than 40%.

$$VQI = (1.3 * 1* 1 * 1)^{1/4} = 1.067$$

Therefore the management quality index MQI for this point is equal to 1.06. The remaining 89 points are treated in the same way and plotted against grazing intensity, AASR/SSR3 (i.e. SSR refers to scenario3):

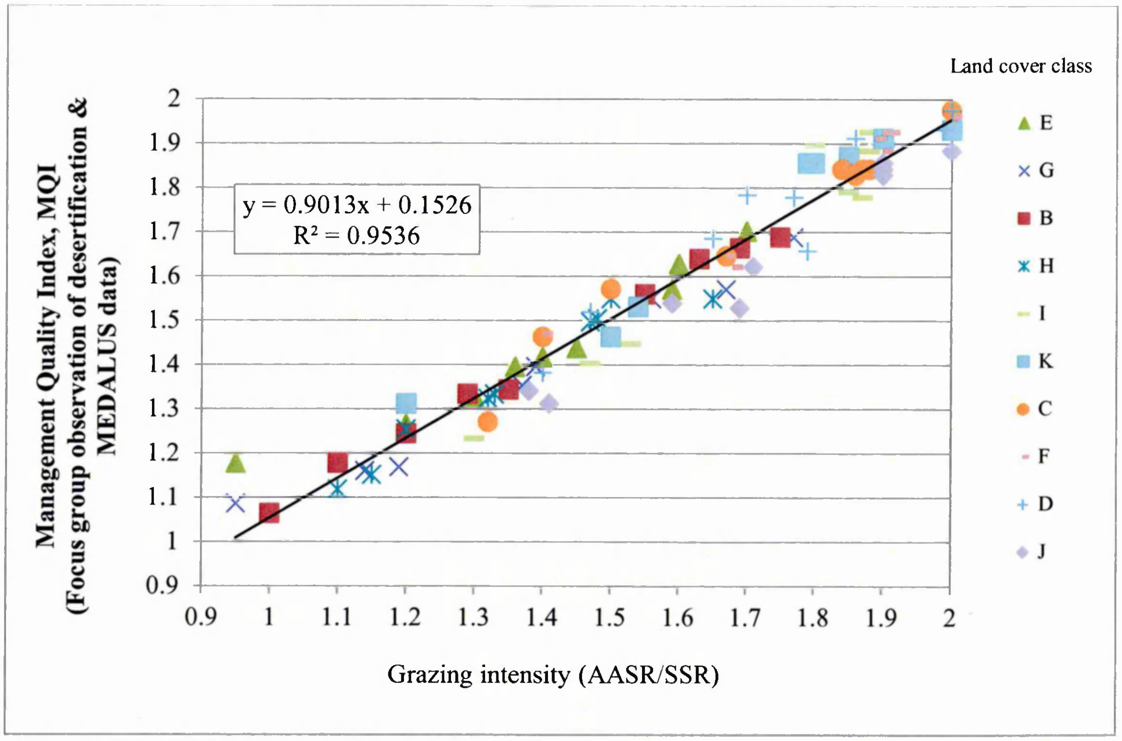


Figure 8.13. Management quality index (MQI) and grazing intensity for the study area.

A good linear relationship was obtained. The importance of Figure 8.13 is that now, for the first time, a value for the Management Quality index for semi-arid climates can be obtained using the linear regression line after calculation of the grazing intensity. The actual stocking rates will be required for the land under consideration, with the appropriate adjustment for any supplemental forage. The sustainable stocking rate can be obtained using Figure 8.7. This will result in greater precision in the MEDALUS model, rather assigning grazing intensities to one of three Management Quality Indices.

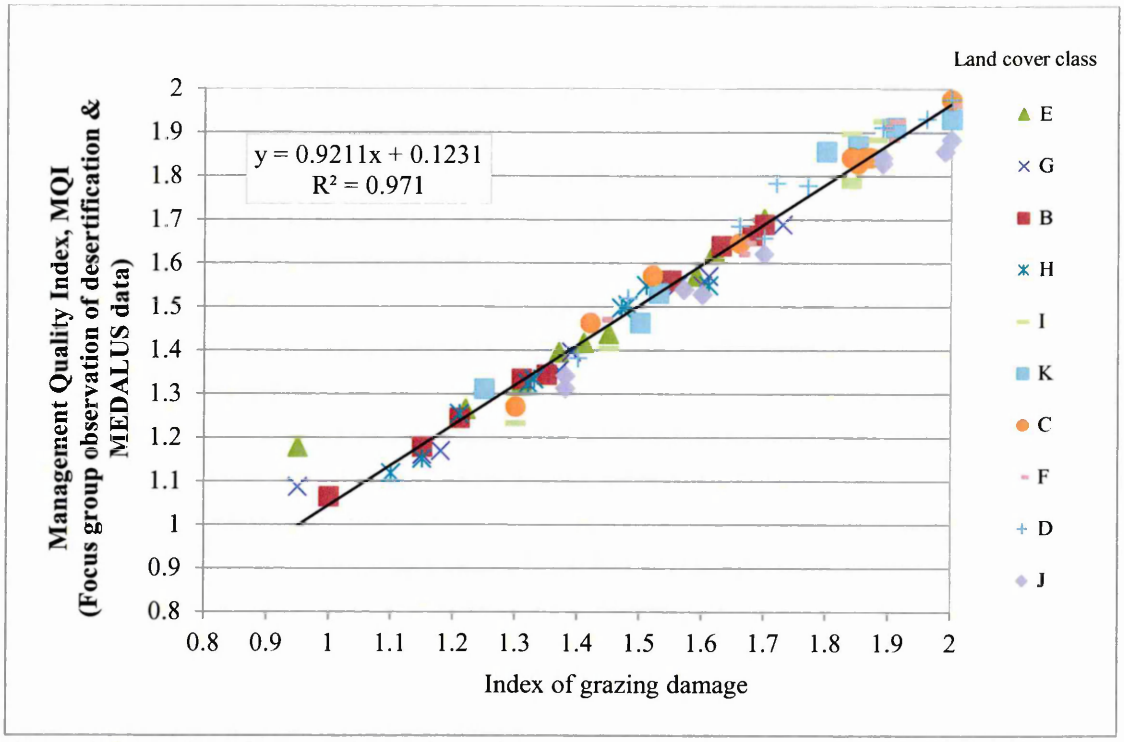


Figure 8.14. Index of grazing intensity and management quality index (MQI).

It is recognised that establishing grazing intensity of actual and sustainable stocking rates is time consuming. By plotting the index of grazing damage versus MQI_{FG}, it is possible to use the trend-line to obtain MQI (Figure 8.14). An excellent correlation is obtained. Using a field assessment procedure developed here is an improvement on the original definitions of the various MEDALUS MQI classes (Kosmas et al. 1999; Kosmas et al 2010), which are a bit vague and open to misinterpretation. The index for grazing damage is not identical to MQI, as the gradient of the trend-line is close but not 1 and the offset is also not zero.

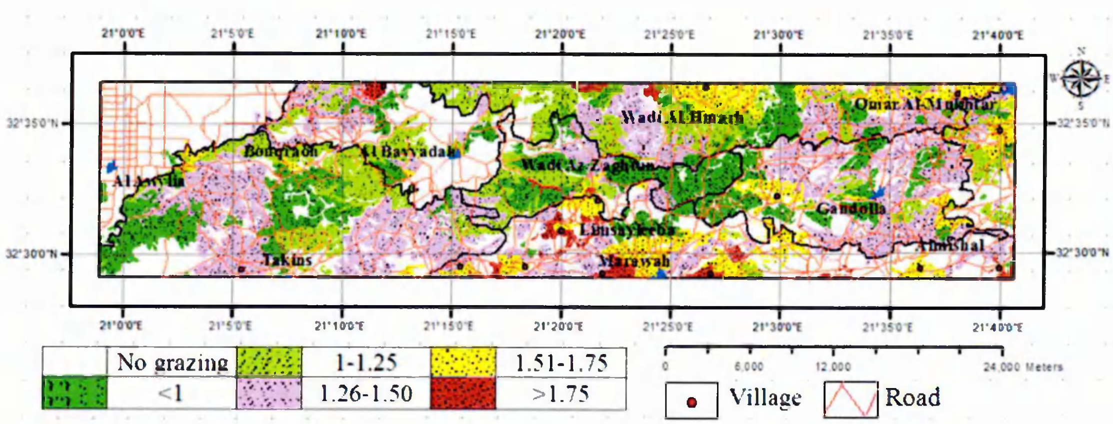


Figure 8.15. Management quality index in the study area in 2008.

The spatial variation of the new MQI within the study area is shown (Figure 8.15). The high grazing intensities illustrated in Figure 8.12 are concentrated in Marawah.

The cover is less than 30% woody plants and shrubs (classes C, D, F J and K, with a small area of H). This area has a concentration of palatable shrubs, such as *Santonica* Wormseed and *Salvia fruticosa*, which is similar to the palatability of the annual grasses present. It is believed that this has encouraged shepherds to overgraze this region. The spatial distribution of more moderately grazed land is associated with the presence of roads, villages and water resources (Figure 8.12 and 8 15). Land with low grazing intensities is generally more inaccessible and remote.

8.4 Verification of improved MEDALUS model including new MQI

In Chapter 6, the verification process identified some mis-assessment in comparison to FG classification of desertification. Verification of the improved MEDALUS model of the study area including the new MQI was performed using 280 points that were assessed by the focus group, but not used in the derivation of and analysis for MQI. The following table shows almost perfect agreement between the improved MEDALUS model and 2010 reference data from the focus group experts (Table 8.7) compared to the results obtained previously (Table 7.10). For example, some locations in Taknis were classified as 'slight' previously whereas they are classified accurately as 'moderate' on the basis of focus group assessment (Figure 8.16). The improved MQI indicator used to assess the sensitivity to desertification is an evolution for MEDALUS assessment for unmanaged natural areas.

Classified data		**Reference data from focus group 2010**							
		F2	**F3**	**C1**	**C2**	**C3**	Row total	User accuracy (%)	Kappa *
MEDALUS 2008 map data	**F2**	**64**	9	4	0	0	77	83.1	0.8267
	F3	12	**89**	6	1	0	108	82.4	0.8197
	C1	0	6	**70**	9	2	87	80.4	0.7983
	C2	0	0	3	**44**	7	54	81. 5	0.8041
	C3	0	0	1	6	**37**	44	84.1	0.8356
Column total		76	104	84	60	46	370		
Producer's accuracy (%)		84.2	85.6	83.3	73.3	80.4			

Note: Number of pixels correctly classified: 304; overall classification accuracy: 81.84%. *Overall Kappa index of agreement: 0.8168.

Table 7.10. Evaluation of MEDALUS map and field classifications of land.

Classified data		Reference data from focus group 2010							
		F2	F3	C1	C2	C3	Row total	User accuracy (%)	Kappa*
MEDALUS 2008 map data	F2	54	5	1	0	0	60	0.9	0.8991
	F3	4	72	6	0	0	82	0.88	0.8765
	C1	1	3	70	1	0	75	0.93	0.9328
	C2	0	0	1	33	2	36	0.92	0.916
	C3	0	0	0	2	25	27	0.93	0.9255
Column total		59	80	78	36	27	280		
Producer's accuracy (%)		0.91	0.90	0.89	0.92	0.92			

Note: Number of pixels correctly classified: 254; overall classification accuracy: 91.1%. *Overall Kappa index of agreement: 0.9063.

Table 8.7. Evaluation of improved MEDALUS map and field classifications of land.

The new sensitivity map to desertification Figure 8.16 has been elaborated after developing the MEDALUS modelling approach. The final product of this MEDALUS work is an accurate map of desertification vulnerability, after adjustment of management quality based grazing intensives in the natural area. This approach will help decision makers to develop the best strategies for rehabilitation works and fight against desertification in sensitive lands.

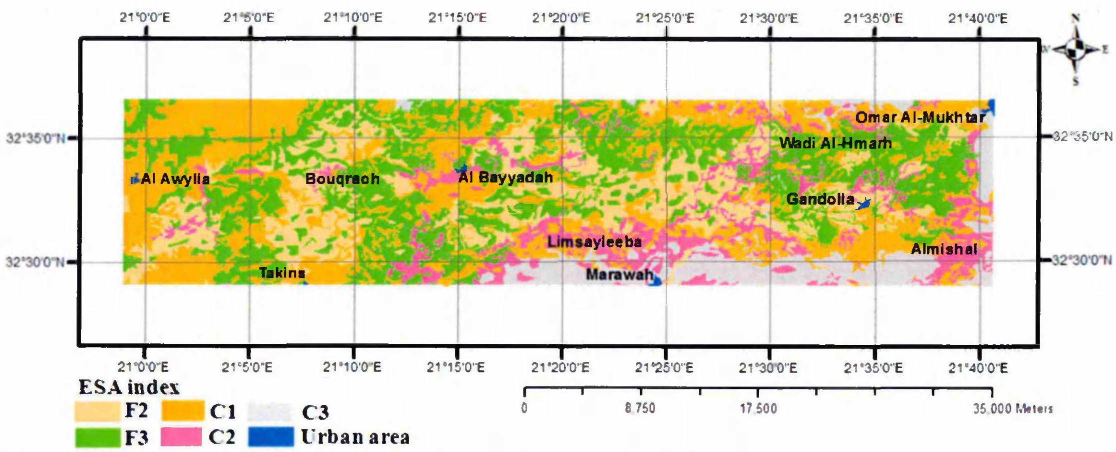


Figure 8.16. Map of the study area showing sensitivity to desertification.

8.5 Conclusions

This study has improved the ability of the MEDALUS model to predict the vulnerability of the semi-arid land in the study area to desertification. This has been achieved in particular for the natural land through extensive and detailed questioning of shepherds to determine stocking rates and measurement and evaluation of what the natural land can support. A new procedure whereby the palatably of available plants in calculation of this sustainable stocking rate resulted in improved correlation with an index of environmental damage caused by grazing in the full range of land cover classes present. This confidence in the new method has allowed development of an expression which allows the MEDALUS management quality index to be calculated directly from the grazing intensity. This has allowed accurate classification of the land MEDALUS management maps. Ultimately, this approach will help decision makers to develop the best strategies for rehabilitation works and fight against desertification in sensitive lands.

CHAPTER 9

IMPROVEMENTS TO CONSERVATION PRACTICE AND COVER MANAGEMENT IN THE USLE MODEL

AND

EXPLORING TEMPORAL CHANGES IN LAND DEGRADATION

9.1 Introduction

It was clear from the earlier USLE modelling results, that whilst this model performs well over a range of land types and practices in the study area, there is scope for improvement (Chapters 5 and 7). This is particularly true for the cover management factor (C) and conservation practice factor (P). The cover management factor accounts for the influence of an increase in cover from plants on the reduction of soil erosion. It was applied originally in Chapter 5 using an empirical equation based on data from the USA (Wischmeier and Smith 1978). However a limitation is that there is a lack of sufficiently detailed data on this factor at the national or regional scale for Libya, as has also been observed for other places (van der Knijff et al. 2000; Morgan 2005). However, there has been a recent study where new values of cover management factors have been obtained for the Al-jabal Alakhdar region (Mabrok 2012), providing an unexpected opportunity to assess whether these may improve the ability of the model to predict levels of soil erosion.

The conservation practice factor identifies soil loss of the land under various management practices and is considered to be the most uncertain factor (Renard et al. 1997). In the USLE model of the study area, a constant value of P = 0.25 was previously assigned to natural areas, following the guidance of Htun et al. (2008). However, this value of the factor does not consider any impact of land management practice in these natural areas. Human activities such as exploitation of natural lands for grazing have been suggested as the main factor in triggering land degradation, causing drastic changes in land cover in semi-arid areas (Geist et al. 2004; Hostert et al. 2003). Excessive livestock grazing can cause soil compaction and erosion, decreased soil fertility and water infiltration, and a loss in organic matter content and water storage capacity. Overgrazing reduces the usefulness, productivity, and biodiversity of the land and is therefore an important cause of degradation. Despite the importance of overgrazing in the process of land degradation, it has not been incorporated within USLE. Following the success of the introduction of grazing intensity to determine the Management Quality Index and its improvement of the MEDALUS model, the P factor for natural areas in the USLE model should therefore be reviewed to assess whether it could be developed in a similar way.

An early finding of this research from satellite imagery was the temporal decrease in natural areas and increase in agricultural areas and bare soil (Figures 4.4 and 4.3).

However, the geographical variation of this behaviour could not be explained in the absence of other knowledge of the environment that can be provided by a verified theoretical model. Such a model may enable the temporal degradation of the study area to be understood.

Consequently, the first aim of this chapter is to investigate whether the USLE model can be improved to achieve a closer agreement with field observation of land degradation. This will be achieved by investigating whether the cover management and conservation practice factors can be developed. Outputs from subsequent re-modelling of the study area can be compared with the original focus group assessment of the level of degradation. The second aim is to use the USLE model to investigate temporal changes in land degradation. This will be achieved by creating two maps of land degradation, one in 1984 and other in 2008, which can be independently verified. The differences between these maps and the reasons for such changes can then be explored.

9.2 Improvement of the USLE model for the Al-jabal Alakhdar region

9.2.1 The cover management factor, C

Mabrok (2012) identified the relationship between water erosion of soil and the percentage and type of vegetative cover, i.e. fields of barley and wheat with autumn ploughing, fruit orchards and irrigated croplands with mulch tillage, at 250 field sites over five years. Natural lands were fenced off to protect them from human activity, so the soil conservation practice value is a constant minimum value. Measurements of ground cover variables were calculated on site by direct measurement. During rainfall, sediment was intercepted and recovered from traps in small ditches at the outlet of the site plots. Monthly and annual averages of soil loss (t ha^{-1} $year^{-1}$) could then be estimated. Amongst the results produced, the linear regression equation of the average annual C factor values and the vegetation cover is most useful to the research here. These values are exchanged for the original C factor values in the current USLE model of the study area (Tables 9.1 and 9.2) to obtain the accurate C-factor map of the study area (Figures 9.1a and 9.1b).

Type of vegetation cover	Land cover class (from Fig 4.5)	Vegetation cover (%)	C-value
Natural woodland with shrubs	B, E, G and H	>40	0.06
Natural woodland with shrubs	I	30-40	0.14
Natural woodland with dwarf shrubs.	K	20-30	0.65
Natural woodland with dwarf shrubs	C	10-20	0.90
Dwarf shrubs with herbaceous plants	F	10-20	0.90
Natural woodland with dwarf shrubs	J	1-10	0.95
Dwarf shrubs with herbaceous plants	D	1-10	0.95

Table 9.1. Cover management factor C for different vegetation cover classes (adapted from Mabrok 2012).

Type of vegetation cover	Land cover class (from Fig 4.5)	C-value
Forest plantations	L	0.11
Irrigated crops (tomatoes) & orchards (grapes) mulch tillage (P = 0.60).	A and N	0.3
Barley & wheat under normal tillage (P=1)	M	0.35

Table 9.2. Cover management factor C for different land use classes (adapted from Mabrok 2012).

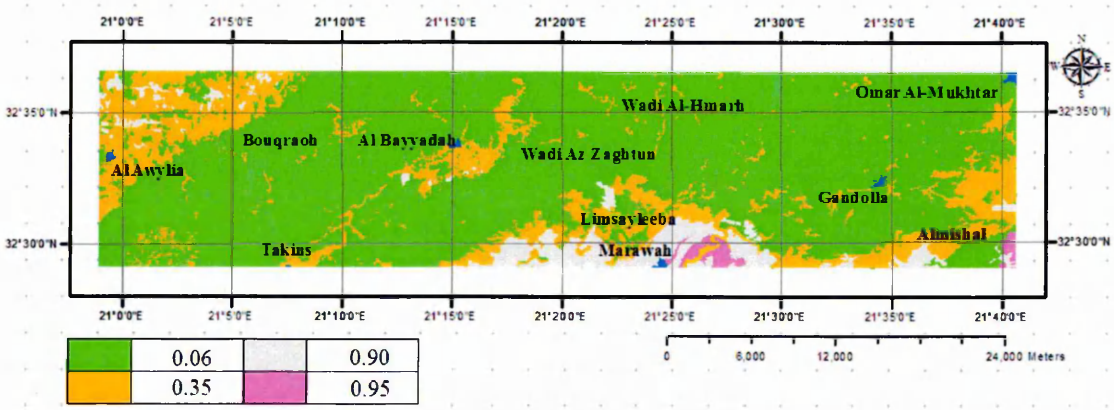


Figure 9.1a. Spatial distribution of cover management C factor in 1984 using values from Mabrok (2012).

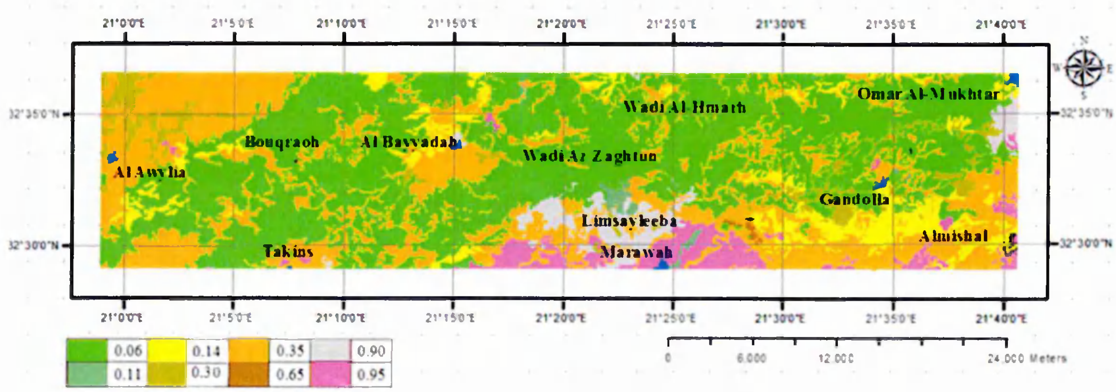


Figure 9.1b. Spatial distribution of cover management C factor in 2008 using values from Mabrok (2012).

9.2.2 Conservation practice factor P on agricultural land

In the initial application of the USLE model (Chapter 5), the magnitude of P is dependent on the time of ploughing. Winter ploughing for barley or wheat and mulch tillage of irrigated lands or orchards are always undertaken in the study area; values for this (P = 1 and 0.6 respectively) were taken from Htun et al. (2008). The focus group assessed that there was less soil loss in field than that forecast by the model, particularly in flat or mildly sloping lands. This overprediction could be reduced by including the impact of the land slope and tillage on erosion (a "slope tillage" variable), which has been identified as an important process of land degradation in hilly cultivated areas (St Gerontidis et al. 2001). Some studies advocate a consideration of just the time of ploughing and others just the tillage slope for up and down-slope ploughing (Lufafa et al. 2003, Fu et al. 2006, Terranova et al. 2009, and Kouli et al. 2010), where

$$P = \text{Slope tillage} = 0.2 + 0.03*S \qquad \textbf{(Equation 9.1)}$$

and S is the slope grade (%). Using the impact of using slope tillage alone was explored and it was found to underpredict the soil erosion compared to the focus group assessment. Therefore the following equation is proposed that includes both variables to calculate the soil conservation practice factor in agricultural areas:

$$P = \left(\frac{\text{slope tillage} + \text{ploughing time or type}}{2}\right) \leq 1 \qquad \textbf{(Equation 9.2)}$$

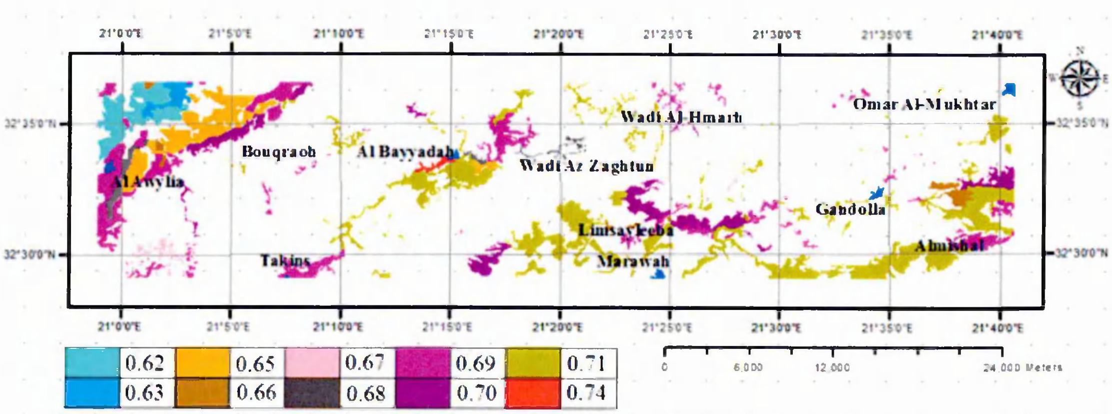


Figure 9.2a. Spatial distribution of improved conservation practice factor P for cultivated agricultural areas in 1984.

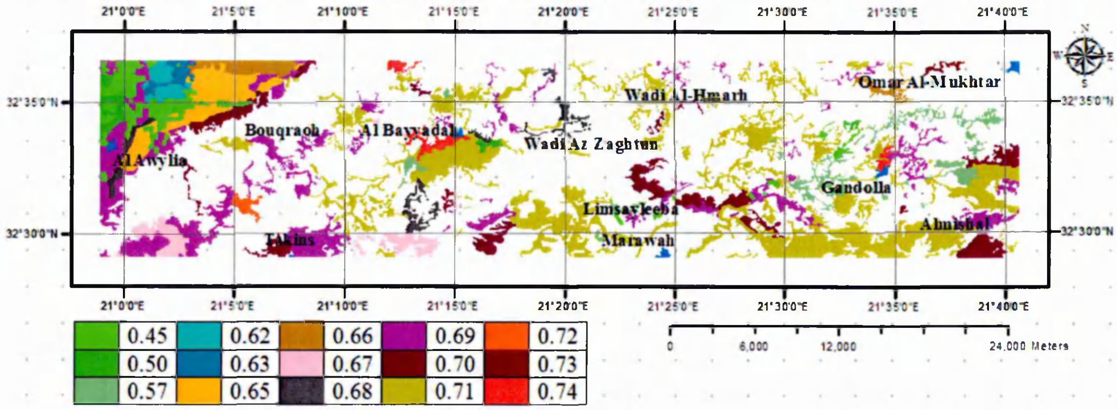


Figure 9.2b. Spatial distribution of improved conservation practice factor P for cultivated agricultural areas in 2008.

Application of equation 9.2 within USLE for the cultivated agricultural areas shows a much wider variation of P values have been obtained when Figure 5.6 and 9.2b are compared, with the new values being lower than the original values. This should reduce the overestimation of soil estimation by the model. Comparison of the maps for 1984 and 2008 (Figure 9.2a and b) shows no temporal change in magnitude for an area under cultivation as the cultivation practice has not changed, however a temporal increase is observed in the spatial extent of natural lands that have been converted to areas under cultivation.

9.2.3 Conservation practice factor P in natural areas

Previously, only a constant value for P factor in natural areas has been suggested. However, the impact of grazing on the environment work was quantified clearly in chapter 8. Using a similar process to that described in section 8.3, the best description of grazing intensity (scenario 3) is compared to a conservation practice factor P derived from USLE factors and the focus group assessment of degradation at the 90 locations mentioned previously, as it was proposed in chapter 7 that the definition of degradation by the focus group, E_{FG}, should be the same as that derived from the USLE model. As

$$E = R*LS*K*C*P \qquad \textbf{(Equation 5.1)}$$

And substituting and rearranging gives

$$E_{FG} = R*LS*K*C*P \qquad \textbf{(Equation 9.3)}$$

$$P = \frac{(E_{FG})}{(R*LS*K*C)}$$ **(Equation 9.4)**

The denominator is based on climatic data, the slope and overland flow length, soil erodibility and land use/land cover map respectively. To illustrate use of equation 9.4, the point B1 in Figure 9.3 is considered:

The classification based on focus group assessment is F2, which gives $E_{FG} = 2.5$

The rainfall erosivity factor is constant for the study area at R = 152.5 (Equation 5.2)

The slope and overland flow length LS = 5 (Figure 5.2)

The soil erodibility factor K = 0.27 (Figure 5.4)

The crop management factor C = 0.06 (Table 9.2)

Therefore, the conservation practice factor P for this point is equal to 0.2. The remaining 89 points are treated in the same way and plotted against grazing intensity (AASR/SSR3).

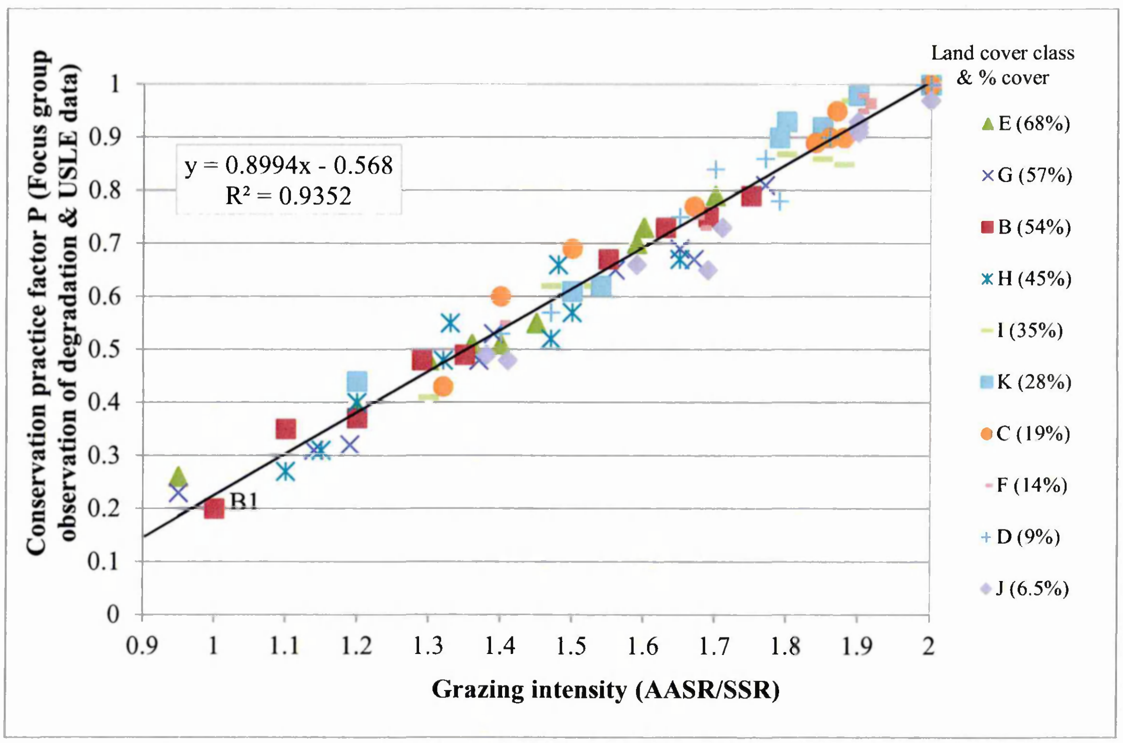


Figure 9.3. Relationship between Conservation Practice factor P and grazing intensity for different land cover classes in rangeland.

An excellent linear relationship between grazing intensity and conservation practice P factor has been revealed. This has not been achieved before. The correlation co-efficient is only slightly lower than obtained for grazing intensity and management quality index (Figure 8.13). Erdogan et al. (2007) noted that cover management and conservation practice factors may vary in magnitude due to the skill and perception of the scientists involved in their assessment. The results demonstrate the skill of the scientists in this study.

This allows the conservation practice factor for the study area to be determined. Following normal practice for USLE, a minimum value of 0.2 is to be used for this factor. The spatial variation of P in 2008 is very similar to the MEDALUS MQI (Figure 8.15).

Shepherds cannot be reliably questioned about historical actual stocking rates. However, data on the grazing intensity in 1984 can be obtained from regional government records (Figure 2.6). Here, the average actual stocking rate for each region is less than 1.5 Head ha^{-1}. It is assumed conservatively that the sustainable stocking rates remain unchanged, with the lowest value in 2008 being 1.98 Head ha^{-1} (Figure 8.7 and Table 8.6). Therefore, the ratio of actual to sustainable stocking rates, or grazing intensity, is 0.758. Substitution of this value into Figure 9.3 indicates that the soil conservation practice factor will be less than 0.11 for all areas, although this requires extrapolation of the linear regression equation. As the minimum allowed for a value in USLE is 0.2, this was assigned as a constant value through the study area for 1984.

9.3 Verification of new USLE model

Before the improved USLE model can be used to investigate temporal degradation of the land, the model results are compared to independent field data. Recognising that water erosion is the main process responsible for land degradation in the study area (Ali 1995; Ben-Mahmoud 1995), a historical map was located of water erosion in 1980, as estimated by scientific experts at that time (Selkhozpromexport 1980). This map has a spatial resolution of 700m x 700m. The water erosion data existed solely in paper tables and maps; although time consuming, this information was transferred into the current GIS database. It is reasonable to assume that the level of water erosion did not change significantly between 1980 and 1984 as this time period was not subject to significant social and agricultural change. Therefore, the USLE 1984 map can be verified using this data. A total of 280 randomly selected points were selected for this, the geographical locations being shown on Figure 9.4.

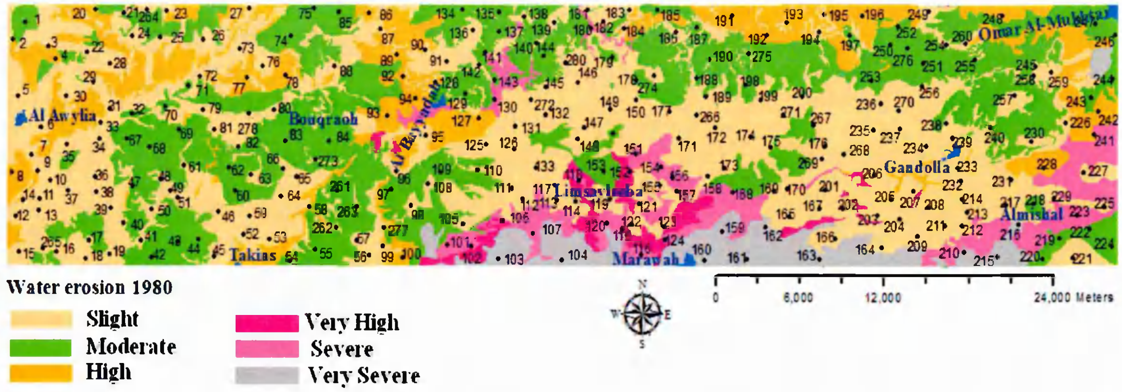


Figure 9.4. Geographical location of randomly selected sample points for statistical comparisons overlaid on 1980 water erosion map.

For the USLE maps, the magnitude of all variables is the same between 1984 and 2008, apart from C and P factors. A USLE map of land degradation for 1984 can be produced (Figure 9.5).

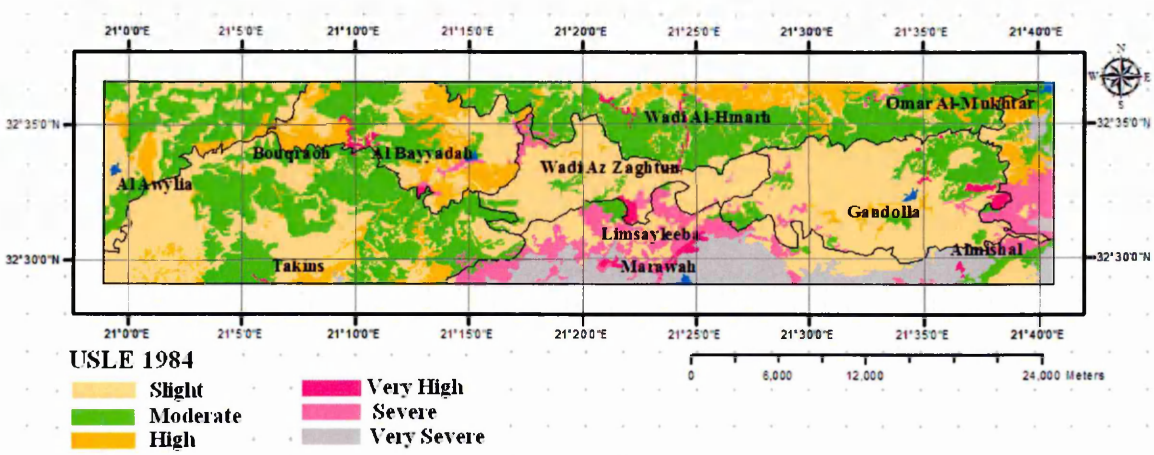


Figure 9.5. USLE land degradation map for study area in 1984.

Classified data		Reference data from water erosion map 1980								
		S	M	H	V.H	SV	V.SV	Row total	User accuracy (%)	Kappa*
USLE 1984 Map data	S	**100**	9	0	0	0	0	109	0.92	0.9170
	M	7	**90**	2	0	0	0	99	0.91	0.9091
	H	0	1	**54**	1	1	0	57	0.95	0.9473
	V.H	0	0	0	**4**	1	0	5	0.80	0.7917
	SV	0	0	0	0	**6**	1	7	0.86	0.8510
	V.SV	0	0	0	0	0	**3**	3	1.00	1.00
Column total		107	100	56	5	8	4	280		
Producer's accuracy (%)		0.93	0.90	0.96	0.80	0.75	0.75			

Note: Number of pixels correctly classified: 257; overall classification accuracy: 91.78%. *Overall Kappa index of agreement: 0.9173.

Table 9.3. Comparison of USLE 1984 land degradation map with 1980 water erosion map.

The accuracy of the USLE 1984 map was verified using the randomly selected points on this and the water erosion map. Almost perfect agreement was obtained when the overall classification accuracy and the Kappa index of agreement were used (Table 9.3), according to the rules established by Viera and Garrett (2005). An improved land degradation map for 2008 was also produced (Figure 9.6), using the new values for the C and P factors (Figures 9.1, 9.2 and 9.3). These data can also be compared with the focus group assessment of land degradation obtained in 2010, as described earlier in Chapter 7.

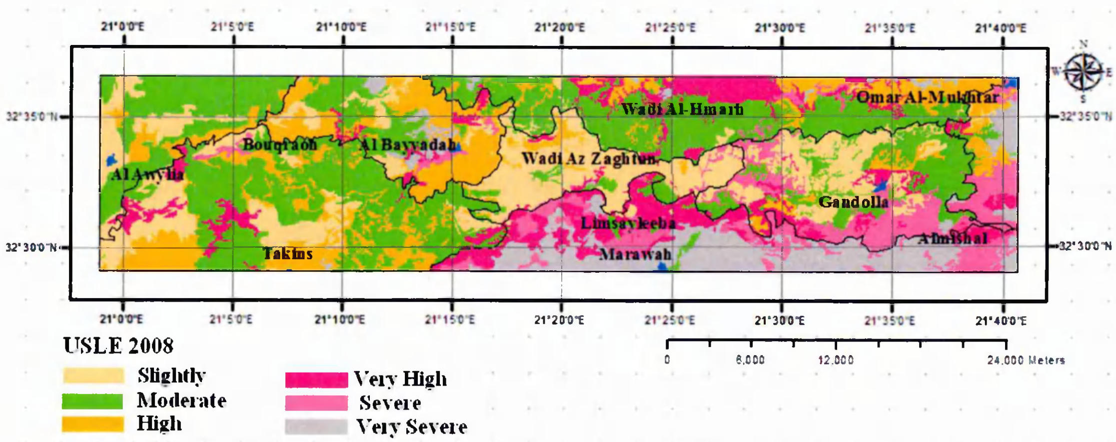


Figure 9.6. USLE land degradation map in 2008, after improvements to C and P factors.

An improvement in the ability of the USLE model to predict land degradation was obtained. As an example, this is illustrated for the improved factors C and P at a few locations in the natural area, where the model now more accurately predicts the impact of overgrazing and land cover description on land degradation (Figure 9.7).

Picture 9.1. Local overgrazing and trampling effects resulting in bare soil, scattering of dense plants and removal of the grass. Gandolla (08/2010), land cover class I (32° 30' 43" N, 21° 34' 35" E). This area was classified as VH by USLE 2008, whereas FG 2010 classifies it as SV which is same as improved USLE.

Picture 9.2. Overgrazing of lower parts of Mastic trees. Burnet and bare soil appear after consumption of grass by goats and sheep. Marawah (08/2010), land cover class D (32° 31' 5" N, 21° 19' 29" E). This land was classified as SV by USLE 2008; however, FG 2010 classified it as V.SV, which is the same as the classification of improved USLE.

Picture 9.3. Effect of overgrazing on the vegetation cover: bare soil present after consumption of grass by goats and sheep. Wadi Al-Hmarh (8/2010), land cover class H (32° 36' 14" N, 21° 28' 47' E). This land was classified as H by USLE 2008, though FG 2010 classified it as VH, which is similar to the classification of improved USLE.

Figure 9.7. Illustration of examples of different levels of land degradation classification.

Classified data		Reference data from focus group								
		S	M	H	V.H	SV	V.SV	Row total	User accuracy (%)	Kappa*
USLE 2008 Map data	S	54	3	0	0	0	0	57	94.7	0.9471
	M	3	66	1	0	0	0	70	94.3	0.9426
	H	0	3	39	1	0	0	43	90.7	0.9062
	V.H	0	0	2	39	0	0	41	95.1	0.9509
	SV	0	0	1	2	36	0	39	92.3	0.9226
	V.SV	0	0	0	1	3	26	30	86.7	0.8667
Column total		57	72	43	43	39	26	280		
Producer's accuracy (%)		94.7	91.7	90. 7	90. 7	92.3	1			

Note: Number of pixels correctly classified: 260; overall classification accuracy: 92.3%. *Overall Kappa index of agreement: 0.9282.

Table 9.4. Comparisons of USLE 2008 map (improved P and C factors) and field classification of water erosion.

When the overall classification accuracy and the Kappa index of agreement are used, there is almost perfect agreement between the improved USLE 2008 model and 2010 reference data from the focus group experts (Table 9.4), according to the criteria of Viera and Garrett (2005). The improvement in C and P factors has increased the overall classification accuracy from 75.6% (Table 7.6) to 92.3% (Table 9.4), with improvement being observed across all classes of land degradation.

9.4 Using USLE to investigate temporal changes in land degradation

The satellite imagery has enabled degradation and desertification to be identified (Figure 4.4) that shows increase in bare soil and farmland, forests have been removed or degraded, but it does not explain why these changes to the land have occurred. A verified model is required to explore what causes the temporal changes to a complex environment. This research should be of subsequent assistance to devise strategies to arrest environmental damage, to inform managers about where an expansion in human activities can be permitted, or where a change to less damaging practice is necessary. Either the USLE or the MEDALUS model would have been acceptable to explore the causes of degradation or desertification, given their high degree of accuracy compared to field observation of desertification or land degradation. The USLE model was chosen because of the availability of the water erosion map from 1980 with which to verify the 1984 USLE. An equivalent map for desertification from this period was not available which would have allowed verification of a MEDALUS model for this period.

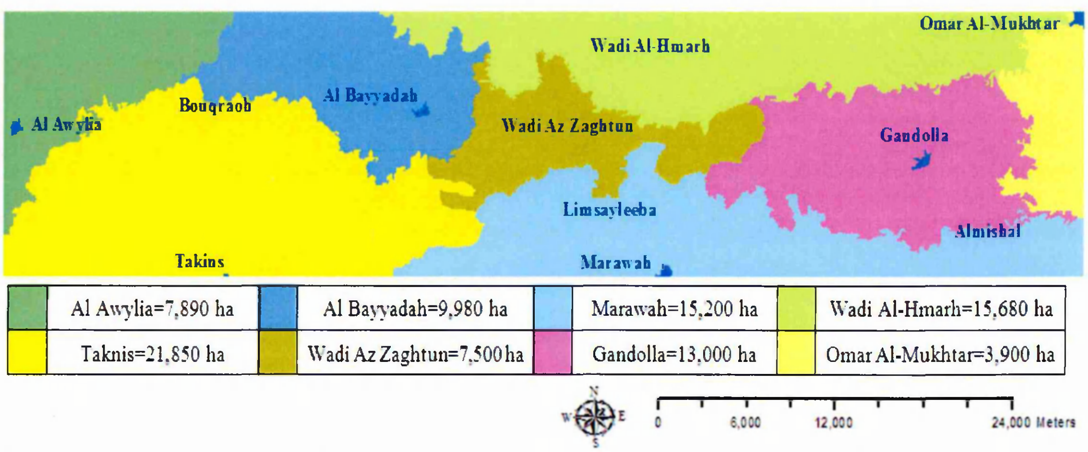


Figure 9.8. Sub-regions in the study area based on observed land degradation.

The temporal changes in the landscape are described by sub-region of the study area, as shown in Figure 9.8, although it should be noted that only the full extent of the Wadi Az Zaghtun and Gandolla sub-regions are contained within the study area. There are physical and human geographic grounds for doing so, for example each sub region tends to be populated by an extended tribal family who tend to conduct similar practices of land management.

9.4.1 Temporal changes in land degradation for Al Awylia region

In the Al Awylia sub-region (Figure 9.8), the land is dominated by wheat and barley fields, orchards and irrigated crops. No temporal change in the slight, moderate and high classifications occurred in 19%, 51% and 7% of the sub-area respectively. A slight classification occurs where the land is flat ($LS < 0.21$); as a result the soil erodibility, cover and conservation practice are not important factors. The land can therefore support natural vegetation or the full range of crop types (Figure 4.3 and 4.5), including rain-fed barley and wheat, irrigated apple, peach, plum and grape orchards, and irrigated fields of cauliflowers, onions and tomatoes. A moderate classification is associated with wheat and barley at a slightly steeper topography, low erodibility and medium soil conservation practice ($LS = 0.5$ to 1; $K < 0.27$; $P = 0.6$). Similar conditions exist for land classified as being subject to a high risk of land degradation, but the soil is more erodible ($K = 0.28$ to 0.34; $P = 0.61$ to 0.67).

For land where the degradation classification increases from slight to moderate (9% of sub-area), the important contributing factors are land cover changes from dense natural vegetation ($C = 0.06$; $P = 0.2$; $LS = 0.7$ to 0.9; $K = 0.27$ to 0.34) to irrigated orchards ($C = 0.3$; $P = 0.45$ to 0.5), which has a better soil conservation practice compared to wheat and barley.

Where the classification increases from a moderate to a high risk of degradation (2% of the sub-area), land cover and practice are important factors as a low natural land cover density with low grazing intensity (cover < 40%; $C = 0.9$, $P = 0.2$) is converted to rain-fed barley and wheat ($C = 0.35$, $P = 0.69$; $LS = 1$; $K = 0.24$ to 0.34), with the latter conditions occurring for 1% of land with a high classification in both 1984 and 2008. This is primarily due to the lack of cover provided by the early growth of these rain-fed crops in the rainy winter season.

An improvement from a moderate to a slight classification (10% of the sub-area) occurred due to an improvement in cover where very sparse shrub cover ($C = 0.95$; $P = 0.25$; $LS = 0.6$-1; $K = 0.27$-0.3) has been converted to orchards ($C = 0.3$; $P = 0.45$ to 0.5). An improvement from a high to moderate classification occurs in 1% of the area due to an improvement in cover and practice where wheat and barley fields have been converted to irrigated orchards (LS = 1; K = 0.31-0.34).

9.4.2 Temporal changes in land degradation for the Taknis region

The south-western sub-region extends from Taknis towards Bouqraoh. Whilst the altitude does not vary greatly, the slope of the topography varies from gentle to steep (Figure 5.2). No temporal change in slight (sub-area = 21.2%; $P \leq 0.3$; LS = 3-7) and moderate classifications (sub-area = 47%; $P \leq 0.3$; LS = 9-11) occurred due to the continuing presence of dense vegetation (C = 0.06), ensuring K has only a weak influence, even though the grazing intensity P increases from 0.2 to 0.2-0.75. Only 4.8% of the sub-area was assigned a high classification in 1984, caused by barley or wheat land cover, even if LS = 1 (nearly flat), P = 0.69 and $K \geq 0.29$ as observed in Al Alwylia. A further 22.2% of the sub-area originally with a slight classification was converted to a high classification by 2008, particularly in the north and north-eastern zones, as dense natural vegetation was removed by bulldozers and other agricultural machinery to allow planting of wheat or barley crops on nearly flat terrain. However, as LS increases to 2 and then 9, the same reduction in cover results in changes from slight to very high (3.2% of sub-area) and moderate to very severe classifications (1% of sub-area) respectively. A change from slight to severe also occurs where there is a change from dense natural vegetation to sparse vegetation (sub-area = 0.6%; LS = 6; K = 0.26).

In this area, K varies from 0.24 to 0.3 and occasionally 0.34 (Figure 5.4), so it only has a weak influence on land classification, unless $LS \geq 1$ when the cover is rain-fed crops or when LS > 5 for dense natural vegetation.

9.4.3 Temporal changes in land degradation for Al Bayyadah region

In the Al Bayyadah sub-region (Figure 9.8), no change in slight, moderate, high, very high and severe classifications occurred in 8.3%, 30%, 16.3%, 0.9% and 1% of the sub-area respectively, with land in the first three classifications being similar to that in the Taknis sub-region described previously, although there are some differences: 10% of the high classification has dense vegetation with LS = 17-18, as the topography is very steep. Although the land slope can be relatively gentle (LS = 2), a very high classification occurs for wheat and barley cover when the soil is highly erodible (K = 0.39).

Conversion from dense natural vegetation to barley and wheat crops causes a change from a slight to a severe classification when LS = 5 and K = 0.28 to 0.3 (4.2% of sub-area). Clearance of dense natural vegetation and terracing for orchards has caused particular environmental damage in this region, with the severity of the impact being dependent on the magnitude of LS: a change from slight to very severe when LS = 9 (3.4% of sub-area), moderate to very severe with LS = 11 (3.2 % of sub-area), and high to very severe with LS = 13 to 14 (4% of sub-area), as K remains at 0.3.

9.4.4 Temporal changes in land degradation for the Wadi Az Zaghtun region

The Wadi Az Zaghtun is in the central part of the study area between Gandolla and Al Bayyadah. The topography varies from gentle to steep. No temporal change has occurred in slight, moderate, high, very high and severe classifications for 84.1%, 1.9%, 0.2%, 0.8% and 4.7% of the sub-area respectively; the type of land cover for these classifications are similar to that in the Taknis and Al Bayyadah sub-regions. When the land classification changes from slight to severe (0.4% of sub-area), some differences are observed. There are increases in the cover and practice factor values occur when a widespread increase in grazing intensity has converted dense vegetation cover (C = 0.06; P = 0.2) to sparse vegetation cover (C = 0.9; P = 0.6-0.7), causing severe levels of water erosion, where LS = 3 and K = 0.2. This also occurs when dense vegetation has been cleared for barley and wheat crops (sub-area = 0.8%; LS = 5; K = 0.28-0.29).

9.4.5 Temporal changes in land degradation for the Marawah region

The south eastern part of the study area extends from Almishal towards Marawah and beyond. The topography varies from steep to very steep. No temporal changes in the slight and moderate classifications occurred for a very small part of the sub-region (0.1% and 1.1% respectively) which contain dense vegetation, with larger values of LS (3-9) resulting in the poorer classification. Very high, severe and very severe classifications occur for 2.8%, 18% and 48% of the sub-area respectively (LS = 2, 3, 5-13; K = 0.28-0.37, 0.3-0.4, 0.32-0.4 respectively). These classifications are due to the presence of rain-fed barley and wheat on land that varies from a gentle slope in the former to a steep slope in the latter. There was a severe and very severe potential for soil erosion over a large area in this sub-region in 1984. This danger increased from 1984 to 2008 as further land (17% of the sub-area) was intensively and inappropriately converted from natural vegetation to rain-fed barley and wheat crops, with a further 8%, 7% and 10% of land in the sub-area being classified as very high, severe and very severe respectively.

A change from dense vegetation (C = 0.06; P = 0.2; LS = 3, K = 0.3-0.34) to a sparse vegetation cover (C = 0.95; P = 0.7-1) occurs in about 20% of the sub-region causing a change from a slight to very severe classification as a result of the increase in the intensity of grazing. In 1984, 48% of this region already had a sparse natural vegetation cover and was classified as very severe even with a low grazing intensity, as LS ranges from 7 to 13 and K ranges from 0.32 to 0.4. The shallow soil depth may also reduce the vigour of the vegetation, though this factor is not considered in USLE.

An improvement from Very Severe to Moderate occurred in 1% of the sub-area as sparsely planted natural small shrubs has been exchanged for afforested land (LS = 9; K = 0.32-0.34).

9.4.6 Temporal changes in land degradation for the Gandolla region

The topography varies from steep to very steep in the Gandolla region, in the eastern part of the study area (Figure 6.2). In 2008, about 36% of this area was natural, dense vegetation cover with slight classification (sub-area = 24.1%; LS = 1-7; K = 0.23-0.28) and moderate classification (sub-area = 14.6%; LS = 9; K = 0.23-0.28). In 1984, only 15% of the land had been converted to barley and wheat from the dense natural vegetation, resulting in a severe classification (LS = 3; K = 0.29-0.3). However, the availability of groundwater close to the surface and good quality soil (Ben-Mahmoud 1995; Selkhozpromexport 1980; Zaed et al. 2005) has resulted in a change from dense natural vegetation to an intensive agriculture of irrigated orchards, inter-planted with annual crops. This cover and practice change results in a deterioration from a slight to a high classification in 11% of sub-area (LS = 2 and K = 0.25-0.3). In some areas, there was an initial attempt to convert land to irrigated crops after 1984, but this land was converted finally to rain-fed barley and wheat after failure of the groundwater supply. This resulted in a deterioration from a slight to a very high (sub-area = 12.1%; LS = 2; K = 0.23-0.27) and severe risk of soil erosion (sub area = 15.2% %; LS = 3-5; K = 0.3).

In the south, 13% of the Gandolla sub-region experienced a reduction from dense to sparse vegetation cover caused by overgrazing, resulting in a change from a slight (C

= 0.06; P=0.2; LS = 2-3; K = 0.28-0.3), to very high classification of land degradation (C = 0.9; P = 0.5-0.7). The impact of overgrazing is not as severe as in Marawah as the topography is not quite as steep or the soil quite as erodible. Tree cutting, fire damage and charcoal making have also had a contribution to soil erosion, although this is not quantified by the USLE conservation factor P.

A small improvement in land degradation from very high to moderate has occurred in 2% of the sub-area (LS = 7 and K = 0.21-0.29) where barley and wheat croplands have been exchanged for irrigated orchards with inter-planting of annual crops, resulting in an improvement in the cover factor.

9.4.7 Temporal changes in land degradation for the Wadi Al-Hmarh region

In the north, the Wadi Al-Hmarh sub-region has steep to very steep topography. A large area still retains natural dense vegetation in 2008 (slight and moderate classifications for 1.7% and 64% of the sub-area with LS = 1-7 and 9-11 respectively, and with K = 0.23-0.27 in both cases). About 20% of the sub-area with dense vegetation retains a high classification due to its steepness (LS = 15 and K = 0.3) as grazing intensity remained at a low level in 2008 ($P < 0.35$).

As observed in other sub-regions, overgrazing in areas of dense natural vegetation resulted in a change to sparse vegetation cover and a consequent deterioration in land degradation classification (slight to severe and high to very severe in 0.1% and 1.8% of the sub-area with LS = 5 and 9-11 respectively; K = 0.3 in both cases). Some dense vegetation was cleared for barley and wheat, changing the classification from slight to high (sub-area = 1.2%; LS = 1; K = 0.3) and very high (sub-area = 1.6%; LS = 2; K = 0.23-0.3).

9.4.8 Temporal changes in land degradation for the Omar Al-Mukhtar region

In the east, no change between 1984 and 2008 occurred for the small percentage of natural vegetation present as there was no increase in grazing intensity, although classifications vary due to slope steepness, soil erodibility and density of vegetation cover (Dense cover: slight classification over 0.4% of sub-area with LS = 1 and K = 0.23; high classification over 27.4% of sub-area with LS = 13 and K = 0.36. Sparse vegetation cover: very severe classification over 21% of sub area with LS = 11-13 and K = 0.38-0.4).

After 1984, about 37% of the dense vegetation cover (slight classification) was converted to irrigate orchard cultivation. This land use change was found to be unsuitable due to the steep topography, soil characteristics and poor management. Death of the trees had occurred by 2000 and a further change to rain-fed wheat and barley production by 2008 ensued. By 2008, these changes had led to a severe (sub-area = 36.5%; LS = 3-5; K = 0.38-0.39) and very severe threat of soil erosion (sub-area = 3%; LS = 9-11; K = 0.38-0.4). Overgrazing of the dense natural vegetation by flocks of sheep and goats has also had an adverse impact on the practice factor and hence the cover factor and soil erosion classifications, causing a change from slight to very high (sub-area = 0.7%; LS = 3; K = 0.3-0.39) and from a moderate to a very severe classification (sub-area = 10%; LS = 9-11; K = 0.28-0.3).

9.4.9 Summary of temporal changes in land degradation for the study area

After the changes occurring in individual sub-regions have been described, it is useful to summarize what has occurred in the whole of the study area (Table 9.5). For example, the numbers in the slight classification column for 1984 indicate the destination of this original classification by 2008. Although 20% remains the same, 11%, 10%, 4% and 1% has changed to high, very high, severe and very severe respectively. A soil loss below 5 tonnes ha^{-1} yr^{-1} is defined as slight degradation and is considered to be within permissible limits (Miguel et al. 2011), but for the purpose of clarity in the summary discussion here, slight and moderate levels of soil erosion risk are grouped together, high and above constitutes significant land degradation.

	1984						
2008	S (%)	M (%)	H (%)	V.H (%)	SV (%)	V.SV (%)	**Total % 2008**
S (%)	**20**	0.1	0	0	0.3	0	20.4
M (%)	0.4	**23.25**	0.3	0.2	0	0	24.15
H (%)	11	0.5	**11.1**	2.7	0	0	25.3
V.H (%)	10	0	0	**0.1**	0.5	0.1	10.7
SV (%)	4.14	0	0	0	**4.2**	0.3	8.64
V. SV (%)	1	2.3	0.31	0	0.1	**7.1**	10.81
Total % 1984	46.54	26.15	11.71	3	5.1	7.5	**100**

Table 9.5. Change in USLE land classification from 1984 to 2008.

In 1984, the region is dominated by natural land with dense cover under sustainable levels of grazing by sheep and goats (71%), and is therefore assigned low USLE C and P factors. As result, 68% of this land cover type has a slight or moderate risk of soil erosion. Dense cover protects the soil and allows LS to be nearly 7 here, a relatively large value, which is found to be only slightly affected by the erodibility of the soil.

Less than 3% of the study area is subjected to high or above risks of degradation under natural cover as a result: the high classification for natural dense vegetation is caused by very steep slopes.

Some historic conversion of about 4% of natural land in the north-west to grow wheat and barley crops on land with a mild slope that poses a low risk to soil degradation had occurred. Poorly planned agricultural activity on steeper slopes in the south east of the study area is also evident (21% of region). This contributes 13.1% to the 25% total for the region that already has an increased risk of land degradation above a moderate classification.

In the same year (1984), the government introduced an agricultural revolution to promote an accelerated conversion of natural land for the growing of food crops, to promote food security as a result of imposed restrictions on trade following the Lockerbie bombing. The impact of this policy can be clearly seen in the risk of land degradation for the study area. Some change of land use was acceptable, for example further conversion (4%) of land with a mild slope (e.g. $LS < 0.24$). The impact of land use change is defined by cover and soil conservation practice factors, with its magnitude depending primarily on the steepness of the land. The erodibility of the soil is medium and similar across the study area.

A small percentage of the land has been assigned a lower risk of erosion, due to improved cover and soil conversion practice, for example the conversion of wheat and barley to orchards. However, further conversion of natural land to agricultural production (20% of area) largely results in a much severer level of soil erosion risk.

The natural land that remains is grazed by sheep and goats with a range of intensities, over the different land cover classes, with the mean impact on all cover classes a 1.5 times increase above sustainable levels. This is a potentially critical level of human activity. However, local grazing intensities are important to soil erosion, especially where cover is sparse and the slope is steep. The grazing intensity is sustainable in about 25% of the total area in 2008, but it is calculated that about 20% of the region (or 47% of the natural area that is left) has a soil erosion risk above a moderate level.

9.5 Conclusions

This research has defined both temporal and spatial deterioration in the land cover of the Al-jabal Alakhdar region, using remote sensing and GIS mapping and culminating in land use maps for both 1984 and improved 2008, with the accuracy of the latter corresponding almost perfectly to field assessment of the land cover. Whilst there has been little change in urbanization, during this time period, in order of priority, an approximate twofold increase occurred in the areas of rain-fed barley and wheat crops, irrigated land and bare soil. This was primarily at the expense of a reduction by just over a quarter of dense vegetated cover, which initially covered nearly three-quarters of the land area. The relative importance of this reduction in vegetation cover for land degradation is influenced by other factors integrated with land topography, soil characteristics, climate, and land management. This was achieved by application of the Universal Soil Loss Equation within GIS, allowing the spatial variation and the temporal change in the magnitude and extent of the risk of land degradation to be determined, with the resulting maps being independently verified. The accuracy of the validation process demonstrates that an accurate and repeatable methodology has been adopted here, particularly the contribution of incorporating overgrazing intensity indicator into the conservation practice factor in the USLE equation.

Soil erosion rates classified as High or above occurred in about half of the study area at the end of the time period, compared to a quarter at the start. The impact of a decrease in land cover density and an increase in the intensity of human activity, as dense natural vegetation is replaced by wheat and barley crops, varies within the study area, primarily because of the spatial variation of topographic steepness and drainage path length, and to a lesser extent because of soil erodibility. Thus, although widespread cereal farming is now undertaken in the north-west, its impact is relatively minor, owing to the flat nature of the land, whereas the same change in land use has a Severe or Very Severe impact on the risk of land degradation in the southern region, due to the steepness of the land (LS value > 0.7). Overgrazing is of primary importance to degradation of the natural rangeland.

Previous studies of the region (e.g. Zaed et al. 2005; Ben-Mahmoud 1995; Selkhozpromexport1980) were able to establish the spatial variation of a number of relevant variables important to land degradation, but were not able to integrate these variables comprehensively to prove the nature of land degradation in the study area.

This work has quantified the rate and extent of land degradation in the semi-arid climate of the mountainous region of north-east Libya. It demonstrates the importance of quantifying the risk of land degradation, which could be used to manage land cover changes more successfully, in order to avoid the dramatic land degradation that has been observed.

CHAPTER 10

CONCLUSIONS

AND

RECOMMENDATIONS FOR FURTHER WORK

10.1 Conclusions

This extensive research has obtained detailed information about the study area in the Green Mountain region, particularly on its vegetation cover and soil. The study revealed that the vegetation cover is fragile, exposed to deterioration, and sensitive to desertification, for many reasons, the most important one being human activity.

The land area examined in this study was believed to be under the threat of serious and continuous damage, but this threat had not been quantified thoroughly or addressed in any coherent way by any previous study. Many local studies of the Al-jabal Alakhdar region aimed to describe soil degradation and land cover, but they did not describe the degradation problem in sufficient detail to allow the causes and processes and their spatial variation to be understood. This has hampered attempts at appropriate land management. This study addresses these deficiencies.

Here, remote sensing techniques were used to classify four (Landsat) satellite images for 1984, 1992, 2000, and 2008. These highlighted the temporal changes of land cover, helping to assess overall desertification trends. Dramatic changes in land cover type were detected between 1984 and 2008, for example 16.3% and 6.5% increases in rain-fed crops and bare soil were observed, together with reductions in forest and shrub areas of about 26% and 2.5% respectively.

In order to understand the degradation and desertification and ultimately promote better land management, two theoretical models, MEDALUS and USLE, were selected and successfully applied to the study area using GIS. They have been chosen due to their suitability for their application at small scales and are sufficiently sensitive to indicate ranges in the risk of degradation and desertification.

A primary requirement to enable application of the models was the creation of a base map of land use / land cover, accurately verified through ground-truthing in 850 locations. Comprehensive paper based information on soil characteristics have been sourced from earlier studies and incorporated into GIS, whilst important topographic data has been digitised from paper maps to enable evaluation of land gradient and orientation. Climatic data has been obtained from a nearby weather station.

The model outputs were compared with field assessment of the risk of desertification and land degradation by water erosion by a team of scientific experts assembled at 370 randomly selected locations within the study area. This process identified that for the MEDALUS model, the impact of human activity in natural areas, which was observed to be primarily from the grazing of sheep and goats, required improvement. Consideration of the policy indicator was set aside as the existing conceptual framework is not appropriate where common grazing rights are available in the natural rangeland.

The methodology used to establish grazing intensity in pastures has been developed for application in natural rangeland with varying percentages of cover of woody plants. An index of environmental damage from grazing was developed for this work and applied at 90 locations. The best correlation of this index with grazing intensity (the ratio of actual to sustainable stocking rates after adjustment following any additional forage supplied to the stock) occurred when a proposed palatability index of local plants was incorporated into calculation of the sustainable stocking rate. Distributions of actual stocking rates were obtained from comprehensive survey of all 6,490 shepherds within the study area to establish flock sizes and size of grazing areas. An estimate of the management quality index was obtained from MEDALUS data and focus group estimation of desertification and correlated with grazing intensity. The very good agreement obtained allowed the impact of human activity from grazing in natural rangeland to be confidently predicted from measurements of actual and sustainable stocking rates. As data was collected over a full range of cover classes, this methodology should be generally transferable to other regions. In the absence of data on grazing intensity, the index of environmental damage from grazing can be used to determine the management quality index.

The quality of the relationship of grazing intensity with desertification encouraged the same procedure to be applied to the USLE model, where previously a constant value across the natural areas had been advocated by other research. After calibration of the model was improved with recently published cover factors, new soil conservation practice factors P were calculated from grazing intensities, which varies spatially across the study area.

The improved theoretical models were verified independently using 280 random points in the study area and excellent agreement obtained for the 2008 maps. As the USLE model identifies the risk of water erosion, the model was also verified against an independent map of water erosion from 1980 and excellent agreement obtained.

Comparison of the two model maps from 1984 and 2008 has allowed the causes of the temporal change in soil erosion risk to be identified. This showed that the dense natural cover subjected to sustainable levels of grazing protected the soil from erosion. Land use change to fields of barley has resulted in a more intensive use of the land and reduced the level cover. This has caused much higher risk erosion, particularly where the slope of the land is steep. Conversion to orchards is less damaging as there is more cover to the soil and soil conservation practices can be more protective of the soil. An increase in the intensity of grazing is demonstrated which also increases soil erosion risk.

10.2 Contribution to science

This research has made the following contribution to science:

- An extensive and comprehensive GIS-based, independently verified, reference database on topography, soil, vegetation and agricultural activities was created. This may be used for future regional studies.

- This was the first regional application of change detection, USLE and MEDALUS methodologies, and the first comparison of USLE and MEDALUS theoretical models in a semi-arid climate. The causes of temporal and spatial changes in land degradation have been identified.

- The development and successful widespread application of assessment by focus groups of land degradation, desertification and environmental damage by grazing.

- The study identified the relationship between grazing intensity and the MEDALUS management quality index and for the USLE soil conservation practice too. This has not been accomplished before. This outcome was achieved for the full range of vegetation cover for open rangeland in semi-arid areas.

- The study identified the extent and severity of land degradation and desertification in the Green Mountain and identified that the development and application of pertinent policies for sustainable land management are necessary.

10.3 Recommendations for further work

The theoretical models are realistic representation of land degradation or desertification in the study area, as verification of the models is almost perfect. Therefore, there seems little need for extensive further development. However, investigation of the following aspects could be addressed: a single climate monitoring station outside study area is potentially a limitation and could be improved by recording stations located throughout the study area, particularly in the south of the green mountain region where it is likely to be more arid and have less rainfall than in the north. This issue could be resolved by a separate investigation and the sensitivity of this data to the outputs of the existing theoretical models assessed.

The relationship between AASR/SSR3 for different cover types is very good, but is based on only one year of dry biomass calculations, which should ideally be increased to annual growth from at least three and preferably seven years. This is because the quantity of biomass is of course dependent on growing conditions for the preceding year for example rainfall intensities, frequencies and time of occurrence in relation to plant growth. In addition, the influence of plant palatability to sheep and goats is appropriately based at present on the opinions of shepherds and local experts. This factor could be investigated further by controlled grazing experiments in the field. This could also investigate the temporal relationship between grazing intensity and loss of cover.

The index of environmental damage from grazing has been shown to be a potentially rapid and accurate method of assessment of the impact of human activities in natural areas. At present, this index requires conversion to an equivalent MEDALUS or USLE quantity. It would be useful to test and recalibrate the assessment methodology to give a direct value of the management quality index of conservation practice factor from a field assessment of environmental damage from grazing.

The USLE does not require government policies to determine the risk of desertification, but this factor has been deemed to be important for MEDALUS. In this research, policies and their implementation have been applied in the agricultural areas, but removed from evaluation of human activities in natural areas. It is believed that this research has demonstrated that the impact of human activity on the natural environment for both USLE and MEDALUS can be successfully achieved by consideration of grazing intensity alone. However a systematic study and evaluation of possible policies and their relative degree of application may allow possible inclusion of the aspect for natural areas and a return to the original philosophy for the management quality index.

The field verification of the theoretical models by focus group assessment of the land is robust. This is particularly appropriate for MEDALUS. However, it is recognised that the definition of the risk of land degradation using USLE is the quantity of soil lost per annum. Though potentially a complex process, it would be interesting to investigate whether the soil loss in natural areas subjected to various grazing intensities could be measured.

It is has been demonstrated that either the USLE or the MEDALUS model is now realistic representation of the study area, and so it should be a straight forward, if time consuming a process, to extend the model to the remainder of the Green Mountain region, if desired. As has been indicated for the study area, the purpose of doing so would be to develop an understanding of the local environment to develop sustainable land management practices that can reduce land degradation or desertification.

Application of sustainable land management requires the engagement, collaboration and partnership of land users, technical experts and policy-makers to ensure that the causes of the degradation and corrective measures such as afforestation are properly identified. This would certainly involve education of land users and politicians to raise environmental awareness and in particular to inform them about the dangers of over intensive land use such as over grazing or the loss of natural areas to agriculture. Policies and the overall regulatory environment need to be properly developed to enable adoption of the most appropriate management measures, to obtain the benefit of land preservation through appropriate planning and funding. Development of this area of work is particularly important if the Green Mountain or Al-jabal Alakhdar region is to be enjoyed by future generations.

Consequently, an appropriate methodology is needed to provide a standardised approach for documentation, evaluation and monitoring of sustainable land use management practices, to create a local network and platform for sharing sustainable land use management knowledge, to assist people in their search for appropriate sustainable land use management approaches and to support people in making decisions in the field and at the planning level. The MEDALUS model is more able to explore such aspects. The principal mechanism by which an improvement of land quality could be achieved is the development of sustainable management.

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12 Appendix

12.1 Field work

The first field survey was carried out in the study area; mainly in Marawah, Gandolla, Omar Al-Mukhtar, Al Bayyadah, Al Awylia and Taknis. This field work has studied all aspects of the problem in the study area that relevant to this research. The questionnaire's questions have been prepared to help this research to discover the main reasons that have led to land degradation and changes in the vegetation cover in this area, as well as laying some emphasis on several important points to develop policies and sustainable management in order to control and reduce future vegetation loss and land degradation.

Steps are being taken to recover land from destruction, the government and the public need to know where, when, how fast, and why (with what causes) such changes occurred. On the basis of such knowledge, a general and sustainable management of these resources may be possible.

Researcher visited the study area in order to identify land units and check land cover classes, which have been derived from the supervised classification map, Land use map, MEDALUS and USLE. The sample transects were selected as near as possible to contain the representative facet of the land unit by using GPS to define land characteristics, land qualities and their threshold values. Land cover map of 2008 produced from Landsat ETM+ data. A total of 850 pixels were selected randomly for the 2008 land cover map. The result pointed to an overall classification accuracy of around.

It was necessary to visit the study area to first confirm the accuracy of the land cover map and then to identify these new land use classes. A total of 850 locations were selected by stratified random sampling for quality control purposes.

The study area was visited two time by two FG, the first visit was from 15 July to 20 October 2010 with (experimenter for MQI), during the field work 370 plots have been visited with number of experimenter to estimate land use intensity. Second field visit was from 22 July to 28 September 2010 for the accuracy for both MEDALUS and USLE maps is computed by dividing the total correct classification (sum of the major diagonal) by the total number of 370 pixels in the error matrix. The geographical location of each point was visited with a panel of academic experts, policy makers and agricultural engineers.

Data elaborating and final land unit map, all the data collected during the field survey were used to create a database and to integrate the overall accuracy, and a KAPPA analysis was used to perform classification accuracy derived from error matrix analysis and correct the preliminary legend and land map. In addition, some photos were taken into account for describing land cover data in the study area.

Interview: This study aims to identify the roots of degradation by using questionnaires distributed to local experts and some policy makers. This questionnaire, which contained questions about the land degradation in the study area, was answered by local experts and officials of the agricultural project in Libya. I have contacted a group of ten people to take part in a focus group interview. Preparation for the interviewees before sending the questionnaire included stating clearly the reasons for the interview and the areas of discussion and providing a general interview plan. The interviews started after I had obtained their permission and their agreement to allow the use of their responses, experiences or information to support my research. The interview and field trip set the framework of the causes of land degradation in the study area. This step specifically looked at some analysis and evidence to investigate in depth the factors that led to land degradation. This specific phenomenon of land degradation is being investigated in one specific region. So, this study has investigated in depth the land degradation policies and strategies in a specific area (Al-jabal Alakhdar) as a case study.

Identifying the researcher

- Mohammed, Ali (Lecturer in Faculty of Natural Resources and Environmental Science-Al Bayda-Libya, school of Forestry and Natural Resources that he achieved from University of Leeds , England UK in 1999 as PhD degree);
- Mostafa, Omar (Lecturer in Faculty of Natural Resources and Environmental Science-Al Bayda-Libya, school of Forestry and Natural Resources that he achieved from University of Newcastle , England UK in 2001 as PhD degree);

- Albady, Khalid (Lecturer in Faculty of Natural Resources and Environmental Science-Al Bayda-Libya, school of Forestry and Natural Resources that he achieved from University of Cairo , Egypt in 2005 as PhD degree);

Identifying the focus group experts

- Prof. Eldommi, Fowzy (Secretary of local authority of agriculture-Al Bayda-Libya, his subject is soil and water that he achieved from Oklahoma university USA in 1984 as PhD degree);

- Prof. Assaadi, Omar (the head of Natural Resources and Environmental Science Faculty Al Bayda-Libya, school of Forestry and Natural Resources that he achieved from Colorado State university USA in 1984 as PhD degree);

- Prof. Yagoub , Mohamed (Lecturer and expert in Faculty of Natural Resources and Environmental Science-Al Bayda-Libya, school of Forestry and Natural Resources that he achieved from Tucson-University of Arizona State university USA in 1984 as PhD degree);

- Prof. Al-Hendawi, Ramadan (Lecturer and expert in Faculty of Natural Resources and Environmental Science-Al Bayda-Libya, school of Forestry and Natural Resources that he achieved from University of Leeds , England UK in 1997 as PhD degree);

- Prof. Moomen, Saad (Lecturer and expert in Faculty of Natural Resources and Environmental Science-Al Bayda-Libya, school of Forestry and Natural Resources that he achieved from Colorado State university USA in 1984 as PhD degree);

- Prof. Bayoumi, M. A. (Lecturer and expert in Faculty of Natural Resources and Environmental Science-Al Bayda-Libya, his subject is soil and water that he achieved from that he achieved from Connecticut State university USA in 1986 as PhD degree);

The following contains the employees in the Libyan Natural Resource Project, Libya and they have more than 20 years' experience.

- Albargathy, Mohamed. BSc (the Advisor pastures, Secretariat of General People's Committee for Agriculture Libya his subject Department of Horticulture and Crop that he achieved from Alfateh University in 1970 as Agricultural Engineering.

- Alshalwee, Muftah. MSc (the head of the Libyan Natural Resource Project in the Eastern Region, Al Bayda, Libya);

- Amtoul, Omar. BSc (Secretary of the People's Committee for Agriculture and Livestock in the Al-jabal Alakhdar region, Al Bayda, Libya his subject Department of Horticulture and Crop that he achieved from Omar Al-Mukhtar University in 1986 as Agricultural Engineering);

- Abohawya, Salim. BSc (the head of the Office of Planning and Follow-up in the Libyan Natural Resource Project in the Eastern Region, Al Bayda, Libya his subject is Horticulture and agricultural crop that he achieved from Garyounis University in 1980 as Agricultural Engineering);

- Shabe, Saad. BSc (the head of the Libyan Natural Resource Project in the Al-jabal Alakhdar region, Al Bayda, Libya his subject is Forestry and Natural Resources that he achieved from Garyounis University in 1980 as Agricultural Engineering);

12.2 General description of vegetation and management in the study area

The Strawberry Tree is evergreen, about 2 to 5 metres tall, and generally widespread in the Mediterranean region, although in the study area it is found only between Omar Al-Mukhtar and Al Bayyadah (Pictures 12.2.1 and 12. 2.2).

Picture 12. 2.1. Strawberry Tree before flowering time

Picture 12 2. 2. Strawberry Tree flowers (white) and fruit (red and yellow)

The Carob tree (*Ceratonia siliqua*) shown in Pictures 12. 2. 3 and 12. 2. 4 is a species of flowering evergreen tree native to the Mediterranean region. It sometimes grows up to 15 metres high but is usually between 6 and 10 metres high, and it is widespread from Omar Al-Mukhtar to Al Bayyadah. The Carob tree grows well in warm temperate and subtropical areas, and tolerates hot and humid coastal areas, so it is well adapted to the ecological conditions of the Mediterranean region. These trees prefer well-drained loamy soil and are intolerant of water-logging, but the deep root systems can adapt to a wide variety of soil conditions.

Picture 12. 2. 3. Carob tree 8m tall, before flowering time

Picture 12. 2. 4. Carob tree with its flowers and 5-7cm pods that appear in red

The native and evergreen species in the study area are varying such as Lotus tree (*Zizyphus lotus*), Kermes Oak (*Quercus coccifera*), Golden Oak (*Quercus alnifolia*) and Holm Oak, Wild Olive, Mastic tree, Cyprus Terebinth tree, Desert Pistachio and lancet-leaved Phillyrea tree.

Imported trees grow in different parts of the study area, being dependent on previous government strategies that attempted to arrest the rate of deforestation through programmes such as afforestation and the protection of threatened species with the involvement of local farmers (Al-Zani 2002). Almost all the imported trees are evergreens such as Brutia pine (*Pinus brutia*), Aleppo pine (Pinus halepensis), Stone pine, Umbrella pine (*Pinus pinea*), Insignis pine (*Pinus radiate*), Canary Islands pine (*Pinus canariensis*), Arizona cypress (*Cupressus arizonica Greene*), Italian cypress (*Cupressus sempervirens*), Blue-leafed wattle (*Acacia cyanophylla*), Cyclops (*Acacia Cyclops*), Cassie flower (*Acacia farnesiana*), River red gum (*Eucalyptus camaldulensis Dehnh*), Tuart(*Eucalyptus gomphocephala*),Coral gum(*Eucalyptus torquata Luehmann*), Yellow Gum (*Eucalyptus leucoxylon)* and Blue Gum *(Eucalyptus tereticornis).*The most widespread species in the study area are Eucalyptus trees as in (Pictures 12. 2. 5 and 12. 2.6).

Picture 12. 2.5. Yellow Gum tree and its pink flowers that start early in May and flower until the end of June

Picture 12. 2. 6. Blue Gum tree and its white flowers that start at the end of August and flower until the end of October

The study area has many different types of shrubs that are evergreen and native to the Mediterranean region, such as Common Rosemary (*Rosmarinus officinalis*) (Pictures 12. 2. 7 and 12. 2. 8), which grows from 50 centimetres to 2 metres tall. The Common Horehound grows up to 1 metre high, and is an evergreen plant native to the Mediterranean region. It has grey leaves, grows 20–40 cm tall and resembles mint in its appearance. It grows frequently in the shade around the trunk of any tree.

Picture 12. 2. 7. Common Horehound herb which is about 20–40 cm tall before flowering time

Picture 12. 2. 8. Common Horehound herb and its white flowers between June and September

Buckthorn (*Rhamnus*) grows from 50 centimetres to 2 metres high. Zoreka (*Globularia alypum*) grows from 50 centimetres to 1.5 metres. Three-lobed Sage is widespread in the study area and is about 1 metre tall. Rock Rose (*Cistus*) grows to about 80 centimetres to 1.2 metres in height. Jerusalem Sage, Phlomis, is a short evergreen plant that grows up to 60 centimetres. The previously described shrubs grow in almost all of the study area except Marawah and Almishal. The following types of shrubs grow in abundance in Marawah, Almishal and south of Omar Al-Mukhtar: Burnet is a thistly plant which represents about 20% to 30% of the study area shrubs and can reach 75 centimetres in height; Santonica Wormseed grows up to 60 centimetres tall and is an evergreen plant; Caper (*Capparis spinosa var*) is an evergreen plant and native to the Mediterranean region; Haloxylon (*Haloxylon articulatum*) is an evergreen plant and ranges between 30 to 75 centimetres high.

Thyme (Thyme) is a very short plant and does not exceed 40 centimetres in height. Thyme is one of the dominant plants on dry rocky slopes (Pictures 12. 2. 9 and 12. 2.10). Its rounded shape acts to reduce the loss of water to a minimum, which allows it to survive long periods of drought.

Picture 12. 2. 11. Thyme before the flowering period

Picture 12. 2. 12. Thyme with its purple flowers beginning in the last week of May and ending in the last week of June or the first week of July

Annual herbs are present in most parts of the study area. They grow in a number of different circumstances, such as around tree trunks, under shrubs and mixed with different plants in pastures, they protect the soil from erosion. Most of the annual herbs grow on calcareous soil. Growth starts in September, the flowering period is from February to April and the plant dies in May. The annual herbs include the following: Sea Onion (*Urginea maritime*), Drias (*Thapsia garganica*), Genus Micromeria (*Micromeria*), Calamin (*Calamintha*), Echinops (*Echinops*), Asteraceae (*Tolpis virgata*) and Fabaceae (*Ononis pusilla*). ThePyrenean Thistle is an annual type of prickly thorn which grows extensively in the study area. Its flowering time is limited, beginning in the middle of March, and continuing until the middle of April. By mid-April, the buds will have opened into purple thistle blossoms (Picture 12. 2.13). After the flowering season, the plants quickly wither and die (Picture 12. 2.14).

Picture 12. 2.13. Pyrenean Thistle during the flowering period (mid-March until mid-April)

Picture 12. 2.14. Pyrenean Thistle after the flowering period

During the field study, the area of the study includes different types of ever green trees and plants such as Strawberry Tree, Phoenician juniper, *Pistaicia atlantica, Pistaicia lentiscus* and *Ceartonia siliqua*. Also, this rich area has some other aromatic plants, herbs and species such as Santonica Wormseed, Thyme and *Rosemarinus officinalis*. These natural treasures, that the natural forests represent one of their important circles, are threatened by extermination owing to many reasons. This might cause problems for the environmental balance that characterizes the region of the Al-jabal Alakhdar in general. Worry and concern about this area have been emphasized by severe soil erosion, which is caused by superficial waters throughout the rainy months of the year. Features of degradation have extended throughout the huge areas of deserted lands surrounding the region of Marawah from both the eastern and southern sides. Also, such degradation features have displayed themselves in all directions alongside Almarj-Salantah motorway with the exemption of some small areas that are orchards which limited production were established and some small parts that cultivated with barley farms. As for the hillsides in such areas, they are at the moment coverless of any vegetation and such characters have continued to be present until the thresholds of Gandolla. For the reason that these areas are identified by high rain levels which are ranging between 450-550 mm every year and are also recognized by very reasonable and moderate temperatures all over the year. This would make us believe that the vanishing of the natural botanical cover, i.e. vegetation, is basically due to unguided and harmful human activities symbolized by the total removal of such vegetation and the unfair and unreasonable grazing which had lasted for long periods of times.

The provinces between Marawah and Gandolla are specified by the obstructive dams, constructed by the Libyan authorities for reducing the effect of superficial water sloping and strongly flowing from hillsides or other areas, which helped in preserving great amount of soil and prevented its erosion. This water then was accumulated in the soil in reasonable amounts and allowed the growing of some orchards such as grapes, fug and barley. As for the area extending from Omar Al-Mukhtar until Salantah alongside the main road, manifestations of the desertification and the existence of some types of thistle (thorny plants) such as Burnet and others of low grazing value are very obvious. The same was seen also in the lands of the eastern side of Gandolla in the direction of the region of Marawah which was vacant of any vegetation with the exclusion of some scattered bushes here. Moreover, there from *Cynara carduncolus, Zizyphus lotus,* Santonica Wormseed, Common Horehound, *Haloxylon articulatum*

(Cav.) *Bunge, Capparis spinosa* var. *rupestris* (Sibth. and Sm) *Viv* and *Rhamnus*. The existence of such plants in this area, even in small numbers, indicates the acclimatization to the current environment despite the increase in the average temperature and the exposure to the upper winds, during the summer months, which represent relatively harsh climate compared with the growth of the same ever green plants in other locations in the northern region to the place of study. In this area, there is a heavy presence of sheep and goats herds, even though the general manifestations of this area indicate dreadful grazing capabilities.

The desertification process continued in the vast lands southern of Marawah excluding very small locations, where there is wide spread of different kinds of plants such as Phoenician juniper, *Zizyphus lotus* and *Rhus tripartite* which are concentrated in the lower parts of stream valleys. The hills to the northern side of Gandolla and for the distance of three kilometres to its west, is semi-covered with the vegetation and then the bushes of Phoenician juniper and Mastic tree would appear covering the hills with an increase in density to the north and west until the valley of Wadi Al-Hmarh, which has very intense vegetation including Phoenician juniper, *Cedrus atlanica 'Manetti'*, *Olea europaea*, Mastic tree, *Ceartonia siliqua, Phillyrea media*, Strawberry Tree and *Pistaicia atlantica* in addition to the bushes of *Globularia alypum*.

Picture 12. 2. 15. Illustrate the Juniperus covered more than 80 % which located in north of Gandolla. X (535754), Y (3602108).

Picture 12. 2. 16. Roman dams located in north of Gandolla. X (554114), Y (3604958).

The Phoenician juniper trees are widely and very clearly spread in this location especially in the hillsides (Picture 12. 2. 15). In this area, the role that was played by the old Roman dams is very clearly manifested in protecting the soil and preventing it from the effect of erosion (Picture 12. 2. 16). The vegetation is very dense on the hills extending to the distance of thirteen km the south western of the Wadi Al-Hmarh after which, the signs of extensive spread fires that extended for a few kilometres appear very noticeably (Picture 12. 2. 17). The water erosion is evident in some areas north of the Wadi Al-Hmarh as shown in Picture 12. 2. 18.

Picture 12. 2. 17. Water erosion in north of Wadi Al-Hmarh. X (553214), Y (3606578)

Picture 12. 2. 18. Extensive fires that extended for a few km^2 in south western of the Wadi Al-Hmarh. X (550094), Y (43607958)

Vegetation cover in Al Bayyadah and south of Taknis include many types of trees and the most widespread are Phoenician juniper, Pistaicia *atlantica, Pistaicia lentiscus, Phillyrea media*, *Globularia alypum*, *Ceartonia siliqua* and *Olea europaea.* South, East and west of Al Bayyadah vegetation cover faced deterioration in some parts during the agricultural revolution in 1980s and such damages features still obvious in these parts. As in the eastern side of the Wadi Al-Hmarh the vegetation starts to decrease in density until it nearly vanishes or about to vanish in the Omar Al-Mukhtar's region. On the other hand, the lands located to the south of Almishal were empty and un-vegetated and this depressing sign included hills and landscapes. Moreover, the exploitation of such huge areas is limited to very weak growing and unplanned farming of the crop of barley. The signs of the soil deterioration have widened to include the extermination of the vegetation on the lands situated in south Almishal to south Marawah, despite the fact that the annual rainfall in that area in particular is enough to sustain the growth of good vegetation. The role that was played by man in the complete removal and extermination of the vegetation in order to face the challenges of life in previous years is, perhaps, the main reason behind the transformation of such vast areas and lands into infertile lands (Pictures 12. 2. 19 and 12. 2. 20).

Picture 12. 2. 19. Bare soil located West of Marawah. X (541754), Y (3594848)

Picture 12. 2. 20. Bare soil located West of Marawah. X (537344), Y (3594428)

Furthermore, the natural botanical coverlet in the area surrounding Almishal is represented in the presence of some spices such as *Thymus capitatus*, Santonica Wormseed, Burnet, *Cynara cardunculus*, *Zizyphus lotus, Capparis spinosa* var. *rupestris*, *Viv* and *Marrubium volgare.* It is worth mentioning that the trees of juniper were scattered as shown in Pictures 12. 2. 21and 12. 2. 22.

Picture 12. 2. 21. *Juniperus* covered less than 10% located in South of Almishal. X (563684), Y (3599108)

Picture 12. 2. 22. Scattered *Juniperus* trees. Located in East of Almishal. X (563444), Y (3598748)

The vegetation does not clearly appear up until the Al Mkaymn area which is piece of Gandolla where there is a thick presence of the trees of juniper (Picture 12. 2. 23) and in the southern side the plants start to decrease gradually until it reaches the stage as shown in Picture 12. 2. 24. In the Hallok Al-Jir and Qasar Al-Mjahir are parts of Gandolla where the main composition of the vegetation are *Zizyphus lotus* particularly in the hubs of the valleys, *Marrubium volgare, Capparis spinosa* var. *rupestris*, Santonica Wormseed, *Rhamnus*, some scattered of Phoenician juniper trees and some other trees spotted and there towards the west until Al-Karm and Khlutiah located in part of Marawah.

Picture 12. 2. 23. *Juniperus* trees with annual grasses in Al Mkaymn area. X (560624), Y (3595898).

Picture 12. 2. 24. *Juniperus* in southern side of Al Mkaymn area. X (560084), Y (3595508).

During the fieldwork, it is obvious that the role of man, in the vegetation's extermination and I believe that there is the most significant and negative one in the area of the study. The lands that were covered with such vegetation in the area of Gandolla are not appeared from such negative human practices and destructive habits even though the soil in this area is considered very deep and has very unique natural characteristics and very good level of productivity. This has caused people to destroy the natural green cover and instead they started the farming of fruits and vegetables and some seasonal yields. After the destruction has been carried out, it is expected that such destructive activities will intensify following the fencing of vast areas as a preparatory procedure to wipe out the natural green cover and farming it straight away. The conditions of this area such as the good soil, moderate climate have participated in the uniqueness of its plants in terms of density, greenness, the incredible growing of plant life, its types which has reached to its best conditions on the hills and hillsides that surrounding the area of Gandolla. In my submission, the strongest competitor to the direct human destructive role is the manifestation of fires whether deliberate or otherwise. The final outcome of such fires is long-lasting loss of our country's natural recourses that cannot be retained in short period of time. Such signs have become much more observable alongside to the way to Madour Al-Zytoun which locates in West of Marawah to Marawah where there was no vegetation seen in that area. Also, hills and wavy lands located East of Marawah are vegetation-less area excluding very small areas on which trees of *Pinus* have been farmed, during the general campaigns of tree-planting, more than a decade ago. Such *Pinus* trees look in a good condition which requires the immediate evaluation of these trees and the urgent development of such projects based on pre-studied and planned programs and strategies.

The results of this study have emphasized that the basic resources of the natural lands in the southern part of the Al-jabal Alakhdar are of very low quality and standard due to the worsening in its plant cover. Moreover, the area has witnessed the extinction of a number of annual plants and the evergreen short bushes or in some cases the decrease in such plants and in their vitality have been observed. In addition, the spread and multiplication of some other plants of very low economic value has been documented. The decline in the soil characteristics after the removal of the lifelong trees especially in the area of high downward slopes and the removal of floodgate and old levees used for obstacle purposes, which identify the forests and bushes regions in the Al-jabal Alakhdar, has resulted in encouraging other destructive processes such us the soil washout and the loss of its fertility. Also, the deliberate and planed fires, which have become very customary, are considered the most obvious physical exhibition to the negative role played by man against nature and the ecosystem. This deliberate destruction of our natural resources was associated with the extinction of the trees of Phoenician juniper.

Even though with existence of agricultural regulations; local residents performed illegal activity at the expense of land cover, which means inadequate actions in the policies enforcement. For example deforestation for household uses is a common activity in the study area as shown in Pictures 12. 2. 25 and 12. 2. 26. This action is illegal, irrespective of whether it is performed by the owner or a passer-by. In Picture 12. 2. 25, about seven *Phoenician juniper* trees have been cut down in an area approximately 10 km from the road, out of sight of the relevant authorities. The current penalty for illegal felling is based on tree type and age and amounts to 220 Libyan dinars per tree (e.g. *Phoenician juniper*). This penalty is distributed as follows: 125 Libyan dinars represent the cost of the *Phoenician juniper* tree, 50% of the tree cost is added for illegal cutting, and 25% of the tree cost is added because the tree is classified as natural vegetation. The sale of wood in the local market is not illegal as people are allowed to collect, use or sell dead wood (Picture 12. 2. 26).

Picture 12. 2. 25. Small scale deforestation of *Phoenician juniper* for domestic household use (open fires, ovens, space heating) in Gandolla (09/2010).(X: 548221, Y: 3601420)

Picture 12. 2. 26.Transport of pine (raw material for utensils, furniture) for sale at a local market in Gandolla (09/2010)

Illegal making of charcoal is another cause of depletion of vegetation cover, resulting in land degradation. About 20 *Phoenician juniper* trees, as shown in Picture 12. 2. 27, have been cut for illegal charcoal making. This incurs a fine of about 4,400 Libyan dinars. This illegal human activity is continuing, particularly among vegetation out of sight of the agricultural police and roads: this site is approximately 7 km from the road, out of sight of any authority. Picture 12. 2. 28 shows that there are about 12 sacks of charcoal made from *Phoenician juniper* trees; each *Phoenician juniper* sack costs 10 Libyan dinars and each sack needs 3 Phoenician juniper trees. These sacks, which are commonly used in Libya, are measured by volume; each sack is about 30 cm wide and 100 cm long. So in Picture 12. 2. 25 about 36 *Phoenician juniper* trees have been used. If the culprits are found, the agricultural police would present the penalty of 7,920 Libyan dinars; the illegal manufacture of this charcoal will gain 120 Libyan dinars for 12 charcoal sacks after three days' work. The protection of vegetation cover by the agricultural police has failed through irresponsibility in applying and presenting the penalties, regulations and laws, and because they do not have enough equipment to perform their job properly. Land protection policies and laws are applied to incorporate some of the targeted voluntary policies under an advanced environmental scheme of stewardship; this is obtained through compulsory compliance with the regulations and by imposing high costs on illegal deforestation.

Picture 12. 2. 27. Station for gathering wood for use as charcoal in Omar Al Mukhtar (08/2010). X (547193), Y (3601489)

Picture 12. 2. 28. Charcoal sacks used in Gandolla (09/2010). X (554389), Y (3600735)

The impacts of industrial activities in the study area are not significant because the main activities in this area are agriculture and grazing (Zaed et al. 2005). There are only five hollow concrete block factories in the whole of the study area, one of them in Gandolla as shown in Picture 2.33. However, land protection laws in the study area must be applied in order to prevent the spreading of such activities. In Picture 12. 2. 29, the hollow concrete block factory was set up on irrigated land in Gandolla and is now considered as an illegal factory; also, the crusher machine resulted in an increase in environmental pollution through aggregate grinding and crushing which led to the soil and vegetation being covered with dust. Many residents and land owners have low educational levels and have no understanding of the risks of desertification of the land, as well as the economic constraints on large families who supplement their income by illegal use of the natural resources of land. The Ministry of Agriculture has started to apply laws and regulations, and one of these decisions, issued in 2006, is to stop all crusher machines working in the Al-jabal Alakhdar region; Picture 12. 2. 30 shows a stopped quarry located in Al Bayyadah, after the new regulation was enforced. Such regulations mean that the managers of agriculture are now starting to take positive steps to protect the environment from human damage.

Picture 12. 2. 29. Hollow block factory in Gandolla (08/2010). (X: 553490, Y: 3599825)

Picture 12. 2. 30. Quarry impact in Al Bayyadah (08/2010).(X: 510219, Y: 3602004)

The Agricultural Research Center (2011) reported that in 2001 a project for vegetation cover development had started in the Al-jabal Alakhdar region. The main aims of this project are reforestation and creation of new plant cover in place of the damaged cover, watershed management of the water resources, and an attempt to implement some regulations for soil conservation.

Picture 12. 2. 31. Reforestation: new vegetation covers in Gandolla (08/2010). (X: 541165, Y: 3596859)

Picture 12. 2. 32. Reforestation: new vegetation cover in Marawah (08/2010). (X: 540953, Y: 3596848)

As appears in Picture 12. 2. 31 and 12. 2. 32, this project has covered about 800 hectares in Marawah and Gandolla with 545,000 trees during the nine years from 2001to 2010. Furthermore, another advantage obtained from this project is the natural re-growth of the Mastic tree and *Phoenician juniper* between the newly planted trees, due to the fencing and irrigating of the plants in this area, as appears in Picture 12. 2. 32.

Picture 12. 2. 33. Nursery germination areas for vegetation and their guardroom in Marawah (08/2010). (X: 535128,Y: 3594434)

Picture 12. 2. 34. Dams about 1-1.5 m wide, 1.5 m high and 200 m long, in Marawah (09/2010). (X: 544906, Y: 3594772)

Nursery germination areas for vegetation with guardrooms have also been set up, as shown in Picture 12. 2. 33. The size of each nursery germination area in Marawah is about three hectares, and its capacity is more than 500,000 plant seedlings; also, two guardrooms have been prepared in Marawah for the purpose of protecting the forestation land and nursery germination area from any damage that might occur, such as animals entering, destruction of the fencing and fire.

To reduce soil erosion by water, dams have been built across some wad is, as shown in Picture 12. 2. 34. During the last nine years, from 2002 to 2010, about 600 dams have been built in Omar Al-Mukhtar, Gandolla, Marawah, Taknis and Al Bayyadah; such dams aim to conserve farmland from water erosion and to keep the soil surface as it is. Another feature in this area is the artesian wells: there are four artesian wells in Marawah, one in Gandolla and two in Taknis.

Picture 12. 2. 35. Spreading of plant diseases in Gandolla (08/2010). (X: 552253, Y: 3601088)

Picture 12. 2. 36. Phoenician juniper diseases (mysterious yellow or silver growth) in Taknis (08/2010)

Plant diseases are spreading in the study area, as shown in Pictures 12. 2. 37 and 12. 2. 38. For example, in Gandolla, as Picture 12. 2. 34 shows, several plant diseases have affected Strawberry Tree, *Phoenician juniper* and Lancet-leaved Phillyrea. In Taknis, as Picture 12. 2. 34 shows, *Phoenician juniper* trees have suffered from the diseases as well. However, the effects of these diseases do not have a great impact on the vegetation cover because they are not the main causes of vegetation degradation (Zaed et al. 2005). Much research is being undertaken by FAO, ACSAD, Oklahoma University and Omar Al-Mukhtar University with the participation of the Ministry of Agriculture to discover the reasons that lead to such diseases, classify these diseases, discover to what extent they might affect the vegetation cover, and find suitable cures for them.

12.3 Penalty costs for actual plants, forest, shrubs and pasture grass

The General People's Committee for Agriculture issued penalty costs in 21/4/1998 in relation to compensation for forest and pastures which face damage or complete removal. The following tables illustrate compensation costs of in Libyan dinars based on plant type, age, whether plants are growing naturally or not, time of deforestation or removal and type of damage.

Penalty type	Percentage increase of plant cost
If the plants are growing naturally	25 %
If the plants are damaged during its flowering time	10 %
If the plants are damaged during fruits growing season	20 %
If the plants deterioration is by damage that is classified as against laws and regulations	50 %
If the removal of plants is caused by agricultural terraces or roads or houses.	20 %

Table 12.3.1. Percentage that added to actual plants cost (Ministry of Agriculture of Libya 2011).

Table 12. 3. 2 shows a selection of penalty costs by Libyan dinars for some important forest and shrubs in Al-jabal Alakhdar region that established in 1998. It includes tree type and age.

Plant's name	Age of plants (year)							
	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71+
	Penalty costs by Libyan dinars							
Cupressus arizonica Greene	35	65	85	125	145	165	175	200
Juniperus phoenicea	40	80	120	160	200	240	280	320
Acacia cyanophylla Lindl	30	50	75					
Acacia cyclopa A.Cunn.ex.G.Don	30	60	90	120	140	160		
Ceratonia siliqua	35	70	105	140	175	210	245	280
Pinus halepensis Mill	40	80	120	160	200	240	280	320
Pinus pinea	40	80	120	160	200	240	280	320
Pinus radiate D.Don	40	80	120	160	200	240	280	320
Eucalyptus spp	40	80	120	160	200	240	280	320
Phillyrea media	30	60	90	120	150	180	210	240
Quercus coccifera	30	60	90	120	150	180	210	240
Quercus ilex	30	60	90	120	150	180	210	240
Pistacia atlantica Desf	30	70	100	120	150	180	210	240
Pistacia lentiscus	30	70	100	120	150	180	210	240
Olea europaea var. oleaster (Hoffm.& Link) DC	35	70	105	140	175	210	245	280
Thymus capitatus Hoffm. & Link	10	20	30	40	50			
Artemisia herba-alba Asso	10	15	20	25	30			

Table 12. 3. 2. Penalty costs for forest and shrubs (Ministry of Agriculture of Libya 2011).

Table 12.3.3 shows the penalty costs in Libyan dinars for pasture grass, based on plant type and density of growth per hectare issued in 1998. Density of pastures grass determining as following: pasture that covered with less than 50% of grass considered as lack density, medium density is greater than 50% and less than 80% and the high density is greater than 80%.

Plants Type Measure unit		Intensity (cover %)		
		Low <50%	Medium 50-75%	High >80%
		Penalty cost by Libyan dinars		
Natural pasture grass	hectare	60	100	125
Artificial (fake) pasture grass	hectare	160	225	325

Table 12. 3. 3. Penalty costs for pasture grass (Ministry of Agriculture, Libya 2011).

However, there are no regulations or laws to protect the natural vegetation and the soil from livestock over population and the intensive overgrazing pressure. Furthermore, the government did not allocate laws for grazing organization; such as, grazing season, duration or a pasture's capacity. The actual problem is that these laws and regulations are not applied at all or applied weakly.