THE UNIVERSITY OF HULL

An Assessment of the Relationships Between the Surface Soil Properties and Components of Slope and Vegetation in the Upper Wadi Bishah Basin, Saudi Arabia

Being a Thesis Submitted for the Degree of Doctor of Philosophy in the University of Hull

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TABLE OF CONTENTS

Acknowledgments i
Table of Contents ii
List of Tables vi
List of Figures ix
List of Plates x
Abstract xi

CHAPTER ONE
<u>Introduction to the Study and Environmental Conditions of the Research Area</u>

1-1 Introduction to the Study 2
1-1-1 Problem of the Research 2
1-1-2 Aims and Purposes of the Research 3
1-1-3 The Significance of the Research 5
1-1-4 Research Management and Plan 5
1-1-5 Organization of the Thesis 6
1-2 Environmental Condition of the Research Area 7
1-2-1 Geographical Location 8
1-2-2 Geological Structure 9
1-2-3 Geomorphology and Drainage System 13
1-2-4 Slope Configurations 18
1-2-5 Climatic Features 20
1-2-5-1 Meteorological Stations 22
1-2-5-2 Solar Radiation 25
1-2-5-3 Temperature 26
1-2-5-4 Rainfall and Relative Humidity 33
1-2-5-5 Evaporation 37
1-2-5-6 Atmospheric Pressure and Wind 39
1-2-6 Hydrological Matters 45

CHAPTER TWO
<u>Literature Review</u>

2-1 Introduction 50
2-2 General Literature on Geological Structure and Topographical Formations in the Research Area 50
2-3 Literature on Soil of the Research Area and its Surroundings 52
2-4 Literature on Vegetation and Grazing in the Research Area 60
2-5 General Literature Concerned with the Relationship Between Slope and Soil Properties 71
2-6 General Literature Concerned with the Relationship Between Vegetation and Soil Properties 80

CHAPTER THREE
<u>Methods of Research</u>

3-1 Introduction 87
3-2 Collection of Raw and Primary Data 88
3-3 Fieldwork and Data Collection 90
3-3-1 Field Surveys of the Research Area 90

3-3-2 Time of Sampling Collection 90
3-3-3 General Field Observations 91
3-4 Methods of Data Collection 91
3-4-1 Determination of Sampling Sites 93
3-5 Collection of Grazing Data 94
3-6 Measurement of Slope Factors 97
3-7 Measurement, Computing and Analysis of Vegetation Data 98
3-7-1 Basal Area 99
3-7-2 Crown Cover 99
3-7-3 Plant Height 100
3-7-4 Estimation of Vegetation Cover Size 100
3-7-5 Plant Identification Guides 101
3-7-6 Collection of Vegetation Samples 102
3-7-7 Quantitative Analysis of the Vegetation Data 102
3-8 Collection, Measurement and Analysis of Soil Samples 105
3-8-1 Sampling Tools 106
3-8-2 Measurement of Soil Depth (In the Field) 106
3-8-3 Preparation of Soil Samples in Laboratory 106
3-8-4 Laboratory Analysis of Soil Samples 106
3-8-4-1 Soil Texture 107
3-8-4-2 Soil Moisture 108
3-8-4-3 Organic Matter 108
3-8-4-4 Organic Carbon (OC) 109
3-8-4-5 Total Calcium Carbonate ($CaCO_3$) 109
3-8-4-6 Nitrogen Content (N) 110
3-8-4-7 Phosphorus Content (P) 110
3-8-4-8 Potassium Content (K) 111
3-8-4-9 Soil pH 112
3-8-4-10 Electrical Conductivity (EC) 112
3-8-5 Quantitative Analysis of Soil Data 113
3-9 Quantitative Analysis of the Relationship Between Soil Properties and Components of Slope and Vegetation 114

CHAPTER FOUR

Vegetation Cover and Grazing Influence

4-1 Introduction 116
4-2 Floristic Composition of the Research Area 125
4-3 Morphology of Vegetation 129
4-4 The Relationship Between Vegetation Components 133
4-5 Classification of Samples and Species 134
4-5-1 Classification of Samples 134
4-5-2 Classification of Species 143
4-6 The Relationship Between Species and Environmental Factors 146
4-7 Features of Subregional Plant Communities and Habitats 150
4-7-1 Mountainous Plant Community 152
4-7-2 Semi-Desert Plant Community 154
4-7-3 Toe-Slope Habitat Type 156
4-7-4 Foot-Slope Habitat Type 159

4-7-5 Mid-Slope Habitat Type 160
4-7-6 Shoulder Slope Habitat Type 162
4-7-7 Summit Slope Habitat Type 164
4-8 Grazing and its Influence on Vegetation and Soil 167
4-8-1 Grazing Zones 178
4-8-1-1 Grazing Status in the Mountainous Zone 169
4-8-1-2 Grazing Status in the Plateau Zone 170
4-8-2 Influence of Grazing on Vegetation and Soil 172
4-8-2-1 Influence of Grazing on Vegetation 175
4-8-2-2 Influence of Grazing on Soil 176
4-8-3 Overall Effects Deterioration of Grazing 178
4-9 Conclusions 179

CHAPTER FIVE

Soil Properties of the Research Area

5-1 Introduction 186
5-2 Background Information 187
5-3 Factors of Soil Formation in the Research Area 192
5-3-1 Parent Material Factor 194
5-3-2 Climate Factor 194
5-3-3 Relief Factor 195
5-3-4 The Biotic Factor 196
5-3-5 The Time Factor 197
5-4 The Relationships Between Soil Properties 197
5-5 Soil Properties 199
5-5-1 Morphological and Physical Properties 200
5-5-1-1 Soil Depth 200
5-5-1-2 Soil Texture 206
5-5-1-3 Soil Moisture 211
5-5-1-4 Organic Matter (OM) 213
5-5-2 Chemical Properties 214
5-5-2-1 Organic Carbon (OC) 214
5-5-2-2 Total Calcium Carbonate ($CaCO_3$) 218
5-5-2-3 Nitrogen Content (N) 219
5-5-2-4 Phosphorus Content (P) 221
5-5-2-5 Potassium Content (K) 222
5-5-2-6 Soil pH 224
5-5-2-7 Electrical Conductivity (EC) 225
5-6 Conclusions 226

CHAPTER SIX

Relationship Between Soil Properties and the Components of Slope and Vegetation

6-1 Introduction 231
6-2 The Relationship Between Soil and Slope 232
6-2-1 Soil Properties and Slope Angle 232
6-2-2 Soil Properties and Slope Gradient 235
6-2-3 Soil Properties and Slope Length 235
6-2-4 Soil Properties and Slope Form 236

6-3 The Relationship Between Soil and Vegetation 236
6-3-1 Soil Properties and Vegetation Cover Value 237
6-3-2 Soil Properties and Vegetation Density 239
6-4 Contribution of Slope and Vegetation to Variation of Soil Properties 240
6-4-1 Contribution of Slope and Vegetation Components to Variation of soil Depth 241
6-4-2 Contribution of Slope and Vegetation Components to Variation of Soil Moisture 242
6-4-3 Contribution of Slope and Vegetation Components to Variation of Soil Texture 243
6-4-4 Contribution of Slope and Vegetation Components to Variation of Organic Matter 244
6-4-5 Contribution of Slope and Vegetation Components to Variation of Organic Carbon 246
6-4-6 Contribution of Slope and Vegetation Components to Variation of $CaCO_3$ 247
6-4-7 Contribution of Slope and Vegetation Components to Variation of Nitrogen 248
6-4-8 Contribution of Slope and Vegetation Components to Variation of Phosphorus 249
6-4-9 Contribution of Slope and Vegetation Components to Variation of Potassium 250
6-4-10 Contribution of Slope and Vegetation Components to Variation of Soil pH 251
6-4-11 Contribution of Slope and Vegetation Components to Variation of Electrical Conductivity (EC) 252
6-5 Conclusions 253

CHAPTER SEVEN
Conclusions and Recommendations 257
7-1 A summary of the Academic Findings of the Thesis 259
7-2 A consideration of the Limitations of the Thesis and Recommendations for Further Work 263
7-3 Land Use Policy Recommendations 265

References 269

APPENDICES
Appendix One: 288
Slope Data 289
Appendix Two A: 295
Growth-Forms of Plants 295
Appendix Two B: 300
Vegetation Data 300
Appendix Three: 325
Questions to be Answered By Shepherds and Owners of Livestock in the Research Area 325
Appendix Four: 329
Soil Data 329

LIST OF TABLES

Table 1-1 Meteorological stations in the catchment area of the Upper Wadi Bishah 24
Table 1-2 Meteorological stations near the catchment area of the Upper Wadi Bishah 24
Table 1-3 Average mean monthly solar radiation in cal/cm² at meteorological stations within and near the catchment area of the Upper Wadi Bishah 26
Table 1-4 Average mean monthly, maximum and minimum temperature values in degrees centigrade of meteorological stations within the catchment area of the Upper Wadi Bishah 30
Table 1-5 Average mean monthly, maximum and minimum temperature values in degrees centigrade of meteorological stations near the catchment area of the Upper Wadi Bishah 30
Table 1-6 Average mean monthly and mean annual rainfall amounts in millimetres at the meteorological stations in the catchment area of the Upper Wadi Bishah 34
Table 1-7 Average mean monthly and mean annual rainfall amounts in millimetres at the meteorological stations near the catchment area of the Upper Wadi Bishah 34
Table 1-8 Seasonal variation of annual rainfall at meteorological stations within and near the catchment area of the Upper Wadi Bishah 35
Table 1-9 Average mean monthly, maximum and minimum relative humidity values in millimetre of meteorological stations within the catchment area of the Upper Wadi Bishah 36
Table 1-10 Average mean monthly, maximum and minimum relative humidity values in millimetre of meteorological stations near the catchment area of the Upper Wadi Bishah 37
Table 1-11 Average mean monthly pan evaporation "Class A" in millimetres at meteorological stations within and near the catchment area of the Upper Wadi Bishah 38
Table 1-12 Average mean monthly wind-speed in km/h at meteorological stations within and near the catchment area of the Upper Wadi Bishah 41
Table 1-13 The main groundwater aquifers of Saudi Arabia 47
Table 3-1 Locations and distribution of transects in the research area 96
Table 3-2 The Domin cover scale 101
Table 4-1 List of families, genera and species encountered within sampling points 126
Table 4-2 List of families, genera and species observed outside of sampling areas 128
Table 4-3 Summary of mean measurements of plant components 131
Table 4-4 Summary of vegetation data of the research area 132
Table 4-5 The relationship between vegetation components 133
Table 4-6 Two way table resulting from an application of TWINSPAN program to classify species and samples of the research area 137
Table 4-7 Summary of vegetation data of mountainous plant community 154
Table 4-8 Summary of vegetation data of semi-desert plant community 156
Table 4-9 Summary of vegetation data of toe-slope habitat type 158
Table 4-10 Summary of vegetation data of foot-slope habitat type 160
Table 4-11 Summary of vegetation data of mid-slope habitat type 162
Table 4-12 Summary of vegetation data of shoulder slope habitat type 164
Table 4-13 Summary of vegetation data of summit slope habitat type 166
Table 4-14 Comparison between livestock numbers in Saudi Arabia and Asir region 167

Table 4-15 Summary of responses of shepherds and owners of livestock on the level of grazing in the research area 172
Table 4-16 Summary of responses of shepherds and owners of livestock on the influence of grazing on the vegetation and soil in the research area 174
Table 4-17 Vegetation features of grazing zones (Mountainous zone and Plateau Zone) in the research area 176
Table 4-18 Chemical and physical characteristics of soil in grazing zones (Mountainous Zone and Plateau Zone) in the research area 177
Table 4-19 Summary of responses of shepherds and owners of livestock on the reason (s) for deterioration of grazing in the research area 178
Table 5-1 Area end percentage of the main types of soils in the research area 192
Table 5-2 A half-matrix showing calculation of the Pearson correlation coefficient for the interrelationships between soil properties of the Upper Wadi Bishah Basin 199
Table 5-3 Data summary of morphological and physical properties of soil in the research area 202
Table 5-4 Data summary of morphological and physical properties of soil in the south-west and north-east regions of the research area 202
Table 5-5 T-test of morphological and physical soil properties variance between the South-west and the North-east regions of the research area 203
Table 5-6 Data summary of morphological and physical properties of soil within slope units of the research area 204
Table 5-7 Analysis of variance of soil morphological and physical properties between slope units 205
Table 5-8 Multiple comparisons test (Least Significant Difference Model) for the differences between the means depth of soil in the slope units 206
Table 5-9 Classification of soil and soil texture in the research area; according to the modern division of the United States 209
Table 5-10 Classification of soil and soil texture within the slope units; according to the modern division of the United States 210
Table 5-11 Data summary of chemical properties of soil in the research area 216
Table 5-12 Data summary of chemical properties of soil in south-west and north-east regions of the research area 216
Table 5-13 T test of chemical soil properties variance between south-west and north-east regions of the research area 216
Table 5-14 Data summary of chemical properties of soil in slope units of the research area 217
Table 5-15 Analysis of variance (One-Way) of soil chemical properties between slope units 218
Table 5-16 Multiple comparisons test (Least Significant Difference Model) for the differences between means of potassium within slope units 224
Table 5-17 Multiple comparisons test (Least Significant Difference Model) for the differences between means of electrical conductivity within slope units 226
Table 6-1 Calculation of the Pearson's correlation coefficient for the relationships between soil properties and slope components 234
Table 6-2 Calculation of the Pearson's correlation coefficient for the relationships between soil properties and vegetation components 238
Table 6-3 Analysis of the multiple regression (Stepwise Model) showing contribution of vegetation and slope components to explanation of soil depth variation 242

Table 6-4 Analysis of the multiple regression (Stepwise Model) showing contribution of vegetation and slope components to explanation of soil moisture variation 243
Table 6-5 Analysis of the multiple regression (Stepwise Model) showing contribution of vegetation and slope components to explanation of texture variation 244
Table 6-6 Analysis of the multiple regression (Stepwise Model) showing contribution of vegetation and slope components to explanation of organic matter variation 246
Table 6-7 Analysis of the multiple regression (Stepwise Model) showing contribution of vegetation and slope components to explanation of organic carbon variation 247
Table 6-8 Analysis of the multiple regression (Stepwise Model) showing contribution of vegetation and slope components to explanation of total calcium carbonate ($CaCO_3$) variation 248
Table 6-9 Analysis of the multiple regression (Stepwise Model) showing contribution of vegetation and slope components to explanation of total nitrogen variation 249
Table 6-10 Analysis of the multiple regression (Stepwise Model) showing contribution of vegetation and slope components to explanation of phosphorus variation 250
Table 6-11 Analysis of the multiple regression (Stepwise Model) showing contribution of vegetation and slope components to explanation of potassium variation 251
Table 6-12 Analysis of the multiple regression (Stepwise Model) showing contribution of vegetation and slope components to explanation of soil pH variation 252
Table 6-13 Analysis of the multiple regression (Stepwise Model) showing contribution of vegetation and slope components to explanation of electrical conductivity variation 253
Table 6-14 Summary of R^2 values resulted from analysis of multiple regression (Stepwise Model) 255

LIST OF FIGURES

Figure 1-1 Geographical and regional location of the research area and Asir region 10
Figure 1-2 The Upper Wadi Bishah basin 11
Figure 1-3 Generalised geological map of the Arabian Peninsula 11
Figure 1-4 Rocky formation in south-west of Saudi Arabia 12
Figure 1-5 Structural provinces of Saudi Arabia and adjacent areas 16
Figure 1-6 Drainage systems in south-west of Saudi Arabia 17
Figure 1-7 Frequency distribution of hill slope gradient 20
Figure 1-8 Frequency distribution of hill slope configurations 20
Figure 1-9 Locations of meteorological stations within and near the research area 23
Figure 1-10 Climatic diagrams of some meteorological stations within the study area 31
Figure 1-11 Climatic diagrams of some meteorological stations near the study area 32
Figure 1-12 Categories of maximum wind speed in Abha and Khamis Mushayt stations 42
Figure 1-13 Location of the research area in Meigs's classification of arid and semi-arid homoclimates in the Arabian Peninsula 43
Figure 1-14 Climatographs of Abha and Khamis Mushayt stations 44
Figure 1-15 Valley sediments layers in Saudi Arabia 48
Figure 3-1 Diagram of the study stages 89
Figure 3-2 Transects of samples collection from the research area 95
Figure 3-3 Method of computing the slope gradient 97
Figure 3-4 Point-centred quarter method 99
Figure 4-1 The Saharo-Arabian and Sudanian floristic regions in the Arabian Peninsula 120
Figure 4-2 Phytogeographical regions of the Kingdom of Saudi Arabia 120
Figure 4-3 The geographic distribution of the dominant species in Saudi Arabia 121
Figure 4-4 Map showing the six vegetation zones of south-western Saudi Arabia 124
Figure 4-5 Selected percentage of species frequency in the sampling points of study 127
Figure 4-6 Samples classification resulting from an application of TWINSPAN hierarchy on the data collected from the research area 136
Figure 4-7 Species classification resulting from an application of TWINSPAN program to the research area data 145
Figure 4-8 The research area data; CCA ordination diagram with plant species and environmental variables 148
Figure 4-9 Perennial vegetation map of the research area 151
Figure 4-10 Livestock numbers in Saudi Arabia and Asir region (1996) 167
Figure 4-11 Absolute density of perennial vegetation in the botanical habitats 181
Figure 4-12 Relative covering value of perennial vegetation in the research area 181
Figure 4-13 Mean of plant heights of the vegetation habitats in the research area 183
Figure 4-14 Mean of basal diameter in the vegetation habitats of the research area 183
Figure 5-1 Soil map of the Kingdom of Saudi Arabia 190
Figure 5-2 Distribution of the main types of soils in the research area 193
Figure 5-3 Variance of soil depth between slope units 205
Figure 5-4 Proportions of the texture class of soil in the research area 209
Figure 5-5 Proportions of the texture classes of soil within slope units 210
Figure 5-6 Diversity of soil moisture within the slope units of the research area 213
Figure 5-7 Diversity of potassium amount within the slope units of the research area 224
Figure 5-8 Diversity of mean electrical conductivity values within the slope units 226

Figure 6-1 Diagram of the relationships between slope and soil variables 234
Figure 6-2 Diagram of the relationships between vegetation and soil variables 239
Figure 6-3 Contribution of slope and vegetation components in explaining the variation in soil properties 255

LIST OF PLATES

Photo. 1- Widespread growth of *Juniperus procera* species in the western part of the Upper Wadi Bishah basin 296
Photo. 2- A good stand of *Juniperus procera* in the eastern slopes of the Asir mountains 296
Photo. 3- A general view of the mixed growth of *Juniperus procera* and *Acacia gerradii* species in the south-western part of Wadi Bishah basin (North Abha City) 296
Photo. 4- A pure stand of *Acacia negrii* in the south and the south-eastern part of Wadi Bishah basin 297
Photo. 5- The mixed growth of *Acacia gerradii* and *Juniperus procera* species in the south-western part of Wadi Bishah basin (South Abha City) 297
Photo. 6- The researcher scrutinizes the *Calotropis procera* species in the eastern part of Wadi Bishah basin (Samakh region) 297
Photo. 7- The mixed growth of *Dodonaea viscosa* shrubs and *Juniperus procera* trees in the northern part of the Asir mountains (west and north-west of Wadi Bishah basin) 298
Photo. 8- Forms of pasture growth in the eastern hill-slopes of the Asir mountains 298
Photo. 9- The mouth of the Upper Wadi basin. Note the wells of groundwater (red circle) and Palm farms on the banks of the wadi 298
Photo. 10- Trees of *Olea europaea* species in the main stream of Wadi Bishah. Note one of the assistant research employees standing in the vicinity of the tree trunk 299
Photo. 11- Growth form of *Acacia negrii* in toe-slopes and foot-slopes 299
Photo. 12- A pure stand of *Acacia arabica* in the northern part of the study area. The degradation of range land can be observed in this plate 299

Abstract

This study, the first of its kind undertaken in Saudi Arabia, investigates and evaluates the condition of soil and vegetation and the relationship between them, as well as their relationship with slope components in the Upper Wadi Bishah basin, south-west Saudi Arabia. It is based mainly on quantitative and laboratory analysis, and provides a scientific basis for exploitation of the basin's slopes and conservation of its soil and vegetation.

The findings reveal that floristic diversity of the research area is low. Only 62 perennial species belonging to 49 genera and 28 families were recorded in the upper Wadi Bishah basin. Of these, only 8 species or 12.9% of all species recorded, account for 89% of the absolute frequency of species in the basin. Although the vegetation density in this basin is low (2.71/ 100 m^2), it is considered relatively high compared with other areas in Saudi Arabia. However, great diversities in density and distribution of vegetation were found between slope segments, and also generally between the south-west and north-east parts of the basin. The floristic composition and distribution of main plant groups were found to reflect the condition of soil and the topographical variety in the wadi basin. Also, it was found that over-grazing, particularly in north-east of the basin, is reflected in deterioration and degradation of vegetation and soil.

In terms of soil properties, this study demonstrates quantitatively that the soil of south-west Wadi Bishah basin is generally loamy sand, shallow and somewhat rich in moisture, organic matter, organic carbon, nitrogen and phosphorus, and lacking in $CaCO_3$, potassium, electrical conductivity and pH, compared with the north-east of the basin. In the north-east of the Wadi Bishah basin, the soil is mostly sandy loam to sand, deep and very lacking in moisture, organic matter, organic carbon, nitrogen and phosphorus. Also, this region is affected by salinity problems. On the vertical level,

deeper soils were found in the lower slopes and shallow soils found in the middle and upper slopes. Soil moisture, potassium and electrical conductivity increase down-slope and decrease in the middle and upper slopes. Soil organic matter, $CaCO_3$ and pH decrease going along the slope units from the top to the bottom.

This study has revealed that slope angle and slope gradient have negative significant relationships with soil depth, sand content, potassium, soil pH and electrical conductivity, and positive significant relationships with moisture, silt content, organic matter, organic carbon and nitrogen. Slope length has inverse significant relationships with organic matter, organic carbon and nitrogen, and positive significant relationships with soil depth and potassium. None of the soil properties are associated significantly with slope form. Vegetation cover value and vegetation density are significantly correlated with almost all soil properties. Only electrical conductivity and clay content are not significantly associated with vegetation density.

It is clearly demonstrated by this study that 51%, 27%, 14%, 56%, 56%, 12%, 45%, 6%, 6%, 31% and 1% of the variation in soil depth, moisture, texture, organic matter, organic carbon, $CaCO_3$, nitrogen, phosphorus, potassium, soil pH and electrical conductivity respectively relate to the function (or to the variation) of slope angle, slope gradient, slope length, vegetation cover value and vegetation density.

CHAPTER ONE

Introduction to the Study and Environmental Conditions of the Research Area

Chapter One
Introduction to the Study and Environmental Conditions of the Research Area

1-1 Introduction to the Study.

This study examines for the first time the current status of soil and vegetation cover and evaluates the interaction and association of various soil properties with slope and vegetation components in the Upper Wadi Bishah basin, Saudi Arabia.

Within this framework, this chapter is divided into two sections. The first section explains the problem, significance, purposes and aims, management and organization of the research. The second section presents a full description of the geographical background of the study site, and the environmental and biotic factors that contribute directly and indirectly in affecting the form, formation and properties of the slope, vegetation and soil of the research area.

1-1-1 Problem of the Research.

Food production is an essential objective that has been adopted by the government of Saudi Arabia during the last few decades. In its efforts to achieve this aim, the Ministry of Agriculture and Water faces a difficult challenge from the natural environment. Many giant agricultural projects have been established in the heart of the desert, but the environmental conditions often defeat these efforts. The soil becomes saline, exhausted, degraded and deteriorated, while the ground water has been depleted. For all these reasons, the agricultural planners in the Ministry of Agriculture and Water have changed the direction of agricultural plans and focused on the south-west of Saudi Arabia. The research area has become the first candidate region for this purpose, since it is the only area in Saudi Arabia which has a mean annual rainfall exceeding 300 mm. The mean annual rainfall reaches 452 mm in Belesmer station (Table 1-6).

Indeed, governmental institutions have started to establish the infrastructure for agricultural projects, such as dam construction and well-digging. Many dams have been built along the main stream of Wadi Bishah and its tributaries, among them King Fahad dam, which is one of the two biggest dams in the Middle East (Al Riyadh, 1996).

In view of the topographical structure of the research area, which is characterised by high mountains, hill slopes and valleys, the planners of these projects intend to establish agricultural terraces on the sides of these slopes, particularly in the zones that have simple slopes.

As Chapter Four will show, the research area is the richest region in Saudi Arabia, in terms of vegetation. However, execution of these projects will mean removal and destruction of a huge part of the vegetation cover and the excoriation and exposure of soil on slopes, affecting adversely the local environmental system.

1-1-2 Aims and Purposes of the Research.

In the present research, it is intended to study in detail the soil and vegetation status, as well as the relationship of soil properties with slope and vegetation components in the Upper Wadi Bishah basin, Saudi Arabia. The main points to be investigated are the following:

1- The main properties of surface soil, some soil properties are distinctive features and can be used as important differentiating criteria while others seems to be have little pedological significance. This study will therefore focus on those properties that are most commonly encountered in the context of soil-environmental study. These properties comprise soil depth, moisture, texture, organic matter, organic carbon, total calcium carbonate, nitrogen, phosphorus, potassium, soil pH and electrical conductivity.

2- The current status of vegetation cover and its relationship with environmental factors. This study will investigate and analyse in detail the perennial vegetation of the research area, in terms of the flora, morphology, ecology and distribution and their relationship with environmental factors, such as slope angle, slope gradient, slope length, soil depth, soil moisture, soil texture, soil pH and organic matter.

3- The relationship between soil properties and slope parameters: slope parameters play a principal role in the formation and development of soil as well as in its degradation and deterioration, therefore, this study will investigate the relationship between soil properties mentioned above and slope parameters, such as slope angle, slope gradient, slope length and slope form.

4- The relationship between soil properties and vegetation components. As well as its role in shaping soil properties, vegetation acts as a protective layer or buffer between the atmosphere and the soil. The above-ground components, such as leaf and stems, absorb some of the energy of falling raindrops, running water and wind, so that less is directed at the soil, whilst the below-ground components, comprising the root system, contribute to the mechanical strength of the soil, therefore, the relationship between soil properties mentioned earlier and vegetation components (vegetation cover value and vegetation density) will investigate in this study.

5- The contribution of each slope parameter and plant component to the extent of variation in each soil property. This will facilitate exploration the contribution of each set of slope and vegetation variables to each soil characteristic.

Other points to be considered and discussed from a scientific standpoint include grazing and its influence on vegetation and soil in the research area. In the light of the above, the potential use of the research area will be evaluated and recommendations presented to the farmers and the governmental institutions that intend to exploit it. It is hoped that the results of this study will contribute greatly in selection of a better use for this region and in efforts at the conservation of soil and vegetation in Saudi Arabia.

1-1-3 The Significance of the Research.

The Upper Wadi Bishah basin is the most important basin in Saudi Arabia, particularly in regard to its topographical, climatic and ecological features (Mohammed, 1989). However, its soil and vegetation features remain almost unknown in detail. Despite its importance, no professional has conducted research in this basin, especially as it relates to the soil and vegetation status. The lack of research in this basin and this field is related to the lack of available data and to environmental and technical difficulties. This study is the first of its kind, and aims to overcome these deficiencies.

Soil and vegetation cover constitute an important element in conservation and the protection of the natural environment and water resources, as well as being important for economic and social activities, such as agriculture, grazing and tourism. The study of soil and vegetation status, as well as of the relationship between soil properties and the components of slope and vegetation, will contribute to a solution of the research problems as indicated above and the choice of suitable projects to eliminate, or at least minimize, adverse effects on the ecosystem.

1-1-4 Research Management and Plan.

This study focuses on the relationship between soil properties and the components of slope and vegetation, and analyses the influence of these components and grazing on soil properties.

The research was funded by King Saud University, Saudi Arabia. The Department of Geography, Faculty of Science and the Environment, the University of

Hull, provided a good deal of support and relevant facilities. King Saud University supported the field work by providing the research equipment, transportation and assistant employees.

The study began in April 1995. In the first year, relevant literature was collected and reviewed. A preliminary field survey was completed during June and July 1995. The objectives of this survey were to collect more information about the possibility of transport and the general forms of topographical structure and vegetation cover, which assisted in the choice and planning of research methods.

In the second year, a further field survey was made by the researcher and the research supervisor during June 1996. The main purpose of this survey was to design the research methods. Field work and sample collection were carried out from June to August 1996. During September and October 1996 laboratory and herbarium analysis were undertaken at the soil laboratories at the Agriculture college and at the herbarium of the Science College, King Saud University, and at the National Agriculture and Water Research Centre (NAWRC), Saudi Arabia. Data analysis and writing the thesis were completed during the third year in Hull.

1-1-5 Organization of the Thesis.

This thesis is arranged in seven chapters. The first chapter presents an introduction to the study and the environmental conditions of the research area. The problems, purposes and aims of the research as well as the format of the thesis are reviewed in this chapter. The environmental conditions of the research area, such as geographical location, geological structure, geomorphological and drainage system, slope forms, climatic condition and hydrological matter, are also discussed in this chapter.

Literature on geological structure and topographical formation, soil, vegetation and grazing, the relationship between slope factors and soil properties, and the relationship between vegetation factors and soil properties is reviewed in Chapter Two.

Chapter Three explains and describes methodologies applied to conduct this research, including field work, data collection, laboratory analysis and statistical analysis.

Chapter Four begins by giving a general background of the vegetation in Saudi Arabia and investigates in detail the vegetation status in the research area. Samples and species are classified and the relationships between plants and those factors of environment which might affect the presence and distribution of vegetation cover are analysed. The condition of pasture and grazing land is also discussed in this chapter.

Chapter Five provides general background information on soil in Saudi Arabia and researches in detail the surface soil properties in the research area. The relationships between soil properties are also discussed in this chapter.

Chapter Six explores and explains the relationship between soil properties and slope parameters and vegetation components. In addition, it evaluates the contribution of each slope parameter and each vegetation component to the variation that is found in each soil property.

A final chapter (Chapter Seven) summarises the conclusions reached by the present research and presents some suggestions for land use and conservation of soil and vegetation that can be taken in the future.

1-2 Environmental Conditions of the Research Area.

The study area is a distinct environmental region in the kingdom of Saudi Arabia, in terms of its geological and topographical formation, climatic variation and botanical riches. For the above reasons, this chapter aims to present a clear and complete description of the geographical background of the study site, and the environmental and biotic factors that contribute directly and indirectly in affecting the form, formation and properties of the slope, vegetation and soil of the research area. These factors are the geological structure, geomorphologic formation and drainage system including slope forms, climate condition and hydrological matter.

1-2-1 Geographical Location.

The Kingdom of Saudi Arabia occupies a unique position in the south-west of Asia and covers an area of 2,200,518 sq. km or about 68.5 % of the Arabian peninsula (Al-Nafie, 1995). This huge mass of land makes Saudi Arabia the tenth largest country of the world. It extends over 16° degrees of latitude, from 16° 30\` at the borders with Yemen in the south to 32° 15\` at the Jordan and Iraq frontier in the north, and between 34° E and 56° E longitude. The whole of the research area is located in the Asir region ("Asir", meaning inaccessible, is so named because of the area's rocky terrain, deep valleys and high mountain tops), in the south-west of Saudi Arabia. The general location of Saudi Arabia, the Asir region and the research area are illustrated on the map given in Fig. 1-1. Fig. 1-2 locates the upper Wadi Bishah, which drains the waters of the upper Bishah basin in the south towards the north, and runs parallel to the eastern foothills of the Asir mountains. It is a connecting element between the regional units of the Al-Hejaz and Asir mountains in the west and the Najd pediplain in the east and northeast. In terms of geographical coordinates, the catchment area of the upper Wadi Bishah lies in the zone between 17° 58\`-19° 48\` N latitudes and between 42° 13\`-43° 09\` E longitudes. The main stream length of the upper Wadi Bishah is 225 km, and the total area of the basin is 7600 km^2. The elevation of the area above sea level ranges from 1250 m to 3130 m (Al-Sharief, 1984, and Arabian peninsula map, I987: scale 1:2000000).

1-2-2 Geological Structure.

In the last three decades, the geology of the Arabian peninsula has been the focal point of a variety of research programmes in the geosciences. This is not only the result of economic interests, but also scientifically because of the area's tectonic position (Hotzi, 1984). These investigations indicated that the Arabian peninsula is a natural extension of the Africa continent. It is separated from this continent by the down-faulted Red Sea, and from Iran by the Arabian Gulf and the Gulf of Oman; it is surrounded to the South by the Arabian Sea, and the Gulf of Aden, and to the North by Jordan and Iraq.

The structural history of the Arabian peninsula has been shaped during Precambrian times by tectonism, and several orogenic cycles characterized by uplift, sedimentation, volcanism, intrusion and metamorphism (El-Khatib, 1980; Brown, 1972). These caused most of the main tectonic trends, and directions of structural weaknesses. A generalised geological map of the Arabian peninsula is given in Fig. 1-3.

Regarding the structural division of the peninsula, most geological studies divide the Arabian peninsula into two major structural provinces: an older, western province, known as the Arabian shield (770,000 square kilometres), and an eastern province, called the Arabian shelf, which forms about two- thirds of the Arabian peninsula (Chapman, 1978; Abu-Saqr, 1981; Al-Sharief, 1994). However, Kent (1978) added two other provinces, namely: the Interior platforms and the Basins (see Fig. 1-5).

The Arabian shield, which consists of mostly igneous, metamorphic rocks of Precambrian age, forms the base of the research area. It remained as a part of the African shield until the Tertiary. During the Tertiary and the early Quaternary periods, the Red Sea Rift opened and separated the Arabian shield from the African shield. Due to these events, the western part of the shield uplifted to form scarp mountains which compose vertical slopes in some places (Al-Sharief, 1984), and plateau basalts have been extruded to the East. Faults of the Precambrian were reactivated during the Tertiary and Quaternary because of volcanism, or opened by the decompression generated during the removal of sediments overlying the Cenozoic.

The Arabian shield is subdivided into three structural regions, which are : the western Arabian shield (the upper Wadi Bishah lies in this region), the Yemen-Aden plateau, and the south Arabian shield (El-Khatib, 1980).

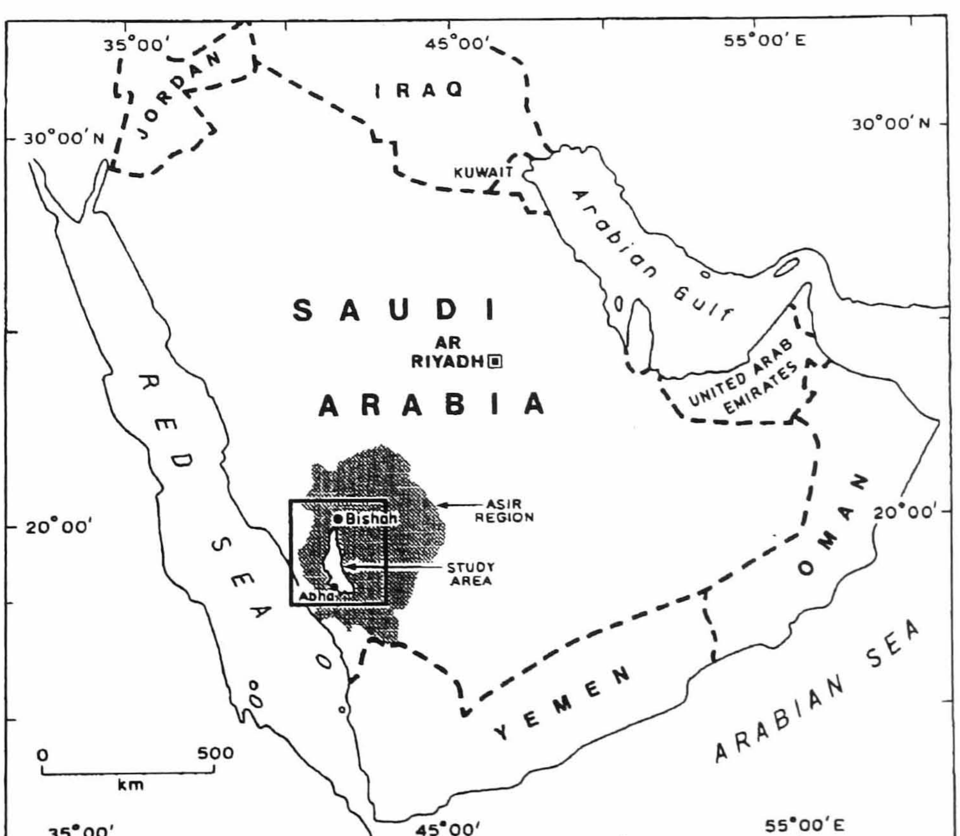


Figure 1-1 Geographical and Regional Location of the Research Area and Asir Region.

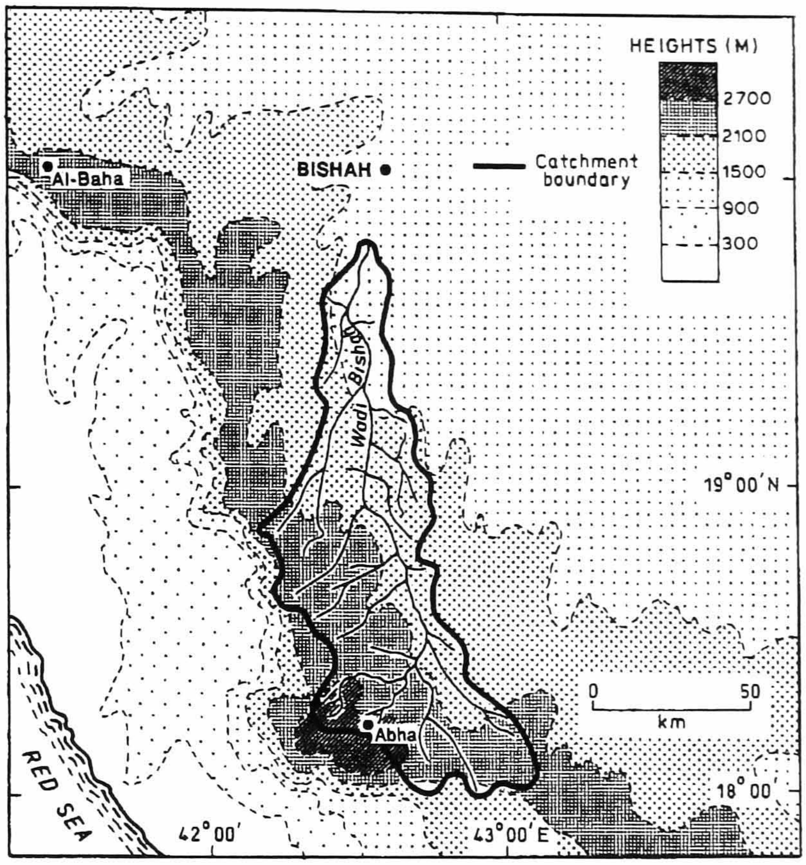


Figure 1-2 The Upper Wadi Bishah Basin.

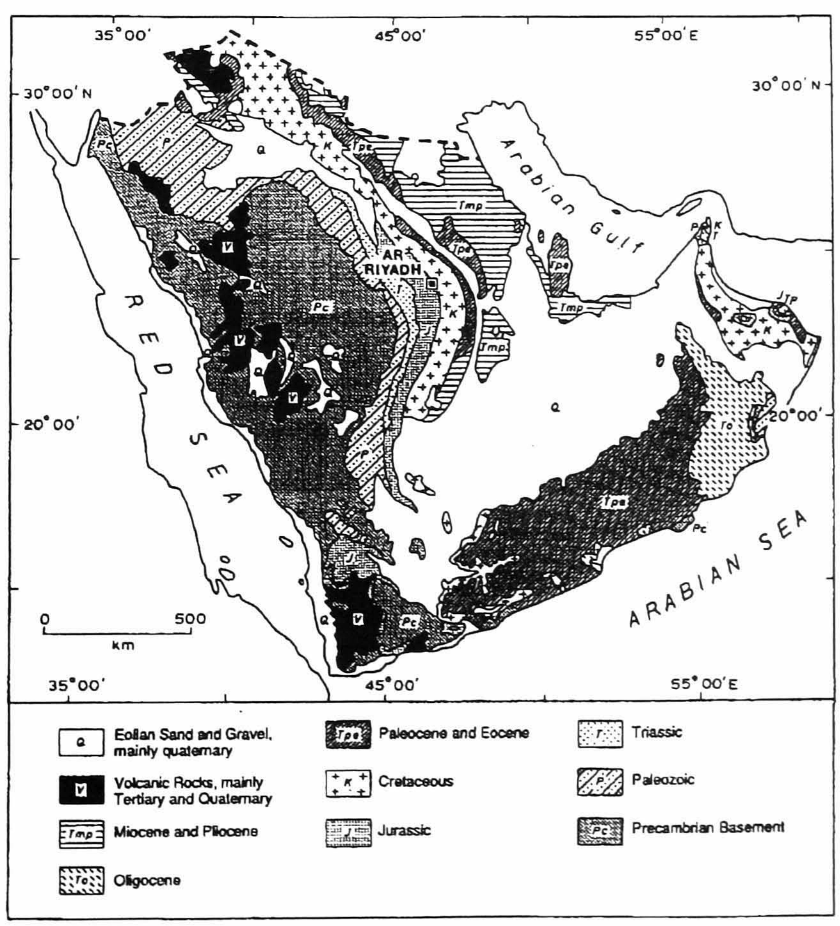


Figure 1-3 Generalised Geological Map of the Arabian Peninsula.
(Source : Chapman, 1978)

The western Arabian shield, which forms central Najd, Hijaz and Asir, is composed of Precambrian plutonic, magmatic and metamorphic rocks with some Tertiary plateau basalts. According to Brown (1972), the gneisses comprising the basement are the oldest rocks of the western Arabian shield (Al-Sharief, 1984). These are generally diorites, quartzdiorites, granodiorites and orthogneisses of granitic origin, and they exhibit metamorphism chiefly in the amphibolite and some in the greenschist facies (see Fig. 1-4).

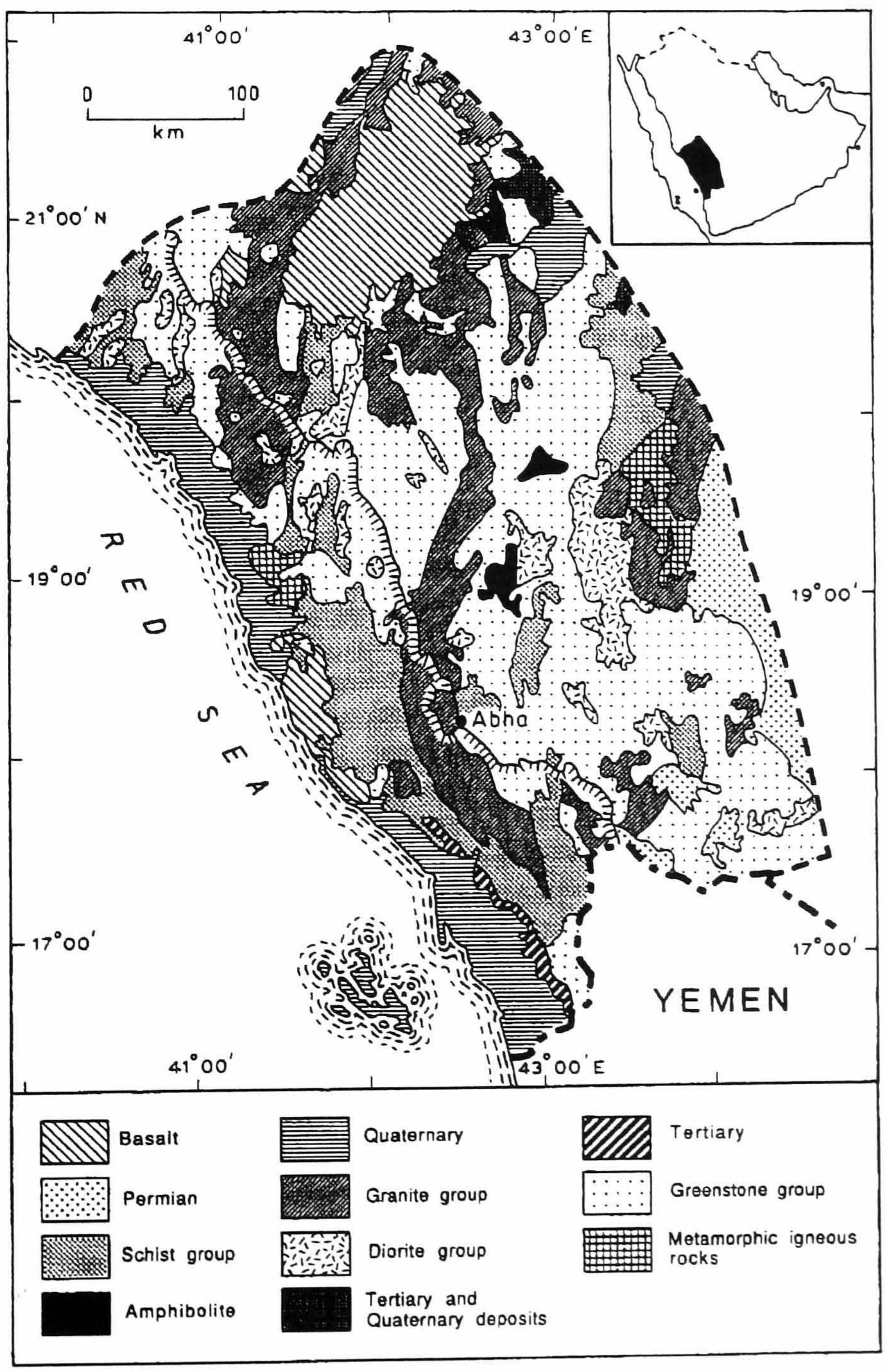


Figure 1-4 Rocky Formation in the South-west of Saudi Arabia.
(Source: Al-Shareef, 1984)

1-2-3 Geomorphology and Drainage System.

Few surficial geological and topographical studies have been conducted in the south-western region of the Kingdom of Saudi Arabia. Most of those that are available have divided this region into four provinces or belts. According to Brown (1960), this region can be divided into four geomorphologic provinces. From the Red Sea in the west and proceeding eastwards, these provinces are the Tehama or the Red Sea coastal plain, the scarp mountains, the Hijaz and Asir plateaus, and the Najid pediplain (Fig. 1-5). As shown in Fig. 1-2, Wadi Bishah lies in the mountains and plateau province of Asir.

The Hijaz and Asir plateaus are a vast pediplain sloping to the north east and the north from a maximum height of 3130 m above sea level (Al-Sharief, 1994, Sagga, 1995, who stated that the height of Al-Sawdah mountain peak is 3207 m above sea level). Formerly regarded as the south- western extension of the Najid pediplain, it is now described as a triangular-shaped plateau extending from Ta'if southward to an area 180 kilometres wide east of Abha. This plateau is built of Precambrian basement complex rocks, and is bounded to the south west by the Red Sea escarpment and to the east by the Wajid plateau geomorphological sub-province. To the north and north-east, the limits are formed by the Najid pediplain along a line running north west, south east to Ta'if and flanking the southern part of the Harat Al Bugum, cutting Wadi Bishah and Wadi Tathlith at Rowshan Oasis and Bir al Hafayr, and extending to the outcrop of the Wajid formation (Abu Saqr, 1981). The Hijaz plateau has been divided into three sub-provinces; these are the highlands, the Hijaz plateau in the North, and the Asir plateau in the South (see Fig. 1-5). The Upper Wadi Bishah extends through the first and the third sub-provinces.

The topography of the area under study (Upper Wadi Bishah) has been described by writers such as Abulfatih (1981), Abu Saqr (1981), and Kollmann (1984), as follows:

"Abha and its surroundings [Upper Wadi Bishah] are considered among the most topographically varied and beautiful natural areas in the Kingdom of Saudi Arabia. The area contains mountains, escarpments, deep valleys, rolling lands, rocky hills, waterfalls and ponds" (Abulfatih, 1981: 143).

"The countryside in the plateau is less rugged than that in the highlands. The Wadis are broader and there is a marked increase in the quantity of the alluvial deposits. Slopes are gentler and the ridges never rise more than 200-300 m above the Wadi bottoms. Wadi and ridges are controlled by the main structural lines and by the schistosity of the metamorphic rocks" (Abu Saqr, 1981: 11).

"The Wadi course, which itself appears to be marked by tectonic faults, is accompanied in the southern hinterland by a mountainous area with differences in elevation of 200-300 meters between the valley floors and summit area. The northern section is characterized by broad alluvial plains in the low hill country with isolated outliers protruding from the cover of debris" (Kollmann, 1984: 226).

Regarding the drainage system, three types can be distinguished in Saudi Arabia. The first type is an escarpment drainage that flows to the Red Sea from the incised, uplifted edge of the shield. This has steep gradients, deeply-incised headwater tributaries, and narrow valleys; if receives high rainfall, and flows a short distance to base level.

The second type of drainage includes the Wadi systems in central and northern Arabia and in the northern Hijaz. In these systems, modern stream activity is characterized by local aggradation, because precipitation and runoff have generally been insufficient either to rework channel alluvium or to incise into it.

The third type of drainage includes those Wadi systems that flow east or northeast into the interior of the Arabian shield. These are the most important drainage systems in Saudi Arabia, and the study area is the foremost of these systems in this region (Fig. 1-6). These systems have headwaters near the westward-facing scarp in the southern Hijaz and Asir. These streams have been strongly influenced by uplift and tilting of the Shield, such that their first-order tributaries originate in high areas where precipitation is greater and evaporation is less than in other regions of Saudi Arabia. Consequently, they receive a greater amount of runoff than other Wadis on the Shield.

even though precipitation over the greater part of these drainage systems is the same as on the central or northern shield. The position of these streams with respect to the monsoons is also important. Moisture from the monsoons is responsible for most of the precipitation in the southern escarpment and Asir region, and any shift in the monsoon path is reflected in the amount of runoff in these drainages. For these reasons, the drainage systems of the southern Shield are probably the most sensitive indicators of climate change in the Kingdom of Saudi Arabia (Whitney, 1983).

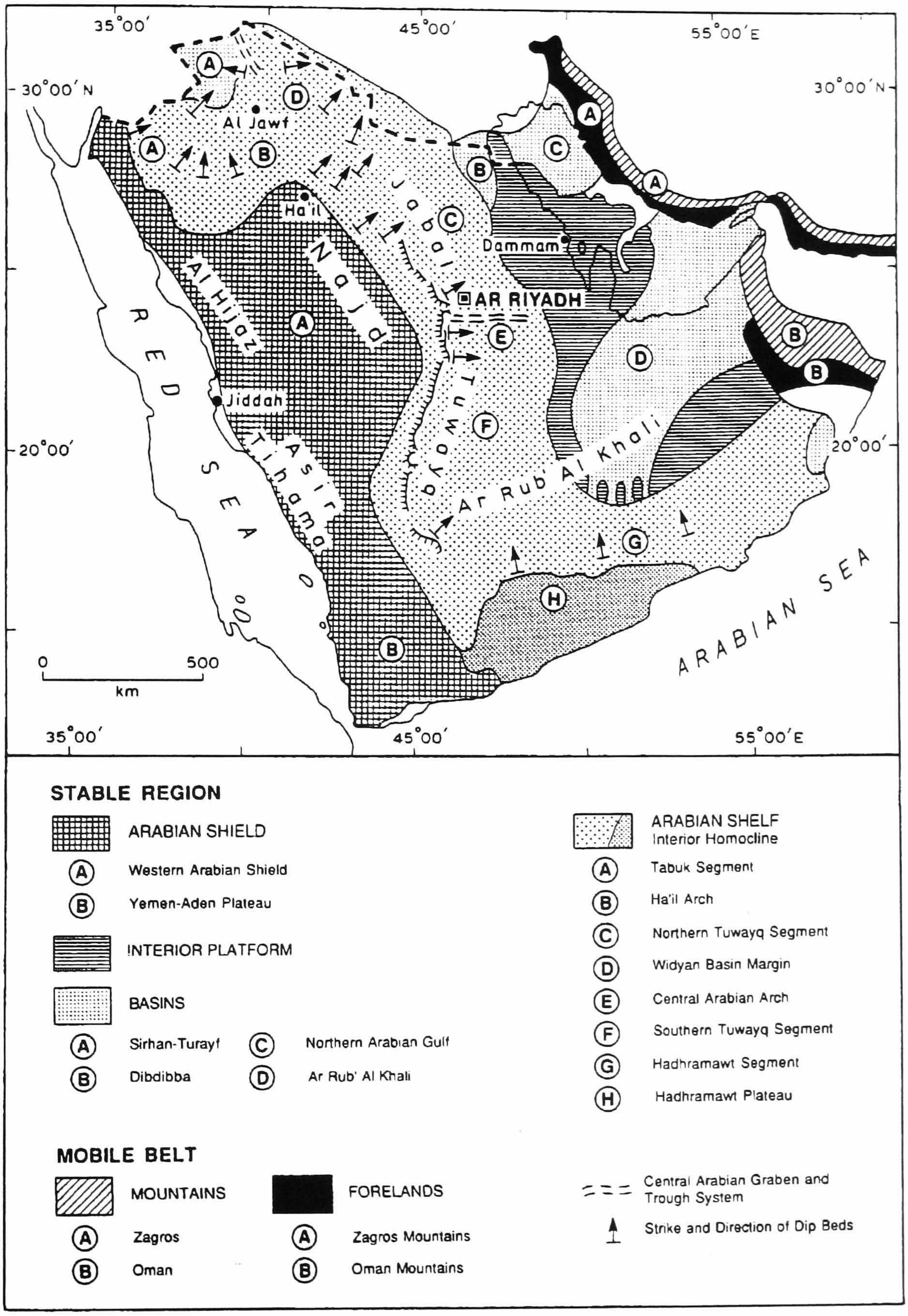


Figure 1-5 Structural Provinces of Saudi Arabia and Adjacent Areas.
(Sources: Powers et al, 1966; Blume, 1976)

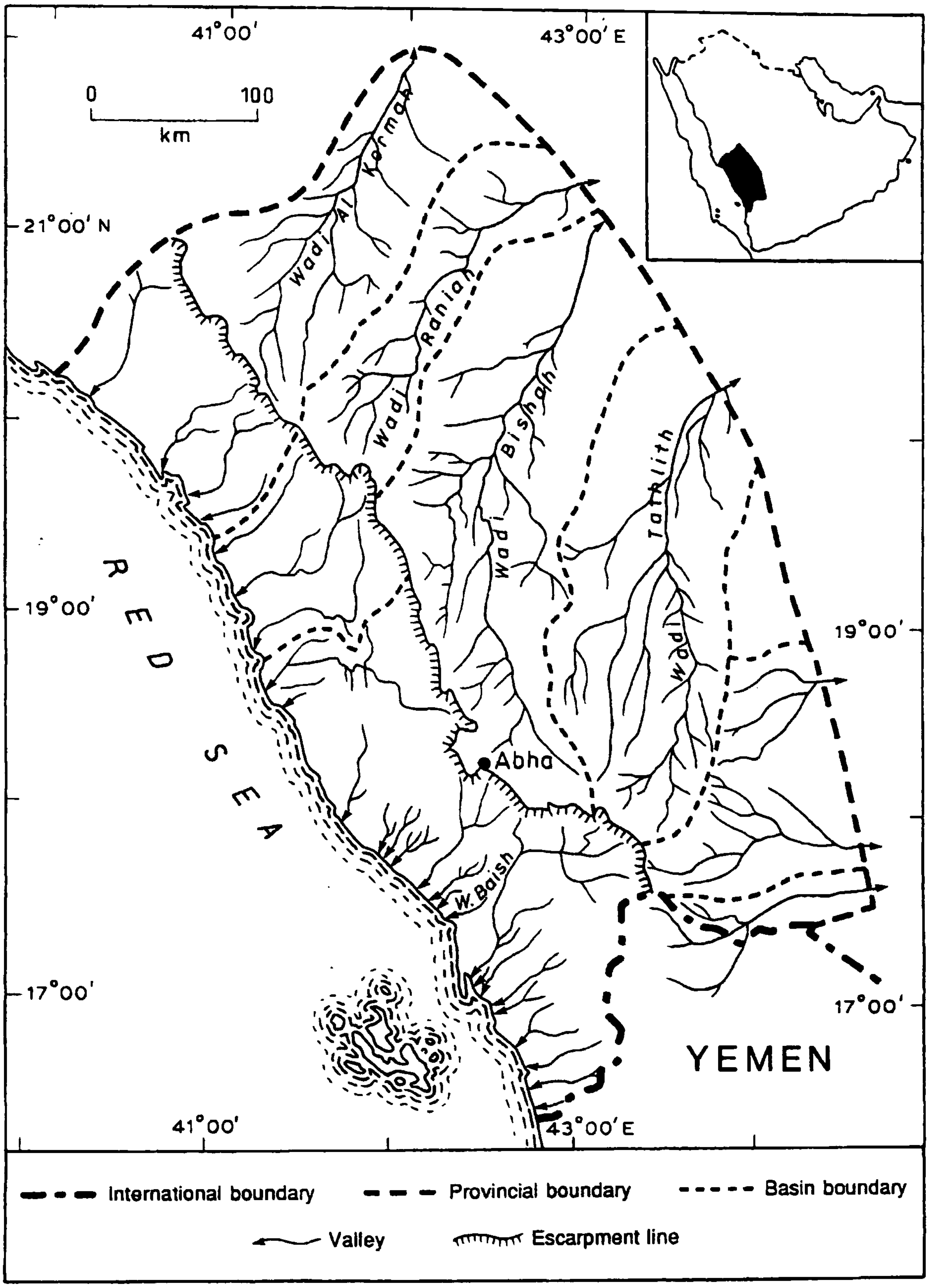


Figure 1-6 Drainage Systems in the South-west of Saudi Arabia.
(Source: Al-Shareef, 1984)

1-2-4 Slope Configurations.

Most of the land surface of the research area is formed by slopes. At a given point on the ground surface it is normally possible to follow the line of maximum slope downwards until a drainage channel is reached. This feature has been little remarked upon, possibly because it is so widespread as to seem part of the natural order. It is, nevertheless, a fundamental and remarkable feature of the research area's surface configuration. The important slope components (slope angle, gradient, slope length and slope form) were measured in each slope segment or unit (toe-slope, foot-slope, mid-slope, shoulder-slope and summit-slope) that lever present along each slope profile. Arising from the data relating to the foregoing components, the slope features are outlined in the following paragraphs.

The frequency distributions of slope angle ranged between 0.5 and 40 degrees (Appendix 1). The mean slope angle varied along the slope profile; it was about 6.19 degrees in toe-slopes, 7.72 degrees in foot-slopes, 13.77 degrees in mid-slopes, 13.68 degrees in shoulder-slopes and 14.88 degrees in top-slope segments. The maximum slope angle (40 degrees) was recorded on only one occasion in the top-slope, whereas the minimum angle (0.5 degree) was also found once in the toe-slope. As can be seen from Fig. 1-7, about 90% of slope-angle values range from 0.5 to 20 degrees, and the remainder (10%) of values are between 21 to 40 degrees. There is a noticeable difference in slope-angle values between the south-west and north- east of the research area, the mean slope angles in these regions being 12.38 and 9.92 degrees respectively. According to the scale of slope classification used in the soil survey of England and Wales (Hodgson, 1978), the slopes of the area under study can be classified as follows:

about 1.3% of slopes are level (0-1 degrees), 13.4% are gently sloping (2-3 degrees), 24% are moderately sloping (4-7 degrees), 20.6% are strongly sloping (8-11 degrees), 13.4% are moderately steeply sloping (12-15 degrees), 21.3% are steeply sloping (16-25 degrees), 5% are very steeply sloping (26-35 degrees) and 1% are precipitous (36+ degrees). As reported later in Chapter Three, the gradient (or slope percentage) was computed using trigonometry and depending on slope-angle values. The frequency distribution of gradients ranged between 2% and 84% (Appendix 1). The mean gradient varied along the hill-slope profile, particularly between those segments that constitute the down-slope (toe-slope and foot-slope) and those segments that comprise the mid-slope, shoulder-slope and top-slope. The mean was about 11% in toe-slopes, 14% in foot-slopes, 25% in mid-slopes and shoulder-slopes and 27% in the top-slopes.

The slope length was measured from the crest of slope to the edge of the Wadi course. Its frequency distribution ranged between about 315 m and 1680 m (Appendix 1). Due to the differences in geological and topographical structure, the length of slope is moderate in the north and south of the research area and longer in the middle, particularly in the western middle. The low average slope angle and gradient in down-slope segments, as well as the increase in slope length, are considered distinct indicators that the hill slopes of the area studied have suffered much from active erosion and slope-retreat processes under a humid palaeoclimate.

The form, shape or configuration of a slope is as important as its gradient. Traditionally, the form of a slope is described according to the line of slope profile in terms such as concave, straight, convex and wavy. As can be seen from Fig. 1-8, about 84% of the studied slope forms were straight and convex. Unfortunately, these forms are much affected by surface erosion processes. Only about 15% of slope forms were concave. These were mostly concentrated on down-slope segments. The wavy form accounted for less than 1% of the slope forms.

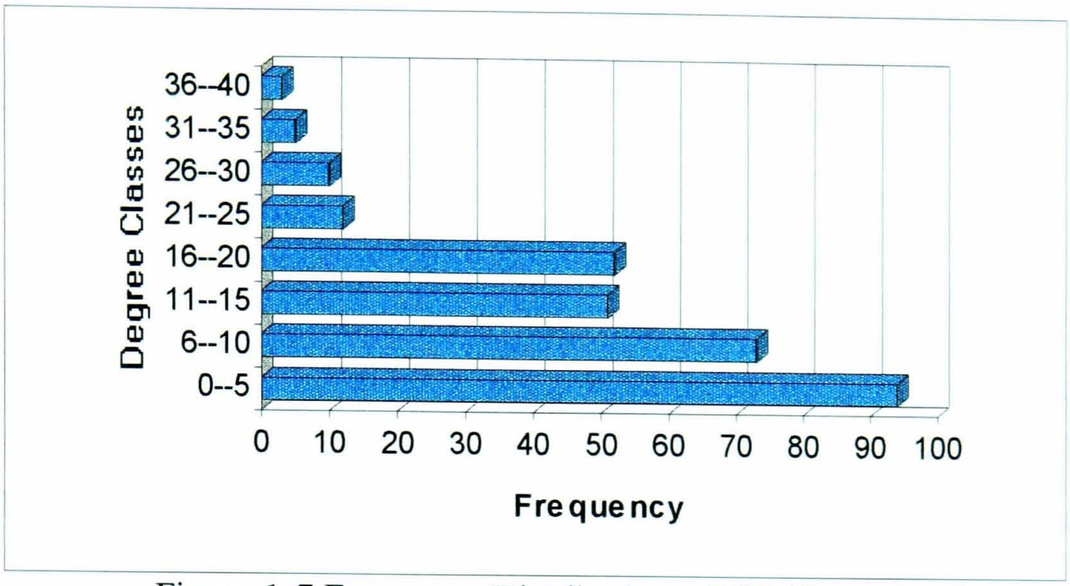


Figure 1-7 Frequency Distribution of Hill Slope Gradient.

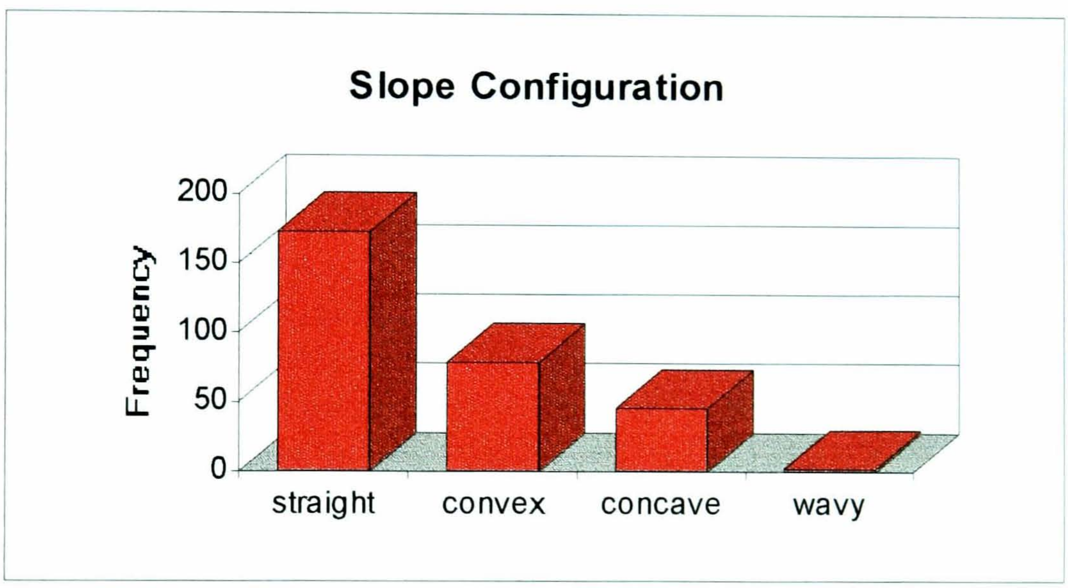


Figure 1-8 Frequency Distribution of Hill Slope Configurations.

1-2-5 Climatic Features.

The climate in the Arabian peninsula in general is characterized by hot and arid summers, and cold and dry winters. However, there are wide variations between these climatic norms and the local climate of south-west Saudi Arabia, in which the study area is located, because of differences in topography, elevation, distance from the sea and the extent of the vegetation cover.

Researchers in climate and environment sciences have summarized the climate of the south-western region of Saudi Arabia, and the study area which is located within the above region, as follows:

" The climate of the south-western region of Saudi Arabia is affected by the prevailing south-westerly wind and the monsoon rains which fall mainly during spring and summer. The coastal plains zone is generally characterized by lower rainfall, high temperature and high relative humidity. Proceeding eastward towards the high mountains a gradual increase in rainfall and decrease in air temperature and relative humidity are observed. The rainshadow slopes zone is characterized by lower annual rainfall and relative humidity, warmer summers and cooler winters compared with the neighboring western high mountains zone" (Abulfatih, 1992: 59).

"The general climate of the Asir region is influenced in part by the southerly monsoon current associated with the Intertropical front which is channellied along the Red Sea trench from which it is diurnally diverted towards Saudi Arabia by differential heating. This warm, moist air rises along the escarpment each day and often converges with cool south-easterly air. Mean annual precipitation of 550 mm results. Although quite evenly distributed throughout most of the year, the spring months tend to be wetter, averaging about 200 mm from March through May. Mean summer temperatures are 18-20 °C while winter temperatures average 8-15 °C." (Brooks and Mandil, 1983: 358).

"The areas of mountainous highland and the eastern slopes in south-western Saudi Arabia are distinguished by moderate temperature throughout most months of the year. Although there is a decrease in temperature in winter, it does not reach freezing point, because these regions face the warm marine wind. And the important thing is that these regions receive a high rainfall. These rains are distributed throughout the year with peaks in spring and summer" (Al-Shareef, 1976: 147, 1984: 53 and 1994: 108).

The annual mean rainfall, temperature and evaporation over the catchment area of the Upper Wadi Bishah are calculated to be 332.05 mm, 17.7 °C, and 2799.4 mm, respectively, and the average mean annual relative humidity is calculated to be 53% (by myself: Tables 1-6, 1-4 and 1-11). Rainfall, temperature and relative humidity observations reveal that the driest months are September and October. The temperature over the catchment area rarely drops below zero. Relative humidity varies during the day and sometimes reaches 100%. The detailed analysis of the climatic features of the area under study depends on the results of measurements taken from the following meteorological stations.

1-2-5-1 Meteorological Stations.

The locations of the meteorological stations within and near the catchment area of the Upper Wadi Bishah are shown on the map in Fig. 1-9 Rainfall measurements are made at the six stations within the catchment area and at the six stations near it. Temperature and relative humidity measurements are made at four stations within the catchment area and at five stations nearby. In addition to the above, parameters such as evaporation, wind velocity and radiation, are also measured at Abha, Sir Lasan, Kamis Mushayt, Sarat Abida, Al-Namas, Bishah, Al-Heifa, Tathlith and Al-Alayah meteorological stations. Some data for meteorological parameters are missing from some measurements of these stations. The characteristics of the meteorological stations within and near the catchment area of the Upper Wadi Bishah, data from which have been utilized, are presented in Tables 1-1 and 1-2.

The results of the measurements such as solar radiation, temperature, rainfall and relative humidity, evaporation, atmospheric pressure and wind velocity which have been carried out at these stations, are presented in the following sections.

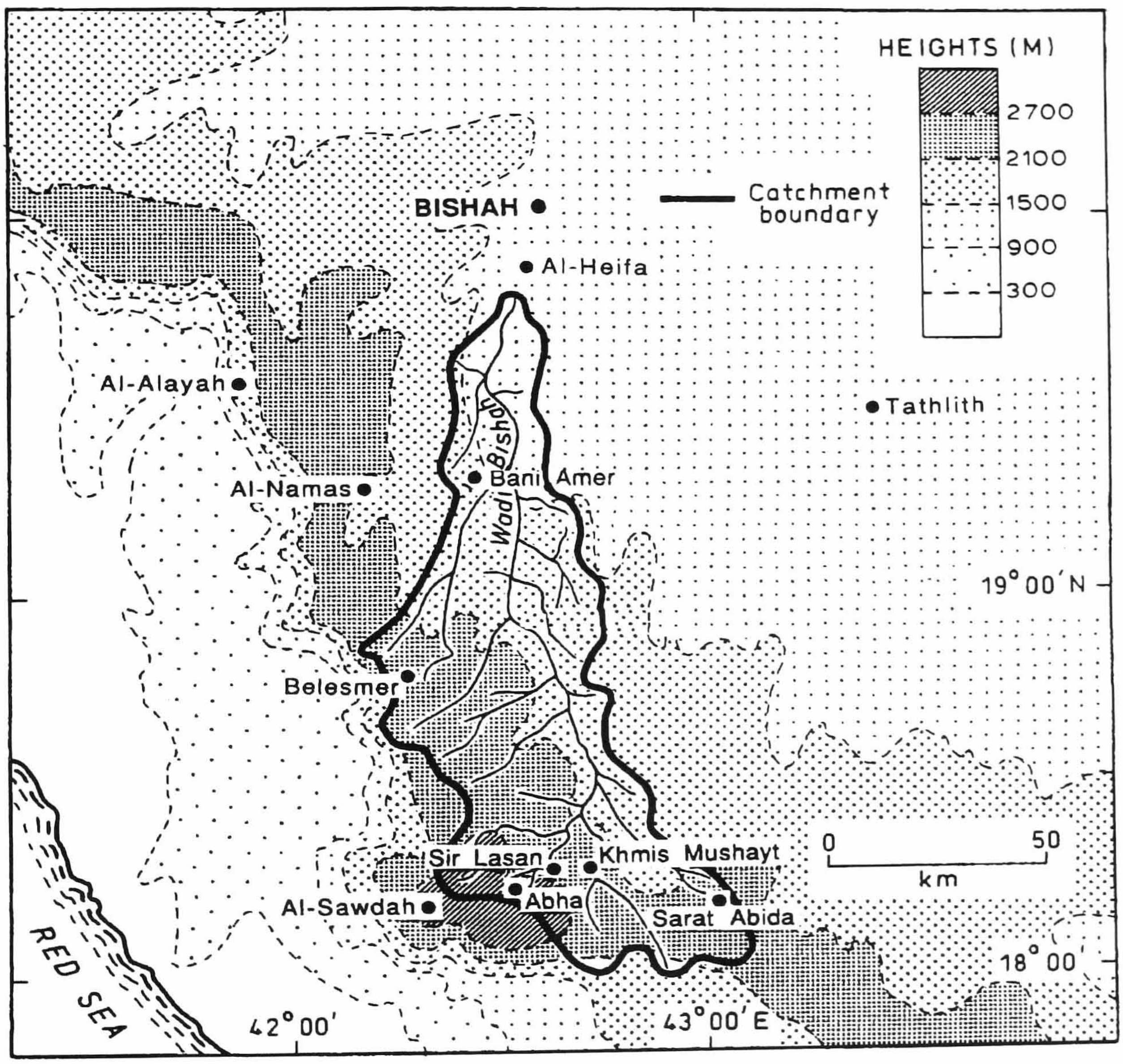


Figure 1-9 Locations of Meteorological Stations Within and Near the Research Area.

Table: 1-1 Meteorological Stations in the Catchment Area of the Upper Wadi Bishah.

Station Number	**Station Name**	**Latitude**	**Longitude**	**Elevation (m a. s. l)**	**Observation period**
A-001	Abha	18° 13`	42° 29`	2200	1966-1993
A-002	Belesmer	18° 47`	42° 15`	2250	1966-1993
A-003	Sir Lasan	18° 15`	42° 36`	1900	1965-1993
A-114	Khamis Mushayt	18° 18`	42° 44`	2066	1967-1993
A-119	Serat Abida	18° 10`	43° 06`	2400	1965-1993
B-216	Bani Amer	19° 29`	42° 31`	1340	1970-1993

Table: 1-2 Meteorological Stations near the Catchment Area of the Upper Wadi Bishah.

Station Number	**Station Name**	**Latitude**	**Longitude**	**Elevation (m a. s. l)**	**Observation period**
A-118	Al-Sawdah	18° 15`	42° 27`	2820	1965-1993
B-002	Al-Namas	19° 06`	42° 09`	2600	1968-1993
B-004	Bishah	20° 00`	42° 36`	1020	1966-1993
B-005	Al-Heifa	19° 52`	42° 32`	1090	1965-1993
B-006	Tathlith	19° 32`	43° 31`	0975	1983-1993
B-221	Al-Alayah	19° 32`	41° 54`	1850	1966- 1993

1-2-5-2 Solar radiation.

Most parts of the research area are mountainous regions, especially in the south and west; clouds are generated over these mountains, decreasing the hours of sunshine especially in the afternoon. The mean daily sunshine in Abha decreases in summer, due to these rainy clouds, and increases in autumn, due to the absence of clouds. Summer and autumn have about 6.8 and 8 hours a day, respectively (Al-Qahtani, 1991).

The intensity of radiation depends on the angle of radiation and the intensity of clouds, as well as the density of sand and dust in the atmosphere. Due to the location of the research area around the Tropic of Cancer, and the intensity of clouds that come in the afternoon and hide sunshine, radiation decreases in the western and north-western slopes of the research area. The north-eastern and eastern parts of the research area are characterized by a clear atmosphere and a large number of cloudless days throughout the year. The few cloudy days in these parts, as well as occasional sand and dust storms, have only a limited effect on the amount of incoming radiation.

Daily radiation measurements are carried out at Abha and Sir Lasan stations within the selected area, and at Bishah, Al-Heifa, Tathlith and Al-Alayah stations near the catchment area. As can be seen from Table 1-3, four general observations can be made, as follows:

1- The average solar radiation intensity increases in the meteorological stations that are situated at high elevations, such as Abha station (2200 m, above sea level) and Sir Lasan station (2400 m, above sea level);

2- The differences in the level of solar radiation totals between the seasons of the year are only slight;

3- In all meteorological stations, the average solar radiation intensity ranges between 323 and 519 langley\day (A langley is 1 gram calorie/cm^2) in summer, and between 235 and 451 langlys\day in winter;

4- The average solar radiation in the spring and autumn seasons falls between the summer and winter levels.

Table: 1-3 Average Mean Monthly Solar Radiation in cal/cm^2 at meteorological Stations within and near the Catchment area of the Upper Wadi Bishah.

Station Name *	Months											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Abha +	382.3	433.4	471.8	475.9	499.2	505.9	467.8	450.6	482.5	497.1	470.4	420.8
Sir Lasan +	424.1	451.4	498.6	490.1	476.8	519.6	471.1	455.5	491.9	417.0	448.1	390.5
Bishah ++	301.1	329.1	364.1	386.3	398.0	382.5	411.1	397.2	391.7	371.2	326.1	295.8
Al-Heifa ++	276.2	315.0	343.9	361.4	382.8	408.2	392.3	377.1	364.6	337.3	298.0	269.2
Tathlith ++	246.0	275.7	333.5	298.5	310.3	348.7	335.0	323.7	316.0	292.7	259.0	235.7
Al-Alayah ++	291.3	332.5	413.3	456.3	495.5	509.5	479.3	461.3	455.3	429.3	372.0	345.5

* Locations of meteorological stations are depicted in Figure 1-9.
+ Stations located within the catchment area of the Upper Wadi Bishah.
++ Stations located near the catchment area of the Upper Wadi Bishah.

1-2-5-3 Temperature.

In general, the area under study and its surroundings are characterized by a moderate temperature regime. The temperature of this region is affected by the elevation, the prevailing south-westerly wind and the monsoon. In addition to these factors, the Upper Wadi Bishah is influenced by the movement of occasional cold continental polar air masses, which come from the middle of Asia, across the Iranian and Turkish plateau; and by occasional northerly winds moving from the eastern Mediterranean towards the north of the study area (Al-Shareef, 1976).

In short, it can be said that the effects of elevation, altitude and the distance from the sea on temperature in south-west Saudi Arabia are more important than the effect of latitude.

The meteorological stations at which temperature measurements are carried out are Abha, Sir Lasan, Khamis Mushayt and Sarat Abida within the area under study, and Al-Namas, Bishah, Al-Heifa, Tathlith and Al-Alayah, near the above area. (Tables 1-1 and 1-2.

The maximum and minimum absolute daily temperature values and the mean monthly temperature values observed at the meteorological stations are given in Tables 1-4 and 1-5. The mean monthly temperature values in Abha, Sir Lasan, Sarat Abida, Al-Namas, Bishah and Tathlith stations are plotted on the curves shown in Fig. 1- 10 and 1-11. The variations of the monthly temperature values can be seen from these curves. The mean temperature decreases from the north to the south and from the east to the west, as a result of the effect of altitude and general increases in elevation. Two examples can be given to explain these variations; the first example relates to the mean monthly temperature values in Bishah and Abha stations. In Bishah station (1020 m, above sea level) which is located to the north of the study area, the mean monthly temperature value is 24.5 °C, whereas in Abha station (2200 m, above sea level) which is located in the south of the study area, it is 17.3 °C, as can be seen from Tables 1-4 and 1-5. The second example relates to the mean monthly temperature values in Tathlith and Al-Namas stations. In Tathlith station (975 m, above sea level) which is located to the east of the Upper Wadi Bishah, and in Al-Namas station (2600 m, above sea level) which is located to the west of the Upper Wadi Bishah, the mean monthly temperature values are 25.2 °C and 15.3 °C, respectively, as can be seen from Table 1-5.

The variations in mean monthly temperature values between seasons are not great, and occur mainly in the stations that are located in the mountainous and plateau regions, such as Abha, Sir Lasan, Khamis Mushayt and Sarat Abida stations within the research area, and Al-Namas and Al-Alayah stations near the research area.

As can be seen from Table 1-5 and Fig. 1-11, some variations can be observed in the mean monthly temperature values between summer (June, July and August) and winter (December, January and February) in the meteorological stations which are located in the intervening zone between the Asir and Al-Hijaz plateau in the west and the desert in the east, such as Bishah and Tathlith stations. In summer, the average daily maximum temperature in the area close to the northern part of the research area ranges from 42 °C(June) to 43.4 °C (August) in Bishah and between 41.4 °C (June) and 43.6 °C (July) in Al-Heifa. In the southern part of the research area, the average daily maximum temperature is 31.8 °C (July), 34 °C (July), 34.4 °C (July) and 33 °C (July) in Abha, Sir Lasan, Khamis Mushayt and Sarat Abida stations, respectively.

On a daily basis, the temperature decreases gradually after sunset, making the nights more comfortable, especially in the middle and southern parts of the study area. The mean daily minimum temperature in the area close to the northern part of the research area ranges between 15 °C (July) and 16 °C (August) in Bishah, and from 10.3 °C (July) to 16 °C (August) in Al-Heifa. In the southern part of the research area, the average daily minimum temperature ranges from 6 °C (June) to 10 °C (July and August), 4.8 °C (June) to 8 °C (August), 11 °C (June) to 12.5 °C (August) and 10 °C (August) to 10.5 °C (July) in Abha, Sir Lasan, Khamis Mushayt, and Sarat Abida stations, respectively. The month of July is the hottest month of the year in the Upper Wadi Bishah.

The winter season is characterized by low temperatures, but these rarely drop below zero. In the winter months (December, January and February) the main daily temperatures to the northern part of the area under study range between 17 °C (Jan.) and 18.9 °C (Feb.) in Bishah and between 17.6 °C (Jan.) and 19 °C (Feb.) in Al-Heifa. In the southern part, the mean daily temperatures range between 12.3 °C (Jan.) and 13.4 °C (Feb.) in Abha, and between 13.6 °C (Jan.) and 15 °C (Feb.) in Khamis Mushayt. The mean daily maximum temperatures in the northern part range between 33.3 °C (Dec.) and 36.4 °C (Jan.) in Bishah, 33 °C (Dec.) and 35.6 °C (Feb.) in Al-Heifa, and in the southern part between 23.6 °C (Dec.) and 24.6 °C (Feb.) in Abha, 27 °C (Jan.) and 27.2 °C (Dec.) in Khamis Mushayt.

As was mentioned above, the minimum temperature in this region rarely drops below zero, and this eventuates mainly in the southern and western stations. In this season, the average minimum daily temperatures in the northern part are between 0.4 °C (Jan.) and 1.0 °C (Feb.) in Bishah, and between 0.0 °C (Dec.) and 1.1 °C (Feb.) in Al-Heifa. In the southern part, they range from 0.6 °C (Feb.) to 1.2 °C (Dec.) in Abha, and from 0.8 °C (Jan. And Feb.) to 3.9 °C (Dec.) in Khamis Mushayt.

The spring season (March, April and May) and autumn season (September, October and November) are considered transition periods between summer and winter seasons, as can be seen from the Tables 1-4 and 1-5 and Figs. 1-10 and 1-11.

Regarding the thermal range, due to the effect of the monsoon which comes to the research area from the south-western direction, the monthly thermal range is small in the mountainous regions, especially in summer. In winter, the monthly thermal range is greater, due to the effect of the continental climate which dominates the north, east and centre of the Arabian peninsula, and extends to cover the northern and eastern borders of the research area.

Table: 1-4 Average Mean Monthly, Maximum and Minimum Temperature Values in Degrees Centigrade of Meteorological Stations within the Catchment area of the Upper Wadi Bishah.

Station Name *	Type of observation	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Mean	Absolute Annual
Abha	Max. abs.	23.8	24.6	30.2	27.0	31.0	31.2	31.8	31.5	30.5	27.5	26.0	23.6		31.8
	Average	12.3	13.4	15.3	16.8	19.3	21.6	21.7	21.1	20.5	17.3	14.7	13.1	17.3	
	Min. abs.	1.0	0.6	2.8	1.2	3.2	6.0	10.0	10.0	9.4	5.5	2.4	1.2		0.6
Sir Lasan	Max. abs.	27.0	25.7	27.3	30.0	32.4	33.5	34.0	33.0	32.2	30.0	29.9	25.6		34.0
	Average	12.7	13.5	15.2	16.5	18.2	20.3	20.6	20.8	19.0	15.4	13.7	13.0	16.6	
	Min. abs.	0.0	-5.0	1.8	1.0	-1.4	4.8	6.5	8.0	2.0	-3.5	-4.0	-3.0		-5.0
Khamis Mushayt	Max. abs.	27.0	27.1	29.6	31.0	34.0	36.0	34.4	34.0	34.0	30.1	27.8	27.2		36.0
	Average	13.6	15.0	14.4	18.3	21.9	23.9	24.1	23.6	22.7	19.1	16.2	14.4	19.2	
	Min. abs.	0.8	0.8	5.2	8.0	9.8	11.0	11.4	12.5	6.7	5.1	3.9	3.9		0.8
Sarat Abida	Max. abs.	27.5	25.8	27.0	29.0	31.7	31.8	33.0	32.0	31.0	28.2	27.5	25.5		33.0
	Average	12.4	13.0	16.0	17.6	20.5	22.0	22.6	22.4	21.0	17.6	14.8	13.2	17.8	
	Min. abs.	0.0	0.0	3.0	3.5	8.0	10.2	10.5	10.0	9.0	4.0	1.1	-1.4		-1.4

* Locations of meteorological stations are depicted in Fig. 1-9.

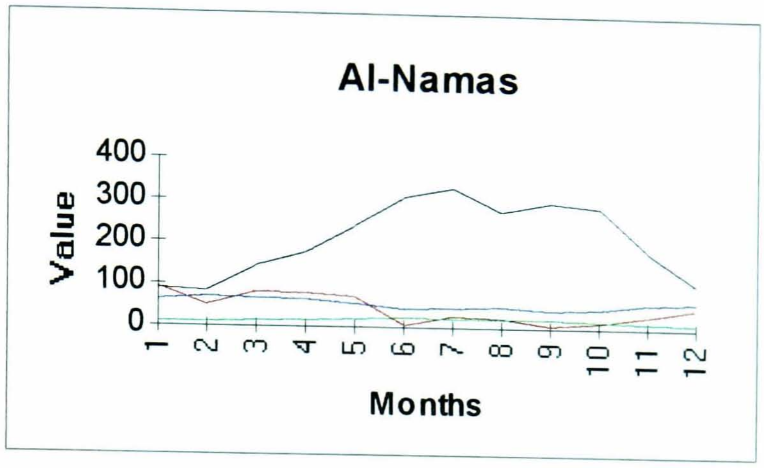
Table: 1-5 Average Mean Monthly, Maximum and Minimum Temperature Values in Degrees Centigrade of Meteorological Stations near the Catchment area of the Upper Wadi Bishah.

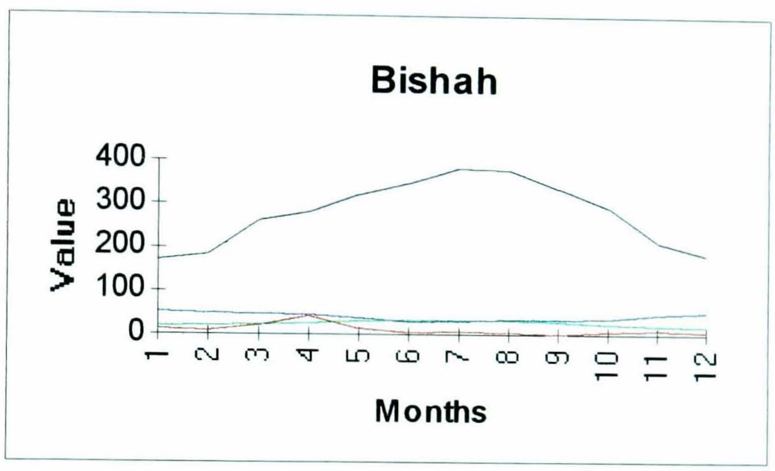
Station Name*	Type of Observation	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Mean	Absolute Annual
Al-Namas	Max. abs.	21.6	24.8	25.1	25.5	28.0	31.0	32.0	31.0	30.2	28.6	22.2	22.6		32.0
	Average	9.3	9.8	12.6	15.0	17.6	21.1	20.4	20.1	19.6	15.5	12.1	10.5	15.3	
	Min. abs.	-7.0	-4.6	-1.8	1.2	5.5	8.8	9.0	5.4	8.0	2.0	-1.0	-2.0		-7.0
Bishah	Max. abs.	36.4	35.2	39.2	40.0	42.0	42.0	43.0	43.4	42.0	37.6	34.0	33.3		43.4
	Average	17.0	18.9	21.2	25.3	29.0	30.5	31.3	31.3	28.1	23.4	20.1	17.8	24.5	
	Min. abs.	0.4	1.0	4.0	6.0	14.0	15.5	15.0	16.0	8.5	4.5	4.0	0.6		0.4
Al-Heifa	Max. abs.	33.3	35.6	36.4	38.3	40.0	41.4	43.6	41.4	40.0	37.1	38.8	33.0		43.6
	Average	17.6	19.0	22.4	24.3	27.6	29.8	30.7	30.8	27.8	22.9	20.1	17.7	24.2	
	Min. abs.	0.6	1.1	5.1	9.1	12.5	15.0	10.3	16.0	10.6	5.1	1.0	0.0		0.0
Tathlith	Max. abs.	35.0	38.4	40.4	41.8	41.6	43.8	43.6	43.8	41.6	40.0	35.0	34.0		43.8
	Average	17.0	19.7	24.4	26.5	29.4	31.0	32.3	23.4	28.6	23.8	20.0	17.3	25.2	
	Min. abs.	-4.4	1.0	6.2	13.4	14.6	15.2	17.6	19.0	9.2	4.8	3.0	0.0		-4.4
Al-Alayah	Max. abs.	23.4	23.0	27.0	29.6	33.2	33.5	34.0	33.2	32.0	29.5	26.0	26.2		34.0
	Average	12.4	12.9	15.4	17.8	20.2	21.1	22.2	22.4	19.9	16.4	13.2	12.5	17.2	
	Min. abs.	-7.0	-5.0	0.0	4.0	7.4	9.0	9.6	11.2	6.6	2.0	-2.0	-3.0		-7.0

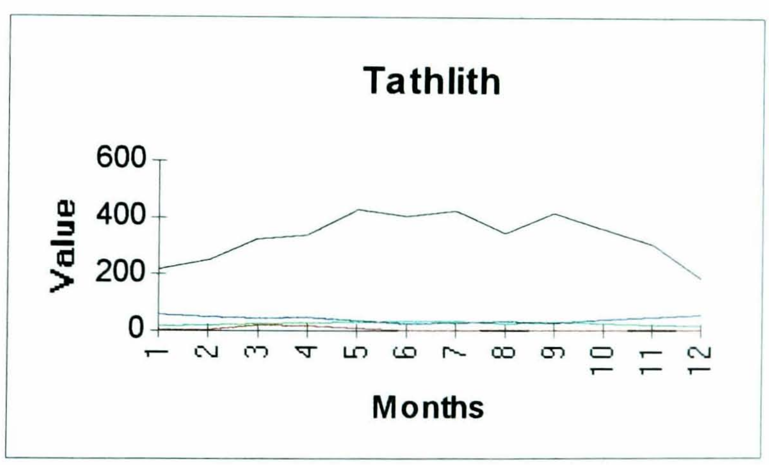
* Locations of meteorological station are depicted in Fig. 1-9.

Rainfall mm Temperature °C
R. Humidity % Evaporation mm

Figure 1-10 Climatic diagrams of some meteorological stations within the study area.
(Source: Tables 1-4, 1-6, 1-9 and 1-11)







Rainfall mm Temperature °C
R. Humidity % Evaporation mm

Figure 1-11 Climatic diagrams of some meteorological stations near the study area.
(Source: Tables 1-5, 1-7, 1-10 and 1-11)

1-2-5-4 Rainfall and Relative Humidity.

The monthly and annual average rainfall values of the catchment area of the Upper Wadi Bishah have been calculated by using the rainfall data of the meteorological stations which are indicated on the map in Fig. 1-9. Monthly mean and annual mean rainfall values of these stations, evaluated in the course of observation period, are given in Tables 1-6 and 1-7. The missing values of monthly rainfall within the observation period of the meteorological stations listed in Tables 1-1 and 1-2, have been estimated, depending on records of the same observation period of the other years. The mean annual rainfall within and near the catchment area of the Upper Wadi Bishah is calculated to be 343.4 mm and 278.6 mm, respectively, as can be seen from Tables 1-6 and 1-7. The annual average rainfall over the area under study increases with elevation and it reaches a maximum value at the elevations near the west and upstream boundary of the catchment area, as can be seen from Tables 1-6 and 1-7 (Al-Sawdah station 529.88 mm, 2820 m, above sea level, and Al-Namas station 507.13 mm, 2600 m, above sea level). Thus, the topography of the area is influential on the area distribution of the rainfall notably since it also causes occurrences of orographic rainfall over the area from the humid air coming to the region from the Red Sea.

The curves showing the distribution of the monthly mean rainfall at the meteorological stations within (Abha, Sir Lasan and Sarat Abida stations)and near (Al-Namas, Bishah and Tathlith stations) the catchment area under study are presented in Figs. 1-10 and 1-11. The curves in these figures also represent the time distribution of the mean monthly rainfall over the catchment area of the Upper Wadi Bishah. Examination of these curves indicates that there is a rainy period over the catchment area and its surroundings from November until the end of May. Rainfall occurring during this period results from moist air masses reaching the region from the low pressure centres and monsoon systems. The small amount of rainfall observed in autumn results from convective instabilities. The source of this rainfall is the airflow, due to the monsoon system. The wettest and driest months in the Upper Wadi Bishah are March, April and September, October, respectively.

Seasonal rainfall percentages of the above-mentioned meteorological stations are shown in Table 1-8. The seasonal rainfall percentage values for the catchment area under study are 52.4% in spring, 16% in summer, 9% in autumn and 22.6% in winter.

Table: 1-6 Average Mean Monthly and Mean Annual Rainfall Amounts in Millimetres at the meteorological Stations in the Catchment Area of the Upper Wadi Bishah.

Station Name *	Months												Mean Annual
	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	
Abha	25.05	25.10	68.40	56.30	52.60	14.40	44.80	42.11	5.40	11.70	20.20	4.90	370.96
Belesmer	47.60	50.40	69.20	98.20	66.50	3.30	27.50	26.50	2.30	6.80	29.60	24.90	452.80
Sir Lasan	21.50	58.90	30.90	51.30	40.50	4.60	52.50	31.10	2.50	5.80	2.00	1.10	302.70
Khamis Mushayt	8.80	13.50	51.60	43.40	33.10	7.20	22.30	23.10	4.30	3.00	17.30	8.60	236.20
Sarat Abida	15.40	24.50	50.40	44.00	36.70	6.70	20.40	15.90	0.50	1.40	11.70	4.30	231.90
Bani Amer	58.30	38.75	70.83	54.50	75.02	5.80	13.55	21.40	2.40	10.13	14.90	32.14	397.72

* Locations of meteorological stations are depicted in Fig. 1-9 .

Table: 1-7 Average Mean Monthly and Mean Annual Rainfall Amounts in Millimetres at the meteorological Stations Near the Catchment Area of the Upper Wadi Bishah.

Station Name *	Months												Mean Annual
	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	
Al-Sawdah	28.38	43.00	55.50	75.50	92.20	23.20	47.50	73.10	23.00	15.60	36.10	16.80	529.88
Al-Namas	91.00	47.80	80.02	77.60	69.81	3.14	24.69	20.09	4.65	12.85	28.66	46.82	507.13
Bishah	10.20	6.70	19.70	40.50	12.10	3.20	4.60	3.20	0.50	5.50	7.80	5.00	118.50
Al-Heifa	13.00	8.20	17.20	27.70	20.00	5.00	6.00	1.70	0.80	7.50	7.50	5.20	119.80
Tathlith	2.10	4.00	18.30	17.41	8.30	0.01	0.12	2.47	0.31	0.10	1.61	0.10	54.83
Al-Alayah	54.10	30.00	41.50	63.50	45.60	7.00	15.90	14.40	7.30	9.00	22.10	31.30	341.70

* Locations of meteorological stations are depicted in Fig. 1-9 .

Table: 1-8 Seasonal Variation of Annual Rainfall at Meteorological Stations Within and Near the Catchment Area of the Upper Wadi Bishah

Station Name *	Mean Annual (mm)	Seasonal Percentage							
		Spring (Mar.-May)		Summer (June-Aug.)		Autumn (Sept.-Nov.)		Winter (Dec.-Feb)	
		Mean (mm)	%	Mean (mm)	%	Mean (mm)	%	Mean (mm)	%
Abha +	370.96	177.10	48	101.31	27	37.30	10	55.05	15
Belesmer +	452.80	233.90	52	57.30	13	33.70	7	122.90	27
Sir Lasan +	302.70	122.70	41	88.20	29	10.30	3	81.50	27
Khamis Mushayt +	236.20	128.10	54	52.60	22	24.60	11	30.90	13
Sarat Abida +	231.90	131.10	57	43.00	18	13.60	6	44.20	19
Bani Amer +	397.72	200.35	50	39.75	10	27.43	8	129.19	32
Al-Sawdah ++	529.88	221.20	42	143.80	27	74.70	14	88.18	17
Al-Namas ++	507.13	227.63	45	47.92	10	46.16	9	185.62	36
Bishah ++	118.50	72.30	61	11.00	9	13.80	11	21.90	19
Al-Heifa ++	119.80	64.90	55	12.20	10	15.80	13	26.40	22
Tathlith ++	54.83	44.01	80	2.91	5	2.02	5	6.20	10
Al-Alayah ++	341.70	150.60	44	37.30	11	38.40	11	115.40	34

* Locations of meteorological stations are depicted in Fig. 1-9.
+ Stations located within the catchment area of the Upper Wadi Bishah.
++ Stations located near the catchment area of the Upper Wadi Bishah.

Relative humidity measurements are undertaken at Abha, Sir Lasan, Khamis Mushayt, and Sarat Abida stations within the catchment area of the study, and at Al-Namas, Bishah, Al-Heifa, Tathlith and Al-Alayah stations near the catchment area. Maximum, minimum and mean monthly relative humidity values of Abha, Sir Lasan, Khamis Mushayt and Sarat Abida stations are given in Table 1-9. In Table 1-10 the maximum, minimum and mean monthly relative humidity values of Al-Namas, Bishah, Al-Heifa, Tathlith and Al-Alayah stations are given. The periods of the measurements are shown in Tables 1-1 and 1-2.

The average daily relative humidity does not exceed 70.4% in any of the stations within and nearby the catchment area of the Upper Wadi Bishah. The mean monthly relative humidity was found to be restricted to between 42.60% and 65.50% within the catchment area, and to between 40% and 54.80% in all stations nearby.

It can be seen from Figs. 1-10 and 1-11 that levels of relative humidity are associated with the seasons. Thus, higher levels of relative humidity are recorded in winter and spring months (December to April), which are the coldest and wettest months, whereas low levels are recorded in summer and autumn months (June to November).

In all stations within and near the research area, maximum relative humidity ranges between 80.80% and 100%, and minimum relative humidity does not drop below 7.20%. It can be said that the distribution of relative humidity in the research area shows an increase in the southern and western parts, and a decrease in the northern and eastern parts.

Table: 1-9 Average Mean Monthly, Maximum and Minimum Relative Humidity Values in Millimetres of Meteorological Stations within the Catchment area of the Upper Wadi Bishah.

Station Name *	Type of observation	Months												Mean	Abs-olute Annual
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
Abha	Max. abs.	99.40	99.00	97.70	95.80	94.50	94.70	95.30	95.30	98.40	96.80	96.40	98.80		99.40
	Average	65.00	70.40	62.00	62.60	53.90	46.20	48.80	51.90	47.20	48.50	57.70	63.60	65.50	
	Min. abs.	13.90	19.80	16.40	20.10	16.50	13.60	13.60	12.80	11.20	10.50	12.40	15.50		10.50
Sir Lasan	Max. abs.	100.0	99.60	99.70	98.10	99.50	97.00	97.00	96.90	95.50	95.50	97.00	94.50		100.00
	Average	63.10	65.00	60.40	61.90	54.50	48.20	48.00	53.70	47.40	49.80	54.00	59.00	55.40	
	Min. abs.	11.20	13.50	13.80	14.50	10.50	12.40	12.60	11.00	10.30	9.00	10.00	12.70		9.00
Khamis Mushayt	Max. abs.	97.60	96.00	95.00	96.30	93.40	86.70	90.00	90.60	88.10	93.10	97.00	97.10		97.60
	Average	62.70	64.60	58.30	56.90	44.10	33.90	38.30	46.60	32.70	35.60	50.10	58.60	48.50	
	Min. abs.	10.40	14.90	14.70	13.10	9.90	7.70	9.60	9.90	8.10	8.70	8.90	9.70		7.70
Sarat Abida	Max. abs.	89.80	87.60	90.60	93.20	87.30	79.40	84.20	86.80	83.50	73.60	78.30	85.10		93.20
	Average	51.70	53.00	50.60	48.20	42.00	35.30	30.00	39.80	33.20	34.80	42.10	49.90	42.60	
	Min. abs.	12.30	15.90	15.00	13.40	13.30	10.50	10.10	11.60	13.40	16.10	15.30	18.00		10.10

* Locations of meteorological stations are depicted in Fig. 1-9.

Table: 1-10 Average Mean Monthly, Maximum and Minimum Relative Humidity Values in Millimetres of Meteorological Stations near the Catchment area of the Upper Wadi Bishah.

Station Name*	Type of Observation	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Mean	Abs-olute Annual
Al-Namas	Max. abs.	100.0	100.0	100.0	99.10	98.50	96.70	97.30	97.50	96.30	97.30	97.80	99.30		100.00
	Average	60.90	67.90	66.30	63.00	54.10	42.80	45.50	47.90	41.50	46.20	57.80	61.10	54.80	
	Min. abs.	9.10	13.30	12.30	16.10	14.10	9.90	9.70	8.80	7.50	9.60	11.40	9.60		7.50
Bishah	Max. abs.	88.80	89.30	88.80	87.90	86.00	63.60	64.00	71.50	70.50	81.10	81.70	88.30		89.30
	Average	51.10	46.70	46.40	43.50	36.60	27.50	29.40	32.70	32.80	36.10	45.60	51.40	40.00	
	Min. abs.	12.50	12.70	11.80	11.00	9.50	9.80	12.60	14.50	15.30	17.10	14.50	14.20		9.50
Al-Heifa	Max. abs.	95.00	92.70	93.60	93.70	94.50	74.50	71.30	79.50	71.60	90.40	91.50	93.30		95.00
	Average	51.50	46.60	45.60	46.40	35.40	29.60	29.30	32.50	31.80	37.40	46.30	52.50	40.40	
	Min. abs.	8.80	9.40	8.60	7.80	7.20	7.60	9.90	11.50	10.60	10.40	7.90	9.90		7.20
Tathlith	Max. abs.	92.90	92.20	86.00	79.20	84.50	54.90	48.20	60.70	46.90	66.90	83.00	86.70		92.90
	Average	56.20	49.10	42.60	45.10	36.10	25.40	26.80	31.00	28.10	36.60	46.50	54.30	44.50	
	Min. abs.	20.00	19.80	21.50	15.00	13.00	14.50	16.20	19.40	18.80	21.00	24.20	22.70		13.00
Al-Alayah	Max. abs.	77.30	80.80	79.00	77.80	78.00	72.50	70.50	76.50	78.00	80.80	79.30	79.80		80.80
	Average	54.00	57.00	51.80	47.30	41.80	36.50	40.00	43.00	39.80	40.80	47.30	50.80	45.80	
	Min. abs.	15.30	18.50	15.80	14.50	15.50	15.50	16.80	17.80	16.30	16.00	11.50	15.00		11.50

* Locations of meteorological station are depicted in Fig. 1-9.

1-2-5-5 Evaporation.

Daily evaporation measurements are carried out at Abha, Sir Lasan, and Sarat Abida meteorological stations within the area under study, and at Al-Namas, Bishah, Al-Heifa, Tathlith and Al-Alayah stations nearby. The mean monthly total "class A" pan evaporation records of these stations are given in Table 1-11. The evaporation records of other stations are not available.

Among the mean monthly total and the annual total evaporation of the mentioned stations, the records reveal the following:

As a result of intense incoming radiation, high temperature, and low humidity, evaporation is high in the summer season, especially in Bishah station, which is located to the north of the research area, and in Tathlith station which is located to the east of the area mentioned above Figs. 1-10 and 1-11. During this season, the range of daily evaporation is between 348 mm and 465.3 mm in the northern stations, and between

188.6 mm and 362.2 mm in the southern stations (Table 1-11). Fortunately, the rainfall of the area under study is concentrated in the cold seasons (winter and spring); therefore, there is less potential evaporation there than in other seasons. In the course of the winter season, the average daily evaporation ranges from 170.5 mm to 220.2 mm a day in the northern stations of the research area. In the southern stations, the average daily evaporation ranges between 143.6 mm and 264.2 mm. In spite of a slight increase in evaporation during the autumn season as compared to that in spring, these seasons appear to be transition periods between summer and winter seasons. The average annual total pan evaporation ranges between 3624 mm in the northern stations and 2799 mm in the southern stations.

Table: 1-11 Average Mean Monthly Pan Evaporation "Class A" in Millimetres at Meteorological Stations within and near the Catchment area of the Upper Wadi Bishah

Station	**Months**												**Annual**
Name *	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**Total**
Abha +	134.6	144.2	196.2	182.8	216.8	240.1	243.1	238.5	273.1	157.8	169.5	153.5	2446.2
Sir Lasan +	140.5	146.7	183.6	176.0	198.6	188.6	193.1	201.1	230.6	222.1	156.0	151.6	2188.1
Sarat Abida +	264.7	230.3	282.6	288.1	330.1	360.0	362.2	341.2	368.8	385.2	286.4	264.2	3763.8
Al-Namas ++	88.1	83.6	144.5	175.5	240.3	310.1	332.4	276.6	297.5	286.6	182.7	104.7	2522.6
Bishah ++	170.5	183.3	262.1	280.9	321.0	348.0	382.2	379.3	337.8	293.4	213.3	182.8	3354.6
Al-Heifa ++	186.0	220.2	300.7	327.5	353.8	432.9	421.4	465.3	398.8	341.4	242.5	202.8	3893.3
Tathlith ++	217.3	249.8	325.3	336.6	428.3	404.0	423.0	345.8	415.5	358.3	305.5	180.8	3990.2
Al-Alayah ++	92.3	96.5	160.8	188.3	242.0	296.3	270.8	251.3	262.0	222.8	114.5	108.0	2305.6

* Locations of meteorological stations are depicted in Fig. 1-9.
+ Stations located within the catchment area of the Upper Wadi Bishah.
++ Stations located near the catchment area of the Upper Wadi Bishah.

1-2-5-6 Atmospheric Pressure and Wind.

Atmospheric pressure is one of the important climatic factors that play a great role in affecting other climatic factors, but unfortunately, the majority of the meteorological stations within and near the research area have not recorded any data on atmospheric pressure, the exception being Khamis Mushayt station, which provides a few data on this parameter.

In summer, the Upper Wadi Bishah comes under the influence of three major low pressure systems, as follows:

1- The low pressure system that develops and centres over the south-west of Asia, mainly north-western India and Pakistan, and extends over south-west Iran and the Gulf of Oman;

2- The African low pressure system that extends from the Gulf of Ghana in the west to the Ethiopian plateau in the east, and stretches to cover the south-western part of the Arabian peninsula;

3- The low pressure system that develops over Cyprus Island, and extends towards the south and covers the northern part of the research area.

In winter, the whole area of the Arabian peninsula comes under the influence at different times of the following pressure systems.

1- The high pressure system that develops in the centre of Asia and extends to cover Iran, the Arabian Gulf and the Arabian peninsula;

2- The equatorial low pressure zone that centres over the equatorial belt;

3- The high pressure that develops over the Sahara and Arabian deserts, as a result of the difference in temperature between the land and the nearby bodies of water;

4- The small low pressure cells or depressions that travel from west to east over the Mediterranean (Al-Nafie, 1995).

Concerning the wind, it blows in the research area from all directions, and in all seasons. In summer, the area under study is one of the regions of the Arabian peninsula nearest to the low pressure system that develops on the Gulf of Ghana, covers the Ethiopian plateau and extends to cover the western, southern and central parts of the research area, so that south-western winds prevail in these parts. These winds bring rainfall in winter, spring and summer (Al- Shareef, 1976). The northern and eastern borders of the selected area are affected by the north-western wind which comes from the eastern Mediterranean basin, and the north-eastern wind that comes from the Iranian plateau and the Gulf of Oman, respectively.

Wind measurements are undertaken at Abha, Sir Lasan, Khamis Mushayt, and Sarat Abida stations inside the catchment of the Upper Wadi Bishah, and at Al-Heifa, Tathlith, and Al-Alayah stations near the research area. The mean values of the wind speed measurements for these stations are given in Table 1-12. This indicates that wind speed and frequency are not very high, averaging between 3.7 and 16.9 km/h. The average mean monthly wind speeds suggest that the wind velocity increases in winter and in the early part of the spring, mainly in the meteorological stations that are located at a high elevation or close to the desert, such as Sarat Abida and Tathlith stations (12.8 km/h and 8.4 km/h, respectively).

In respect of the maximum wind, it is observed that there are two sources of the maximum wind in the selected area, from the south-west and the north-east. These sources provide 91% and 71% of the maximum wind in Abha and Khamis Mushayt stations, respectively (Al-Qahtani, 1991). These winds prevails over most parts of the research area, and have a great destructive effect on erosion and weathering processes of the surface soil. As shown in Fig. 1-12, measurements of maximum wind speed.

maximum wind frequency and maximum wind direction in Abha and Khmis Mushayt stations are given as examples, to illustrate the prevalence of these winds.

Finally, Meigs's classification (1968)(Fig. 1-13) and the records and data available from the weather observation stations that are situated inside and near the research area indicate that the research area may be categorized as an arid to semi-arid region in terms of rainfall quantity. According to the mean monthly temperature and relative humidity recorded by Abha and Khamis Mushayt stations, the upstream of Wadi Bishah is located between the wet cold and dry cold climates (Fig. 1-14).

Table: 1-12 Average Mean Monthly Windspeed in km/h at Meteorological Stations within and near the Catchment area of the Upper Wadi Bishah.

Station Name*	Months												Annual Mean
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Abha +	8.70	10.30	9.10	7.50	6.40	6.90	7.40	7.10	7.90	7.70	6.60	7.10	7.70
Sir Lasan +	7.70	9.40	8.60	7.80	6.60	5.50	5.70	5.90	5.60	6.30	6.50	6.60	6.90
Khamis Mushayt +	5.90	6.90	6.10	6.50	4.70	4.60	5.00	4.70	5.30	4.70	3.70	4.70	5.20
Sarat Abida +	13.40	13.80	16.90	14.10	11.20	11.20	11.70	10.70	14.10	13.60	11.40	11.20	12.80
Al-Heifa ++	4.90	6.60	6.80	6.10	6.30	6.90	8.20	7.30	5.50	5.30	4.10	4.20	6.00
Tathlith ++	7.30	9.90	9.70	8.80	8.70	7.90	9.40	8.80	7.50	7.70	7.50	7.20	8.40
Al-Alayah ++	10.40	11.60	9.50	7.50	5.70	7.00	6.80	6.20	6.40	6.80	4.80	7.00	7.50

* Locations of meteorological stations are depicted in Fig. 1-9.
+ Stations located within the catchment area of the Upper Wadi Bishah.
++ Stations located near the catchment area of the Upper Wadi Bishah.

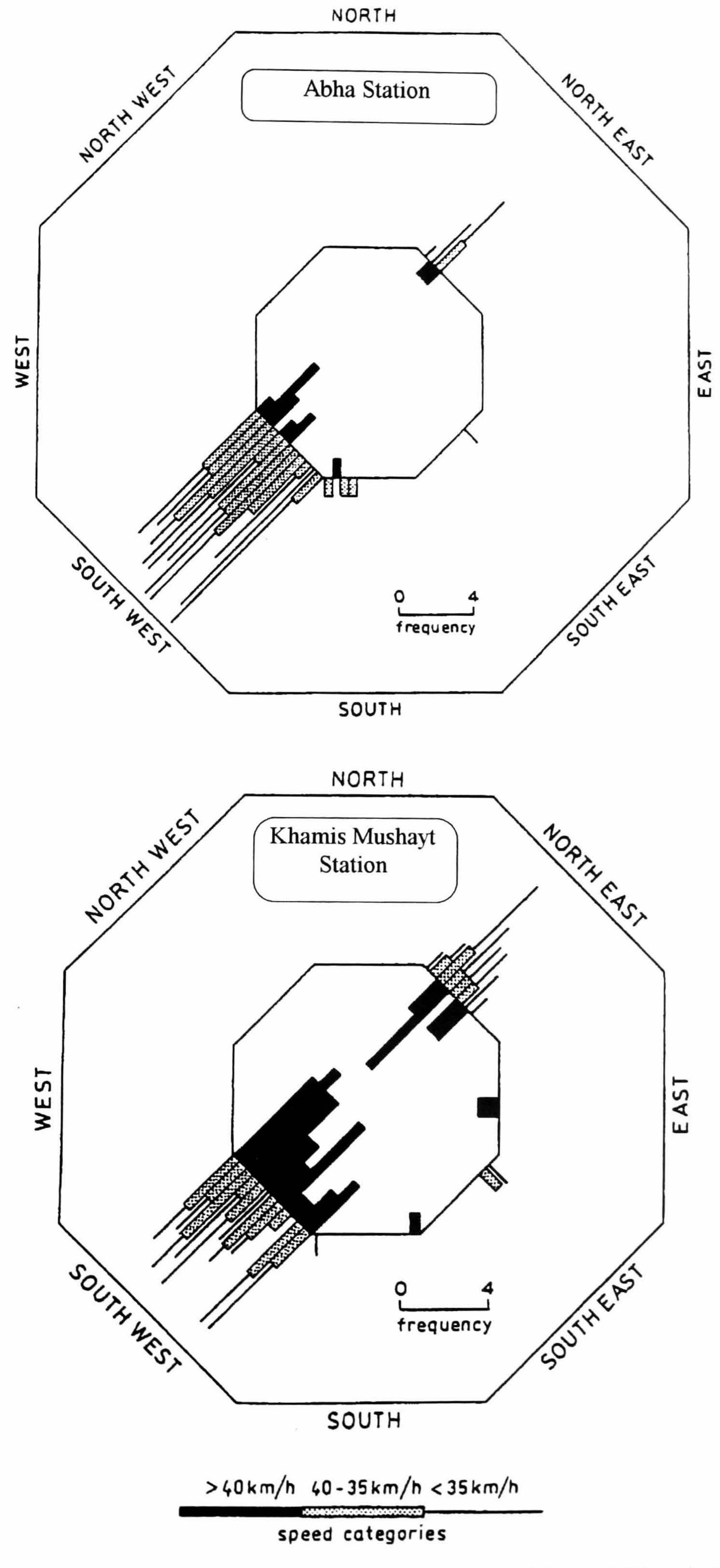


Figure 1-12 Categories of Maximum Wind Speed in Abha and Khamis Mushayt Stations (1978-1988). (Source: Al-Qahtani, 1991).

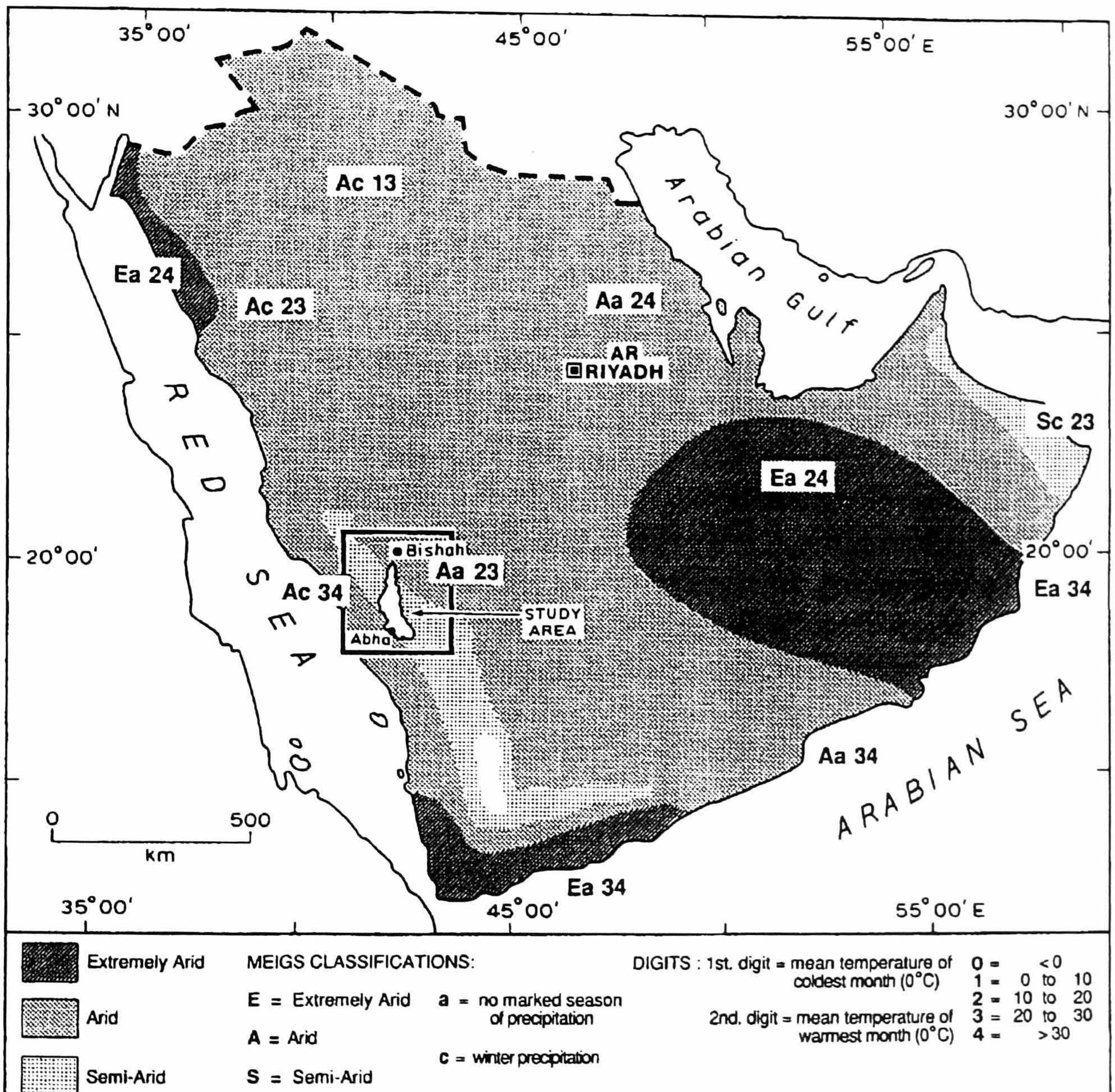
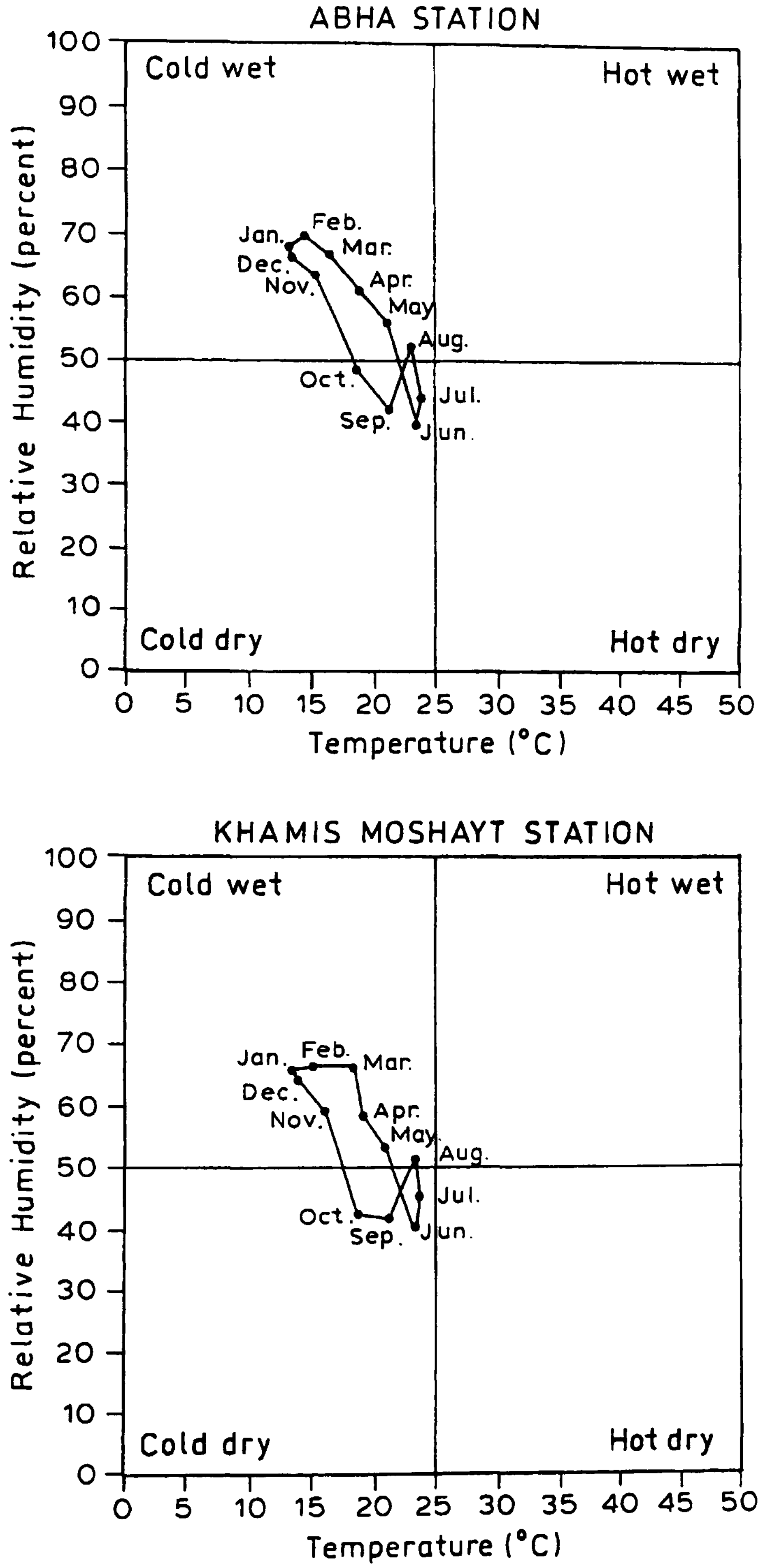


Figure 1-13 Location of the Research Area in Meigs's Classification of Arid and Semi-arid Homoclimates in the Araban Peninsula.
(Source: McGinnies et al. 1968)



Fiigure 1-14 Climatographs of Abha and Khamis Mushayt Stations.
(Source: Al-Qahtani, 1991)

1-2-6 Hydrological Matters.

The water resources of the research area can be divided into two main types, namely surficial water and groundwater. The surficial water comes mainly from the rainfall that falls in the catchment area of the research and exists in the form of small lakes, ponds, flowing water, dam water, reservoirs, and watery basins. The groundwater consists of soil water and aquifers.

In terms of *surficial water*, no perennial rivers exist within the research area, but it would appear that, at some time in the past, large river systems, now often partially or completely buried by alluvial or aeolian sediments, may have carried runoff from the south-western region, where the research area is located, to the Arabian Gulf in the east (Beaumont, 1977). As mentioned earlier (1.2.3), Wadi Bishah is located in the third type of drainage system in Saudi Arabia. This type of drainage includes those Wadi systems that flow east or northeast into the interior of the Arabian shield, and are the important drainage systems in Saudi Arabia. Wadi Bishah is the main drainage system in this region, in terms of stream length (450 km), amount of rainfall and the amount of water draining. In fact, this Wadi possesses important water resources, and large in its higher reaches amounts of rainfall. Its first order tributaries originate in high areas where precipitation is greater and evaporation is less than in other regions of Saudi Arabia. Consequently, this valley receives a greater amount of runoff than other valleys in Saudi Arabia. The mean annual flow of torrents in this valley is 5 m^3 per second. Wadi Najran comes in as second order, after Wadi Bishah with 3.17 m^3 per second (Ministry of Agriculture and Water, Water Atlas, 1984).

Despite the high order of Wadi Bishah torrents, a study by Abdulrazzak et al. (1989) that was carried out in Tabalah basin (Wadi Tabalah is one of the important tributaries of Wadi Bishah) indicated that 63 per cent of precipitation is lost through evaporation from the water surface during flooding, and from the upper layers of the soil surface immediately after storms. Another 32 per cent is stored in the form of soil moisture in the unsaturated layers below the effective evaporation depth. Only 3 per cent of the precipitation is transformed into surface runoff; however, 75 per cent of this contributes towards groundwater recharge.

As said before (1.2.5.4), the mean annual rainfall in the catchment of the research area falls from the west (Al-Sawdah station, 529.88 mm) to the east (Tathlith station, 54.83 mm), and from the south (Sarat Abida station, 232 mm) to the north (Bishah station, 118.50 mm). Nevertheless, average mean annual rainfall between the meteorological stations located within and near the research area is 311 mm, as can be observed from Tables 1-6 and 1-7. On the basis of these facts, the government of Saudi Arabia has established in the area the biggest dam in the country and the second biggest dam in the middle east, after the High Dam in Egypt (Al Riyadh, 1996).

As for *groundwater*, geologically, Saudi Arabia can be divided into two regions, which are also the major groundwater provinces. These are the basement complex of the west and the sedimentary formations of the east (Beaumont, 1977). Throughout much of the higher western parts of the country, in which Wadi Bishah is located, igneous and metamorphic rocks outcrop to form a resistant and rigid basement complex of largely pre-Cambrian age. The permeability of such rocks is low and so groundwater tends to concentrate in patches of alluvial deposits along the lines of the major valleys. This water can normally be tapped by shallow wells, but the quality and yield from such aquifers can vary considerably, dependent on local environmental conditions. There is a tendency for it to become more saline towards the coastal plain (Burdon and Otkun, 1968a).

Previous studies that have been carried out in the research area and its surroundings by Italconsult (1967 and 1968), Burdon and Otkun (1968a and 1968b), Burdon (1973), Kollmann (1984) and a team from the Ministry of Agriculture and Water in Saudi Arabia (Water Atlas, 1984), divided the groundwater in Saudi Arabia into two types, as follows:

1- Major aquifer systems: The number of these aquifers is listed in Table 1-13. Concentration of these aquifers is in sedimentary regions, mainly in the north, centre, east and south-east of Saudi Arabia. The amount of stored water in these aquifers is enormous. Wajid aquifer is the nearest aquifer to the research area.

Table 1-13 The Main Groundwater Aquifers of Saudi Arabia.

Age	Major aquifer	Lothology	Thickness (metres)
Neogene	Neigene	Terrestrial	variable
Eocene	Ad Dammam	Carbonate	32+
Palaeocene	Umm ar Radhuma	Carbonate	490
Middle and Lower Cretaceous	Wasia and Riyadh	Sandstone	c.600-650
Lower Jurassic and Upper Triassic	Minjur and Dhurma	Sandstone and Carbonate	350-400
Paleozoic (Permian)	Wajid *	Sandstone	c.1000
Ordovician/Silurian	Tabuk	Sandstone	c.600
Cambrian	Suq	Sandstone	1000+

* The nearest Aquifer to the Research Area.

(Source: Burdon, 1973)

2- Minor aquifer systems, comprising nine aquifers: The most important aquifer of this type is the Wadi sedimentary layer, which prevails in the Arabian shield, where Wadi Bishah is located (Fig. 1-15).

As for the water table, Abu Saqr's study (1981), which was carried out in the lower part of the Upper Wadi Bishah, indicated that during the dry period in every year (between June and November), the water level tended to decline and from December to May there was a rise in the water level. This happened in most wells that were investigated, but there were some wells which did not show much change. The water table is encountered at depths ranging from 1.93 m and 15.48 m to the south-west of Al-Heifa. The depth of the water table increases in the downstream direction and as the distance increases from the main Wadi channel (Abu Saqr, 1981).

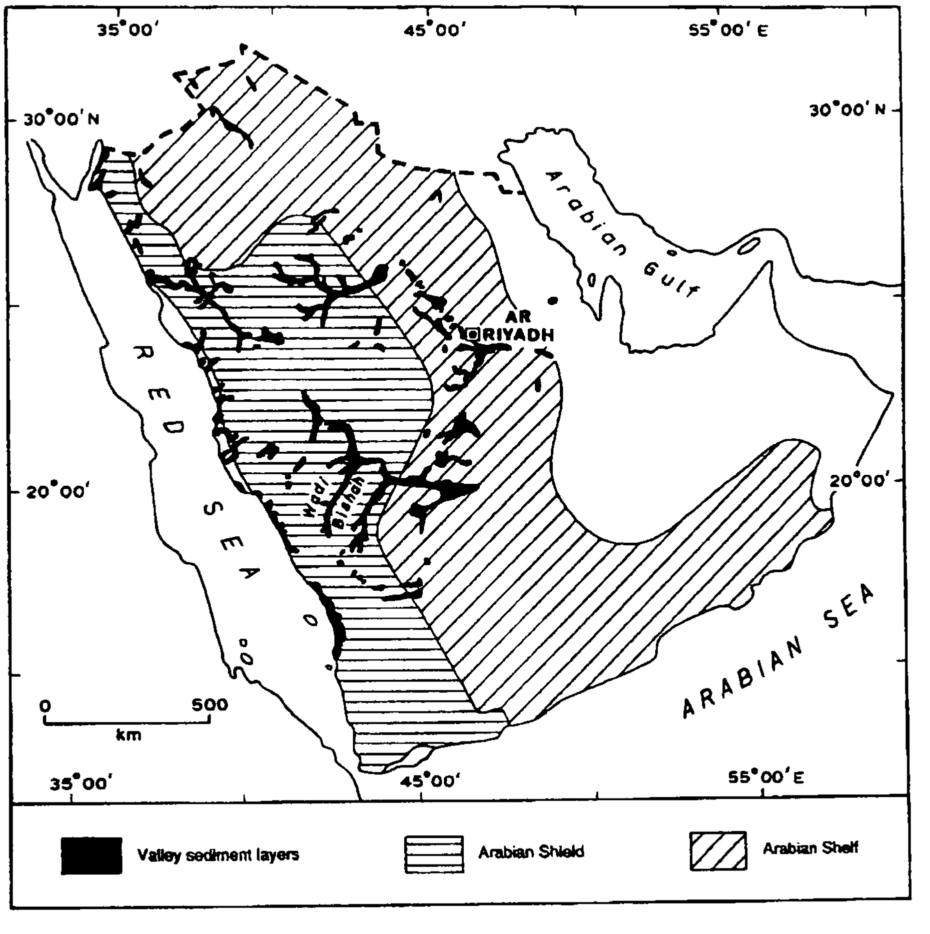


Figure 1-15 Valley sediments layers in Saudi Arabia.
(Source: Ministry of Agriculture and Water, Water Atlas, 1984)

CHAPTER TWO

Literature Review

Chapter Two
Literature Review

2-1 Introduction.

This chapter presents a review of previous works on topics related to the present research and their main findings. The studies considered are divided into two main types. The first are those relatively few studies that were conducted in the research area and its surroundings, especially those which have investigated and discussed the area's geological structure, topographic formation, soil, vegetation and grazing. These are subdivided into three categories and presented as follows:

2.2- General literature on geological structure and topographical formations in the research area;

2.3- Literature on the research area's soil;

2.4- Literature on the research area's vegetation and grazing.

The second type of literature embraces studies more specifically concerned with matters of wider interest related to the present research. These studies are subdivided into two sections, and presented as follows:

2.5- Literature concerned with the relationship between slope factors and soil properties;

2.6- Literature concerned with the relationship between vegetation components and soil properties.

2-2 General literature on Geological Structure and Topographical Formations in the Research Area;

Studies of geological structure and topographical formations are considered to be important for an understanding of the genesis and forming of soil, and the relationship between these topics and slope factors and vegetation cover. The history of geographical and geological studies in Saudi Arabia is relatively recent and there have, so far, been no detailed geographical or geological studies of the research area. The little information available comes from generalised studies, reports and maps made by writers on the Arabian shield, or by some consultative companies working under the supervision of the Ministry of Petroleum and Mineral Resources and the Ministry of Agricultural and Water in Saudi Arabia. Most of these studies were conducted during the two decades of 1960 - 1980. However, a few books and reports written in the first half of the twentieth century contain interesting geographical descriptions of the region, including the research area.

The first authors to take more than a casual interest in the landscape were Philby (1933), Huzauyyin (1938), Oversheet et al. (1977) and Chapman (1978). They ascribed most of the landscape in the research area to the effect of climatic factors in the distant past. These studies indicated that there is evidence of two "physiographic cycles", that is, episodes of deposition followed by downcutting; and that Wadi Bishah's floor consists mostly of sand and clayey sediments. Large blocks and coarse debris material occur only in marginal part of the Wadi.

Karpoff (1957), Brown & Jackson (1960), Brown (1972), Greenwood & Brown (1972), Schmidt et al. (1973), Ryall & Taylor (1981) and Whitney (1983) presented a description of the various lithological types found on the research area, and a correlation of the Precambrian and Cambrian intrusive period. These studies indicated that the research area is composed of the following formations (i) metamorphosed sedimentary rocks, volcanic rocks and greenstone, showing lineaments, but also including units younger than the granitoides related to the Hijaz orogenesis; (ii) basement gneiss, in part remobilized during the late pre-Cambrian Najid orogenesis; and (iii) Late tectonic calc-alkaline granitic rocks. They also indicated that the lack of development of the soil profile is thought to be a direct consequence of the general arid conditions present during

Quaternary time, and confirmed that all surficial deposits in the research area are Quaternary in origin, the majority of them being products of fluctuating climate during the last 40,000 years.

Brown (1960), and Robinson (1977) presented a general studies of the geomorphology of the western and central parts of Saudi Arabia, in which they broke down the area into three geomorphological provinces, namely Al-Hijaz, Asir and the west and middle of Najid. They indicated that the most important groups of soil are those developed from alluvial and colluvial parent material, such as those scattered on old dry river flood plains, in Wadi bottoms and at the foot of slopes such as Wadi Bishah.

2-3 Literature on Soil of the Research Area and its Surroundings.

Until the end of the first half of the twentieth century, pedological studies in Saudi Arabia in general and in the research area in particular received no interest and attention from scientists and researchers. There was a limited amount of information, including some descriptive signals and field observations, but most was subject to mistakes and fallacies.

In the beginning of the second half of the twentieth century, geologists began to become interested in the soil of Saudi Arabia, especially after the discovery of oil and minerals. Consequently, a substantial volume of data has been accumulated from geological studies, e.g. Brown (1960, 1970) Powers et al.(1966), Greenwood & Brown (1972), Breare (1976), Fairer (1985), Gerrard et al.(1986), Gettings et al.(1986) and Abu Sagr (1981). On the other hand, pedogenesis studies still are comparatively few and widely scattered. Therefore, it is difficult to present a clear picture of the soil pedology of the research area from previous studies.

The studies relevant to the soil of south-western Saudi Arabia are for the most part relatively recent. Some of these studies, such as that of Al-Barrak (1985), are very specific and focused on small areas, e.g. the Al-Sawdah area. Other studies have given a general description and distribution of the main soil types. The more important findings of these works are as follows.

During the period 1966-1969, and under the supervision of the Ministry of Agriculture and Water, Saudi Arabia, Italconsult carried out three soil studies in two areas, both of them located in south-western Saudi Arabia (the upper Wadi Bishah falls within these areas). The study areas were divided into three regions: mountain, highland and lowland.

The mountain region included the Hijaz and Asir mountain chains, which rose to an elevation of between 1400-3000 m a.s.l. In the vicinity of Abha, several typical and widely-diffused soils were encountered, which have fairly uniform profiles. The parent material of these soils consist of metamorphic rocks, granites and diorites, which form the region's basement complex. In the small valleys which wind between the mountains, sandy deposits are encountered, sometimes of considerable thickness. The depth of soil in this region is, however, generally slight.

The highland region covered most of the area, and sloped gently down from the mountain peaks to the lowland. Elevation ranged between 1000-1400 m a.s.l. Here, the thickness of the soils varied, the soil on the ground connecting the alluvial plain with the surrounding mountains being sometimes shallow, whereas the main characteristics of the alluvial plain were flatness, fine texture and good depth.

The lowland region connected the highland with the desert. Its elevation ranged between 600-1000 m a.s.l. Here, the basic structure is entirely formed of sedimentary rocks and mainly by Quaternary formations. Striking evidence of erosion and sand accumulation was observed here (Italconsult, 1969).

In 1977 the Food and Agriculture Organization of the United Nations (FAO) examined the soils of the Arabian Shield as a part of south Asia and reported the following findings. Most of the Shield has an elevation of less than 1000 metres, about one third lies between 1000 and 2000 metres, and some mountains (the Asir and the Hijaz) rise to over 3000 metres above sea level. Dominant soils are lithosols on mountains and rock outcrops, and yermosols on peneplains and Pleistocene alluvial terraces. The yermosols are mostly shallow, stony, or both, but in some spots they are deep, yellowish loams.

On a more local scale, at Al-Bassam village which is located on the upper headwaters of Wadi Bishah (2344 m. a.s.l), where the amount of annual rainfall ranges between 300-400, mm as reported by Schyfsma (1978), Dixon & Viani (1980) emphasised that soil has been developed there on basaltic volcanic rocks. It possesses a fine texture, with plenty of sodium and calcium carbonate, particularly in the B horizon.

Some differences in soil characteristics according to elevation were noticed by Aba-Husayn et al.(1980). Soils developed on stable landscapes at higher than 2000 m elevation were found to have well-developed profiles and neutral pH values. Alluvial terraces near Wadi banks at medium elevations (1500-2000 m) were found to be characterised by deep soils, a weakly-developed profile, and pH values slightly greater than neutral. Mineralogical variations among various locations were also reported. Kaolinite was reported to be the most abundant clay mineral in soil developed on well-drained highlands, whereas smectite was the most abundant clay mineral in the alluvial soils developed on lower terrace areas.

Similarly, research carried out for some parts of south-western Saudi Arabia by Al-Souli et al. (1980) revealed that soils on steep slopes of mountains and hills are rocky, shallow and greyish brown to yellowish red in colour. Deeper soil occurs at the foot of slopes. Terrace soils have the same medium texture, and are fertile and suitable for agriculture.

During an ecological study of Dalaghan park, which forms part of the upper Wadi Bishah, the park soils were examined by Abulfatih (1981). Three habitats were studied: the rocky area, the flat area and the Wadi area. In all studied habitats, soils were sandy, poorly-developed and alkaline. Sand and small fractions of rocks appeared to be the main components of the soil. Levels of nitrogen, phosphorus and potassium did not significantly differ from one habitat to another.

Further to this, and under the title of "The influence of grazing on vegetation and soil of the Asir highlands in south western Saudi Arabia," Abulfatih et al. (1989) sampled the surface soil (5 cm) in two stands, a protected area and a grazed area. One square kilometre was studied in each case. The study revealed that water content, organic matter and total nitrogen were relatively higher in the soils of the grazed area when compared with that in the soils of the protected area. Mechanical analysis of soil showed that the soil of the hills, both protected and grazed, was mostly sandy loam, while that of the protected and grazed flats was generally loamy.

In 1981, Abu-Saqr investigated the geology and soil of a small part of Wadi Bishah. The results of the research indicated that the Wadi Bishah basin is built of heterogeneous layers (a system consisting of more than one feature) of alluvial sediments, with a very wide range of grain-size fractions and considerable variation in their extent and thickness. The sediments consist of three types (gravel, sand and mud) which are mixed together in varying percentages to give hybrid sediments. They were formed by different flood features, each of them with its own volume, capacity and energy of transport.

A more comprehensive series of studies, programmes and projects was carried out by the Ministry of Agriculture and Water, Saudi Arabia, to collect necessary data and information about the soil of Saudi Arabia, such as a soil map (scale 1:6,000,000) and soil atlas (scale 1:250,000) in 1981 and 1985 respectively. These publications indicated that most soil in Saudi Arabia is not as developed as it should be, due to drought factors. Concerning the soil of valleys and sedimentary plains, it exists in the form of sedimentary layers, and consists of silt with some sand and gravels. According to the aforementioned atlas, soil-forms in the upper Wadi Bishah basin appear to be categorised into 6 groups: a)Rock outcrop-torriorthents: mountains. b)Calciorthids-rock outcrop: loamy, deep, nearly level and gently sloping soils and hills of rock. c)Torriorthents-rock outcrop-torrifluvents: loamy, deep soils; hills of rock; and intermittent streams. d)Lithic torriorthents-rock outcrop-xerorthents: mountains and nearly level agricultural terraces. e) Calciorthids-rock outcrop: Plains of loamy, deep soils and knolls and hills of rock. f)Calciorthids-torrifluvents: Loamy and sand, deep soils.

A brief study of the morphology and composition of some soils under cultivation in Saudi Arabia then was presented by Bashour et al. in 1983. This study was conducted on five major agriculture areas (Al-Kharj, Gassim, Hafuf, Taif and Wadi Al-dawasir). The findings of this investigation indicated that all five areas were saline and calcareous, and most were also sandy. Furthermore, amounts of nutrient elements such as phosphorus, iron and zinc in surface layers are below minimum levels for adequate plant growth. The successful use of the soils will thus require reductions in salinity, increased levels of nutrient elements, and skilful irrigation to provide adequate moisture.

In one of the relatively recent studies that were conducted on the mineralogy of Saudi Arabian soils, Viani et al. (1983) provided basic chemical, physical and mineralogical data for certain central alluvial basins. Some of these data were collected from the lowermost part of Wadi Bishah, and from its eastern borders. The findings of this study indicated that the calcareous soil of the central basins show minimal profile development. Particle-size classes ranged from sandy-skeletal to fine silty. Soils with shallow water tables were saline. The clay minerals in soils of the basins were primarily inherited. Soils developed in alluvium from mixed igneous rocks had clay fractions in which smectite > mica > kaolinite > chlorite, palygorskite, vermiculite. Soils formed from Permian sedimentary rocks had kaolinitic clay fractions. The soil clay of the central basins had greater smectite contents than those of the kaolinitic western highland soils and the palygorskite-rich eastern-region soils.

Zahran et al. (1983) summarised the soil characteristics of the Saudi Arabian Red Sea coast, located west of Wadi Bishah, as follows. The soils had considerable amounts of salts, and total soluble salts do not decrease in the lower layers. In the examined sites, the pH was lower than 8.5. The analysis of soluble cations and anions indicated that sodium is the chief cation, while chlorides dominated the anions, followed by sulphates. Bicarbonates were very low. Calcium carbonate content was high in all soil samples. The organic matter content also was relatively high.

The soils of Al Sawdah area, which is situated in the highest part of the research area (about 3000 m. a.s.l) were studied by Al Barrak in 1985. This study indicated that differences in elevation have produced variations in the clay and free iron oxides content. Types of parent material in the study area are mostly residuum, in which soils formed in situ from bed rock and alluvium in terraces and wadi bottoms. Porphyritic diorite and chlorite schist were the dominant rocks in the residuum.

A glimpse of the soil of Saudi Arabia was presented by Yousef (1987) in Chapter Four of his book on pedology. The author classified the soil of the research area as being within the Mollisls order and under the Xerolls order and the great group of Argixeralls. He agreed with Aba-Husayn et al. (1980), who indicated that the soil of most of the research area is developed and deep.

The most recent specialised study of soil was conducted by Al-Arifi (1992). This study investigated, along three east-west transects across the cities of Al-Taif, Al-Baha and Abha, the genesis and formation of some soils of the south-western region of Saudi Arabia (upper Wadi Bishah is within this region). The results of the study indicated that there are gradual changes in soil development under the simultaneous changes of elevation and vegetation. On this basis the study region was divided into four distinct regions, as follows:

a) The upper mountainous region consisting of the area lying above 2000 m elevation. This area has two distinct horizons: a surface horizon (A) where organic matters predominates, and a subsurface horizon (B) where clay is dominant. Soils here have nearly neutral pH values.

b) The lower mountainous region lying between 1500 and 2000 m in elevation. Most of the soil contents here are formed of clay and kaolin.

c) The region of lower elevations, lying between 500 and 1500 m elevation. There are accumulations of organic matter here in the surface layers. The subsurface layers are enriched with soluble salts. The pH values are significantly alkaline.

d) The coastal plain region of the Red Sea (which is not included in upper Wadi Bishah) is largely a depositional surface of variable features. It is characterised by a hot and dry climate.

Al-Awajy et al. (1993) subsequently presented a brief study of the characterisation of some genetic soils of the south-western mountainous region, Saudi Arabia. This investigation also showed that soils within this mountainous region displayed different features and properties as a function of elevation. The latter varied widely, and is associated with marked simultaneous changes in precipitation, temperature and the nature of the flora cover. The soil moisture regimes are either Torric, Xeric or Ustic, and soil temperature regimes are either hyperthermic or thermic. A mesic temperature regime is only associated with elevation exceeding 2850 m. a.s.l. The relative density of vegetation cover in some areas leads to an increase of organic matter. These factors resulted in mollic epipedon argillic, combic and calcic horizons. Therefore, and according to the American division system (1975), the soils of this region were divided to four categories, namely Argiustolls, Haplustolls, Camborthids and Calciorthids.

Under the title " A physically-based model for the prediction of flood hydrographs in arid zone catchments", El-Hames (1993) further touched on soil features in the mountains and valleys of the Asir region, Saudi Arabia. The study proposed that the steeply-sloping mountain ridges here are typically covered with shallow soil, with rock outcrops that are mainly composed of Precambrian plutonic, granitic and metamorphic rocks. The main Wadi channels in the area are infilled with predominantly sandy and silty alluvium, while in the upstream areas on the ridge slopes, boulders and gravel are more common. The thickness of the alluvium in valleys in the Asir highlands ranged from a few metres to less than 13 metres.

Finally, Hajar (1993) carried out a comparative study between the soils of protected and grazed areas in Hema Sabihah, which is located toward the north west of Wadi Bishah. The results of the study indicated that the average soil-water soluble nitrogen (N) was higher in the grazed part than in the protected part. However, similarities in some soil properties were found, e. g . the average soil water content (2%), pH (8) and organic matter (8%).

In the light of the foregoing review, there is little doubt that the views of pedologists and geomorphologists thus for have varied widely as to the development and characteristics of soil properties in the research area, and there is little general consensus concerning the nature of the soils within it. Overall, it can be indicated that various environmental factors have played a major role in the formation and composition of soil in the research area.

According to the United States system (USDA) it can be characterised the soil of the research area as shallow, coarse and poor soil in most of the nutrient elements, and belongs to the broad Entisol and Aridisol hierarchies, except for those with a humid local climate in the south-western part. Comparison of this soil with soil of similar region (Murcia region) in Spain indicated that there is close similarity between most of the soil characteristics in both regions. The only exemption is that soils of Murcia region have a high $CaCO_3$ and silt and clay being predominant fractions in this region (Fernandez et al. 1995).

2-4 Literature on Vegetation and Grazing in the Research Area.

Several ecological studies have dealt with different general features of certain phytogeographical regions of the Arabian peninsula (e. g. Vesey-Fitzgerald, 1955; 1957a, 1957b; Popov & Ziller, 1963; Batanouny, 1979; Zahran et al. 1983; Younes et al. 1983; Zahran, 1981; and Batanouny & Baeshin, 1983). These, however, are of only limited use for any study of the research area though, from them, it is clear that, in Saudi Arabia, the greatest number of plant species is found in the highlands of the south-west (including the Asir region), where vegetation linked to east African formations contributes strongly to the character of the region. Forty-four per cent of the flora in south-western Arabia represents Sudanian biogeographic elements found mainly in savanna scrub and montane woodlands (Zohary, 1973). These two vegetation types are also prevalent in Somalia, Ethiopia and Kenya. According to Al-Hubaishi & Hohenstein (1984), southern Arabian phytogeographical region (including Yemen), in which the Asir region is located, contains 2000-2500 flowering species.

The Asir region, which includes Wadi Bishah, biologically lies between Asia and Africa next to the Arabian desert, and is in contact with Mediterranean mountain floras northward (about 1400 km distance) and with the subtropical mountains of Yemen to the south (about 200 km distance). Therefore, a wide range of desert, temperate and tropical region plants all are found here (Abulfatih, 1984).

The upper Wadi Bishah is considered to be among the most topographically varied and beautiful natural areas in the Kingdom of Saudi Arabia. The area contains mountains, escarpments, deep valleys, rolling lands, rocky hills, waterfalls and ponds. Such a topography, with its relatively high rainfall and moderate temperature, has created a diversity of habitats for plant growth (Abulfatih, 1981b). However, the upper Wadi Bishah and its surrounding areas have received little attention from researchers, because of the complexity of its topographical composition, and difficulty of transport. The little information on vegetation which is available in this area comes from generalised studies, books and some maps. Thus, Novikova (1970) defined fifty areas in Saudi Arabia dominated by an abundance of some species and plant communities, and produced what is the first detailed vegetation map for the whole Arabian Peninsula. This map was based on the botanical work and description of geographers, geologists and travellers. The research area was classified as supporting tropical types of vegetation.

The most comprehensive and useful check-list reference for the vegetation of Saudi Arabia as a whole to date is that compiled by Migahid & Hammoda in 1974. This reference work was enhanced and revised by Migahid in 1978, 1988 and 1990. In 1980, Migahid also published two studies on the vegetation of Saudi Arabia and divided the country into two main regions:

1- The western region.

2- The eastern region.

The western region was subdivided into two subregions, one to the north of the Tropic of Cancer and the other (which includes the research area) to the south. The eastern region was determined to have less vegetation cover than the western region, due to its dry desert climate.

In 1988, Migahid described ten phytogeographical regions as comprising the vegetation cover in Saudi Arabia (see Fig. 4-2: 123). This division appears to be based on geographical location, topography and geological formation. The research area was described as being situated within two regions, namely the Southern region and the south Hijaz region.

Under the title "The production energy of grazing and its development methods in Saudi Arabia", Al-Saleh & Abu Al-Aula (1977) reported that natural pasture in Saudi Arabia comprised about 85 million hectares, providing grazing for more than 11.7 million livestock units (livestock unit = one camel, or one cow, or five sheep, or five goats). They related the deterioration of pasture to drought, overgrazing, wood-cutting and increase of soil salinity. They recommended a reduction of animal numbers and the development of grazing management techniques.

During the period of 1979-1992, Abulfatih investigated, in a series of published scientific studies and books, the plant species, distribution of plants, environment of plants and biogeography in some parts of the research area. These works made useful contributions to an explanation of the complex composition of the vegetation in the research area. These studies and their results are examined in the following few pages.

Thus, in a brief study, Abulfatih (1979) researched the vegetation of the higher elevations of Asir (Abha and Khamis Mushayt), which is located in the south west of the head of Wadi Bishah. The results of this study revealed that the predominant vegetation on these mountains is characterised by **Juniperus procera,** which maintains some good stands in the vicinities of Abha and Khamis Mushayt at elevations ranging between 2210 and 2740 m. a.s.l. The second prominent tree species on these mountains is **Acacia spp.**, which is found at 2360 m. a.s.l. or lower, on less rugged slopes and bottom lands.

Under the title of "Biological Survey of Abha Dam Lake" (situated at the uppermost part of Wadi Bishah), Abulfatih & Kalili (1979) then summarised the plant groups of Abha dam lake as follows: a) Emergent plants were widely distributed along the shore and were characterised by their tolerance to the fluctuation of water level. b) Floating plants covered some large areas of the lake, in water varying in depth between a few to 80 cm. c) Submerged plants were represented by **Chara spp.**, which was found at depths ranging between 0 and 100 cm.

The wild plants of Abha (in the uppermost part of Wadi Bishah) and its surroundings were studied in detail by Abulfatih (1981b). Plants were divided into two groups according to topography. The first group of plants were those found on the highlands of Asir at elevations ranging between 2000 and 2740 m. The second group were those distributed over slopes westward of Asir highlands, at elevations between 1700 and 2700 m. 272 plant species were recorded, including herbs, shrubs and trees. Estimates of plant diversity showed a relatively higher percentage of plant species belonging to the highlands of Asir. Plants generally formed a higher percentage of cover over the highlands, reaching up to 90 per cent in some places.

Dalaghan National park is a small part of the upper Wadi Bishah. The vegetation habitats in this park were studied by Abulfatih in 1981, and divided into three types related to rocky, flat and Wadi habitats. Many plant species were found on the rocky habitats, including trees, shrubs, ferns, mosses, algae and lichens. Trees, shrubs and herbaceous plant were found to be sparsely distributed in flat habitats. A thick mat of herbaceous plants was found in most parts of the Wadi habitat. Also, the study showed that the land had good potential for wildlife development, especially after grazing was stopped and human disturbance was curtailed.

At one of the uppermost parts of Wadi Bishah, Abulfatih (1984) studied the elevationally restricted floral elements and reported that the complexity of the plant communities in these regions is related to variations in topography, elevation, moisture and temperature. Four dominant wild species of trees were encountered. At Agabat Thila'a (1300 m. a. s. l) **Ficus salicifolia** grows in warm microhabitats along Wadis. **Ficus plamata** grows in crevices between large boulders in Abha (2200 m. a. s. l). **Acacia spp.** grow sparsely at Agabat Thila'a and in Abha forming 4-5 per cent crown cover. At Al Sawdah (2740 m. a. s. l) **Juniperus procera** trees contribute 12 per cent crown cover. Among the common plants there are also 17 shrubs, 65 herbaceous plants, 13 succulents and two parasites (on **Acacia spp.** trees).

A comparative study was conducted to examine the vegetation of a protected area and a grazed area in the Asir highlands by Abulfatih et al. (1989). The findings of this study indicated that grazing by sheep and goats has a significant impact on species composition, plant biomass, and soil chemical and physical properties. The comparison between grazed and protected areas revealed that the protected area had higher species diversity, plant biomass, plant heights, soil carbonates, cation exchange capacity, and electrical conductivity, whereas the grazed area contained relatively lower plant biomass, plant heights, soil water content, organic matter and total nitrogen.

The biogeography of the Kingdom of Saudi Arabia was discussed by Abulfatih (1991) in his book, "Environment Science" (Chapter 11). The author indicated that differences of topography and climate among various parts of Saudi Arabia have produced seven types of broad vegetation cover. These types are xerophytic vegetation, ephemeral vegetation, salt flat and salt marsh vegetation, shallow-fresh water vegetation, mangrove vegetation, vegetation of slopes and valley and woodland-mountainous vegetation. The research area is located in the last two types. A brief description and colour photographs were provided for each plant species.

In one of the most recent and important studies of vegetation in south west Saudi Arabia, Abulfatih (1992) presented a detailed study of vegetation zonation along altitudinal gradients between sea level and 3000 m a.s.l. The study emphasised that on this basis the vegetation of the study area can be divided into six major zones: coastal plains (0-300 m), foothills (300-1000 m), lower escarpments (1000-1600 m), upper escarpments (1600-2200 m), high mountains (2200-3000 m) and rain shadow slopes (1700-2200 m). The upper Wadi Bishah is located in the last two zones (see Fig. 4-4). The plant species of each of these ecological units then were recorded.

Of other recent authors, Youssef & El-Sheikh (1981) presented a study of observations on the vegetation of gravel desert towards the north-east of the research area (central Saudi Arabia). This study related the changes in vegetation condition and type in this area as being, due to environmental factors, such as drought, gravely texture, small depth of soil and depression of soil moisture. As a result of all these unfavourable environmental conditions, the vegetation of gravel deserts in this area is an open scrub of poorly developed xerophytic perennial herbs.

As part of an ecological study of the Makkah region, which is situated to the north-western of Wadi Bishah, Organgi (1982) studied the vegetation development of Wadi Fatema. Two habitats are situated in this Wadi: a) natural habitats and b) disturbed habitats. The natural habitats include three microhabitats, the first of which is delimited by the stratified communities of the Wadi-beds characterised by the presence of a tree stratum composed of **Acacia tortilis** or **Capparis decidua** and a ground or field stratum composed of herbaceous plants. The second is formed by unstratified Wadi-bed communities, distinguished by the presence of seven associations. The third comprises Wadi cliffs, which are characterised by the presence of dwarf shrubs of **Acacia spp**.

Also in 1982, Nader said in his study, " First records of Flora from the Highlands of Asir", a resume of botanical explorations in south-western Saudi Arabia, that nine species belonging to seven families had been recorded. These species and their families are: **Caralluma plicatiloba**, **Caralluma quadrangula**, **Huernia lodarensis** (Asclepiadaceae.), **Paronychia chlorothyrsa** (Caryophyllaceae.), **Falkia oblonga** (Convolvulaceae.), **Salvia schimperi** (Labiataceae.), **Lathyrus pratensis** (Leguminoseae.), **Lathyrum salicaria** (Lythraceae.) and **Craterostigma pumilum** (Scrophulariaceae.).

Subsequent to this, Brooks & Mandil, (1983) investigated the vegetation dynamic in the Asir woodlands which are located within the Wadi Bishah secondary watershed system. The study revealed that two tree species (**Acacia seyl.** and **Juniperus procera.**) and five shrubs (**Clutia richardiana**, **Conyza incana**, **Dodonaea viscosa**, **Euryops arabicus** and **Lavandula dentata.**) dominated the woody vegetation in the juniper woodlands. Plant densities are generally higher in the lower elevations and on south-west and west-facing slopes. Species segregate on the basis of ecological importance depending on slope aspect, elevation and human impact through wood gathering and grazing activities.

A descriptive study of the vegetation cover in the republic of Yemen (to the immediate south of the research area) was conducted by Sankary also in 1983. The author discussed the distribution of plants and their habitats, and suggested that the Yemen Republic has just 370 species. The distribution of vegetation is scattered, and it is low in density (1%).

In the following year (1984), Kurschner published two articles relating to epiphytic communities and an epilithic bryophyte community in the Asir mountains (SW Saudi Arabia). The first article indicated that there are four epiphytic communities here, comprised of 13 lichens and 10 mosses. The distribution of these communities is closely correlated with climatic and biotic factors, and is determined by the range of the summer monsoon. The second article revealed that the study area is very poor in epilithic bryophyte species.

The vegetation life in the kingdom of Saudi Arabia then was discussed in an overview by Al-Aodat et al. (1985) in their book, "Plant Geography". Flora and plant geography in Saudi Arabia are discussed in Chapter Three. The authors indicated that Saudi Arabia falls within two plant biogeographic regions: the Saharo-Arabian region which covers the northern, central and eastern parts of the Arabian peninsula, and the more tropical Sudanian region, which covers the south, south-western and south-east of the Arabian peninsula (see Fig. 4-1). Vegetation genera, species, families and classes in each region are listed. Vegetation regions and habitats are classified in chapters Five and Six. The results are similar to those presented by Migahid (1980), mentioned above.

In the Arab Gulf countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates), Batanouny (1987) carried out a survey study of plant ecology, listing the plant species and plant communities, and investigating the climatological data and physiography of the area as regards their influence on plant life. The author divided the whole area into three groups, namely,

a- desert plant communities, dominated by 36 plant communities,

b- Halophytic plant communities, dominated by nine plant communities,

c- mountainous plant communities (Upper Wadi Bishah is located within this group), dominated by five plant communities. These latter communities are dominated by: **Juniperus procera**, **Olea africana**, **Acacia asak**, **Ficus salicifolia** and **Acacia seyal**.

Muller et al. (1987) confirmed in their brief study, "Applied Vegetation Studies in the Yemen Arab Republic", that the south-western part of the Arabian peninsula (which includes Wadi Bishah) is the richest vegetation region in Arabia, containing more than two thousand different plant species, belonging to about 120 families, a considerable advance on the number suggested by Sankary (1983).

A descriptive and analytic study of the phytogeography of south-western Saudi Arabia then was conducted by Konig (1988). He focused on three regions: Tihamah, the Asir mountains and the eastern slopes (Wadi Bishah stretches over the Asir mountains and the eastern slopes). The study revealed that 50.8% of the plant species have belonged to the Sudano-Zambezo-Sindian (Sudanian) chorotype, Specially in the low and middle altitudes. Within the Tihamah plain, as well as on the eastern slopes, the Saharo-Arabian influence is obvious. Towards the montane region, the Afromontane taxa increase and characterise the vegetation. High percentage of Mediterranean and Irano-Turanian species are also found here.

Subsequently, Frey & Kurschner (1989) produced a vegetation map for the Middle-East. On this map, eight major plant types were grouped in the Arabian Peninsula as follows: 1) Closed forests, 2) Woodland, 3) Scrub, 4) Dwarf-scrub and related communities, 5) Herbaceous terrestrial communities, 6) Deserts and other scarcely vegetated areas, 7) Wadi communities, and 8) Other vegetated forms. Against the opinion of all previous studies that had been done in this region, Frey & Kurschner classified the research area as being rock desert. It should be indicated that this is a misinterpretation, or a cartographic error for this part of Arabian Peninsula. It should be classified as woodland in high mountains, and savanna in highland and basins.

Zoght (1989) presented a brief scientific study of the growth and distribution of Acacia trees in Saudi Arabia. The results of his study indicated that Saudi Arabia has nineteen species of these plants. Three species (**Acacia arabica** or **Acacia nilotica**, **Acacia gerradii** and **Acacia negrii**) are encountered in Wadi Bishah.

In 1991, Al-Qahtani investigated the interrelationships between characteristics of soil and morphology of trees in Wadi Wad (south west Saudi Arabia). His study revealed 30 arboreal species, belonging to 17 families, and dominated by **Acacia gerrdii** and **Acacia negrii**. The arboreal density was 1.1% and the relative density was 26%.

A brief study of the distribution of plant communities across the Al-Abna escarpment was presented by El-Karemy & Zayed in 1992. This region is located to the north-west of the upper Wadi Bishah, and extends for a distance of 65 km with a sharp rise from 280 to 2000 m above sea level. Three altitudinal sectors could be distinguished along the course of the escarpment: the Tehama sector (less than 600 m in altitude), a gentle-slope sector (600-900 m), and a steep-slope sector (900-2000 m). 141 plant species were listed, belonging to 15 plant communities.

"Deterioration of grazing status and methods of improvement in Saudi Arabia" was the title of a report presented by Al-Hassan (1993). The author attributed the deterioration of vegetation to overgrazing, departure from the traditional pattern of grazing, the use of modern equipment, construction activities and wood-cutting. He recommended the creation of an environmental data base, delimitation of grazing lands, cessation of commercial wood-cutting with provision of alternative sources of energy, restriction of the nomads' methods of transport, provision of forages, and guidance programmes and restoration of the protection system.

A comparative ecological study on the vegetation of protected and grazed areas was conducted by Hajar (1993) in the Al-Bahah region, to the north west of Wadi Bishah. His findings revealed 72 species belonging to 32 families. The protected part maintained a higher species diversity and more edible plants, such as **Combopogon schoenanthus**, **Hyperhenia hirta**, **Osteospermum vaillantii Norl.**, **Cenchrus ciliaris**, **Eragrostis pilosa** and **Rumax vesicurius**. The plants open to grazing had a low cover, and consisted mainly of non-edible species, such as **Asphodelus fistulosus**, **Psiadia punctutata**, **Lavandula dentata**, **Blepharis ciliaris** and **Francoeuria crispa**. Moreover the plant species of the latter area were severely damaged.

In the Gizan region, which is located to the west of Wadi Bishah, Basahy & Monawar (1994) studied the weeds there and listed 28 species belonging to 16 families. A brief description of each plant was provided for easy reference. Plants were listed in alphabetical order, by family.

In the same year, El-Demerdash & Zilay (1994) presented a brief study of the plant ecology of the Tihamah plains which are situated to the west of Wadi Bishah. The study showed that there are five distinct habitat types in the Tihamah plains, namely: shore-line, sand formation, salt marshes, Wadis and rocky hills. A total of 153 plant species belonging to 46 families occupied the different habitat types of the Tihamah plains. Chamaephytes and therophytes were the most dominant life-forms in the study area.

In the same region, El-Demerdash, et al. (1994) presented a study under the title, "Distribution of Plant Communities". Their results indicated that eight major community types constitute the major part of the natural vegetation of the study area and are dominated by nine perennials:

Ziziphus spina-christi, **Calotropis procera**, **Leptadenia pyrotechnica**, **Suaeda monoica**, **Panicum turgidum**, **Salvadora persica**, **Acacia tortilis**, **Tamarix aphyll** and **Cyperus conglomeratus**. Moreover the results confirmed that the study area is a subtropical desert and belongs floristically to the Sudanian territory and also that therophytes are the most frequent life-form in this region.

Although some of the above studies are quite detailed (while other are generalised), it is to be noted that thus for there has be no comprehensive botanical survey of the Wadi Bishah itself.

2-5 General Literature on the Relationship Between Slope and Soil Properties.

Topography is one of the five main factors of soil formation, and the slope is the most important topographical factor affecting soil. Most of the differences in soil can be explained by the variation in slope factors (Jenny, 1941). Many studies have shown that various soil properties are related to the position of a soil along a slope (Yair, 1990), as well as to the slope's angle, length and form.

The processes of erosion, deposition, movement of water and materials are governed by the geometric configuration of the slope and by the manner of vegetation distribution (Gerrard, 1992; Youssef, 1987). This is the result of interaction between slope factors and soil properties. It is clear that there are fundamental differences between soil relationships on convex and straight units and on concavities (Gerrard, 1992).

Unfortunately, thus for, most distinct studies similar to the present research, especially studies which focused on the relationship between slope and soil properties, have been conducted in humid regions, such as Furley (1968 and 1971), Gerrard (1988), Marts (1992), Liu et al. (1994), and Makhnach (1994), whereas the research area is located in a semi-arid and arid region. Therefore, the following paragraphs concentrate on the literature which has been executed in arid and semi-arid areas.

In one of the earliest and best studies, Duley & Hays (1932) investigated the effect of the degree of slope on run-off and soil erosion. Two methods were used, one of them applied in the laboratory, and the second carried out in the field. The sample plots were placed at different angles on hill-sides. The results from the two methods indicated that the run-off was found to increase rapidly as the slope increased from zero to about 3 per cent gradient. The increase in run-off was then very slight for each further per cent of increase in slope. Soil erosion increased very gradually until the slope was about 4 per cent, then the increase was found to be more rapid up to about 7 or 8 per cent. The amount of run-off water required to erode 1 pound of soil decreased rapidly as the slope increased from 1 per cent to about 10 per cent. Soil erosiveness was shown to depend not merely on the physical properties of the soil, but also on the degree of slope and possibly on several other factors. A silty clay loam gave greater erosion on the lower slopes, whereas a sandy soil gave more erosion than did the silty clay loam on steep slopes.

Under the title "Soil Losses as Affected by Cover, Rainfall and Slope", Gard & Doren (1949) studied the influence of these factors on soil of the lower Mississippi region (U.S.A). The results of their study showed that steepness of slope is a dominant factor in influencing soil losses, but is not the only one. On 5% slopes, soil losses in tons per acre increased as plot length increased from 35 feet to 140 feet. Plots 210 feet in length lost less soil per unit area than those of 140 feet. Soil losses on 9% slopes increased with an increase in length of plot from 35 to 210 feet. In the case of slopes combining both convex and concave shapes, the steepness and length were less important than the sequence of adjoining segments.

Bushnell (1943) confirmed that the slope angle affects soil genesis in several ways. Flat regions and simple slope regions possess more accumulation and a lot of minor minerals, whereas the erosion and soil content of primary minerals increases and accumulation decreases, with an increase of slope angle; as a result, the profile of soil becomes shallow, and vegetation cover is reduced.

In 1962, Walker presented a brief study of soil layers on hillslopes in New South Wales, Australia. The results of this study indicated that the sequence of soil layers could be considered to be evidence of the soil's history of evolution. The evidence suggested that a phase of instability resulted from a change to relatively dry climatic conditions and involved processes such as hillslope, gully erosion and soil creep.

Pediment slope and particle size at middle Pinnacle, near Broken Hill, New South Wales, was the subject of Dury's study (1966), in which he studied two traverses of a pediment. From the collected data, Dury constructed logarithmic regressions of slope and the particle size quartiles on distance down pediment. The regression plots show that on both traverses all the particle size statistics decline in an orderly manner down slope, and the regression slope coefficients are less than those calculated for the pediment slope itself. In other words, the rates of particle-size decrease appear to be less than the rate of slope decline.

Cooke & Reeves (1972) investigated the relations between particle size and slope along traverses across mountain fronts and pediments on quartz-monzonite and other rock types in the Mojave desert, California. The results showed that slope usually declines with distance along a traverse, except on some quartz-monzonite pediments. The size of the largest particle generally decreases most rapidly down slope, but less rapidly than the decline of slope. The change of slope between mountain front and pediment is most pronounced on the quartz-monzonite surface, and this is attributed to the presence of both boulders and grus on the mountain fronts, and the absence of boulders on the pediment.

Batanouny (1973) carried out a valuable study of soil properties as affected by topography in Wadi Hof, Egypt. The studied area has numerous terraces and an irregular topography. The changes in topography led to the existence of five different habitats, namely shaded habitat; Wadi bed; the terraces, i.e. first terrace, second terrace "A", second terrace "B"; slope; and plateau. Each of these has peculiar environmental conditions and plant cover. Slope profiles in the different habitats were investigated. Soil texture, soil moisture content and total soluble salts were examined on samples collected from the different habitats. The results of the study emphasised the role of topography as an influential factor on soil properties. Regarding slope, materials transported from high levels on the plateau lodge among the angular stones on the slope. These materials are fine and have a high water holding capacity. The highest soluble salt content among all habitats was recorded in the slope habitat (5.5%). During the wet season, the soil solution in the upper layer is diluted. Generally, changes in soil properties and plant growth on the slopes were found to depend on the exposure and degree of slope.

Reid (1973) presented a brief study of the influence of slope orientation upon the soil moisture regime upon it. The results of this study indicated that the spatial inequalities on slope sides are diminutive. Nevertheless, a seasonal divergence of soil and the soil-moisture condition is sufficient to effect within-catchment differences in water organisation.

Yair & Klein (1973) carried out a brief study of the influence of surface properties on flow and erosion processes on debris-covered slopes in a small drainage basin, in Israel. The study aimed to obtain quantitative data on the processes of slope runoff and erosion under arid conditions. Two results were obtained from the study, namely:

1-For a small drainage basin, the threshold values for slopes and channel flow are 3 mm and 5 mm per day, respectively;

2-No clear relation exists between slope angle and slope runoff, and an inverse relation exists between slope angle and slope erosion.

In a vital study of the influence of mulch rate and slope-steepness on interrill erosion, Lattanzi et al.(1974) investigated this situation and summarised the following important results:

-Interrill erosion can be virtually eliminated by complete mulch cover, but lesser amounts of mulch will greatly reduce interrill soil losses.

-Interrill erosion is influenced much less by slope steepness than is rill erosion or total field erosion.

-Interrill erosion is a major source of soil eroded from bare upland slopes.

Zouzou & Furley (1975) presented a detailed study of the nature and formation of a toposequence of arid soil over the terraces of the Balick valley, Northern Syria. The objective of their study was to describe and interpret the nature of soil and its relationship with natural environmental factors, such as topography, drainage and geomorphology. The study confirmed that the pattern of soil properties could be seen to be closely associated with the distribution of geomorphologic units over the toposequence. The two factors of distance downslope and gradient together explained much of the distribution of surface soil properties. One group of properties increased over the lower slope elements. These included sand percentage, clay percentage, moisture loss percentage and pH, which bore a highly significant positive relationship to distance downslope. The total soluble salt level decreased with distance. These findings seemed reasonable in view of the calcareous and gypsifereous nature of the upper slope. Another group of properties was found to be inversely correlated with gradient. These included clay and sand percentages, pH and moisture loss.

In 1977, Hadley & Toy presented a short study of the relationships of surfacial erosion on hillslopes to profile geometry. The data were collected from western Colorado, USA. The findings of the study clarified that the erosion from straight hillslope segments was about twice the amount from convex and concave segments along hillslope transects. Standard deviations of erosion measurements for each segment show that the greatest variation occurs in concave slope segments. This is probably because the concave segment is the only place on the profile where deposition occurs. Analysis of variance indicated that the amount of erosion is significant at the 1-per cent level of confidence between convex and straight slope segments, and at the 5-per cent level of confidence between straight and concave slope segments.

In 1979, Bryan tested the impact of slope angle on loss of soil materials by sheetwash and rainsplash in Alberta, Canada. Eight soils and ten slopes from 3° to 30° were chosen. The findings of the study indicated that the material eroded was separated into that transported by rainsplash and that by sheetwash. The influence of changes in slope angle on soil transport is best described by a polynomial relationship. Also, the findings showed that there are other factors than slope angle which result in a high variability in soil properties.

Akagi (1980) studied the relationship between particle size and slope along traverses on several types of basement rock in southern Arizona. The results of his study clarified the strong relation between particle size and inclination of slope on each traverse. However, between the different rock type traverses, on slopes of the same inclination, there were differences in particle size . On non-granite rock capped by hard rocks, particle size increased with the decrease of slope in some parts of the traverses. A positive relationship between particle size and slope decline was apparent.

The characteristics of soil and their relationships on arid hill-slopes were the main objectives of the study that was conducted by Wieder et al. (1985) in the Negev, Israel. Two catenas, on a north-facing slope and on a south-facing slope in an area with 90 mm annual average rainfall were selected. The slopes were subdivided into two distinct parts. The upper one was characterised by extensive bedrock outcrops and discontinuous shallow lithosols. The lower part of the slope was colluvial. Vertical lateral soil differentiation in the colluvium, as expressed by lateral and vertical distribution of secondary carbonates, gypsum and soluble salts, indicated a down-slope decrease in the intensity of leaching. The highest intensity of secondary carbonate accumulation occurred in the upper part of the north-facing colluvium where most of the overland flow infiltrated. In the middle part of the colluvium, where the amount of infiltrated water was limited, a loessial serozem soil type occurred with a calcic horizon overlying a gypsum horizon. At the lowest part of the colluvium, runoff contribution was very limited leading to the formation of a gypsic horizon in the upper part of the profile. Gypsum accumulation was associated with the partial dissolution of carbonates. The pronounced soil differentiation into calcic and gypsic horizons suggests a relative high stability with slow rates of erosion and deposition in the colluvium.

The effect of slope angle (5-30%) and the addition of phosphogypsum that changes the water quality, on the infiltration rate, runoff and erosion from an unstable sandy loam soil material was studied using a rain simulator, in samples taken from the coastal plain of Israel, by Warrington et al. (1989). The results of their study revealed that increasing the slope slightly reduced the amount of runoff and increased the final infiltration rate. Phosphogypsum application reduced erosion by 60% of the gentlest slope angle. Change in slope angle from 5-25% doubled soil loss in the phosphogypsum-treated soil samples but increased seven-fold soil loss from the untreated soil samples.

The role of topography and surface cover upon soil formation along hill slopes was investigated by Yair (1990). Two slopes were selected within the northern Negev desert, in Israel. Both slopes were composed of an upper rocky and a lower colluvial section. Similar trends were found along both slopes. A high salt content was characteristic of soils at the top of the slope. Salinity decreased downslope within the rocky slope section. The opposite occurred along the colluvial slopes, with salinity increasing sharply downslope. Also, the results of the study confirmed the importance of the rainfall ratio on soil formation along hill slopes.

The effects of slope length and phosphogypsum on runoff and erosion from steep slopes were the main focus of a study by Agassi & Ben-Hur (1991), conducted in the centre of the coastal plain of Israel, and using field work and quantitative analysis. The results of the study emphasised the importance of the role of phosphogypsum to runoff, and slope length to soil loss. Phosphogypsum reduced runoff by 23%, and erosion was 2-3 times less than on the control slope. The length of the plots had no effect on the runoff;

however, soil loss was 6.4 times higher in the longer plots. High correlations were found between the amount of erosion and the amount of runoff.

In a recent and important study that was conducted in semi-arid land, and discussed the relationship between slope factors and vegetation type and cover as independent variables and the surface soil as well as the surface rock fragment cover as dependent variables, Simanton et al.(1994) demonstrated that slope and vegetation factors play the major role in surface soil properties, soil profile and surface rock fragment cover. The method of this study depended upon field measurements and laboratory and statistical analysis. Correlation analysis showed that both slope gradient and soil profile rock fragment content were significantly ($P < 0.01$) correlated to surface rock fragment cover. Further analysis indicated that the combined effects of slope gradient and soil profile rock content were better defined by a soil-slope factor. The findings of the foregoing study, carried out in Arizona and Nevada, USA, suggested that similar relations may exist in areas with similar geology and climate, such as parts of Africa, Asia, Australia and South America.

The relations between particle size and pediment slope was the focal point of a study that was carried out by Vincent & Sadah (1995) in the Al Aqiq and Al Jobub areas of the southern Hijaz region, Saudi Arabia. This was examined over 15 traverses on rock-cut pediment. Analysis of data collected from these traverses showed the following findings.

- On 9 out of 15 traverses the rate of down-slope change in the mean particle size of the fine sediment fraction was statistically less than that of the pediment slope itself.
- On 5 out of 12 traverses the rate of down-slope change in the mean particle size of the coarse fraction was also statistically less than the pediment slope.

- The rapid down-slope disintegration of weathered granites in the Al Jobub area is probably the reason why there are statistically similar rates of change in the mean particle size and pediment slope, for both fine and coarse components.
- The storing of the fine fractions appears to be little related to pediment slope.

Finally, the majority of studies mentioned above have indicated that the various soil properties are related to the slope's angle, gradient length and form, as well as the position of soil along a slope.

2-6 General Literature on the Relationship Between Vegetation and Soil Properties.

The biotic factor (plant, human, animal and microbiology) is considered one of the basic five factors of soil formation (parent material, topography, climate, biotic factor and time) (Yousef, 1987). It is clear that there are intimate interrelationships between the vegetation cover and the kind of soil in each plot upon the earth surface (Kayani & Sheikh, 1981; Abulfatih, 1991). Previous and recent researches have confirmed that vegetation cover has led to clear changes in soil type and formation (Yousef, 1987). Unfortunately, previous works in this direction are very few and most of them have focused more on the influence of soil on vegetation, than the influence of vegetation on soil. The important results of these studies, particularly those studies that were conducted in arid and semi-arid areas, are as follows.

Kayani & Sheikh (1981) investigated the interrelationships between soil and vegetation in the south-eastern coastal lands of Pakistan. The study indicated that these relationships are governed by a complex of environmental factors including climate, soil, geology, topography and biotic factors. However the results of the study confirmed the close relationship between soil and plants.

A specialised biological study was carried out by El-Naggar (1982), under the title "Inhibition of Nitrification in Soil under **Juniperus procera** Woods in Asir region, Saudi Arabia". Two plots were studied, one representing an area dominated by **Juniperus procera** and another lacking this species, at two localities near Abha (south west side of Wadi Bishah). Soil samples taken from the 0-15 cm and 35-50 cm level were analysed for ammonium and nitrate nitrogen. The counts of Nitrosomonas and Nitrobacter were determined in the 0-15 cm level. Both Nitrosomonas and Nitrobacter were lower in frequency in soil samples collected from **Juniperus procera** dominated areas than from those lacking this plant. The depletion in counts of Nitrobacter and in the amount of nitrate nitrogen in plots with **Juniperus procera** indicates an inhibitory effect exerted by this plant on nitrifiers.

Younes et al. (1983) presented a brief study of the relationship between soil characteristics and vegetation in a small part of the western coastal plain, Saudi Arabia. Three vegetation types were recognised in the study site, namely (a) mangal, dominated by **Avicennia marina,** (b) salt marsh, dominated by **Halopeplis perfolliata, Aeluropus massauensis** and **Zygophyllum coccineum** and (c) coastal desert, dominated by **Panicum turgidum** and **Acacia tortilis.** Soil samples collected from sites of these communities were analysed chemically and physically. The results revealed strong interrelationships between soil characteristics, the volume of vegetation cover and vegetation density.

A study of the relationship between soil properties, soil moisture and vegetation was the focus of interest of Kadmon et al. (1989), in a study carried out in the Negev desert, Israel. Two slopes representative of the area were chosen for the study. A transect running from the top to the base of each slope was then selected, and soil and vegetation selected for study along each transect. The findings support the view that environmental aridity increases in the downslope direction and in more general terms, that water availability in a non-sandy desert depends mainly on the ratio of bare bedrock to soil cover.

The relationship between soil and vegetation at several arid microsites in the Wadi Araba (Jordan) was studied by Jenny et al. (1990). Although the study centred on the influence of soil properties on plants and their habitats, its results have emphasised the importance of the plant role on soil formation.

Al-Qahtani (1991) examined the characteristics of soils on the slopes of Wadi Wad (south west Saudi Arabia), and emphasised the importance of vegetation and slope degree to the stability and formation of soil.

In semi-arid lands, the spatial and temporal influence of vegetation on surface soil factors was investigated in different plant communities by Blackburn et al. (1992). Their findings indicated that vegetation was the primary factor influencing the spatial and temporal variability of surface soil processes controlling infiltration and interrill erosion rates. On sagebrush dominated landscapes, vegetation growth form was the primary factor influencing surface soil factors that control infiltration and erosion rates. On grass-dominated landscapes, the temporal response of surface soil factors induced by normal variations in climate, plant cover and biomass was greater than the spatial variability induced by grass growth form.

Smettan et al. (1993) studied the relationships between plant distribution and soil conditions in sand dune and playa in Wadi Araba, Jordan. Four sites were selected for study of vegetation and soil, namely, top of the dune, middle of the dune, bottom of the dune and the playa. The results of the study confirmed the importance of soil water to plant distribution, and the importance of plant density to soil stability.

"Vegetation-soil relationships" was the title of a study carried out by El-Demerdash et al. (1995) in the Tihamah coastal plains of the Jizan region, Saudi Arabia. Contrary to what is suggested by the study title, the authors concentrated their investigation on the distribution, density and species of plants, giving only a simple glimpse of the effect of some soil attributes on the distribution of vegetation. The results of their study indicated that the study area is a tropical desert and belongs floristically to the Sudan territory and also that therophytes are the most frequent life-form in the communities. The distribution of the recognised plant communities is affected mainly by physiographic features and climatic conditions, as well as soil attributes. Eight major community types constitute the major part of the natural vegetation of the study area and are dominated by nine perennials: **Ziziphus spina-christi**, **Calotropis procera**, **Leptadenia pyrotechnica**, **Suaeda monoica**, **Panicum turgidum**, **Salvadora persica**, **Acacia tortitis**, **Tamarix mannifera** and **Cyperus conglomeratus**. Analysis of the correlation between the vegetational gradients and the edifice factors showed that soil pH, moisture, electric conductivity, organic carbon, calcium carbonate, bicarbonate, soil cations: sodium, potassium, calcium and the sodium adsorption ratio are the main operating edaphic factors in the area.

The relationships between soil, vegetation and land use were the main objective of Fernandez's et al. study (1995), that was carried out in a Mediterranean ecosystem, El Ardal, Mrcia, Spain. Several pedological (water retention capacity, hydraulic conductivity, distribution and stability of aggregates, organic matter content, and texture) and vegetal characteristics (litter production and litter decomposition, below ground biomass) were studied. The study of the soil characteristics was made along a transect, which descended from the top of the slope to the valley bottom. Vegetal cover was measured using the line transect and point quadrat methods. This transect reflects several typical land use types of a Mediterranean semi-arid environment. The results show a close relationship between soil development and vegetation characteristics, a notable difference between soils from cultivated plots and those in a semi-natural state, and an appreciable recovery of the soil characteristics of plots where cultivation has been abandoned.

Finally, it is noteworthy that the foregoing review of literature relevant to the area and subject of the present study has discussed in detail several aspects covered by the present research, such as the vegetation cover of the study area and the impact of some slope factors (slope angle and slope gradient) on erosion and property of soil. On the other hand, some aspects dealt with in the present research have not received much attention. These aspects and others are:

-Few and scattered studies have been carried out in the research area of the geological structure, topographical formation and soil. The majority of these studies were descriptive and lacking in scientific analysis.

-There is a considerable amount of literature on the effect of vegetation on soil, but most of these studies have concentrated solely on the effect of vegetation intensity on soil stability.

-Regarding the influence of slope factors on soil properties, there is an abundance of studies, but most of these studies were carried out in humid regions and focused on only one or two slope factors.

-Several studies have emphasised the importance of the impact of slope form (straight, convex, concave and wavelike) on erosion and properties of soil, but this factor has not received a great deal of critical attention.

Based on the current level of understanding of this research topic, some conceptual ideas provided by the available literature can be developed as follows:

- Despite the majority of soil studies were descriptive, it can be characterised the soils of the research area as shallow and coarse and belong to the broad Entisol and Aridisol hierarchies.
- Literature on vegetation of the research area have demonstrated that Acacia arabica, Acacia negrii, Juniperus procera, Euryops arabicus and Dodonaea viscosa are the species that compose and provide the main vegetation characteristics of Wadi Bishah basin.
- In modest signals, the previous studies indicated that floristic composition and the distribution of main plant groups have reflected the conditions of climate and topographical variety.

CHAPTER THREE
Methods of Research

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3-1 Introduction.

This chapter explains the main methods that were selected and applied to serve the purposes and aims of the present research. Following the selection of the research area, and the setting of study goals and objectives, all available literature and primary information and data relevant to the purposes and scope of the study were obtained and carefully examined in order to understand their contribution to the research topic. Methods and techniques for application in the present research were selected when the researcher had satisfied himself that these were the best and most suitable methods and techniques for the topics and in the location of the study. These methods and techniques are standard ones which are described in detail in many text books and have been applied in many similar studies, such as Soil Survey Staff (1992), Al-Mashhady (1984).

Implementation of these methods and techniques involved seven stages, namely, primary data collection, reconnaissance-surveys, fieldwork, laboratory and herbarium analysis, statistical treatment and analysis, discussion of the results and the conclusion and recommendations. Each stage was divided into substages, as can be seen from Fig. 3-1. Several difficulties faced the researcher during the execution of these stages and substages. Some of these pertained to transport and communication, and the nature of the topography and climate of the study area. The other difficulties related to the style of dealing and customs of the people who live in this area. The first problem was transport. Some parts of the study area have very few or no roads and tracks even for four-wheel drive vehicles which might provide access to their interior sites, therefore, in many cases sites were reached on foot. Animals (camels and donkeys) were used to convey the research equipment to certain sites. The second problem was how to establish sites for measurement and sample collection in this rough terrain. As indicated in Chapter One, the research area is very varied in its topography. It contains high mountains, escarpments, deep valleys, rolling lands and rocky hills, which pose a great challenge of access to researchers in this field. The resolution of this problem depended on the researcher's prior experience in this area, in which he was raised, and on consultation with the research supervisor, who visited the study area for this purpose. The third difficulty was the daily climatic changes, especially in July (see Chapter One). These changes reduced the daily work hours in the field. The fourth difficulty was the remoteness of some parts of the research area from urban centres, so that the researcher had to make long daily journeys from the nearest small urban centre to the area under study. Finally, there was a difficulty in obtaining help in digging and portage of equipment. Often, employees were unwilling to work in the study area because of its rough terrain; therefore, considerable reliance was placed on the assistance of relatives and friends of the researcher.

3-2 Collection of Raw and Primary Data.

For the identification of environmental conditions in the research area, raw and primary data were collected during June and July 1995, such as climate and vegetation cover, together with geographical and geological maps and various other statistical and hydrological information needed, all of which were obtained from a variety of sources and government departments in Saudi Arabia, such as the Ministry of Agriculture and Water, Ministry of Finance and National Economy, Ministry of Petroleum and Mineral Resources, and the Meteorology and Environmental Protection Administration (MEPA).These data were presented and discussed in Chapter One.

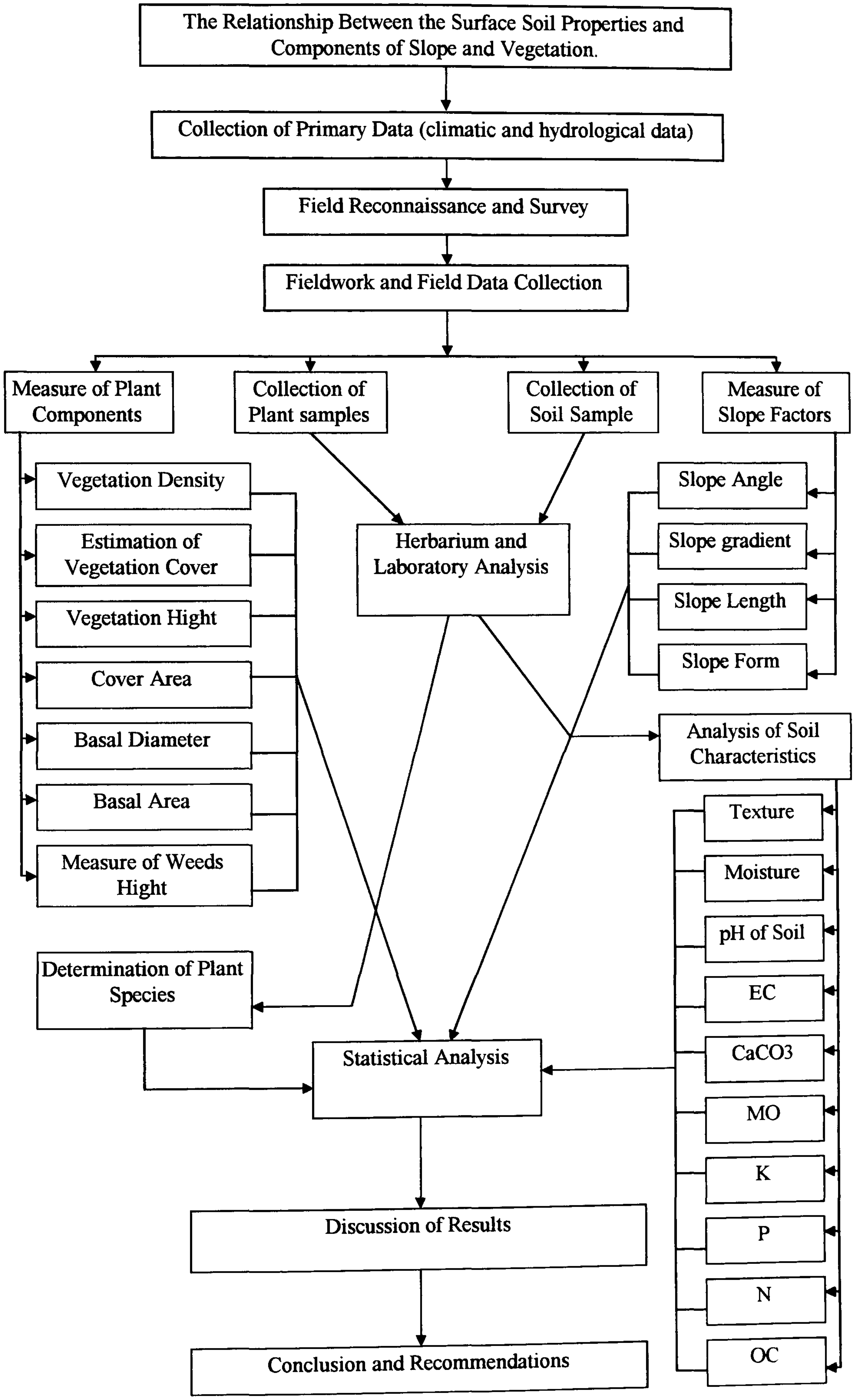

Figure 3-1 Diagram of the study stages.

3-3 Fieldwork and Data Collection.

As mentioned earlier, the field study was carried out in wide and rough terrain, over a total area of about 7,600 square km, stretching 225 km from north to south (Mohammed, 1989). The aims of the fieldwork were collection of data and samples of slope, vegetation and soil, as well as writing down important field observations that might assist in an explanation of some variations in soil properties.

3-3-1 Field Surveys of the Research Area.

In order to achieve the purposes and aims of the present study, two detailed surveys were accomplished by the researcher and the supervisor of the present research during the summers of 1995 and 1996. The first survey was carried out by the researcher, and the second was carried out by both. These surveys involved thousands of kilometres of inland travel in the mountains and plains of the research area. In view of the limitations of satellite images and the unavailability of aerial photographs, as well as the impossibility of an aerial flight over the research area, which might have helped in setting the sampling sites, the choice of transects and sites was determined by careful survey of the land using available maps, and aided by the experience of local people in some areas. Considerable information was collected via these surveys, such as the possibility of future transport, the general forms of topographical structure and vegetation cover, and additional environmental data. This information assisted in the choice and planning of research methods.

3-3-2 Time of Sampling Collection.

According to ecologists and pedologists, e.g. Migahid et al. (1987) and Youssef (1987), the best and most suitable period for gathering samples of soil and vegetation is after rain. As shown in Chapter One, the climatic data obtained from twelve meteorological stations within and near the research area indicated that the main rainy period over the catchment area and its surroundings stretches from November until the end of May (see Tables 1-6 and 1-7). As a result and, also, on the basis of the author's own experience and familiarity with the research area, which has extended over several years and in all seasons, direct observation and fieldwork were carried out in the period June to August 1996. During this period, the fieldwork was divided into two stages. In the first stage, fieldwork focused mainly on studying, measuring and evaluating the slope factors, vegetation cover and interviews with the herdsmen controlling the livestock herds. In the second stage, collection of soil samples and vegetation samples was carried out at the sites selected during the reconnaissance surveys. Gathering of these samples was delayed to the second stage so they would be fresh when transferred to laboratory and herbarium. In view of the increase of temperature at midday, all samples of soil were collected in the early morning or late in the day, to minimise the influence of temporal changes on soil moisture content.

3-3-3 General Field Observations.

Many observations which helped to explain variations in the soil characteristics and vegetation cover, were recorded during the fieldwork period, as well as the registration of encountered vegetation species that were not located at any sampling point.

3-4 Methods of Data Collection.

To realise the purposes and objectives of the present research, and taking into consideration the topographical structure, climatic condition and vegetation cover of the area under study, both systematic transect and point-centred quarter methods were adopted as the most appropriate to carry out the present study. These methods have been explained in many text books and applied in many scientific researches, such as Goldsmith et al.(1986), Kershaw (1973), Kent & Coker (1992) and Mueller-Dombois and Ellenberg (1974), etc.

Goldsmith et al. (1986: 456) summarised the advantages of the systematic transect method as follows:

"Transects are a form of systematic sampling in which samples are arranged linearly and usually contiguously. They are very commonly used in studies and are appropriate to the investigation of gradients of change when they should be positioned at right angles to the zonation".

Kershaw (1973: 34) presented the advantages of transects as follows:

"Transects are of considerable importance in the description of vegetation change along an environmental gradient, or in relation to some marked feature of topography. The method simply consists of laying out a line running across the zones to be sampled and then placing quadrats at known intervals along the line".

Kent & Coker (1992: 54) summarised the transect approach and its importance to the study and analysis of vegetation cover as follows:

" The transect approach is very popular in vegetation work. A transect is a line along which samples of vegetation are taken. Transects are usually set up deliberately across areas where there are changes in vegetation and marked environmental gradients. It is possible to locate the start and end of a transect at random and then take samples along the line connecting the two points. Classic examples of laying out of transects across gradients are up hillsides, where slope angle, gradient and altitude combine; across changes in geology. The main purpose in using transects in these situations where the change in vegetation is clearly directional is to describe maximum variation over the shortest distance in the minimum time".

Additional support for this method has come from Kadmon et al. (1989), Ukpoing and Areola (1995), Zouzou & Furley (1975), Campbell (1975) and Youssef & El-Sheikh (1981).

Especial support for the point-centred quarter method is afforded by Cottam & Curtis (1956: 455), who summarised the advantages of this method as follows:

"The quarter method gives the least variable results for distance determinations, provides more data on tree species per sampling point, and is least susceptible to subjective bias. The mathematical characteristics are known. It requires no correction factor, the mean of the distances equalling the square root of the mean area. The apparent disadvantage of requiring more time per point is compensated for by the necessity for sampling fewer points. It is the opinion of the authors that the quarter method is, in most respects, superior to the other distance methods studied, and its use is recommended".

Mueller-Dombois & Ellenberg (1974) have supported this method, which was applied recently for the first time in dry land areas with sparse vegetation in Saudi Arabia by Al-Nafie (1995).

Both of these methods were applied in conjunction with each other, as required by the objectives of the present study.

3-4-1 Determination of Sampling Sites.

The delimitation of the study sampling site and form is very important, because it constitutes the main basis for data collection. Particular attention and care should be given to obtaining typical and representative samples of the situation studied. Therefore, especial attention was paid to selecting the sample sites. Delimitation of sample sites was based on the scientific methods mentioned earlier and were carried out as follows:

Sixty transects were selected systematically as profile lines along slopes in the study area. Thirty transects were established on the eastern slopes of the Upper Wadi Bishah, and the other thirty on the western slopes (Fig. 3-2). The slopes were straight in plan and convex-concave in profile. As can be seen from Table 3-1, each transect started from a specific measured point on the main stream and crossed the facing slope to the edge of the catchment area. The distance between transects was 7.5 km. Each transect was subdivided into five slope units from the ridge to the toe: summit, shoulder, mid-slope, foot-slope, and toe-slope. These units covered all the physiographic and physiognomic variations of the region. The summit was the nearly level section at the top of the slope and the shoulder was the convex section below the summit. The mid-slope was the linear section between the upper convexity and lower concavity of the slope. The foot-slope was the lower concavity and the toe-slope was the nearly level section below the lower concavity. Selection of these units, which can be seen every where, depended on variation of slope gradient and form, with soil uniformity and vegetation distribution being secondary considerations. Sample collection sites were established in the centre of each slope unit on each transect. As a result of this technique, 300 sites were determined and studied. In each site, slope factors and vegetation components were measured, and samples of soil and plants were collected. This technique has proven to be sufficient and effective in previous investigations of the relationship between slope, vegetation and soil, such as Martz (1992), Derose et al. (1993), Makhnach (1994) and Simanton et al. (1994).

3-5 Collection of Grazing Data.

In order to study and discuss the impact of grazing on soil and vegetation in the research area, sixty interviews were completed with the shepherds controlling livestock (30 interviews in the north-eastern of the study area, and 30 interviews in the south-western). The heights of weeds and grasses in each measured plot (see 3.4.1) were measured and averaged to give the mean height at each sampling point. As well as measurement of vegetation, the morphological components of trees and shrubs were assessed, and analysis of soil characteristics undertaken.

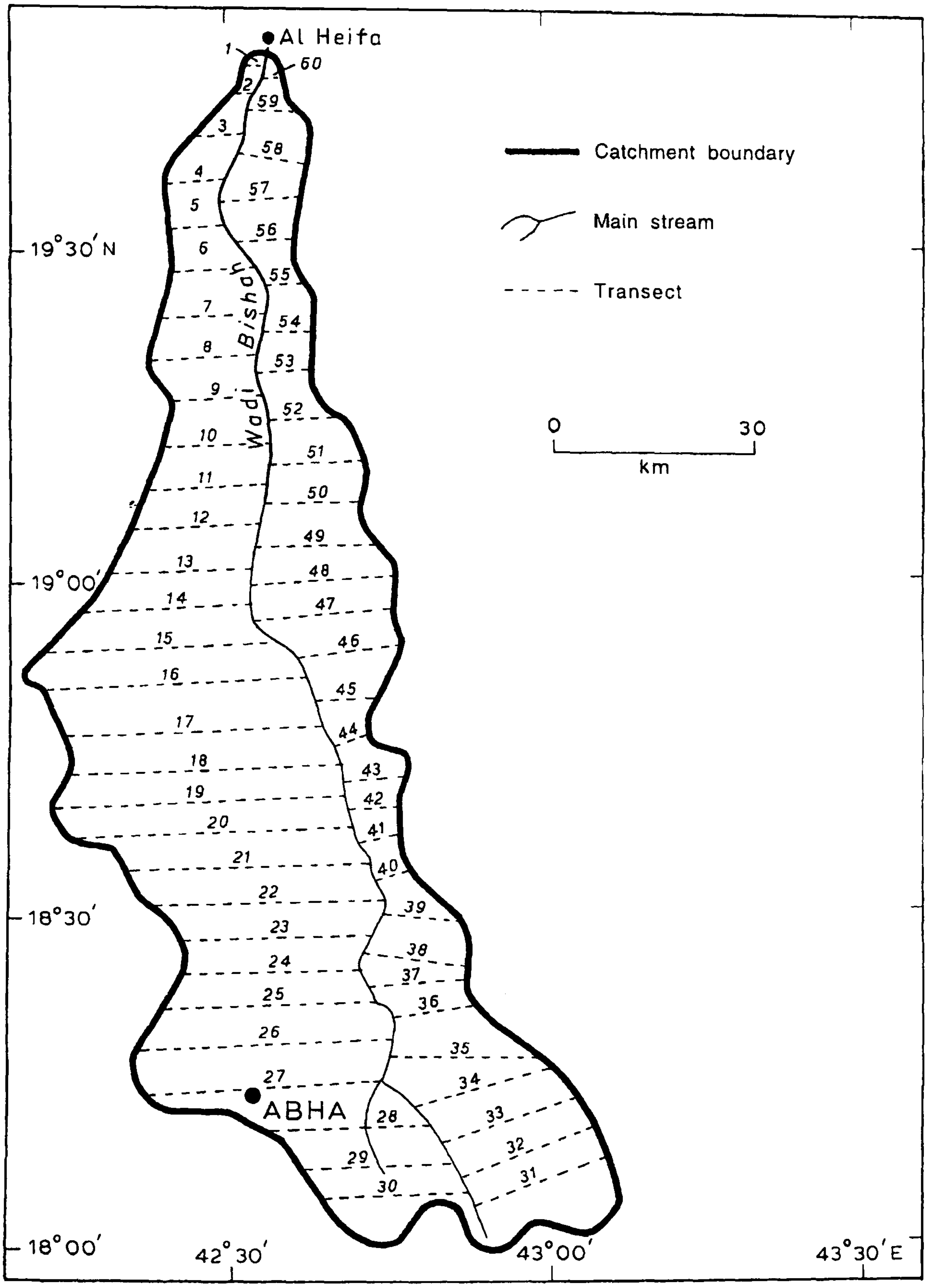

Figure 3-2 Transects of Samples Collection From the Research Area.

Table 3-1 Locations and Distribution of Transects in the Research Area.

Transect NO	Location (Point of start)	Latitude	Transect NO	Location (Point of start)	Latitude
1	West of Al Hifah	19° 48`	31	Sarat Abidah	17° 59`
2	Wa'ir	19° 44`	32	Al Ayid	18° 02`
3	Al Bahim	19° 40`	33	Al Wahabah	18° 06`
4	Jibal Halhal	19° 36`	34	Al Rabbah	18° 10`
5	Al Qawba	19° 32`	35	Kamis Mushait	18° 14`
6	Wadi Dhi Natil	19° 28`	36	Tindahah	18° 18`
7	Wadi Huwaran	19° 24`	37	Jabal Ad Dur	18° 22`
8	Wadi Nikib	19° 20`	38	Arayis	18° 25`
9	Wadi Miri	19° 16`	39	Wadi Al Majal	18° 28`
10	Jabal Bahth	19° 12`	40	Wadi Ibn Hashbal	18° 31`
11	Shaib damm Al Hamar	19° 08`	41	Al Bi Thawr	18° 34`
12	Jibal Al mashriqah	19° 05`	42	Al Ghurayra	18° 37`
13	Wadi hanif	19° 01`	43	Shaffan	18° 40`
14	Wadi Ibn Urfut	18° 57`	44	Jabal Rabhah	18° 44`
15	Al Rahwah	18° 53`	45	Timah	18° 48`
16	Jabal Dihya	18° 50`	46	Al Batnah	18° 52`
17	Umm Khisah	18° 46`	47	Al Hithadah	18° 55`
18	Al Haymah	18° 42`	48	Bir Abu Jinniyah	18° 59`
19	Jabal Al Haqba	18° 39`	49	Wadi Al Mahyub	19° 03`
20	Al Hasad	18° 36`	50	Jibal Taymar	19° 07`
21	Al Maddah	18° 33`	51	Samran	19° 10`
22	Wadi Abu Nadarah	18° 30`	52	Jibal Muharraqah	19° 14`
23	Jibal Adanah	18° 26`	53	Jibal Bu Ghuduwi	19° 18`
24	Al Utfah	18° 23`	54	Hidab Az Zuwayra	19° 22`
25	Jabal Al Wasil	18° 20`	55	Jibal Bani Luwan	19° 26`
26	Abu Nakhlah	18° 16`	56	Jabal Ash shahad	19° 30`
27	Al Sawh	18° 12`	57	Shaib Al Hanakah	19° 34`
28	Al Safrah	18° 08`	58	Wadi Runum	19° 38`
29	Al Qarha	18° 04`	59	Al Fayd	19° 42`
30	Ayn Allewy	18° 01`	60	East of Al Hifah	19° 46`

(Source: personal field work and Asir Principality and King Khaled College, 1985).

3-6 Measurement of Slope Factors.

As depicted in Fig. 3-2 and shown above, 300 sites were located on sixty transects. Each transect was subdivided into five slope units: summit, shoulder, mid-slope, foot-slope, and toe-slope. The measurement of slope factors was carried out in the centre of each slope unit. Four slope factors (slope angle, slope gradient, slope length and slope form) were measured, computed and determined as follows:

-A clinometer was used to measure the slope angle at each sample site, after careful study convinced the researcher of its suitability. Full instructions were applied and especial care was paid to using this instrument properly.

-According to the measurement of the slope angle between top of slope and the sampling point, the slope gradient was computed using trigonometry (David, 1987), as follows:

Slope gradient = B/C × 100 (Fig. 3-3).

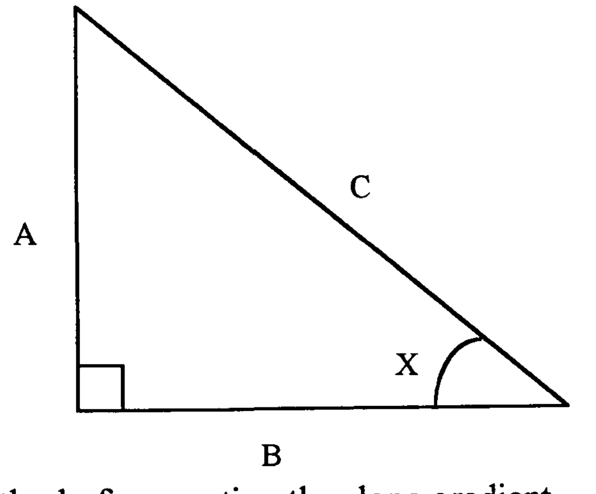

Figure 3-3 Method of computing the slope gradient.

Sin X = A/C

Cos X = B/C

$$\frac{\text{Sin X}}{\text{Cos X}} = \frac{A/C}{B/C}$$

Sin X / Cos X = A/C × C/B = A/B × 100 = slope gradient

-Slope length was determined by measuring the distance in metres and centimetres from the peak of the slope to the centre of the sampling point. This distance was measured at the ground surface, with a tape measure.

-Determination of slope form depended on the field observations that were reported in each slope unit by the author during execution of the fieldwork. Four forms of slope were observed and reported, namely, straight, convex, concave and wavy.

3-7 Measurement, Computing and Analysis of Vegetation Data.

The establishment of vegetation sampling stands was based at first on dividing the research area into 60 transects, and subdividing each transect into five slope units, as can be seen from Fig. 3-2. The point-centred quarter method (Fig. 3-4), which is widely used for the sampling of gradient vegetation in forest and woodland ecosystems as well as in sparsely-vegetated areas, was applied at the centre of these units. In other words, this technique was used to measure, investigate and analyse 1200 samples of perennial plants in 300 sites. Due to the diversity in size of slope units, the length of transects differed from one site to another. These sites covered all the physiographic variation in the area under study. The use of this method in the research area, where the vegetation cover is semi-forest, and a dry land area, was considered appropriate and helped to overcome problems that might result from the sometimes wide spaces between species and individuals. In the point-centred quarter method, four distances were measured at each sampling point. Four quarters were established at each sampling point, through the intersection of the transect mentioned above, and a line running perpendicular to it through the sampling point. The distance to the mid-point of the nearest tree or shrub from the sampling point was measured in each quarter. The four distances of a number of sampling points were averaged and squared, to give the mean area occupied by each tree or shrub. In addition to the distance and due to the composition of life-forms reflects the response of vegetation to variation in certain environmental factors, the basal area, crown area and height of each sample were measured and the plant cover on each quarter was also estimated. The life-form spectrum is thought to be either a hereditary adjustment to environment or to represent the residual effects of some historical, topographical, climatic or biotic condition on the plant population. These measurements were accomplished as follows:

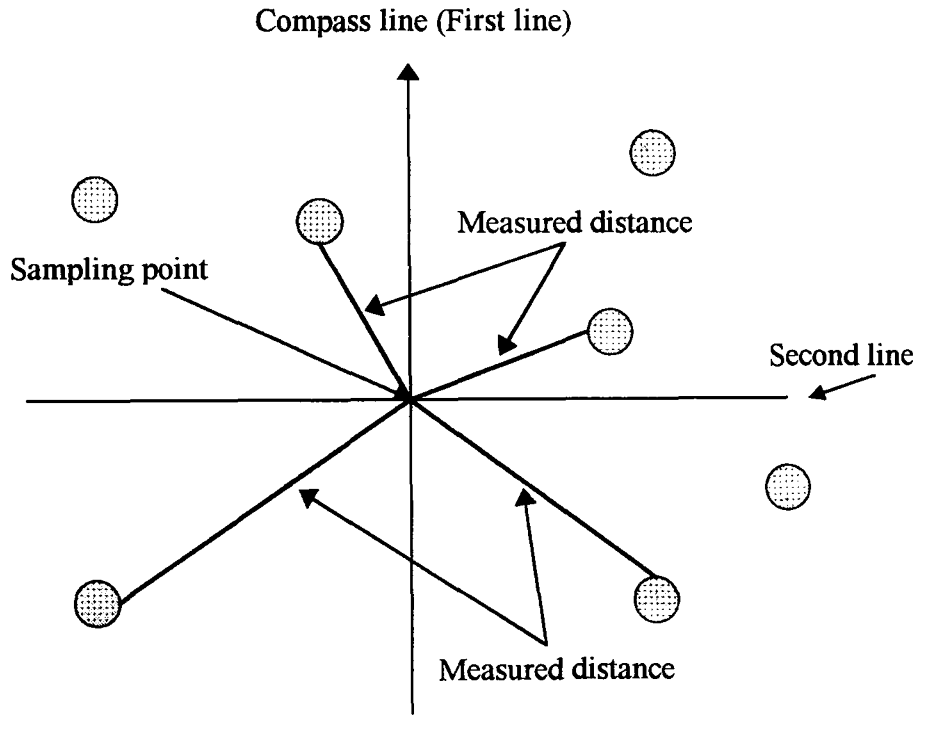

Figure 3-4 Point-centred quarter method.
(Source: Mueller-Dombois & Ellenberg, 1974)

3-7-1 Basal Area.

Depending on the measurement of the basal diameter near the ground surface, the basal area was computed according to the formula, Πr^2 = circle area

3-7-2 Crown Cover.

In view of the differences in the height of plants, two methods were adopted to measure the crown cover of each sample. The first method was to measure the diameter of the tree crown shadow at midday, and by using the formula " Πr^2= circle area", the crown area was computed. The second method of measuring crown cover, used for shrubs, was to run a cloth measurement tape around the shrub. These measurements were made easily as there was a reasonable amount of space between the trees and shrubs.

3-7-3 Plant Height.

The height of each tree or shrub from the highest branches to the ground surface was measured in meters and centimetres.

3-7-4 Estimation of Vegetation Cover Size.

Cover is defined as the area of ground within a quadrat which is occupied by the above-ground parts of each species when viewed from above. Cover is usually estimated visually as a percentage. Depending on the vegetation cover type in the research area, the plant cover at each sampling point was estimated and recorded at first as a relative value, according to the following methods:

In each sampling point, 4 quadrats resulted from the use of the point-centred quarter method. Inside each quadrant, 3 small squares (1m×1m) were randomly chosen (Kent & Coker 1992). An aluminium frame (1m×1m) was used to establish these squares. As a result of this method, vegetation cover was estimated in 12 squares and averaged to be the mean percentage of vegetation cover in each sampling point. This percentage was amended to the actual number according to the Domin cover scale (Table 3-2). The process was then repeated until an adequate number of sampling points had been obtained.

Table 3-2 The Domin cover scale.

Value	Percentage
+	A single individual. No measurable cover
1	1-2 individuals. No measurable cover. Individuals with normal vigour
2	Several individuals but less than 1% cover
3	1-4% cover
4	4-10% cover
5	11-25% cover
6	26-33% cover
7	34-50% cover
8	51-75% cover
9	76-90% cover
10	91-100% cover

(Source: Kent & Coker 1992)

3-7-5 Plant Identification Guides.

Identification of plant species and nomenclature encountered in the area under study was based on the following references available on the flora of Saudi Arabia and its surrounding countries, and with some assistance from the staff of the botany department in King Saud University, Al Riyadh, Saudi Arabia. These references are:

Abulfatih, H; 1984. **Wild Plants from Abha and its Surrounding Regions**. Saudi House for Publication and Distribution. Saudi Arabia, Jeddah.

Abulfatih, H; 1987. **Medical Plants from the South-west of Saudi Arabia**, (in Arabic and English). Al Thagher press, Saudi Arabia, Khamis Mushayt.

Al-Qahtani, M; 1991. **Effect of Soil Characteristics on Morphology of Wood-plant in Wadi Wad., Saudi Arabia.** (In Arabic) MA thesis. Department of Geography, King Saud University.

Blatter, E; 1907. The Flora of Aden. **Journal of Bombay-Natural History Society**. Vol. 17: 895-920.

Hassan, M; 1981. Flora of Saudi Arabia, and Neighbouring areas. **In Fifth Conference on the Biological Aspects of Saudi Arabia,** Saudi Biological Society. King Saud University, Abha: 169-237.

Khaleefah, S; 1980. **Trees and Shrubs in Saudi Arabia,** (in Arabic), Al Khaled press. Al Riyadh.

Mandaville, J; 1990. **Flora of Eastern Saudi Arabia**, London: Kegan Paul International.

Migahid, A; 1980a. Natural vegetation of Saudi Arabia, (in Arabic).**Al Majallah Al Arabiyah** (Arabic Journal), Saudi Arabia, Al Riyadh No. 5: 32-43.

Migahid, A; 1980b. Natural vegetation of Saudi Arabia, (in Arabic).**Al Majallah Al Arabiyah** (Arabic Journal), Saudi Arabia, Al Riyadh, No. 6: 40-47.

Migahid, A; 1988. **Flora of Saudi Arabia.** 3rd, ed. (2 vols.) King Saud University Publication. Saudi Arabia, Al Riyadh.

Zoght, M; 1989. Acacia trees of Saudi Arabia (in Arabic). **Desert Studies Centre, King Saud University.** Saudi Arabia, Al Riyadh No. 1

Some of these references are very important for identification of plant species, such as Abulfatih (1984 and 1987), Al-Qahtani (1991), Khaleefah (1980) and Migahid (1988).

3-7-6 Collection of Vegetation Samples.

Plant species were identified in situ in most of the studied sites by the means of the available scientific references. However, it was very hard to determine the plant species in some sites by using these references alone. Therefore, plant samples were gathered from these sites as well. The collected samples were taken from fresh branches and affixed to special forms, on which were recorded the date of collection, the region, habitat and the collector's name. All samples were transferred as soon as possible to the herbarium of King Saud University in Al Riyadh, Saudi Arabia and later identified by Professor Dr: Hasan Mostafa.

3-7-7 Quantitative Analysis of the Vegetation Data.

The first stage in analysing the data that were measured and collected from the field was to transfer the data from field sheets to raw data tables and double-check the tables against the original data. Using point-centred quarter analysis, it was aimed to measure and determine the following parameters:

1- The absolute density of the perennial species;

2- The covering value of the perennial species;

3- The density of each perennial species;

4- The dominance of each perennial species;

5- The frequency of each perennial species;

6- The importance value for each species;

7- Estimation of the plant cover on each quarter;

After conversion of these absolute values into relative values the density, covering value, dominance, frequency and importance value were computed using the following equations:

Absolute density = Area / D^2
Where D = mean distance

$$\text{Relative covering value} = \frac{\text{mean crown area} \times \text{absolute density}}{\text{area}} \times 100$$

Absolute dominance = mean basal area per tree × number of trees in species.

$$\text{Absolute frequency} = \frac{\text{number of points with species}}{\text{total points}} \times 100$$

$$\text{Relative density} = \frac{\text{number of individuals of species}}{\text{total number of individuals}} \times 100$$

$$\text{Relative dominance} = \frac{\text{dominance of a species}}{\text{dominance of all species}} \times 100$$

$$\text{Relative frequency} = \frac{\text{frequency of species}}{\text{sum frequency of all species}} \times 100$$

Importance value (I.V.) = relative density + relative dominance + relative frequency (Mueller-Dombois & Ellenberg, 1974; Cottam & Curtis, 1956). Computing of the above parameters gave full information of the research area plants, and enabled the author to present a quantitative representation of the vegetation of the area under study.

For classification of samples and species, clustered classification techniques were applied to the vegetation data, using two-way indicator species analysis (TWINSPAN) (Hill, 1979b). TWINSPAN is a computer program in FORTRAN designed primarily for ecologists and phytosociologists who have collected data on the occurrence of a set of species in a set of samples. It is one of the most widely used computer programs in community ecology to analyse original raw vegetation data. It is a very popular method for community classification, as a results of its quickness, and its ability to categorise and classify both sample sites and species. Version 1.0 of TWINSPAN was written in 1994, and is essentially the same as the original program, though redesigned for modern hardware (Hill, 1994). The most significant new feature is that the program first constructs a classification of the samples, and then uses this classification to obtain a classification of the species according to their ecological preferences. The two classifications are then used together to obtain an ordered two-way table that exhibits the relation between the species and the samples as clearly as possible.

In order to determine the relationships between vegetation and environmental factors, the DECORANA program (DEtrended CORrespondence ANAlysis) was used. It is also a computer program designed primarily for ecologists who have collected data on the occurrence of a set of species in a set of samples. The main purpose of this program is to make ordinations by the method of detrended correspondence analysis (Hill, 1994). It is the most widely applied method used to discover how a multitude of species respond to environmental variables (Ter Braak, 1988).

Additionally, Pearson's correlation coefficient was applied on the vegetation data to test and determine the internal relationships between the vegetation parameters. The significance of correlation values was tested at a significance level of 0.05.

3-8 Collection, Measurement and Analysis of Soil Samples.

As mentioned earlier, the samples of soil were collected from 300 stands in the research area. Each sample was collected from the same position from which the slope factors were measured. Because of the shallowness of the slope soils as well as the occurrence of most physical and chemical interactions in the top part of the soil, two composite soil samples were taken from the ground surface of each position to a depth of 25 cm: one sample (250 grams) was taken to analyse soil moisture, and the another sample (2 kilograms) for other soil characteristics (texture, organic matter, organic carbon, total calcium carbonate, nitrogen, phosphorus, potassium, soil pH and electrical conductivity). Selection of these properties depended mainly on the importance of these properties as essential elements in soil fertility and plant nutrition, as well as that these properties are most commonly encountered in the context of soil-environmental study. In other words, 120 samples were gathered from summits, 120 from shoulders, 120 from mid-slopes, 120 from footslopes and 120 from toeslopes. To minimise the influence of climatic variability on soil samples during collection, samples were collected in the early morning or late in the day. All samples collected were conserved in clean plastic bags and moisture cans, and transported to soil laboratories in the Agriculture College, King Saud University and the National Agriculture and Water Research Centre (Soil and Irrigation Section) (NAWRC), Ministry of Agriculture and Water in Al-Riyadh, Saudi Arabia. Analyses were conducted as soon as possible, to minimise possible deterioration.

3-8-1 Sampling Tools.

Several different tools, such as chrome auger, stainless steel soil sampling tubes, plastic spades, moisture conservation cans and clean plastic bags were used. These special tools were used to avoid contamination from other sources.

3-8-2 Measurement of Soil Depth (in the field).

Depth of soil was measured in each site from the ground surface to a depth of 50 cm whenever possible. However, it should be mentioned that in some sites, the depth of soil is less than 25 cm. Two methods were used to measure soil depth. The first was by digging the ground and measuring using a meter rule; the second was by using the auger.

3-8-3 Preparation of Soil Samples in Laboratory.

It should be mentioned that the all procedures suggested by Tarzi (1984) were applied in the collecting and preparation of soil samples. First, the samples were spread on a plastic sheet for air drying. Then the clods and large aggregates were reduced to less than 2 mm, using a mallet. The samples were passed through a 2 mm ground sieve. The sieved soils then were placed on a plastic sheet for uniform mixing. Then the mixed samples were transferred to sealed plastic containers for detailed analysis.

3-8-4 Laboratory Analysis of Soil Samples.

Several mechanical, physical and chemical characteristics were analysed according to the procedures that are applied at the soil laboratories at the Agriculture College, King Saud University and the National Agriculture and Water Research Centre in Al-Riyadh, Saudi Arabia. In all samples, the texture, moisture, pH, electrical conductivity (EC), total calcium carbonate ($CaCO_3$), organic matter (OM), organic carbon (OC), potassium (K), phosphorus (P), and total nitrogen (N) were analysed as follows:

3-8-4-1 Soil Texture.

Texture was determined according to the hydrometer method. 50 g of dry soil was weighed and transferred into a 1000 ml beaker. 100 ml of 55 sodium hexamataphosphats plus 0.5% $Na2CO_3$ solution then were added and the sample allowed to soak for at least 15 minutes. Approximately 400 ml of distilled water was added and stirred for 10-15 minutes with an electric stirrer. The mixture was transferred into a 1000 ml graduated cylinder with the help of a stream of distilled water from a plastic bottle. The level of the liquid was brought to the 1000 ml mark with distilled water, and temperature of the sample was recorded when it became constant. A plunger was inserted into the sample and moved up and down to mix the contents. Special care was taken to avoid spilling the contents when moving the plunger. After removing the plunger, a few seconds were allowed until the swirling motion gave place to a settling motion. Then the stop watch was started (zero time). After one minute from zero time, the hydrometer was removed, rinsed and wiped with a soft towel. After two hours, the hydrometer was immersed into the sample, without disturbing it, and a further reading taken. The hydrometer readings represented the amount of silt plus clay at one minute and clay at 2 hours. From the above actions the following equations were obtained.

$$\text{Silt and clay percentage} = \frac{\text{the reading after one minute}}{\text{weight of dry soil}} \times 100$$

$$\text{Clay percentage} = \frac{\text{the reading after 2 hours}}{\text{weight of dry soil}} \times 100$$

Silt percentage = silt and clay percentage - clay percentage.

Sand percentage = 100 - silt and clay percentage.

Particular care was taken to avoid the possible impacts of temperature gradient and added chemical materials.

Soil texture classes then were determined, depending on the percentages of silt, clay and sand, and their locations on a texture triangle.

3-8-4-2 Soil Moisture.

During the collection of moisture samples, each sample was conserved in a metal can with a tight-fitting lid, and transferred as soon as possible to laboratory. The direct method (weight method) was used to measure the moisture as follows:

50 g of soil was weighed accurately, and placed in a weighed metal can with a tight-fitting lid. Then the sample was placed in a drying oven at 105° C with the lid off for 24 hours. After that, the sample was removed from the oven, the lid replaced and the can placed in a desiccator. After cooling, the sample was weighed again and the weight of oven dry soil was recorded. The moisture percentage was computed by the following equations:

Weight of water = weight of dry soil - weight of oven dry soil.

$$\text{Percentage moisture content} = \frac{\text{weight of water}}{\text{weight of oven dry soil}} \times 100$$

3-8-4-3 Organic Matter.

In order to determine the organic matter in soils, it is necessary first to determine the percentage of organic carbon (OC). This was done as follows:

1 g of finely ground soil was weighed (2 g soil was weighed for sandy soils) and placed in a 500 ml conical flask. 10 ml of 1 ON potassium dichromate and 20 ml of concentrated H2SO4 were added to the flask and mixed by swirling the flask. The contents were allowed to stand for 30 minutes. 200 ml of water, 10 ml of 85% phosphoric acid, 0.2 g of solid NaF and 30 drops of phenyldamine indicator were added. The mixture was titrated with 0.5 N ferrous ammonium sulphate to a brilliant green end point using a magnetic stirrer. A percentage reading of organic carbon was obtained and the organic matter (OM) was computed by the following equation:

$$OM\% = OC\% \times 1.724$$

where the factor 1.724 is the result of the percentage of organic carbon in organic matter, which is equal to 100/58, because organic matter in soils in general contains 58% carbon.

3-8-4-4 Organic Carbon (OC).

As indicated above, the method used to determine the organic matter, was also used to determine the organic carbon in soils.

3-8-4-5 Total Calcium Carbonate ($CaCO_3$).

In view of the importance of laboratory temperature constancy for the determination of total calcium carbonate ($CaCO_3$), special care was taken to maintain a constant laboratory temperature. The details of this experiment were as follows:

1 g of the soil was taken and transferred to the conical flask connected by tubing to a manometer. 20 ml of HCL was taken in a vial and the vial inserted in the flask. The flask was tilted to allow the acid and soil to mix and react, giving off CO_2. When the reaction was complete , the CO_2-developed pressure was read on the manometer and correlated with $CaCO_3$ content by means of a standard curve graph.

3-8-4-6 Nitrogen Content (N).

Determination of total nitrogen in the soil depended on the Kjeldahl method, described below:

10 g of soil was weighed and transferred into an 800 ml Kjeldahl flask. 40 ml of sulphuric salicylic acid mixture was added to the flask and swirled to bring the sample quickly into intimate contact. 5 g of sodium thiosulfate was added and the mixture heated gently for about 5 minutes. At this stage, particular care was taken to avoid frothing during cooling. 10 g of sulphate mixture was added and digested on the Kjeldahl apparatus, gradually raising the temperature until the contents became clear. The mixture was digested further at full heat for 15 minutes. When digestion was completed, 300 ml of distilled water and 100 ml of concentrated sodium hydroxide were added. A large piece of mossy zinc was added and a spoon of glass beads were added. The flask was connected to the distillation head. 150 ml of the mixture was distilled into 50 ml of 4 percent boric solution. 10 drops of bromcresol green-methyl red indicator were added, and titration was carried out to the first faint pink end point with standard sulphuric acid. Finally, the total nitrogen of soil was calculated as follows:

$$\text{Total nitrogen in soil\%} = (T\text{-}B) \times N \times \frac{1.4}{S}$$

Where T = ml of standard acid with sample titration,
B = ml of standard acid with blank titration,
N = Normality of sulphuric acid,
and S = Weight of soil in grams.
Then the percentage of nitrogen was computed in parts per million as follows:
Total nitrogen = N% × 10000.

3-8-4-7 Phosphorus Content (P).

Available phosphorus was determined according to the following procedure:

5 g of soil was weighed and transferred into a 250 ml flask. 0.5M $NaHCO_3$ solution was added and pH was adjusted to 8.5. The mixture was shaken on a shaker for half an hour

and filtered through a Wattman filter paper no. 42. Five ml of the clear filtrate was taken in a 25 ml volume flask. A drop of paranitrophenol was added and the mixture neutralised with 5N $H2SO_4$. Water was added to bring the volume to about 20 ml, then 4 ml of molybdate ascorbic acid was added, and the volume made up to the mark. A blank and a series of standards taking 5 ml of $NaHCO_3$ were prepared. The intensity of the blue colour was read after 10 minutes on a spectrophmeter at a wave length of 840 nm using a red filter. From the absorbency readings of the standards, the amount of P in soil was calculated as below:

$$\text{amount of P in soil} = \frac{R \times \text{volume of the extractant}}{\text{ml of aliquot taken} \times \text{weight of soil}} = \text{PPM}$$

Where R is ugs of P in the sample as determined by comparing it with standard.

3-8-4-8 Potassium Content (K).

Available potassium was determined by extracting the soil with neutral ammonium acetate solution and reading the extracted potassium on a flame photometer. This procedure was carried out as follows:

5 g of soil was weighed and transferred to a 250 ml conical flask. 50 ml of CH_3 $COONH_4$ solution was added to the soil sample. The flask was shaken on a shaker for half an hour, and then the mixture was filtered through a Wattman paper number 42. An extract was taken in a vial and K was determined on the flame photometer. The K was calculated in parts per million according to the following equation:

K PPM in soil = $R \times 10$

Where R is the flame photometer reading of K in the extract.

3-8-4-9 Soil pH.

The determination of the hydrogen ion (pH) content depended on the potentiometric method, which is the most accurate available. The apparatus and reagents required to carry out this method were a pH meter with glass electrode, 100 ml glass beakers and buffer solutions of pH 4.0 and 7.0 pH.

The determination was carried out as follows:

10 g of soil was weighed and transferred to a glass beaker. 50 ml of distilled water was added to the soil sample. The soil and water mixture was shaken and left for 30 minutes. The electrodes were immersed in the standard pH buffers, and the pH meters were standardised at laboratory temperature. After that, the electrodes were immersed 2 cm into the paste. It was necessary to wait until a stable reading was obtained. The obtained reading was the pH value.

3-8-4-10 Electrical Conductivity (EC).

The electrical conductivity (EC) of an extract is a useful indicator for measuring the total concentration of solutes, and thus reflects the degree of salinity percentage in the soil system. Measurement of EC depended on the following methods:

A conductivity meter with cell and 25 ml beakers were prepared. The conductivity cell was rinsed and filled with standard kcl solution. The EC meter was adjusted to read the standard conductivity. The conductivity cell was rinsed and filled with the soil extract obtained from the saturated paste. Alternately, 1:1 soil suspension was taken in the beaker. The conductivity cell was dipped in the suspension and the reading was taken. The EC reading was read directly from the digital display and corrected to 25 °C.

3-8-5 Quantitative Analysis of Soil Data.

Statistical techniques applied to the collected data involved the use of the correlation coefficient, mean, standard deviation, variance, t-test (independent samples model), analysis of variance (one-way model), and multiple comparisons test (least significant difference model). The correlation coefficient was applied to the soil data to examine and delimit the strength or degree of a supposed linear association between soil properties. The most familiar correlation coefficient, the Pearson correlation, was used. Many studies and textbooks, such as Webster & Oliver (1990) and Gilbertson et al. (1985) recommend using this coefficient for aims of this sort. The significance of correlation values was listed at a significance level of 0.05 (Two-tailed test). Mean data were used as general indicators of soil properties. Standard deviation and variance were used to describe the distribution and diversity of soil data. Because the research area included two regions, a mountainous region and plateau region, which differ from one to another in elevation, morphology, climate and vegetation cover, the differences in soil properties between these regions were examined by using a t-test coefficient (independent samples model). This test and model is recommended by West (1991) and Shaw & Wheeler (1996). One way analysis of variance (ANOVA) was used to test the diversity in soil properties between slope units (toe-slope, foot-slope, mid-slope, shoulder-slope and summit-slope). This technique examines the variability of the observations within each slope units as well as the variability between the slope unit means. It is a very common method in examination of differences when only one variable is used to classify cases into the different groups (Norusis, 1985). Several studies and textbooks have recommended using this technique, such as Webster & Oliver (1990), West (1991) and Bryman & Cramer (1994). Multiple comparisons test (least significant difference model) was used to delimit the sites of significant differences that resulted from an application of ANOVA.

3-9 Quantitative Analysis of the Relationship Between Soil Properties and Components of Slope and Vegetation.

For examination and determination of the relationship between soil properties and components of slope and vegetation, the correlation and regression coefficients were used. The first technique was applied to study the strength and type of a supposed linear association between slope and vegetation components and the essential soil properties. To achieve this purpose, the Pearson correlation coefficient, which is the most familiar coefficient in studies of this kind was applied. Many researchers and authors have recommended using this coefficient for such purposes, such as Gilbertson et al. (1985), Martz (1992) and Simantan et al. (1994). The importance of correlation values was tested at a significance level of 0.05 (Two-tailed test). The second technique was the multiple regression coefficient (Stepwise model). This is the most important coefficient in studying and determining the contribution of slope and vegetation components in diversity of soil features. This technique has been applied in many similar studies and has been recommended in many textbooks, such as Webster & Oliver (1990), King (1969), Makhnach (1994), Young & Mutchler (1969), Dadkhah & Gifford (1980) and Al-Qahtani (1991).

CHAPTER FOUR

Vegetation Cover and Grazing Influence

Chapter Four
Vegetation Cover and Grazing Influence

4-1 Introduction

This chapter aims to investigate and analyse in detail the perennial vegetation of the research area, in terms of the flora, morphology, ecology and distribution and their relationship with habitats and environmental factors. Investigation and analysis of the above points is based on data of 1200 vegetation samples collected from the research area (as well as the data of slope and soil factors that were collected from 300 quadrats). Moreover, grazing and its influence on vegetation and soil are investigated. To facilitate full understanding of this analysis and of the association between the vegetation habitats, first, a brief summary of the vegetation of the Arabian Peninsula, with special emphasis on the south-western territory, is presented as follows:

As was mentioned and depicted in Chapter One, the Arabian Peninsula is located in the south-west of Asia. It therefore encompasses wide parts of two phytogeographical regions that cover many parts of the Middle East and north Africa. These regions are as follows:

1- The Sahara-Arabian region;

2- The Sudanian region (Fig. 4-1).

From the viewpoint of ecologists, phytogeographers and biogeographers, such as Al-Aodat, et al. (1985), and according to the classifications of Eig, (1931-1933), and Takhtajan (1986), the south-western territory of Saudi Arabia, which includes the research area, falls entirely within the east Sudanian region.

The flora and vegetation of the Sudanian region are characterized by hundreds of genera, numerous species and plant communities. The main vegetation types of this region are open woodland, savanna and grassland. The Eritrean-Arabian subregion of the

Sudanian, south Arabian province, in the south and south-west of the Arabian peninsula is the richest and the most complex with its latitudinal zonation and species diversity containing about 225 endemic species (Takhtajan, 1986; Zohary, 1973). Also, the same region is characterized climatically by a tropical climate with high temperatures in summer and warm temperatures throughout the rest of the year. Precipitation and atmospheric humidity are normally high, with the average rainfall exceeding 400 mm per year. Due to the monsoon, it is evenly distributed through the rainy season and takes place mainly during the spring months (Table 1-8). High mountains in the area receive rainfall throughout the year but rainfall reaches its peak in the spring season. The Sudanian regions in the Arabian peninsula are mainly characterized by temperatures that are high enough to support a tropical vegetation.

Although there have not been many vegetation studies in the Arabian Peninsula and most writing has been at the level of general information, there are a few studies which have made a good contributions in showing some important aspects of classification and distribution of vegetation cover in the Arabian Peninsula. Most of these contributions have come as books and maps, such as Vesey-Fitzgerald (1955, 1957a and 1957b), Novikova (1970), Zohary (1973), the Water Atlas of Saudi Arabia (1984), Migahid (1988) and Frey & Kurschner (1989).

As was mentioned in Chapter Two, Vesey-Fitzgerald, (1955, 1957a and 1957b) divided the Arabian Peninsula into six extra-tropical and five inter-tropical plant associations. The research area was situated on this map as part of the Acacia Association habitat within the Inter-Tropical Association.

In 1988, Migahid, designated ten phytogeographical regions as comprising the vegetation cover in Saudi Arabia (Fig. 4-2). These regions are as follows:

1-Northern region (N), including Tabuk, Al-Jawf and Sakaka areas;

2-Nefud region (NF), including the great northern Nefud area, Dahna and Al-Qasim area;

3-North Hijaz (NH), representing the western part of Saudi Arabia that extends alongside the Red Sea coast north of Jeddah;

4-South Hijaz (SH), representing the southern part of the western region extending south of Jeddah to the Yemen border;

5-Southern region (S), lying to the east of South Hijaz, to the south of Najd and to the north of Yemen, and including Abha, Bishah and Najran regions;

6-Western Najd (NJw);

7-Eastern Najd (NJe);

8-Eastern region (E), between Dahna and the Arabian Gulf;

9-Al-Rub'Al-Khali (R), representing most of the southern and south-eastern part of Saudi Arabia;

10-Red Sea region (RS), representing a narrow strip of Red Sea water alongside the Saudi coast.

According to this classification, the research area falls within the southern region (Fig. 4-2), which is affected by the south-western monsoon, and is distinguished by the presence of **Juniperus procera**, **Olea chrysophylla**, **Ficus palmata**, **Acacia neegrii**, **Acacia gerradii**, **Dodonaea viscosa**, **Rumex nervosus**, **Psiadia arabica**, **Euryops arabicus**, **Lavandula dentata** and **Adenium obesum**.

A preliminary vegetation map of Arabia was produced by Novikova (1970). Fifty plant areas were defined in this map according to the presence and abundance of some species and plant communities. Production of this map was based on the botanical work and description of geographers, geologists and travellers. The research area was classified in this map within the tropical types of vegetation.

In 1973, Zohary produced a general map for the Middle East vegetation and classified the vegetation of the Arabian Peninsula into nine plant types. The Upper Wadi Bishah basin was distinguished as a part of the tropical mountain forest and savanna of the Acacietea Sudano-Arabica.

In 1989 Frey & Kurschner produced a vegetation map for the Middle East. In this map, eight major plant types were grouped in the Arabian Peninsula. Most of the research area was classified as rock desert, but the author corroborates that a misinterpretation or cartographical error was made with regard to this part of the Arabian Peninsula.

In the vegetation communities map of Saudi Arabia (Fig. 4-3) produced by the Ministry of Agriculture and Water (1994), the dominant species were classified into 10 groups. The research area has been reported as having **Juniperus Procera** in the high mountains and **Acacia spp** in the highlands and basins.

In most cases the vegetation cover in south-west Saudi Arabia is not uniform, because of the variations in topography, elevation, soil, moisture and temperature. The natural factors mentioned above are not the only factors that affect vegetation (grazing is one of the other important factors), but they play a major role in vegetation distribution and growth.

According to Abulfatih (1992), who conducted a series of ecological studies in the south-western part of Saudi Arabia, depending on altitude above sea level, the vegetation cover of this region can be divided into six major zones (Fig. 4-4). These vegetation zones are as follows:

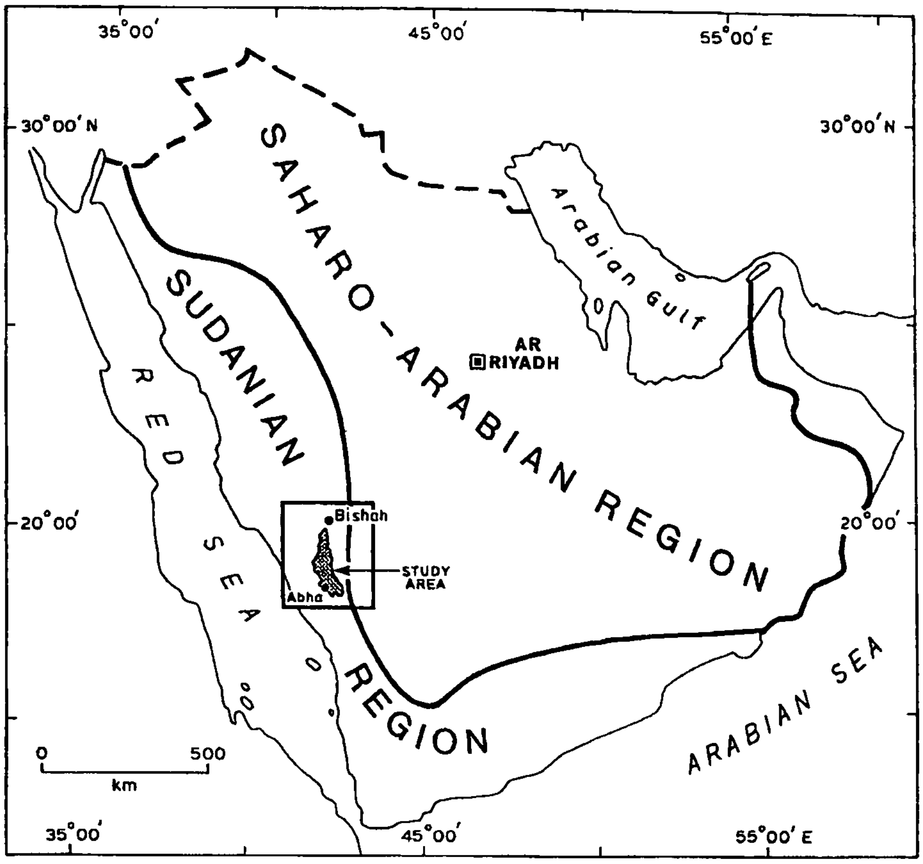

Figure 4-1 The Saharo-Arabian and Sudanian Floristic Regions in the Arabian Peninsula.
(Source: Al-Nafie, 1995)

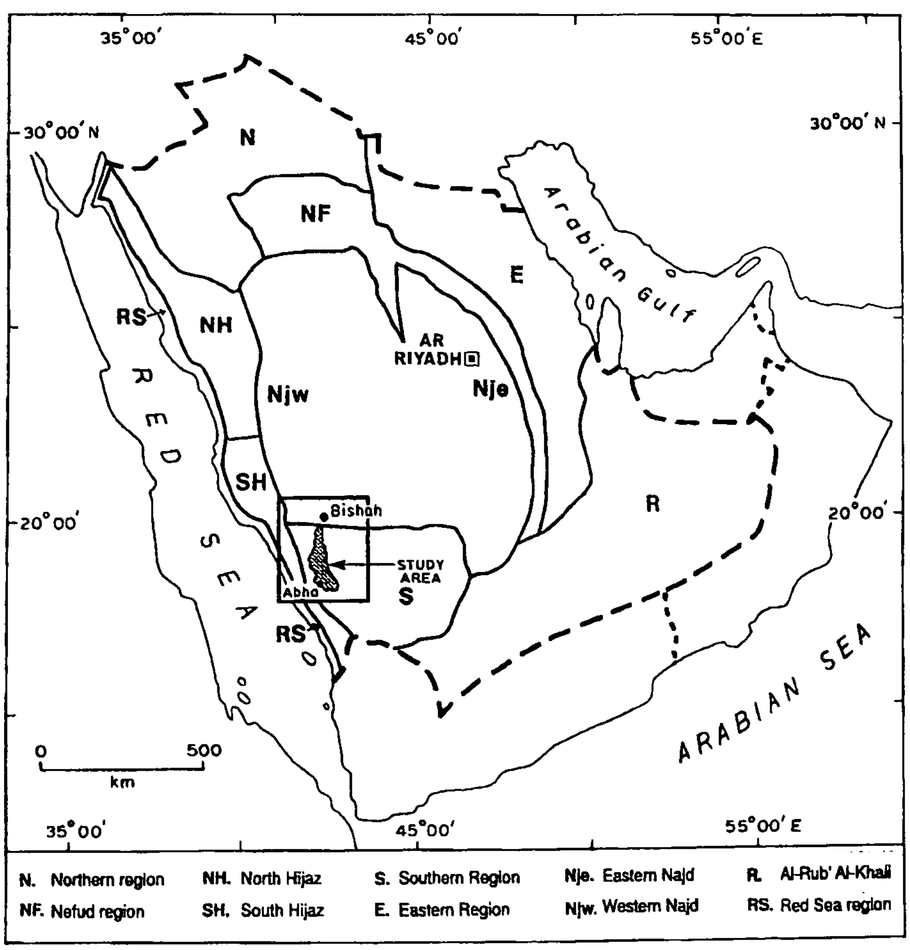

Figure 4-2 Phytogeographical Regions of the Kingdom of Saudi Arabia.
(Source: Migahid, 1988)

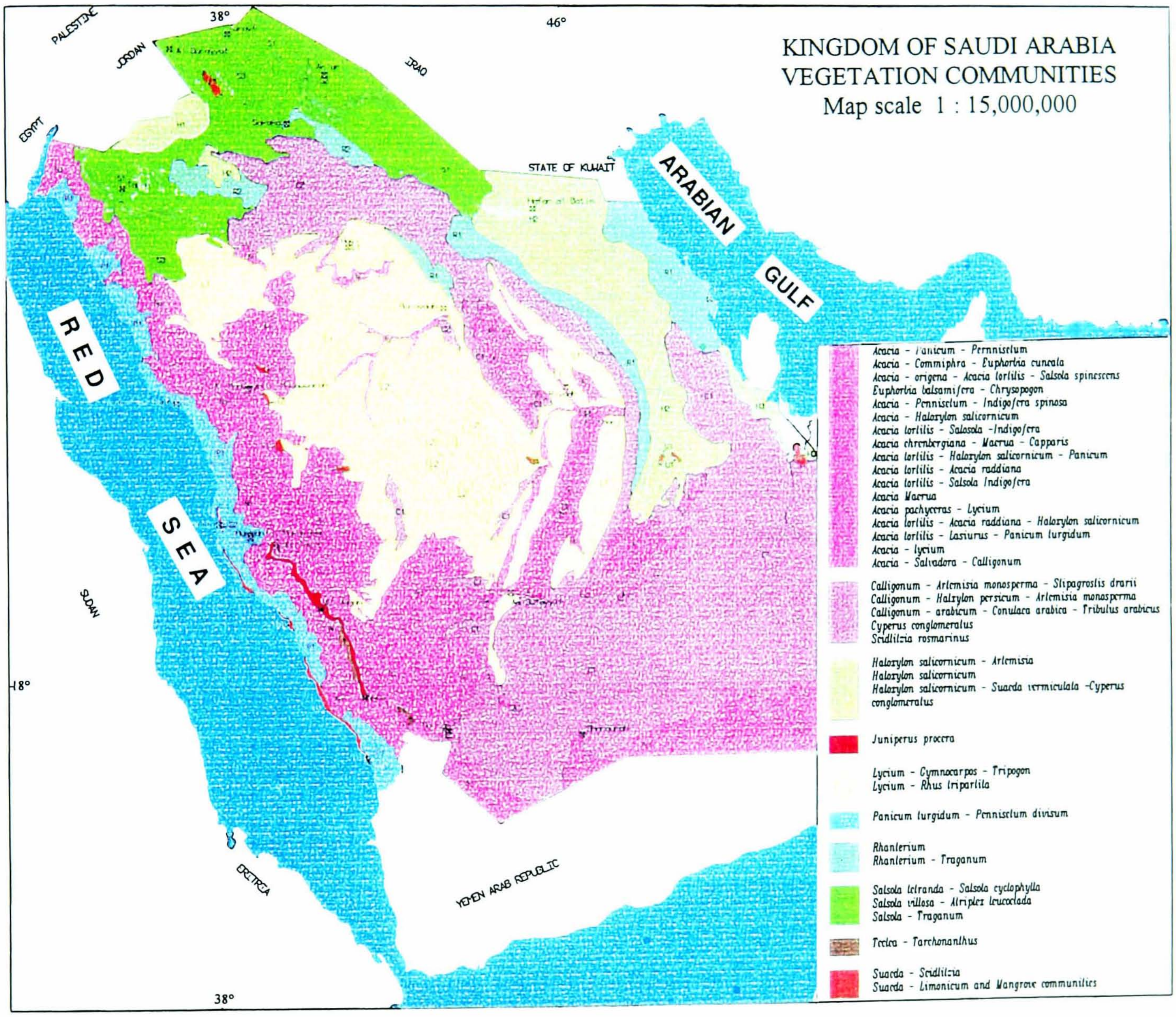

Figure 4-3 The geographic distribution of the dominant species in Saudi Arabia.
(Source: Ministry of Agriculture and Water, 1994)

1- Coastal plains (0-300 m)
2- Foothills (300-1000 m)
3- Lower escarpments (1000-1600 m)
4- Upper escarpments (1600-2200 m)
5- High mountains (2200-3000 m)
6- Rainshadow slopes (1200-2200 m)

The last two vegetation zones, which form the research area, are characterized by a variety of plant distribution and growth forms. This variety reflects the kind of adaptation found in these plants in response to the environment in which they exist. Such a distribution, and the growth forms in these areas, are summarized in the following paragraphs, with reference to some representative plant species.

In the high mountain zones, plants are distributed on hillsides, water courses, and plains and are characterized by the following very varied growth forms: evergreen woodlands (**Juniperus excelsa**, **Olea chrysophylla**), drought deciduous woodlands (**Acacia negrii**), succulents (**Aloe spp**., **Caralluma spp.,** **Delosperma harazianum**, **Euphorbia spp**.), shrubs (**Dodonaea viscosa**, **Withania somnifera**, **Lycium shawii**, **Salvia meriamie**, **Lavandula dentata**, **Psiadia arabica**, **Rhamnus oleoides**, **Rosa abyssinica**, **Solanum incanum**, **Rumex nervosus**), herbs (**Cichorium bottae**, **Teucrium yemense**, **Campanula edulis**, **Crassula alba**, **Primula verticillata**, **Micromeria imbricata**, **Dianthus zonatus**), grasses (**Pennisetum spp**., **Andropogon distachyos**, **Bromus pulchellus**, **Themeda triandra**, **Tetrapogon villosus**), ferns (**Ceterach officinarum**, **Cheilanthus spp**.), epiphytes (**Usnea articulata**), hemiparasitic plants (**Phragmanthera sp. Aff. Rufescens**), and climbing plants (**Asparagus africanus**, **Lonicera etrusca**).

On the rain shadow slopes, the plants are distributed on hillsides, water courses, plains, and disturbed ground and characterized by the following growth forms: drought-deciduous trees (**Acacia spp**., **Ficus carica**, **Ziziphus spina-christi**), evergreen microphyllous trees (**Tamarix aphylla**, **Tamarix nilotica**), succulents (**Aloe vacillans**, **Kalanchoe lanceolata**, **Euphorbia schimperi**, **Caralluma petraea**), dune-forming plants (**Calligonum polygonoides ssp.comosum**, **Leptadenia pyrotechnica**, **Panicum turgidum**, **Salvadora persica**), shrubs (**Lycium shawii**, **Euphorbia balsamifera**, **Withania somnifera**, **Rhazya stricta**, **Calotropis procera**, **Arnebia hispidissima**), herbs (**Plantago ciliata**, **Fagonia spp**.), halophytes (**Suaeda monoica**), hemiparasitic plants (**Phragmanthera sp. aff. rufescens**, **Oncocalyx schimperi**, **Plicosepalus curviflorus**), grasses (**Phragmites australis**), and climbers (**Cocculus pendula**).

Within the study area, ecologists and phytogeographers have indicated in brief comments, that this area is an important part of Saudi Arabia, in terms of the magnitude of its vegetation cover. Some of these studies have described the vegetation of this area as follows.

Brooks & Mandil (1983: 357) studied the "Vegetation Dynamics in Asir Woodlands" and reported the following:

"In Saudi Arabia, the greatest number of plant species is found in the highlands of the south and south-west where East African vegetation contributes to the character of the region. Forty-four per cent of the flora in southern and south-western Arabia represents Sudanian elements found in the altitudinal zonation of the savanna scrub and the montane woodlands".

Konig (1988: 75) investigated the "Phytogeography of South-western Saudi Arabia" and described the vegetation in the study area as follows:

"The vegetation of the study area is climatically influenced and characterized mainly by forest, woodland and xeromorphic woodland communities - in contrast to the central parts of the Arabian peninsula, which are dominated by dwarf-shrub communities, grassland and deserts".

In his study, "Geology and Ground Water Resources of Wadi Bishah basin", Abu Sagr (1981: 9) discussed the natural vegetation in Wadi Bishah in Chapter Two and reported the following:

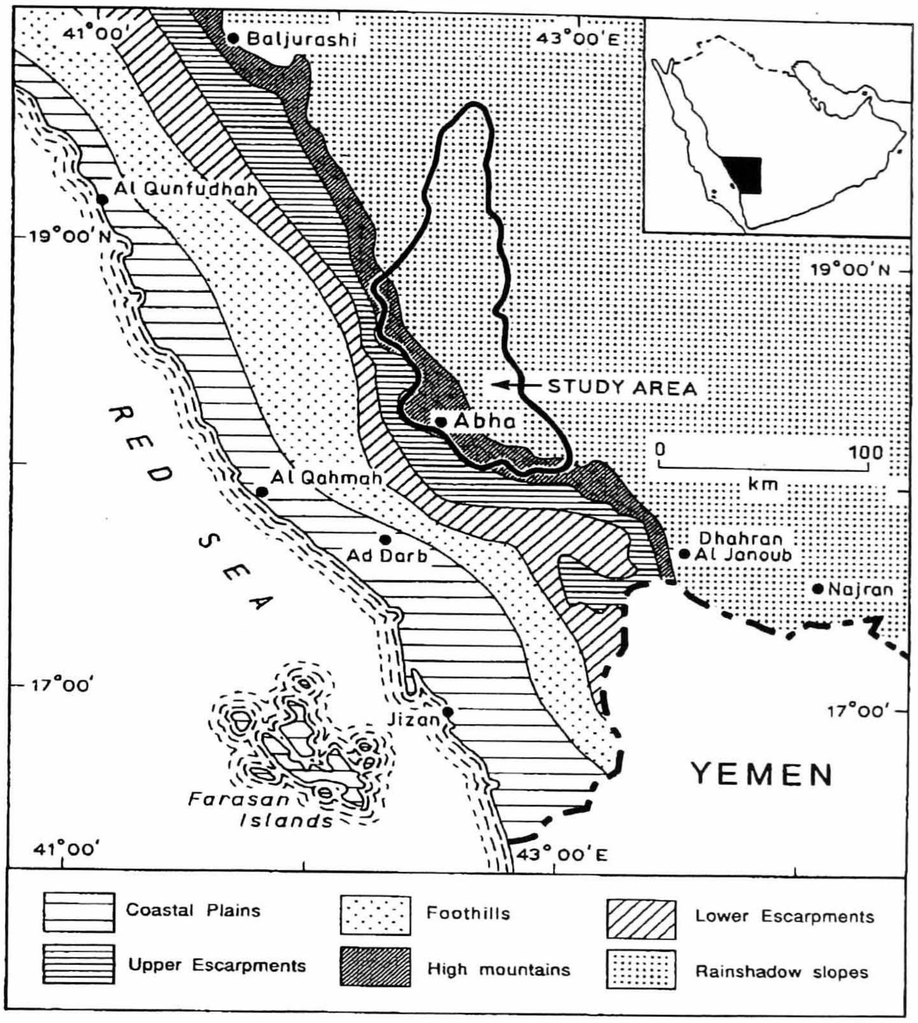

Figure 4-4 Map Showing the Six Vegetation Zones of the South-western Saudi Arabia.
(Source: Abulfatih, 1992)

"The Wadi Bishah beds can be divided according to width into three areas as follows:

*1- The present course of the Wadi, always affected by floods with strong water erosion and accumulation of alluvial material. The soil consists of loose sand to gravely muddy sand. The vegetation in this zone includes **Calotropis procera**, and shrub forms of **Tamarix sp.***

*2- Areas bordering the Wadi course, not always flooded, with strong to moderate erosion. The soil is muddy sand and sandy mud, apparently compact. The vegetation is mostly arboraceous **Tamarix sp.**, **Calotropis procera**, **Leptadenia pyrotecnica**, **Rhozia stricta**, and mixed by almost pure **Haloxylon salicornicum**.*

*3- Wadi banks, rarely flooded, with cropped zones. The soil is mainly sandy mud. The vegetation consists of farm crops, **Phoenix dactylifera**, **Medicago sativa**, arboraceous **Tamarix sp**, **Haloxylon solicornicum** and **Razia stricta**".*

4-2 Floristic Composition of the Research Area.

According to Al-Hubaishi and Hohenstein (1984), the subdivision of the south Arabian phytogeographical region (including Yemen) contains 2000-2500 species of flowering plants. About 20% of the floristic elements of southern Arabia are endemic (Schwartz, 1939). The present study recorded 62 perennial species in the research area of Wadi Bishah. These plant species belong to 49 genera and 28 families. The recorded species were grouped into two Tables (Tables 4-1 and 4-2). Each plant species table was assembled systematically according to divisions, family, genera and species and arranged alphabetically.

Table 4-1 represents the plant species that were encountered within the sampling sites within Wadi Bishah. The Table involves 28 perennial species belonging to 24 genera and 12 families. Through this Table, and as can be seen from Fig. 4-5, **Acacia arabica**, **Acacia gerradii**, **Acacia negrii**, **Lycium shawii**, **Dodonaea viscosa**, **Kleinia odora**, **Juniperus procera** and **Euryops arabicus** species comprise about 89 percent of the frequency of species in my 1200 samples, whereas the remaining species (20 species) comprise merely 11 percent. This result indicates that the species diversity of the vegetation in the research area is quite low. Among the identified plants, the **Sageretia thea** species can be considered new to the flora of Saudi Arabia. This species is marked by an asterisk in Table 4-1.

Table 4-2 represents the plant species that were observed outside of the sampling points of the present study, but not within them. As shown in this Table, 34 perennial species were observed, belonging to 29 genera and 24 families. Again, these results confirm what Blatter (1907) and Sankary (1983) indicated, namely, that the south-west of Arabia is distinguished by a general abundance in vegetation families and genera but with a paucity of species.

Table 4-1 List of Families, Genera and Species Encountered within Sampling Points. **TF** = Total Frequency, **FC** = Frequency Class, **AB** = Abundance Percentage.

S/ NO	Family	Genera	Species	TF	FC	Ab %
1	Adenium.	Adenium	**Adenium obesum** (Forssk.) Roem & Schultz.	2	22	0.0017
2	Asclepiadaceae.	Calotropis	**Calotropis procera** (Ait.) Ait.f.	4	15	0.0033
		Leptadenia	**Leptadenia pyrotechnica** (Forssk.) Decne.	8	12	0.0067
		Periploca	**Periploca aphylla** Decne.	2	23	0.0017
3	Compositae.	Euryops	**Euryops arabicus** Steud.	70	8	0.0583
		Kleinia	**Kleinia odora** (Forssk.) DC.	79	6	0.0658
		Psiadia	**Psiadia arabica** Jaub. et Sp.	35	9	0.0292
4	Cupressaceae	Juniperus	**Juniperus procera** Hochst. ex Endl.	71	7	0.0592
5	Euphorbiaceae.	Cluytia	**Cluytia richardiana** Muell. Arg. in DC.	2	24	0.0017
6	Labiatae.	Lavandula	**Lavandula dentata** L.	3	19	0.0025
		Menthal	**Mentha lavandulacea** Willd.	3	20	0.0025
7	Leguminosae.	Acacia	**Acacia arabica** (Lam.) Willd.	313	1	0.2608
		Acacia	**Acacia gerradii** Benth.	152	3	0.1267
		Acacia	**Acacia negrii** Pichi-Sermolli.	120	4	0.1
		Lagonychium	**Lagonychium farctum** (Banks & Sol.) Bober.	7	13	0.0058
		Tephrosia	**Tephrosia apollinia** (Del.) Link.	1	26	0.0008
8	Polygonaceae.	Rumex	**Rumex nervosus** Vahl.	4	16	0.0033
9	Resedaceae.	Reseda	**Reseda sphenocleoidis** Deflers.,	3	21	0.0025
10	Rhamnaceae.	Phoenix	**Phoenix dactylifera** L.	1	27	0.0008
		Rhamnus	**Rhamnus disperma** Ehrenb.	4	17	0.0033
		Sageretia	***Sageretia thea** (Osb.) M.C. Johnst.	6	14	0.005
		Ziziphus	**Ziziphus spina-christi** (L.) Willd.	1	28	0.0008
11	Sapindaceae.	Dodonaea	**Dodonaea viscosa** Jacj.	96	5	0.08
12	Solanaceae.	Lycium	**Lycium barbarum** L.	25	10	0.0209
		Lycium	**Lycium shawii** Roem. et Sch.	173	2	0.1442
		Solanum	**Solanum incanum** L.	9	11	0.0075
		Solanum	**Solanum schimperianum** Hochst. ex A. Rich.	4	18	0.0033
		Withania	**Withania somnifera** (L.) Dun. in DC.	2	25	0.0017
	Total	**24**	**28**	**1200**		**100**

Source: personal field work.

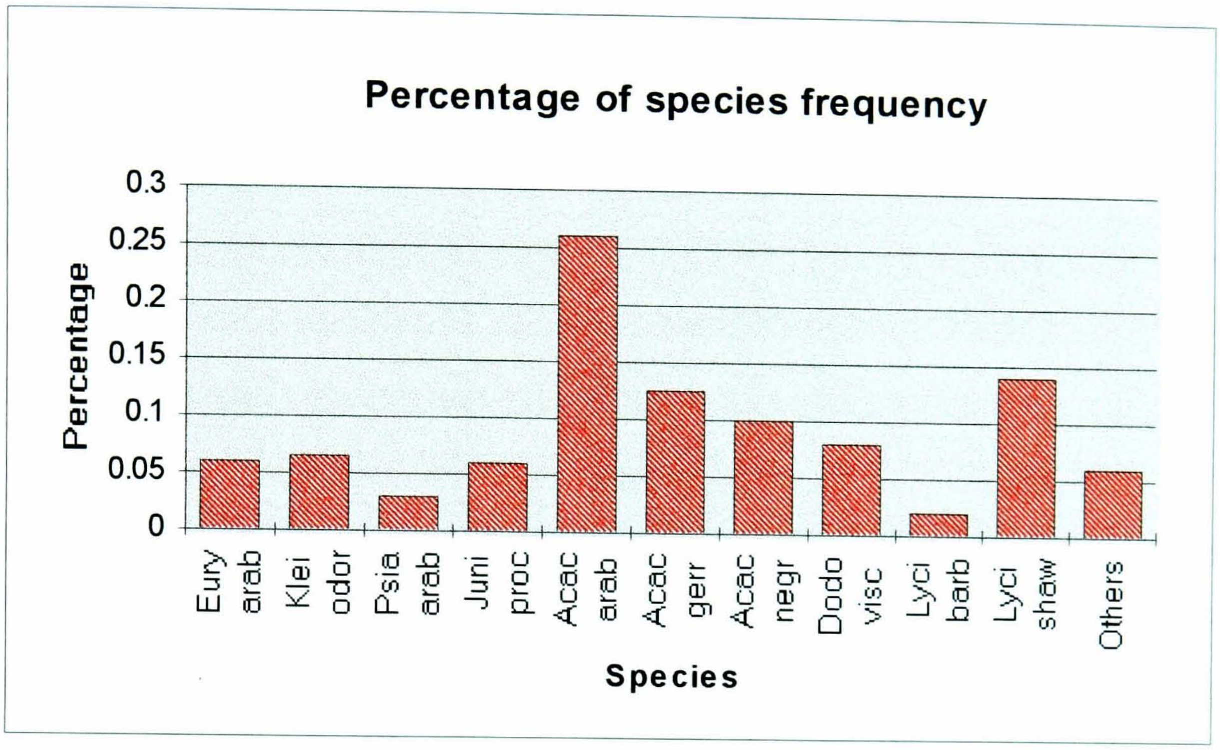

Figure 4-5 Selected Percentage of Species Frequency in the Sampling Points of Study.
(Source: Table 4-1)

Key to Species (see Table 4-1).

Eury arab = **Euryops arabicus**
Klei odor = **Kleinia odora**
Psia arab = **Psiadia arabica**
Juni proc = **Juniperus procera**
Acac arab = **Acacia arabica**
Acac gerr = **Acacia gerradii**
Acac negr = **Acacia negrii**
Dodo visc = **Dodonaea viscosa**
Lyci barb = **Lycium barbarum**
Lyci shaw = **Lycium shawii**
Others = **Adenium obesum**, **Calotropis procera**, **Leptadenia pyrotechnica**, **Periploca aphylla**, **Cluytia richardiana**, **Lavandula dentata**, **Mentha lavandulacea**, **Lagonychium farctum**, **Tephrosia apollinia**, **Rumex nervosus**, **Reseda sphenocleoidis**, **Phoenix dactylifera**, **Rhamnus disperma**, **Sageretia thea**, **Ziziphus spina-christi**, **Solanum incanum**, **Solanum schimperianum**, **Withania somnifera**.

Table 4-2 List of Families, Genera and Species Observed Outside of Sampling sites.

NO	Family	Genera	Species
1	Acanthaceae.	Anisoltes	**Anisoltes trisuleus** (Forssk.) Nees.
2	Amaranthaceae.	Aerva	**Aerva javanica** (Burmf.) Spreng.
3	Apocynaceae.	Rhazya	**Rhazya stricta** Decne.
4	Asclepiadaceae.	Gomphcarpus Periploca	**Gomphcarpus sinaicus** Boiss. **Periploca aphylla** Decne.
5	Boraginaceae.	Trichodesma	**Trichodesma calathiforme** Hochst.
6	Cactaceae.	Opuntia	**Opuntia Ficus-Indica** (L.) Miller.
7	Capparaceae.	Capparis	**Capparis spinosa** L.
8	Compositae.	Echinops	**Echinops spinosissimus** Turra.
9	Cupressaceae	Juniperus	**Juniperus polycarpos** C. Koch.
10	Euphorbiaceae.	Cluytia Euphorbia Ricinus	**Cluytia myricoides** Jaub and Spach. **Euphorbia schimperiana** Scheele. **Ricinus communis** L.
11	Guttiferae.	Hypericum	**Hypericum revolutum** Vahl.
12	Labiatae.	Nepeta Otostegia Salvia	**Nepeta deflersiana** Schweinf. **Otostegia fruticosa** (Forssk.) Briq. **Salvia aegyptiaca** L.
13	Leguminosae.	Cadia	**Cadia purpurea** (Pice.) Ait.
14	Litiaceae.	Dracaena	**Dracaena serrulata** Bak.
15	Loganiaceae.	Buddleia	**Buddleia polystachya** Fres.
16	Moraceae.	Ficus	**Ficus carica** L. **Ficus plamata** Forssk. **Ficus salicifolia** Vahl. **Ficus sycomorus** Decne. **Ficus vasta** Forssk.
17	Oleaceae.	Olea	**Olea europaea** L.
18	Passifloraceae.	Adenia	**Adenia venenata** Forssk.
19	Resedaceae.	Otchradenus	**Otchradenus baccatus** Del.
20	Rhamnaceae.	Rhamnus	**Rhamnus staddo** A. Rich. var. deflersii (Schweinf.) Chiov.
21	Rosaceae.	Rosa	**Rosa abyssinica** R.Br.
22	Rutaceae.	Ruta	**Ruta chalepensis** L.
23	Tamaricaceae.	Tamarix	**Tamarix aphylla** (L.) Karst. **Tamarix nilotica** (Ehrenb.) Bge.
24	Tiliaceae.	Grewia	**Grewia mollis** Juss.
	Total	**29**	**34**

Source: personal field work.

4-3 Morphology of Vegetation.

Beside spatial variation in the species composition of the plant communities, the composition of life-forms reflects the response of vegetation to variation in certain environmental factors. The life-form spectrum is thought to be either a hereditary adjustment to environment or to represent the residual effects of some historical, topographical, climatic or biotic condition on the plant population (El-Demerdash et al. 1994; and Raunkiaer, 1934). It is clear that the morphology of vegetation composition of the research area is affected by all the factors mentioned above, but in varying degrees. As mentioned in Chapter Three, four plant morphology elements (height, basal diameter, basal area and crown area) were measured, and are summarised in Table 4-3. **Juniperus procera** recorded the greatest crown area (707.14 m^2), whereas **Phoenix dactylifera** recorded the greatest height (14 m) and the biggest basal diameter (149 cm) in the research area. As can be seen from Table 4-3, the mean of height, basal diameter, basal area and crown area of the perennial species were calculated to be 2.59 m, 12.72 cm, 736.51 cm^2 and 12.04 m^2 respectively. Depending on the mean of height and crown area, **Phoenix dactylifera**, **Ziziphus spina-christi**, **Juniperus procera**, **Acacia gerradii**, and **Acacia negrii** are distinguished by a large size compared with the other species, being the five biggest trees, whereas **Lagonychium farctum, Rumex nervosus, Lycium barbarum, Reseda sphenocleoidis** and **Tephrosia apollinia** are characterised by smaller shrubs. The standard deviation values indicate that there are big variations between the maximum and minimum values in most of these plant morphology elements. Due to the grazing factor that operates in the north-eastern areas, and an inequality of moisture from one place to another, the plant cover value is also particularly varied, reaching 75% in some places in the south-western part and decreasing sharply in the north-eastern part of the research area. The plant cover value ranges from less than 1%

to 75%. According to Domin's scale, the mean estimation of plant cover value was computed to be 4.26, which equals 10 to 25%.

Quantitative analysis of the plant species based on absolute density, relative covering value, number of points with particular species, total number of individuals, abundance of species/100 m^2, absolute dominance, absolute frequency, relative density, relative dominance, relative frequency and importance value can be seen in Table 4-4. As can be seen from this table, the absolute density of the perennial plants in the research area is 2.71/100 m^2. This is a low density, yet it may be considered relatively high compared with other areas in Saudi Arabia. Despite the low absolute density, the relative covering value was calculated to be 21.70, indicating that many species are distinguished by their large size. With regard to the abundance of species, **Acacia arabica** (0.71/100 m^2), **Lycium shawii** (0.38/100 m^2), **Acacia gerradii** (0.34/100 m^2), **Acacia negrii** (0.27/100 m^2), and **Dodonaea viscosa** (0.22/100 m^2) are the most abundant species in the research area as a whole. Absolute dominance values (cm^2 of stem /100 m^2) indicated that **Juniperus procera** (190.32 cm^2/100 m^2), **Acacia gerradii** (67.68 cm^2/100 m^2), **Acacia arabica** (37.17 cm^2/100 m^2), **Phoenix dactylifera** (34.89 cm^2/100 m^2) and **Acacia negrii** (29.55 cm^2/100 m^2) have bigger stem sizes than the other species. The importance value has confirmed that **Acacia arabica** (IV = 61.68), **Juniperus procera** (IV = 60.54), **Acacia gerradii** (IV = 42.65), **Lycium shawii** (IV = 31.21) and **Acacia negrii** (IV = 27.56) are the most important perennial species in the research area. The other species listed in Table 4-4 are considered to be species of less importance. More information about the morphology of vegetation in the research area can be seen in the photographs and data illustrated in Appendix **2A** and **2B** respectively.

Table 4-3 Summary of Mean Measurements of Plant Components.

S/NO	Species	Mean of height m	Mean of basal diameter cm	Mean of basal area cm²	Mean of crown area m²
1	**Acacia arabica**	1.44 *(1.05)	6.46 (5.03)	52.57 (113.40)	3.62 (6.63)
2	**Acacia gerradii**	2.9 (2.32)	11.73 (10.69)	197.31 (512.05)	15.8 (21.77)
3	**Acacia negrii**	2.62 (1.48)	10.11 (6.07)	109.03 (146.77)	20.4 (32.14)
4	**Lagonychium farctum**	0.55 (0.07)	3.43 (0.35)	9.32 (1.87)	0.57 (0.06)
5	**Tephrosia apollinia**	0.7 (0.00)	2.5 (0.00)	4.91 (0.00)	0.52 (0.00)
6	**Lycium shawii**	1.01 (0.62)	4.71 (2.80)	23.56 (59.27)	1.67 (3.40)
7	**Lycium barbarum**	0.65 (0.06)	3.36 (0.51)	9.07 (2.77)	0.59 (0.10)
8	**Solanum incanum**	0.64 (0.10)	3.67 (0.430)	10.58 (2.40)	1.31 (2.16)
9	**Solanum schimperianum**	1.23 (0.18)	3.45 (0.04)	9.35 (0.22)	0.85 (0.31)
10	**Withania somnifera**	0.71 (0.02)	4 (0.00)	12.57 (0.00)	0.61 (0.06)
11	**Dodonaea viscosa**	1.31 (0.79)	5.67 (4.25)	39.29 (129.04)	2.63 (4.38)
12	**Kleinia odora**	0.77 (0.16)	4.27 (1.10)	15.24 (8.18)	0.88 (0.60)
13	**Euryops arabicus**	0.9 (0.40)	4.16 (2.35)	17.89 (44.44)	1.04 (1.65)
14	**Psiadia arabica**	0.74 (0.17)	3.43 (0.67)	9.59 (4.31)	0.76 (0.33)
15	**Juniperus procera**	4.04 (1.70)	31.72 (22.69)	1189.53 (1603.28)	36.18 (83.70)
16	**Leptadenia pyrotechnica**	1 (0.47)	4.72 (1.30)	17.87 (9.40)	0.96 (0.66)
17	**Calotropis procera**	1.87 (1.45)	5.7 (2.77)	30.04 (28.51)	1.65 (1.53)
18	**Periploca aphylla**	1.21 (0.16)	5.75 (0.35)	26.03 (3.20)	1 (0.18)
19	**Sageretia thea**	0.7 (0.14)	3.5 (0.55)	9.82 (3.01)	0.65 (0.13)
20	**Rhamnus disperma**	1.42 (0.64)	12.57 (8.46)	169.91 (167.06)	5.88 (5.15)
21	**Phoenix dactylifera**	14 (0.00)	149 (0.00)	17443.64 (0.00)	176.79 (0.00)
22	**Ziziphus spina-christi**	5.5 (0.00)	34 (0.00)	908.29 (0.00)	56.57 (0.00)
23	**Rumex nervosus**	0.64 (0.15)	3.38 (0.25)	8.88 (1.28)	0.55 (0.07)
24	**Reseda sphenocleoidis**	0.68 (0.08)	2.83 (0.29)	6.35 (1.25)	0.55 (0.09)
25	**Lavandula dentata**	0.82 (0.12)	4 (0.00)	12.57 (0.00)	0.84 (0.09)
26	**Mentha lavandulacea**	1.18 (0.37)	7.33 (0.58)	42.43 (6.81)	3.66 (0.91)
27	**Adenium obesum**	0.89 (0.25)	17 (1.41)	227.86 (37.78)	0.6 (0.13)
28	**Cluytia richardiana**	0.88 (0.04)	3.75 (1.41)	11.25 (1.87)	0.61 (0.04)
	Mean	**2.09**	**12.72**	**736.51**	**12.04**

**(1.05) Standard Deviation.*
Source: personal field work.

Table 4-4 Summary of Vegetation Data of the Research Area: **NPS** = number of point with species, **TNI** = total number of individuals, **AS** = abundance of species in 100 m^2, **AD** = absolute dominance (cm^2 / 100 m^2), **AF** = absolute frequency (percent), **RDE** = relative density, **RDO** = relative dominance, **RF** = relative frequency, **IV** = importance value and **IVR** = importance value rank.

No. Of Sampling points = 300 No. Of Species samples = 1200								**Absolute density (per 100 m^2) =2.71 Relative Covering Value = 21.70**			
S/ NO	Species	NPS	TNI	AS	AD	AF	RDE	RDO	RF	IV	IVR
1	Acacia arabica	92	313	0.707	37.17	30.67	26.09	9.514	26.08	61.68	1
2	Acacia gerradii	63	152	0.343	67.68	21.00	12.66	17.324	12.67	42.65	3
3	Acacia negrii	54	120	0.271	29.55	18.00	10.00	7.564	10.00	27.56	5
4	Lagonychium farctum	5	7	0.016	0.15	1.67	0.60	0.038	0.58	1.22	14
5	Tephrosia apollinia	1	1	0.002	0.01	0.33	0.07	0.002	0.09	0.16	28
6	Lycium shawii	84	173	0.381	9.21	28.00	14.43	2.357	14.42	31.21	4
7	Lycium barbarum	14	25	0.056	0.51	4.67	2.07	0.130	2.08	4.28	11
8	Solanum incanum	6	9	0.020	0.21	2.00	0.74	0.053	0.75	1.54	12
9	Solanum schimperianum	2	4	0.009	0.08	0.67	0.33	0.020	0.33	0.68	18
10	Withania somnifera	1	2	0.005	0.06	0.33	0.18	0.066	0.17	0.42	25
11	Dodonaea viscosa	48	96	0.217	8.53	16.00	8.01	2.183	8.00	18.19	6
12	Kleinia odora	36	79	0.178	2.71	12.00	6.57	0.693	6.58	13.84	7
13	Euryops arabicus	36	70	0.158	2.83	12.00	5.83	0.724	5.83	12.38	8
14	Psiadia arabica	23	35	0.079	0.76	7.67	2.92	0.194	2.92	6.03	10
15	Juniperus procera	45	71	0.160	190.32	15.00	5.90	48.719	5.92	60.54	2
16	Leptadenia pyrotechnica	5	8	0.018	0.32	1.67	0.67	0.081	0.67	1.42	13
17	Calotropis procera	3	4	0.009	0.27	1.00	0.33	0.069	0.33	0.73	17
18	Periploca aphylla	1	2	0.005	0.13	0.33	0.18	0.033	0.17	0.38	26
19	Sageretia thea	6	6	0.013	0.13	2.00	0.48	0.033	0.50	1.01	16
20	Rhamnus disperma	2	4	0.009	1.53	0.67	0.33	0.391	0.33	1.05	15
21	Phoenix dactylifera	1	1	0.002	34.89	0.33	0.07	8.931	0.08	9.08	9
22	Ziziphus spina-christi	1	1	0.002	1.82	0.33	0.07	0.465	0.08	0.62	21
23	Rumex nervosus	3	4	0.009	0.08	1.00	0.33	0.020	0.33	0.68	19
24	Reseda sphenocleoidis	1	3	0.007	0.04	0.33	0.26	0.010	0.25	0.52	24
25	Lavandula dentata	3	3	0.007	0.09	1.00	0.26	0.023	0.25	0.53	23
26	Mentha lavandulacea	2	3	0.007	0.30	0.67	0.26	0.076	0.25	0.59	22
27	Adenium obesum	1	2	0.005	1.14	0.33	0.18	0.291	0.17	0.64	20
28	Cluytia richardiana	2	2	0.005	0.06	0.67	0.18	0.015	0.17	0.37	27
	Total		**1200**	**2.71**	**390.66**	**180.34**	**100**	**100**	**100**		

Source: personal field work.

4-4 The Relationship Between Vegetation Components.

The vegetation components associate and interact with each other to comprise a fully integral system for growth, and to create appropriate life-forms for individuals. Analysing the relationships between these components helps to explain and interpret the power of the relationships that constitute this system. The Pearson correlation coefficient was used to determine these relationships. As can be seen from Table 4-5, this correlation coefficient was calculated between the four most important components (height, crown area, basal diameter and basal area) as follows:

Table 4-5 The Relationship Between Vegetation Components.

Plant components	**Height**	**Basal diameter**	**Basal area**
Crown cover	R = 0 .51 $p < 0.01$	R = 0.42 $p < 0.01$	R = 0.33 $p < 0.01$
Basal area	R = 0.53 $p < 0.01$	R = 0.87 $p < 0.01$	
Basal diameter	R = 0.75 $p < 0.01$		

R = Correlation Coefficient.
p = Level of Significance.

-All plant components under the present study are positively associated with each other.

-Correlation relationships between all plant components are significant at 1% significance level and two-tailed test.

-The positive relationship between height and crown area (R= 0.51), height and basal diameter (R= 0.75), height and basal area (R= 0.53), crown area and basal diameter (R= 0.42), crown area and basal area (R= 0.33) and between basal diameter and basal area (R= 0.87) denote that each component would be affected whether directly or indirectly by a change in another.

4-5 Classification of Samples and Species.

As was mentioned earlier, the diversity of species in the research area is relatively low; 8 of the 28 species encountered and recorded within the sampling points comprise about 90 percent of the frequency of species. These common and important species are: **Acacia arabica**, **Acacia gerradii**, **Acacia negrii**, **Dodonaea viscosa**, **Lycium shawii**, **Juniperus procera**, **Kleinia odora** and **Euryops arabicus** (Table 4-1). For investigation of the research area vegetation, 60 transects were distributed in the research area. Five quadrats were determined and investigated in each transect. A total of 1200 plant samples were collected from 300 quadrats. These quadrats and species (28 species) were classified by clustered classification using two-way indicator species analysis (TWINSPAN) (Hill, 1979b). TWINSPAN is a computer program in FORTRAN designed primarily for ecologists and phytosociologists who have collected data on the occurrence of a set of species in a set of samples. Version 1.0 of TWINSPAN, written in 1994, is essentially the same as the original program, but has been redesigned for modern hardware (Hill, 1994). The program first constructs a classification of the samples, and then uses this classification to obtain a classification of the species according to their ecological preferences. The two classifications are then used together to obtain an ordered two-way table that exhibits the relation between the species and the samples as clearly as possible.

4-5-1 Classification of Samples.

Only six levels emerged from running this program on the data of samples and species collected from the research area. These levels are illustrated in Fig. 4-6. The classification led to the identification of 14 important groups of plant community types. As can be seen from Fig. 4-6 and Table 4-6, the important groups emerged from the first three levels, and form the major part of the natural vegetation. Two major groups (0 and 1) have formed in level one. Four medium groups (00, 01, 10, and 11) have formed in level two and eight submedium groups (000, 001, 010, 011, 100, 101, 110 and 111) have formed in level three. Investigation and analysis of these groups are as follows:

Group 0 (Major Group).
Location: mostly, west and south of the research area.
Transects: 11-40 (see Fig. 3- 2 and Table 3- 1 in Chapter Three).

This group is concentrated in particular in the west and south of the research area. These locations are represented by transects 11- 40 and are characterised by the abundance of **Dodonaea viscosa** as a main indicator, and presence of **Juniperus procera, Acacia gerradi**, **Acacia negrii**, and **Lycium shawii**. This group has a wide distribution; therefore it subdivided and formed two medium groups (00 and 01) in level two.

Group 00 (Medium Group).
Location: west and south-west of the research area.
Transects: 11- 30.

Group 00 predominates in the west and south-west of the research area, where the transects 11- 30 were distributed. These sites are characterised by the abundance of **Juniperus procera**. This group subdivided further and formed two submedium groups (000 and 001) in level three.

Group 000 (Submedium Group).
Location: west of the research area.
Transects: mostly in 9-25.

This group extends in general along the west of the research area, and in particular in transects 9-25. This region is represented by the high western mountains where the **Juniperus procera** is concentrated in a 100 percentage.

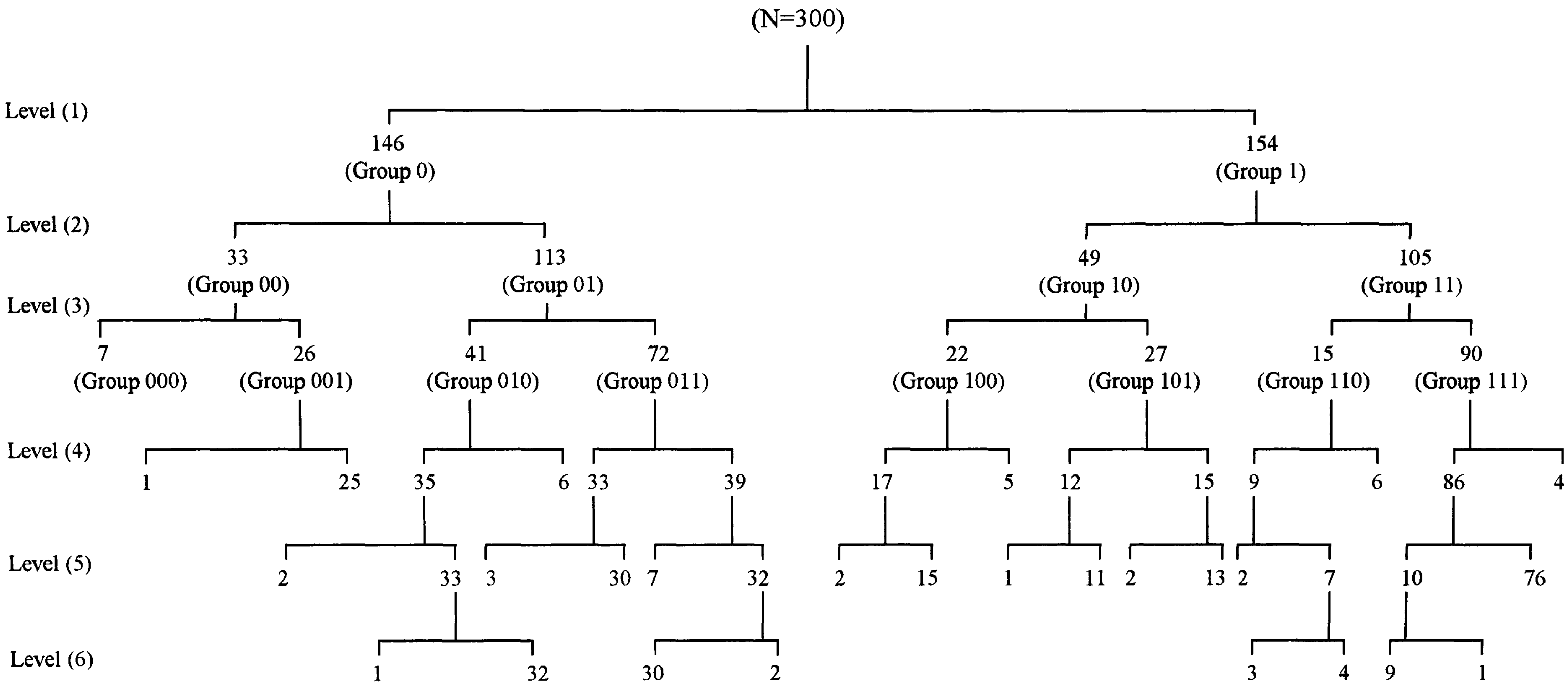

Figure 4-6 Samples Classification Resulting from an Application of TWINSPAN Hierarchy on the Data Collected from the Research Area.

Table 4-6 Two way table resulting from an application of TWINSPAN .program to classify species and samples of the research area

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(Table 4-6)Continued

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Group 001 (Submedium Group).
Location: west of the research area.
Transects: 6-24.

This location has been classified as one group due to the presence and abundance of **Psiadia arabica** species. This species is distributed in a 100 percentage within the western parts of the research area, containing the transects 6-24.

Group 01 (Medium Group).
Location: south and south-east of the research area.
Transects: 21- 45.

This group is widely prevalent in the regions containing transects 21-45, located in the south and south-east of the research area. These regions are distinguished by the dominance of **Acacia gerradii** as a main indicator, and the presence of **Acacia negrii** and **Lycium shawii**. This group subdivided further and formed two submedium groups (010 and 011) in level three.

Group 010 (Submedium Group).
Location: south of the research area.
Transects: 26- 45.

The southern part of the research area has been classified as one group due to the presence and abundance of **Lycium shawii**. This species is present in this part in a 100 percent concentration.

Group 011 (Submedium Group).
Location: south of the research area.
Transects: 17- 45.

This group prevails in the south of the research area, where transects 17-45 are situated. This location is distinguished by dominance of **Acacia negrii** as a main indicator and by the presence of **Lycium shawii** species.

Group 1 (Major Group).
Location: mostly in the north and east of the research area.
Transects: 1-10 and 41-60.

This group is prevalent in transects 1- 10 and 41- 60, located in the north and east of the research area. These locations have been classified as one group due to the abundance of **Acacia arabica**, which is the important species in the research area, but its distribution is not wide. 75 % of this species is concentrated in the north-east, whereas the remainder is distributed in the north-west of the research area. **Kleinia odora**, **Euryops arabicus**, **Juniperus procera** and **Lycium barbarum** are common species in this group . This group has a wide distribution; therefore it subdivided and formed two medium groups (10 and 11) in level two.

Group 10 (Medium Group).
Location: south and south-east of the research area.
Transects: 21- 45.

As mentioned earlier, this group was created from the splitting of group 1. It appears obviously in the south and south-east of the research area. It is characterised by having abundance of **Kleinia odora**, **Euryops arabicus**, **Juniperus procera** and **Lycium barbarum** species. This group subdivided further and formed two submedium groups (100 and 101) in level three.

Group 100 (Submedium Group).
Location: south-east of the research area.
Transects: 31- 45.

This group predominates over an important part of the south-eastern of the research area. This part has been classified as one group due to the abundance of **Kleinia odora** and presence of **Lycium barbarum** species, which are concentrated in this part at 71% and 100% levels, respectively.

Group 101 (Submedium Group).
Location: south-west of the research area.
Transects: 9-29.

The south-west of the research area has been classified as one group due to the dominance of **Euryops arabicus** as a main indicator and presence of **Juniperus procera** species. The presence and absence of these two species appear to be associated widely in the research area. They appear together strongly in the south-west and are both absent in other parts of the research area.

Group 11 (Medium Group).
Location: north of the research area.
Transects: 1- 10 and 46- 60.

Group 11 is prevalent in particular in the north of the research area, where transects 1-10 and 46- 60 are located. This part of the research area is classified as one group due to the presence and abundance of **Acacia arabica**, **Lycium shawii**, **Psiadia arabica**, **Solanum incanum**, **Leptadenia pyrotechnica** and **Periploca aphylla**. This group subdivided further and formed two submedium groups (110 and 111) in level three.

Group 110 (Submedium Group).
Location: mostly east and south-east of the research area.
Transects: mostly 31- 54.

In view of the dominance of **Acacia arabica, Lycium shawii** as main indicators and the presence of **Psiadia arabica**, **Solanum incanum**, **Leptadenia pyrotechnica** and **Periploca aphylla**, the east and south-east of the research area have been classified as one group. It is worth noting that **Solanum imcanum**, **Leptadenia pyrotechnica** and **Periploca aphylla** are present in the research area in small numbers (Table 4-1 and Fig. 4-5), but they are distributed over a wide area.

Group 111 (Submedium Group).
Location: mostly north-east of the research area.
Transects: 46- 60.

Due to the presence of **Lagonychium farctum**, **Calotropis procera**, and **Rhamnus disperma**, the north-east of the research area has been classified as one group.

The very small groups produced in levels 4, 5 and 6 were not analysed further, because they make no ecological sense and they are not important in the vegetation composition of the research area.

4-5-2 Classification of Species.

Species classification is an additional classification produced from an application of TWINSPAN program on the species data. The species were classified by TWINSPAN in much the same way as the sample. However, there is an important difference in that the species classification was made in the light of the sample classification, and not using the raw data. In fact, the species classification was made on the basis of fidelity, namely, using the degree to which species are confined to particular groups of sample.

As can be seen from Fig. 4-7 the 28 species shown in Table 4-1 divided in level one and comprised two main groups (0 and 1). Group 0 comprises 27 species (**Acacia gerradii**, **Acacia negrii**, **Lagonychium farctum**, **Tephrosia apollinia**, **Lycium shawii**, **Lycium barbarum**, **Solanum incanum**, **Solanum schimperianum**, **Withania somnifera**, **Dodonaea viscosa**, **Kleinia odora**, **Euryops arabicus**, **Psiadia arabica**, **Juniperus procera**, **Leptadenia pyrotechnica**, **Calotropis procera**, **Periploca aphylla**, **Sageretia thea**, **Rhamnus disperma**, **Phoenix dactylifera**, **Ziziphus spina-christi**, **Rumex nervosus**, **Reseda sphenocleoidis**, **Lavandula dentata**, **Mentha lavandulacea**, **Adenium obesum**, and **Cluytia richardiana**), whereas group 1 contains 1 species (**Acacia arabica**). Group 0 subdivided in level two to give a further two groups (00 and 01). Group 00 involves **Acacia gerradii**, **Acacia negrii** and **Lycium shawii**, whereas group 01 contains **Lagonychium farctum**, **Tephrosia apollinia**, **Lycium barbarum**, **Solanum incanum**, **Solanum schimperianum**, **Withania somnifera**, **Dodonaea viscosa**, **Kleinia odora**, **Euryops arabicus**, **Psiadia arabica**, **Juniperus procera**, **Leptadenia pyrotechnica**, **Calotropis procera**, **Periploca aphylla**, **Sageretia thea**, **Rhamnus disperma**, **Phoenix dactylifera**, **Ziziphus spina-**

christi, **Rumex nervosus**, **Reseda sphenocleoidis**, **Lavandula dentata**, **Mentha lavandulacea**, **Adenium obesum** and **Cluytia richardiana**.

As shown in Table 4-6, **Acacia gerradii**, **Acacia negrii**, **Dodonaea viscosa**, **Rumex nervosus** and **Adenium obesum** are together completely faithful to group 0 of the sample hierarchy. However, **Dodonaea viscosa** is also completely faithful to group 00 of the sample hierarchy, whereas **Acacia gerradii**, **Acacia negrii**, **Rumex nervosus** and **Adenium obesum** are not. **Acacia gerradii** and **Acacia negrii** are both completely faithful to group 01, but **Acacia gerradii** is also very highly faithful to group 010, whereas, **Acacia negrii** is very highly faithful to group 011 of the sample hierarchy.

On the other side, **Lagonychium farctum**, **Lycium barbarum**, **Withania somnifera**, **Leptadenia pyrotechnica**, **Calotropis procera**, **Periploca aphylla**, **Sageretia thea**, **Rhamnus disperma**, **Reseda sphenocleoidis**, **Mentha lavandulacea** and **Acacia arabica** are together completely faithful to group 1 of the sample hierarchy. However, **Lycium barbarum** is also completely faithful to group 10, whereas **Lagonychium farctum**, **Withania somnifera**, **Leptadenia pyrotechnica**, **Calotropis procera**, **Periploca aphylla**, **Sageretia thea**, **Rhamnus disperma**, **Reseda sphenocleoidis**, **Mentha lavandulacea** and **Acacia arabica** are not. **Withania somnifera**, **Leptadenia pyrotechnica**, **Calotropis procera**, **Periploca aphylla**, **Sageretia thea**, **Rhamnus disperma**, **Reseda sphenocleoidis**, **Menthal lavandulacea** and **Acacia arabica** are together completely faithful to group 11, but **Periploca aphylla** and **Mentha lavandulacea** are also very highly faithful to group 110, whereas **Calotropis procera**, **Sageretia thea**, **Rhamnus disperma** and **Reseda sphenocleoidis** are very highly faithful to group 111 of the sample hierarchy.

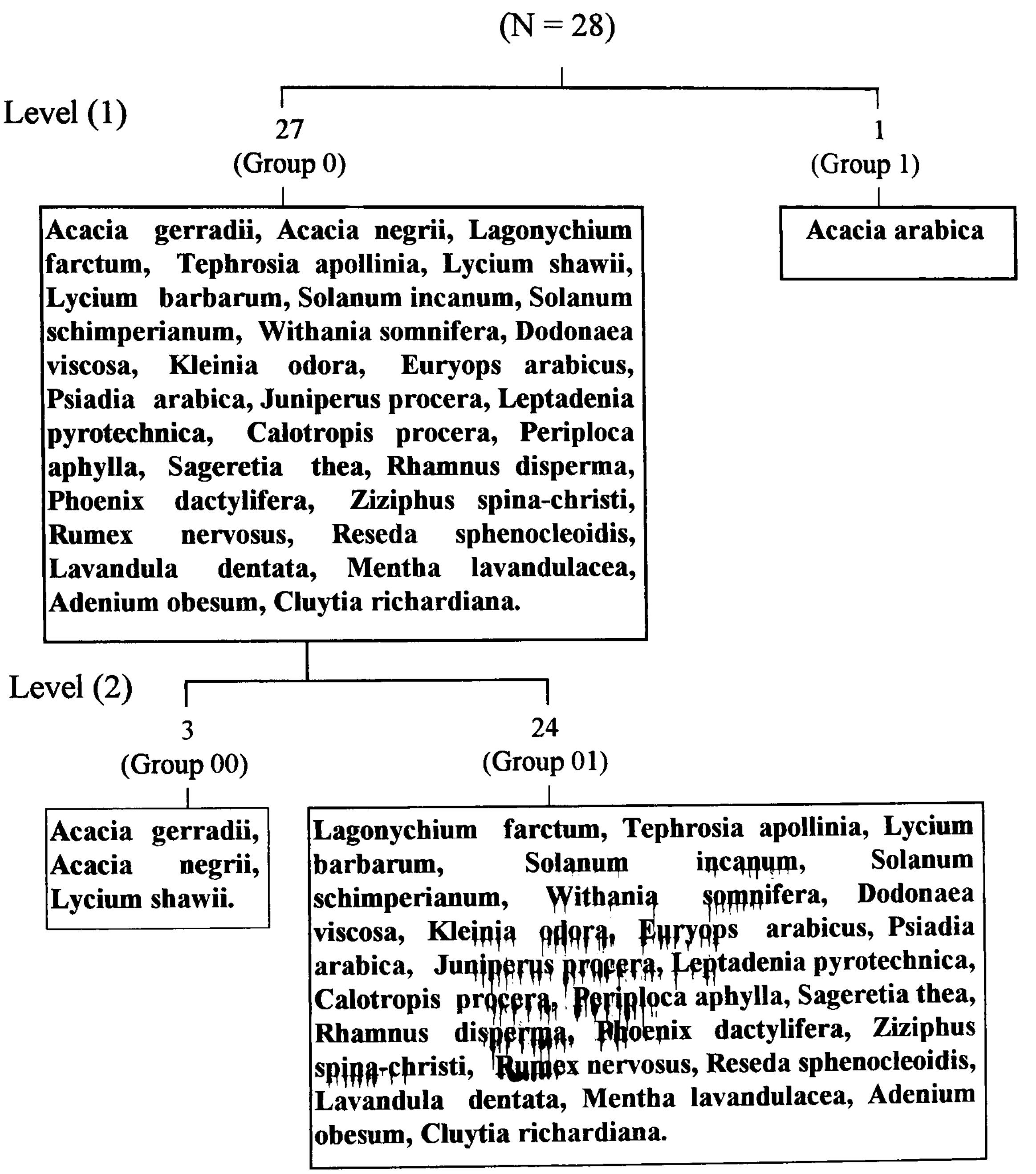

Figure 4-7 Species classification resulting from an application of TWINSPAN program to the research area data.

4-6 The Relationship Between Species and Environmental Factors.

The classifications of samples and species produced by using the TWINSPAN program make it possible to investigate and discover the relationship between species distribution and the associated environmental variables that have been collected from the research area. The 28 species listed in Table 4-1 and 8 environmental variables, namely slope angle, slope gradient, slope length, soil depth, soil moisture, texture class, pH of soil and organic matter were investigated and included. In order to find out the relations between them, the DECORANA (CANOCO/DECORANA) program was used (Ter Braak, 1988 and Hill, 1994).

The classification of floristic data using the DECORANA program gave strongly similar results to the classification results of the floristic data using TWINSPAN. DECORANA analysis (Fig. 4-8; eigenvalues: axis 1= 0.158; axis 2= 0.040) showed that the floristic composition and distribution of the main plant groups reflected the conditions of soil and the topographical variety in the research area. 22 of the 28 species agglomerated to compose 6 clusters. Two species (**Lagonychium farctum** and **Mentha lavandulacea**) were located out of the clusters. Other species, such as **Reseda sphenocleoidis**, **Lavandula dentata**, **Adenium obesum** and **Clytia richardiana** were located out of the diagram. The 6 clusters obtained by this analysis were considered vegetation types. Most of these types are associated with one or more of the environmental factors. The environmental factors display variation in species composition. They are represented by arrows in Fig. 4-8. The arrow for an environmental variable points in the direction of maximum change of that environmental variable across the diagram, and its length is proportional to the rate of change in this direction. Environmental variables with long arrows are more strongly correlated with the ordination axes than those with short arrows. As can be seen from Fig. 4-8, **Acacia**

arabica, **Acacia gerradii**, **Acacia negrii**, **Lycium shawii** and **Rhamnus disperma** were found to have positive correlation with deep soils, sandy soils and alkali soils. **Sageretia thea**, **Tephrosia apollinia** and **Solanum schimperianum** are strongly associated with slope angle, slope gradient and moisture and somewhat associated with organic matter. **Juniperus procera**, **Euryops arabicus**, **Dodonaea viscosa**, **Leptadenia pyrotechnica** and **Psiadia arabica** also have correlation with organic matter.

Despite the few attempts that have been made by ecologists and phytogeographers, such as Vesey-Fitzgerald (1955, 1957a and 1957b), Novikova (1970), Zohary (1973), Migahid (1988) and Frey & Kurschner (1989), as well as the Water Atlas of Saudi Arabia (1984 and 1994), to draw a vegetation map for the research area, many mistakes have been perpetrated in these maps. These mistakes have resulted either from erroneous data or general information. Hence and depending on the data collected from the research area, reconnaissance surveys and the classification of vegetation and samples resulting from an application of the TWINSPAN and DECORANA computer programs, a new perennial vegetation map of the research area has been produced and is depicted in Fig. 4-9. This map illustrates the actual status of vegetation types in the research area. As can be seen from this map, the vegetation of the research area has been divided into 5 distinct plant groups. In order to avoid the problem of overcrowding in the map, very small plant groups which are of very little importance, have been combined with the nearest group. These groups are as follows:

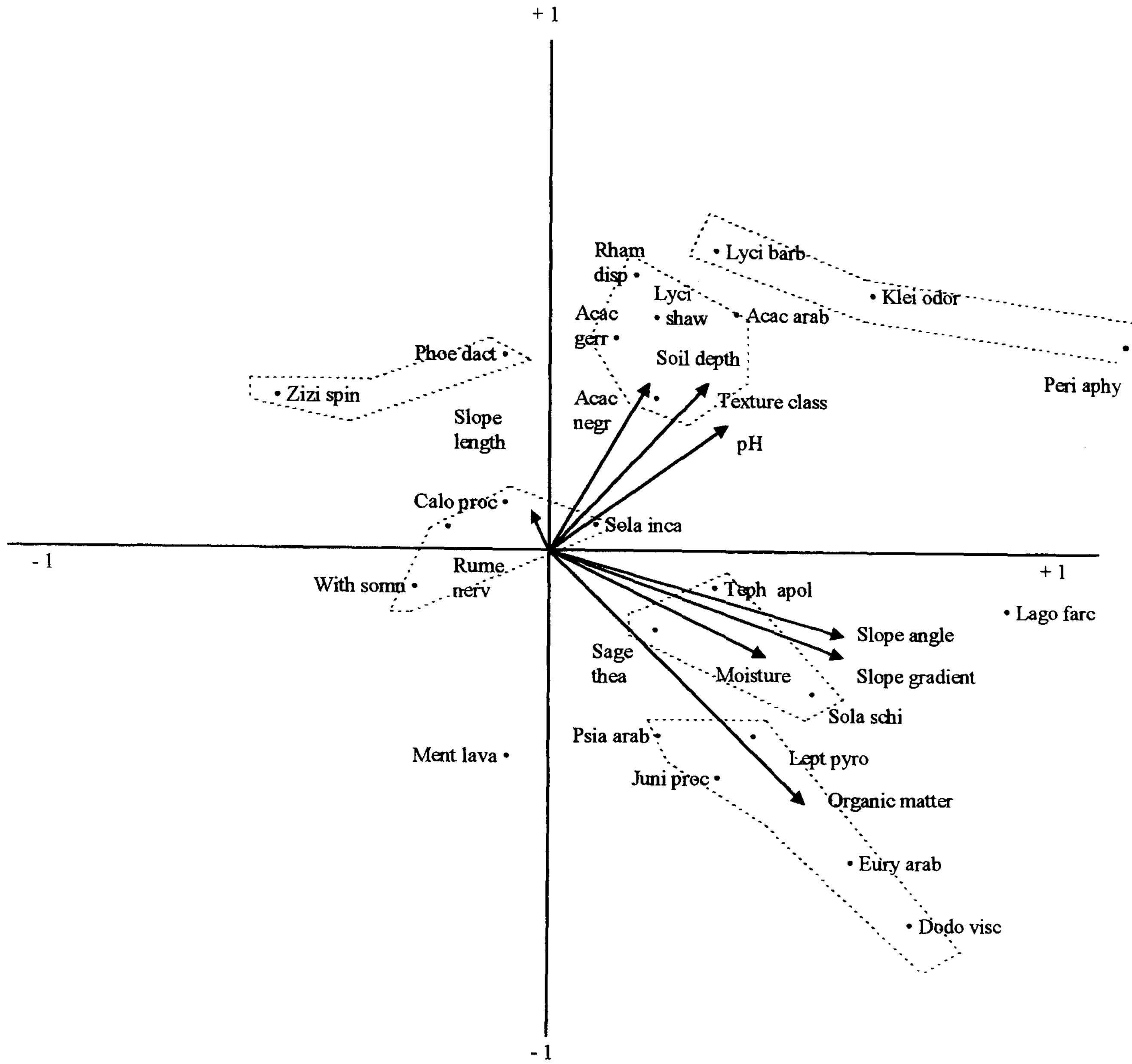

Figure 4-8 The Research Area Data; CCA Ordination Diagram with Plant Species (•) and Environmental Variables (arrows); First Axis is Horizontal, Second Axis Vertical.

Key to Species:

Eury arab = **Euryops arabicus**	Klei odor = **Kleinia odora**	Psia arab = **Psiadia arabica**
Juni proc = **Juniperus procera**	Acac arab = **Acacia arabica**	Acac gerr = **Acacia gerradii**
Acac negr = **Acacia negrii**	Dodo visc = **Dodonaea viscosa**	Lyci barb = **Lycium barbarum**
Lyci shaw = **Lycium shawii**	Sage thea = **Sageretia thea**	Rume nerv = **Rumex nervosus**
Calo proc = **Calotropis procera**	Sola inca = **Solanum incanum**	Peri aphy = **Periploca aphylla**
Ment lavan = **Mentha lavandulacea**	Rume nerv = **Rumex nervosus**	Phoe dact = **Phoenix dactylifera**
Lago farc = **Lagonychium farctum**	Teph apol = **Tephrosia apollinia**	
Zizi spin = **Ziziphus spina-christi**	Lept pyro = **Leptadenia pyrotechnica**	
Sola schi = **Solanum schimperianum**	With somn = **Withania somnifera**.	

The first group consists largely of **Acacia arabica**. This species and other perennial minor species spread in the dry north and north-east of the research area, particularly between 1000 and 1500 m a.s.l. Notably, **Acacia arabica** is completely absent from the south of the research area. These species all have long roots that enable them to get the water from deep layers. It should be mentioned that these species are suffering from human activities, such as overgrazing and somewhat wood cutting. This result is consistent with that of Brooks & Mandil (1983).

The second group consists mainly of **Juniperus procera**, **Euryops arabicus** and **Dodonaea viscosa**. These species are widespread above 1500 m altitude, on the tops and eastern hillsides of the Asir and Al-Hijaz mountains which extend along the wetter west part of the research area. The association of these species with this altitude also has been indicated by Batanouny (1987) and Brooks & Mandil (1983). One of the main characteristics of the plant species of this group is that they are perennial green trees and shrubs and they are usually festooned with lichens.

The third group appears in most head sources of Wadi Bishah. The familiar species in this group are **Acacia gerradii** and **Dodonaea viscosa**. The main characteristics of the vegetation of this group are that they have big bodies and are concentrated mostly close to water courses.

The fourth group of plants appears to occupy the south-eastern part of the Wadi Bishah catchment. This botanical group consists of **Lycium shawii** and **Acacia negrii**. Due to the scarcity of water in this part, the vegetation colour of this group appears to be grey, particularly during the winter and autumn seasons.

The fifth group consists of **Kleinia odora**, **Lycium barbarum**, **Lycium shawii**, **Psiadia arabica**, **Solanum incanum**, **Leptadenia pyrotechnica** and **Periploca aphylla**. These species are spread in the middle and east of the research area. Most of these areas plants are a mixture of succulent plants and needle-bearing plants (Abulfatih, 1984).

4-7 Features of Subregional Plant Communities and Habitats.

The following discussion and analysis provide quantitative estimates of vegetation structure and distribution of the plant communities and habitats in the research area. They focus particularly on the data collected from the research area, and the reconnaissance surveys that were explained in more detail in Chapter Three.

Data analysis and reconnaissance surveys showed that from an ecological and geomorphological point of view, the research area could be divided horizontally into two distinct plant communities (mountainous plant community and semi-desert plant community) and vertically into five plant habitat types, namely the toe-slope habitat, foot-slope habitat, mid-slope habitat, shoulder slope habitat and summit slope habitat. The recognised communities and habitat types varied in their environmental features (topography, soil conditions and the degree of animal impacts) and consequently in their vegetation composition. This fact has confirmed what Batanouny (1987) stated, that topography and soil properties, especially the physical attributes and water resources, play an important role in the distribution of the different plant communities in the western mountains of Arabian peninsula. Analysis and discussion of these communities and habitat types are presented below.

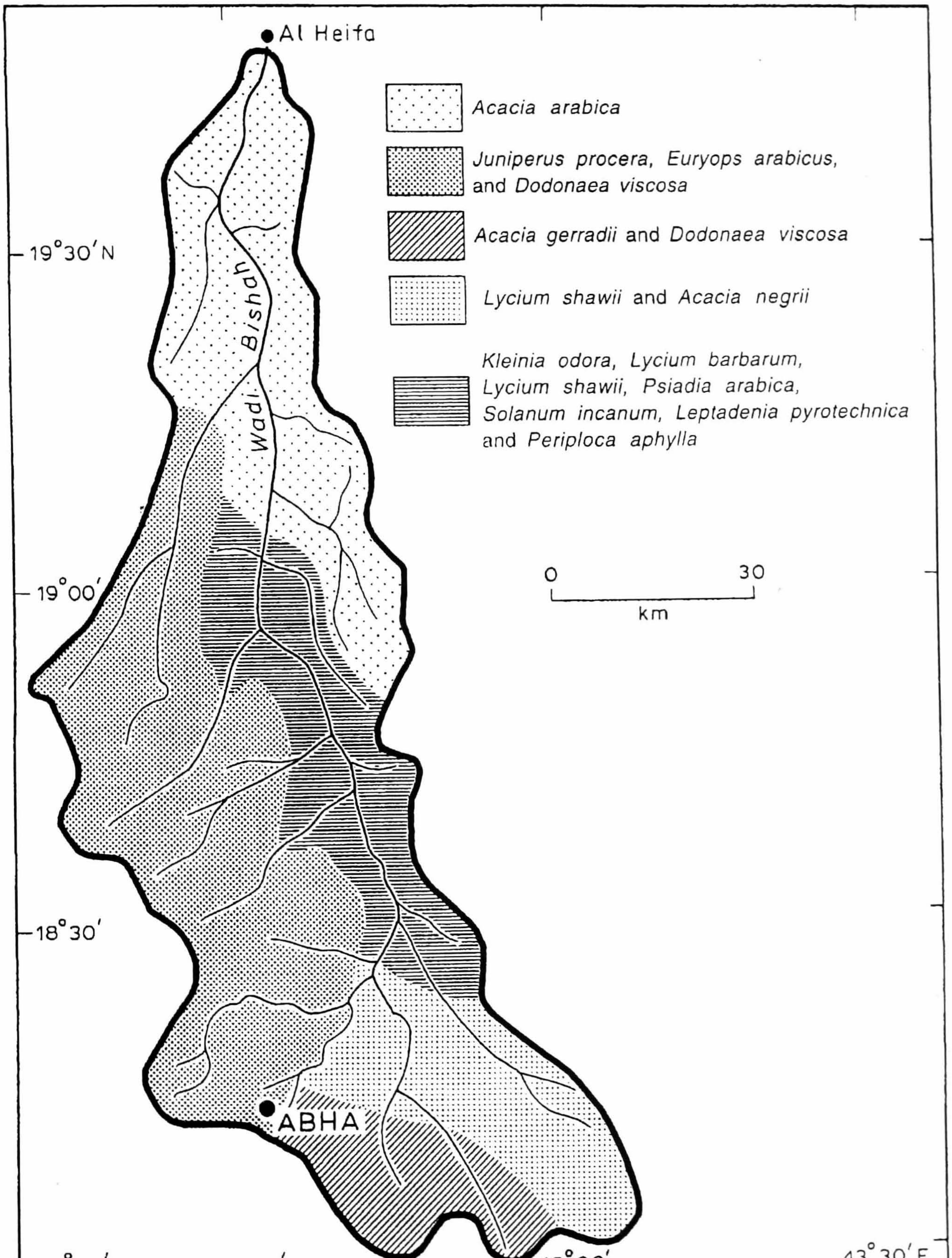

Figure 4-9 Perennial Vegetation Map of the Research Area.
(Source: Personal work)

4-7-1 Mountainous Plant Community.

Brooks & Mandil (1983) stated that the south-western highlands of the research area have the greatest number of plant species in Saudi Arabia. A mountainous plant community is distributed in this area. Its topography and climate are widely different from those of the semi-desert plant community located in the north-east of the research area. This is due to the high altitude (2000-3130 m above sea level) with its consequences for air temperature, and to relatively high rainfall without a prolonged dry period as in the desert and semi-desert plant communities. It contains high mountains, rocky hills, escarpments and rolling lands. Such topography, with its relatively high rainfall and moderate temperature, has created a distinct type of habitat for plant growth. As can be seen from Table 4-7, 21 perennial species belonging to 12 botanical families were recorded in the mountainous plant community. Most of these species need relatively high moisture levels and a low temperature. Most botanical species found in this community are distinguished by moderate to small sizes. The mean of height, basal diameter, basal area and crown area of the perennial species in this community were calculated to be 1.68 m, 6.50 cm, 80.34 cm^2 and 2.45 m^2 respectively. As can be seen from Appendix **2B**, **Acacia gerradii** species recorded the greatest height (7.85 m) in the mountainous plant community, whereas **Juniperus procera** species recorded the biggest basal diameter (72 cm) and the greatest crown area (707.14 m^2). The plant cover value varies from one stand to another, but overall it is better than the plant cover value in the semi-desert plant community. According to Domin's scale, the mean estimation of plant cover value was counted to be 4.94, which equals about 11 to 25 %.

Quantitative analysis of species in the mountainous plant community, covering absolute density, relative covering value, number of point with species, total number of individuals, abundance of species, absolute dominance, absolute frequency, relative density, relative dominance, relative frequency and importance value is presented in Table 4-7. The absolute density and relative covering value of perennial species in this community are 3.01/100 m^2 and 32 respectively. These are considered high values, compared with the absolute density and relative covering value in the semi-desert plant community (2.46/100 m^2 and 13.21 respectively). Absolute dominance values indicate that **Juniperus procera** (217.66 cm^2/100 m^2), **Acacia gerradii** (82.06 cm^2/100 m^2), **Acacia negrii** (65.38 cm^2/100 m^2), **Dodonaea viscosa** (15 cm^2/100 m^2) and **Lycium shawii** (6.82 cm^2/100 m^2) are the most dominant in this community. Importance values indicate that **Juniperus procera** (IV = 69.76) **Acacia negrii** (IV = 55.93) **Acacia gerradii** (IV = 54.4) **Lycium shawii** (IV = 28.34) and **Dodonaea viscosa** (IV = 24.73) are the important perennial species, whereas the other species recorded in south-western mountains are considered to be of less importance.

Table 4-7 Summary of Vegetation Data of Mountainous Plant Community: **NPS** = number of points with species, **TNI** = total number of individuals, **AS** = abundance of species in 100 m^2, **AD** = absolute dominance (cm^2 / 100 m^2), **AF** = absolute frequency (percent), **RDE** = relative density, **RDO** = relative dominance, **RF** = relative frequency, **IV** = importance value and **IVR** = importance value rank.

No. Of Sampling points = 150 No. Of Species samples = 600							**Absolute density (per 100 m^2) =3.01 Relative Covering Value = 32**				
S/ NO	**Species**	NPS	TNI	AS	AD	AF	RDE	RDO	RF	IV	IVR
1	**Acacia gerradii**	38	102	0.512	82.06	25.33	17.01	20.39	17.00	54.40	3
2	**Acacia negrii**	53	119	0.597	65.38	35.33	19.84	16.25	19.84	55.93	2
3	**Lycium shawii**	37	80	0.401	6.82	24.67	13.32	1.69	13.33	28.34	4
4	**Lycium barbarum**	6	13	0.065	0.60	4.00	2.16	0.15	2.17	4.48	9
5	**Solanum incanum**	5	7	0.035	0.37	3.33	1.16	0.09	1.17	2.42	10
6	**Solanum schimperianum**	2	4	0.020	0.19	1.33	0.66	0.05	0.67	1.38	12
7	**Withania somnifera**	1	2	0.010	0.13	0.67	0.33	0.03	0.33	0.69	18
8	**Dodonaea viscosa**	31	63	0.316	15.00	20.67	10.50	3.73	10.50	24.73	5
9	**Kleinia odora**	22	53	0.266	3.60	14.67	8.84	0.90	8.83	18.57	7
10	**Euryops arabicus**	35	59	0.296	5.50	23.33	9.83	1.37	9.83	21.03	6
11	**Psiadia arabica**	19	27	0.136	1.35	12.67	4.52	0.34	4.50	9.36	8
12	**Juniperus procera**	30	47	0.236	217.66	20.00	7.84	54.09	7.83	69.76	1
13	**Leptadenia pyrotechnica**	3	6	0.030	0.51	2.00	1.00	0.13	1.00	2.13	11
14	**Calotropis procera**	1	1	0.005	0.14	0.67	0.17	0.03	0.17	0.37	20
15	**Periploca aphylla**	1	2	0.010	0.26	0.67	0.33	0.06	0.33	0.72	17
16	**Sageretia thea**	3	4	0.020	0.17	2.00	0.66	0.04	0.67	1.37	13
17	**Rumex nervosus**	2	3	0.015	0.13	1.33	0.50	0.03	0.50	1.03	15
18	**Reseda sphenocleoidis**	1	3	0.015	0.10	0.67	0.50	0.02	0.50	1.02	16
19	**Lavandula dentata**	1	1	0.005	0.06	0.67	0.17	0.01	0.17	0.35	21
20	**Adenium obesum**	1	2	0.010	2.28	0.67	0.33	0.57	0.33	1.23	14
21	**Cluytia richardiana**	2	2	0.010	0.11	1.33	0.33	0.03	0.33	0.69	19
	Total		**600**	**3.01**	**402.42**	**196.01**	**100**	**100**	**100**		

Source: personal field work.

4-7-2 Semi-Desert Plant Community.

The semi-desert plant community is clearly evident in the north-east of the research area. This part of the research area is located between 1000-2000 m altitude, and links the south-western highlands with the desert regions to the east. The soil in this part is relatively deep and alkaline, with little organic matter. Values of rainfall in the north-east of the research area are too low to support a perennial vegetation cover (see

Chapter One (1.2.5.4). However, many perennial species have adapted to this environmental situation and have appeared and are distributed in this region. As can be seen from Table 4-8, 22 perennial species belonging to 19 genera and 9 botanical families were recorded in the semi-desert plant community. As can be observed from Appendix 2B, **Phoenix dactylifera** recorded the greatest height (14 m), the biggest basal diameter (149 cm) and the greatest crown area (176.79 m^2) in the semi-desert plant community. Due to the overgrazing that occurs in this zone, and the low level of rainfall, the plant cover value is very weak in this community. According to Domin's scale, the mean estimation of plant cover value was computed to be 3.59 (or 1-4%).The common species recorded in this community are either spiny or succulent plants which can endure and adapt to low moisture and high temperature. Absolute density and relative covering value of perennial species were calculated to be 2.46/100 m^2 and 13.21 respectively. Comparing the absolute density and relative covering value in this community with the equivalent values in the mountainous plant community, it is found that the north-eastern part of the research area has less density and relative cover. Values of species abundance showed that **Acacia arabica** (1.283/100 m^2), **Lycium shawii** (0.381/100 m^2), **Acacia gerradii** (0.205/100 m^2), **Dodonaea viscosa** (0.135/100 m^2) and **Kleinia odora** (0.107/100 m^2) are very common species in north-western part of the research area. Absolute dominance values showed that **Juniperus procera** (167.87 cm^2/100 m^2), **Phoenix dactylifera** (69.77 cm^2/100 m^2), **Acacia arabica** (67.45 cm^2/100 m^2) and **Acacia gerradii** (57.30 cm^2/100 m^2) are the most dominant in this community. Importance values have confirmed that **Acacia arabica** (IV = 121.68), **Juniperus procera** (IV = 51.18), **Lycium shawii** (IV = 33.58) and **Acacia gerradii** (IV = 31.41) are the important perennial species, whereas the other species are of comparatively little importance.

Table 4-8 Summary of Vegetation Data of Semi-desert Plant Community: **NPS** = number of points with species, **TNI** = total number of individuals, **AS** = abundance of species in 100 m^2, **AD** = absolute dominance (cm^2 / 100 m^2), **AF** = absolute frequency (percent), **RDE** = relative density, **RDO** = relative dominance, **RF** = relative frequency, **IV** = importance value and **IVR** = importance value rank.

No. Of Sampling points = 150 No. Of Species samples = 600							Absolute density (per 100 m^2) =2.46 Relative Covering Value = 13.21				
S/ NO	Species	NPS	TNI	AS	AD	AF	RDE	RDO	RF	IV	IVR
1	Acacia arabica	92	313	1.283	67.45	61.33	52.15	17.357	52.17	121.68	1
2	Acacia gerradii	25	50	0.205	57.30	16.67	8.33	14.745	8.33	31.41	4
3	Acacia negrii	1	1	0.004	0.20	0.67	0.16	0.051	0.17	0.38	21
4	Lagonychium farctum	5	7	0.029	0.26	3.33	1.18	0.067	1.17	2.42	11
5	Tephrosia apollinia	1	1	0.004	0.02	0.67	0.16	0.005	0.17	0.34	22
6	Lycium shawii	47	93	0.381	11.13	31.33	15.49	2.864	15.50	33.85	3
7	Lycium barbarum	8	12	0.049	0.44	5.33	1.99	0.113	2.00	4.10	8
8	Solanum incanum	1	2	0.009	0.09	0.67	0.37	0.023	0.33	0.72	17
9	Dodonaea viscosa	17	33	0.135	3.19	11.33	5.49	0.820	5.50	11.81	6
10	Kleinia odora	14	26	0.107	1.98	9.33	4.35	0.509	4.33	9.19	7
11	Euryops arabicus	11	11	0.046	0.64	7.33	1.87	0.165	1.83	3.89	9
12	Psiadia arabica	4	8	0.033	0.28	2.67	1.34	0.072	1.33	2.74	10
13	Juniperus procera	15	24	0.098	167.87	10.00	3.98	43.20	4.00	51.18	2
14	Leptadenia pyrotechnica	2	2	0.008	0.16	1.33	0.33	0.041	0.33	0.70	18
15	Calotropis procera	2	3	0.012	0.37	1.33	0.49	0.095	0.50	1.09	15
16	Sageretia thea	3	2	0.009	0.10	2.00	0.37	0.026	0.33	0.73	16
17	Rhamnus disperma	2	4	0.016	2.72	1.33	0.65	0.700	0.67	2.02	12
18	Phoenix dactylifera	1	1	0.004	69.77	0.67	0.16	17.954	0.17	18.28	5
19	Ziziphus spina-christi	1	1	0.004	3.63	0.67	0.16	0.934	0.17	1.26	13
20	Rumex nervosus	1	1	0.004	0.40	0.67	0.16	0.102	0.17	0.43	20
21	Lavandula dentata	2	2	0.008	0.10	1.33	0.33	0.026	0.33	0.69	19
22	Mentha lavandulacea	2	3	0.012	0.51	1.33	0.49	0.131	0.50	1.12	14
	Total		600	2.46	388.61	171.32	100	100	100		

Source: personal field work.

4-7-3 Toe-Slope Habitat Type.

Toe-slope zones are comprised of wadi sides which are one of the characteristic geomorphologic features of the research area. These wadis are formed of a complex network of the main stream of Upper Wadi Bishah and its tributaries. The soil of toe-slope zones is formed of materials derived from the surrounding mountains (El-demerdash & Zilay, 1994) and receives more water from surface flow and flood than elsewhere. The results of soil analysis show that these zones have deep soil, high moisture and fertility, compared with the other habitats in the research area (see Tables 5-6 and 5-14).

As listed in Table 4-9, this habitat is occupied by 21 perennial species. These species are **Acacia arabica**, **Acacia gerradii**, **Acacia negrii**, **Lycium shawii**, **Lycium barbarum**, **Solanum incanum**, **Solanum schimperianum**, **Withania somnifera**, **Dodonaea viscosa**, **Kleinia odora**, **Euryops arabicus**, **Psiadia arabica**, **Juniperus procera**, **Leptadenia pyrotechnica**, **Calotropis procera**, **Sageretia thea**, **Phoenix dactylifera**, **Ziziphus spina-christi**, **Rumex nervosus**, **Lavandula dentata** and **Mentha lavandulacea**. Mean height (2.33 m), basal diameter (15.43 cm) and crown area (16.40 m^2) of the perennial species recorded in this habitat indicate that the plants of this habitat are characterised by large size, compared with the other habitats in the research area. Abundance values of species indicate that the most common species in this habitat are **Acacia arabica** (0.70/100 m^2), **Acacia gerradii** (0.58/100 m^2), **Acacia negrii** (0.54/100 m^2), **Lycium shawii** (0.44/100 m^2) and **Juniperus procera** (0.27/100 m^2). The relative covering value of perennial species in the toe-slope habitat (44.01) is consistent with the comment made above regarding the large size of the trees and shrubs of this habitat. The absolute density of perennial plants in this habitat is 2.95/100 m^2. This is considered high density, compared with the absolute density in the other habitats of the research area. Absolute dominance values show that **Acacia gerradii** (190.55 cm^2/100 m^2), **Phoenix dactylifera** (174.44 cm^2/100 m^2), **Acacia arabica** (70.50 cm^2/100 m^2), **Juniperus procera** (61.15 cm^2/100 m^2) and **Acacia negrii** (56.62 cm^2/100 m^2) are the most dominant in this habitat. Importance values indicate that **Acacia gerradii** (IV = 72.22), **Acacia arabica** (IV = 59.67), **Acacia negrii** (IV = 46.43), **Lycium shawii** (IV = 31.42) and **Phoenix dactylifera** (IV = 30.95) are the important perennial species.

According to the importance value and the rank of importance value, **Lycium barbarum**, **Solanum incanum**, **Solanum schimperianum**, **Withania somnifera**, **Dodonaea viscosa**, **Kleinia odora**, **Euryops arabicus**, **Psiadia arabica**, **Juniperus procera**, **Leptadenia pyrotechnica**, **Calotropis procera**, **Sageretia thea**, **Ziziphus spina-christi**, **Rumex nervosus**, **Lavandula dentata** and **Menthal lavandulacea** are associated with this habitat, but are less important than those mentioned above.

Table 4-9 Summary of Vegetation Data of Toe-slope habitat type: **NPS** = number of points with species, **TNI** = total number of individuals, **AS** = abundance of species in 100 m², **AD** = absolute dominance (cm² / 100 m²), **AF** = absolute frequency (percent), **RDE** = relative density, **RDO** = relative dominance, **RF** = relative frequency, **IV** = importance value and **IVR** = importance value rank.

No. Of Sampling points = 60 No. Of Species samples = 240						Absolute density (per 100 m²) =2.95 Relative Covering Value = 44.01				
S/ NO	Species	NPS	TNI	AS	AD	AF	RDE	RDO	RF	IV	IVR
1	Acacia arabica	17	57	0.70	70.50	28.33	23.72	12.20	23.75	59.67	2
2	Acacia gerradii	20	47	0.58	190.55	33.33	19.66	32.98	19.58	72.22	1
3	Acacia negrii	16	44	0.54	56.62	26.67	18.30	9.80	18.33	46.43	3
4	Lycium shawii	19	36	0.44	8.71	31.67	14.91	1.51	15.00	31.42	4
5	Lycium barbarum	3	3	0.04	0.36	5.00	1.36	0.06	1.25	2.67	11
6	Solanum incanum	1	2	0.03	0.33	1.67	1.02	0.06	0.83	1.91	14
7	Solanum schimperianum	1	1	0.01	0.10	1.67	0.34	0.02	0.42	0.78	18
8	Withania somnifera	1	2	0.03	0.38	1.67	1.02	0.07	0.83	2.70	9
9	Dodonaea viscosa	3	5	0.06	0.79	5.00	2.03	0.14	2.08	4.25	8
10	Kleinia odora	2	2	0.03	0.61	3.33	1.02	0.11	0.83	1.96	13
11	Euryops arabicus	4	7	0.09	1.60	6.67	3.05	0.28	2.92	6.25	7
12	Psiadia arabica	3	3	0.04	0.43	5.00	1.36	0.07	1.25	2.68	10
13	Juniperus procera	10	22	0.27	61.15	16.67	9.15	10.58	9.16	28.89	6
14	Leptadenia pyrotechnica	1	1	0.01	0.28	1.67	0.34	0.05	0.42	0.81	17
15	Calotropis procera	1	1	0.01	0.71	1.67	0.34	0.12	0.42	0.88	16
16	Sageretia thea	1	1	0.01	0.13	1.67	0.34	0.02	0.42	0.78	19
17	Phoenix dactylifera	1	1	0.01	174.44	1.67	0.34	30.19	0.42	30.95	5
18	Ziziphus spina-christi	1	1	0.01	9.08	1.67	0.34	1.57	0.42	2.33	12
19	Rumex nervosus	1	1	0.01	0.10	1.67	0.34	0.02	0.42	0.78	20
20	Lavandula dentata	1	1	0.01	0.13	1.67	0.34	0.02	0.42	0.78	21
21	Mentha lavandulacea	1	2	0.02	0.77	1.67	0.68	0.13	0.83	1.64	15
	Total		240	2.95	577.77	180.04	100	100	100		

Source: personal field work.

4-7-4 Foot-Slope Habitat Type.

The pediment or foot-slope is the greatest slope unit in the research area, in terms of its area and low slope angle (mean angle = 7° 43`). These zones connect the wadi habitat (toe-slope habitat) and mid-slope habitat where the slope angle exceeds 13°. Although the rainfall in these zones is somewhat scanty, they receive more water from surface flow than elsewhere. Soil properties are deep and moist compared with the other habitats, and the texture class is loamy sand. It is noted that these zones are affected by overgrazing, particularly in the north-east of the research area, due to its their accessibility to livestock.

In terms of the vegetation, 16 perennial species were recorded in the foot-slope habitat and are listed in Table 4-10. These botanical species are **Acacia arabica**, **Acacia gerradii**, **Acacia negrii**, **Lagonychium farctum**, **Lycium shawii**, **Lycium barbarum**, **Solanum incanum**, **Solanum schimperianum**, **Dodonaea viscosa**, **Kleinia odora** , **Euryops arabicus, Psiadia arabica**, , **Sageretia thea**, **Rhamnus disperma** and **Rumex nervosus**. As mentioned above, the impact of grazing, which has resulted in deterioration of the foot-slope habitat, has affected the plant morphology of this habitat. The trees and shrubs are dispersed and stunted. The absolute density is 2.78/100 m^2 and the mean height is 1.07 m. The relative covering value of perennial species is also low (20.68). Abundance values of species show that the most common species in this habitat are **Acacia arabica**, **Acacia gerradii**, **Lycium shawii**, **Acacia negrii** and **Dodonaea viscosa**. They recorded 0.76/100 m^2, 0.46/100 m^2, 0.41/100 m^2, 0.34/100 m^2 and 0.16/100 m^2 respectively. Absolute dominance values indicate that **Juniperus procera** (110.73 cm^2/100 m^2), **Acacia gerradii** (80.33 cm^2/100 m^2), **Acacia negrii** (46.12 cm^2/100 m^2) and **Acacia arabica** (39.90 cm^2/100 m^2) are the most dominant in this habitat. According to importance value, **Acacia arabica** (IV = 68.44), **Acacia gerradii**

(IV = 60.61), **Juniperus procera** (IV = 45.50), **Acacia negrii** (IV = 40.05) and **Lycium shawii** (31.35) are the most important perennial species, whereas the other species listed in Table 4-10 (11 species) are considered common associate species in this habitat, but with less importance.

Table 4-10 Summary of Vegetation Data of Foot-Slope Habitat Type: **NPS** = number of points with species, **TNI** = total number of individuals, **AS** = abundance of species in 100 m², **AD** = absolute dominance (cm² / 100 m²), **AF** = absolute frequency (percent), **RDE** = relative density, **RDO** = relative dominance, **RF** = relative frequency, **IV** = importance value and **IVR** = importance value rank.

No. Of Sampling points = 60 **No. Of Species samples = 240**						**Absolute density (per 100 m²) = 2.78** **Relative Covering Value = 20.68**				
S/ NO	**Species**	NPS	TNI	AS	AD	AF	RDE	RDO	RF	IV	IVR
1	**Acacia arabica**	18	66	0.76	39.90	30.00	27.33	13.61	27.50	68.44	1
2	**Acacia gerradii**	16	40	0.46	80.33	26.67	16.54	27.41	16.66	60.61	2
3	**Acacia negrii**	14	29	0.34	46.12	23.33	12.23	15.74	12.08	40.05	4
4	**Lagonychium farctum**	1	1	0.01	0.07	1.67	0.35	0.02	0.42	0.79	16
5	**Lycium shawii**	16	35	0.41	5.91	26.67	14.75	2.02	14.58	31.35	5
6	**Lycium barbarum**	1	1	0.01	0.07	1.67	0.36	0.02	0.42	0.80	15
7	**Solanum incanum**	2	1	0.01	0.13	3.33	0.36	0.04	0.42	0.82	13
8	**Solanum schimperianum**	1	1	0.01	0.09	1.67	0.36	0.03	0.42	0.81	14
9	**Dodonaea viscosa**	7	14	0.16	3.24	11.67	5.76	1.11	5.83	12.70	6
10	**Kleinia odora**	5	10	0.12	1.96	8.33	4.32	0.67	4.17	9.16	9
11	**Euryops arabicus**	11	13	0.15	2.21	18.33	5.40	0.75	5.42	11.57	7
12	**Psiadia arabica**	7	11	0.13	1.06	11.67	4.68	0.36	4.58	9.62	8
13	**Juniperus procera**	7	9	0.11	110.73	11.67	3.96	37.79	3.75	45.50	3
14	**Sageretia thea**	4	4	0.05	0.49	6.67	1.80	0.17	1.67	3.64	10
15	**Rhamnus disperma**	1	2	0.02	0.51	1.67	0.72	0.17	0.83	1.72	12
16	**Rumex nervosus**	2	3	0.03	0.26	3.33	1.08	0.09	1.25	2.42	11
	Total		**240**	**2.78**	**293.08**	**188.35**	**100**	**100**	**100**		

Source: personal field work.

4-7-5 Mid-Slope Habitat Type.

The mid-slopes are very complex zones, in terms of topographical structure and botanical composition. The mean slope angle of these zones is 13° 46` and slope forms are mostly straight though in a few places they are concave. The soil is shallow and has moderate moisture (2.38%) while the texture class is loamy sand. As for vegetation of this habitat, 16 perennial species were recorded and listed in Table 4-11. The body size of plant species in this habitat appear to be small, with a mean height, basal diameter and crown area of 1.39 m, 8.60 cm and 5.07 m^2 respectively. As can be noted from Appendix 2B, **Juniperus procera** recorded the greatest height (6.80 m) and the biggest basal diameter (100 cm), whereas **Acacia negrii** recorded the greatest crown area (78.29 m^2) in this habitat. The percentage of plant cover value in this habitat was estimated at each sampling point. According to Domin's scale, the mean estimation was computed to be 4.33. This value equals 11 to 25%. Abundance of species indicated that **Acacia arabica** (0.86/100 m^2), **Lycium shawii** (0.41/100 m^2), **Acacia gerradii** (0.30/100 m^2), **Dodonaea viscosa** (0.29/100 m^2), **Kleinia odora** (0.25/100 m^2), **Acacia negrii** (0.24/100 m^2), **Euryops arabicus** (0.19/100 m^2) and **Juniperus procera** (0.18/100 m^2) are very common and widespread species in this habitat. **Psiadia arabica**, **Leptadenia pyrotechnica**, **Lycium barbarum**, **Solanum incanum**, **Calotropis procera**, **Langonychium farctum**, **Rhamnus disperma** and **Mentha lavandulacea** are considered common associate components. Computation of absolute density (2.99/100 m^2) indicated that the distance between perennial species is low; nevertheless, viewing the plants of this habitat from high stands gives the impression that the absolute density is more than 2.99/100 m^2. Relative covering value (18.33) confirmed what was mentioned above, that the body sizes of plant species in this habitat are small. Absolute dominance values show that **Juniperus procera** (332.04 cm^2/100 m^2), **Acacia arabica** (40.85 cm^2/100 m^2), **Acacia gerradii** (37.95 cm^2/100 m^2), **Acacia negrii** (19.20 cm^2/100 m^2) and **Dodonaea viscosa** (12.51 cm^2/100 m^2) are the most dominant in this habitat. On the other hand, the importance values indicate that **Juniperus procera** (IV = 83.60), **Acacia arabica** (IV = 66.28), **Lycium shawii** (IV = 29.71), **Acacia gerradii** (IV = 28.19) and **Dodonaea viscosa** (IV = 21.97) are the important perennial species in this habitat.

Table 4-11 Summary of Vegetation Data of Mid-Slope Habitat Type: **NPS** = number of points with species, **TNI** = total number of individuals, **AS** = abundance of species in 100 m^2, **AD** = absolute dominance (cm^2 / 100 m^2), **AF** = absolute frequency (percent), **RDE** = relative density, **RDO** = relative dominance, **RF** = relative frequency, **IV** = importance value and **IVR** = importance value rank.

No. Of Sampling points = 60 No. Of Species samples = 240							Absolute density (per 100 m^2) =2.99 Relative Covering Value = 18.33				
S/ NO	Species	NPS	TNI	AS	AD	AF	RDE	RDO	RF	IV	IVR
1	Acacia arabica	20	69	0.86	40.85	33.33	28.76	8.77	28.75	66.28	2
2	Acacia gerradii	10	24	0.30	37.95	16.67	10.04	8.15	10.00	28.19	4
3	Acacia negrii	10	19	0.24	19.20	16.67	8.03	4.12	7.92	20.07	6
4	Lagonychium farctum	1	1	0.01	0.07	1.67	0.33	0.02	0.42	0.77	16
5	Lycium shawii	15	33	0.41	10.45	25.00	13.71	2.25	13.75	29.71	3
6	Lycium barbarum	2	3	0.04	0.50	3.33	1.34	0.11	1.25	2.70	12
7	Solanum incanum	2	3	0.04	0.39	3.33	1.34	0.08	1.25	2.67	13
8	Dodonaea viscosa	13	23	0.29	12.51	21.67	9.70	2.69	9.58	21.97	5
9	Kleinia odora	9	20	0.25	3.69	15.00	8.36	0.79	8.33	17.48	7
10	Euryops arabicus	10	15	0.19	2.27	16.67	6.36	0.49	6.25	13.10	8
11	Psiadia arabica	4	6	0.07	0.62	6.67	2.34	0.13	2.50	4.97	9
12	Juniperus procera	10	15	0.18	332.04	16.67	6.02	71.33	6.25	83.60	1
13	Leptadenia pyrotechnica	2	4	0.05	0.69	3.33	1.67	0.15	1.66	3.48	10
14	Calotropis procera	2	3	0.04	0.66	3.33	1.34	0.14	1.25	2.73	11
15	Rhamnus disperma	1	1	0.01	3.14	1.67	0.33	0.67	0.42	1.42	14
16	Mentha lavandulacea	1	1	0.01	0.50	1.67	0.33	0.11	0.42	0.86	15
	Total		240	2.99	465.53	186.68	100	100	100		

Source: personal field work.

4-7-6 Shoulder Slope Habitat Type.

Although many researchers in geomorphology and environmental science have not regarded the shoulder slope as an independent slope unit and distinct plant habitat, other researchers, such as Martz (1992), and Makhnach (1994) have distinguished this type of slope unit in their studies. The reconnaissance, surveys and data analysis of the present study indicated that this slope unit is a distinct plant habitat in the research area. Comparing this habitat with the other communities and habitats, it has the lowest absolute density (2.59/100 m^2) and the lowest plant diversity (only 15 perennial species were recorded in the sampling points of this habitat). The soil of this habitat is alkaline and in general its texture is coarse, while its mean moisture is very low (2.33%). The sizes of plant species of this habitat seem to be small. The mean of height, basal diameter and crown area of perennial plants were found to be 1.27 m, 5.59 cm and 7.38 m^2 respectively. As can be seen from Appendix 2B, **Juniperus procera** recorded the biggest basal diameter (52 cm) and the greatest crown area (707.14 m^2), whereas **Dodonaea viscosa** recorded the greatest height (7.30 m) in this habitat.

As mentioned above and listed in Table 4-12, 15 perennial species were recorded in the sampling points of this habitat. The relative covering value of these species was computed to be 20.28, and the mean vegetation cover value of this habitat was estimated according to Domin's scale to be 4.03, which equals about 4 to 10%. Abundance of species (Table 4.12) indicated that **Acacia arabica** (0.71/100 m^2), **Lycium shawii** (0.39/100 m^2), **Dodonaea viscosa** (0.28/100 m^2), **Acacia gerradii** (0.24/100 m^2), **Kleinia odora** (0.22/100 m^2), and **Euryops arabicus** (0.18/100 m^2) are very common species in the shoulder slope habitat. **Juniperus procera** (0.15/100 m^2), **Acacia negrii** (0.11/100 m^2), **Psiadia arabica** (0.11/100 m^2), **Lycium barbarum** (0.10/100 m^2), **Solanum incanum** (0.03/100 m^2), **Leptadenia pyrotechnica** (0.03/100 m^2), **Cluytia richardiana** (0.02/100 m^2), **Tephrosia apollinia** (0.01/100 m^2) and **Lavandula dentata** (0.01/100 m^2) are considered common associate components in this habitat. Absolute dominance value indicated that **Juniperus procera** (74.81 cm^2/100 m^2), **Dodonaea viscosa** (19.12 cm^2/100 m^2), **Acacia gerradii** (18.41 cm^2/100 m^2), **Acacia arabica** (15.56 cm^2/100 m^2), and **Acacia negrii** (13.85 cm^2/100 m^2) are the most dominate species in this habitat. According to computing of importance value, **Acacia arabica** (IV = 64.67), **Juniperus procera** (IV = 58.53), **Lycium shawii** (IV = 35.20), **Dodonaea viscosa** (IV = 33.63), and **Acacia gerradii** (IV = 29.98) are the important perennial species in this habitat. The other species listed in Table 4-12 are considered important species, but to a much lesser degree.

Table 4-12 Summary of Vegetation Data of Shoulder Slope Habitat Type: **NPS** = number of points with species, **TNI** = total number of individuals, **AS** = abundance of species in 100 m^2, **AD** = absolute dominance (cm^2 / 100 m^2), **AF** = absolute frequency (percent), **RDE** = relative density, **RDO** = relative dominance, **RF** = relative frequency, **IV** = importance value and **IVR** = importance value rank.

No. Of Sampling points = 60 No. Of Species samples = 240							Absolute density (per 100 m^2) =2.59 Relative Covering Value = 20.28				
S/ NO	Species	NPS	TNI	AS	AD	AF	RDE	RDO	RF	IV	IVR
1	Acacia arabica	18	66	0.71	15.56	30.00	27.41	9.76	27.50	64.67	1
2	Acacia gerradii	9	22	0.24	18.41	15.00	9.26	11.55	9.17	29.98	5
3	Acacia negrii	5	10	0.11	13.85	8.33	4.25	8.69	4.17	17.11	7
4	Tephrosia apollinia	1	1	0.01	0.05	1.67	0.39	0.03	0.42	0.84	15
5	Lycium shawii	17	36	0.39	8.20	28.33	15.06	5.14	15.00	35.20	3
6	Lycium barbarum	4	9	0.10	0.83	6.67	3.86	0.52	3.75	8.13	10
7	Solanum incanum	1	3	0.03	0.32	1.67	1.16	0.20	1.25	2.61	12
8	Dodonaea viscosa	13	26	0.28	19.12	21.67	10.81	11.99	10.83	33.63	4
9	Kleinia odora	9	20	0.22	3.49	15.00	8.49	2.19	8.33	19.01	6
10	Euryops arabicus	8	17	0.18	2.51	13.33	6.95	1.57	7.08	15.60	8
11	Psiadia arabica	6	10	0.11	1.34	10.00	4.25	0.84	4.17	9.26	9
12	Juniperus procera	10	14	0.15	74.81	16.67	5.79	46.91	5.83	58.53	2
13	Leptadenia pyrotechnica	2	3	0.03	0.61	3.33	1.16	0.38	1.25	2.79	11
14	Lavandula dentata	1	1	0.01	0.13	1.67	0.39	0.08	0.42	0.89	14
15	Cluytia richardiana	2	2	0.02	0.23	3.33	0.77	0.15	0.83	1.75	13
	Total		240	2.59	159.46	176.67	100	100	100		

Source: personal field work.

4-7-7 Summit Slope Habitat Type.

In general, this habitat's soil is partly shallow (mean depth = 20.88 cm), alkaline (mean pH = 8.31) and moist (mean moisture = 2.53%) while its texture is coarse (loamy sand). The botanical formation of the mountain top habitat differs markedly from the other plant habitats in the area under study. Although the mean ground plant cover of this habitat is weak (4.03 according to Domin's scale), the absolute density of perennial species is very high (6.22/100 m^2) compared with other habitats in the research area. The distance between trees and shrubs is small. The greater plant density can be attributed to augmentation of rainfall amount in this habitat, particularly in the south-western mountains, and to its remoteness from human activities, especially from the grazing in the north-east of the research area. The vegetation of this habitat gives the appearance of hats covering the mountain peaks, especially in the south-western mountains.

According to the mean of trees and shrubs height (1.27 m), basal diameter (7.59 cm), crown area (3.76 m²) and the relative covering value (38.38), it is possible to say that the sizes of this habitat's species are moderate. **Acacia arabica** recorded the greatest height (6.56 m) and **Juniperus procera** recorded the biggest basal diameter (62 cm) whereas **Acacia gerradii** recorded the greatest crown area (68.98 m²) in this habitat. As listed in Table 4-13, 18 perennial species belonging to 10 botanical families and 15 genera were recorded at the tops of slopes. Quantitative analysis (Table 4-13) of the number of points with species, total number of individual, abundance of species, absolute dominance, absolute frequency, relative density, relative dominance, relative frequency and importance value gave the following results:

According to abundance of species, **Acacia arabica** (1.42/100 m²), **Lycium shawii** (0.85/100 m²), **Dodonaea viscosa** (0.73/100 m²), **Kleinia odora** (0.70/100 m²), **Acacia gerradii** (0.49/100 m²), **Euryops arabicus** (0.47/100 m²) and **Acacia negrii** (0.46/100 m²) are very common species in summit slope habitats, whereas **Juniperus procera** (0.29/100 m²), **Lycium barbarum** (0.23/100 m²), **Lagonychium farctum** (0.13/100 m²), **Psiadia arabica** (0.13/100 m²), **Reseda sphenocleoidis** (0.08/100 m²), **Solanum schimperianum** (0.05/100 m²), **Periploca aphylla** (0.05/100 m²), **Adenium obesum** (0.05/100 m²), **Sageretia thea** (0.03/100 m²), **Rhamnus disperma** (0.03/100 m²)and **Lavandula dentata** (0.03/100 m²) are considered common associate components. Absolute dominance values show that **Juniperus procera** (209.42 cm²/100

m^2), **Acacia gerradii** (73.25 cm^2/100 m^2), **Acacia arabica** (65.69 cm^2/100 m^2), **Acacia negrii** (44.88 cm^2/100 m^2) and **Lycium shawii** (32.47 cm^2/100 m^2) are the most dominant species in this habitat. Importance values confirmed the importance of **Acacia arabica** (IV = 59.27), **Juniperus procera** (IV = 52.36), **Lycium shawii** (IV = 34.10), **Acacia gerradii** (IV = 30.88), **Dodonaea viscosa** (IV = 26.92), **Kleinia odora** (IV = 24.57) and **Acacia negrii** (IV = 24.14) in the mountain tops of the area under study. The other perennial species listed in Table 4-13 are also considered important species in the research area, but to a lesser degree.

Table 4-13 Summary of Vegetation Data of Summit Slope Habitat Type: **NPS** = number of points with species, **TNI** = total number of individuals, **AS** = abundance of species in 100 m^2, **AD** = absolute dominance (cm^2 / 100 m^2), **AF** = absolute frequency (percent), **RDE** = relative density, **RDO** = relative dominance, **RF** = relative frequency, **IV** = importance value and **IVR** = importance value rank.

No. Of Sampling points = 60 No. Of Species samples = 240							Absolute density (per 100 m^2) =6.22 Relative Covering Value = 38.38				
S/ NO	Species	NPS	TNI	AS	AD	AF	RDE	RDO	RF	IV	IVR
1	Acacia arabica	19	55	1.42	65.69	31.67	22.83	13.52	22.92	59.27	1
2	Acacia gerradii	8	19	0.49	73.25	13.33	7.88	15.08	7.92	30.88	4
3	Acacia negrii	9	18	0.46	44.88	15.00	7.40	9.24	7.50	24.14	7
4	Lagonychium farctum	3	5	0.13	1.33	5.00	2.09	0.27	2.08	4.44	10
5	Lycium shawii	17	33	0.85	32.47	28.33	13.67	6.68	13.75	34.10	3
6	Lycium barbarum	4	9	0.23	2.05	6.67	3.70	0.42	3.75	7.87	9
7	Solanum schimperianum	1	2	0.05	0.47	1.67	0.80	0.10	0.83	1.73	16
8	Dodonaea viscosa	12	28	0.73	17.07	20.00	11.74	3.51	11.67	26.92	5
9	Kleinia odora	11	27	0.70	10.04	18.33	11.25	2.07	11.25	24.57	6
10	Euryops arabicus	12	18	0.47	4.87	20.00	7.56	1.00	7.50	16.06	8
11	Psiadia arabica	3	5	0.13	0.99	5.00	2.09	0.21	2.08	4.38	11
12	Juniperus procera	8	11	0.29	209.42	13.33	4.66	43.12	4.58	52.36	2
13	Periploca aphylla	1	2	0.05	1.30	1.67	0.80	0.27	0.83	1.90	15
14	Sageretia thea	1	1	0.03	0.21	1.67	0.48	0.04	0.42	0.94	18
15	Rhamnus disperma	1	1	0.03	9.43	1.67	0.48	1.94	0.42	2.94	13
16	Reseda sphenocleoidis	1	3	0.08	0.50	1.67	1.29	0.10	1.25	2.64	14
17	Lavandula dentata	1	1	0.03	0.38	1.67	0.48	0.08	0.42	0.98	17
18	Adenium obesum	1	2	0.05	11.39	1.67	0.80	2.35	0.83	3.98	12
	Total		240	6.22	485.74	188.35	100	100	100		

Source: personal field work.

4-8 Grazing and its Influence on Vegetation and Soil.

Despite the dwindling of grazing activity in Saudi Arabia since the discovery of oil, which has led to an increase in national and individual income, the Asir region, which includes the research area, has remained one of the important grazing regions in Saudi Arabia. According to the most recent statistics (1996) (compiled by the Ministry of Agriculture and Water, Saudi Arabia), the Asir region includes 1,166,472 goats, 1,512,471 sheep, 21,188 cattle and 29,936 camels. By comparing these numbers of livestock in Asir region with those for the country as a whole, which encompasses 13 statistical regions, the importance of grazing activity in the Asir region can be seen clearly (Table 4-14 and Fig. 4-10). As can be seen from this Table and Figure, the Asir region contains 27% of the country's goats, 26% of its sheep, 14% of its cattle and 7% of its camels. However, the distribution of livestock within the Asir region is not known as yet, nor has the influence of grazing on soil and vegetation in the research area been studied.

Table 4-14 Comparison between livestock numbers in Saudi Arabia and Asir region.

Area	goats		sheep		cattle		camels	
	Number	%	Number	%	Number	%	Number	%
Saudi Arabia	4308509	100	5856394	100	147046	100	415468	100
Asir region	1166472	27	1512471	26	21188	14	29936	7

(Source: Agriculture Statistical Year Book (1996), Ministry of Agriculture and Water Saudi Arabia)

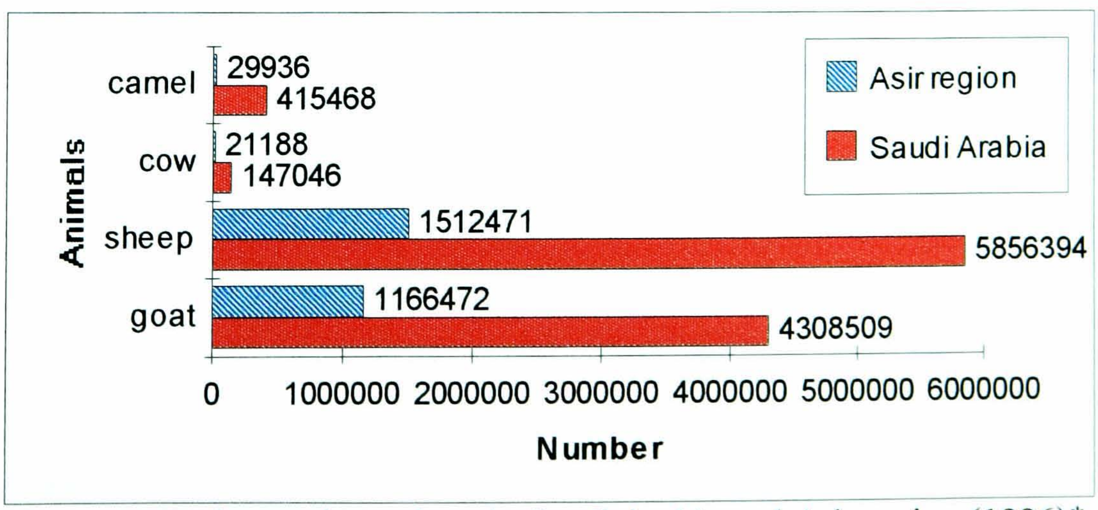

Figure 4-10 Livestock numbers in Saudi Arabia and Asir region (1996)*.
*Source: Agriculture Statistical Year Book (1996), Ministry of Agriculture and Water Saudi Arabia.

During the summer of 1996, a detailed survey was completed by the researcher and the research supervisor (Dr. Watts). This survey involved thousands of kilometres of inland travel in the mountains and plains of the research area. During this survey, the effect of grazing, which can be considered as the only human factor affecting soil and vegetation cover, was observed, particularly in the north-eastern part of the research area. For this reason, sixty interviews were later conducted with shepherds and livestock owners (30 interviews in the north-east of the research area; and 30 interviews in the south-west) (Appendix 3). The heights of weeds and grasses were measured and averaged to give the mean height at each sampling point mentioned in Chapter Three (3.4.1). In addition, the morphological components of trees and shrubs were measured and analysis of soil properties undertaken. Based on these data and information, a picture was formed of the pattern of grazing and its influence on soil and vegetation in the region, are discussed below.

4-8-1 Grazing Zones.

During the field survey, in June 1996, several important observations were made of grazing and its zones. Based on these observations, interviews with shepherds and owners of livestock, measurement of weeds and grass height as well as measurement of perennial vegetation, it appears that the research area can be divided into two distinct grazing zones, namely the mountainous grazing zone (in the west and the south-western) and the plateau grazing zone (in the east and the north-eastern) (refer to Fig. 1-2). The following paragraphs discuss the grazing status in these zones.

4-8-1-1 Grazing Status in the Mountainous Zone.

This zone extends along the western and the south-western boundary of the research area, approximately from Tanomah and Belesmer to Abha and Khamis Mushayt, and on the east and north-east it is bounded by the plateau zone. Elevations in this zone range from about 2000 to 3130 m above sea level. Rainfall is in the range 300-500 mm annually. The average temperatures in this zone are the lowest in the research area (about 17 °C) and average relative humidity is about 55%. The landscape is generally dominated by mountains with occasional very narrow valleys.

Since the discovery and exploration of oil in Saudi Arabia, the number of nomads has decreased rapidly and most Bedouins have successfully exchanged nomadism for an urban environment, particularly in the mountainous grazing zone mentioned above. Table 4-15 indicates the results that have emerged from the 30 interviews carried out with shepherds and owners of livestock herds in the mountainous grazing zone. The average size of herds in this zone is 39. 56% of the livestock are goats, 43% sheep, only 1% cattle and no camels in this zone. The majority of respondents (60%) indicated that the purpose of livestock breeding is for personal use and self sufficiency, while 40% of owners kept livestock for both personal use and local commercial marketing. Only 7% of herd owners depended completely on the livestock as their only source of income. The other 93% of herd owners had various other sources of income, including employment by government institutions, and their own businesses.

As regards downgrading of grazing, opinion is split. 60% of respondents indicated that the pastures in the mountainous zone are enough to support their livestock all year round, whereas 40% thought that additional forage was needed to feed their livestock. However, only one respondent (3%) moved his livestock northward in search of new pastures during the winter. Weeds and shrubs such as **Cenchrus ciliaris** and

Cymbopogon **Schoenanthus** are the favourite pasture plants in this zone (Hajar, 1993). 67% of respondents emphasized that their livestock, particularly the sheep, prefer weeds and grass, while 33% indicated that their livestock prefer both weeds and shrubs. Although the mountainous grazing zone receives more than 300 mm of annual rainfall, only 16% of herds are watered entirely from rainfall water; 48% are watered from supplies transported in by cars and water tankers, while 27% and 9% are watered from wells and springs respectively. This finding can be related to the increasing of slope gradient which leads to increase velocity of runoff from this zone toward the desert, where the wadi flows. These indications suggest that grazing in the mountainous zone is not intensive and its main purpose is to provide some of the necessary food requirements of the inhabitants of the area.

4-8-1-2 Grazing Status in the Plateau Zone.

This zone covers a wide area in the north-eastern portion of the research area. Elevations in this zone range from about 1000 to 2000 m above sea level. Temperatures are higher than in the mountainous zone, while rainfall is less both in intensity and frequency. The average relative humidity is about 40%. The topography is variable with a generally dissected and rolling aspect and with widespread rocky hills and rock outcrops of low relief.

As can be seen from Table 4-15, the results that emerged from the 30 interviews carried out with shepherds and owners of livestock herds in the plateau grazing zone indicate that the average size of herds in this zone (171) is much larger than in the mountainous zone, of which 83% are sheep, 9% goats and, 8% camels and donkeys. These animals roamed the plateau zone and its surroundings in search of rich vegetation cover. The majority of respondents (93%) indicate that the purpose of livestock breeding is for both personal use and commercial marketing, while only 7% of owners kept livestock purely for personal use and self sufficiency. This finding is different from that found in mountainous zone. As shown in Table 4-15, 70% of herd owners depended completely on livestock as the only source of their income, while 30% of owners had other sources of income. One of the most important findings is that all respondents indicated that natural vegetation cover in the plateau zone is not enough to feed their livestock all year round. Therefore, 50% of herds are moved, particularly during the autumn and winter seasons, to those areas located toward the north and the east of the plateau zone, in search of new pastures. The other livestock owners (50%) indicated that they imported forage for their livestock from the local markets. The responses of shepherds and owners of livestock (Table 4-15) indicated that trees, shrubs and weeds such as **Acacia arabica** and **Commicarpus grandiflous** are favoured by all kinds of livestock. Due to the drilling of water wells, and the availability of cars and water tankers, the majority of shepherds and owners of herds reported that their livestock did not suffer any shortage of water.

Overall, the increase of grazing in the plateau zone can be related to the simplicity of transport, increased percentage of sheep and camels, availability of water wells and preference for this zone as a connection zone between the mountainous zone and the desert. Availability of roads and tracks in the plateau zone encouraged the Bedouins to move their animals easily in search of pasture and water. Most of the herds in this zone are sheep and camels, which face some difficulties in movement in the mountainous zone. The Bedouins prefer this zone because it enables their animals to graze in the margins of the mountainous zone (in the south-west) and the desert (in the north-east).

From this information, it is possible to say that grazing is an essential occupation for most inhabitants of the oases, villages and wastelands of the plateau zone.

Table 4-15 Summary of Responses of Shepherds and Owners of Livestock on the Level of Grazing in the Research Area.

Question	Response	Mountainous grazing zone %	Plateau grazing zone %
What kind of animals and how many do you have?	Sheep	43	83
	Goat	56	9
	Camel		8
	Cow	1	
	Donkey		
What is the purpose (s) of breeding these livestock?	Personal use	60	7
	Personal and commercial	40	93
Does your income depend only on livestock breeding or do you have another source of income?	Only from livestock breeding	7	70
	Livestock and other sources	93	30
Is the pasture in your current area sufficient for feeding your animals?	Sufficient	60	
	Insufficient	40	100
Do you move your animals to other areas?	Yes	3	50
	No	97	50
What is/are the reason (s) for movement?	Look for new pasture	100	71
	Look for water		29
In which direction do you usually move your animals?	North		60
	South	100	
	East		40
In which season (s) do you move to the new grazing land ?	Spring		13
	Winter	100	54
	Autumn		33
***What kind (s) of vegetation do your animals depend on for grazing?**	Trees		20
	Shrubs	33	37
	Weeds	67	43
What kind (s) of water source (s) do you use for your animals?	Wells	27	41
	Rainfall water	16	24
	Springs	9	
	Water transported by cars	48	35

* For further details, see text

4-8-2 Influence of Grazing on Vegetation and Soil.

Grazing in general, and over-grazing in particular, has been regarded as the prime cause of desertification and environmental degradation, especially in arid and semi-arid areas (Goudie, 1990; Hajar, 1993). This idea also has been demonstrated at the local level in Saudi Arabia by Draz (1965) and Abulfatih et al. (1988). Until the beginning of the second half of the twentieth century, most of the research area was located under the *hema* system.

(The hema system means protection of the lands from grazing and wood-cutting, particularly those lands on which rain has recently fallen. It is a full regulation established between and by the tribes living in the region, and aims to protect and conserve the pastures and plants from random exploitation, especially during growth periods. It prohibits grazing in protected lands, except in special circumstances, such as a drought. This system was applied between the tribes till 1953, particularly in the western and the south-western regions of Saudi Arabia).

This system supported the growth of vegetation cover. After the establishment of Saudi Arabia (1932), and due to the problems between the tribes resulting from application of the *hema* system, the government of Saudi Arabia abandoned this system in 1953 (Al-Welaie 1996). Since that time livestock, particularly sheep, goats and camels, have roved the research area in search of rich vegetation cover all year round. Unfortunately, despite the decline of nomadism during the last few decades, the vegetation cover has decreased due to uncontrolled grazing, especially the favourite plants for animals in the plateau grazing zone in the north-east of the research area.

It is known that there are several factors which influence deterioration of vegetation cover and soil, but over-grazing and mismanagement of range-lands are the main factors contributing to deterioration of natural vegetation cover and soil in the area under study.

As was mentioned earlier, the vegetation and soil of the research area has suffered from several impacts, such as reduction of rainfall, augmentation of slope gradient and over-grazing. Therefore, five questions on these matters were asked to shepherds and owners controlling livestock (Table 4-16). As can be seen from this Table, 50% of shepherds and owners of livestock do not know the impact of livestock on vegetation and soil. The other 50% of shepherds and owners realize that their livestock influences the disappearance of vegetation (71%), the fatigue of pastures (23%), crumbling of soil (3%) and increase of soil fertility (3%). However, 72% of shepherds and owners of livestock who know the impact of animals on vegetation and soil believe that stopping wood-cutting and protection of soil and vegetation against fire and pollution are the best ways to conserve them. Despite the relatively limited impact of wood-cutting, fire and pollution on vegetation and soil of the research area, the shepherds and livestock owners obviously preferred to blame these factors rather than their animals and their grazing methods, for deterioration of vegetation and soil. It can be noted that the contribution of the shepherds and owners of livestock in avoidance of over-grazing is very weak. In interview, 48% of them said they made no effort to avoid over-grazing. The others tried to avoid it by buying forage (48%) and moving to a new grazing land (52%) during drought seasons.

In fact, the influence of grazing on deterioration of vegetation and soil in the research area appears to be clear, especially if the vegetation features (Table 4-17) and soil characteristics (Table 4-18) in the mountainous grazing zone and plateau grazing zone are compared. The following two headings deal with this subject.

Table 4-16 Summary of Responses of Shepherds and Owners of Livestock on the Influence of Grazing on the Vegetation and Soil in the Research Area.

Question	Response	%
Do you know, what is the effect of livestock on vegetation and soil?	Known	50
	Unknown	50
What kind (s) of effect do livestock have on vegetation and soil?	Increasing of soil fertility	3
	Crumbling+exposure of soil	3
	Crumbling of vegetation	71
	Fatigue of grazing	23
What can be done to conserve the vegetation and soil?	Protect soil and vegetation against fire and pollution	25
	Stop wood-cutting	47
	Unknown	28
Do you try to avoid over-grazing?	Yes	52
	No	48
How do you avoid over-grazing?	Move to new grazing land	52
	Buy forage	48

4-8-2-1 Influence of Grazing on Vegetation

Mutual impacts can be recorded between livestock and vegetation cover in the research area, but the distinct impacts are the following.

It has been recognized that grazing animals eat particular plants or graze particular plant communities with relish and reject others such as **Juniperus procera** and **Calotropis procera**. Sheep and goats select the leaf in preference to the stem and green (or young) material in preference to dry (or old) material. Younger material may be preferred because it is generally shorter or because it differs in chemical composition from older material (Arnold, 1964). These selective actions cause more destruction to the vegetation cover because the leaves and green materials are the active parts in which support continuance of plant growth. Camels also graze and eat the higher stems and branches of trees and shrubs such as **Acacia arabica**, **Acacia gerradii**, **Acacia negrii**, **Tamarix aphylla**, **Lycium barbarum** and **Lycium shawii**. They are able to break down the branches of plants and get access to leaves that are out of the reach of sheep and goats.

Due to over-grazing, some palatable species such as **Commicarpus grandiflous** and **Periploca aphylla** have disappeared, while the less palatable and poisonous species such as **Solanum incanum** and **Solanum schimperianum** have occupied their places in several parts of the research area, particularly in the plateau grazing zone. This can be related to grazing during the earlier stages of plant growth, which leads to loss of seeds and finally, to cessation of regeneration. The effect of over-grazing, mainly by sheep and goats, can be seen clearly in the vicinity of water sources (mostly wells in the plateau zone and springs in mountainous zone); vegetation cover is almost absent from the areas that surround these sources.

As can be seen from Table 4-17, the mean size of livestock herds (171) is much higher in the plateau grazing zone compared with that (39) in the mountainous grazing zone. This finding, as well as field observations collected by the researcher, indicated that the plateau zone contains far more livestock than the mountainous zone. The comparison between vegetation features in these zones shows the following:

1- Absolute density of the perennial vegetation was relatively higher in the mountainous grazing zone (3.01/100 m^2) when compared with that in the plateau grazing zone (2.46/100 m^2).

2- Relative covering value in the mountainous zone (32) was more than double that in the plateau zone (13.21).

3- Trees and shrubs were generally taller in the mountainous zone (Table 4-17).

4- Mean height of weeds and grasses in the mountainous zone (17.25 cm) was much higher than that in the plateau zone (5.41 cm).

Table 4-17 Vegetation Features of Grazing Zones (Mountainous zone and Plateau Zone) in the Research Area.

Grazing zone	Mean herd	Vegetation features			
		absolute density	relative covering value	mean trees and shrubs heights m	mean weeds and grass height cm
Mountainous zone	39	3.01	32	1.79	17.25
Plateau zone	171	2.46	13.21	1.61	5.41

4-8-2-2 Influence of Grazing on Soil.

Livestock and over-grazing influence soil either directly or indirectly. The direct impacts are seen in the trampling of livestock on soil materials, soil flakiness, soil abrasion, soil exposure and supply of organic matter. The indirect impacts are represented mainly by the influence of livestock and over-grazing on vegetation cover and finally on soil. It is known that vegetation cover acts as a protective layer or buffer between the atmosphere and the soil. The above-ground components, such as leaves and stems, absorb some of the energy of falling raindrops, running water and wind, so that less is directed at the soil, whilst the below ground components, comprising the root system, contribute to the mechanical strength of the soil (Morgan, 1995). The problem of soil erosion is a natural result of plant disappearance. However, this problem become more serious when the grazing zone is located on hill-slopes, where soil erosion is faster and accumulation is less (Hajar, 1993).

As mentioned earlier, the plateau grazing zone supports a larger livestock population than the mountainous zone. The comparison between soil properties (Table 4-18) in these zones shows the following:

1- Soil mechanical analysis determined by the hydrometer method showed that soils of the mountainous grazing zone were generally loamy sand, while those of the plateau grazing zone were mostly sandy loam to sand.

2- Due to the decrease of slope gradients, the soils were somewhat deeper in the plateau zone (Table 4-18).

3- Physical and chemical analysis revealed that moisture content, organic matter, organic carbon, nitrogen and phosphorus were much higher in the soils of the mountainous grazing zone than in the soils of the plateau grazing zone.

4- Also, chemical analysis revealed that $CaCO_3$, potassium, pH and electrical conductivity were higher in the soils of plateau grazing zone, compared with the soils of the mountainous grazing zone.

Table 4-18 Chemical and Physical Characteristics of Soil in Grazing Zones (Mountainous zone and Plateau Zone) in the Research Area.

Grazing	Mean	Soil properties									
zone	herd	soil depth	mois-ture	OM	OC	Ca-CO_3	N	P	K	pH	EC
Mountainous zone	39	30.07	3.47	1.51	0.88	2.09	496.03	54.03	91.41	8.12	0.27
Plateau zone	171	32.55	1.45	0.71	0.41	3.60	227.42	43.02	140.45	8.40	0.51

4-8-3 Overall Effects: Deterioration of Grazing.

In order to avoid the deterioration of grazing which leads eventually to deterioration of vegetation and soil status, it must first be known what is/are the reason (s) for deterioration of grazing in the research area? This question was asked to the shepherds and owners of livestock herds. Their responses (Table 4-19) indicated that increasing of livestock, weakness of the traditional *hema* system (refer to 4.8.2), wood-cutting and weakness of planning for exploitation of pastures are the main reasons for deterioration of grazing, while decreased rainfall, over-grazing, governmental support to the Bedouins (the government was funding the Bedouins to buy the tankers and digging the wells during the last two decades), concentration close to the resources of water and increased Bedouin movements are lesser reasons. However, from the available evidence, the author thinks that the government support and over-grazing are the main reasons for deterioration of grazing, vegetation cover and soil status.

Table 4-19 Summary of Responses of Shepherds and Owners of Livestock on the Reason (s) for Deterioration of Grazing in the Research Area.

Question	Response	%
What do you think are the reason (s) for deterioration of grazing in your current area?	Decreasing of rainfall	7
	Increasing of livestock	22
	Weakness of planning	16
	Concentration close to the resources of water	5
	Over-grazing	7
	Governmental support	5
	Increasing of Bedouin movement	3
	Wood-cutting	17
	Weakness of traditional hema system	18

Overall, the effect of overgrazing on the vegetation of the research area is manifested in the disappearance of the species preferred by animals, such as **Commicarpus grandiflous**, **Periploca aphylla**, **Cymbopogon schoenanthus**, **Hyperhenia hirta** and **Rumec vesicurius** (Hajar, 1993), and the presence of the less palatable species such as **Psiadia arabica**, **Euryops arabicus**, **Lavandula dentata**, **Solanum incanum** and **Solanum schimperianum**, as well as the deterioration in quality of plants, e.g. **Acacia arabica** in the north-eastern part of Wadi Bishah basin. Also, this effect extends to the soil, particularly in the plateau zone, where the soil is coarse and poor in nutrients.

Finally, these findings correspond with those of several other research works conducted in desert and semi-desert areas. For instance, in the Mediterranean desert of Egypt, and in Southern Tunisia, density, relative covering value frequency and presence of perennial species were found to increase as a result of reduction of livestock and control of grazing (Ayyad & El-Kadi, 1982; Floret, 1981).

4-9 Conclusions.

Reconnaissance surveys and intensive quantitative analysis of the vegetation of the research area have demonstrated that **Acacia arabica**, **Juniperus procera**, **Acacia gerradii**, **Acacia negrii**, **Euryops arabicus**, **Dodonaea viscosa**, **Lycium shawii**, **Kleinia odora**, **Lycium barbarum**, **Psiadia arabica**, **Solanum incanum**, **Leptadenia pyrotechnica**, and **Periploca aphylla** are the species that compose and provide the main vegetative characteristics of the Upper Wadi Bishah basin. The other plant species that were found within the sampling point of the present study and are listed in Table 4-1, and the plant species that were observed outside these points (Table 4-2) have less significance in composition of the vegetation attributes of this basin. The assemblage of these species in the research area is little and their distribution is patchy.

From the foregoing, it emerges that the vegetation of the area under study is associated clearly with numerous environmental parameters, such as topography, altitude, soil condition and moisture amount (Alwelaie et al. 1993), as well as other climatic and human factors. These circumstances and factors influence the distribution, establishment, growth and regeneration of the plants (Batanouny, 1987) and have produced different plant shapes inside the research area (Bloot, 1996; El-Demerdash et al. 1994). The following paragraphs summarize the differences in plants between habitats.

As mentioned earlier, due to the greater precipitation amount on the habitat of peak-slopes the absolute density of this habitat (6.22/100 m^2) is more than double the absolute density in any other habitat (Fig. 4-11), while the shoulder slope habitat recorded the lowest absolute density (2.59/100 m^2). The toe-slope habitat, foot-slope habitat, and mid-slope habitat also had a relatively low density (2.95/100 m^2, 2.78/100 m^2 and 2.99/100 m^2 respectively). As can be seen from Fig. 4-12, the relative covering values in the toe-slope habitat (44.01) and peak-slope habitat (38.38) are high, compared with other habitats. The augmentation of relative covering value in these two habitats is imputed mostly to individual sizes in toe-slope habitat and the greater plant density in the peak-slope habitat.

The height of plants is one of the important botanical components that comprise the life-form of individuals. As said before and as can be noted from Fig. 4-13, the individuals of the toe-slope habitat are characterised by large breadth and height. The mean of perennial plant heights in this habitat is 2.33 m, whereas it ranges between 1.07 to 1.39 m in the other habitats. One of the main reasons why plants in the toe-slope habitat flourish, is the soil conditions; the soil is deeper and more moist than in the other habitats. These conditions enable the individuals to extend their roots faraway to stabilize themselves and to obtain water. In addition, the lower elevation and low wind speed in this habitat has allowed the plants to grow more and achieve greater height (Abulfatih, 1981).

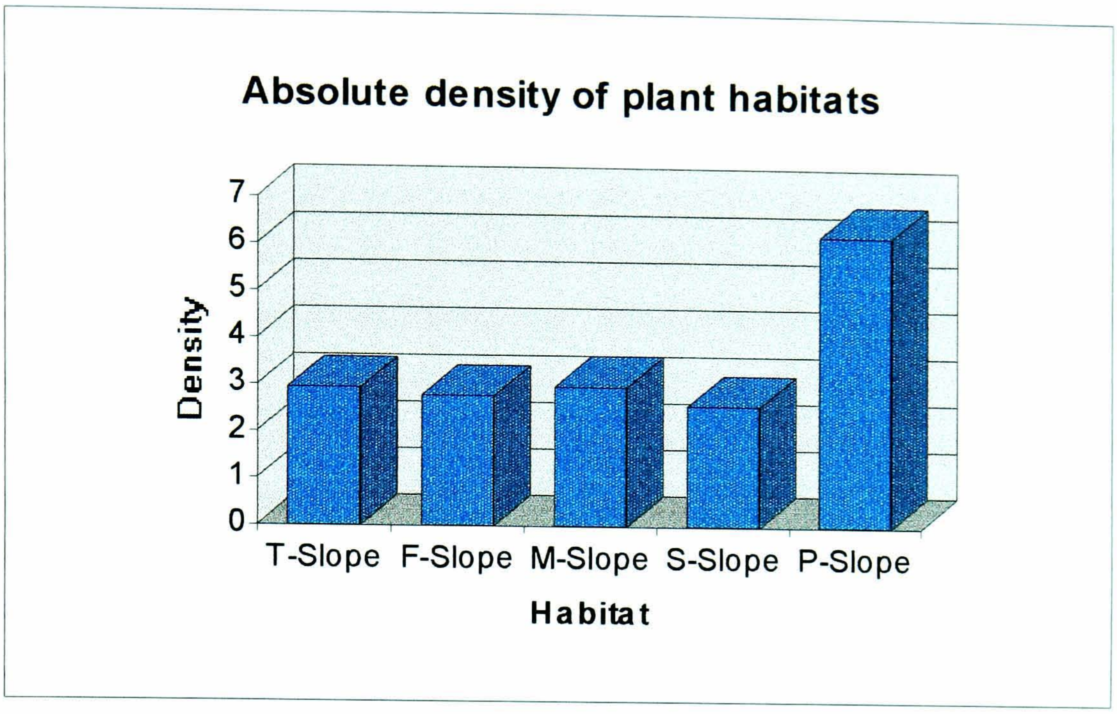

Figure 4-11 Absolute density of perennial vegetation in the botanical habitats in the research area.

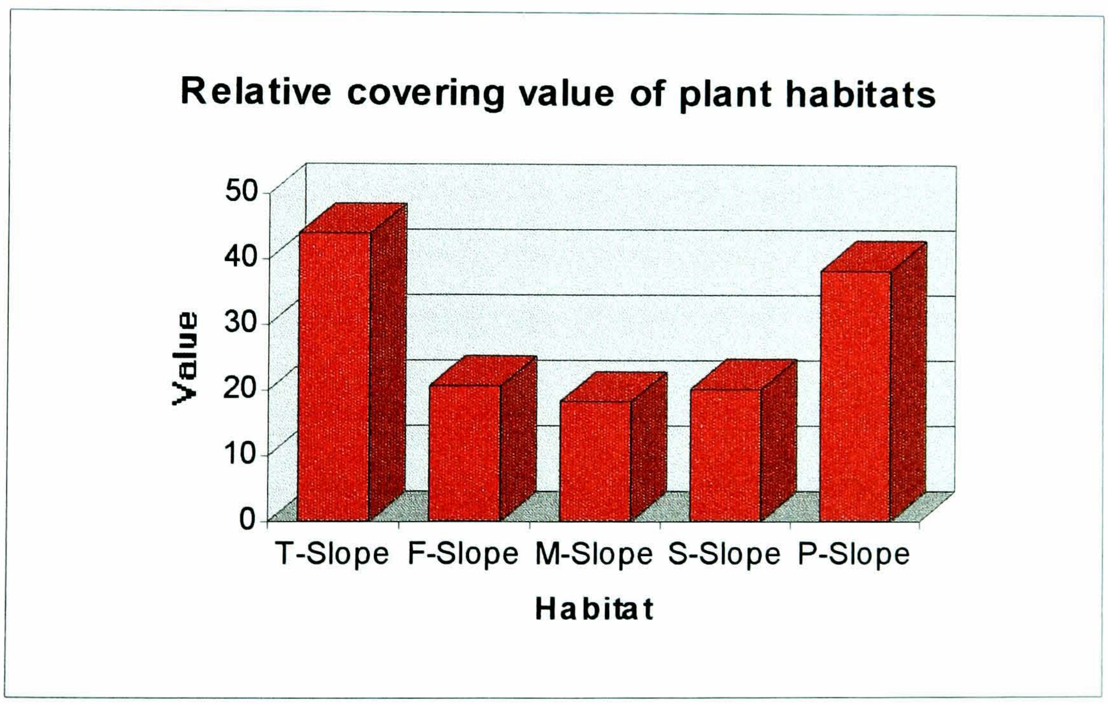

Figure 4-12 Relative covering value of perennial vegetation in the research area.

Mean basal diameter again confirmed the distinctiveness of toe slope habitat plants. It is considered very high in this habitat (15.43 cm) compared with the mean basal diameter in the other habitats. Probably, the augmentation of mean basal diameter in the toe-slope habitat is related to the concentration in this habitat of **Acacia spp**, which have big stems, as well as to availability of other environmental factors, such as moisture, soil depth and conservation. As can be seen from Fig. 4-14, the means of plant basal diameters in the other habitats are moderate to small.

Classification of samples and species using the TWINSPAN program led to identification of 14 important plant groups (refer to Fig. 4-6).

Depending on the data collected from the Upper Wadi Bishah basin during the field work, reconnaissance surveys and the classification of samples and species resulting from an application of the TWINSPAN and DECORANA computer programs, the perennial vegetation cover of this basin has been divided into five distinct plant groups (refer to Fig. 4-9). The first group is spread over the north and north-east of the basin and consists largely of **Acacia arabica**. The second group covers the tops and eastern hillsides of the Asir and Al-Hijaz mountains, and consists mainly of **Juniperus procera**, **Euryops arabicus**, and **Dodonaea viscosa**. The third group is speared in most head sources of Wadi Bishah, and consists mainly of **Acacia gerradii** and **Dodonaea viscosa**. The fourth group occupies the south-eastern part of the basin and contains at most of **Lycium shawii** and **Acacia negrii**. The fifth group occupies the middle and east of the basin and consists of **Kleinia odora**, **Lycium barbarum**, **Lycium shawii, Psiadia arabica**, **Solanum incanum**, **Leptadenia pyrotechnica** and **Periploca aphylla**.

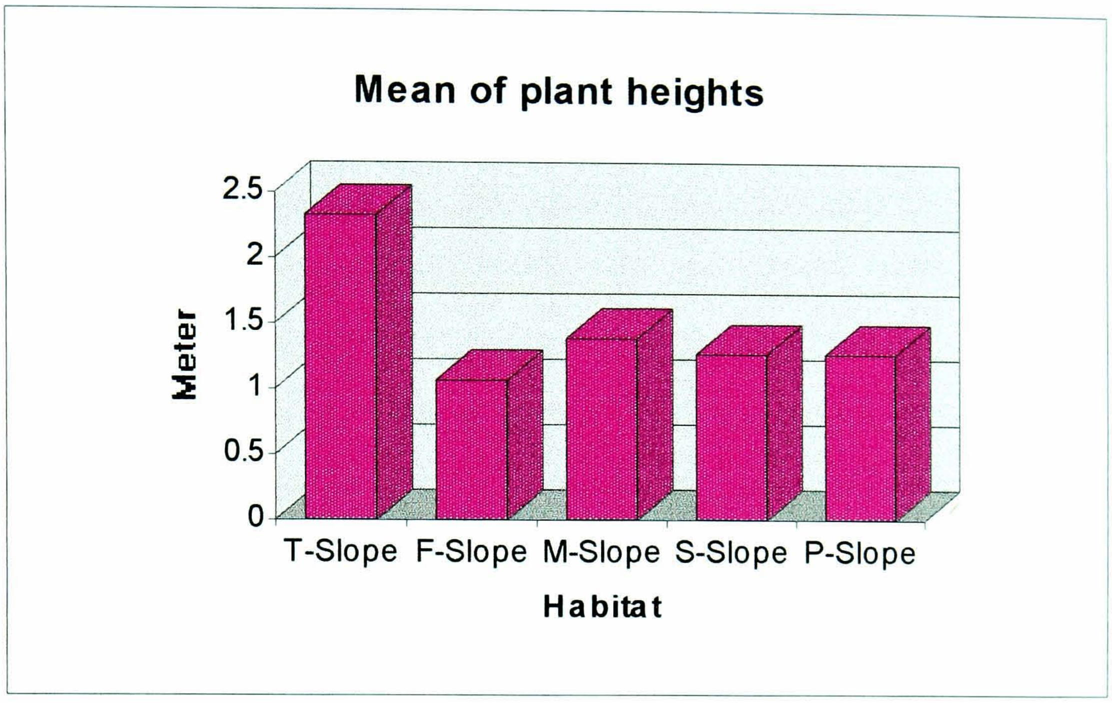

Figure 4-13 Mean of plant heights of the vegetation habitats in the research area.

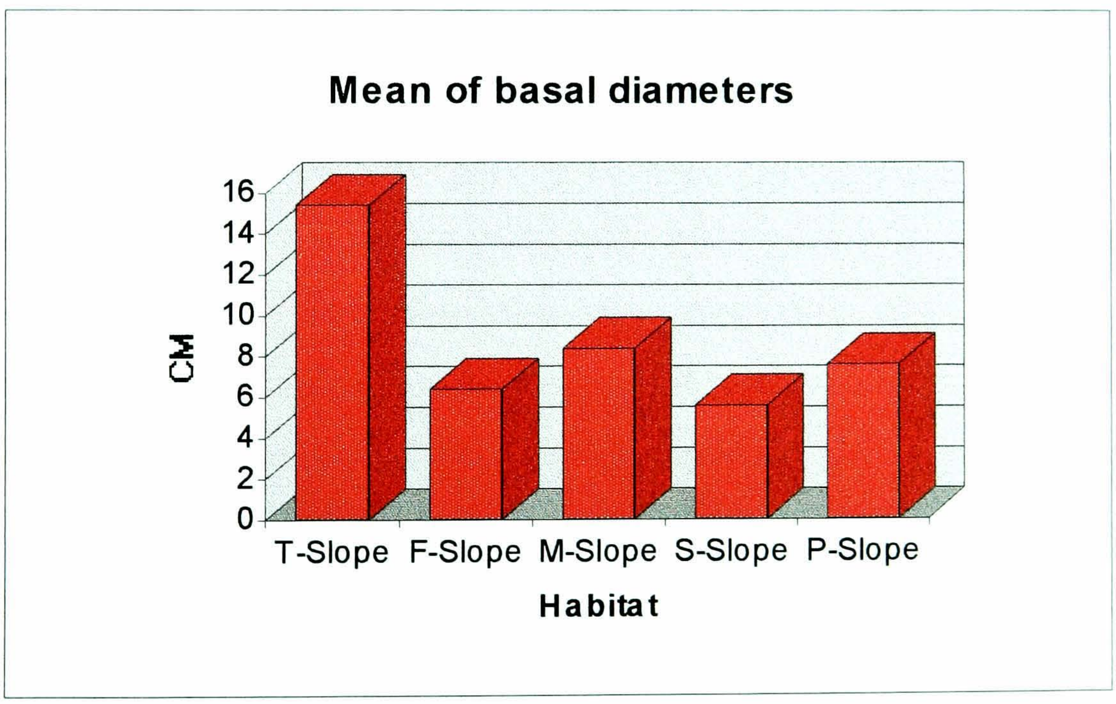

Figure 4-14 Mean of basal diameter in the vegetation habitats of the research area.

Investigation of the relationship between vegetation cover and environmental factors indicated that floristic composition and the distribution of main plant groups reflected the condition of soil and topographical variety.

The impact of over-grazing on vegetation cover and soil appears to be clear, particularly in the north-eastern part of the Wadi Bishah basin, where the condition of vegetation cover and soil in this part of the research area is very degraded.

CHAPTER FIVE

Soil Properties of the Research Area.

Chapter Five
Soil Properties of the Research Area.

5-1 Introduction.

Despite the vast area of the Kingdom of Saudi Arabia (2,200,518 sq. Km), there has unfortunately so far been little study of its soil, which has not attracted the interest of specialists, particularly in the south-west part where the research area is situated. This is because of the lack of agricultural planning and the difficulty of carrying out research in a tough region such as the area of the present study. However, in 1965 the Ministry of Agriculture and Water in Saudi Arabia initiated a wide plan for water, soil and agriculture potentiality studies. According to this plan, the Kingdom of Saudi Arabia was divided into eight areas and each was given to international engineering consultants to investigate and report on the natural potentialities of those areas (Al-Jerash, 1968). The research area was located in areas two and three. Unfortunately, the deficit of soil information is still found because the results of these investigations were either very weak or so far have not seen the light of day.

For the above reasons, the first purpose of this chapter is to investigate and analyse in detail the soil properties of the research area, in terms of its formation, morphological types and distribution. The second aim of this chapter is to prepare for the investigation of the relationship between soil properties and the components of slope and vegetation in the next chapter. These investigations, and the analyses of soil properties depend on data collected from 300 soil samples taken from the research area. To facilitate full understanding of these investigations and analysis, a brief account of the present knowledge of soil of Saudi Arabia, with special emphasis on the south-western territory, is presented in the following section.

5-2 Background Information.

According to the United States system (USDA), studies of soil genesis indicate that the soils of Saudi Arabia belongs to the broad Entisol and Aridisol hierarchies, except for those with a humid local climate, and older soils that had been created under different climatic conditions.

In respect of this latter point, Powers et al. (1966), Chapman (1978), Sharief (1984) and Youssef (1987) all have indicated that the Arabian Peninsula was located under a humid climate during the Upper Pleistocene (2.5 million years B.P), Early Pleistocene (3 million years B.P) and Late Pliocene (13 million years B.P) periods (Moshrif, 1990). In particular, the Arabian Shield soils were formed then. After these periods, the soils of Saudi Arabia then underwent a change in climate to reach their current condition (Arid zones in most parts and Semi-arid zone in the south-western mountains). A general description of the present soils of Saudi Arabia was given by Al Souli et al. (1980: 117). Their description is as follows:

" The soils of the Kingdom of Saudi Arabia are varied, but can generally be correlated with present surface geological conditions (Soil parent materials) as modified by climate, vegetation, relief and time or age. The major soil parent materials consist of metamorphic and igneous rocks of the Arabian Shield, the limestone, sandstone and shale deposits of the eastern sedimentary basin or plateau, marine deposits of coastal plains, colluvial and alluvial deposits and deep sandy deposits".

In terms of soil classification, so far only two works have been carried out in this field, namely a soil map (Ministry of Agriculture and Water, 1981) and the general soil map (Ministry of Agriculture and Water, 1985) of Saudi Arabia (Fig. 5-1). These works, production of which depended strongly on both general information and field observations, both confirmed that the soils of Saudi Arabia are Entisols and Aridisols and mainly undeveloped.

Due to the small scale (1:6,000,000) of the soil map (1981), the soil of Saudi Arabia was classified within it solely into nine main types (Fig. 5-1), namely calciorthids-camborthids (stony, deep soils and lava rock), calciorthids-torripsamments (sandy, deep soils), calciorthids-torriorthids-rock outcrop (loamy, deep, nearly level and gently sloping soils and loamy skeletal, shallow and hills of rock), gypsiorthids-calciorthids-torripsamments (plains of loamy soils with gypsum pan and loamy, deep soils), torripsamments-sandy dunes (plains of sandy, deep soils and dunes less than 2 meters high), torripsamments-rock outcrop (plains of sandy, deep soils and hills of rock), salorthids-torripsamments (dunes and basins), calciorthids-rock outcrop (plains of loamy, moderately deep soils and rock) and rock outcrop-calciorthids-torriorthents (loamy and loamy-skeletal, shallow, nearly level and gently sloping soils). In contrast, the scale of the general soil map of Saudi Arabia (1985), was somewhat larger (1:250,000), and in this the soil was classified into 49 types. The research area consists of five of these types, namely lithic torriorthents-rock outcrop-xerorthents (mountains and nearly level agricultural terraces), rock outcrop-torriorthents (mountains), torriorthents-rock outcrop-torrifluvents (loamy, deep soils, hills of rock and intermittent streams), calciorthids-rock outcrop (loamy, deep, nearly level and gently sloping soils and hills of rock) and calciorthids-rock outcrop (plains of loamy, deep soils and knolls and hills of rock).

Concerning the soil of the south-western part of Saudi Arabia, which includes the research area, the studies of soil in this region have been either general studies, depending on general information and field observations, or very specialized studies, conducted in a very small part of this region. Unfortunately, the results of these studies have, without any reservation, usually been generalized to the whole region and used to describe the overall soil properties. However, the results of these studies have varied, and were at times conflicting. Some of them have described the soil of this region as being shallow and undeveloped, while others have not. The following paragraphs are presented as examples of these discrepancies.

Al Souli et al. (1980: 117) stated the following of the soil of the Arabian shield:

"The soils are often shallow, rocky and occur on relatively steep slopes. They are grayish brown to yellowish red in color. Local areas of soil are found in creek positions. Foot slopes, terrace and some nearly level areas have deeper soils which have medium texture (loams and sandy loams), are fertile and are suitable for cultivation. The sedimentary limestone, sandstone and shale areas of basin also have shallow soils and may, in places, be deeply dissected".

In 1993 (p: 154), El-Hames gave the following description of the soil of the south-western highlands of Saudi Arabia:

"The steeply-sloped mountain ridges are covered with shallow soils with rock outcrops which are mainly composed of Precambrian plutonic, granitic and metamorphic rocks. The main wadi channels are infilled with predominantly sandy silty alluvium, while in the upstream areas on the ridge slopes, boulders and gravel are more common. The thickness of the alluvium in valleys in the Asir highlands ranges from a few metres to less than 13 metres".

Aba-Husayn et al. (1980: 643), presented a mineralogical description of the soil of the mountains of Asir region as follows:

"Soils developed on stable landscapes at higher elevation, (>2,000 m) have well-developed profiles, a clay loam texture, about 6% organic material, and near neutral pH. Soils developed on alluvial terraces near wadi banks at lower elevations (>1,500 m) have a deep but less developed profile, a loamy sand texture, about 1% organic material, and higher than neutral pH with carbonate minerals. Quartz, feldspars, and micaceous minerals are the major components of the silt and sand fractions of the soil. Clay fractions of the soils are composed mainly of kaolinite, smectite, vermiculite, mica and chlorite minerals. Kaolinite is the most abundant clay mineral of the soils developed on well drained highland areas. On the other hand, smectite is the most abundant clay mineral in the alluvial soils developed on lower terrace area".

In respect of the research area, there have not been many soil studies of any kind and all writing has been at the level of general information. The only work which can be considered a good contribution in showing some important aspects of classification and distribution of the main types of soil is the general soil map of the Kingdom of Saudi Arabia (Ministry of Agriculture and Water, 1985).

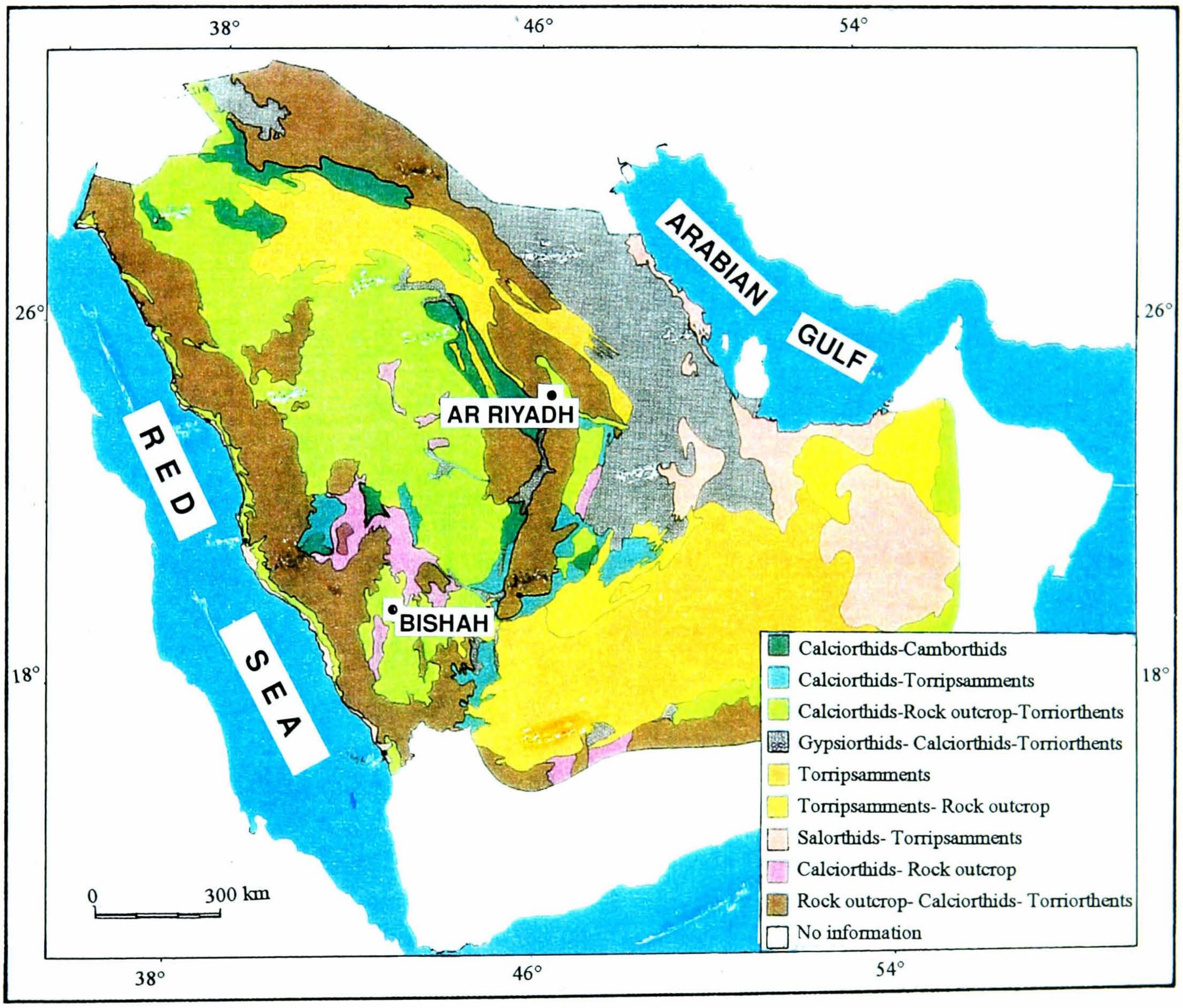

Figure 5-1 Soil Map of the Kingdom of Saudi Arabia.
(Source: Al-Welaie, 1996)

According to the classification and distribution of the main types of soil in this map, the soil of the research area consists of five types, namely, calciorthids-rock outcrop (loamy, deep, nearly level, and gently sloping soils and hills of rock), calciorthids-rock outcrop (plains of loamy, deep soil and knolls and hills of rock), lithic torriorthents-rock outcrop-xerorthents (mountains and nearly level agricultural terraces), rock outcrop-torriorthents (mountains) and torriorthents-rock outcrop-torrifluvents (loamy, deep soils, hills of rock and intermittent streams). These types are depicted in Fig. 5-2, while the percentage of each soil type in the research area is indicated in Table 5-1.

As can be seen from Fig. 5-2 and Table 5-1, the type of lithic torriorthents-rock outcrop-xerorthents is spread along the higher elevations of the Asir mountains that shapes the west and south-west of the area under study. This type of soil composes 0.3% of Saudi Arabian land and 23% of the research area. Rock outcrop-torriorthents is the most prevalent type in the research area. It occupies a big part of the plateau located between the Asir mountains and the main stream of Wadi Bishah, as well as most of the southern lands of Upper Wadi Bishah basin (311,600 hectares). This type composes 10.3% of Saudi Arabia lands and 41% of the research area. Torriorthents-rock outcrop-torrifluvents is widespread in the south-east of the area under study. Individual areas of this type are irregular in shape and mostly located toward the east of the catchment. Although this type does not compose more than 0.5% of Saudi Arabia lands, however it occupies 182,400 hectares (24%) of the research area lands (Table 5-1). The presence of calciorthids-rock outcrop is intermittent in the middle and east of the research area lands. It consists of nearly level and gently sloping soils on plains and areas of rock outcrop on steep, isolated hills. Individual areas of this type are irregular in shape and range from

5,588 to 39,117 hectares in size. It comprises about 10% (76,000 hectares) of the research area.

Table 5-1 Area end Percentage of the Main Types of Soils in the Research Area.

Soil Type	Saudi Arabia		Research Area	
	Hectare	%	Hectare*	%*
Lithic Torriorthents-Rock outcrop-Xerorthents	525,150	0.3	174,800	23
Rock outcrop-Torriorthents	19,826,700	10.3	311,600	41
Torriorthents-Rock outcrop-Torrifluvents	916,000	0.5	182,400	24
Calciorthids-Rock outcrop	2,801,400	1.5	76,000	10
Calciorthids-Rock outcrop	5,705,150	2.9	15,200	2
Total	**29,249,250**	**15.5**	**760,000**	**100**

**Area and percentage of soil types in the research area are personal work.*

(Source: General soil map of the Kingdom of Saudi Arabia, 1985)

Another type of calciorthids-rock outcrop occupies a small part of the north of the Upper Wadi Bishah catchment. This part consists of nearly level and gently sloping soils on plains and areas of rock outcrop on nearly level and gently sloping plains and knolls and strongly sloping and steep hills. This type of soil comprises 2% (15,200 hectares) of the area under study.

5-3 Factors of Soil Formation in the Research Area.

Soil formation and soil characteristics in any given ecological zone are a product of the interaction of the main five factors of soil formation; parent material, climate, relief, biotic factors and time or soil age. Other factors may be important locally, such as the human factor (Birkeland, 1984). For this reason, the following subsections, briefly describe how these factors have affected the soil of the research area.

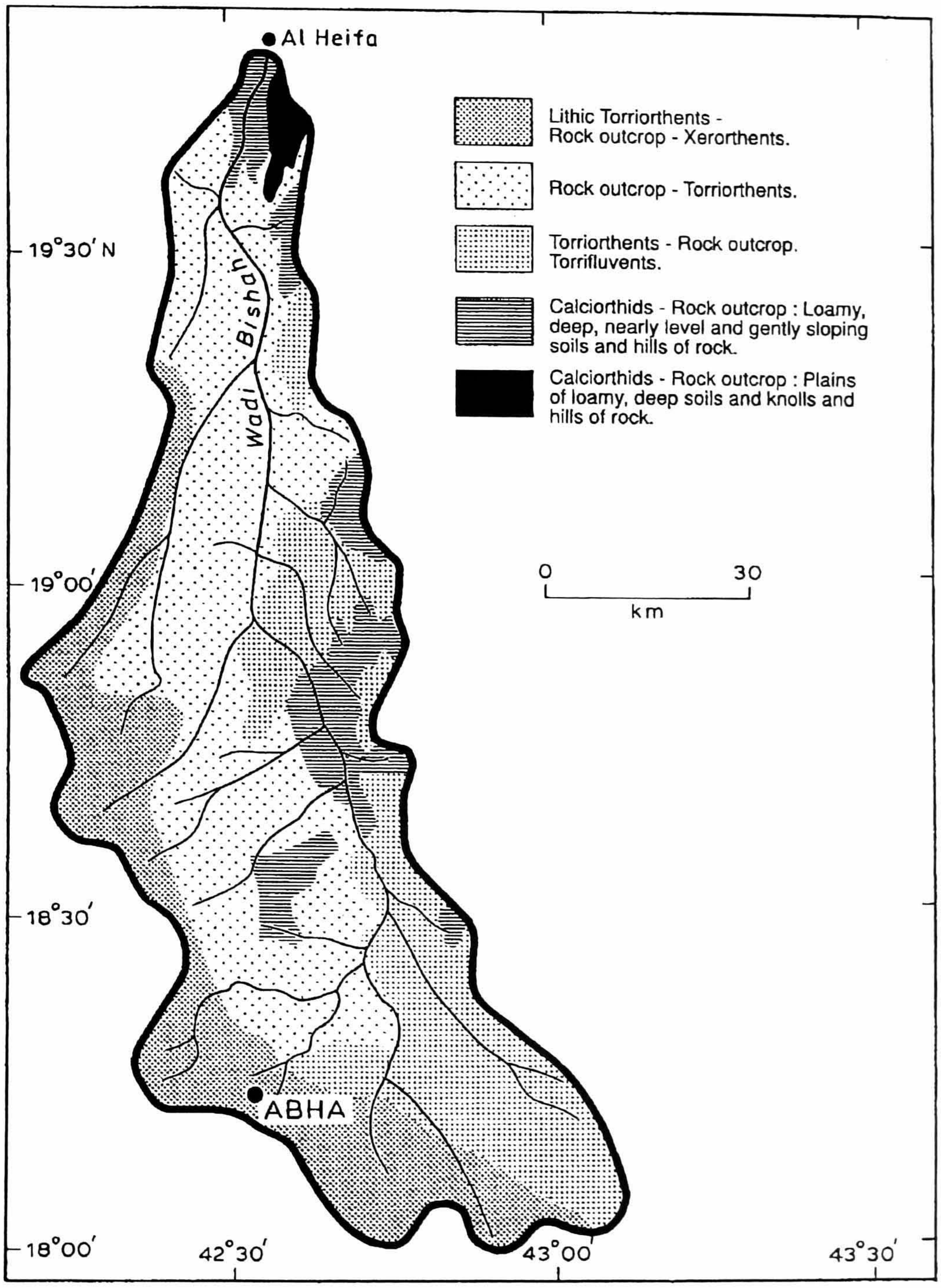

Figure 5-2 Distribution of the Main Types of Soils in the Research Area.
(Source: Table 5-1 and personal work)

5-3-1 Parent Material Factor.

Parent material is the unconsolidated material in which the soil profile forms. It may be the residual material that has weathered in place from rock, or it may be alluvial, or colluvial or eolian material transported from one place to another by water, gravity or wind. The effect of parent material on soil formation in the research area is reflected in terms of texture, mineralogical composition and degree of stratification. As mentioned in Chapter One (1.2.2), the parent materials of the soils in the area under study come from several sources. There are areas of intensely folded Precambrian rocks, predominantly granite, schist, diorite, gneiss and sandstone and some scattered basaltic deposits (refer to Fig. 1-4). The soil in these areas is formed in residuum or as alluvium from these rocks (General Soil Map of Saudi Arabia, 1985). In the sedimentary basins, the soils on plains are formed mostly in a parent material of old alluvium. On fault scarps where gently tilted sandstone, shale, limestone and marl are exposed, the parent material is colluvium.

5-3-2 Climate Factor.

In general, the influence of climate on soil formation is significant, especially in this area. However the current evidence (e. g. The position of calcium carbonate along soil horizons) indicates that the influence of the present climate on soil formation of the research area comes second in degree, after the influence of the relief factor. Fossil evidence found in the south-west of Saudi Arabia indicates that a period of more moist climate than the present ended about 8,000 years ago (Al-Welaie, 1996), and the soil profile formation cannot be considered to be the product of the present climate only. This battern is similar to that in East and North Africa (Youssef, 1987). Horizons with an accumulation of calcium carbonate are not all in accord with expectations, due to the present climate. The horizons indicate that calcium carbonate was added by dust and overwash in some places and leached to a depth of 125 to 150 centimetres. Later additions were leached to a lesser depth as the climate became progressively drier, resulting in very thick horizons of calcium carbonate accumulation (General Soil Map of Saudi Arabia, 1985). The few studies conducted in the south-west of Saudi Arabia, such as Al- Barrak (1985), Al-Sharief (1984) and Youssef (1987), all have confirmed the occurrence of a moist Paleoclimate in the area under study during the Upper Pleistocene (2.5 million years B.P), Early Pleistocene (3 million years B.P) and Late Pliocene (13 million years B.P) periods.

5-3-3 Relief Factor.

Relief is the configuration of the land, including slope shape and slope gradient. It is very important and one of the main themes of the thesis. It includes land-forms and landscape features such as mountains, plains, alluvial fans, valleys, stream terraces, flood plains, playas, back-slopes, foot-slopes and toe-slopes. The influence of the relief factor in soil formation appears in many ways, for example, profile thickness, increasing or decreasing erosion, amount of water entering the soil and amount of sunshine received by the land surface.

Some pedologists and geomorphlogists, such as Al-Arifi (1992), Al-Shalash (1985) and FitzPatrick (1980), have considered relief to be among the most important factors that affect soil formation. Others such as Jenny (1994) have claimed that the relief factor is the main factor in soil formation. In the research area which is characterized by a complex terrain, the relief factor undoubtedly plays the greatest role in soil formation (see Youssef, 1987), particularly with the reduced importance of climate. Therefore, the role of relief or slope has been a major focus of the present study. More details of slopes and their impact on the soil of the research area can be seen in Chapter One (1.2.4) and in Chapter Six respectively.

5-3-4 The Biotic Factor.

Plants and animals, including microorganism and man, are important in soil formation. In fact, nearly every organism that lives on the surface of the earth or in the soil affects the development of soils in one way or another. The variation is so wide that any grouping in order of their taxonomy really has little meaning from the pedological standpoint. However, an arbitrary and somewhat crude classification of the more important soil organisms has been attempted as follows: Higher plants; Vertebrates; Mammals; Other vertebrates; Microorganisms; Mesofauna and Man (FitzPatrick, 1980). This classification is not included in this thesis.

In the research area, the higher plants, which are mostly perennial plants have, more importance in local soil formation. As mentioned in Chapter Four, the density and size of plants are very varied, horizontally from stand to stand and vertically from one slope unit to another. Such a wide variation in the vegetation cover of the area under study has contributed to many differences in soil properties. The influence of animals in soil formation is noted, particularly in the north-east of the research area. Human influence is very limited and present only through the effects of grazing animals and the use of woody plants for craftsmanship. More details of animal and vegetation factors and their influences in soil formation can be seen in Chapter Four (8.4), later in the present chapter and in Chapter Six, respectively.

5-3-5 The Time Factor.

In general, the formation of soil is a very slow and complex phenomenon involving the interaction of physical, chemical and biological processes. The time required for development of a mature soil depends not only on the intensity of these processes, but on the nature of parent material. Pedologists estimate that the development of 1 inch of topsoil derived from hard rock-like basalt or granite may require from 200 to 1,200 years, depending on the climate, vegetation cover and topography. However, soft rocks, such as volcanic ash and shale and such parent material as sand dunes and river sediments, may develop into mature vegetation-supporting soil within a few decades. For the reasons mentioned above, estimation of soil age is somewhat speculative (Youssef, 1987).

Despite the great geological age of the research area, which was shaped during the Precambrian time, from the pedological standpoint, this age is not very important for soil formation, because the important age is the maturing age of the soil (Omer & Metwally, 1978). As mentioned earlier, during the Tertiary and Quaternary times, the area under study passed through various geological and climatic conditions. These conditions, particularly the alternation of rainy and drier periods, formed a soil which is relatively immature soil today.

5-4 The Relationships Between Soil Properties.

The soil is an environmental milieu involving the interaction of physical, chemical and biological processes. This complex interaction causes all soil properties to be associated with each other, whether directly or indirectly, to comprise a fully integral system of soil conditions. From this point of view, it is a very natural thing to find association and interrelationships between soil properties. However, the important thing is the nature of these relationships. The major aim of analysing the relationships between soil properties is to explain and interpret the strength of the relations that constitute this system and this forms one of the emphases of my research. As mentioned in Chapter Three and exhibited in Table 5-2, the Pearson correlation coefficient was used to determine these relationships. As can be seen from this Table, the correlation coefficient was carried out between all the studied soil properties, and the following summary findings are reported:

a) 49% of the correlation relationships between soil properties under the present study are positively associated with each other.

b) About 71% of the relationships between soil properties are significant at the 0.05 level (Two-tailed test), whereas the remainder (29%) are not significant at this level, but most of them are close to it.

c) About 26% of the relationships between soil properties are moderate to high (R = 0.40-0.99).

d) Each soil property is associated with one or more of the other properties with a moderate or strong relationship, except electric conductivity (EC), potassium (K), phosphorus (P) and total calcium carbonate ($CaCO_3$).

e) The strength of the relationships between organic matter (OM) and soil pH (R = - 0.60), organic matter and nitrogen (N) (R = 0.78), organic matter and organic carbon (OC) (R = 0.99), organic carbon and soil pH (R = - 0.60), organic carbon and nitrogen (R = 0.78) and between nitrogen and soil pH (R = 0.78) denotes that each one of these properties would be affected strongly by a change in another, whether directly or indirectly. A more detailed examination of these relationships follows.

Table 5-2 A half-matrix Showing Calculation of the Pearson Correlation Coefficient for the Interrelationships Between Soil Properties of the Upper Wadi Bishah Basin.

Soil properties	Morphological and physical properties				chemical properties						
	Soil depth	text-ure	mois-ture	OM	OC	$CaCO_3$	N	P	K	pH	EC
EC	.16 **	-.07 *	.04 *	-.02 *	-.02 *	.29 **	-.05 *	-.03 *	.16 **	-.20 **	XX
pH	.09 *	.43 **	.44 **	-.60 **	-.60 **	.18 **	.78 **	-.07 *	.04 *	XX	
K	.23 **	-.06 *	-.13 **	-.17 **	-.17 **	.14 **	-.12 **	-.07 *	XX		
P	.09 *	-.12 **	.20 **	.34 **	.34 **	-.06 *	.24 **	XX			
N	.23 **	-.35 **	.47 **	.78 **	.78 **	-.25 **	XX				
CaCO3	.02 *	-.13 **	-.11 **	-.26 **	.26 **	XX					
OC	-.27 **	-.41 **	.56 **	.99 **	XX						
OM	-.27 **	-.41 **	.56 **	XX							
mois-ture	-.09 *	-.50 **	XX								
text-ure	.10 *	XX									
soil depth	XX										

XX Rank Correlation Coefficient not Calculated.
** Correlations Are Significant at 0.05 level (Two-tailed test).
* Correlations Are not Significant at 0.05 level (Two-tailed test).

5-5 Soil Properties.

Some soil properties are distinctive features and can be used as important differentiating criteria while others seems to be have little pedological significance but are important in relation to crop production. The following paragraphs will therefore focus only on those morphological, physical and chemical properties that are most commonly encountered in the context of soil-environmental study. The morphological and physical properties comprise soil depth (thickness), moisture, texture (sand, silt and clay) and organic matter. The chemical properties comprise organic carbon, total calcium carbonate, nitrogen, phosphorus, potassium, pH of soil and electrical conductivity.

Analysis of each soil property will start first by examining the summary soil data in the whole research area, as these are fundamental to an understanding of soil properties. Secondly, because the research area includes two regions, a mountainous region and a plateau region, which differ greatly from one to another in terms of elevation, morphology, climate and vegetation cover, the diversity of soil properties between these regions and also between slope units (toe-slope, foot-slope, mid-slope, shoulder-slope and top-slope) is examined in the following paragraphs.

5-5-1 Morphological and Physical Properties.

Soil depth, texture, moisture and organic matter are the most important morphological and physical properties of soil. Selection of these properties is based on their important role in formation and production of soil, as well as their direct relationship with environmental factors, such as slope and vegetation factors. The study and analysis of these four properties are the focal point of the following paragraphs:

5-5-1-1 Soil Depth.

Perhaps it is questionable whether soil depth or thickness of soil should be considered as an important differentiating property. In most circumstances, the depth of soil is considered as one of the major indications of soil development. However, it should be noted that the development of soil can occur in a few centimetres when the environmental conditions are appropriate (FitzPatrick, 1980). Soil depth or thickness (T) consists of the vertical arrangement of all the soil horizons down to the parent material (Birkeland, 1984; Al-Shalash, 1985) and reflects the relative amounts of deepening (D), upbuilding (U) and removals (R) that occurred during the evolution of the soil, where $T = D + U - R$ (Johnson, 1985). Deepening refers to the down-migration of the lower soil boundary, via leaching and weathering. Upbuilding refers mainly to surface additions of minerals and organic materials derived from eolian and slope processes. Removal refers mainly to surface-material losses through erosion and mass wasting. In reference to the relationship T = D + U - R, soil thinning (or shallowing) occurs when D + U < R, and soil thickening occurs when D + U > R, D > U - R, or U > D - R (Johnson, 1985).The surface part of soil that extends from the top of the ground to c. 50 centimetres depth generally is the important part that plays a major role in plant life. Most interactions occur in this zone and reflect their influence, either negative or positive, on life forms. For the above reasons, as well as other environmental and research factors, the soil depth in this study was measured only up to 50 centimetres thickness. As mentioned in Chapter Three, two methods were utilised to measure the depth of soil, namely digging the ground and using the auger. As can be seen from Table 5-3, the mean depth of soil in the 300 stands surveyed in the research area was 31.31 centimetres. Values of standard deviation (13.50) and variance (182.267) as well as range value (40) indicated a somewhat high variation in soil depths in the research area. Frequency of soil depth in the 300 sites confirmed this result, with 52% of soil depth values less than 30 centimetres, 23% between 30 and 50 centimetres and 25% more than 50 centimetres (Appendix 4). From the above results, it is possible to say that the current soil of the research area is rather shallow. Overall this state has resulted due to removal factors (erosion and mass wasting) exceeding deepening and upbuilding factors (interior and surface additions of minerals and organic matter).

Comparison of the mean soil depth (30.07) and the standard deviation (12.58) in the south-west with equivalent values (32.55 and 14.29 respectively) in the north-east of the research area (Table 5-4) indicates that the soils of the south-western region are more shallow than the soils of the north-eastern region. As can be seen from Table 5-5, the significance of a difference between the means of soil depth in the south-western and the north-eastern regions was examined, using the t-test (Independent samples; t-test model). T-value (- 1.59) and t-probability ($p > 0.05$) indicate that the difference between the means of soil depth in these regions is not insignificant, at least from the statistical standpoint, at the 95 percent confidence level.

Table 5-3 Data Summary of Morphological and Physical Properties of Soil in the Research Area; N = 300.

Soil properties	Items					
	Mean	**std Deviation**	**Variance**	**Range**	**Minimum**	**Maximum**
Soil depth	31.31	13.50	182.267	40.00	10	>50
Sand	80.14	9.80	95.967	60	36	96
Silt	13.78	7.61	57.838	42	0	42
Clay	6.08	4.01	16.101	32	0	32
Moisture	2.46	2.11	4.437	10.53	0.30	10.83
OM	1.11	1.35	1.814	9.68	0.0130	9.6900

Table 5-4 Data Summary of Morphological and Physical Properties of Soil in the South-west and North-east Regions of the Research Area.

	South-western region			North-eastern region		
Soil properties	**Mean**	**std. deviation**	**Variance**	**Mean**	**std. deviation**	**Variance**
Soil depth	30.07	12.58	158.37	32.55	14.29	204.29
Sand	78.64	9.94	98.81	81.64	9.45	89.24
Silt	14.87	7.46	55.59	12.69	7.62	58.09
Clay	6.49	4.32	18.63	5.67	3.65	13.34
Moisture	3.47	2.42	5.84	1.45	1.00	0.99
OM	1.51	1.44	2.06	0.71	1.12	1.25

Table 5-5 T-test of Morphological and Physical Soil Properties Variance Between the South-west and the North-east Regions of the Research Area with 298 Degrees of Freedom.

Soil properties	Mean		T value	T probability
	South-west	North-east		
Soil depth	30.0667	32.5467	- 1.59	0.112
Texture	5.6533	6.0533	- 2.25	0.025
Moisture	3.4744	1.4461	9.50	0.000
Organic matter	1.5120	0.7074	5.41	0.000

In terms of vertical extent, the mean, standard deviation and variance of soil depth (thickness) were also computed in each slope unit (toe-slope, foot-slope, mid-slope, shoulder-slope and summit-slope or top-slope), and these results are exhibited in Table 5-6. Comparison of the mean depth of soil between slope units (44.03, 38.98, 28.35, 24.42 and 20.88 respectively) indicates that the depth of soil increases downward of slope and decreases upward of slope, while the standard deviation values (10.04, 11.60, 11.97, 10.01 and 7.87 respectively) and variance values (100.81, 134.59, 136.30, 10.29 and 61.87 respectively) show little differences in soil depth within each slope unit. The differences in soil depth between slope units, shown above, were examined further by using one way ANOVA. As can be seen from Table 5-7 and Fig. 5-3, the F-value (45.0002) and an F-significance value ($p<0.01$) indicate that the differences in soil depth between slope units are significant. This result is confirmed by Fig. 5-3. Multiple comparison tests for the differences in the mean depth of soil in the slope units (Table 5-8) indicate that there are significant differences at the level of 0.05 between means of soil depth in most slope units.

Table 5-6 Data Summary of Morphological and Physical Properties of Soil within Slope Units of the Research Area.

Slope units	Soil properties	Items		
		Mean	**std. deviation**	**Variance**
Toe-slope	**Soil depth**	44.03	10.04	100.81
	Sand	79.63	11.36	129.15
	Silt	13.63	8.17	66.78
	Clay	6.53	4.61	21.27
	Moisture	2.60	2.58	6.66
	OM	1.03	1.17	1.38
Foot-slope	**Soil depth**	38.98	11.60	134.59
	Sand	79.87	10.30	106.15
	Silt	14.23	8.33	69.44
	Clay	5.90	3.67	13.48
	Moisture	2.48	2.33	5.45
	OM	1.06	1.21	1.47
Mid-slope	**Soil depth**	28.35	11.67	136.30
	Sand	79.47	9.64	93.00
	Silt	13.80	6.46	41.72
	Clay	6.73	4.72	22.23
	Moisture	2.38	1.97	3.89
	OM	1.15	1.40	1.95
Shoulder-slope	**Soil depth**	24.52	10.01	100.29
	Sand	81.27	7.91	62.50
	Silt	13.00	6.28	39.39
	Clay	5.73	3.42	11.72
	Moisture	2.33	1.48	2.20
	OM	1.16	1.36	1.86
Summit-slope	**Soil depth**	20.88	7.87	61.87
	Sand	80.43	9.66	93.30
	Silt	14.07	8.55	73.08
	Clay	5.50	3.43	11.75
	Moisture	2.53	2.06	4.25
	OM	1.15	1.59	2.52

Table 5-7 Analysis of Variance of Soil Morphological and Physical Properties Between Slope Units (toe-slope, foot-slope, mid-slope, shoulder-slope and top-slope).

Soil properties	Analysis of variance					
	source of variance	**D.F**	**Sum of squares**	**mean squares**	**F value**	**F sig.**
Soil depth	between groups	4	23062.8133	5765.7033	45.0002	0.0000
	within groups	295	31497.7333	106.7720		
	Total	**299**	**54560.5467**			
Texture	between groups	4	5.8133	1.4533	0.6007	0.6624
	within groups	295	713.7333	2.4194		
	Total	**299**	**719.5467**			
Moisture	between groups	4	2.7692	0.6923	0.1542	0.9610
	within groups	295	1324.4779	4.4898		
	Total	**299**	**1327.2471**			
Organic matter	between groups	4	0.8985	0.2246	0.1224	0.9744
	within groups	295	541.4570	1.8354		
	Total	**299**	**542.3555**			

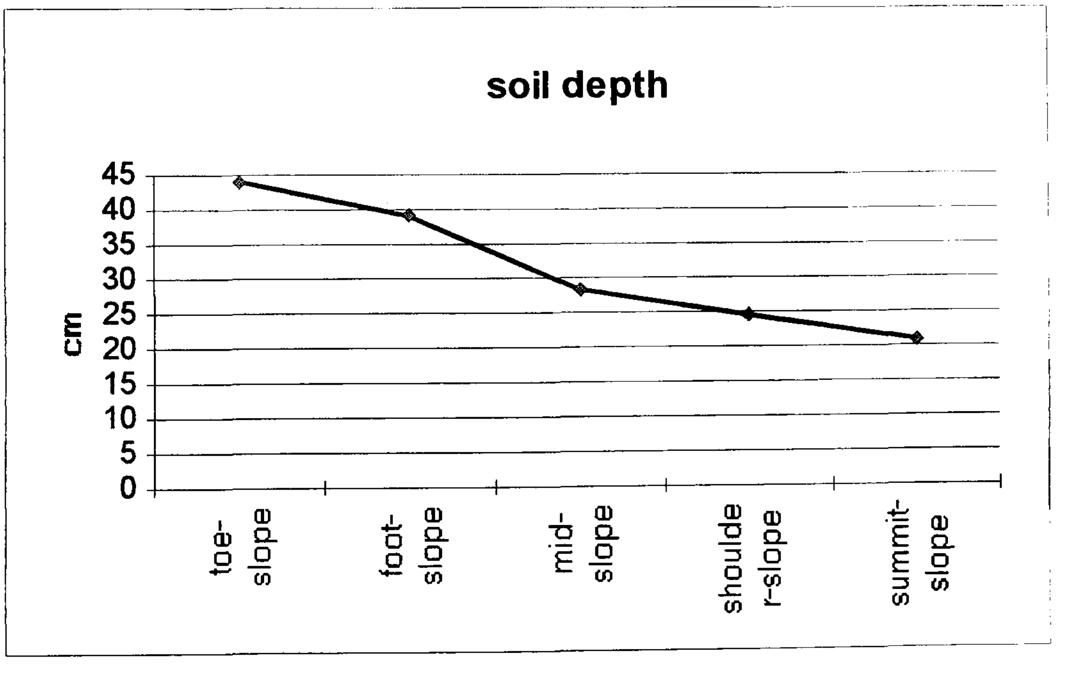

Figure 5-3 Amount of Soil Depth Between Slope Units.

Table 5-8 Multiple Comparisons Test (Least Significant Difference Model) for the Differences Between the Means Depth of Soil in the Slope Units.

Slope units	toe-slope	foot-slope	mid-slope	shoulder-slope	summit-slope
toe-slope		*	*	*	*
foot-slope			*	*	*
mid-slope				*	*
shoulder-slope					
summit-slope					

* Significant at 0.05 level.

5-5-1-2 Soil Texture.

Soil texture is one of the important internal characteristics of soil. The principal property of soil mineral particles in an environmental context is their size. The mineral fraction of soils consists of particles that vary dramatically in size from large boulders (several m in diameter) through cobbles and pebbles (several cm in diameter) to sand, slit and clay (less than 2 mm in diameter) (Ellis & Mellor, 1995). Most studies of soil texture depend upon the proportion of sand, silt and clay sizes, as based on the inorganic soil fraction that is less than 2 mm in diameter (Birkeland, 1984). The dominant size fraction is used to describe the texture. If no fraction is dominant, the soil is described as a loam (Wild, 1994). The commonly-used textural classification systems are the International system, United States system and British standards system (White, 1987). The United States system (USDA) is used in this study to classify the texture of soil into sand, silt and clay. In this, particles of sand range from 0.05 to 2.0 millimetres in diameter. The individual particles of silt are microscopic in size (0.002 to 0.05 millimetre). The individual clay particles are even more minute (less than 0.002 millimetre). The hydrometer method described in Chapter Three (3.8.4.1) was used as the best method of analysing soil texture. The texture triangle was used to determine the soil texture classes. The results of soil texture analysis are reported in the following paragraphs.

The means of sand, silt and clay in the research area are about 80%, 14% and 6% respectively. Although the range values of sand (60), silt (42) and clay (32) are very wide, the values of standard deviation (9.80, 7.61 and 4.01 respectively) and variance (95.967, 57.838 and 16.101 respectively) indicate that the sand, silt and clay proportions in most samples appear to be homogeneous (Table 5-3). Nevertheless, comparison of the mean proportions of sand (78.64), silt (14.87) and clay (6.49) in the south-western region with the equivalent values (81.64, 12.69 and 5.67 respectively) in the north-eastern region of the research area (Table 5-4) indicates that the sand proportion increases in the north-eastern region, whereas the silt and clay proportions decrease. Conversely, the sand proportion decreases in the south-western region whereas the silt and clay proportions increase. As can be seen from Table 5-4, the standard deviation and variance values denote that the sand, silt and clay proportions are somewhat homogeneous within each region. The importance of differences in soil texture between the south-western region and north-eastern region was examined by using t-test (Table 5-5). The t-value (- 2.25) and t-probability ($p<0.05$) indicate that the diversity of soil texture between the south-western and the north-eastern regions is significant. Through the slope units (toe-slope, foot-slope, mid-slope, shoulder-slope and summit-slope) or soil catena, small differences were noted between the mean proportions of sand (79.63, 79.87, 79.47, 81.27 and 80.43 respectively), silt (13.63, 14.23, 13.80, 13.00 and 14.07 respectively) and clay (6.53, 5.90, 6.73, 5.73 and 5.50 respectively) (Table 5-6). The variance of soil texture between slope units, mentioned above, was also examined via ANOVA (Table 5-7). As can be seen from this table, the f-value (0.6007) and f-significance ($p>0.05$) denote that the differences in soil texture between slope units are not significant at the level of 0.05, at least from the statistical point of view. This finding can be attributed mainly to the short distances between slope segments and to increased vegetation density in the upper parts of slopes that reduces migration of fine materials toward the lower parts of slopes.

According to the modern division system of the United States, the soils of the research area were classified into two types: loamy soils and sandy soils (Table 5-9). Loamy soils comprise 31.7% and consist of sandy clay loam (1%), sandy loam/sandy clay (0.7%), loam (1%), sandy loam (24.3%) and loam sandy/sandy loam (4.7%). Sandy soils comprise 68.3% and consist of loamy sand (42%), sandy loam sand (3.3%)and sand (23%). As can be seen from Fig. 5-4, the loamy sand (LS), sandy loam (SL) and sand (S) predominate, accounting for about 89% of the soil texture classes in the research area, whereas the other classes constitute less than 11%.

In terms of the soil type and texture class within each slope unit, sandy soils compose most of the stands within each slope unit, covering about 75%, 70%, 68.3%, 66.6% and 61.7% of top-slope, shoulder-slope, mid-slope, foot-slope and toe-slope respectively (Table 5-10). As can be seen from this Table and Fig. 5-5, loamy sand occupies the first rank in summit-slopes (48.3%), shoulder-slopes (40%), mid-slopes (53.3%) and foot-slopes (38.3%), and the second rank in toe-slopes (30%) after sand (31.7%). Some texture classes are not found in some slope units. Sandy loam/sandy clay and sandy loamy sand are not found in toe-slopes. Sandy loam/sandy clay and loam sandy/sandy loam do not appear in foot-slopes. Sandy clay loam is absent from mid-slopes. Sandy loam/sandy clay, sandy clay loam and loam are not found in shoulder-slopes. Due to the down migration of fine materials, via leaching as well as wind-erosion, particularly in the north-eastern part of the research area, the last two soil texture classes also are not found in summit-slopes.

Table 5-9 Classification of Soil and Soil Texture in the Research Area; According to the Modern Division of the United States.

Soil type	Percent	Texture class	Percent
Loamy soils	31.7	**Sandy clay loam (SCL)**	1.0
		Sandy loam / Sandy clay (SL/SC)	0.7
		Loam (L)	1.0
		Sandy loam (SL)	24.3
		Loam sandy / Sandy loam (LS/SL)	4.7
Sandy soils	68.3	**Loamy sand (LS)**	42.0
		Sandy loamy sand (S/LS)	3.3
		Sand (S)	23.0
Total	**100.0**		**100.0**

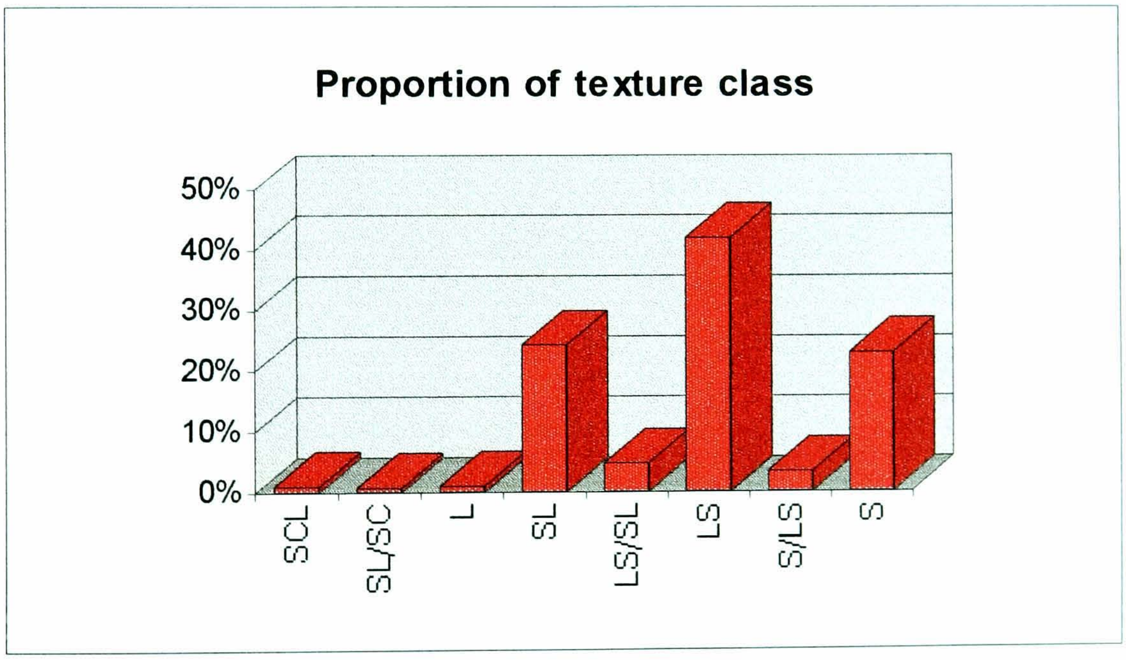

Figure 5-4 Proportions of the Texture Class of Soil in the Research Area. (Source: Table 5-9)

Key to Texture Classes (see Table 5-9)

SCL = **Sandy clay loam**
SL/SC = **Sandy loam / Sandy clay**
L = **Loam**
SL = **Sandy loam**
LS/SL = **Loam sandy / Sandy loam**
LS = **Loamy sand**
S/LS = **Sandy loamy sand**
S = **Sand**

Table 5-10 Classification of Soil and Soil Texture within the Slope Units; According to the Modern division of the United States.

Soil type	Texture class	Toe- slope %	Foot- slope %	Mid- slope %	Shoulder- slope %	Summit- slope %
Loamy soils	Sandy clay loam	3.3	1.7	0.0	0.0	0.0
	Sandy loam / Sandy clay	0.0	0.0	1.7	0.0	1.7
	Loam	1.7	1.7	1.7	0.0	0.0
	Sandy loam	26.7	30.0	23.3	21.7	20.0
	Loam sandy / Sandy loam	6.7	0.0	5.0	8.3	3.3
Sandy soils	Loamy sand	30.0	38.3	53.3	40.0	48.3
	Sandy loamy sand	0.0	5.0	1.7	5.0	5.0
	Sand	31.7	23.3	13.3	25.0	21.7
Total		**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

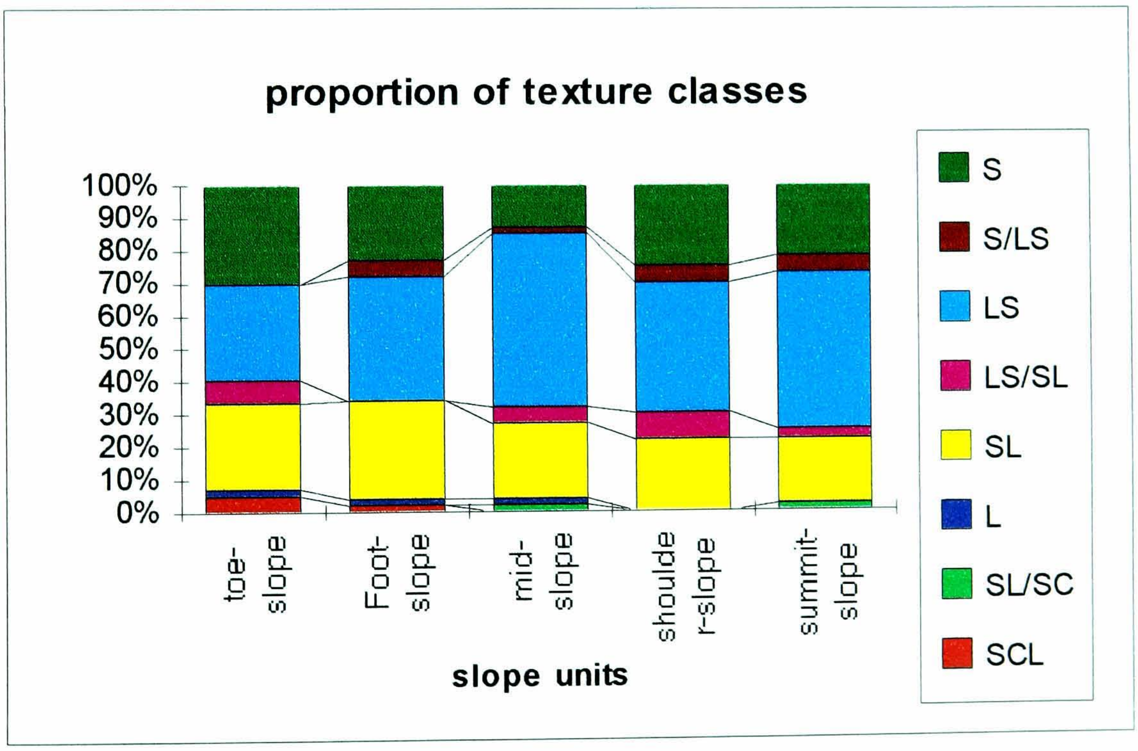

Figure 5-5 Proportions of the Texture Classes of Soil Within Slope Units. (Source: Table 5-10)

Key to Texture Classes (see Table 5-10)

SCL = **Sandy clay loam**
L = **Loam**
LS/SL = **Loam sandy / Sandy loam**
S/LS = **Sandy loamy sand**
SL/SC = **Sandy loam / Sandy clay**
SL = **Sandy loam**
LS = **Loamy sand**
S = **Sand**

5-5-1-3 Soil Moisture.

Soil moisture is defined as the solvent medium by which minerals are transported upward to the leaves of plant and sugar is transported downward to the roots. Soil moisture potential is the total effect of all types of energy acting on water in the soil, including gravity, capillary, surface adsorption and osmois (Pitty, 1978; Omer & Metwally, 1978; Ellis & Mellor, 1995). The amount of moisture content in soil depends basically on its mechanical texture; the smaller the particle size, the higher the amount of soil moisture and its availability (Migahid et al. 1987). Rainfall is the most important source and in some conditions is the single source of soil moisture in the research area (Al-Qhatani, 1991).

The soil moisture content of the research area samples was measured in the laboratory, using the weight method (refer to 3.8.4.2). The summarized results in Table 5-3 show that the mean moisture of soil is 2.46%. Comparing this mean with the equivalent value in the humid regions gives an initial impression that soil moisture in the research area is very low, but in fact, it may be considered a high value when compared with other regions in Saudi Arabia, e.g. the moisture content of soil in the central region of Saudi Arabia is about 1% or less (Youssef & El-Sheikh, 1981). Standard deviation (2.11) and variance value (4.437) as well as the range value (10.53) denote that soil moisture varies strongly from site to site. This variation may be related to differences in soil texture, elevation factor and its relationship with the amount of rainfall, vegetation cover size, etc. Frequency of soil moisture in the 300 examined samples confirmed the inequality of soil moisture throughout the research area: 55% of moisture amount values were less than 2%, 34% were between 2% to 5% and 11% were more than 5%.

As can be seen from Table 5-4, the standard deviation and variance values in the south-western region (2.42 and 5.84 respectively) and the north-eastern region (1.00 and

0.99 respectively) of the research area indicate that the soil moisture proportion within each region appears to be homogenous. However, variance is observed between the mean moisture of soil in the south-western region (3.47%) and the north-eastern region (1.45%). This variance relates in most conditions to the differences in elevation, rainfall amount, evaporation amount, vegetation cover size and soil texture class. The first region lies between 2000 m and 3130 m above sea level. The mean annual rainfall in this region is more than 300 millimetres, with an annual total of evaporation of about 2446.2 mm (Abha meteorological station) and an absolute vegetation density is 3.01/100 m^2. The second region is located at less than 2000 metres above sea level. The main annual rainfall of this region is less than 150 millimetres, with an annual total of evaporation of about 3893.3 mm (Al-Heifa meteorological station) and the absolute vegetation density is 2.46/100 m^2. Furthermore, the soil texture class in the south-western region is finer than in the north-eastern region. Reliability of the differences between mean moisture in both regions was examined, using the t-test (Table 5-5). The t-value (9.50) and t-probability ($p < 0.01$) show that the diversity of soil moisture between south-west and north-east of the research area is significant.

As can be seen from Table 5-6 and Fig. 5-6, the mean moisture of soil in slope units (toe-slope, foot-slope, mid-slope, shoulder-slope and summit-slope or top-slope) is 2.60%, 2.48%, 2.38%, 2.33% and 2.53% respectively. Standard deviation and variance value in toe-slopes (2.58 and 6.66 respectively) and foot-slopes (2.33 and 5.45 respectively) indicate that the soil moisture within these two units is somewhat different, whereas it is homogenous in the other units. The ANOVA of mean moisture in slope units (Table 5-7) indicates that the differences between these means are not significant, since f-value equals 0.1542 and the significance of F is 0.9610.

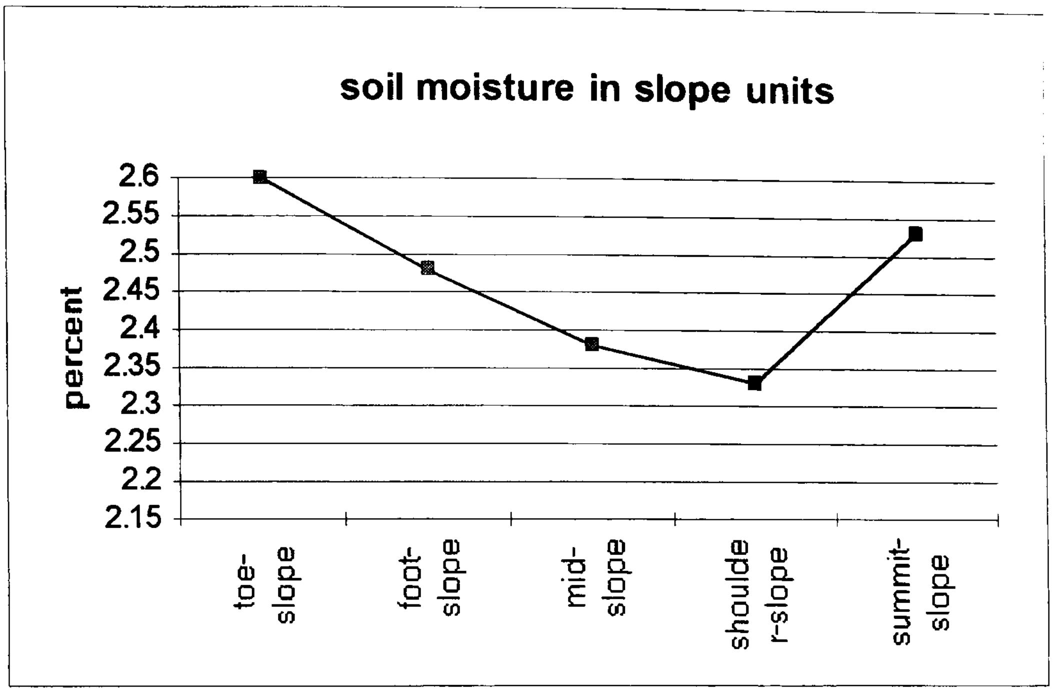

Figure 5-6 Diversity of Soil Moisture Within the Slope Units of the Research Area.

5-5-1-4 Organic Matter (OM).

Organic matter plays an important initial role in the physical, chemical and biotic properties of soils. It ranges in most soils between 1% and 7% (Bin Sadig, 1994). Forest soils have organic matter contents between 5.2% and 10.5% (Pitty, 1978). The percentage of organic matter in semi-arid region soils is very low, usually around 1% (Al-Mashhady et al. 1984). The main source of organic matter in the research area is dead roots, stems, seeds and leaves of vegetation cover. The second source is animal wastes, particularly in the north-east of the research area. Wind also plays a major role in carrying organic matter from source to other areas. Mean organic matter in the research area is very low (1.11%) (Table 5-3). Organic matter percentages range between 0.013% and 9.690% (Appendix 4). Distribution of these percentages confirms the lack of organic matter in the research area: 69% of organic matter values are less than 1%, 21% are between 1% and 3%, and 10% are more than 3%. As can be seen from Table 5-4, mean organic matter in the south-west of the research area was found to be higher than that found in the north-east (1.51% and 0.71% respectively). The significance of this variance between means of organic matter in the south-western and the north-eastern regions was examined, using the t-test. T-value (5.41) and t-probability ($p < 0.01$)) (Table 5-5) confirmed the significance of this variance. The increased proportion of organic matter in the south-west of the research area relates mainly to the greater vegetation cover there. As illustrated in Table 5-6, organic matter in the upper slopes was found to be a little higher than that found in the lower slopes, with the means of organic matter in top-slopes (1.5%), shoulder-slopes (1.16%) and mid-slopes (1.15%) being higher than those in foot-slopes (1.06%) and toe-slopes (1.03%). Despite these differences in organic matter between slope units, the f-value (0.2246) and f-significance (0.9744) (Table 5-7) resulting from ANOVA between means of organic matter in these units indicated that these differences are not important, at least from the statistical standpoint.

5-5-2 Chemical Properties.

Seven of the most important chemical properties of soil were selected to represent soil conditions in the research area, and with a view to study their relationship with slope and vegetation factors. These properties are organic carbon (OC), total calcium carbonate ($CaCO_3$), nitrogen (N), phosphorus content (P), potassium content (K), soil pH and electrical conductivity (EC).

5-5-2-1 Organic Carbon (OC).

As stated in Chapter Three (3.8.4.4), the organic carbon content of soil may be reported directly as percentage of C; or calculated as organic matter by multiplication by a factor. The conventional carbon to organic matter factor of long standing is 1.724, based on the assumption that soil organic matter is 58 percent C. The importance of carbon lies in its major contribution to the formation of humus, as well as the fact that fungi reform about 20% to 60% of carbon and divert it to protoplasm (Migahid et al. 1987). As expected in a semi-arid land, the soil of the research area has a low OC content, ranging from 0.0075% to 5.62% (Appendix 4). About 79% of OC values are below 1.0% and 21% are between 1.0% and 5.62%. As can be seen from Table 5-11, the mean OC content in the surface soil of the research area is 0.64%. Although the values of standard deviation (0.78) and variance (0.606) (Table 5-11) gave an initial impression that the values of OC content are somewhat homogeneous, however, in fact, there is a great variance between the means of OC in both the south-west and the north-east of the research area. Mean OC increases to 0.88% in the south-western region and drops to less than half that percentage in the north-eastern region (Table 5-12). Examination of this variance, using the t-test (Table 5-13) indicates that the difference between the means in both regions is quite significant at a level of 0.05, with t-value equal to 5.48 and t-probability, $p < 0.01$. This variance in OC content between the two regions can be attributed mainly to differences between them in vegetation cover size, organic matter content, texture class and climatic conditions. Along the slope catena, slight variations can be observed between means of OC content in slope units (Table 5-14), where mean OC content increases with elevation toward the top-slopes. This variation relates mainly to the augmentation of organic matter in upper slope units (refer to Table 5-6).

Table 5-11 Data summary of chemical properties of soil in the research area; N = 300.

Soil properties	Items					
	Mean	**std Deviation**	**Variance**	**Range**	**Minimum**	**Maximum**
OC	0.64	0.78	0.606	5.61	0.0075	5.6200
$CaCO_3$	2.85	2.58	6.633	18.29	0.72	19.01
N	361.72	484.60	234834.965	3883.16	7.56	3890.72
P	48.52	28.25	797.989	215	1	216
K	115.93	105.36	11101.367	917.08	2.92	920
pH	8.26	0.50	0.252	5.52	3.88	9.40
EC	0.39	1.60	2.582	24.85	0.05	24.90

Table 5-12 Data summary of chemical properties of soil in south-west and north-east regions of the research area.

	South-western region			North-eastern region		
Soil properties	**Mean**	**std. deviation**	**Variance**	**Mean**	**std. deviation**	**Variance**
OC	0.88	0.83	0.69	0.41	0.65	0.41
$CaCO_3$	2.09	1.39	1.94	3.60	3.20	10.22
N	496.03	533.68	284809.14	227.42	387.45	150117.85
P	54.03	27.87	776.47	43.02	27.64	763.89
K	91.41	67.87	4606.31	140.45	128.30	16460.26
pH	8.12	0.40	0.16	8.40	0.55	0.30
EC	0.27	0.61	0.37	0.51	2.19	4.78

Table 5-13 T test of chemical soil properties variance between south-west and north-east regions of the research area with degree of freedom 298.

	Mean			
Soil properties	**South-west**	**North-east**	**T value**	**T probability**
OC	0.8767	0.4060	5.48	0.000
$CaCO_3$	2.0907	3.6003	- 5.30	0.000
N	496.0316	227.4171	4.99	0.000
P	54.0267	43.0200	3.43	0.001
K	91.4087	140.4515	- 4.14	0.000
pH	8.1160	8.4005	- 5.11	0.000
EC	0.2710	0.5097	- 1.29	0.200

Table 5-14 Data summary of chemical properties of soil in slope units of the research area.

Slope units	Soil properties	Items		
		Mean	**std. deviation**	**Variance**
Toe-slope	**OC**	0.59	0.67	0.45
	$CaCO_3$	2.97	2.98	8.87
	N	318.93	385.74	148796.93
	P	51.62	30.65	939.26
	K	146.73	139.05	19334.62
	pH	8.21	0.46	0.21
	EC	0.96	3.47	12.05
Foot-slope	**OC**	0.61	0.70	0.49
	$CaCO_3$	2.46	1.41	2.00
	N	352.07	550.52	303072.87
	P	50.12	26.88	722.31
	K	146.58	147.29	21695.53
	pH	8.24	0.69	0.47
	EC	0.35	0.58	0.34
Mid-slope	**OC**	0.67	0..81	0.64
	$CaCO_3$	2.44	1.54	2.37
	N	357.84	438.49	192273.75
	P	46.87	27.11	735.17
	K	108.30	78.78	6205.57
	pH	8.23	0.47	0.22
	EC	0.31	0.53	0.28
Shoulder-slope	**OC**	0.67	0.79	0.62
	$CaCO_3$	3.12	3.21	10.28
	N	351.89	414.34	171673.86
	P	49.42	33.17	1100.42
	K	96.31	56.80	3226.01
	pH	8.32	0.43	0.18
	EC	0.16	0.16	0.02
Summit-slope	**OC**	0.67	0.92	0.85
	$CaCO_3$	3.24	3.09	9.53
	N	428.64	608.10	369787.80
	P	44.60	22.70	515.33
	K	82.05	46.88	2197.97
	pH	8.31	0.44	0.19
	EC	0.17	0.07	0.01

Table 5-15 Analysis of Variance (One-Way) of Soil Chemical Properties Between Slope Units (Toe-slope, Foot-slope, Mid-slope, Shoulder-slope and Top-slope).

Soil properties	Analysis of variance					
	source of variance	**D.F**	**Sum of squares**	**mean squares**	**F value**	**F sig.**
OC	between groups	4	0.3346	0.0836	0.1364	0.9688
	within groups	295	180.9066	0.6132		
	Total	**299**	**181.2412**			
$CaCO_3$	between groups	4	33.4688	8.3672	1.2659	0.2835
	within groups	295	1949.8234	6.6096		
	Total	**299**	**1983.2922**			
N	between groups	4	390819.8078	97704.952	0.4120	0.7999
	within groups	295	69950707.63	237121.04		
	Total	**299**	**70341527.44**			
P	between groups	4	1862.5533	465.6383	0.5802	0.6772
	within groups	295	236736.2833	802.4959		
	Total	**299**	**238598.8367**			
K	between groups	4	208755.2013	52188.800	4.9553	0.0007
	within groups	295	3106922.300	10531.940		
	Total	**299**	**3315677.501**			
pH	between groups	4	0.5845	0.1461	0.5728	0.6826
	within groups	295	75.2503	0.2551		
	Total	**299**	**75.8348**			
EC	between groups	4	26.0650	6.5163	2.5654	0.0384
	within groups	295	749.3142	2.5400		
	Total	**299**	**775.3792**			

5-5-2-2 Total Calcium Carbonate ($CaCO_3$).

The content of soil from calcium carbonate ($CaCO_3$) varies with the soil type, parent material and climate condition. In most soils, $CaCO_3$ is distinct from other nutrients in being originally derived from the weathering of primary minerals, and occurring in significant quantities in exchangeable form. It occurs in highly variable amounts, ranging from traces of less than 0.05% to quantities amounting to over a quarter of the bulk of some soils in arid areas (Pitty, 1978). The natural sources of soil calcium carbonate are boulders, rocks and the primary and minor minerals (Al-Niemi, 1987).

The soil of the research area appears to be marginally calcic with $CaCO_3$ contents ranging from 0.72% to 19.01% (Appendix 4). However, most of the values were between 0.72% and 4.27%. About 91% of the values were less than 5%, whereas 9% of the values were between 5% and 19.01%. Although the mean calcium carbonate ($CaCO_3$) in the research area was 2.58% (Table 5-11), this percentage decreases to 2.09% in the south-west of the research area, and increases to 3.60% in the north-east (Table 5-12). Augmentation of calcium carbonate in the north-east of the research area relates mainly to the parent material type, airborne calcium, a low level of organic matter (0.71%) and the arid climate, where the temperature is very high and the rainfall is limited, so that the removal of carbonate by rainfall is negligible. The variation between mean values of calcium carbonate ($CaCO_3$) in the south-west and in north-east of the research area (2.0907% and 3.6003% respectively) was examined, via the t-test (Table 5-13). T-value (- 5.30) and t-probability ($p < 0.01$) indicate that this variation is significant. As can be seen from Table 5-14, values of total calcium carbonate ($CaCO_3$) in the upper slopes were found to be higher than those found in lower slopes, where mean $CaCO_3$ in summit-slopes (3.24%) and shoulder-slopes (3.12%) was greater than those in the mid-slopes (2.44%), foot-slopes (2.46%) and toe-slopes (2.97%). However, results of ANOVA (Table 5-15) between mean values of $CaCO_3$ within slope units denote that the differences in means of $CaCO_3$ are not significant, at least from the statistical viewpoint, with an f-value of 1.2659 and f-significance of 0.2835.

5-5-2-3 Nitrogen Content (N).

According to Campbell (1989) and Al-Niemi (1987), nitrogen is the most important element in soil organic matter, when considered from the economic standpoint. The other nutrients are also important but nitrogen is required in much larger amounts and accordingly is more likely to be deficient. About 97.82% of nitrogen is present in rocks in the lithosphere, 1.96% is in the atmosphere and only 0.02% in the biosphere. About 86.7% of the biosphere nitrogen is relatively inert and only slowly made available to plants by microbial degradation. The lithosphere nitrogen is of very low concentration and not available to plants (Campbell, 1989). The amount of nitrogen exceeds 1% in some soils that are rich in organic matter, but it decreases to less than 0.03% in arid and semi-arid soils (Al-Niemi, 1987).

The surface soil of the area under study appears to be very variable in respect of nitrogen with nitrogen contents ranging from 7.56 ppm (sample 196 in the eastern part of the research area) to 3890.72 ppm (sample 55 in the western part of the research area) (Appendix 4). About 42% of nitrogen values are less than 100 ppm, 50% are between 100 ppm and 1000 ppm and 8% are more than 1000 ppm. As can be seen from Table 5-11, although the mean nitrogen amount in soil of the research area is 361.72 ppm, the values of standard deviation (484.60) and variance (234834.965) as well as the range value (3883.16) indicate that the nitrogen amounts are not homogeneous in the research area. Heterogeneity of nitrogen amounts also appears to be obvious between the south-west and the north-east of the research area, where mean nitrogen amount is 496.03 ppm in the first region and 227.42 ppm in the second region. The difference between mean nitrogen amounts in both regions was examined via the t-test (Table 5-13). T-value (4.99) and t-probability ($p < 0.01$) signify that the difference is very significant. These differences between mean nitrogen amounts in the two regions relate mainly to differences in their organic matter content (1.51% and 0.71% respectively), climate conditions and, to some extent, to the broad differences in soil type. As can be seen from Table 5-14, due to the augmentation of organic matter and decreasing of temperature, the amount of N in the upper slopes was found to be higher than that found in lower slopes, where mean N in summit-slopes (428.64 ppm) is more than the equivalent in toe-slopes (318.93%). The mean N in foot-slopes, mid-slopes and shoulder-slopes is 352.07 ppm, 357.84 ppm and 351.89 ppm respectively. However, the result of ANOVA (Table 5-15) between the mean N amounts in slope units mentioned above denotes that the differences between these means are not significant, where the f-value equals 0.4120 and f-significance is 0.7999.

5-5-2-4 Phosphorus Content (P).

Phosphorus is an essential nutrient element for plant life; indeed it is called the key to life. It plays a major role in storing and transferring the energy in soil and plants (Omer & Metwally, 1978). The amount of phosphorus in most soils ranges between 0.02% (or 200 ppm) and 0.15% (or 1,500 ppm), and it is concentrated mainly in the surface layer of soils. However, this amount may decrease to less than 0.02% in soil that contains only small amounts of organic matter (Al-Niemi, 1987).

The soils of the research area are variable in phosphorus content, with a mean phosphorus amount of only 48.52 ppm (or 0.005%) (Table 5-11). Although the phosphorus values in the samples analysed ranged between 1 ppm and 216 ppm (Appendix 4), P values in most samples (95%) ranged between 1 ppm and 100 ppm., which is less than the desirable level for plant growth (Al-Niemi, 1987). Phosphorus deficiency is common in arid and semi-arid regions as a result of soil formation factors, the interaction of soil chemical properties, a coarse soil texture and the deficiency of organic matter. The values of standard deviation (28.25) and variance (797.989) of P in the research area indicate that the P amount in soil is somewhat homogeneous. However, moderate differences can be noted between mean P amounts in the south-west (54.03 ppm) and north-east (43.02 ppm) of the research area (Table 5-12). These differences could be related to variations in the amount of organic matter and texture class as well as the temperature rate in both regions. The significance of the difference between mean P amount in the south-west and north-east of the area under study was tested, using the t-test (Table 5-13). T-value (3.43) and t-probability ($p < 0.01$) confirm that the difference is very important. As shown in Table 5-14, due to the decrease in silt and clay on the upper slopes, the phosphorus amount also decreases toward the upper slopes, with mean P values in toe-slopes, foot-slopes, mid-slopes, shoulder-slopes and summit-slope of 51.62 ppm, 50.12 ppm, 46.87 ppm, 49.42 ppm and 44.60 ppm, respectively. The importance of the diversity in P amounts between slope units was examined via ANOVA (Table 5-15). As can be seen from this Table, f-value (0.5802) and f-significance (0.6772) indicate that the variation is not important.

5-5-2-5 Potassium Content (K).

Potassium is an important element in soil fertility and plant nutrition. The main sources of potassium are rocks that contain the primary potassium minerals, such as feldspar, muscovite and biotite. According to Al-Niemi (1987), potassium is widespread in the earth's crust, particularly in the fine soil texture, and its average in most soils is about 1.5% (or 15,000 ppm). The larger proportion of this potassium is fixed by most soil clay minerals in a form not available to plants, because the potassium ion fits precisely and is held in the hexagonal holes in the oxygen sheet of the silicate layers (Pitty, 1978).

The soil of the research area has low potassium levels, ranging from 2.92 ppm to 920 ppm (Appendix 4). About 55% of potassium values are less than 100 ppm and 34% are between 100 ppm to 200 ppm, whereas only 11% are more than 200 ppm. As can be seen from Table 5-11, the mean potassium content in surface soil of the research area is 115.93 ppm, but the values of standard deviation (105.36) and variance (11101.367) as well as the range (917.08) between minimum and maximum values indicate that the potassium amounts are not identical in most analysed samples. This variation in the soil content of potassium is clearly evident in the mean K values in the south-west and north-east of the research area (Table 5-12), and also between the mean K values among slope units (Table 5-14). The importance of differences in the mean potassium amount in the south-west (91.41 ppm) and north-east (140.45 ppm) of the research area was examined, using the t-test (Table 5-13). T-value (4.14) and t-probability ($p < 0.01$) confirm that the difference between potassium amount in both regions is quite significant. This difference in the potassium amount can be attributed to the augmentation of washing and leaching processes in the south-western region as a result of the higher rainfall there. Due to the washing of potassium from the upper slopes toward the lower slopes, the mean potassium amount decreases in the upper slope units and increases in the down slope units, giving mean potassium values in toe-slopes, foot-slopes, mid-slopes, shoulder-slopes and top-slopes of 146.73 ppm, 146.58 ppm, 108.30 ppm, 96.31 ppm and 82.05 ppm respectively (Table 5-14 and Fig. 5-7). As can be seen from Table 5-15, the f-value (4.9553) and f-significance (0.0007), resulting from ANOVA analyses between mean potassium amounts within the slope units confirms that the differences are quite significant. Multiple comparison tests (Table 5-16) indicate that there are significant differences in mean potassium between most slope units at a level of 0.05. These differences can be attributed mainly to the washing and erosion of potassium from the upper slope segments, as well as the increase in vegetation density in these segments, which led to increase of absorption of potassium from the soil. Moreover, the augmentation of organic matter, and a decrease of temperature, in the upper slope segments, further contributed to the decrease in the amount of potassium there (Al-Niemi, 1987).

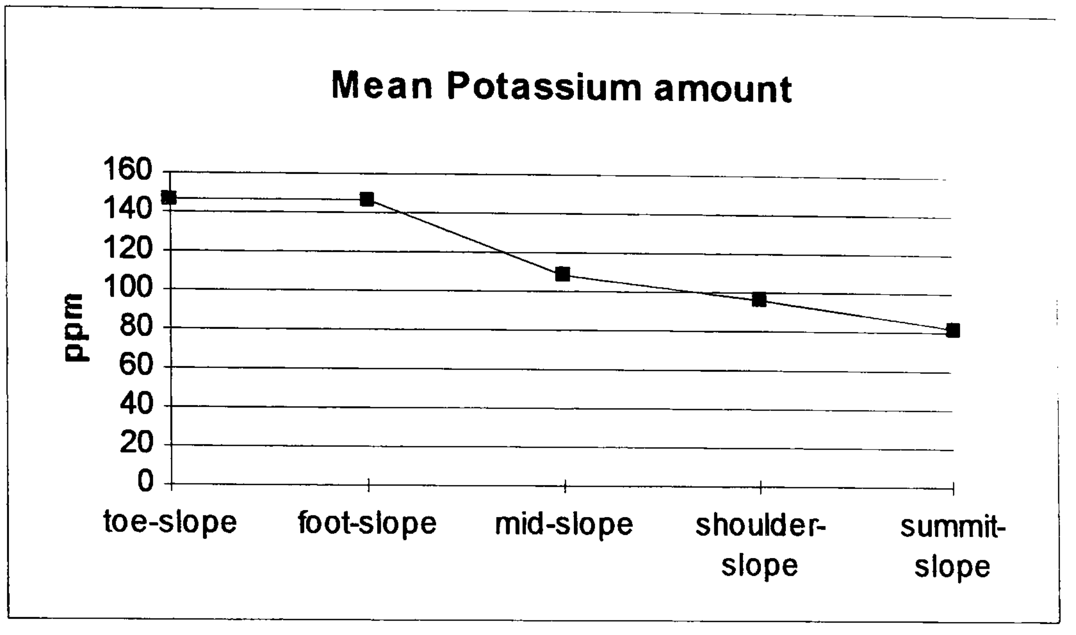

Figure 5-7 Diversity of Potassium Amount Within the Slope Units of the Research Area.

Table 5-16 Multiple Comparisons Test (Least Significant Difference Model) for the Differences Between Means of Potassium within Slope Units.

Slope units	toe-slope	foot-slope	mid-slope	shoulder-slope	summit-slope
toe-slope			*	*	*
foot-slope			*	*	*
mid-slope					
shoulder-slope					
summit-slope					

* Significant at 0.05 level.

5-5-2-6 Soil pH.

Soil pH is dependent on the ionic content and concentration in both the soil solution and the exchangeable action complex adsorbed to the surface of colloids (Birkeland, 1984). The pH scale ranges from 1.0 at the most acidic extreme to 14.0 at the alkaline extreme, with a value of 7.0 at neutrality (Ellis & Mellor, 1995). Good soils for plant growth have a value around 6.0 to 7.0 (Al-Niemi, 1987). The pH values in the soil of the research area range from 3.88 to 9.40 (Appendix 4). However, more than 99% of pH values are slightly to strongly alkaline in reaction, ranging from 7.10 to 9.40. Only 2 of 300 soil samples were found to be not alkaline. One of them is neutral (6.80) and the another sample is acidic (3.88), found in a foot-slope in Al Qawba. As can be seen from Table 5-11, the values of standard deviation (0.50) and variance (0.252) denote that the values of pH are somewhat homogeneous around the mean pH (8.26). However, a slight difference can be noted between mean pH values in the south-west (8.12) and the north-east (8.40) of the research area (Table 5-12). The significance of this difference was examined via the t-test (Table 5-13). T-value (- 5.11) and t-probability ($p < 0.01$) indicate that this difference is significant at the 0.05 level. Augmentation of pH values in the north-eastern region may relate to the reduction of organic matter and washing processes there, resulting from a scattered vegetation cover and a low rainfall amount, as well as an increase in evaporation processes. As can be seen from Tables 5-14 and 5-15, no considerable changes in pH values were observed through slope catenas; mean pH values in toe-slopes, foot-slopes, mid-slopes, shoulder-slopes and top-slopes are 8.21, 8.24, 8.23, 8.32 and 8.31 respectively.

5-5-2-7 Electrical Conductivity (EC).

EC is a good indicator for measuring the degree of soil salinity. Electrical conductivity analysis of soil samples collected from the research area indicates that the soil has a very low quantity of soluble salts, ranging between 0.05 mmhos/cm and 24.90 mmhos/cm (Appendix 4). About 95% of the electrical conductivity values lie between 0.05 mmhos/cm and 0.96 mmhos/cm. Only 1 of the 300 samples exceeds 7.38 mmhos/cm, at 24.90 mmhos/cm. As can be seen from Tables 5-12, 5-13, and 5-15, the only noticeable differences in electrical conductivity values are those between slope units, particularly between toe-slope units and the other units (foot-slope, mid-slope, shoulder-slope and summit-slope) (Table 5-17 and Fig. 5-8). According to the US Salinity Laboratory Staff scale, and as Ellis & Mellor (1995) have defined it, the soils of the research area are Nonsaline-Alkali soil; 99% of the electrical conductivity of the saturated extract is less than 4 mmhos/cm at 25 °C and the pH values range between 3.88 and 9.40. The low quantities of salt in the majority of soil samples can be related, in addition to the primary minerals found in the soil, to the high rates of leaching with the reasonable permeability of the soil, particularly after rainfall, in the upper slope units.

Table 5-17 Multiple Comparisons Test (Least Significant Difference Model) for the Differences Between Means of Electrical Conductivity within Slope Units.

Slope units	toe-slope	foot-slope	mid-slope	shoulder-slope	summit-slope
toe-slope		*	*	*	*
foot-slope					
mid-slope					
shoulder-slope					
summit-slope					

* Significant at 0.05 level.

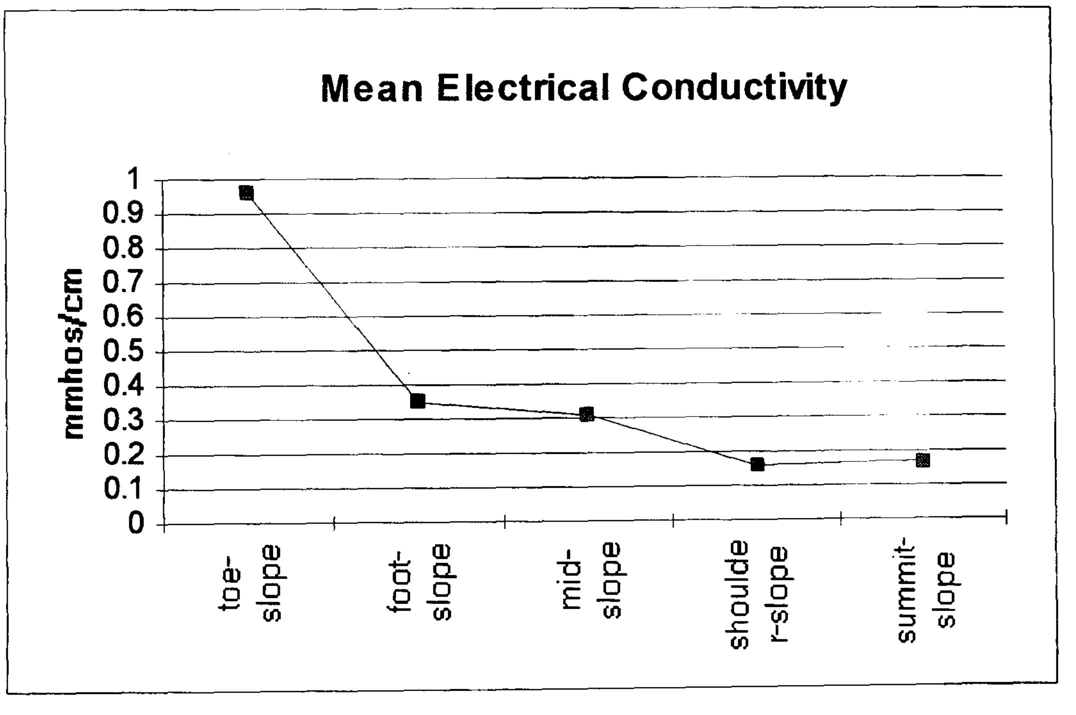

Figure 5-8 Diversity of Mean Electrical Conductivity Values Within the Slope Units of the Research Area.

5-6 Conclusions.

This chapter began with a glimpse of the soil of Saudi Arabia, particularly the soil of the south-western part, followed by a discussion of the main soil formation factors in the research area. The spatial interrelationships between soil properties were explored, then the most important properties of soil of the Upper Wadi Bishah basin were examined under morphological, physical and chemical headings, using my own data, and using different scales(e.g. the south-western region and the north-eastern region on the vertical level, and slope segments on the horizontal level). Morphological properties have included soil depth. Physical properties have included those relating to the basic constituents of soil, such as soil texture, moisture and organic matter. The chemical characteristics of soil cover a wide range of the common elements and compounds in soil-environmental studies, such as organic carbon (OC), total calcium carbonate ($CaCO_3$), nitrogen (N), phosphorus (P), potassium (K), soil pH and electrical conductivity (EC). Each soil property is associated with one or more of the other properties with moderate or strong relationships, except $CaCO_3$, P, K and EC. The strong relationships between OM and pH ($R = -0.60$), OM and N ($R = 0.78$), OM and OC ($R = 0.99$), OC and pH ($R = -0.60$), OC and N ($R = 0.78$) and between N and pH ($R = 0.78$) denote that each one of these properties would be affected strongly whether directly or indirectly by a change in another.

In terms of soil properties, it is obvious that various environmental factors have played a major role in the formation and composition of soil attributes in the research area. The impact of these factors in the formation of soil properties appears conspicuous on two levels, namely the horizontal level and the vertical level. On the horizontal level and according to the examined soil characteristics, the research area can be divided into two distinct regions, namely the mountainous region and the plateau region.

The mountainous region includes the Asir mountains which run from the south and form the west and south of the area under study. This region has a very harsh morphology rising to elevations between about 2000 m and 3130 m above sea level.

elevations which ensure low temperature as well as abundant rainfall. The soil texture of this region is generally loamy sand. However, gravels and stones are encountered in abundance, particularly in the bare lands. The upper parts of the wadis mostly have coarse mountain materials; in the soils of the alluvial plains, and where the valleys widen, fine grain-size soils are encountered including silt and clay, and these become gradually coarser as the wadi beds are reached. In view of the steep-slopes and the abundance of gravels and stones, the depth of soil is generally slight and shallow. The soil is somewhat rich in moisture, organic matter, organic carbon, N and P, whereas the values of $CaCO_3$, K, EC and pH in these soils are considered low compared with the plateau region.

The plateau region covers the north and east of the research area. Elevations in this region range from about 1000 m to 2000 m above sea level. The temperature rises to higher levels than in the mountainous region, while rainfall is less both in intensity and frequency. This region is arid with sparse vegetation. Sedimentation is more marked, so that wide, deep alluvial plains, extensive scree, river terraces and piedmont deposits are encountered. The soil always has coarse and mostly sandy loam to sand and has good depth. Soil contents of moisture, organic matter, organic carbon, N and P are very low. Although this soil suffers from an insufficiency of the above elements, it is also affected by salinity problems, as well as increasing of pH values.

On the vertical level and through the catenas, the slope and vegetation factors have played the most distinct role in formulation of soil properties. This role has varied from one site to another and also from one attribute to another (see Chapter Six). Soil properties were examined in relation to the main slope segments (toe-slope, foot-slope, mid-slope, shoulder-slope and summit-slope) from toe to ridge, and the following results can be reported.

a) Although soil depth does not exceed 50 cm, two distinct thicknesses can be noted; namely, somewhat deeper soil in toe-slopes (44 cm) and foot-slopes (39 cm) and shallow or thin soil in mid-slopes (28 cm), shoulder-slopes (25 cm) and top-slopes (21 cm). These differences in soil depth between slope units, show above, have resulted due to removal factors (erosion and mass wasting) exceeding deepening and upbuilding factors (interior and surface additions of minerals and organic matter) in mid-slopes, shoulder-slopes and top-slopes.

b) Due to the augmentation of fine fractions (silt and clay), washing of potassium from the upper slopes toward the lower slopes and the high rates of leaching with the reasonable permeability of the soil, particularly after rainfall, in the upper slope units, The soil moisture, potassium (K) and electrical conductivity (EC) increase down-slope (on the toe-slopes and foot-slopes) and decrease in the middle and upper slopes.

c) Little difference can be observed in soil texture classes, organic carbon (OC) and phosphorus content (P) along the slope segments. These results can be attributed mainly to the short distances between slope segments and to increased vegetation density in the upper parts of slopes that reduces migration of fine materials toward the lower parts of slopes and weakness of variation in organic matter and soil texture along the slope segments.

d) Due to the increase of vegetation density, boulders, rocks and washing processes in the upper slope segments, soil organic matter, $CaCO_3$ content and pH values decrease going along the slope units from the top to the bottom.

These characteristics form the background to the more detailed examination of soil properties, and their relationships with components of slope and vegetation, which follows.

CHAPTER *SIX*

Relationship Between Soil Properties and the Components of Slope and Vegetation

Chapter Six
Relationship Between Soil Properties and the Components of Slope and Vegetation

6-1 Introduction.

Since the introduction of the soil catena concept by Milne (1935 a), many studies have examined the relationship between topography and soil properties. Most of these studies and investigations have confirmed this concept (see Chapter Two). However, soil property variations also remain subject to major differences in environmental factors from one region to another. For instance, both slope and vegetation components have played an important role in the formulation of the soil characteristics of the research area. For this reason and after an examination of the current status of the environmental conditions including slope aspect (Chapter One), vegetation and grazing (Chapter Four) and soil (Chapter Five) in the area under study, the major focus of this chapter is to examine and analyse in detail for the first time in this region the relationships between soil properties and the components of slope and vegetation. It also provides an estimation of the contribution of slope and vegetation components to the diversity of soil properties in the research area, and offers some interpretation as to the causes of variation.

Despite the importance of the association, whether direct or indirect, between soil properties and those environmental factors which play a principal role in the formation and development of soil as well as in its degradation and deterioration, very few studies have considered this aspect in Saudi Arabia in general and in the research area in particular. In particular, so far no study has been conducted on the association between soil properties and the components of slope and vegetation in the research area. Therefore, this section concentrates mainly on these issues. Since all the variables were normally distributed, Pearson correlation coefficients were calculated to clarify these associations.

6-2 The Relationship Between Soil and Slope.

The variety of soil properties would normally be expected to increase with increases in slope steepness and slope length and also with the change of slope form, as a result of corresponding increases in the velocity and volume of surface runoff (Youssef, 1987). The variables can be categorized into two groups: the soil variables (soil depth, soil moisture, texture which includes sand, silt and clay, organic matter, organic carbon, $CaCO_3$, N, P, K, soil pH, and EC) and the slope variables (slope angle, gradient ratio, slope length and slope form). The relationships between these variables are interpreted under the following four headings: soil properties and slope angle, slope gradient, slope length, and slope form.

6-2-1 Soil Properties and Slope Angle.

The degree of slope has long been considered one of the major factors governing soil type (e.g. Jenny, 1941; Yiar, 1990; Youssef, 1987 and Gerrard, 1992). Few attempts, however, have been made to establish even the most simple mathematical relationships between the degree of slope of land and the diversity of soil properties. Unfortunately, so far there is no detailed information concerning the variable development of soil properties on valley-side slopes in Saudi Arabia.

The results presented here for the Upper Wadi Bishah basin confirm the existence for the first time of relationships between soil properties and slope angle in Saudi Arabia. A correlation matrix of the measured variables (Table 6-1) shows that slope angle is significantly ($p < 0.05$) correlated to soil depth, moisture, texture (sand and silt), organic matter, organic carbon, nitrogen, potassium, soil pH and electrical conductivity. The relationship between slope angle and soil depth, sand, potassium, soil pH and electrical conductivity is negative, while the relationship with moisture, silt, organic matter, organic carbon and nitrogen is positive (Fig. 6-1). Due to the lack of interaction between slope angle and $CaCO_3$ and phosphorus as well as the concentration of clay in the subsurface horizon (Al-Arifi, 1992), no statistically significant relationships ($p > 0.05$) have been found between these variables and slope angle. The strong negative relationship between slope angle and soil depth (R = - 0.62) is considered a clear indicator of the activity of erosion processes, in which the upper parts of slopes represented zones where erosion was dominant over deposition and the lower parts of slopes represented zones where deposition was dominant over erosion (Al-Welaie, 1996; Hajar, 1993). The simple positive relationship between slope angle and soil moisture refers mainly to the increase of rainfall and vegetation density which prevail in the upper parts of slopes. Due to washing processes from the upper parts of slopes to the lower parts, and the reduction of organic matter in the lower slopes resulting from the relative weakness of vegetation cover value and rainfall there, as well as an increase of evaporation processes, the relationships between slope angle and potassium (R= - 0.24), slope angle and soil pH (R= - 0.21) and slope angle and electrical conductivity (R= - 0.12) were negative.

Table 6-1 Calculation of the Pearson's Correlation Coefficient for the Relationships Between Soil Properties and Slope Components.

Slope components	Soil Properties												
	soil depth	mois-ture	sand	silt	clay	OM	OC	Ca-CO_3	N	P	K	pH	EC
slope angle	- 0.62 **	0.20 **	- 0.18 **	0.21 **	0.02 *	0.34 **	0.34 **	- 0.05 *	0.31 **	0.06 *	- 0.24 **	- 0.21 **	- 0.12 **
slope gradient	- 0.58 **	0.18 **	- 0.16 **	0.18 **	0.04 *	0.31 **	0.31 **	- 0.06 *	0.28 **	0.06 *	- 0.24 **	- 0.18 **	- 0.12 **
slope length	0.59 **	0.03 *	- 0.04 *	0.03 *	0.04 *	- 0.12 **	- 0.12 **	- 0.03 *	- 0.14 **	0.05 *	0.12 **	0.00 *	0.08 *
slope form	0.05 *	0.04 *	- 0.10 *	0.11 *	0.02 *	0.00 *	0.00 *	0.02 *	0.05 *	0.02 *	- 0.04 *	- 0.08 *	0.04 *

** Correlations are Significant at 0.05 level (Two-tailed test).

* Correlations are not Significant at 0.05 level (Two-tailed test).

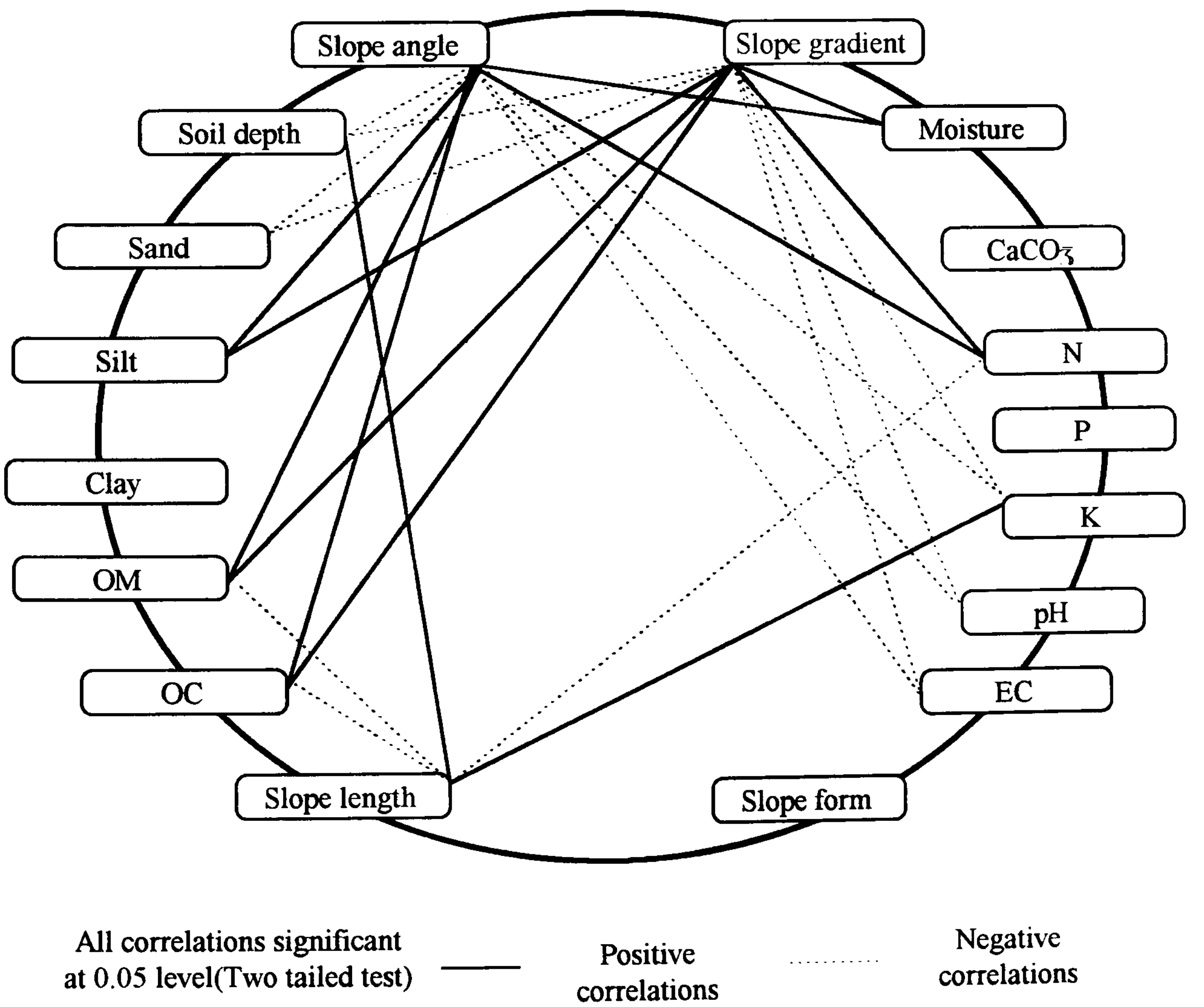

Figure 6-1 Diagram of the Relationships between Slope and Soil Variables.

6-2-2 Soil Properties and Slope Gradient.

Several studies, such as Acton (1964), Agbenin & Tiessen (1995) and Kinnell & Cummings (1993) have stressed the role of slope gradient in soil type, and confirm that the influence of slope increases with an increase of slope gradient and decreases with a decrease of slope gradient. Despite the difference in measuring methods (refer to 3.6), the correlations between slope gradient and soil properties are similar in direction to those between slope angle and soil properties (Table 6-1 and Fig. 6-1): the only distinction between them is that the relationships between slope angle and soil properties tend to be stronger than the relationships between slope gradient and soil properties. However, this finding can be attributed to the fact that both slope angle and soil sample were measured and collected from particular sites, while slope gradient is taken to be the percentage of slope between this site and the top of slope. Increase of vegetation density, vegetation cover value and variety of slope forms in the upper parts of slopes might be the causes of the inverse relationship between sand proportion and slope gradient ($R = -0.16$).

6-2-3 Soil Properties and Slope Length.

The relationship between slope length and soil type has been examined in several studies. Zingg (1940), Young & Mucher (1969), Furley (1971) and Anderson & Furley (1975) all examined this relationship and emphasized the importance of slope length in the variation of soil properties, but Agassi & Ben-Hur (1991) and Gard & Van-Doren (1949) were less inclined to see slope length as an important contributor in the diversity of soil properties.

The results presented here for the relationship between slope length and soil properties (Table 6-1) show that the slope length is significantly ($p < 0.05$) correlated to soil depth, organic matter, organic carbon, nitrogen and potassium, whereas there are no significant relationships ($p > 0.05$) between slope length and soil moisture, texture (sand, silt and clay), $CaCO_3$, P, soil pH and EC. Decrease of slope degree led to an increase of slope length and later to an increase of deposition and soil depth. For this reason, a close positive relationship was found between slope length and soil depth ($R = 0.59$). Significant negative correlations exist between slope length and amounts of organic matter, organic carbon and nitrogen (Fig. 6-1): an increase of washing processes, as well as exposure to more solar-radiation as slope length increases, may explain this. The lack of correlation between other soil properties and slope length is consistent with the results presented by Agassi & Ben-Hur (1991) and Gard & Van-Doren (1949).

6-2-4 Soil Properties and Slope Form.

Many studies, such as Yair (1990), have indicated that slope form is an important factor in determining soil variation. The relationships between soil properties and slope form presented here, however, are extremely weak. As can be seen from Table 6-1, there are no statistically significant relationships between soil properties and slope form. The lack of relationships between slope form and soil properties suggests that the individual slopes are not acting as integrated systems. A similar finding was reported by Gerrard (1982 and 1988) in the drainage basin of the River Cowsic, Central Dartmoor, England.

6-3 The Relationship Between Soil and Vegetation.

As well as its role in shaping soil properties, vegetation acts as a protective layer or buffer between the atmosphere and the soil. The above-ground components, such as leaves and stems, absorb some of the energy of falling raindrops, running water and wind, so that less is directed at the soil, whilst the below-ground components, comprising the root system, contribute to the mechanical strength of the soil (Morgan, 1995). The variables can be grouped into two broad classes: the soil variables (soil depth, soil moisture, texture which includes sand, silt and clay, organic matter, organic carbon, $CaCO_3$, N, P, K, soil pH, and EC) and the vegetation variables (vegetation cover value and vegetation density). The correlations between soil and vegetation variables tend to be stronger than the correlations between soil variables and those variables appertaining to the slope. This result, inter alia, is discussed under the following two headings: soil properties and vegetation cover; and soil properties and vegetation density.

6-3-1 Soil Properties and Vegetation Cover value.

Although several researches and studies, such as El-Naggar (1982) and El-Demerdash et al. (1995), have examined the development of soil phases under different plant cover conditions in the south-western region of Saudi Arabia, no researcher has yet examined the relationship between soil properties and changes in the extent of vegetation cover. This work is the first to address these issues. The result of correlation analysis (Table 6-2) reveals that all studied soil properties except electrical conductivity show significant correlations ($p < 0.05$) with vegetation cover values. The degree of correlation varies from high (R= 0.69), to only slight (R= - 0.05). The soil depth, sand proportion, $CaCO_3$, K and soil pH values decrease as the vegetation cover value increases (R values between vegetation cover value and these properties are - 0.12, - 0.42, - 0.35, - 0.12, - 0.55 respectively), whereas the moisture, silt, clay, organic matter, organic carbon, N and P values increase as the vegetation cover value increases (R values between vegetation cover value and these properties are 0.52, 0.42, 0.23, 0.69, 0.69, 0.63, 0.25 respectively) (Fig. 6-2).

Because the vegetation cover is the main source of organic matter in soil, particularly from humus, and due to the positive association between organic matter and nitrogen, strong positive relationships were found between vegetation cover values and organic matter (R = 0.69), organic carbon (R = 0.69) and nitrogen (R = 0.63). As a result of the vegetation cover acting to reduce soil erosion, wind velocity and evaporation amount, a moderate positive relationship was found between vegetation cover value and soil moisture. Due to the role of vegetation cover in the fixation of fine soil particles, the silt and clay proportion increases as the vegetation cover increases, whereas the sand percentage decreases with an increase in the vegetation cover value. Although most of the research area appears to be alkaline (pH value is more than 7) the deceleration in the disintegration processes of plant residue has resulted in the existence of a negative correlation between vegetation cover value and soil pH.

Table 6-2 Calculation of the Pearson's Correlation Coefficient for the Relationships Between Soil Properties and Vegetation Components

Slope comp-onents	Soil Properties												
	soil depth	mois-ture	sand	silt	clay	OM	OC	Ca-CO_3	N	P	K	pH	EC
vegetati-on cover value	- 0.12 **	0.52 **	- 0.42 **	0.42 **	0.23 **	0.69 **	0.69 **	- 0.35 **	0.63 **	0.25 **	- 0.12 **	- 0.55 **	- 0.05 *
vegetat-ion density	- 0.20 **	0.31 **	- 0.20 **	0.20 **	0.09 *	0.57 **	0.57 **	- 0.15 **	0.49 **	0.16 **	- 0.13 **	- 0.35 **	- 0.04 *

** Correlations are Significant at 0.05 level (Two-tailed test).

* Correlations are not Significant at 0.05 level (Two-tailed test).

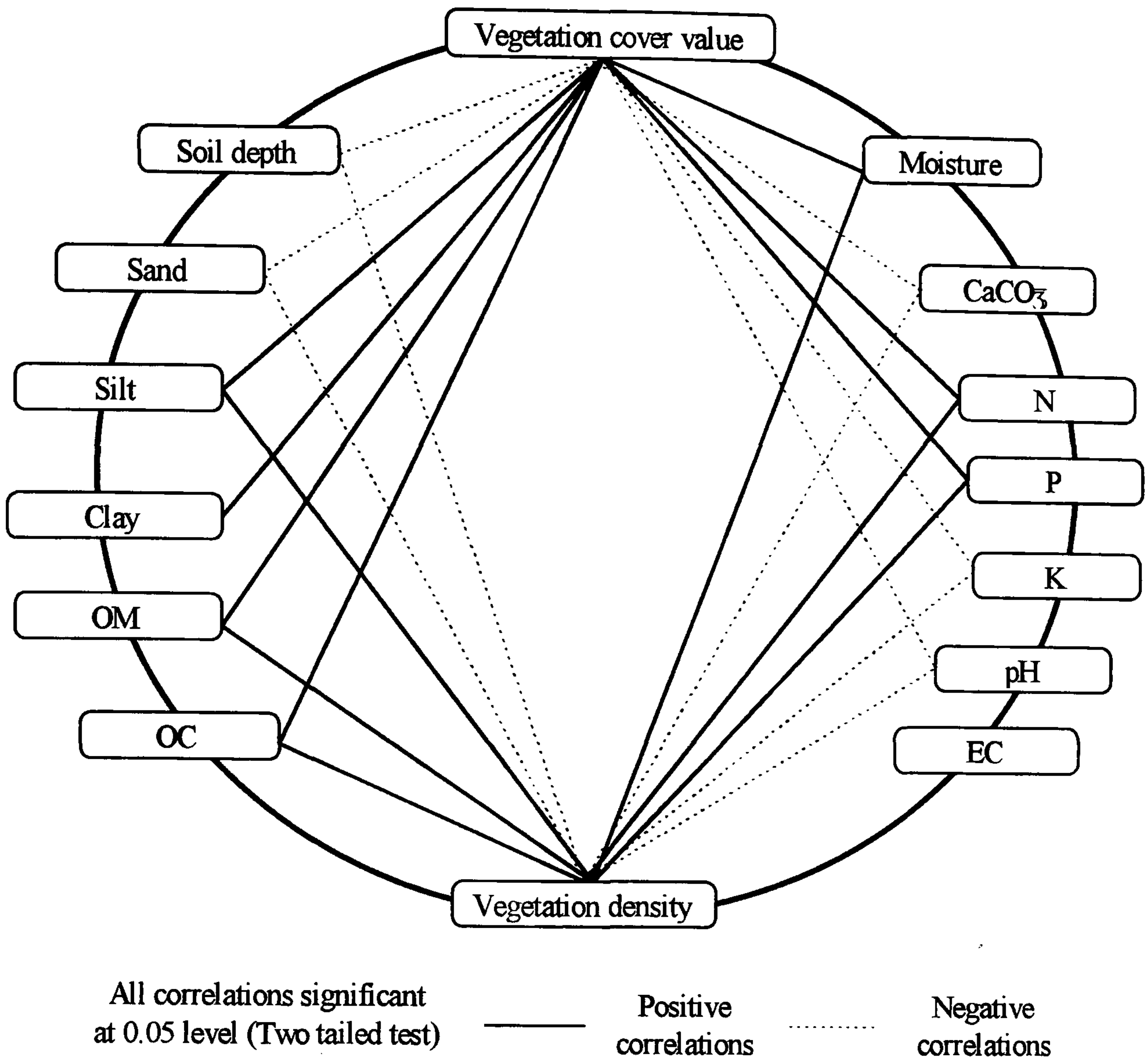

Figure 6-2 Diagram of the Relationships between Vegetation and Soil Variables.

6-3-2 Soil Properties and Vegetation Density.

Once again, interesting relationships occur between vegetation and soil properties, where the vegetation density is significantly ($p < 0.05$) correlated with all the measured soil properties, except clay proportion and electrical conductivity. As can be seen from Table 6-2, variations in soil moisture, silt content, organic matter, organic carbon, N and P are positively related to variations in vegetation density. This might suggest that greater variation in vegetation density diversity encourages variation in the above soil properties. The other properties, such as soil depth, sand percentage, $CaCO_3$, K and soil pH are negatively correlated with vegetation density (Fig. 6-2). As mentioned earlier, these findings indicate that soil-plant relationships appear to be more important than the relationships between soil and slope.

Although the association between soil properties and the components of slope and vegetation varies considerably from strong to moderate and slight, it is very important here to clarify that the association does not indicate the causality between variables. In other words, the correlation is not a condition for causality, though causality might be a condition for association (Abu-Ayyash, 1984). According to this conception, the following section discusses the contribution of slope and vegetation components in the possible explanation of variation in soil properties.

6-4 Contribution of Slope and Vegetation to Variation of Soil Properties.

This section reports the results of the regression analyses which explored the contribution of each set of slope and vegetation variables to each soil characteristic.

In the last section, a correlation matrix was used to investigate the relationships between slope and vegetation components and soil properties, but because such associations do not mean causality between variables, the researcher undertook sets of regression analyses as an appropriate statistical technique to evaluate the contribution of each independent variable (predictor variable) to the variance of a dependent variable. In these analyses, the stepwise multiple regression model was used. This method was identified by Youngman (1979) as the best predictor method in which more predictor variables than are considered relevant are included, so that only the significant predictors are identified, much as principal components analysis extracts factors of decreasing importance. Stepwise regression picks the most important independent variables contributing to the variation of a dependent variable. More recently, the stepwise technique also has been recommended by Norusis (1993: 350) who stated:

"Regression analysis (stepwise) selection of independent variables is probably the most common technique used in testing regression. It is really a combination of backward and forward selection. If the variable fails to meet entry requirements, the procedure terminates with no independent variables in the equation. If it passes the criteria, the second variable is selected based on the highest partial correlation. If it passes the entry criteria, it also enters the equation".

The variables can be grouped into two broad classes: the slope and vegetation components as independent variables and the soil characteristics as dependent variables. The results of the analysis are discussed in the following sub-sections.

6-4-1 Contribution of Slope and Vegetation Components to Variations of Soil Depth.

As well as its importance as one of the morphological characteristics of soil, soil depth or thickness of soil is considered to be one of the major indications of soil development. Various factors of slope and vegetation were examined in regression analyses in an attempt to assess their relative importance to the depth of soil. Slope angle, slope gradient, slope length, slope form, vegetation cover value and vegetation density were included in the multiple regression-stepwise equation as independent variables, with soil depth as the dependent variable. The results presented in Table 6-3 show that only slope angle and slope length variables entered the regression equation and were significant at the 95 percent confidence level. Slope angle entered first as the primary predictor, accounting for more than 38 percent of the variability in soil depth. Slope length entered second and accounted for another 13 percent of the variability. None of the other slope and vegetation variables was able to meet the entry level criterion; in other words, they do not contribute significantly to soil depth variability. Beta values of slope angle (- 0.616859) and slope length (0.400117) as well as values and probabilities of F and T also demonstrate these results. From these results it can be estimated that about 51 percent of variation in soil depth is a function of slope angle and slope length. Based on the results shown in Table 6-3, it can be suggested that an increase of slope angle led to a similar increase of erosion and then a decrease of accumulation because of the increasing downslope component of gravity. The increase of slope length led to a decrease of gravity and strength of surface runoff velocity and subsequently to an increase of deposition and then soil depth, a feature previously noted by Lal (1990).

Table 6-3 Analysis of the Multiple Regression (Stepwise Model) Showing Contribution of Vegetation and Slope Components to Explanation of **Soil Depth** Variation.

Items							
st-ep	**variables**	**multiple R**	**R square**	**Rsq. change**	**Beta**	**F**	**T**
1	**Slope angle**	0.61686	0.38051	0.38051	- 0.616859	183.04456 P < 0.01	- 13.529 P < 0.01
2	**Slope length**	0.71692	0.51397	0.13346	0.400117	157.03660 P < 0.01	9.031 P < 0.01
Total of variance				**51%**			

* Level of Significance = 0.05.

6-4-2 Contribution of Slope and Vegetation Components to Variation of Soil Moisture.

Regression analysis was also used to examine the possible contribution of slope and vegetation components (slope angle, slope gradient, slope length, slope form, vegetation cover value and vegetation density) as independent variables to soil moisture as a dependent variable. As shown in Tables 6-1 and 6-2, significant relationships were found between soil moisture and slope angle (R = 0.20), slope gradient (R = 0.18), vegetation cover value (R = 0.52) and vegetation density (R = 0.31). However, and as can be seen from Table 6-4, only vegetation cover value passed the criterion of entry into the multiple regression-stepwise equation. It accounted for more than 27 percent (R^2 = 0.27156) of variability in the data on soil moisture. The beta value (0.521112) also confirmed the relative importance of vegetation cover value as a predictor of soil moisture variation. Values and probabilities of F (111.09294 and P < 0.01 respectively) and T (10.540 and P < 0.01 respectively) demonstrated these results, which can be used to estimate about 27% of soil moisture variance as a function of vegetation cover value. This result can be attributed to the increasing of vegetation cover value leading to a reduction in the penetration of solar radiation to the surface land, and thus a decrease of the evaporation process (Migahid et al, 1987). Furthermore, an increase of vegetation cover value can lead to an increase of organic matter and fine soil particles which would help to increase the soil's ability to retain water. None of the other slope and vegetation variables was able to meet the entry requirements for the regression equation; in other words, they did not contribute to the variation of soil moisture.

Table 6-4 Analysis of the Multiple Regression (Stepwise Model) Showing Contribution of Vegetation and Slope Components to Explanation of **Soil Moisture** Variation.

Items							
st-ep	**variables**	**multiple R**	**R square**	**Rsq. change**	**Beta**	**F**	**T**
1	**vegetation cover value**	0.52111	0.27156	0.27156	0.521113	111.09294 P < 0.01	10.540 P < 0.01
Total of variance				**27%**			

* Level of Significance = 0.05.

6-4-3 Contribution of Slope and Vegetation Components to Variation of Soil Texture.

Several studies, such as Derose et al. (1993), Simanton et al. (1994) and Lal (1990), have suggested that most variation in soil texture is attributable first to the slope factors where erosion is activated and secondly to the level of vegetation cover and other environmental factors. In the present study, and as shown in Tables 6-1 and 6-2, several significant relationships were found between components of slope and vegetation and soil texture (sand, silt and clay). However, only one of these components (vegetation cover value) was found to make a significant contribution towards soil texture variation. Vegetation cover value passed the entry requirements to the multiple regression-stepwise equation and accounted for about 14 percent ($R^2 = 0.13657$) of the variation in the soil texture data (Table 6-5). The beta coefficient value (- 0.369548) demonstrated the relative importance of the vegetation cover value as a predictor of soil texture variance. Values and probabilities of F (47.13338 and $P < 0.01$ respectively) and T (- 6.865 and $P < 0.01$ respectively) confirmed the above results. They are consistent with what has been suggested earlier, and has been proposed by Youssef (1987), that an increase of vegetation cover value leads to an increase in silt and clay and a decrease in the proportion of sand in soil. None of the other independent variables tested (slope angle, slope gradient, slope length, slope form and vegetation density) was able to meet the entry requirements and account for the variation in soil texture; in other words, they did not contribute significantly to the variation of soil texture.

Table 6-5 Analysis of the Multiple Regression (Stepwise Model) Showing Contribution of Vegetation and Slope Components to Explanation of **Texture** Variation.

Items							
st-ep	**variables**	**multiple R**	**R square**	**Rsq. change**	**Beta**	**F**	**T**
1	**Vegetation cover value**	0.36955	0.13657	0.13657	- 0.369548	47.13338 P < 0.01	- 6.865 P < 0.01
Total of variance				**14%**			

* Level of Significance = 0.05.

6-4-4 Contribution of Slope and Vegetation Components to Variation of Organic Matter.

As mentioned in Chapter Five (5.5.1.4), the main source of organic matter in the research area is the dead roots, stems, seeds and leaves of vegetation cover. Thus, it is not surprising to find a high contribution of vegetation variables to variation of organic matter. As for the positive contribution of slope angle in the variability of organic matter, this can be related to the decrease of temperature and increase of rainfall and vegetation density on the upper slope areas in the research area, where the slope angle is normally higher than elsewhere. Slope and vegetation components (slope angle, slope gradient, slope length, slope form, vegetation cover value and vegetation density) were examined in the multiple regression analysis in an attempt to assess their relative importance as independent variables to organic matter as the dependent variable. Three variables entered the multiple regression equation (stepwise model), namely: vegetation cover value, vegetation density and slope angle, and were significant at the 95 percent confidence level. Vegetation cover value entered first as the primary predictor, and accounted for more than 47 percent ($R^2 = 0.47394$) of the variation in the data relating to organic matter. Vegetation density entered second, accounting for about 7 percent ($R^2 = 0.06891$) of the variation. Finally, slope angle accounted for another 1.6 percent ($R^2 = 0.01607$) of the variation. Also, the beta weight of vegetation cover value (0.688432), vegetation density (0.300922) and slope angle (0.133445) further demonstrated the relative importance of these variables as predictors of organic matter variation. As can be seen from Table 6-6, the values and probabilities of F and T confirmed the results mentioned above which can be used to explain 56% of the organic matter variance as a function of vegetation cover value, vegetation density and slope angle variables. None of the other independent variables was able to meet the requirements for entry into the regression equation, indicating that they did not contribute to the variation of organic matter data.

Table 6-6 Analysis of the Multiple Regression (Stepwise Model) Showing Contribution of Vegetation and Slope Components to Explanation of **Organic matter** Variation.

Items							
st-ep	**variables**	**multiple R**	**R square**	**Rsq. change**	**Beta**	**F**	**T**
1	**Vegetation cover value**	0.68843	0.47394	0.47394	0.688432	268.47425 P<0.01	16.385 P<0.01
2	**Vegetation density**	0.73679	0.54285	0.06891	0.300922	176.34147 P<0.01	6.691 P<0.01
3	**Slope angle**	0.74761	0.55892	0.01607	0.133445	125.02503 P<0.01	3.283 P<0.01
Total of variance				**56%**			

* Level of Significance = 0.05.

6-4-5 Contribution of Slope and Vegetation Components to Variations in Organic Carbon.

Six independent variables (slope angle, slope gradient, slope length, slope form, vegetation cover value and vegetation density) were examined by multiple regression (stepwise model) to estimate their contribution in explaining the variation of soil organic carbon as a dependent variable. Table 6-7 gives the results of the multiple regression analyses. As can be seen from this Table, three variables passed the criterion and entered the regression equation, namely: vegetation cover value, vegetation density and slope gradient (or gradient ratio) and were significant at the 95 percent confidence level. Vegetation cover value entered in the first step as the most important predictor and accounted for about 47 percent (R^2 = 0.46987) of the variation in organic carbon data. Vegetation density entered in the second step and accounted for 7 percent (R^2 = 0.07018) of the variation. Gradient ratio entered in the third step and accounted only for another 1.5 percent (R^2 = 0.01582) of the variability. Beta weights of these variables were computed to be 0.685473, 0.303658 and 0.130710 respectively, further indicating the relative importance of these independent variables. The values and probabilities of F and T (Table 6-7) confirmed the above results which can be used to explain about 56% of variations in organic carbon as a function of the three variables mentioned above. None of the other independent variables (slope angle, slope length and slope form) satisfied the criteria for entry to the regression equation and contribute in explaining the variation in levels of organic carbon.

Table 6-7 Analysis of the Multiple Regression (Stepwise Model) Showing Contribution of Vegetation and Slope Components to Explanation of **Organic Carbon** Variation.

Items							
st-ep	**variables**	**multiple R**	**R square**	**Rsq. change**	**Beta**	**F**	**T**
1	**Vegetation cover value**	0.68547	0.46987	0.46987	0.685473	264.13021 $P < 0.01$	16.252 $P < 0.01$
2	**Vegetation density**	0.73488	0.54005	0.07018	0.303658	174.35929 $P < 0.01$	6.731 $P < 0.01$
3	**Gradient ratio**	0.74557	0.55587	0.01582	0.130710	123.49084 $P < 0.01$	3.247 $P < 0.05$
Total of variance				**56%**			

* Level of Significance = 0.05.

6-4-6 Contribution of Slope and Vegetation Components to Variation of $CaCO_3$.

It appears that the contribution of slope and vegetation variables in explaining variation in $CaCO_3$ is very slight. Although six independent variables (slope angle, slope gradient, slope length, slope form, vegetation cover value and vegetation density) were entered in a stepwise equation with $CaCO_3$ as the dependent variable, only one of the independent variables (vegetation cover value) passed the entry criteria and was significant at the 95 percent confidence level. This variable entered into the equation as the only important predictor and accounted for 12 percent (R^2 = 0.11904) of the variation in $CaCO_3$ data (Table 6-8). Also, the beta weight of vegetation cover value was computed to be - 0.345029 and demonstrated the relative importance of this variable as a predictor of $CaCO_3$ variation. The values and probabilities of F (40.26916 and P < 0.01 respectively) and T (- 6.346 and P < 0.01 respectively) confirmed these results (which might explain about 12% of $CaCO_3$ variance as a role of vegetation cover value). None of the other independent variables was able to meet the entry requirements of the regression equation, indicating that they did not contribute significantly in explaining $CaCO_3$ variation.

Table 6-8 Analysis of the Multiple Regression (Stepwise Model) Showing Contribution of Vegetation and Slope Components to Explanation of **Total Calcium Carbonate** ($CaCO_3$) Variation.

Items							
st-ep	**variables**	**multiple R**	**R square**	**Rsq. change**	**Beta**	**F**	**T**
1	**Vegetation cover value**	0.34503	0.11904	0.11904	- 0.345029	40.26916 P < 0.01	- 6.346 P < 0.01
Total of variance				**12%**			

* Level of Significance = 0.05.

6-4-7 Contribution of Slope and Vegetation Components to Variation of Nitrogen.

In an attempt to assess their relative importance to total nitrogen, the slope and vegetation components (slope angle, slope gradient, slope length, slope form, vegetation cover value and vegetation density) were entered in a multiple regression equation (stepwise model) as independent variables with total nitrogen as the dependent variable. The results illustrated in Table 6-9 indicated that three independent variables entered into the equation, namely vegetation cover value, vegetation density and slope length. Vegetation cover value entered first as the primary predictor, accounting for 39 percent ($R^2 = 0.39194$) of the variation in nitrogen data. Vegetation density entered in the second step and accounted for another 4 percent ($R^2 = 0.04481$) of the variation. Slope length passed the criterion but accounted for less than 2 percent ($R^2 = 0.01752$) of the variation. The importance of these three variables as predictors of nitrogen variation was demonstrated via beta weights (0.626048, 0.242670 and - 0.133646 respectively). The values and probabilities of F and T (Table 6-9) indicate that these three variables were significant at the 95 percent confidence level. As a result of this analysis, it is possible to relate 45% of the nitrogen variance to the function of vegetation cover value, vegetation density and slope length. None of the other independent variables was able to meet the requirements for entry into the regression equation and contribute in explaining the variation in nitrogen data.

Table 6-9 Analysis of the Multiple Regression (Stepwise Model) Showing Contribution of Vegetation and Slope Components to Explanation of **Total Nitrogen** Variation.

Items							
st-ep	**variables**	**multiple R**	**R square**	**Rsq. change**	**Beta**	**F**	**T**
1	**Vegetation cover value**	0.62605	0.39194	0.39194	0.626048	192.08029 P < 0.01	13.859 P < 0.01
2	**Vegetation density**	0.66087	0.43675	0.04481	0.242670	115.14976 P < 0.01	4.861 P < 0.01
3	**Slope length**	0.67399	0.45427	0.01752	- 0.133646	82.12951 P < 0.01	- 3.082 P < 0.05
Total of variance				**45%**			

* Level of Significance = 0.05.

6-4-8 Contribution of Slope and Vegetation Components to Variation of Phosphorus.

As can be seen from Table 6-9, regression analysis also was used to assess the possible contribution of slope and vegetation components as independent variables in explaining phosphorus variation as the dependent variable. Although six independent variables (slope angle, slope gradient, slope length, slope form, vegetation cover value and vegetation density) were included in the analysis, however, only vegetation cover value met the criterion for entry into the multiple regression equation (stepwise model) and was significant at the 95 percent confidence level. This variable accounted for only about 6 percent (R^2 = 0.06382) of the variation in the phosphorus data. The relative importance of vegetation cover value was confirmed by beta weight, which was computed to be 0.252624. The values and probabilities of F (20.31447 and $P < 0.01$ respectively) and T (4.507 and $P < 0.01$ respectively) demonstrated the significance of the above results.

Table 6-10 Analysis of the Multiple Regression (Stepwise Model) Showing Contribution of Vegetation and Slope Components to Explanation of **Phosphorus** Variation.

Items							
st-ep	**variables**	**multiple R**	**R square**	**Rsq. change**	**Beta**	**F**	**T**
1	**Vegetation cover value**	0.25262	0.06382	0.06382	0.252624	20.31447 P < 0.01	4.507 P < 0.01
Total of variance				**6.4%**			

* Level of Significance = 0.05.

6-4-9 Contribution of Slope and Vegetation Components to Variation of Potassium.

As can be seen from Table 6-11, only one of the studied independent variables has contributed to an explanation of potassium variation as dependent variable. This independent variable is slope angle, which met the requirements of entry into the multiple regression equation (stepwise model) and accounted for about 6 percent (R^2 = 0.05823) of the variation in potassium data. Beta weight (- 0.241309) demonstrated the relative importance of slope angle in explaining the variation of potassium values. The values and probabilities of F (18.42541 and $P < 0.01$ respectively) and T (- 4.292 and $P < 0.01$ respectively) emphasized the significance of these results at the 95 percent confidence level. The inverse significant relationship between slope angle and potassium can be related to washing of potassium from the upper slope, where the slope angle is greater, toward the lower slope, where the slope angle is smaller. Due to the lack of interaction between potassium and the other independent variables (slope gradient, slope length, slope form, vegetation cover value and vegetation density) none of these independent variables satisfied entry requirements for the multiple regression equation and was able to contribute in explaining variation in potassium data, at least from the statistical standpoint.

Table 6-11 Analysis of the Multiple Regression (Stepwise Model) Showing Contribution of Vegetation and Slope Components to Explanation of **Potassium** Variation.

Items							
st-ep	**variables**	**multiple R**	**R square**	**Rsq. change**	**Beta**	**F**	**T**
1	**Slope angle**	0.24131	0.05823	0.05823	- 0.241309	18.42541 P < 0.01	- 4.292 P < 0.01
Total of variance				**6%**			

* Level of Significance = 0.05.

6-4-10 Contribution of Slope and Vegetation Components to Variation of Soil pH.

Regarding the relative importance of slope and vegetation components (slope angle, slope gradient, slope length, slope form, vegetation cover value and vegetation density) in relation to soil pH, in multiple regression analysis (stepwise model), Table 6-12 indicates that only vegetation cover value entered the multiple regression equation as a primary predictor of soil pH, accounting for more than 30 percent ($R^2 = 0.30774$) of the variation in values. Beta weight (- 0.170337) confirmed the relative importance of vegetation cover value in explaining the variation in soil pH values. Values and probabilities of F (132.47694 and $P < 0.01$ respectively) and T (- 11.510 and $P < 0.01$ respectively) emphasized the significance of these results which can be used to explain about 31% of soil pH variation as a function of vegetation cover value. Despite the significant relationships between soil pH and the other slope and vegetation variables, particularly vegetation density ($R = - 0.35$), slope angle ($R = - 0.21$) and slope gradient

(R = 0.18), none of them was able to make a further contribution in explaining variation of soil pH, at least from the statistical viewpoint.

Table 6-12 Analysis of the Multiple Regression (Stepwise Model) Showing Contribution of Vegetation and Slope Components to Explanation of **Soil pH** Variation.

Items							
st-ep	**variables**	**multiple R**	**R square**	**Rsq. change**	**Beta**	**F**	**T**
1	**Vegetation cover value**	0.55475	0.30774	0.30774	- 0.554747	132.47694 P < 0.01	- 11.510 P < 0.01
Total of variance				**31%**			

* Level of Significance = 0.05.

6-4-11 Contribution of Slope and Vegetation Components to Variation of Electrical Conductivity (EC).

As can be seen from Table 6-13, the influence of slope and vegetation components on electrical conductivity (EC) is very weak and restricted to a small contribution provided by slope angle. This contribution was revealed by using multiple regression analysis (stepwise model) to assess the relative importance of independent variables (slope angle, slope gradient, slope length, slope form, vegetation cover value and vegetation density) in accounting for the variation of EC data. Only slope angle passed the requirements for entry to the multiple regression equation and accounted for 1.4 percent ($R^2 = 0.01440$) of the variation in EC values. Also, beta weight (- 0.120005) emphasized the relative importance of slope angle as a contributor toward the variation of EC, at a 95 percent confidence level. Values and probabilities of F (4.35424 and $P < 0.05$ respectively) and T (- 2.087 and $P < 0.05$ respectively) confirmed the significance of these results, which can be used to explain 1.4% of the variation in EC as a function of slope angle.

Table 6-13 Analysis of the Multiple Regression (Stepwise Model) Showing Contribution of Vegetation and Slope Components to Explanation of **Electrical Conductivity** Variation.

Items							
st-ep	**variables**	**multiple R**	**R square**	**Rsq. change**	**Beta**	**F**	**T**
1	**Slope angle**	0.12000	0.01440	0.01440	- 0.120005	4.35424 P < 0.05	- 2.087 P < 0.05
Total of variance				**1.4%**			

* Level of Significance = 0.05.

6-5 Conclusions.

In this chapter, the relationships between soil characteristics (soil depth, moisture, texture, organic matter, organic carbon, $CaCO_3$, nitrogen, phosphorus, potassium, soil pH and electrical conductivity) and components of slope and vegetation (slope angle, slope gradient, slope length, slope form, vegetation cover value and vegetation density) were examined and explored, then the contribution of these components in explaining the variation of each soil property was estimated.

According to the Pearson correlation coefficient equation, slope angle and slope gradient have negative significant relationships with soil depth, sand content, potassium (K), soil pH and electrical conductivity (EC) and positive significant relationships with moisture, silt content, organic matter (OM), organic carbon (OC) and nitrogen (N). None of the other soil properties, namely, clay content, $CaCO_3$ and phosphorus (P) was significantly associated with slope angle and slope gradient. Slope length was found to be associated with OM, OC and N by inverse significant relationships and with soil depth and K by positive significant relationships. None of the soil characteristics showed significant relationships with slope form (or slope configuration).

Vegetation variables (vegetation cover value and vegetation density) were significantly correlated with almost all soil properties to varying degrees (somewhat strong, moderate and weak). Only EC and clay content were not significantly associated with vegetation density. These results indicate that the increase of vegetation cover led to increases in soil moisture, silt content, clay content, OM, OC, N and P, whereas a decrease in vegetation led to increases in sand content, $CaCO_3$, K and soil pH.

In terms of the contribution of slope and vegetation components in explaining the variation of soil properties, it appears that the vegetation cover value is the primary predictor of soil moisture, texture, OM, OC, $CaCO_3$, N, P and soil pH, whereas the slope angle is the primary predictor of soil depth, K and EC, and the third predictor of OM (Table 6-14 and Fig. 6-3). Vegetation density came as the second predictor of OM, OC and N. Slope length occupied the second and the third position in explaining the variation of soil depth and N respectively. Despite the significant correlations between slope gradient and most soil properties (Table 6-1), the strong relationship between slope gradient and slope angle ($R = 0.95$) might reduce the power of the multiple regression to predict accurately the contribution of slope gradient toward the variation in soil properties. As Youngman (1979: 116) indicated:

"if two predictors are highly correlated with each other, one will necessarily attract a low beta weight simply because its effect has already been included in the other".

Slope form did not make any significant contribution to an explanation of variation for any soil property.

Table 6-14 Summary of R^2 Values Resulted from Analysis of Multiple Regression (Stepwise model).

Soil properties	Slope and vegetation components						Total R^2
	slope angle	Slope gradient	Slope length	Slope form	Vegetation cover value	Vegetation density	
Soil depth	0.38	**	0.13	**	**	**	0.51
Moisture	**	**	**	**	0.27	**	0.27
Texture	**	**	**	**	0.14	**	0.14
OM	0.02	**	**	**	0.47	0.07	0.56
OC	**	0.02	**	**	0.47	0.07	0.56
$CaCO_3$	**	**	**	**	0.12	**	0.12
N	**	**	0.02	**	0.39	0.04	0.45
P	**	**	**	**	0.06	**	0.06
K	0.06	**	**	**	**	**	0.06
pH	**	**	**	**	0.31	**	0.31
EC	0.01	**	**	**	**	**	0.01

** Contributions (R^2) are not Significant at 0.05 level.

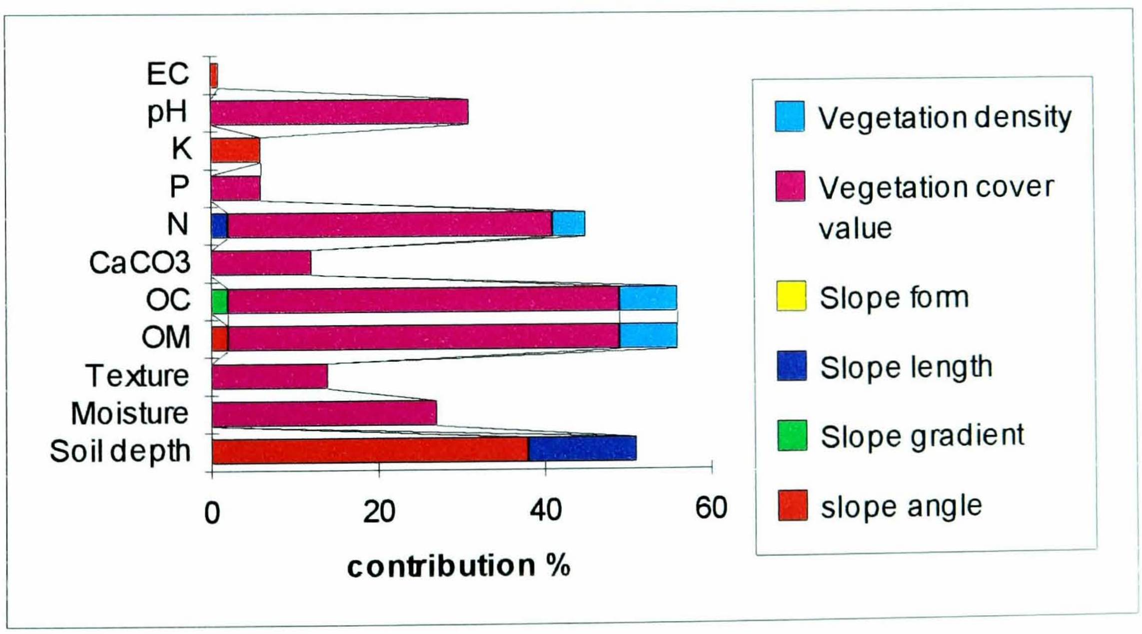

Figure 6-3 Contribution of Slope and Vegetation components in Explaining the Variation in Soil Properties.

(Source: Table 6-14)

CHAPTER SEVEN

Conclusions and Recommendations

Chapter Seven
Conclusions and Recommendations

The Upper Wadi Bishah basin is located in the Asir region (south-west of Saudi Arabia). The geological, topographical and climatic features of this region are completely different from those of the other regions in Saudi Arabia. It contains high mountains (reaching 3130 m a.s.l), escarpments, plateaus, deep valleys, rolling lands, rocky outcrops and waterfalls (Abulfatih, 1981). The climate of this region is affected by the prevailing south-westerly wind and the monsoon rains which fall mainly during spring and summer (see Table 1- 8 and Fig. 1- 10). It is distinguished by moderate temperatures throughout most months of the year. The annual mean rainfall and temperature over the catchment area of the Upper Wadi Bishah are 332.05 mm and 17.7 °C respectively.

Several difficulties faced the researcher during the execution of this research particularly during the fieldwork. Some of these appertained to transport and the nature of the topography of the research area. Other difficulties related to the style of dealing and customs of the people who live in this area. The main problems were the following. Some parts of the research area have very few or no roads and tracks even for four-wheel drive vehicles which might provide access to their interior sites. Therefore, in many cases, animals (camels and donkeys) were used to convey the research equipment to certain sites. It was very difficult to talk to most of the people who live in the research area, particularly those people who still practice the nomadic life, and believe in tribal rights in possession of the lands, and still more difficult to persuade them of the aims of this research. Indeed, shots were fired at the researcher twice during the fieldwork.

These people consider any work inside the area where they live as an attempt to rob them of their lands.

After the deterioration of soil, and depletion of ground-water in the regions of agricultural projects that have formerly been established in the heart of the Saudi desert, the Upper Wadi Bishah basin has become the first potential candidate for the establishment of new agricultural projects, since it is the only region in Saudi Arabia which has mean annual rainfall exceeding 300 mm. The mean annual rainfall reaches 529 mm in the Al-Sawdah station (see Table 1- 7).

This basin is characterized by the prevalence of sloping terrain which comprises most of its total area. At the same time, it is the richest region, in terms of vegetation species and vegetation cover, in Saudi Arabia. This basin has so far received little attention from botanists, ecologists and pedologists, and the execution of the proposed projects, without intensive and detailed studies of vegetation and soil, is unwise; it will mean removal and destruction of a huge part of the vegetation cover, and excoriation and exposure of soil on the slope, as well as affecting totally the local overall environmental system. Unfortunately, so far all these aspects have been largely neglected by the agricultural planners. This study represents the first contribution which will, it is hoped, redress the balance. It not only deals with the relationships between soil properties and the components of slope and vegetation, but is also concerned with the current condition of vegetation and soil, as well as of grazing, the latter being the main and possibly the only human factor currently influencing vegetation and soil in the research area. The main findings and conclusions of this research can be summarized in the following paragraphs.

7-1 A summary of the Academic Findings of the Thesis

Although all the findings mentioned earlier are very important, for more clarification, the following findings are highlighted as the most important.

The slopes of the research area have been classified into eight levels. 1.3% of these slopes are level (0-1 degrees), 13.4% are gently sloping (2-3 degrees), 24% are moderately sloping (4-7 degrees), 20.6% are strongly sloping (8-11 degrees), 13.4% are moderately steeply sloping (12-15 degrees), 21.3% are steeply sloping (16-25 degrees), 5% are very steeply sloping (26-35 degrees) and 1% are precipition (36+ degrees). However, a noticeable difference was found between the angles of slope in the south-west and north-east of the research area, the mean slope angle in these regions being 12.38 and 9.92 degrees respectively. The low average slope angle and gradient in down-slope segments (toe-slope and foot-slope) as well as the increase in slope length there are considered distinct indicators that the hill slopes of the Upper Wadi Bishah basin have suffered much from active erosion and slope retreat processes, particularly under a humid palaeoclimate. However, 84% of the measured slope forms were straight and convex, configurations which are much affected by surface erosion processes now, particularly in those areas where vegetation cover is sparse.

Floristic analysis of the flora of Wadi Bishah basin has revealed that floristic diversity is higher than elsewhere in Saudi Arabia. This study recorded 62 perennial species (89% of these species are trees and shrubs, while 11% are subshrubs or herbs) in this basin. These plant species belong to 49 genera and 28 families. The more common species are **Acacia arabica**, **Acacia gerradii**, **Acacia negrii**, **Lycium shawii**, **Dodonaea viscosa**, **Kleinia odora**, **Juniperus procera**, and **Euryops arabicus**, while **Acacia arabica** (IV = 61.68), **Juniperus procera** (IV = 60.54), **Acacia gerradii** (IV =

42.65), **Lycium shawii** (IV = 31.21) and **Acacia negrii** (IV = 27.56) are the most important species.

The composition and distribution of vegetation reflect the conditions of the environmental factors in the research area. The soil, topography and climate of the south-western part (or mountainous plant community) differ widely from those of the semi-desert plant community located in the north-eastern part. This is due to the high altitude (2000-3130 m a.s.l) of the former area with its consequences for air temperature, and to relatively high rainfall without a prolonged dry period, as in the semi-desert plant community. The vegetation density in the south-western part (3.01/100 m^2) is higher than that in the north-eastern part (2.46/100 m^2). Also, the vegetation density in the upper slope segments, namely summits and shoulders of slopes (4.41/100 m^2) is higher than that in the lower slope segments, namely toes and feet of slopes (2.87/100 m^2).

Arising from the data collected from Wadi Bishah basin, reconnaissance surveys and the classification and analysis of samples and species resulting from an application of TWINSPAN and DECORANA computer programs, a new perennial vegetation map of Wadi Bishah basin has been produced. The perennial vegetation cover of Wadi Bishah basin has been divided on this map into five distinct plant groups. These groups are as follows:-

The first group is dominated by **Acacia arabica**. This species and its associated minor species (e.g. **Acacia gerradii**, **Leptadenia pyrotechnica** and **Solanum incanum**) are spread over the north and north-east of Wadi Bishah basin, particularly between 1000-1500 m altitude. Species of this group have long roots that enable them to get water from the deeper layers of soil. The second group consists mainly of **Juniperus procera**, **Euryops arabicus**, and **Dodonaea viscosa**, which are widespread above 1500 m altitude, on the tops and eastern hillsides of the Asir and Al-Hijaz mountains. The third group appears in most of the head waters of the Wadi Bishah. The familiar species in this region are **Acacia gerradii** and **Dodonaea viscosa,** which are large in size and are concentrated mostly close to water courses. The fourth group of plants occupies the south-eastern part of Wadi Bishah and consists mainly of **Lycium shawii** and **Acacia negrii**. The fifth group consists of **Kleinia odora**, **Lycium barbarum**, **Lycium shawii**, **Psiadia arabica**, **Solanum incanum**, **Leptadenia pyrotechnica** and **Periploca aphylla**, and occupies the middle and east of Wadi Bishah basin. Species of this group have adapted their morphology and life-form with the local environmental condition, where most of these species are mixture of succulent plants and needle-bearing plants.

Investigations of the relationships between vegetation cover and environmental factors (slope angle, slope gradient, slope length, soil depth, soil moisture, texture, soil pH and organic matter) showed that the floristic composition and distribution of the main plant groups reflected the conditions of soil and topographical variety in the research area. The spiny plants (**Acacia arabica**, **Acacia gerradii,** **Acacia negrii,** **Lycium shawii** and **Rhamnus disperma**) were found to have significant positive relationships with deep soils, sandy soils and alkali soils. It can be related this result to adaptation of the morphological and physiological characteristics of the species with this kind of soils, particularly in the north-east of Wadi Bishah basin. Due to the main source of organic matter in the research area is dead roots, stems, seeds and leaves, and that most of **Juniperus procera**, **Euryops arabicus**, **Dodonaea viscosa**, **Leptadenia pyrotechnica** and **Psiadia arabica** species are characterised by large size and masses, a strong correlations were found between these species and an abundance of organic matter. **Sageretia thea**, **Tephrosia apollinia** and **Solanum schimperianum** were found to be strongly associated with slope angle, slope gradient and moisture. This can be attributed mainly to the small sizes of these species which can adapt with an increase of slope angle on the upper slopes, where the moisture is high (see 5-5-1-3).

The influence of over-grazing on vegetation and soil condition in Wadi Bishah basin appears to be clear, particularly in the plateau grazing zone. The comparison between vegetation and soil features in the mountainous grazing zone (south-west of the basin), where there are fewer livestock, and the plateau grazing zone (north-east of the basin), where there are more livestock, indicated that the condition of vegetation cover and soil in the plateau grazing zone is very degraded compared with their condition in the mountainous grazing zone.

The soils of Wadi Bishah basin were classified into two main types, namely loamy soils which were mostly encountered in the west and south-west of the basin and sandy soils which were mostly encountered in the north and north-east of the basin. Loamy soils comprise 31.7% of the total area and consist of sandy clay loam (1%), sandy loam/sandy clay (0.7%), loam (1%), sandy loam (24.3%) and loam sandy/sandy loam (4.7%). Sandy soils comprise 68.3% of the total area and consist of loamy sand (42%), sandy loam sand (3.3%) and sand (23%).

Overall, the soil of the research area is shallow, coarse and poor in most of the nutrient elements, particularly in the north-eastern part. However the nutrient elements in the soil of the south-western part were found to be greater than that in the north-eastern part, and its particles are finer.

All components of slope and vegetation possess significant correlation (positive and negative) with most of the studied soil properties, except slope form. The lack of relationships between slope form and soil properties suggests that the individual slopes are not acting as integrated systems. However, the relationships between soil properties and vegetation components tend to be stronger than those between soil properties and slope components. This result can be attributed to the important role of vegetation in shaping soil properties, as well as the vegetation cover acts as a protective layer or buffer between the atmosphere and the soil.

Finally, investigation of contribution of slope and vegetation components in explaining the variation of soil properties indicated that the vegetation cover value is the primary predictor of soil moisture, texture, OM, OC, $CaCO_3$, N, P and soil pH, whereas the slope angle is the primary predictor of soil depth, K and EC, and the third predictor of OM. Vegetation density came as the second predictor of OM, OC and N. It can be attributed these results to that, an augmentation of vegetation cover reduces evaporation and increases fine fractions and organic matter which has positive association with organic carbon and nitrogen. As well as an increase of slope angle reduces accumulation processes. Slope length occupied the second and the third position in explaining the variation of soil depth and N respectively.

This research has developed our knowledge of slope configurations and the conditions of vegetation, soil and grazing in the Upper Wadi Bishah basin, and represents the first basic step towards integrating some of the sciences to study a specific subject from several aspects in this area. The findings of this research are able to provide a scientific basis for exploitation and development of this basin, and will thus help in the selection of projects appropriate to the local environmental conditions. Indirectly, these findings will further lead to environmental and economic benefit in the study area concerned.

7-2 A consideration of the Limitations of the Thesis and Recommendations for Further Work

Wadi Bishah basin is the most important basin in Saudi Arabia, particularly in regard to its topographical, climatic and ecological features. However, its soil and vegetation features remain almost unknown in detail. Despite its importance, no professional has conducted research in this basin, especially as it relates to the soil and vegetation status. The lack of research in this basin and this field is related to the lack of available data and to environmental and technical difficulties. This study is the first of its kind, and aims to overcome these deficiencies.

Soil and vegetation cover constitute an important element in conservation and the protection of the natural environment and water resources, as well as being important for economic and social activities, such as agriculture, grazing and tourism. Here, it is necessary to claim that the study aspires to expose the current status of soil and vegetation, and their relationships with various environmental variables, which are the major points of this study. Findings of this study will contribute to a solution of the research problems and the choice of suitable projects to eliminate, or at least minimize, adverse effects on the ecosystem.

From the findings of this research, and the review of available literature on the research area and on Saudi Arabia as a whole, it appears that many issues remain to be investigated with regard to the vegetation, soil and their relationship with environmental factors in these areas. Recommendations for further work and studies are summarised and offered below:-

1- In addition to the findings mentioned above, this research has provided and developed a suitable methodology for other researches of this kind. This methodology is recommended to be used in similar regions out and inside Saudi Arabia.

2- With a few exceptions, there appears to be an absence of detailed published research concerning all aspects related to the vegetation, soil and their relationship with environmental factors in all arid and semi-arid regions. The neglect of this unique areas, both in Saudi Arabia and foreign literature, might be due to the limited land use in these regions. Most studies of these issues are more extensive in the humid regions, such as Europe and North America. Most information regarding the soil and its relationship with vegetation and slope in all arid and semi-arid regions appears incidentally in studies with other objectives, such as geomorphology, geology and botany. Therefore, there is a significant need to fill out the gaps in knowledge of the relationship between soil, vegetation and slope by better-directed research. Pedological, ecological and biogeographical issues related to the Saudi Arabia soil, vegetation and ecology have hardly been investigated and are still of special research interest. One of the major findings of this research is that there is a need to support field work and additional quantitative studies concerning all aspects related to the soil and vegetation complex as well as their relationship with the environmental variables, particularly slope and climate factors in the south and west of Saudi Arabia.

3- Soil and vegetation-environmental relationships in south-west Saudi Arabia should be analysed using modern methods,such as remote sensing techniques that involve all the environmental variables such as topography, climate, geology, geomorphology, location and land use.

4- There is a need for detailed soil and vegetation maps for the whole of Saudi Arabia. These maps should describe the distribution of soil types and plant communities and their relationships to other environmental variables.

7-3 Land use Policy Recommendations

For the conservation and protection of soil and natural vegetation as well as the potential use of Wadi Bishah land, the following recommendations are offered:

1- Because the foot slope areas in Wadi Bishah basin possess an extensive area, deep soil, slight plant density, gentle slopes and a good proportion of nutrients, such as phosphorus and potassium, compared with the other slope segments, it is suggested that modest agricultural projects be established in these areas. Execution of this kind of project in these areas will be beneficial, especially in those areas that are close to the ground water level and will gain more water coming from the upper slope segments. Moreover, their effect on vegetation cover and the local environmental system will be weak.

2- Because the trees and shrubs in toe-slope areas have a relatively large mass and relatively high density, it is recommended to leave these areas in their current condition to conserve and protect the foot-slope areas from flood-dangers, with the possibility of exploitation of these areas for recreation activities (picnicking and camping) in the future.

3- The upper and mid-slopes are distinguished by a high density of vegetation, shallow soils and steep slopes, so that these areas should remain in their present condition, because any attempt to exploit these areas will mean removal and destruction of a huge part of vegetation cover and excoriation and exposure of slope soil, as well as affecting the environmental system as a whole. Also, the importance of vegetation in these areas relates to the fact that a greater proportion of vegetation here is perennial trees and shrubs. In addition to the above, these areas and their plants provide a good source of water and organic matter that can be useful for agricultural projects in down-slope areas.

4- Road-building should avoid the steep slopes and areas dense in vegetation. Roads could, however, be established across the valley course sides which are usually bare of vegetation cover. Successful projects of this kind can be already seen in the Tehamah region, south-west of Saudi Arabia.

5- The successful method of conservation (the *hema* system) that was adopted over a very long period of time by the tribes in the Al-Hejaz region to protect the trees, shrubs and pastures should be reapplied, with some modifications to be appropriate to the present time (e.g. cancellation of tribal quality). This system should be carried out under supervision of the Ministry of Agriculture and Water and with the cooperation of the Ministry of Interior.

6- Reforestation and planting of trees and shrubs that are well adapted to the environmental conditions of the Wadi Bishah basin, such as **Tamarix aphylla**, **Olea europaea** and **Acacia negrii** should be encouraged. Successful attempts of this kind can be found in Dalaghan National Park in the upper sources of the Wadi Bishah.

7- Whatever agricultural and construction activities may be necessary, exposure of the soil on the hill-slopes in Wadi Bishah basin should be avoided. If necessary the plains and bare areas could be used for these kind of activities.

8- Cutting green trees and shrubs should be prevented completely by enforcement of laws prohibiting it. Alternative sources of fuel (e.g. Gas) should be provided by the Government in the markets. If no alternatives are available, the inhabitants of the Wadi Bishah basin will be forced to obtain fuel from **Acacia arabica**, **Acacia gerradii**, **Acacia negrii** and **Juniperus procera**.

9- Grazing should be prohibited in the research area, at least for a limited period (e.g. three months after rainfall period), and the numbers of livestock should be reduced, particularly in the north-east of Wadi Bishah basin. This would allow the vegetation cover to recover from the intense overgrazing and trampling by animals.

10- The Bedouin should be encouraged to replace traditional grazing methods with specialized grazing methods, such as fattening methods which can be based largely on modern technology.

11- Educational programmes should be provided for the Bedouins to make them understand the importance of vegetation and soil in human life.

Finally, it is hoped that this research has fulfilled its purposes and aims, and contributed to the enrichment of knowledge. It is also hoped that the findings and recommendations of this research have paved the way for more much-needed researches and studies concerned with all aspects related to soil and vegetation in Saudi Arabia, which are urgently required as a basis for further development.

REFERENCES

References

Aba Husayn, M; Dixon, J; and Lee, S., (1980). Mineralogy of Saudi Arabian Soils, South-western Region. **Journal of Soil Science of America.** Vol. 44, No. 3: 643-649.

Abdulrazzak, M., Sorman, A., and Alhames, A.., (1989). Water Balance Approach under Extreme Arid Conditions-A case study of Tabalah Basin. **Hydrological Processes,** vol. 3: 107-122.

Abu-Ayyash, A., (1984) **Statistics and Computer in Treatment of Data with Geographical Applications.** (In Arabic) Printing Agency. Al-Kuwait. 368 pp.

Abulfatih, H., (1979). Vegetation of Higher Elevations of Asir, Saudi Arabia. **Proceedings of Saudi Biology Society.** Vol. 3: 139-148.

Abulfatih, H., (1981a). Plant Ecology of Dalaghan National Park, Asir Province, Saudi Arabia. **Proceedings of Saudi Biology Society.** Vol. 5: 131-141.

Abulfatih, H., (1981b). Wild Plants of Abha and its Surroundings. **Proceedings of Saudi Biology Society.** Vol. 5: 143-159.

Abulfatih, H., (1984). Elevationally Restricted Flora Elements of the Asir Mountains, Saudi Arabia. **Journal of Arid Environment.** Vol. 7: 35-41.

Abulfatih, H., (1984). **Wild Plants from Abha and its Surrounding Regions**. Saudi House for Publication and Distribution. Saudi Arabia, Jeddah. 125 pp.

Abulfatih, H., (1987). **Medical Plants from South-west of Saudi Arabia**, (in Arabic and English). Al Thagher press. Khamis Mushayt. 153 pp.

Abulfatih, H., (1991). **Environment Science**, (in Arabic). King Saud University Publication. Al Riyadh, edition 1: 163-203.

Abulfatih, H., (1992). Vegetation Zonation along Altitudinal Gradients Between Sea Level and 3000 metres in south-western, Saudi Arabia. **Science Journal of King Saud University**. Vol. 4, No. 1: 57-97.

Abulfatih, H; & Al-Khalili, A., (1979). Biology Survey of Abha Lake. **Journal of the Saudi Arabian Natural History Society.** Vol. 25: 17-22.

Abulfatih, H; Emara, H; and Elhashish, A., (1989). The influence of Grazing on Vegetation and Soil of Asir Highlands in South-western Saudi Arabia. **Arab Gulf Journal of Scientific Research, B-Agriculture and Biological Science.** Vol. 7, No. 1: 69-78.

Abu Saqr, M., (1981). **Geology and Groundwater Resources of the Wadi Bishah Basin-South-west of Saudi Arabia.** Ph.D. thesis, Department of Geology, University of Sheffield. 181 pp.

Acton, D., (1964). The Relationship of Pattern and Gradient of Slope to Soil Type. **Canadian Journal of Soil Science.** Vol. 45: 96-101.

Agassi, M; & Ben-Hur, M., (1991). Effect of Slope Length, Aspect and Phosphogypsum on Runoff and Erosion from Steep Slope. **Australian Journal of Soil Research.** Vol. 29, No. 2: 197-207.

Agbenin, J; & Tiessen, H., (1995). Soil Properties and their Variations on Two Contiguous Hill-slopes in Northeast Brazil. **Journal of Soil Science.** Vol. 24: 147-161.

Akagi, Y., (1980). Relationship between rock type and the slope form in the Sonora Desert, Arizona. **Zeitschrift Fur Geomorphologie.** Vol. 24, No. 2: 129-140.

Al-Aodat, M; Abdullah, A; and Al Sheikh, A., (1985). **Plant Geography.** King Saud University Publication. Al Riyadh. 326 pp.

Al-Arifi, F., (1992). **Studies on the Genesis and Formation of Some Soils of the South-western Region, Saudi Arabia.** M.Sc. thesis, Department of Soil, King Saud University. 130 pp.

Al-Awajy, M; El-kady, H; Sallam, A; and Al-Arifi, F., (1993). Characterization of Some Genetic Soils at South-Western Mountainous region, Saudi Arabia. **Annals of Agricultural Science, Ain Shams University;** Cairo, Vol. 38, No. 2: 823-839.

Al-Barrak, S., (1985). Characterisation and Classification of Some Soils in Al-Sawdah, South-western Saudi Arabia. **Journal of Agriculture College, King Saud University.** No. 7: 269-283.

Al-Hassan, H., (1993). **Deterioration of Range Lands Condition and Ways to their Improvement in Saudi Arabia**, (in Arabic). The Ministry of Agriculture and Water, Saudi Arabia, Al Riyadh. 13 pp.

Al-Hubaishi, A; & Hohenstein, K., (1984). **An Introduction to the Vegetation of Yemen.** Ecological Basis, Floristic Composition and Human Influence. Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH. 209 pp.

Al-Jerash, M, A., (1968). **Soils and Agricultural Development in the Region of Al-Qassim, Saudi Arabia**. Master thesis, Durham University, England. 232 pp.

Al-Mashhady, A; Al-Domaty, A; and Fahmi, M., (1984). **Practical Experiments in Soil Science Essentials.** (In Arabic), King Saud University, Riyadh, Saudi Arabia. 191 pp.

Al-Nafie, A., (1995). **Natural Vegetation of the Sand Seas of Central and Northern Saudi Arabia.** Ph.D. thesis. School of Geography and Earth Resources, The University of Hull. 503 pp.

Al-Niemi, S., (1987). **Fertilizers and Soil Fertility.** (In Arabic), Al-Mousil University, Iraq. 340 pp.

Al-Qahtani, M., (1991). **Effect of Soil Characteristics on Morphology of Wood-plant in Wadi Wad., Saudi Arabia.** MA thesis. Department of Geography, King Saud University. 155 pp.

Al Riyadh, N., (1996). The Biggest Dam in Saudi Arabia. **Al Riyadh Newspaper.** Al Riyadh, No 10108.

Al-Saleh, N & Abu Alaula, S., (1977). Production Energy of Grazing and Ways to their Development in Saudi Arabia. **The First Agricultural proceeding of Moslem Scientists**, Al Riyadh University, Saudi Arabia, Al Riyadh. Vol. 3: 115-123.

Al-Shalash, A, H., (1985) **Geography of Soil**. (In Arabic). Second edition. Basrah University, Iraq. 167 pp.

Al-Shareef, A., (1976). Climate of Southwest Saudi Arabia, (in Arabic) **Journal of Al Darah,** Vol. 1: 128-153.

Al-Shareef, A., (1984). Geography of Saudi Arabia (Vol. 2) (in Arabic). **Dar Al Marrikh,** Al Riyadh, Saudi Arabia: 481 pp.

Al-Shareef, A., (1994). Geography of Saudi Arabia. (Vol. 1) (in Arabic) **Dar Al Marrikh**. Al Riyadh, Saudi Arabia: 383 pp.

Al-Souli, S; Robinson, G; and Al-Khatib, A., (1980). **The Soil of Saudi Arabia.** Report from Department of Land Management, Ministry of Agriculture and Water, Saudi Arabia. P 117-123.

Al-Welaie, A., (1996). **The Biogeography of Saudi Arabia**, National King Fahad Library. Al Riyadh, Saudi Arabia. 342 pp.

Al-Welaie, A; Choudary, S; and Al Wetaid, Y., (1993). Vegetation of Some Red Sea Islands of the Kingdom of Saudi Arabia. **Journal of Arid Environments.** Vol. 24, No. 3: 287-296.

Anderson, K; & Furley, P., (1975). An Assessment of the Relationship Between the Surface Properties of Chalk Soils and Slope Form Using Principal Components Analysis. **Journal of Soil Science.** Vol. 26: 130-143.

Arnold, G., (1964). Factors Within Plant Associations Affecting the Behaviour and Performance of Grazing Animals. In: Grisp, D; (1964) **Grazing in Terrestrial and Marine Environments**. Blackwell Scientific Publications, Oxford: 133-154.

Asir Principality, & King Khaled College., (1985) **Atlas of Asir Administrative region.** National Guard printing press.

Ayyad, M & El-Kadi, H., (1982). Effect of Protection on the Vegetation of a Mediterranean Desert Ecosystem in Northern Egypt. **Vegetation,** Vol. 49: 129-139.

Basahy, A; & Monawar, M., (1994). A Check List of Weeds in the Jizan Area of Saudi Arabia. **Arabic Gulf Journal of Ccientific Research.** Vol. 12, No. 3: 489-508.

Bashour, I; Al-Mashhady, A; Deviprasad, J; Miller, T; and Nazroa, M., (1983). Morphology and Composition of Some Soils Under Cultivation in Saudi Arabia. **Geoderma.** No. 29: 327-340.

Batanouny, K., (1973). Soil Properties as Affected by Topography in Desert Wadis. **Acta Botanica Academia Scientiarum Hungaricae.** Vol. 19: 13-21.

Batanouny, K., (1979). Vegetation Along the Jeddah -Mecca Road: Pattern and Process as Affected by Human Impact. **Journal of Arid Environments.** Vol. 2: 21-30.

Batanouny, K; & Baeshin, N., (1983). Plant Communities Along the madina-Badr Road Across the Hijaz Mountains, Saudi Arabia. **Journal of Vegetation.** Vol. 53: 33-43.

Batanouny, K., (1987). Current Knowledge of Plant Ecology in the Arabian Gulf Countries. **Catena.** Vol. 14: 291-315.

Beaumont, P., (1977). Water and Development in Saudi Arabia. **The Geographical Journal.** London. Vol. 143: 42-60.

Bin Sadig, A., (1994). **Practical Experiments in Science of Mining Microbiology.** (In Arabia), King Saud University, Riyadh, Saudi Arabia. 125 pp.

Birkeland, P., (1984). **Soil and Geomorphology.** Oxford University Press, New York. 372 pp.

Blackburn, W; Pierson, F; Hanson, C; Thurow, T; and Hanson, A., (1992). The Spatial and Temporal Influence of Vegetation on Surface Soil Factors in Semi-arid Rangelands. **Transactions of the ASAE.** Vol. 35, No. 2: 479-485.

Blatter, E., (1907). The Flora of Aden. **Journal of Bombay-Natural History Society.** Vol. 17: 895-920.

Bloot, J., (1996). Plants of Juniperus species in monkey stomachs. **Okad Newspaper.** Jeddah, No 10946.

Blume, H., (1976). **Saudi Arabia.** Horst Erdmann Verlag, Tuingen Und Basel.

Breare, R., (1976). **Farpic and Mineral Analysis of Soils.** (2 ed. ed), Robert, E. Krieyer Pub. Co. Inc, N. Y.

Brooks, W; & Mandil, K., (1983). Vegetation Dynamics in the Asir Woodlands of South-western Saudi Arabia. **Journal of Arid Environments,** Vol. 6, No. 4: 357-362.

Brown, G., (1960). Geomorphology of Western and Central Saudi Arabia: Report of **the International Geological Congress, Copenhagen proceedings,** 21st Session. part xx1. p 150-169.

Brown, G, F; & Jackson, R., (1960). The Arabian Shield . **International Geological Congress, Copenhagen,** Report 9, part Ix. p 69-77.

Brown, G., (1970). **Eastern Margin of the Red Sea and The Coastal Structure in Saudi Arabia.** Royal Society. London Phil. Trans. A267. p 75-89.

Brown, G; F., (1972). **"Tectonic map of the Arabian peninsula".:** Kingdom of Saudi Arabia, Ministry of Mineral Resources. Directoral General of Mineral Resources, Map AP 2. 1:4000 000, Jeddah, Saudi Arabia.

Bryan, R., (1979). The influence of slope angle on soil intrainment by sheetwash and rainsplash. **Earth Surface Processes,** Vol. 4: 43-58.

Bryman, A & Cramer, D., (1994) **Quantitative Data Analysis for Social Scientists**. (Revised edition). Routledge, London. 294 pp.

Burdon, D., & Otkun, G., (1968a). Hydrogeological content of development in Saudi Arabia. **XIII International Geological Congress,** No. 12: 145-153.

Burdon, D., & Otkun, G., (1968b). Groundwater potential of karst aquifers in Saudi Arabia. **Presented at the international Association of Hydrogeologists, Istanbul Congress,** (typescript).

Burdon, D., (1973). Groundwater resources of Saudi Arabia. **Groundwater Resources in Arab Countries,** ALESCO, Science Monograph , No 2.

Bushnell, T., (1943). Some Aspects of the Soil Catena Concept. **Proceedings Soil Science Society of America.** Vol. 7: 466-476.

Campbell, C., (1989). Soil Organic Carbon, Nitrogen and Fertility In: Soil Organic Matter, Developments in Soil Science NO 8. 4 edition, Schnitzer, M; and Khan, S; (Editors). **Elsevier Science Publishing Company,** Amsterdam, 319 pp.

Campbell, I., (1975). Pattern of Vegetation in Steep-land Soils: Soil Differences in Complex Topography. **New Zealand Journal of Science.** Vol. 18: 53-66

Chapman, R., (1978). Geology of the Arabian Peninsula In: Al-Sayari, S; and Zotl, J (eds). **Quaternary Period in Saudi Arabia,** Vol. 1: 4-18. Springer-Verlag, New York.

Chapman, R., (1978). Geomorphology of the Arabian Peninsula In: Al-Sayari, S; and Zotl, J (eds). **Quaternary Period in Saudi Arabia,** Vol. 1: 19-30. Springer-Verlag, New York.

Cooke, R; & Reeves, R., (1972). Relationship Between Debris Size and the Slope of Mountain Fronts and Pediment in the Mojave Desert California. **Z. Geomorphology.** Vol. 16: 76-82.

Cottam, G & Curtis, J., (1956). The Use of Distance Measures in Phytosociological Sampling. **Ecology.** Vol. 37: 451-460.

Dadkhah, M; & Gifford, G., (1980). Influence of vegetation, rock cover, and trampling on infiltration rates and sediment production. **Water Resources Bulletin,** Vol. 16, No. 6: 979-986.

David, R., (1987). **Mathematics for GCSE,** (Book 1). Oxford University Press, Oxford. 185 pp.

Derose, R; Trustrum, N; and Blaschke, P., (1993). Post-Deforestation soil loss from steepland hillslopes in Taranaki, New Zealand. **Earth Surface Processes and Landforms,** Vol. 18: 131-144.

Dixon, J; & Viani, B., (1980). **Mineralogy of Saudi Arabia.** Project Update.

Draz, O., (1965). **The "Hema" System of range reserves in the Arabian Peninsula; its Possibilities in range Improvement and Conservation Projects** in Middle East, Rome. 11 pp.

Duley, F; & Hays, O., (1932). The Effect of the Degree of Slope on Runoff and Soil Erosion. **Journal of Agriculture Research.** Vol. 45: 349-360.

Dury, G., (1966). Pediment slope and particle size at Middle Pinnacle, near Broken Hill, New South Wales. **Australian Geographical Studies,** Vol. 4: 4-17.

Eig, A., (1931-1932). Les elements et les groups phytogeographiques auxiliaries dans la flora palestinienne, 2 pts. Feddes report., **Beih.** 63: 1-201; 120 Tafl.

Eig, A., (1933). A historical-phytosociological essay on Palestinian forests of Quercus aegilops L. ssp. Itbaburensis (Desc.) in past and present. **Beih. Bot.cbl. Abt. B**. 51: 225-272.

El-Demerdash, M; Hejazy, A; and Zilay, A., (1994). Distribution of the Plant Communities in Tihamah Coastal Plains of Jizan Region, Saudi Arabia. **Journal of Vegetation.** Vol. 112, No. 2: 141-151.

El-Demerdash, M; & Zilay, A., (1994). An introduction to the Plant Ecology of Tihamah Plain of Jizan Region, Saudi Arabia. **Arab Gulf Journal of Scientific Research.** Vol. 12, No. 2: 285-299.

El-Demerdash, M; Hegazy, A; and Zilay, A., (1995). Vegetation-soil relationships in Tihamah coastal plains of Jazan region, Saudi Arabia. **Journal of Arid Environments,** Vol. 30: 161-174.

El-Hames, A., (1993). **A physically-based Model for the Prediction of flood hydrographs in arid zone catchments**. Unpublished PhD thesis. Department of Geography, Cambridge University. 154 pp.

El-Karemy, Z; & Zayed, K., (1992). Distribution of plant communities across Al-Abna escarpment, South-western Saudi Arabia. **Phyton, Annales Rei Botanicae.** Vol. 32, No. 1: 79-101.

El-Katib, A., (1980). **Seven Green Spikes**, Al Riyadh. Ministry of Agriculture and Water. Al Riyadh, Saudi Arabia: 361 pp.

Ellis, S, & Mellor, A., (1995). **Soil and Environment**. Routledge, London. 364 pp.

El-Naggar, M., (1982). Inhibition of nitrification in soil under Juniperus Procera woods in Asir Region, Saudi Arabia. **Journal of the College of Science, King Saud University.** Vol. 13, No. 2: 193-203.

Fairer, G., (1985). Evaluation of the Asir terrain and phanerozoic rifting in south-western Saudi Arabia. **US Geological Survey.** No. 73996.

Fernandez, J; Bermudez, F; Fernandez, J; and Diaz, A., (1995). Land use and soil-vegetation relationships in a Mediterranean ecosystem: El Ardal, Murcia, Spain. **Catena,** Vol. 25: 153-167.

FitzPatrick, E., (1980). **Soils: Their Formation, Classification and Distribution.** Longman Group Limited, London and New York. 353 pp.

Floret, C., (1981). The Effect of Protection on Steppic Vegetation in the Mediterranean Arid Zone of Southern Tunisia. **Vegetation**. Vol. 46: 117-129.

Food and Agriculture Organization of United Nations (FAO)., (1977). **Soil map of the world**: scale, 1: 5,000,000. Food and Agriculture Organization of the United Nations, United Nations Educational, Scientific and Cultural Organization (Unesco), Paris.

Frey, W; & Kurschner, H., (1989). **Die Vegetation im Vorderem Orient.** Erlauerungen zur karte A VI Beih. Tubinger Atlas Vorderen Orients, A Nr. 30.

Furley, P., (1968). Soil formation and slope development: 2-The relationship between soil formation and gradient angle in the Oxford area. **Zeitschrift Fur Geomorphology.** Vol. 12: 25-42.

Furley, P., (1971). Relationship between slope form and soil properties developed over chalk parent materials. In: slope form and process. **Institute of British Geography**. No 3: 141-164.

Gard, L; & Van-Doren, C., (1949). Soil losses as affected by cover, rainfall and slope. **Proceedings of Soil Science Society of America.** Vol. 14: 374-378.

Gerrard, A., (1982). **Slope Form, Soil and Regolith Characteristics in the Basin of the River Cowsic, Central Dartmoor, Devon.** Ph.D. thesis, London University, UK, London. 784 pp.

Gerrard, A., (1988). Soil-Slope relationship: A Dartmoor example. **University of Birmingham, occasional publication.** No. 26: 1-70.

Gerrard, A., (1992). **Soil Geomorphology, an integration of pedology and geomorphology.** Chapman and Hall, London. 269 pp.

Gerrard, A; Thouvenot, F; and Huber, R., (1986). Tectonic stress in the south-western Arabian shield. **Elsevier Sci. Pub;** Vol. 3, No. 22: 247-255.

Getting, M; Blank, H; Mooney, W; and Healy, J., (1986). Crystal structure of south-western, Saudi Arabia. **Journal of Geophysical Res**. Solid Earth and Plants. Vol. 6, No. 91: 6491-6512.

Gilbertson, D; Kent, M and Pyatt, F., (1985). **Practical Ecology for Geography and Biology Survey, Mapping and Data Analysis**. Unwin Hyman Ltd. London, 320 pp.

Goldsmith, F; Harrison, C and Morion, A., (1986). "Description and Analysis of Vegetation" In: P. D. Moore and S. B. Chapman (ed). **Methods in Plant Ecology**. (2 Ed.) Blackwell Scientific Publications, Oxford. 589 pp.

Goudie, A., (1990). "Desert Degradation" In: Goudie A. Ed. **Techniques for Desert Reclamation**. John Wiley and Sons, Chrchester.

Greenwood, W; & Brown, G., (1972). Petrology and chemical analysis of selected platonic rocks from the Arabian shield, Saudi Arabia. **Ministry of Petroleum and Mineral Resources.** Direct. General of Min. Resource. Bull. No. 9, Jeddah.

Hadley, R; & Toy, T., (1977). Relation of surfacial erosion on hillslopes to profile geometry. **Journal of Research US Geological Survey,** Vol. 5, No. 4: 487-490.

Hajar, A., (1993). A comparative ecological study on the vegetation of the protected and grazed parts of the Hema Sabihah in Al-Bahah region, Saudi Arabia. **Arab Gulf Journal of Scientific Research.** Vol. 11, No. 2: 259-280.

Hassan, M., (1981). Flora of Saudi Arabia and Neighbouring areas. **In Fifth Conference on the Biological Aspects of Saudi Arabia,** Saudi Biological Society. King Saud University, Abha: 169-237.

Hill, M., (1979b). **TWINSPAN-A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes**. Ecology and Systematics, Cornell University, Ithaca, New York 14850. 48 pp.

Hill, M., (1994). **DECORANA and TWINSPAN, for ordination and classification of multivariate species data: a new edition together with supporting programs, in FORTRAN 77.** Institute of Terrestrial Ecology, Huntingdon, England. 58 pp.

Hodgson, M., (1978). **Soil Sampling and Soil Description.** Clarendon Press, Oxford. 241 pp.

Hotzi, H., (1984). "**The Red Sea**" In: Jado, A., and Zotl, J. (Eds.). **Quaternary Period in Saudi Arabia**. Vol. 2: 13-26. Springer-Verlag, New York.

Huzauyyin, S., (1938). Climate changes in South-west Arabian during Pleistocene and recent times: **International Geological Congress, Amsterdam Congress.** Vol. 1: 165-166.

Italconsult., (1967). **"Wadi Bishah Pilot Project. Feasibility Study"** (unpublished report), Kingdom of Saudi Arabia. Ministry of Agriculture and Water. Rome. 28 pp

Italconsult., (1968-1969). **"Water and Agriculture Studies for Areas II and III.** Final report. Wadi Bishah selected area. Ministry of Agriculture and Water. Saudi Arabia. Rome. 25 pp.

Jenny H., (1941) **Factors of Soil Formation**:A System of Quantitative Pedology, McGraw-Hill Book Co., Inc, New York, USA. 281 pp.

Jenny, H (Foreword by Amundson, R)., (1994). **Factors of Soil Formation.** Dover Publications, INC. New York. 281 pp.

Jenny, M; Smettan, U; and Moniak, M., (1990). Soil-Vegetation at several arid microsites in the Wadi Araba, Jordan. **Vegetation Journal.** Vol. 89: 149-164.

Johnson, D., (1985) Soil Thickness Processes. In: P, Jungerus (Editor), **Soils and Geomorphology.** Catena supplement. No 6: 29-40. Cremlingen-destedt, Germany.

Kadmon, R; Yair, A; and Danin, A., (1989). Relationship between soil properties, soil-moisture and vegetation along losses-covered hill-slope, northern Nagev, Israel. **Catena, Supplement.** Vol. S14: 43-57.

Karpoff, R., (1957). Esquisse geologique de L'Arabie Seoludit. **Soc. Geol. Franc. Bull.** Vol. 7: 653-697.

Kayani, S; & Sheikh, K., (1981). Interrelationships of vegetation, soil and termiles in Pakistan: 1-Arid marine tropical coast-land. **Pakistan Journal of Botany.** Vol. 13, No. 2: 165-188.

Kent, M & Coker, P., (1992) **Vegetation Description and Analysis: A Practical Approach,** Belhaven Press, London. 363 pp.

Kent, P., (1978). "Middle East, the geological background", in Proceedings of the Conference on Engineering problems Associated with Ground Conditions in the Middle East: **Q. Jl. Enge.** Geol., No. 11: 2-7.

Kershaw, K., (1973). **Quantitative and Dynamic Plant Ecology.** (2nd. ed.). Edward Arnold, London. 308 pp.

Khaleefah, S., (1980). **Trees and Shrubs in Saudi Arabia,** (in Arabic), Al Khaled press, Al Riyadh. 321 pp.

King, L., (1969). **Statistical Analysis in Geography.** Prentice-Hall, Inc., Englewood Cliffs, N. J. USA. 288 pp.

Kinnell, P; & Cummings, D., (1993). Soil, slope gradient interactions in erosion by rain-impacted flow. **Transactions of American Society of Agriculture Engineering.** Vol. 36, No. 2: 381-387.

Kollmann, W., (1984). "Hydrological Studies in the Upper Wadi Bishah" In: Jado, A., and Zotl, J. (Eds.) **Quaternary Period in Saudi Arabia**, Vol. 2: 226-245 New York: Springer-Verlag.

Konig, P., (1988). Phytogeography of South-western Saudi Arabia. **Die Erde.** Vol. 119: 75-89.

Kurschner, H., (1984a). Epiphytic Communities of the Asir mountains, South-west Saudi Arabia. Studies in Arabian bryophyte-2- **Nova Hedwigia.** Vol. 39: 177-199.

Lal, R., (1990). **Soil Erosion in the Tropics: Principles and Management.** McGraw-Hill. Inc. USA, New York. 581 pp.

Lattanzi, A; Meyer, L; and Baumgardner, M., (1974). Influence of mulch rate and slope steepness on interrill erosion. **Proceedings of Soil Science Society of America,** Vol. 38: 946-950.

Liu, B; Nearing, M; and Risse, L., (1994). Slope gradient effects on soil loss for steep slopes. **American Society of Agricultural Engineers,** Vol. 37, No. 6: 1835-1840.

Makhnach, N., (1994). Distribution of Minerals of the Fine-sand fraction in slope soil of Byelarus. **Eurasia Soil Science.** Vol. 26, No. 8: 57-66.

Mandaville, J., (1990). **Flora of Eastern Saudi Arabia**. Kegan Paul International, London. 482 pp.

Martz, L., (1992). The variation of soil erodibility with slope position in a cultivated Canadian Prairie landscape. **Earth Surface Processes and Landforms,** Vol. 17: 543-556.

McGinnies, W., Goldman, B., and Paylore, P., (eds.)(1968). **Deserts of the World,** University of Arizona, Tucson. 788 pp.

Migahid, A; Al-Oudat, M; Abdullah, A; Al-Shaikh, A; and Ba Sahi, A., (1987). **Plant Environment science.** (In Arabic), King Saud University, Riyadh, Saudi Arabia. 386 pp.

Migahid, A; & Hammoda, M., (1974). **Flora of Saudi Arabia.** (2 vols). King Saud University Publication. Al Riyadh.

Migahid, A., (1978). **Flora of Saudi Arabia.** 2nd ed, (2 vols.) King Saud University Publication. Al Riyadh.

Migahid, A., (1980a). Natural vegetation of Saudi Arabia, (in Arabic). **Al Majallah Al Arabiyah** (Arabic Journal), No. 5: 32-43.

Migahid, A., (1980b). Natural vegetation of Saudi Arabia, (in Arabic). **Al Majallah Al Arabiyah** (Arabic Journal), No. 6: 40-47.

Migahid, A., (1988). **Flora of Saudi Arabia.** 3rd ed. (2vols.) King Saud University Publication. Al Riyadh. Saudi Arabia.

Migahid, A., (1990). **Flora of Saudi Arabia.** 3rd ed. (3vols.) King Saud University Publication. Al Riyadh. Saudi Arabia.

Milne, G., (1935a). Some Suggested Units for Classification and Mapping, Particularly for East African Soils, **Soil Research**, Berlin, V. 4: 183-198.

Ministry of Agriculture and Water, (1981). **Soil Map of Saudi Arabia,** scale, 1:6,000,000, The Ministry of Agriculture and Water, Land Management Department. Al Riyadh, Saudi Arabia.

Ministry of Agriculture and Water, (1984 & 1994). **Water Atlas of Saudi Arabia.** Ministry of Agriculture and Water, Al Riyadh. Saudi Arabia.

Ministry of Agriculture and Water, (1985). **General Soil Map of Saudi Arabia (Soil Atlas),** Saudi Arabia-United States Joint Commission for Economic Development, Land Management Department. Al Riyadh, Saudi Arabia.

Ministry of Agriculture and Water, (1995). **Summary of climatological Data,** Department of Hydrology, Ministry of Agriculture and Water. (1966-1993), Al Riyadh. Saudi Arabia.

Ministry of Agriculture and Water, (1996). Agriculture Statistical Year Book. **Department of Economic Studies and Statistics, Ministry of Agriculture and Water**. Al Riyadh, Saudi Arabia. P 66-79.

Ministry of Finance and National Economy, (1994). **The Annual Statistical Books.** Central Department of Statistics, Ministry of Finance and National Economy. (1966-1992). Al Riyadh, Saudi Arabia.

Ministry of Petroleum and Mineral Resources, (1987). Arabian Peninsula Map, (in Arabic). **Ministry of Petroleum and Mineral Resources**. Al Riyadh, Saudi Arabia.

Mohammed, H., (1989). "Bishah dam project-the effect of topography and hydraulic on torrent water and agricultural development" (in Arabic) In: **Workshop on Desert Studies in the Kingdom of Saudi Arabia**, King Saud University, Centre for Desert Studies. P 113-128.

Morgan, R; (1995). **Soil Erosion and Conservation.** (2nd edition) Longman Group Limited, UK. London. 198 pp.

Moshrif, M & Edris, E., (1990). **Illustrated Dictionary of Sedimentological Terms**. (In English and Arabic) King Saud University Publication. Al Riyadh. Saudi Arabia. 243 pp.

Mueller-Dombois, D & Ellenberg, H., (1974). **Aims and Methods of Vegetation Ecology.** John Wiley and Sons, New York. 547 pp.

Muller, K; Grosser, L; and Roppenhoner, D., (1987). Applied vegetation studies in the Yemen Arab Republic: Range management and terrace stabilisation. **Catena.** Vol. 14: 249-265.

Nader, A., (1982). First records of flora from the highlands of Asir Kingdom of Saudi Arabia. **Senckenberagiana Biologica,** Vol. 62, No. 4: 405-412.

Norusis, M., (1985). **SPSSX Advanced Statistics Guide**. McGraw-Hill, USA. New York.

Norusis, M., (1993). SPSS For Windows Base System User's Guide. Release 6.0. **SPSS Inc.** Chicago. 828 pp.

Novikova, N., (1970). Drawing up a preliminary vegetation map of Arabia. **Geobotanicheskoe Karo-Gratifovanie:** 61-71. RTS 12072, English tr. By Russian Translation Service, the British Library.

Omer, A; & Metwally, A., (1978). **Soils: Genesis and Classification and Physical, Chemical and Biotic Properties.** (In Arabic) Second addition, Agriculture college, Al-Azhar University. Cairo, Egypt. 220 pp.

Organgi, R., (1982). Ecological studies in Makkah region. 1- vegetation development at Wadi Fatma, Saudi Arabia. **Journal of College of Science, King Saud University.** Vol.13, No. 1: 25-51.

Oversheet, W; Stoeser, D; Overstreet, E; and Goudarzi, G., (1977). **Tertiary laetrile of the As Sarat mountain, Asir province, Saudi Arabia.** Bulletin No. 21, DGMR, Jeddah.

Philpy, H., (1933). **The Empty Quarter**: Constable, London. 433 pp.

Pitty, A., (1978). **Geography and Soil Properties.** Methuen and Co Ltd, London: 287 pp.

Popov, G; & Ziller, W., (1963). **Ecological survey report on the 1962 survey in the Arabian Peninsula.** FAO. Progress report No. UNSAFE / ES. Rome: Food and Agriculture Organisation of the United Nations. Mimeo.

Powers, R; Ramirez, L; Redmond, C; and Elberg, E., (1966). Geology of Arabian Peninsula. Sedimentary geology of Saudi Arabia. **U. S. Geol. Survey Prof**. Paper 560-D. 147 pp.

Raunkiaer, C., (1934). **The Life Forms of Plants and Statistical plant Geography**. Oxford University Press, London, UK. 632 pp.

Reid, I., (1973). The influence of slope orientation upon the soil moisture regime, and its hydrogeomorphological significance. **Journal of Hydrology.** Vol. 19: 309-321.

Robinson, G., (1977). Soil profile descriptions of the Kharj area distributed on field trip during the soil water and plant analysis. Workshop (1977). **Ministry of Agriculture and Water, Saudi Arabia, and Arab Centre for the Study of Arid Zones and Dry lands.** Al Riyadh.

Ryall, W; & Taylor, G., (1981). Gossan evaluation manual for use in the Kingdom of Saudi Arabia: **Saudi Arabia Deputy Ministry for Mineral Resources Technical Record** RF-TR- 01-3.

Sagga, A., (1995). **The Physical Geography of Saudi Arabia,** (in Arabic). Zahran house, Saudi Arabia, Jeddah. 238 pp.

Sankary, M., (1983). Survey study of the vegetation cover in Republic of Yemen (in Arabic). **Journal of Gulf Studies and Arabian Peninsula.** No. 33: 99-144.

Schmidt, D; Hadley, D; Greenwood, W; Gonzales, L; Coleman, R; and Brown, G., (1973). Stratigraphy and tectonism of the southern part of the Precambrian shield of Saudi Arabia. **Dir. Gen. Mineral Resources, Min. Bull:** 8, 13, Jeddah.

Schwartz, O., (1939). **Flora des tropischen Arabian**. Mitt. Inst. Allg. Bot. Hamburg 10. 393 pp.

Schyfsma, E., (1978). "General information on Arabian Peninsula" In: Al-Sayari, S; and Zotl, J; (eds.). **Quaternary Period in Saudi Arabia.** Vol. 1: 31-44. Springer-Verlag, New York.

Sharief, F., (1984). Stratigraphical Review and Petrology of the Exposed Triassic Rocks of Saudi Arabia. **Journal of Science College, King Saud University, Riyadh, Saudi Arabia**. Vol. 15, No. 1: 219-244.

Shaw, G & Wheeler, D., (1996). **Statistical techniques in Geographical Analysis**. 2nd ed. David Fulton Publishers, London. 359 pp.

Simanton, J; Renard, K; Christiansen, C; and Lane, L., (1994). Spatial distribution of surface rock fragments along catenas in semi-arid Arizona and Nevada, USA. **Catena,** Vol. 23: 29-42.

Smettan, U; Jeeny, M; and Facklammoniak, M., (1993). Soil Dynamics and plant distribution of sand dune playa microchore catena after winter rain in the Wadi Araba, Jordan. **Catena.** Vol. 20: 179-189.

Soil Survey Staff., (1992). **Keys to Soil Taxonomy. Soil Management Support Services Technical Monograph** No. 19 (5th ed). Pocahontas Press, Blacksbury, Virginia. 541 pp.

Takhtajan, A., (1986). **Floristic Regions of the world** (Translated by Theodore, J. Crovello). University of California Press, Berkeley, Los Angeles. 208 pp.

Tarzi, J., (1984). **Procedures for Collecting Soil Samples for Different Purposes Under the Condition of the Kingdom of Saudi Arabia,** (in English and Arabic). Ministry of Agriculture and Water, Directorate of Agricultural Research, Al Riyadh, Saudi Arabia. 50 pp.

Ter Braak, C., (1988). **CANOCO- an a FORTRAN program forcanonical ordination by [partial] [detrended] [canonical] correspondence analysis, principal components analysis and redundancy analysis**. (Version 2.1) Agricultural mathematics group, Ministry of Agriculture and fisheries. Wageningen. 95pp.

Ter Braak, C., (1988). CANOCO- an extension of DECORANA to analyze species-environment relationships. **Vegetatio**. Vol. 75: 159-160.

Ukpoing, I; and Areola, O., (1995). Relationship between vegetation and soil variables of mangrove swamps in south-western Nigeria. **African Journal of Ecology.** Vol. 33, No. 1: 14-24.

Vesey-Fitzgerald, D., (1955). Vegetation of the Red Sea coast south of Jeddah, Saudi Arabia. **Journal of Ecology,** Vol. 43: 477-489.

Vesey-Fitzgerald, D., (1957a). The vegetation of the Red Sea coast north of Jeddah, Saudi Arabia. **Journal of Ecology,** Vol. 45: 547-562.

Vesey-Fitzgerald, D., (1957b). The vegetation of central and Eastern Arabia. **Journal of Ecology,** Vol. 45: 77-88.

Viani, B; Al-Mashhady, A; and Dixon, J., (1983). Mineralogy of Saudi Arabia Soils: Central Alluvial Basins. **Journal of Soil Science Society of America,** Vol. 47: 149-157.

Vincent, P; & Sadah, A., (1995). Particle size-pediment slope relations: Findings from Saudi Arabia. **Catena,** Vol. 24: 91-103.

Walker, P., (1962a). Soil layers on hillslope: A study at Nowra, N. S. W, Australia. **Journal of Soil Science.** Vol. 13: 167-177.

Warrington. D; Shainberg, I; and Agassi, M., (1989). Slope and phosphogypsum's effect on runoff and erosion. **Journal Soil Science Society of America.** Vol. 53: 1201-1205.

Webster, R & Oliver, M., (1990). **Statistical Methods in Soil and Land Resource Survey**. Oxford University Press, Oxford. 316 pp.

West, R., (1991). **Computing for Psycologists, Statistical Analysis Using, SPSS and MINITAB**. Harwood Academic Publishers, London. 243 pp.

White, R., (1987). **Introduction to the Principles and Practice of Soil Science.** 2nd ed. Blackwel, Oxford. 244 pp.

Whitney, J., (1983). Erosional history and surficial geology of western Saudi Arabia. **Ministry of Petroleum and Mineral Resources**, Technical Record USGS-TR-04-1. Saudi Arabia, Jeddah.

Whitney, J., Faukender, D., and Rubin, M., (1983). The Environmental history and present condition of the northern sand Seas of Saudi Arabia: **Deputy Ministry of Petroleum and Mineral Resources,** Open-File Report USGS- 0F-03-95. P 42, 43.

Wieder, M; Yair, A; and Arzi, A., (1985). Catenary soil relationships on arid hill-slopes. **Soils and Geomorphology (Catena Supplement),** Vol. 6: 41-57.

Wild, A., (1994). **Soils and the Environment: An Introduction.** 2nd ed. Cambridge University Press, Cambridge. 287 pp.

Yair, A., (1990). The role of topography and surface cover upon soil formation along hill-slope in arid climates. **Journal of Geomorphology.** Vol. 3: 287-299.

Yair, A; & Klein, M., (1973). The influence of surface properties on flow and erosion processes on debris covered slopes in an arid area. **Catena.** Vol.1: 1-18.

Younes, H; Zahran, M; and El-Qurashy, E., (1983). Vegetation -soil relationship of a sea-inlandward transect, red sea coast, Saudi Arabia. **Journal of Arid Environment,** Vol. 6: 349-356.

Youngman, M., (1979). **Analysing Social and Educational Data.** School of Education, University of Nottingham. McGraw-Hill. 235 pp.

Young, R; & Mutcher, C., (1969). Effect of slope shape on erosion and runoff. **Transactions of the ASAE:** P 231-239.

Youssef, A., (1987). **The Pedology, Genesis, Morphology and Division of Soil** (in Arabic). King Saud University Publication, Saudi Arabia. Al Riyadh. 500 pp.

Youssef, H; & El-Sheikh, A., (1981). Observation on the vegetation of gravel desert areas, with special reference to succession in central Saudi Arabia. **Journal of the College of Science, University of Riyadh.** Vol. 12, No. 2: 331-351.

Zahran, M., (1981). Vegetation types of Saudi Arabia. **Faculty of Meteorology and Environmental Studies, King Abdulaziz University.** Jeddah, Saudi Arabia.

Zingg, A., (1940). Degree and length of land-slope as it affects soil loss in runoff. **Journal of Agriculture engineering.** Vol. 21: 59-64.

Zoght, M., (1989). Acacia trees of Saudi Arabia (in Arabic). **Desert Studies Centre, King Saud University.** No. 1. Al Riyadh.

Zohary, M., (1973). **Geobotanical foundations of the Middle East,** 2 vols. Stuttgart: Gustav Fischer Verlag. 244 pp.

Zouzou, R; & Furley, P., (1975). The natural and formation of toposequence of arid soils over the terraces of the Balik River, northern Syria. Research discussion Paper. **Department of Geography, University of Edinburgh,** No. 7: 1-57.

Further readings

Al-Welaie, A., (1996). **Geology and Geomorphology of Saudi Arabia**, National King Fahad Library. Al Riyadh, Saudi Arabia. 526 pp.

Asadu, C., (1990). A Comparative Characterisation of Two Foot-slope Soils in The Nsukka Area of Eastern Nigeria. **Journal of Soil Science Society of America.** Vol. 150, No. 2: 527-534.

Backeus, I, Rulangaranga, Z and Skoglund, J., (1994). Vegetation Changes Formerly Overgrazing Hill Slopes in Semi-arid central Tanzania. **Journal of Vegetation Science**, No. 5: 327-336.

Baize, D., (1993) **Soil Science Analyses: A Guide to Current Use.** (Translated from French to English by Groham Corss). John Wiley and Sons, New York. 192 pp.

Bishop, P; Mitshell, P; and Paton, T., (1980). The Formation of Duplex Soils on Hill-slope in the Sydney Basin, Australia. **Geoderama.** Vol. 33: 175-189.

Brooks, S; & Anderson, M., (1995). Modelling the role of climatic, vegetation and pedogenesis in shallow translational hillslope failure. **Earth Surface Processes and Landforms,** Vol. 20: 231-242.

Campbell, I., (1973). Pattern of Vegetation in Steep-land Soils: Variation on a Single Slope. **New Zealand Journal of Science.** Vol. 16: 413-424.

Cox, C & Moore, P., (1994). **Biogeography: An ecological and Evolutionary Approach**. (5th ed) Blackwell Scientific Publications, London. 326 pp.

Dyrness, C; & Grigal, D., (1979). Vegetation Soil Relationships along a spruce Forest Transect in Interior Alaska. **Canadian Journal of Botany.** Vol. 57, No. 3: 2644-2656.

El-Hassanin, A; Labib, T; and Gaber, E., (1993). Effect of Vegetation Cover and land slope on runoff and soil losses from the watersheds of Burundi. **Journal of Agriculture Ecosystems and Environment.** Vol. 43: 301-308.

Friis, I., (1992). **Forests & Forest Trees of Northeast Tropical Africa: Their Natural Habitats and Distribution Patterns in Ethiopia, Djibouti and Somalia.** Kew Bulletin Additional Series, London. 396 pp.

Furley, P; & Newey, W., (1983). **Geography of the Biosphere: an Introduction to the Nature, Distribution and Evolution of the World's Life Zones.** Butterworths, London. 413 pp.

Hahn, D; Moldenhour, W; and Roth, C., (1985). Slope gradient effect on erosion of reclaimed soil. **Transactions of American Society of Agricultural Engineering.** Vol. 28, No. 3: 805-808.

Martz, L; & de Jong, E., (1987). 'Using Cesium-137 to assess the variability of net soil erosion and its association with topography in a Canadian Prairie landscape', **Catena**, Vol. 14: 439-451.

Martz, L; & de Jong, E., (1991). 'Using Cesium-137 and landform classification to develop a net soil erosion budget for a small Canadian Prairie watershed', **Catena**, Vol. 18: 289-308.

Moeyersons, J., (1988). The Complex Nature of Creep Movements on Steeply Sloping Ground in Southern Rwanda. **The Journal of the British Geomorphological Research Group**. Vol. 13: 511-524.

Moss, R., (1965). Slope development and soil morphology in a part of south-west Nigeria. **Journal of Soil Science**. Vol. 16: 192-209.

Nornberg, P; Sloth, L; and Nielsen, K., (1993). Rapid changes of sandy soils caused by vegetation changes. **Canadian Journal of Soil Science,** Vol. 73: 459-468.

Ovalles, F; & Collins, M., (1986). Soil land-scape relationships and soil variability in North Central Florida. **Journal of Soil Science Society of America,** Vol. 50: 401-408.

Pennock, D; & Jong, E., (1987). The influence of slope curvature deposition in Hummock terrain, **Journal of Soil Science Society of America.** Vol. 144, No. 3: 209-216.

Pregotzer, K; Barnes, B; and Lemme, G., (1983). Relationship of topography to soil and vegetation in an upper Michigan ecosystem. **Journal of Soil Science Society of America.** Vol. 47: 117-123.

Righi, D; & Lorphelin, L., (1987). The soil of a typical slope in the Himalayas (Nepal): their main characteristics and distribution. **Catena.** Vol. 14: 533-551.

Stone, J; Giliam, J; Cassel, D; Daniels, R; Nelson, L; and Kleiss, J., (1985). Effect of erosion and landscape position on the productivity of Piedmont soils. **Journal of Soil Science Society of America.** Vol. 49: 987-991.

Ter Braak, C., (1987). The Analysis of Vegetation-environmental Relationships by Canonical Analysis. **Vegetation**. Vol. 69: 69-77.

Thomas, D., (1992). **Arid Zone Geomorphology**. Edited by David, S, G, Thomas. Belhaven press, London. 372 pp.

Tsukamoto, Y., (1990). Effect of vegetation on debris slide occurrences on steep forested slope in Japan Islands. **International Association of Hydrological Sciences.** No. 192: 183-191.

Watts, D., (1971). **Principles of Biogeography: An introduction to the Functional Mechanisms of Ecosystems**. McGraw-Hill, London. 402 pp.

White, E., (1991). Vegetation-soil relationship on thin or shallow range sites in western south Dakota. **Journal of Soil Science Society of America.** Vol. 55, No. 5: 1453-1456.

Whitfield, W; & Furley, P., (1971). The relationship between soil patterns and slope form in the Ettrick Association, South-east Scotland. In: **Slope Form and Process.** Institute of British Geography. No. 3: 165-175.

Young, A., (1972). **Slopes**. Oliver and Boyd, Edinburgh, UK. 288 pp.

Zahran, M; Younes, H; and Hajrah, H., (1983). On the ecology of mangel vegetation of Saudi Arabia, Red Sea coast. **Journal of the University of Kuwait (Sci.).** Vol. 10: 87-99.

APPENDIX ONE

Slope Data

Slope Data

Location/ Upper Wadi Bishah.
Researcher/ Al-Qahtani
Date of measurement: 1July to 30 september 1996.

Transect NO	Sample NO	angle	gradient	Slope length	Slope form
1	1	7	0.12	367.5	Convex
1	2	14	0.25	255	Straight
1	3	29	0.55	158	Concave
1	4	14	0.25	92	Concave
1	5	16	0.29	32	Convex
2	6	2	0.03	581.5	Straight
2	7	4	0.07	380	Straight
2	8	17	0.31	168.5	Straight
2	9	10	0.18	106	Straight
2	10	15	0.27	56	Straight
3	11	3	0.05	595.4	Convex
3	12	3	0.05	428.5	Straight
3	13	8	0.14	313	Straight
3	14	15	0.27	220	Concave
3	15	17	0.31	70	Straight
4	16	2	0.03	703	Straight
4	17	6	0.11	253	Straight
4	18	12	0.21	113.5	Straight
4	19	17	0.31	48	Concave
4	20	16	0.29	13	Convex
5	21	6	0.11	632.3	Straight
5	22	6	0.11	352	Convex
5	23	20	0.36	262	Straight
5	24	21	0.38	122	Convex
5	25	10	0.18	11	Convex
6	26	4	0.07	469	Straight
6	27	5	0.09	429	Straight
6	28	8	0.14	438	Straight
6	29	9	0.16	253	Straight
6	30	16	0.29	47.5	Straight
7	31	6	0.11	786.5	Convex
7	32	18	0.32	283	Straight
7	33	16	0.16	141	Straight
7	34	8	0.14	15.6	Convex
7	35	14	0.25	59.7	Convex
8	36	16	0.29	406.5	Straight
8	37	15	0.27	266.2	Straight
8	38	22	0.4	86.3	Concave
8	39	9	0.16	86.5	Convex
8	40	5	0.09	42.6	Convex
9	41	8	0.14	595.5	Convex
9	42	6	0.11	509	Concave
9	43	12	0.21	388	Straight
9	44	4	0.07	253	Concave
9	45	8	0.14	67	Straight
10	46	3	0.05	495.35	Concave
10	47	11	0.19	450.7	Straight

10	48	14	0.25	365	Straight
10	49	9	0.19	285.4	Straight
10	50	12	0.21	25.5	Convex
11	51	18	0.32	618	Convex
11	52	13	0.23	468	Straight
11	53	32	0.62	218	Straight
11	54	31	0.6	102.5	Straight
11	55	18	0.32	20	Convex
12	56	22	0.4	740.5	Straight
12	57	10	0.1	560	Straight
12	58	28	0.53	420	Straight
12	59	29	0.55	270	Straight
12	60	23	0.42	50	Straight
13	61	9	0.16	477.3	Concave
13	62	10	0.18	388	Straight
13	63	12	0.21	298	Straight
13	64	17	0.31	152.33	Concave
13	65	21	0.38	65	Straight
14	66	2	0.03	29	Straight
14	67	5	0.09	66	Convex
14	68	11	0.19	129	Concave
14	69	18	0.32	226	Concave
14	70	4	0.07	4	Convex
15	71	3	0.05	1680	Straight
15	72	4	0.07	1430	Straight
15	73	2	0.03	830	Wavy
15	74	5	0.09	330	Concave
15	75	11	0.19	60	Convex
16	76	11	0.19	275.8	Convex
16	77	9	0.16	215	Concave
16	78	20	0.36	105	Straight
16	79	40	0.84	55.5	Straight
16	80	19	0.34	30.5	Convex
17	81	10	0.18	529	Convex
17	82	19	0.34	439	Concave
17	83	12	0.21	269	Convex
17	84	10	0.18	139	Straight
17	85	20	0.36	70	Straight
18	86	10	0.18	497.5	Convex
18	87	12	0.21	339	Concave
18	88	16	0.29	161.5	Straight
18	89	22	0.4	73	Straight
18	90	18	0.32	11	Convex
19	91	14	0.25	825	Concave
19	92	11	0.19	685	Concave
19	93	16	0.29	435	Straight
19	94	7	0.12	280	Straight
19	95	20	0.36	50	Straight
20	96	10	0.18	240	Convex
20	97	16	0.29	135	Straight
20	98	18	0.32	25.5	Straight
20	99	11	0.19	25	Concave

20	100	5	0.09	3.1	Convex
21	101	6	0.14	210.22	Concave
21	102	15	0.27	170.15	Straight
21	103	14	0.25	113.2	Convex
21	104	10	0.18	75	Convex
21	105	14	0.25	10	Convex
22	106	10	0.18	376.35	Convex
22	107	15	0.27	315	Concave
22	108	18	0.32	213.2	Straight
22	109	20	0.36	78	Straight
22	110	18	0.32	10.1	Convex
23	111	12	0.21	384	Convex
23	112	28	0.53	304	Straight
23	113	23	0.42	236	Straight
23	114	32	0.62	166.3	Straight
23	115	15	0.27	98.3	Convex
24	116	14	0.25	397.21	Straight
24	117	12	0.21	260	Concave
24	118	38	0.78	171.37	Straight
24	119	9	0.16	110	Concave
24	120	20	0.36	25	Convex
25	121	19	0.34	446.1	Convex
25	122	10	0.18	296.22	Concave
25	123	30	0.58	186.3	Straight
25	124	30	0.58	115.35	Straight
25	125	20	0.36	45.35	Straight
26	126	8	0.16	196.15	Convex
26	127	14	0.25	221.09	Convex
26	128	11	0.19	170.1	Straight
26	129	20	0.36	40	Straight
26	130	9	0.16	11	Convex
27	131	8	0.14	863.2	Convex
27	132	3	0.05	707.12	Convex
27	133	17	0.31	447.18	Straight
27	134	23	0.42	287.13	Straight
27	135	31	0.6	97.13	Straight
28	136	3	0.05	1317.77	Convex
28	137	4	0.07	1067.57	Straight
28	138	7	0.12	567.57	Straight
28	139	5	0.09	232.15	Straight
28	140	15	0.27	150.15	Straight
29	141	4	0.07	158.65	Straight
29	142	6	0.11	660	Concave
29	143	20	0.36	312.2	Straight
29	144	22	0.4	162.35	Straight
29	145	20	0.36	60.35	Convex
30	146	4	0.07	174.2	Concave
30	147	3	0.05	14.3	Straight
30	148	9	0.16	94.32	Concave
30	149	8	0.14	132.2	Concave
30	150	8	0.14	54.13	Straight
31	151	5	0.09	1137	Convex

31	152	3	0.05	987	Convex
31	153	7	0.12	580	Straight
31	154	8	0.16	230	Straight
31	155	18	0.32	50	Straight
32	156	7	0.12	1159	Straight
32	157	8	0.16	687.5	Straight
32	158	39	0.81	158	Straight
32	159	10	0.18	94	Convex
32	160	20	0.36	11	Straight
33	161	5	0.09	247.5	Concave
33	162	10	0.18	185	Straight
33	163	8	0.14	97.5	Straight
33	164	5	0.09	33.5	Convex
33	165	7	0.12	2.5	Straight
34	166	5	0.09	525	Concave
34	167	3	0.05	445	Straight
34	168	3	0.05	295	Straight
34	169	5	0.05	232	Straight
34	170	2	0.03	10	Straight
35	171	6	0.11	367.4	Convex
35	172	4	0.07	242	Convex
35	173	4	0.07	162.5	Straight
35	174	10	0.18	87	Straight
35	175	12	0.21	36	Straight
36	176	5	0.09	515	Convex
36	177	6	0.11	436	Straight
36	178	3	0.05	373	Convex
36	179	4	0.07	138	Convex
36	180	5	0.09	30	Convex
37	181	2	0.03	987	Concave
37	182	4	0.07	782	Straight
37	183	4	0.07	579	Straight
37	184	4	0.07	279	Concave
37	185	15	0.27	20.5	Convex
38	186	3	0.05	358	Straight
38	187	8	0.14	292	Straight
38	188	8	0.14	142.3	Straight
38	189	17	0.31	82	Concave
38	190	18	0.32	15	Convex
39	191	4	0.07	356	Convex
39	192	4	0.07	216	Straight
39	193	10	0.18	126	Straight
39	194	12	0.21	86	Concave
39	195	7	0.12	7	Straight
40	196	4	0.07	720	Convex
40	197	3	0.05	675	Convex
40	198	11	0.19	343	Convex
40	199	4	0.07	267	Straight
40	200	10	0.18	80	Straight
41	201	4	0.07	461	Straight
41	202	4	0.07	339	Convex
41	203	7	0.12	234	Straight

41	204	3	0.05	122	Concave
41	205	3	0.05	10	Convex
42	206	8	0.14	435	Convex
42	207	12	0.21	349	Concave
42	208	10	0.18	169	Straight
42	209	6	0.14	79	Convex
42	210	5	0.09	12	Convex
43	211	3	0.05	646	Straight
43	212	4	0.07	466	Straight
43	213	4	0.07	296	Straight
43	214	11	0.19	146	Straight
43	215	20	0.36	16	Straight
44	216	4	0.07	597.5	Straight
44	217	4	0.07	517.3	Straight
44	218	3	0.05	301.5	Straight
44	219	6	0.11	170	Straight
44	220	3	0.05	81.5	Convex
45	221	2	0.03	420	Straight
45	222	13	0.23	350	Straight
45	223	8	0.14	230	Straight
45	224	20	0.36	160	Straight
45	225	33	0.65	50	Straight
46	226	2	0.03	761.3	Straight
46	227	3	0.05	647	Straight
46	228	5	0.09	433	Straight
46	229	4	0.07	283	Convex
46	230	7	0.12	29.5	Straight
47	231	2	0.03	429.46	Straight
47	232	3	0.05	353	Straight
47	233	8	0.14	233	Straight
47	234	8	0.14	103	Convex
47	235	8	0.14	23	Convex
48	236	10	0.18	320	Straight
48	237	5	0.09	270	Straight
48	238	13	0.23	200	Straight
48	239	6	0.11	128	Concave
48	240	12	0.21	38	Convex
49	241	3	0.05	707.5	Convex
49	242	4	0.07	442	Convex
49	243	10	0.18	352	Concave
49	244	12	0.21	148	Concave
49	245	8	0.14	23	Convex
50	246	5	0.09	722	Straight
50	247	2	0.03	382	Straight
50	248	10	0.18	258	Straight
50	249	16	0.29	52	Straight
50	250	5	0.09	7	Convex
51	251	1	0.02	1070.45	Straight
51	252	4	0.07	788.5	Straight
51	253	4	0.07	388	Straight
51	254	16	0.29	138.5	Concave
51	255	17	0.31	53.5	Straight

52	256	3	0.05	1561.5	Straight
52	257	4	0.07	1221	Straight
52	258	4	0.07	391	Straight
52	259	12	0.21	184.5	Concave
52	260	30	0.58	112.5	Straight
53	261	0.5	0.51	443.4	Straight
53	262	5	0.09	361	Straight
53	263	13	0.23	282.5	Straight
53	264	19	0.34	173	Concave
53	265	29	0.55	21	Straight
54	266	11	0.19	565.6	Convex
54	267	7	0.12	393	Straight
54	268	14	0.25	153	Straight
54	269	19	0.34	95	Straight
54	270	21	0.38	50	Convex
55	271	2	0.03	590	Straight
55	272	10	0.18	464	Straight
55	273	13	0.23	264	Straight
55	274	19	0.34	158	Convex
55	275	27	0.51	78	Straight
56	276	3	0.05	630.45	Convex
56	277	1	0.02	400	Straight
56	278	10	0.18	209.5	Straight
56	279	19	0.34	119	Straight
56	280	14	0.84	43	Straight
57	281	1	0.02	652	Concave
57	282	4	0.07	470	Straight
57	283	21	0.38	156	Straight
57	284	12	0.21	65	Concave
57	285	13	0.23	11	Straight
58	286	2	0.03	413.5	Straight
58	287	2	0.03	297	Straight
58	288	16	0.29	143	Straight
58	289	21	0.38	71	Straight
58	290	18	0.32	11	Convex
59	291	2	0.03	270.6	Wavy
59	292	9	0.16	172	Straight
59	293	26	0.49	108	Straight
59	294	16	0.29	22.5	Concave
59	295	3	0.05	3.5	Convex
60	296	2	0.03	578.5	Straight
60	297	2	0.03	461.5	Straight
60	298	18	0.32	251.4	Straight
60	299	11	0.19	148	Concave
60	300	19	0.34	38	Straight

APPENDIX TWO A

Growth-forms of Plant

Photo. 1- Widespread growth of *Juniperus procera* species in the western part of the Upper Wadi Bishah basin.

Photo. 2- A good stand of *Juniperus procera* in the eastern slopes of the Asir mountains.

Photo. 3- A general view of the mixed growth of *Juniperus procera* and *Acacia gerradii* species in the south-western part of Wadi Bishah basin (North Abha City).

Photo. 4- A pure stand of *Acacia negrii* in the south and the south-eastern part of Wadi Bishah basin.

Photo. 5- The mixed growth of *Acacia gerradii* and *Juniperus procera* species in the south-western part of Wadi Bishah basin (South Abha City).

Photo. 6- The researcher scrutinizes the *Calotropis procera* species in the eastern part of Wadi Bishah basin (Samakh region).

Photo. 7- The mixed growth of *Dodonaea viscosa* shrubs and *Juniperus procera* trees in the northern part of the Asir mountains (west and north-west of Wadi Bishah).

Photo. 8- Forms of pasture growth in the eastern hill-slopes of the Asir mountains.

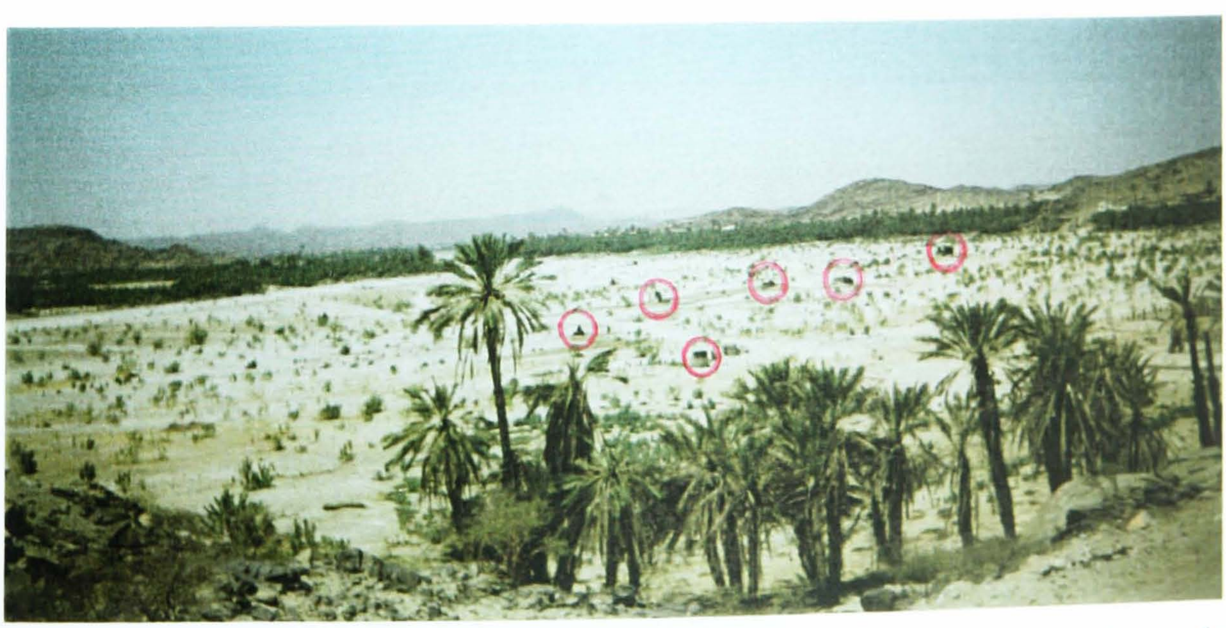

Photo. 9- The mouth of the Upper Wadi basin. Note the wells of groundwater (red circle) and Palm farms on the banks of the wadi.

Photo. 10- Trees of *Olea europaea* species in the main stream of Wadi Bishah. Note one of the assistant research employees standing in the vicinity of the tree trunk.

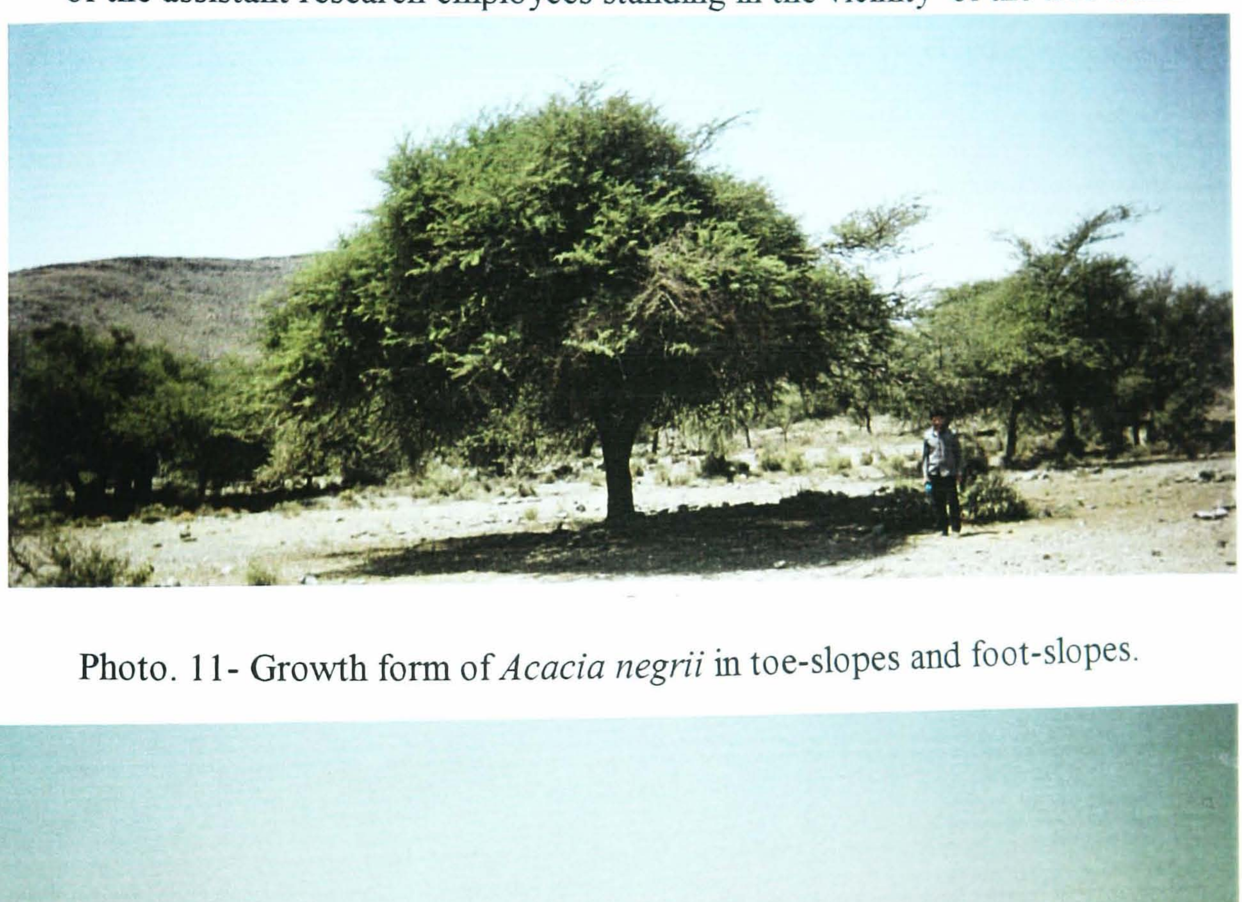

Photo. 11- Growth form of *Acacia negrii* in toe-slopes and foot-slopes.

Photo. 12- A pure stand of *Acacia arabica* in the northern part of the study area. The degradation of range land can be observed in this plate.

APPENDIX TWO B
Vegetation Data

Vegetation Data

Location / Upper Wadi Bishah.

Researcher / Al- Qatani M.

Date: from 1 July 1996 to 30 september 1996

Cover value % was computed according to Domin scale.

Tra-nse-ct NO	Sa-mpl-e NO	qu ar-ter NO	Plant species	Dista-nce m/c	Heig-ht m/c	Basal diamet-er c	Basal area c²	Crown area m²	Co-ver val-ue *	Mean heig-ht of wee-ds c
1	1	1	Acacia arabica (Lam.) Willd.	4.00	0.50	3.00	7.07	0.54	3	3
1	1	2	Acacia arabica (Lam.) Willd.	9.00	8.00	9.97	78.10	9.18	3	3
1	1	3	Phoenix dactylifera L.	9.50	14.00	149.00	17443.64	176.79	3	3
1	1	4	Acacia arabica (Lam.) Willd.	6.08	2.15	7.00	38.50	3.14	3	3
1	2	1	Acacia arabica (Lam.) Willd.	2.10	1.72	7.00	38.50	1.13	3	2
1	2	2	Acacia arabica (Lam.) Willd.	1.27	1.10	3.50	9.63	1.13	3	2
1	2	3	Lycium shawii Roem. et Sch.	3.50	1.67	4.98	19.49	3.14	3	2
1	2	4	Acacia arabica (Lam.) Willd.	9.20	1.20	4.00	12.57	0.79	3	2
1	3	1	Acacia arabica (Lam.) Willd.	9.00	3.60	9.97	78.10	9.18	3	2
1	3	2	Acacia arabica (Lam.) Willd.	2.20	2.50	7.00	38.50	3.84	3	2
1	3	3	Lagonychium farctum (Banks & Sol.) Bober.	1.50	0.50	3.00	7.07	0.54	3	2
1	3	4	Acacia arabica (Lam.) Willd.	5.00	2.00	8.50	56.77	3.14	3	2
1	4	1	Acacia arabica (Lam.) Willd.	10.00	1.82	10.00	78.57	3.13	3	2
1	4	2	Acacia arabica (Lam.) Willd.	8.33	2.70	7.00	38.50	3.84	3	2
1	4	3	Acacia arabica (Lam.) Willd.	9.00	0.95	4.00	12.57	1.13	3	2
1	4	4	Acacia arabica (Lam.) Willd.	7.17	0.50	3.50	9.63	0.79	3	2
1	5	1	Acacia arabica (Lam.) Willd.	4.00	2.35	24.00	452.57	7.07	3	2
1	5	2	Acacia arabica (Lam.) Willd.	5.21	1.97	9.00	63.64	7.07	3	2
1	5	3	Acacia arabica (Lam.) Willd.	6.58	1.96	6.00	28.29	7.07	3	2
1	5	4	Acacia arabica (Lam.) Willd.	7.09	2.19	12.00	113.14	12.57	3	2
2	6	1	Acacia arabica (Lam.) Willd.	8.40	4.78	28.00	616.00	19.64	3	1
2	6	2	Acacia arabica (Lam.) Willd.	3.72	2.00	8.00	50.29	1.13	3	1
2	6	3	Acacia arabica (Lam.) Willd.	4.15	1.60	8.00	50.29	1.13	3	1
2	6	4	Acacia arabica (Lam.) Willd.	6.39	0.86	3.00	7.07	0.79	3	1
2	7	1	Acacia arabica (Lam.) Willd.	3.60	0.85	4.00	12.57	0.79	3	1
2	7	2	Acacia arabica (Lam.) Willd.	4.56	1.63	8.00	50.29	3.13	3	1
2	7	3	Acacia arabica (Lam.) Willd.	5.70	0.87	6.00	28.29	0.84	3	1
2	7	4	Acacia arabica (Lam.) Willd.	8.50	1.50	6.97	38.17	3.13	3	1
2	8	1	Acacia arabica (Lam.) Willd.	4.00	1.18	4.00	12.57	0.79	3	2
2	8	2	Acacia arabica (Lam.) Willd.	6.19	2.33	8.00	50.29	3.13	3	2
2	8	3	Acacia arabica (Lam.) Willd.	9.62	1.25	7.00	38.50	3.74	3	2
2	8	4	Acacia arabica (Lam.) Willd.	6.30	2.40	7.00	38.50	3.84	3	2
2	9	1	Acacia arabica (Lam.) Willd.	9.90	2.00	4.00	12.57	1.13	3	2
2	9	2	Acacia arabica (Lam.) Willd.	9.85	1.00	4.00	12.57	0.79	3	2
2	9	3	Acacia arabica (Lam.) Willd.	7.79	1.52	6.00	28.29	1.34	3	2
2	9	4	Acacia arabica (Lam.) Willd.	8.75	0.90	4.00	12.57	0.84	3	2
2	10	1	Acacia arabica (Lam.) Willd.	8.20	1.00	6.00	28.29	1.84	3	2
2	10	2	Acacia arabica (Lam.) Willd.	9.15	0.92	4.00	12.57	0.79	3	2
2	10	3	Acacia arabica (Lam.) Willd.	9.95	1.25	6.00	28.29	1.84	3	2
2	10	4	Acacia arabica (Lam.) Willd.	9.54	1.02	4.00	12.57	1.13	3	2
3	11	1	Lycium shawii Roem. et Sch.	8.50	2.00	6.00	28.29	3.13	2	1
3	11	2	Lycium shawii Roem. et Sch.	6.00	2.32	7.00	38.50	3.13	2	1
3	11	3	Acacia arabica (Lam.) Willd.	5.10	3.15	14.00	154.00	12.57	2	1

3	11	4	Acacia arabica (Lam.) Willd.	4.50	2.70	18.00	254.57	9.63	2	1
3	12	1	Lagonychium farctum (Banks & Sol.) Bober.	7.00	0.53	3.00	7.07	0.50	2	1
3	12	2	Acacia arabica (Lam.) Willd.	9.15	1.53	4.00	12.57	1.33	2	1
3	12	3	Acacia arabica (Lam.) Willd.	2.40	0.67	3.00	7.07	0.64	2	1
3	12	4	Acacia arabica (Lam.) Willd.	3.00	1.73	7.00	38.50	3.14	2	1
3	13	1	Acacia arabica (Lam.) Willd.	8.00	2.60	7.00	38.50	3.14	2	1
3	13	2	Acacia arabica (Lam.) Willd.	9.30	3.00	6.00	28.29	3.14	2	1
3	13	3	Acacia arabica (Lam.) Willd.	9.05	1.55	3.50	9.63	2.79	2	1
3	13	4	Acacia arabica (Lam.) Willd.	2.53	2.70	6.00	28.29	3.84	2	1
3	14	1	Acacia arabica (Lam.) Willd.	6.37	0.50	3.00	7.07	0.50	2	2
3	14	2	Lycium shawii Roem. et Sch.	10.00	3.00	18.00	254.57	12.57	2	2
3	14	3	Acacia arabica (Lam.) Willd.	8.90	2.80	6.00	28.29	7.07	2	2
3	14	4	Acacia arabica (Lam.) Willd.	2.10	1.82	7.00	38.50	3.14	2	2
3	15	1	Lagonychium farctum (Banks & Sol.) Bober.	4.00	0.54	3.50	9.63	0.65	2	1
3	15	2	Acacia arabica (Lam.) Willd.	1.80	0.50	3.00	7.07	0.50	2	1
3	15	3	Lycium shawii Roem. et Sch.	8.30	2.33	6.23	30.50	19.64	2	1
3	15	4	Lycium shawii Roem. et Sch.	2.51	2.46	30.00	707.14	19.64	2	1
4	16	1	Acacia arabica (Lam.) Willd.	3.35	2.55	9.94	77.63	6.64	2	2
4	16	2	Acacia arabica (Lam.) Willd.	7.20	1.73	4.00	12.57	3.13	2	2
4	16	3	Acacia arabica (Lam.) Willd.	4.50	0.72	3.50	9.63	0.79	2	2
4	16	4	Acacia arabica (Lam.) Willd.	7.00	0.58	3.00	7.07	0.57	2	2
4	17	1	Acacia arabica (Lam.) Willd.	3.50	2.10	7.00	38.50	19.64	2	2
4	17	2	Acacia arabica (Lam.) Willd.	3.00	1.50	6.00	28.29	4.91	2	2
4	17	3	Acacia arabica (Lam.) Willd.	7.50	1.00	4.00	12.57	2.10	2	2
4	17	4	Acacia arabica (Lam.) Willd.	2.00	0.50	3.00	7.07	0.54	2	2
4	18	1	Acacia arabica (Lam.) Willd.	8.35	0.55	3.00	7.07	0.64	2	2
4	18	2	Acacia arabica (Lam.) Willd.	9.20	1.73	4.00	12.57	3.13	2	2
4	18	3	Acacia arabica (Lam.) Willd.	4.50	0.72	3.50	9.63	0.79	2	2
4	18	4	Acacia arabica (Lam.) Willd.	7.00	2.08	7.00	38.50	12.57	2	2
4	19	1	Acacia arabica (Lam.) Willd.	9.70	1.50	7.00	38.50	3.14	2	2
4	19	2	Acacia arabica (Lam.) Willd.	9.86	2.00	4.00	12.57	3.14	2	2
4	19	3	Acacia arabica (Lam.) Willd.	6.35	1.72	7.00	38.50	3.14	2	2
4	19	4	Acacia arabica (Lam.) Willd.	5.20	1.53	6.00	28.29	2.12	2	2
4	20	1	Acacia arabica (Lam.) Willd.	10.00	1.20	6.00	28.29	0.96	2	1
4	20	2	Acacia arabica (Lam.) Willd.	8.64	0.89	3.50	9.63	0.79	2	1
4	20	3	Lycium shawii Roem. et Sch.	9.92	0.98	4.00	12.57	0.84	2	1
4	20	4	Lycium shawii Roem. et Sch.	6.00	1.35	6.00	28.29	1.13	2	1
5	21	1	Lycium shawii Roem. et Sch.	3.00	0.50	3.00	7.07	0.50	5	5
5	21	2	Acacia gerradii Benth.	7.39	9.23	80.00	5028.57	132.79	5	5
5	21	3	Acacia gerradii Benth.	3.82	4.37	7.00	38.50	12.57	5	5
5	21	4	Acacia gerradii Benth.	6.88	3.08	6.00	28.29	3.14	5	5
5	22	1	Euryops arabicus Steud.	9.89	0.65	4.00	12.57	0.60	4	4
5	22	2	Acacia gerradii Benth.	5.55	3.00	10.00	78.57	9.63	4	4
5	22	3	Acacia gerradii Benth.	8.90	2.20	6.00	28.29	9.63	4	4
5	22	4	Acacia gerradii Benth.	9.00	3.10	10.00	78.57	10.25	4	4
5	23	1	Acacia arabica (Lam.) Willd.	9.60	2.00	7.00	38.50	2.25	5	5
5	23	2	Dodonaea viscosa Jacj.	10.00	1.20	4.70	17.36	1.97	5	5
5	23	3	Dodonaea viscosa Jacj.	6.00	0.63	4.00	12.57	0.50	5	5
5	23	4	Lycium shawii Roem. et Sch.	9.22	0.50	3.50	9.63	0.50	5	5
5	24	1	Psiadia arabica Jaub. et SP.	2.80	0.50	3.50	9.63	0.54	4	4
5	24	2	Lycium shawii Roem. et Sch.	10.00	0.50	3.00	7.07	0.50	4	4
5	24	3	Psiadia arabica Jaub. et SP.	9.80	0.80	4.00	12.57	0.54	4	4

5	24	4	Leptadenia pyrotechnica (Forssk.) Decne.	6.50	0.60	4.00	12.57	0.54	4	4
5	25	1	Lycium shawii Roem. et Sch.	2.00	0.50	3.00	7.07	0.50	4	4
5	25	2	Lycium shawii Roem. et Sch.	8.70	0.72	3.50	9.63	0.50	4	4
5	25	3	Lycium shawii Roem. et Sch.	8.00	0.80	3.50	9.63	0.54	4	4
5	25	4	Acacia gerradii Benth.	7.58	1.80	6.00	28.29	1.15	4	4
6	26	1	Acacia gerradii Benth.	4.92	10.20	40.00	1257.14	95.07	8	5
6	26	2	Acacia gerradii Benth.	5.05	9.87	30.00	707.14	38.50	8	5
6	26	3	Acacia gerradii Benth.	7.76	11.50	18.00	254.57	63.64	8	5
6	26	4	Acacia gerradii Benth.	9.50	10.30	20.00	314.29	63.64	8	5
6	27	1	Acacia gerradii Benth.	9.40	3.20	6.00	28.29	3.14	6	4
6	27	2	Acacia gerradii Benth.	4.00	9.65	24.50	471.63	50.29	6	4
6	27	3	Acacia gerradii Benth.	6.50	9.00	25.00	491.07	28.29	6	4
6	27	4	Acacia gerradii Benth.	5.60	1.80	7.00	38.50	3.14	6	4
6	28	1	Acacia gerradii Benth.	6.50	6.75	29.00	660.79	12.57	4	5
6	28	2	Acacia gerradii Benth.	6.40	1.75	6.00	28.29	3.14	4	5
6	28	3	Acacia gerradii Benth.	6.30	1.50	6.00	28.29	2.01	4	5
6	28	4	Acacia gerradii Benth.	6.80	6.71	27.00	572.79	15.91	4	5
6	29	1	Acacia gerradii Benth.	8.00	3.20	7.00	38.50	5.24	4	6
6	29	2	Acacia gerradii Benth.	9.90	3.00	7.00	38.50	4.38	4	6
6	29	3	Acacia gerradii Benth.	10.00	2.25	6.00	28.29	3.14	4	6
6	29	4	Psiadia arabica Jaub. et SP.	7.60	0.80	3.00	7.07	0.50	4	6
6	30	1	Psiadia arabica Jaub. et SP.	10.00	0.60	3.00	7.07	0.50	4	4
6	30	2	Psiadia arabica Jaub. et SP.	9.30	0.75	3.00	7.07	0.54	4	4
6	30	3	Acacia gerradii Benth.	10.00	1.30	4.00	12.57	1.39	4	4
6	30	4	Psiadia arabica Jaub. et SP.	8.10	0.70	3.50	9.63	0.50	4	4
7	31	1	Menthal lavandulacea Willd.	6.50	0.90	7.00	38.50	3.14	6	6
7	31	2	Menthal lavandulacea Willd.	4.70	1.05	7.00	38.50	4.71	6	6
7	31	3	Solanum incanum L.	4.85	0.59	4.00	12.57	0.65	6	6
7	31	4	Solanum incanum L.	4.00	0.53	3.50	9.63	0.50	6	6
7	32	1	Psiadia arabica Jaub. et SP.	9.95	0.62	3.00	7.07	0.54	6	6
7	32	2	Dodonaea viscosa Jacj.	3.38	1.15	6.00	28.29	9.63	6	6
7	32	3	Dodonaea viscosa Jacj.	9.70	1.00	4.00	12.57	8.45	6	6
7	32	4	Psiadia arabica Jaub. et SP.	7.60	0.50	3.00	7.07	0.50	6	6
7	33	1	Menthal lavandulacea Willd.	4.06	1.60	8.00	50.29	3.14	7	8
7	33	2	Dodonaea viscosa Jacj.	5.00	2.30	8.00	50.29	7.07	7	8
7	33	3	Euryops arabicus Steud.	1.20	0.78	4.00	12.57	0.65	7	8
7	33	4	Dodonaea viscosa Jacj.	3.20	1.92	7.00	38.50	2.01	7	8
7	34	1	Dodonaea viscosa Jacj.	2.30	0.69	3.50	9.63	0.65	5	7
7	34	2	Lavandula dentata L.	2.00	0.75	4.00	12.57	0.79	5	7
7	34	3	Dodonaea viscosa Jacj.	3.10	0.70	4.00	12.57	0.94	5	7
7	34	4	Dodonaea viscosa Jacj.	10.00	0.58	4.00	12.57	0.54	5	7
7	35	1	Dodonaea viscosa Jacj.	6.00	1.30	6.00	28.29	3.14	7	8
7	35	2	Dodonaea viscosa Jacj.	9.05	0.50	3.00	7.07	0.50	7	8
7	35	3	Dodonaea viscosa Jacj.	4.00	1.25	7.00	38.50	2.01	7	8
7	35	4	Dodonaea viscosa Jacj.	6.30	1.36	6.00	28.29	3.14	7	8
8	36	1	Juniperus procera Hochst. ex Endl.	10.00	10.35	80.00	5028.57	50.29	7	30
8	36	2	Juniperus procera Hochst. ex Endl.	1.80	2.60	7.00	38.50	1.33	7	30
8	36	3	Lavandula dentata L.	2.00	0.75	4.00	12.57	0.95	7	30
8	36	4	Juniperus procera Hochst. ex Endl.	5.20	6.47	35.00	962.50	78.57	7	30
8	37	1	Acacia gerradii Benth.	1.58	1.12	4.00	12.57	1.34	8	32
8	37	2	Juniperus procera Hochst. ex Endl.	3.50	3.09	13.00	132.79	7.07	8	32
8	37	3	Dodonaea viscosa Jacj.	2.30	1.90	7.00	38.50	2.01	8	32

8	37	4	Dodonaea viscosa Jacj.	4.45	1.40	7.00	38.50	2.27	8	32
8	38	1	Euryops arabicus Steud.	1.30	1.08	3.50	9.63	0.79	8	35
8	38	2	Dodonaea viscosa Jacj.	0.65	1.55	7.00	38.50	1.13	8	35
8	38	3	Acacia negrii Pichi-Sermolli.	0.65	3.20	8.00	50.29	1.13	8	35
8	38	4	Juniperus procera Hochst. ex Endl.	3.00	6.60	100.00	7857.14	28.29	8	35
8	39	1	Dodonaea viscosa Jacj.	4.00	0.83	4.50	15.91	1.54	6	28
8	39	2	Lycium shawii Roem. et Sch.	5.50	0.80	4.00	12.57	1.13	6	28
8	39	3	Juniperus procera Hochst. ex Endl.	4.25	3.38	32.00	804.57	28.29	6	28
8	39	4	Dodonaea viscosa Jacj.	3.38	1.00	6.00	28.29	1.13	6	28
8	40	1	Juniperus procera Hochst. ex Endl.	4.43	2.43	18.76	276.52	9.63	6	26
8	40	2	Euryops arabicus Steud.	1.30	0.88	4.00	12.57	0.65	6	26
8	40	3	Juniperus procera Hochst. ex Endl.	1.30	3.18	40.00	1257.14	28.29	6	26
8	40	4	Dodonaea viscosa Jacj.	2.00	0.75	3.50	9.63	0.65	6	26
9	41	1	Juniperus procera Hochst. ex Endl.	8.00	5.86	68.00	3633.14	63.64	8	45
9	41	2	Juniperus procera Hochst. ex Endl.	4.08	7.72	90.00	6364.29	78.57	8	45
9	41	3	Dodonaea viscosa Jacj.	5.05	0.93	4.00	12.57	0.79	8	45
9	41	4	Dodonaea viscosa Jacj.	5.00	0.61	3.50	9.63	0.65	8	45
9	42	1	Euryops arabicus Steud.	1.40	1.00	4.00	12.57	0.79	8	43
9	42	2	Juniperus procera Hochst. ex Endl.	3.38	7.95	82.00	5283.14	28.29	8	43
9	42	3	Dodonaea viscosa Jacj.	2.00	0.89	3.50	9.63	1.13	8	43
9	42	4	Dodonaea viscosa Jacj.	2.10	0.90	3.50	9.63	0.79	8	43
9	43	1	Dodonaea viscosa Jacj.	4.00	0.95	3.50	9.63	0.69	6	35
9	43	2	Dodonaea viscosa Jacj.	2.00	1.15	4.00	12.57	0.53	6	35
9	43	3	Juniperus procera Hochst. ex Endl.	6.30	2.36	33.00	855.64	15.61	6	35
9	43	4	Euryops arabicus Steud.	3.20	0.76	3.50	9.63	0.55	6	35
9	44	1	Dodonaea viscosa Jacj.	8.10	1.18	7.00	38.50	1.13	6	33
9	44	2	Dodonaea viscosa Jacj.	5.30	1.09	6.00	28.29	1.33	6	33
9	44	3	Juniperus procera Hochst. ex Endl.	6.30	3.39	20.00	314.29	12.57	6	33
9	44	4	Juniperus procera Hochst. ex Endl.	7.25	3.50	22.00	380.29	63.64	6	33
9	45	1	Dodonaea viscosa Jacj.	3.20	1.06	7.00	38.50	1.13	5	28
9	45	2	Dodonaea viscosa Jacj.	5.50	2.76	7.00	38.50	0.79	5	28
9	45	3	Juniperus procera Hochst. ex Endl.	7.23	4.70	34.00	908.29	19.64	5	28
9	45	4	Juniperus procera Hochst. ex Endl.	3.70	4.37	8.00	50.29	1.54	5	28
10	46	1	Juniperus procera Hochst. ex Endl.	8.50	3.80	6.00	28.29	7.55	6	27
10	46	2	Acacia gerradii Benth.	5.00	3.00	12.00	113.14	12.57	6	27
10	46	3	Juniperus procera Hochst. ex Endl.	3.22	5.60	40.00	1257.14	19.64	6	27
10	46	4	Euryops arabicus Steud.	7.55	0.65	4.00	12.57	0.64	6	27
10	47	1	Juniperus procera Hochst. ex Endl.	3.38	3.50	12.00	113.14	3.14	7	32
10	47	2	Euryops arabicus Steud.	2.20	1.10	6.00	28.29	1.13	7	32
10	47	3	Sageretia thea (Osb.) M.C. Johnst.	2.05	0.65	4.00	12.57	0.65	7	32
10	47	4	Juniperus procera Hochst. ex Endl.	5.30	3.30	25.00	491.07	2.36	7	32
10	48	1	Lycium shawii Roem. et Sch.	2.05	1.40	3.50	9.63	1.13	7	35
10	48	2	Dodonaea viscosa Jacj.	3.50	1.38	6.00	28.29	1.13	7	35
10	48	3	Juniperus procera Hochst. ex Endl.	0.80	4.77	68.00	3633.14	19.64	7	35
10	48	4	Euryops arabicus Steud.	0.90	0.88	3.00	7.07	0.50	7	35
10	49	1	Juniperus procera Hochst. ex Endl.	3.70	2.70	18.00	254.57	2.70	5	30
10	49	2	Dodonaea viscosa Jacj.	2.30	1.26	7.00	38.50	1.26	5	30
10	49	3	Euryops arabicus Steud.	4.00	0.97	6.00	28.29	0.97	5	30
10	49	4	Juniperus procera Hochst. ex Endl.	3.10	2.30	38.00	1134.57	2.30	5	30
10	50	1	Dodonaea viscosa Jacj.	3.20	1.30	6.00	28.29	1.30	6	31
10	50	2	Juniperus procera Hochst. ex Endl.	3.50	1.10	8.00	50.29	1.10	6	31
10	50	3	Dodonaea viscosa Jacj.	2.30	0.60	4.00	12.57	0.60	6	31

10	50	4	Euryops arabicus Steud.	5.50	0.80	3.50	9.63	0.80	6	31
11	51	1	Dodonaea viscosa Jacj.	2.00	1.20	4.00	12.57	0.79	7	38
11	51	2	Acacia gerradii Benth.	3.20	3.10	14.00	154.00	28.29	7	38
11	51	3	Juniperus procera Hochst. ex Endl.	4.50	3.20	25.00	491.07	23.77	7	38
11	51	4	Juniperus procera Hochst. ex Endl.	4.55	5.00	26.00	531.14	50.29	7	38
11	52	1	Sageretia thea (Osb.) M.C. Johnst.	2.10	0.80	3.00	7.07	0.64	7	42
11	52	2	Acacia gerradii Benth.	3.20	3.60	6.00	28.29	12.57	7	42
11	52	3	Juniperus procera Hochst. ex Endl.	5.18	3.80	24.00	452.57	9.63	7	42
11	52	4	Euryops arabicus Steud.	0.60	0.76	4.00	12.57	0.57	7	42
11	53	1	Acacia negrii Pichi-Sermolli.	6.40	4.00	8.00	50.29	12.57	7	48
11	53	2	Dodonaea viscosa Jacj.	2.00	2.30	6.00	28.29	1.77	7	48
11	53	3	Dodonaea viscosa Jacj.	2.10	1.50	4.00	12.57	3.14	7	48
11	53	4	Juniperus procera Hochst. ex Endl.	6.00	6.80	60.00	2828.57	56.57	7	48
11	54	1	Euryops arabicus Steud.	3.90	1.25	3.50	9.63	0.79	8	50
11	54	2	Dodonaea viscosa Jacj.	7.50	7.30	39.00	1195.07	38.50	8	50
11	54	3	Juniperus procera Hochst. ex Endl.	4.10	1.30	4.00	12.57	3.14	8	50
11	54	4	Euryops arabicus Steud.	2.50	0.80	3.00	7.07	1.13	8	50
11	55	1	Acacia negrii Pichi-Sermolli.	2.08	3.50	15.00	176.79	44.20	8	62
11	55	2	Euryops arabicus Steud.	3.00	1.20	6.00	28.29	3.14	8	62
11	55	3	Lavandula dentata L.	1.25	0.95	4.00	12.57	0.79	8	62
11	55	4	Dodonaea viscosa Jacj.	2.00	0.60	4.00	12.57	0.79	8	62
12	56	1	Acacia negrii Pichi-Sermolli.	6.00	4.30	8.00	50.29	7.07	5	17
12	56	2	Juniperus procera Hochst. ex Endl.	5.50	2.50	14.00	154.00	12.57	5	17
12	56	3	Juniperus procera Hochst. ex Endl.	3.00	2.70	18.00	254.57	3.14	5	17
12	56	4	Acacia negrii Pichi-Sermolli.	5.30	2.65	8.00	50.29	12.57	5	17
12	57	1	Dodonaea viscosa Jacj.	1.55	1.00	3.50	9.63	1.00	6	20
12	57	2	Juniperus procera Hochst. ex Endl.	4.00	3.35	18.00	254.57	12.57	6	20
12	57	3	Dodonaea viscosa Jacj.	3.60	0.95	4.00	12.57	0.79	6	20
12	57	4	Dodonaea viscosa Jacj.	2.20	0.83	3.50	9.63	0.65	6	20
12	58	1	Dodonaea viscosa Jacj.	2.00	1.33	3.50	9.63	0.79	6	21
12	58	2	Juniperus procera Hochst. ex Endl.	6.60	4.75	30.00	707.14	28.29	6	21
12	58	3	Juniperus procera Hochst. ex Endl.	4.50	3.70	30.00	707.14	12.57	6	21
12	58	4	Euryops arabicus Steud.	2.35	0.58	3.00	7.07	0.54	6	21
12	59	1	Euryops arabicus Steud.	4.00	0.90	3.50	9.63	0.79	5	13
12	59	2	Juniperus procera Hochst. ex Endl.	10.00	5.10	6.00	28.29	707.14	5	13
12	59	3	Euryops arabicus Steud.	3.00	0.50	3.00	7.07	0.54	5	13
12	59	4	Dodonaea viscosa Jacj.	3.10	0.80	3.50	9.63	0.79	5	13
12	60	1	Euryops arabicus Steud.	2.00	0.72	3.00	7.07	0.64	7	23
12	60	2	Dodonaea viscosa Jacj.	1.30	1.00	4.00	12.57	2.36	7	23
12	60	3	Dodonaea viscosa Jacj.	5.00	1.15	6.00	28.29	2.36	7	23
12	60	4	Dodonaea viscosa Jacj.	1.10	1.10	6.00	28.29	3.14	7	23
13	61	1	Euryops arabicus Steud.	7.00	0.78	6.00	28.29	0.79	5	16
13	61	2	Acacia negrii Pichi-Sermolli.	5.10	2.33	10.00	78.57	7.07	5	16
13	61	3	Euryops arabicus Steud.	5.15	1.30	7.00	38.50	3.14	5	16
13	61	4	Acacia negrii Pichi-Sermolli.	5.00	3.18	12.00	113.14	23.77	5	16
13	62	1	Psiadia arabica Jaub. et SP.	9.00	0.50	4.00	12.57	0.54	7	21
13	62	2	Euryops arabicus Steud.	5.00	0.50	4.00	12.57	0.50	7	21
13	62	3	Euryops arabicus Steud.	4.00	0.78	6.00	28.29	0.74	7	21
13	62	4	Acacia negrii Pichi-Sermolli.	4.00	0.65	6.00	28.29	1.13	7	21
13	63	1	Psiadia arabica Jaub. et SP.	9.00	0.50	3.00	7.07	0.65	7	29
13	63	2	Juniperus procera Hochst. ex Endl.	5.50	4.20	20.00	314.29	28.29	7	29
13	63	3	Euryops arabicus Steud.	7.00	0.85	4.00	12.57	0.79	7	29

13	63	4	Euryops arabicus Steud.	8.20	0.60	4.00	12.57	0.65	7	29
13	64	1	Euryops arabicus Steud.	8.60	0.60	3.00	7.07	0.50	5	19
13	64	2	Euryops arabicus Steud.	9.55	0.57	3.00	7.07	0.54	5	19
13	64	3	Euryops arabicus Steud.	10.00	0.70	3.50	9.63	0.79	5	19
13	64	4	Euryops arabicus Steud.	10.05	0.50	4.00	12.57	0.65	5	19
13	65	1	Euryops arabicus Steud.	4.00	0.50	3.00	7.07	0.55	5	20
13	65	2	Euryops arabicus Steud.	2.50	0.67	3.00	7.07	0.65	5	20
13	65	3	Euryops arabicus Steud.	2.90	0.82	3.50	9.63	0.79	5	20
13	65	4	Sageretia thea (Osb.) M.C. Johnst.	3.00	0.70	3.00	7.07	0.50	5	20
14	66	1	Acacia gerradii Benth.	9.70	3.00	6.00	28.29	12.14	4	5
14	66	2	Acacia gerradii Benth.	9.90	2.20	6.00	28.29	2.56	4	5
14	66	3	Acacia gerradii Benth.	3.50	4.20	8.00	50.29	23.14	4	5
14	66	4	Acacia gerradii Benth.	6.00	1.60	6.00	28.29	2.56	4	5
14	67	1	Lycium shawii Roem. et Sch.	4.00	0.35	3.00	7.07	0.50	3	2
14	67	2	Acacia gerradii Benth.	3.00	0.50	4.00	12.57	0.45	3	2
14	67	3	Acacia gerradii Benth.	4.00	0.55	4.00	12.57	1.30	3	2
14	67	4	Acacia gerradii Benth.	6.00	5.20	60.00	2828.57	28.29	3	2
14	68	1	Acacia gerradii Benth.	8.00	0.65	4.00	12.57	0.65	3	3
14	68	2	Acacia gerradii Benth.	9.90	0.95	3.50	9.63	0.79	3	3
14	68	3	Acacia gerradii Benth.	9.75	1.20	6.00	28.29	0.94	3	3
14	68	4	Acacia gerradii Benth.	2.50	3.80	12.00	113.14	12.00	3	3
14	69	1	Acacia gerradii Benth.	1.50	0.60	3.00	7.07	0.45	3	3
14	69	2	Acacia gerradii Benth.	9.95	1.00	7.50	44.20	0.78	3	3
14	69	3	Acacia gerradii Benth.	5.00	0.70	4.00	12.57	0.78	3	3
14	69	4	Acacia gerradii Benth.	5.33	4.80	28.00	616.00	50.00	3	3
14	70	1	Acacia gerradii Benth.	9.20	1.30	3.00	7.07	12.14	3	2
14	70	2	Acacia gerradii Benth.	10.00	1.45	4.00	12.57	2.56	3	2
14	70	3	Acacia gerradii Benth.	8.76	0.95	4.00	12.57	1.30	3	2
14	70	4	Acacia gerradii Benth.	9.80	2.10	7.50	44.20	4.18	3	2
15	71	1	Lycium shawii Roem. et Sch.	3.90	1.90	4.00	12.57	0.79	3	4
15	71	2	Acacia gerradii Benth.	4.15	4.00	18.00	254.57	19.64	3	4
15	71	3	Lycium shawii Roem. et Sch.	8.00	0.65	3.00	7.07	0.50	3	4
15	71	4	Lycium shawii Roem. et Sch.	3.00	0.72	3.00	7.07	0.50	3	4
15	72	1	Lycium shawii Roem. et Sch.	8.20	0.92	4.00	12.57	0.50	3	3
15	72	2	Kleinia odora (Forssk.) DC.	9.00	0.70	3.00	7.07	0.45	3	3
15	72	3	Lycium shawii Roem. et Sch.	9.90	1.30	6.00	28.29	1.43	3	3
15	72	4	Kleinia odora (Forssk.) DC.	10.00	0.83	4.00	12.30	0.54	3	3
15	73	1	Lycium shawii Roem. et Sch.	4.00	1.70	6.00	28.29	0.79	3	5
15	73	2	Lycium shawii Roem. et Sch.	9.00	1.50	4.00	12.57	0.79	3	5
15	73	3	Lycium shawii Roem. et Sch.	9.90	1.20	4.90	18.87	0.94	3	5
15	73	4	Acacia gerradii Benth.	10.00	0.60	3.00	7.07	0.50	3	5
15	74	1	Lycium shawii Roem. et Sch.	4.20	1.25	6.00	28.29	1.33	4	4
15	74	2	Lycium shawii Roem. et Sch.	4.60	1.75	6.00	28.29	3.14	4	4
15	74	3	Acacia gerradii Benth.	8.50	1.00	8.00	50.29	2.01	4	4
15	74	4	Lycium shawii Roem. et Sch.	5.30	1.60	5.00	19.64	1.54	4	4
15	75	1	Lycium shawii Roem. et Sch.	6.00	1.10	4.00	12.57	0.79	3	2
15	75	2	Lycium shawii Roem. et Sch.	5.50	0.50	4.00	12.57	0.45	3	2
15	75	3	Kleinia odora (Forssk.) DC.	10.00	0.79	6.00	28.29	0.79	3	2
15	75	4	Kleinia odora (Forssk.) DC.	8.10	0.65	6.00	28.29	0.60	3	2
16	76	1	Euryops arabicus Steud.	3.00	0.60	4.00	12.57	0.55	8	40
16	76	2	Acacia negrii Pichi-Sermolli.	3.10	2.15	10.00	78.57	4.91	8	40
16	76	3	Euryops arabicus Steud.	3.15	0.72	4.00	12.57	0.95	8	40

16	76	4	Euryops arabicus Steud.	3.45	0.85	3.00	7.07	0.50	8	40
16	77	1	Sageretia thea (Osb.) M.C. Johnst.	2.20	0.50	3.00	7.07	0.79	5	48
16	77	2	Juniperus procera Hochst. ex Endl.	1.95	1.85	12.00	113.14	15.91	5	48
16	77	3	Sageretia thea (Osb.) M.C. Johnst.	7.00	0.90	4.00	12.57	0.79	5	48
16	77	4	Euryops arabicus Steud.	4.00	0.70	4.00	12.57	0.54	5	48
16	78	1	Euryops arabicus Steud.	2.50	0.79	4.00	12.57	0.50	7	39
16	78	2	Euryops arabicus Steud.	1.10	0.82	5.00	19.64	0.90	7	39
16	78	3	Acacia negrii Pichi-Sermolli.	2.30	0.75	4.00	12.57	0.90	7	39
16	78	4	Dodonaea viscosa Jacj.	3.30	2.75	25.00	491.07	7.07	7	39
16	79	1	Dodonaea viscosa Jacj.	1.65	1.50	7.00	38.50	3.14	7	35
16	79	2	Psiadia arabica Jaub. et SP.	0.40	0.70	6.00	28.29	1.77	7	35
16	79	3	Cluytia richardiana Muell. Arg. in DC.	6.60	0.85	4.00	12.57	0.64	7	35
16	79	4	Juniperus procera Hochst. ex Endl.	2.30	1.45	12.00	113.14	4.91	7	35
16	80	1	Euryops arabicus Steud.	7.00	0.79	4.00	12.57	0.90	7	35
16	80	2	Dodonaea viscosa Jacj.	2.70	0.80	4.00	12.57	1.13	7	35
16	80	3	Acacia negrii Pichi-Sermolli.	2.75	2.20	13.00	132.79	19.64	7	35
16	80	4	Euryops arabicus Steud.	2.30	0.65	3.00	7.07	0.64	7	35
17	81	1	Acacia negrii Pichi-Sermolli.	5.20	5.20	22.00	380.29	15.91	7	20
17	81	2	Psiadia arabica Jaub. et SP.	3.50	1.00	4.00	12.57	1.77	7	20
17	81	3	Acacia negrii Pichi-Sermolli.	9.15	1.90	6.00	28.29	2.12	7	20
17	81	4	Acacia negrii Pichi-Sermolli.	3.55	4.00	14.50	165.20	12.57	7	20
17	82	1	Acacia negrii Pichi-Sermolli.	6.00	1.88	10.00	78.57	15.41	5	22
17	82	2	Euryops arabicus Steud.	7.07	0.75	3.00	7.07	0.55	5	22
17	82	3	Psiadia arabica Jaub. et SP.	6.20	0.82	3.00	7.07	0.55	5	22
17	82	4	Acacia negrii Pichi-Sermolli.	6.85	2.05	8.00	50.29	2.84	5	22
17	83	1	Psiadia arabica Jaub. et SP.	1.80	0.68	3.00	7.07	0.59	5	18
17	83	2	Psiadia arabica Jaub. et SP.	1.70	0.70	4.00	12.57	1.23	5	18
17	83	3	Acacia negrii Pichi-Sermolli.	3.35	2.06	7.00	38.50	4.61	5	18
17	83	4	Psiadia arabica Jaub. et SP.	2.10	0.72	3.00	7.07	0.95	5	18
17	84	1	Psiadia arabica Jaub. et SP.	2.00	0.70	4.00	12.57	0.59	7	27
17	84	2	Acacia negrii Pichi-Sermolli.	8.05	1.50	6.00	28.29	1.13	7	27
17	84	3	Psiadia arabica Jaub. et SP.	9.50	1.17	4.82	18.25	1.22	7	27
17	84	4	Psiadia arabica Jaub. et SP.	5.50	0.85	4.00	12.57	1.13	7	27
17	85	1	Dodonaea viscosa Jacj.	5.00	1.45	6.00	28.29	1.13	5	23
17	85	2	Dodonaea viscosa Jacj.	5.10	1.10	6.00	28.29	1.13	5	23
17	85	3	Dodonaea viscosa Jacj.	7.22	2.05	7.00	38.50	3.14	5	23
17	85	4	Euryops arabicus Steud.	6.15	0.95	4.00	12.57	0.79	5	23
18	86	1	Acacia negrii Pichi-Sermolli.	5.00	2.56	9.00	63.64	12.57	5	24
18	86	2	Acacia negrii Pichi-Sermolli.	9.70	1.10	4.40	15.21	9.09	5	24
18	86	3	Acacia negrii Pichi-Sermolli.	2.20	1.30	6.00	28.29	1.13	5	24
18	86	4	Acacia negrii Pichi-Sermolli.	7.70	2.60	6.00	28.29	4.91	5	24
18	87	1	Acacia negrii Pichi-Sermolli.	2.95	2.00	6.00	28.29	4.91	5	15
18	87	2	Acacia negrii Pichi-Sermolli.	1.90	0.60	4.00	12.57	0.64	5	15
18	87	3	Psiadia arabica Jaub. et SP.	2.60	0.95	3.00	7.07	0.79	5	15
18	87	4	Acacia negrii Pichi-Sermolli.	3.40	1.85	6.00	28.29	4.91	5	15
18	88	1	Dodonaea viscosa Jacj.	6.47	1.15	4.00	12.57	1.33	5	13
18	88	2	Psiadia arabica Jaub. et SP.	4.05	0.80	3.00	7.07	0.79	5	13
18	88	3	Dodonaea viscosa Jacj.	2.50	1.25	6.00	28.29	1.50	5	13
18	88	4	Euryops arabicus Steud.	8.00	0.78	4.00	12.57	0.79	5	13
18	89	1	Dodonaea viscosa Jacj.	3.00	1.92	8.00	50.29	4.91	4	9
18	89	2	Dodonaea viscosa Jacj.	3.15	1.25	6.00	28.29	1.54	4	9
18	89	3	Dodonaea viscosa Jacj.	5.18	2.00	8.00	50.29	7.07	4	9

18	89	4	Psiadia arabica Jaub. et SP.	2.10	0.76	3.00	7.07	0.64	4	9
18	90	1	Dodonaea viscosa Jacj.	5.10	1.87	4.00	12.57	1.77	5	12
18	90	2	Dodonaea viscosa Jacj.	4.53	1.30	6.00	28.29	9.63	5	12
18	90	3	Dodonaea viscosa Jacj.	2.80	1.30	6.00	28.29	1.65	5	12
18	90	4	Euryops arabicus Steud.	2.92	0.76	3.00	7.07	0.64	5	12
19	91	1	Solanum schimperianum Hochst. ex A. Rich.	3.20	1.15	3.50	9.63	0.50	8	37
19	91	2	Acacia negrii Pichi-Sermolli.	3.20	4.72	15.00	176.79	28.29	8	37
19	91	3	Acacia negrii Pichi-Sermolli.	3.50	6.13	12.00	113.14	28.29	8	37
19	91	4	Acacia negrii Pichi-Sermolli.	5.00	6.03	17.00	227.07	19.64	8	37
19	92	1	Psiadia arabica Jaub. et SP.	9.68	0.87	3.75	11.05	0.88	5	29
19	92	2	Psiadia arabica Jaub. et SP.	1.10	0.70	3.50	9.63	0.95	5	29
19	92	3	Acacia negrii Pichi-Sermolli.	3.70	2.50	13.00	132.79	7.07	5	29
19	92	4	Acacia negrii Pichi-Sermolli.	9.00	1.32	7.00	38.50	7.07	5	29
19	93	1	Acacia negrii Pichi-Sermolli.	5.20	1.90	7.50	44.20	2.55	5	25
19	93	2	Leptadenia pyrotechnica (Forssk.) Decne.	7.15	1.20	4.00	12.57	0.64	5	25
19	93	3	Dodonaea viscosa Jacj.	2.10	0.70	3.50	9.63	4.91	5	25
19	93	4	Acacia negrii Pichi-Sermolli.	2.50	1.90	9.00	63.64	3.14	5	25
19	94	1	Dodonaea viscosa Jacj.	7.00	0.80	3.50	9.63	0.79	4	21
19	94	2	Dodonaea viscosa Jacj.	8.30	0.70	3.50	9.63	0.79	4	21
19	94	3	Dodonaea viscosa Jacj.	10.00	0.67	3.50	9.63	0.68	4	21
19	94	4	Dodonaea viscosa Jacj.	9.08	0.65	3.00	7.07	0.64	4	21
19	95	1	Acacia negrii Pichi-Sermolli.	6.00	1.95	4.00	12.57	4.91	7	38
19	95	2	Psiadia arabica Jaub. et SP.	2.00	0.70	3.00	7.07	0.79	7	38
19	95	3	Acacia negrii Pichi-Sermolli.	3.70	3.20	22.00	380.29	19.64	7	38
19	95	4	Lycium shawii Roem. et Sch.	3.00	1.00	6.00	28.29	1.13	7	38
20	96	1	Juniperus procera Hochst. ex Endl.	5.55	5.08	15.00	176.79	19.64	8	57
20	96	2	Juniperus procera Hochst. ex Endl.	6.40	5.60	30.00	707.14	78.57	8	57
20	96	3	Juniperus procera Hochst. ex Endl.	8.10	7.22	67.50	3579.91	95.07	8	57
20	96	4	Juniperus procera Hochst. ex Endl.	2.55	1.50	5.00	19.64	3.14	8	57
20	97	1	Dodonaea viscosa Jacj.	1.52	0.95	4.00	12.57	0.50	7	34
20	97	2	Dodonaea viscosa Jacj.	5.90	1.15	5.00	19.64	5.03	7	34
20	97	3	Juniperus procera Hochst. ex Endl.	1.72	3.60	11.00	95.07	7.07	7	34
20	97	4	Juniperus procera Hochst. ex Endl.	3.15	4.27	52.00	2124.57	7.07	7	34
20	98	1	Euryops arabicus Steud.	2.05	0.80	4.00	12.57	0.64	7	33
20	98	2	Dodonaea viscosa Jacj.	3.20	1.00	5.00	19.64	2.41	7	33
20	98	3	Juniperus procera Hochst. ex Endl.	1.50	5.35	38.00	1134.57	12.57	7	33
20	98	4	Dodonaea viscosa Jacj.	1.80	0.75	5.00	19.64	1.13	7	33
20	99	1	Juniperus procera Hochst. ex Endl.	4.70	3.75	11.00	95.07	15.91	5	31
20	99	2	Dodonaea viscosa Jacj.	2.80	0.90	5.00	19.64	2.57	5	31
20	99	3	Dodonaea viscosa Jacj.	5.30	1.10	4.50	15.91	1.19	5	31
20	99	4	Cluytia richardiana Muell. Arg. in DC.	2.95	0.90	3.50	9.93	0.58	5	31
20	100	1	Dodonaea viscosa Jacj.	2.10	1.90	3.87	11.77	1.54	8	41
20	100	2	Juniperus procera Hochst. ex Endl.	5.30	6.00	16.00	201.14	19.64	8	41
20	100	3	Juniperus procera Hochst. ex Endl.	3.90	3.60	9.00	63.64	4.91	8	41
20	100	4	Dodonaea viscosa Jacj.	1.90	1.40	6.50	33.20	1.64	8	41
21	101	1	Lycium shawii Roem. et Sch.	5.00	0.95	3.00	7.07	0.50	4	22
21	101	2	Lycium shawii Roem. et Sch.	9.98	0.98	3.44	9.30	0.72	4	22
21	101	3	Acacia negrii Pichi-Sermolli.	5.50	6.20	17.00	227.07	7.07	4	22
21	101	4	Acacia negrii Pichi-Sermolli.	10.00	2.00	4.00	12.57	3.47	4	22
21	102	1	Acacia negrii Pichi-Sermolli.	9.50	1.00	3.00	7.07	0.64	4	15
21	102	2	Lycium shawii Roem. et Sch.	7.10	1.30	4.00	12.57	0.64	4	15
21	102	3	Lycium shawii Roem. et Sch.	5.50	0.70	3.00	7.07	0.64	4	15

21	102	4	Acacia negrii Pichi-Sermolli.	9.20	1.25	4.00	12.57	1.13	4	15
21	103	1	Kleinia odora (Forssk.) DC.	5.00	0.72	3.00	7.07	0.50	4	11
21	103	2	Kleinia odora (Forssk.) DC.	5.10	0.75	3.00	7.07	0.50	4	11
21	103	3	Kleinia odora (Forssk.) DC.	4.45	0.65	4.00	12.57	0.64	4	11
21	103	4	Kleinia odora (Forssk.) DC.	7.35	0.62	4.00	12.57	0.95	4	11
21	104	1	Kleinia odora (Forssk.) DC.	10.00	0.67	3.60	10.18	0.66	3	7
21	104	2	Kleinia odora (Forssk.) DC.	6.60	0.70	4.00	12.57	0.99	3	7
21	104	3	Kleinia odora (Forssk.) DC.	6.45	0.55	3.00	7.07	0.64	3	7
21	104	4	Kleinia odora (Forssk.) DC.	9.48	0.55	4.00	12.57	0.54	3	7
21	105	1	Kleinia odora (Forssk.) DC.	3.00	0.62	7.00	38.50	0.50	3	8
21	105	2	Kleinia odora (Forssk.) DC.	5.10	0.63	4.00	12.57	0.90	3	8
21	105	3	Kleinia odora (Forssk.) DC.	2.80	0.65	3.00	7.07	0.54	3	8
21	105	4	Kleinia odora (Forssk.) DC.	4.60	0.80	4.00	12.57	2.55	3	8
22	106	1	Juniperus procera Hochst. ex Endl.	4.05	5.23	40.00	1257.14	56.57	8	43
22	106	2	Dodonaea viscosa Jacj.	9.97	1.00	4.80	18.10	1.13	8	43
22	106	3	Juniperus procera Hochst. ex Endl.	9.48	6.20	40.00	1257.14	60.11	8	43
22	106	4	Dodonaea viscosa Jacj.	3.20	1.30	4.00	12.57	1.77	8	43
22	107	1	Acacia negrii Pichi-Sermolli.	3.90	2.00	7.00	38.50	12.57	7	42
22	107	2	Dodonaea viscosa Jacj.	1.60	0.75	4.00	12.57	0.64	7	42
22	107	3	Acacia negrii Pichi-Sermolli.	2.30	4.15	15.00	176.79	38.50	7	42
22	107	4	Euryops arabicus Steud.	0.40	0.70	4.00	12.57	0.50	7	42
22	108	1	Dodonaea viscosa Jacj.	4.10	1.30	4.00	12.57	0.69	6	30
22	108	2	Dodonaea viscosa Jacj.	3.80	1.31	7.00	38.50	1.77	6	30
22	108	3	Juniperus procera Hochst. ex Endl.	2.65	3.20	20.00	314.29	23.77	6	30
22	108	4	Dodonaea viscosa Jacj.	2.85	1.80	7.00	38.50	7.55	6	30
22	109	1	Dodonaea viscosa Jacj.	1.80	1.85	7.00	38.50	5.31	7	32
22	109	2	Dodonaea viscosa Jacj.	4.88	1.66	6.00	28.29	3.80	7	32
22	109	3	Dodonaea viscosa Jacj.	2.60	2.31	7.00	38.50	12.57	7	32
22	109	4	Euryops arabicus Steud.	1.80	0.90	4.00	12.57	0.64	7	32
22	110	1	Dodonaea viscosa Jacj.	2.60	1.20	7.00	38.50	7.07	5	18
22	110	2	Dodonaea viscosa Jacj.	4.00	1.50	7.00	38.50	4.53	5	18
22	110	3	Dodonaea viscosa Jacj.	9.70	1.55	4.00	12.57	2.84	5	18
22	110	4	Euryops arabicus Steud.	2.60	1.20	4.00	12.57	1.03	5	18
23	111	1	Acacia negrii Pichi-Sermolli.	3.50	0.70	4.00	12.57	1.54	7	39
23	111	2	Juniperus procera Hochst. ex Endl.	9.15	4.70	15.00	176.79	28.29	7	39
23	111	3	Juniperus procera Hochst. ex Endl.	4.75	5.35	13.00	132.79	33.20	7	39
23	111	4	Acacia negrii Pichi-Sermolli.	1.55	2.10	9.00	63.64	2.27	7	39
23	112	1	Euryops arabicus Steud.	1.50	0.95	5.00	19.64	0.64	7	34
23	112	2	Acacia negrii Pichi-Sermolli.	3.00	3.15	9.00	63.64	19.64	7	34
23	112	3	Dodonaea viscosa Jacj.	1.85	2.10	8.00	50.29	1.13	7	34
23	112	4	Dodonaea viscosa Jacj.	1.60	2.40	5.00	19.64	2.01	7	34
23	113	1	Dodonaea viscosa Jacj.	2.50	1.00	3.00	7.07	0.64	7	34
23	113	2	Dodonaea viscosa Jacj.	3.30	0.95	6.00	28.29	0.87	7	34
23	113	3	Dodonaea viscosa Jacj.	2.70	1.55	6.00	28.29	2.01	7	34
23	113	4	Euryops arabicus Steud.	1.55	1.45	4.00	12.57	0.64	7	34
23	114	1	Juniperus procera Hochst. ex Endl.	2.75	2.32	12.00	113.14	7.94	6	31
23	114	2	Euryops arabicus Steud.	0.75	1.05	6.00	28.29	0.79	6	31
23	114	3	Euryops arabicus Steud.	7.10	3.47	22.00	380.29	12.57	6	31
23	114	4	Dodonaea viscosa Jacj.	4.80	1.75	6.00	28.29	3.14	6	31
23	115	1	Dodonaea viscosa Jacj.	2.70	1.27	4.00	12.57	0.95	6	28
23	115	2	Juniperus procera Hochst. ex Endl.	3.15	2.92	15.00	176.79	28.29	6	28
23	115	3	Dodonaea viscosa Jacj.	1.90	1.51	4.00	12.57	0.64	6	28

23	115	4	Dodonaea viscosa Jacj.	1.91	1.05	3.00	7.07	0.87	6	28
24	116	1	Acacia negrii Pichi-Sermolli.	3.60	2.50	22.00	380.29	23.76	5	13
24	116	2	Psiadia arabica Jaub. et SP.	2.75	0.90	4.00	12.57	0.79	5	13
24	116	3	Juniperus procera Hochst. ex Endl.	2.52	4.32	42.00	1386.00	44.20	5	13
24	116	4	Acacia negrii Pichi-Sermolli.	5.40	2.50	7.00	38.50	12.57	5	13
24	117	1	Acacia negrii Pichi-Sermolli.	9.60	2.70	15.00	176.79	19.74	5	16
24	117	2	Acacia negrii Pichi-Sermolli.	5.28	2.00	8.00	50.29	4.16	5	16
24	117	3	Psiadia arabica Jaub. et SP.	2.90	0.65	3.00	7.07	0.50	5	16
24	117	4	Psiadia arabica Jaub. et SP.	0.80	0.75	3.00	7.07	0.58	5	16
24	118	1	Juniperus procera Hochst. ex Endl.	5.60	3.76	50.00	1964.29	28.29	7	26
24	118	2	Psiadia arabica Jaub. et SP.	2.52	0.95	4.00	12.57	0.95	7	26
24	118	3	Juniperus procera Hochst. ex Endl.	4.85	3.12	43.00	1452.79	28.29	7	26
24	118	4	Acacia negrii Pichi-Sermolli.	1.40	3.45	22.00	380.29	28.29	7	26
24	119	1	Juniperus procera Hochst. ex Endl.	6.20	2.75	52.00	2124.57	38.50	5	29
24	119	2	Juniperus procera Hochst. ex Endl.	8.80	2.75	16.00	201.14	19.64	5	29
24	119	3	Dodonaea viscosa Jacj.	1.40	0.70	3.00	7.07	0.50	5	29
24	119	4	Dodonaea viscosa Jacj.	1.00	0.90	3.00	7.07	0.58	5	29
24	120	1	Euryops arabicus Steud.	3.50	0.70	4.00	12.57	0.54	5	30
24	120	2	Acacia negrii Pichi-Sermolli.	6.60	2.00	6.00	28.29	1.77	5	30
24	120	3	Psiadia arabica Jaub. et SP.	1.80	0.60	3.00	7.07	0.55	5	30
24	120	4	Euryops arabicus Steud.	4.00	0.65	3.00	7.07	0.50	5	30
25	121	1	Psiadia arabica Jaub. et SP.	1.30	1.10	3.00	7.07	0.50	7	28
25	121	2	Euryops arabicus Steud.	1.16	1.50	4.00	12.57	0.55	7	28
25	121	3	Juniperus procera Hochst. ex Endl.	3.40	4.20	72.00	4073.14	50.28	7	28
25	121	4	Juniperus procera Hochst. ex Endl.	6.90	5.72	52.00	2124.57	38.50	7	28
25	122	1	Euryops arabicus Steud.	1.55	1.20	3.00	7.07	4.07	7	27
25	122	2	Psiadia arabica Jaub. et SP.	0.80	0.75	3.00	7.07	0.78	7	27
25	122	3	Psiadia arabica Jaub. et SP.	0.85	0.80	3.00	7.07	0.78	7	27
25	122	4	Euryops arabicus Steud.	6.40	1.72	4.47	15.70	6.16	7	27
25	123	1	Juniperus procera Hochst. ex Endl.	8.90	3.00	32.00	804.57	40.20	5	24
25	123	2	Juniperus procera Hochst. ex Endl.	9.58	4.12	39.15	1204.28	48.15	5	24
25	123	3	Juniperus procera Hochst. ex Endl.	3.00	3.40	62.00	3020.29	38.50	5	24
25	123	4	Juniperus procera Hochst. ex Endl.	9.30	2.10	7.00	38.50	2.28	5	24
25	124	1	Psiadia arabica Jaub. et SP.	2.35	0.59	3.00	7.07	0.60	5	29
25	124	2	Psiadia arabica Jaub. et SP.	1.50	0.50	3.00	7.07	0.51	5	29
25	124	3	Juniperus procera Hochst. ex Endl.	3.70	2.80	5.00	19.64	33.20	5	29
25	124	4	Juniperus procera Hochst. ex Endl.	4.70	3.65	42.00	1386.00	38.50	5	29
25	125	1	Juniperus procera Hochst. ex Endl.	4.90	3.20	32.00	804.57	15.21	5	30
25	125	2	Juniperus procera Hochst. ex Endl.	6.90	2.85	62.00	3020.29	15.91	5	30
25	125	3	Euryops arabicus Steud.	1.20	0.85	3.00	7.07	0.50	5	30
25	125	4	Euryops arabicus Steud.	2.70	0.65	3.00	7.07	0.50	5	30
26	126	1	Acacia negrii Pichi-Sermolli.	10.00	2.00	7.00	38.50	3.14	5	19
26	126	2	Acacia negrii Pichi-Sermolli.	6.30	2.92	10.00	78.57	4.91	5	19
26	126	3	Acacia negrii Pichi-Sermolli.	3.18	2.23	8.00	50.29	4.91	5	19
26	126	4	Acacia negrii Pichi-Sermolli.	1.30	4.12	11.00	95.07	5.94	5	19
26	127	1	Euryops arabicus Steud.	1.15	1.20	3.55	9.90	1.13	4	11
26	127	2	Acacia negrii Pichi-Sermolli.	2.08	7.33	26.87	567.28	78.57	4	11
26	127	3	Acacia negrii Pichi-Sermolli.	9.88	3.18	26.87	567.28	38.54	4	11
26	127	4	Solanum schimperianum Hochst. ex A. Rich.	4.54	1.17	3.40	9.08	1.23	4	11
26	128	1	Acacia negrii Pichi-Sermolli.	1.24	3.05	12.00	113.14	12.57	5	18
26	128	2	Acacia negrii Pichi-Sermolli.	4.12	2.55	8.00	50.29	3.98	5	18
26	128	3	Acacia negrii Pichi-Sermolli.	8.90	2.12	8.61	58.25	3.14	5	18

26	128	4	Acacia negrii Pichi-Sermolli.	9.70	1.80	7.00	38.50	2.50	5	18
26	129	1	Euryops arabicus Steud.	1.50	0.80	3.00	7.07	0.60	4	17
26	129	2	Acacia negrii Pichi-Sermolli.	1.95	3.12	16.00	201.14	7.07	4	17
26	129	3	Euryops arabicus Steud.	2.00	0.75	3.00	7.07	0.50	4	17
26	129	4	Acacia negrii Pichi-Sermolli.	5.20	0.80	3.00	7.07	0.60	4	17
26	130	1	Euryops arabicus Steud.	1.85	0.80	3.00	7.07	0.60	4	20
26	130	2	Acacia negrii Pichi-Sermolli.	3.35	2.00	9.00	63.64	8.30	4	20
26	130	3	Acacia negrii Pichi-Sermolli.	9.95	2.20	9.73	74.39	8.55	4	20
26	130	4	Acacia negrii Pichi-Sermolli.	5.60	1.50	5.00	19.64	4.53	4	20
27	131	1	Acacia gerradii Benth.	9.15	3.15	17.00	227.07	19.64	6	10
27	131	2	Acacia gerradii Benth.	9.60	2.20	17.18	231.91	12.57	6	10
27	131	3	Acacia gerradii Benth.	5.75	4.20	31.00	755.07	56.77	6	10
27	131	4	Acacia gerradii Benth.	7.12	4.36	28.00	616.00	23.77	6	10
27	132	1	Acacia gerradii Benth.	8.00	2.10	8.61	58.25	20.08	4	9
27	132	2	Acacia gerradii Benth.	8.48	1.80	6.00	28.29	5.06	4	9
27	132	3	Acacia gerradii Benth.	9.90	1.15	7.00	38.50	3.14	4	9
27	132	4	Acacia gerradii Benth.	9.16	3.20	20.00	314.29	95.07	4	9
27	133	1	Acacia gerradii Benth.	9.50	1.57	7.00	38.54	3.14	4	13
27	133	2	Acacia gerradii Benth.	8.15	2.00	10.10	80.15	12.29	4	13
27	133	3	Acacia gerradii Benth.	9.90	2.30	12.42	121.20	16.00	4	13
27	133	4	Acacia gerradii Benth.	2.90	2.83	16.00	201.14	18.54	4	13
27	134	1	Acacia gerradii Benth.	9.68	4.20	6.98	38.28	29.28	4	20
27	134	2	Acacia gerradii Benth.	9.00	2.37	5.00	19.64	19.64	4	20
27	134	3	Acacia gerradii Benth.	2.13	3.47	13.00	132.79	19.64	4	20
27	134	4	Acacia gerradii Benth.	10.00	1.42	6.10	29.24	12.54	4	20
27	135	1	Acacia gerradii Benth.	9.90	4.00	23.10	419.27	18.50	5	25
27	135	2	Lycium shawii Roem. et Sch.	9.78	1.80	4.00	12.57	0.54	5	25
27	135	3	Lycium shawii Roem. et Sch.	1.85	2.32	5.00	19.64	0.50	5	25
27	135	4	Acacia gerradii Benth.	4.18	6.38	32.00	804.57	36.33	5	25
28	136	1	Acacia gerradii Benth.	8.05	7.85	7.00	38.50	95.94	5	4
28	136	2	Acacia gerradii Benth.	10.00	3.65	15.00	176.79	19.64	5	4
28	136	3	Acacia gerradii Benth.	9.10	7.53	22.00	380.29	28.29	5	4
28	136	4	Acacia gerradii Benth.	10.00	3.00	14.00	154.00	18.67	5	4
28	137	1	Acacia gerradii Benth.	8.15	4.75	17.00	227.07	18.10	5	8
28	137	2	Acacia gerradii Benth.	8.60	4.00	21.54	364.55	12.57	5	8
28	137	3	Acacia gerradii Benth.	7.12	4.08	20.00	314.29	16.63	5	8
28	137	4	Acacia gerradii Benth.	9.58	2.70	10.00	78.57	9.07	5	8
28	138	1	Acacia gerradii Benth.	10.00	3.30	12.37	120.23	12.29	5	7
28	138	2	Acacia gerradii Benth.	10.12	3.40	14.00	154.00	10.18	5	7
28	138	3	Acacia gerradii Benth.	10.17	3.90	22.00	380.29	29.24	5	7
28	138	4	Acacia gerradii Benth.	7.50	2.80	14.00	154.00	18.54	5	7
28	139	1	Acacia gerradii Benth.	3.40	1.30	5.00	19.64	1.74	4	11
28	139	2	Acacia gerradii Benth.	3.65	3.90	17.00	227.07	19.25	4	11
28	139	3	Acacia gerradii Benth.	3.60	3.50	15.00	176.79	15.56	4	11
28	139	4	Acacia gerradii Benth.	5.55	1.33	4.00	12.57	1.77	4	11
28	140	1	Acacia gerradii Benth.	10.00	4.20	15.00	176.79	19.64	5	15
28	140	2	Acacia gerradii Benth.	3.40	4.80	17.00	227.07	23.77	5	15
28	140	3	Acacia gerradii Benth.	9.80	3.40	15.00	176.79	12.57	5	15
28	140	4	Acacia gerradii Benth.	7.00	3.20	17.00	227.07	12.57	5	15
29	141	1	Acacia gerradii Benth.	9.00	6.47	50.00	1964.29	50.15	4	8
29	141	2	Acacia gerradii Benth.	4.15	1.05	3.50	9.63	5.50	4	8
29	141	3	Acacia gerradii Benth.	5.20	2.79	8.00	50.29	11.95	4	8

29	141	4	Acacia gerradii Benth.	9.86	2.16	11.95	112.24	12.52	4	8
29	142	1	Acacia gerradii Benth.	7.09	3.05	13.00	132.79	12.26	4	10
29	142	2	Acacia gerradii Benth.	8.20	0.50	3.50	9.63	2.20	4	10
29	142	3	Rumex nervosus Vahl.	7.10	0.80	3.50	9.63	0.50	4	10
29	142	4	Acacia gerradii Benth.	9.18	0.90	3.00	7.07	0.79	4	10
29	143	1	Acacia gerradii Benth.	7.63	5.00	15.00	176.79	58.11	6	16
29	143	2	Euryops arabicus Steud.	2.17	0.91	3.00	7.07	0.48	6	16
29	143	3	Euryops arabicus Steud.	1.50	0.87	4.00	12.57	0.74	6	16
29	143	4	Euryops arabicus Steud.	9.59	0.90	4.82	18.25	0.74	6	16
29	144	1	Acacia gerradii Benth.	4.67	2.92	6.00	28.29	2.41	7	18
29	144	2	Euryops arabicus Steud.	2.40	1.21	4.00	12.57	0.67	7	18
29	144	3	Euryops arabicus Steud.	6.52	1.51	4.00	12.57	0.55	7	18
29	144	4	Euryops arabicus Steud.	9.88	1.00	4.00	12.57	0.54	7	18
29	145	1	Solanum schimperianum Hochst. ex A. Rich.	2.61	1.50	3.45	9.35	0.76	6	18
29	145	2	Solanum schimperianum Hochst. ex A. Rich.	9.00	1.10	3.45	9.35	0.92	6	18
29	145	3	Acacia gerradii Benth.	8.95	2.36	14.00	154.00	8.12	6	18
29	145	4	Acacia gerradii Benth.	2.97	4.70	22.00	380.00	68.98	6	18
30	146	1	Acacia negrii Pichi-Sermolli.	5.03	5.94	14.15	157.32	77.10	5	9
30	146	2	Acacia negrii Pichi-Sermolli.	9.12	3.18	14.15	157.32	18.50	5	9
30	146	3	Acacia negrii Pichi-Sermolli.	5.60	5.54	28.00	616.00	198.64	5	9
30	146	4	Acacia negrii Pichi-Sermolli.	3.69	1.91	6.00	28.29	19.25	5	9
30	147	1	Acacia negrii Pichi-Sermolli.	3.41	3.79	20.00	314.29	109.03	4	7
30	147	2	Acacia negrii Pichi-Sermolli.	8.40	2.00	10.10	80.15	98.06	4	7
30	147	3	Acacia negrii Pichi-Sermolli.	9.08	1.85	4.85	18.48	38.50	4	7
30	147	4	Acacia negrii Pichi-Sermolli.	10.00	1.60	4.00	12.57	28.29	4	7
30	148	1	Acacia negrii Pichi-Sermolli.	9.75	3.10	11.56	105.00	78.29	5	11
30	148	2	Acacia negrii Pichi-Sermolli.	9.90	2.32	8.00	50.29	54.13	5	11
30	148	3	Acacia negrii Pichi-Sermolli.	4.51	2.84	8.00	50.29	54.13	5	11
30	148	4	Acacia negrii Pichi-Sermolli.	8.13	2.08	7.00	38.50	39.27	5	11
30	149	1	Acacia negrii Pichi-Sermolli.	5.11	1.02	4.00	12.57	6.38	6	16
30	149	2	Acacia negrii Pichi-Sermolli.	6.70	3.90	12.00	113.14	87.31	6	16
30	149	3	Acacia negrii Pichi-Sermolli.	4.68	4.80	28.00	616.00	187.31	6	16
30	149	4	Acacia negrii Pichi-Sermolli.	5.55	1.02	4.00	12.57	8.05	6	16
30	150	1	Juniperus procera Hochst. ex Endl.	7.40	4.26	38.00	1134.57	45.14	5	19
30	150	2	Euryops arabicus Steud.	3.60	0.52	4.00	12.57	0.50	5	19
30	150	3	Acacia negrii Pichi-Sermolli.	5.12	1.02	4.00	12.57	2.41	5	19
30	150	4	Acacia negrii Pichi-Sermolli.	9.88	0.82	3.40	9.08	0.64	5	19
31	151	1	Acacia negrii Pichi-Sermolli.	9.60	2.85	12.00	113.14	12.60	5	12
31	151	2	Acacia negrii Pichi-Sermolli.	7.50	1.80	9.86	76.39	12.60	5	12
31	151	3	Acacia negrii Pichi-Sermolli.	8.22	2.10	11.07	96.29	18.46	5	12
31	151	4	Acacia negrii Pichi-Sermolli.	3.20	0.98	5.00	19.64	7.07	5	12
31	152	1	Acacia negrii Pichi-Sermolli.	9.20	0.96	3.30	8.56	3.14	6	11
31	152	2	Solanum incanum L.	5.58	0.67	4.00	12.57	0.61	6	11
31	152	3	Acacia negrii Pichi-Sermolli.	4.27	3.20	6.00	28.29	12.64	6	11
31	152	4	Acacia negrii Pichi-Sermolli.	7.00	1.70	7.90	49.04	4.42	6	11
31	153	1	Solanum incanum L.	7.58	0.69	4.00	12.57	0.54	7	20
31	153	2	Acacia negrii Pichi-Sermolli.	1.30	1.31	6.00	28.29	0.45	7	20
31	153	3	Acacia negrii Pichi-Sermolli.	9.90	3.60	8.50	56.77	12.60	7	20
31	153	4	Solanum incanum L.	2.33	0.83	3.50	9.63	7.07	7	20
31	154	1	Acacia negrii Pichi-Sermolli.	7.10	2.56	10.00	78.57	7.00	6	19
31	154	2	Solanum incanum L.	8.00	0.70	4.00	12.57	0.61	6	19
31	154	3	Solanum incanum L.	7.50	0.69	4.00	12.57	0.65	6	19

31	154	4	Solanum incanum L.	5.00	0.55	3.00	7.07	0.56	6	19
31	155	1	Acacia negrii Pichi-Sermolli.	6.36	6.20	14.00	154.00	28.29	5	19
31	155	2	Acacia negrii Pichi-Sermolli.	3.08	4.23	14.00	154.00	17.12	5	19
31	155	3	Acacia negrii Pichi-Sermolli.	8.60	0.75	6.00	28.29	0.65	5	19
31	155	4	Acacia negrii Pichi-Sermolli.	8.00	0.89	4.00	12.57	0.56	5	19
32	156	1	Lycium shawii Roem. et Sch.	4.30	0.65	4.00	12.57	0.50	4	8
32	156	2	Acacia negrii Pichi-Sermolli.	9.00	2.20	7.00	38.50	2.55	4	8
32	156	3	Withania somnifera (L.) Dun. in DC.	9.80	0.72	4.00	12.57	0.65	4	8
32	156	4	Withania somnifera (L.) Dun. in DC.	6.76	0.69	4.00	12.57	0.57	4	8
32	157	1	Acacia negrii Pichi-Sermolli.	4.50	4.85	35.00	962.50	78.57	3	8
32	157	2	Rumex nervosus Vahl.	7.09	0.72	3.50	9.63	0.54	3	8
32	157	3	Rumex nervosus Vahl.	4.00	0.53	3.00	7.07	0.50	3	8
32	157	4	Acacia negrii Pichi-Sermolli.	3.00	0.66	4.00	12.57	0.50	3	8
32	158	1	Leptadenia pyrotechnica (Forssk.) Decne.	7.80	0.58	3.00	7.07	0.50	5	11
32	158	2	Solanum incanum L.	4.15	0.52	3.00	7.07	0.56	5	11
32	158	3	Leptadenia pyrotechnica (Forssk.) Decne.	3.86	0.50	3.00	7.07	0.50	5	11
32	158	4	Leptadenia pyrotechnica (Forssk.) Decne.	5.20	0.80	6.00	28.29	0.65	5	11
32	159	1	Kleinia odora (Forssk.) DC.	9.70	0.80	4.00	12.57	0.79	5	12
32	159	2	Kleinia odora (Forssk.) DC.	9.00	0.67	4.00	12.57	0.56	5	12
32	159	3	Kleinia odora (Forssk.) DC.	8.79	0.92	3.50	9.63	0.64	5	12
32	159	4	Kleinia odora (Forssk.) DC.	7.20	1.07	4.50	15.91	0.83	5	12
32	160	1	Kleinia odora (Forssk.) DC.	8.72	0.80	3.00	7.07	0.54	5	13
32	160	2	Kleinia odora (Forssk.) DC.	9.95	0.68	4.00	12.57	0.56	5	13
32	160	3	Kleinia odora (Forssk.) DC.	7.20	0.74	3.50	9.63	0.63	5	13
32	160	4	Kleinia odora (Forssk.) DC.	1.10	0.55	4.00	12.57	0.54	5	13
33	161	1	Lycium shawii Roem. et Sch.	4.00	0.55	4.00	12.57	0.50	4	8
33	161	2	Lycium shawii Roem. et Sch.	6.20	2.00	6.00	28.29	7.10	4	8
33	161	3	Acacia negrii Pichi-Sermolli.	3.55	4.86	15.00	176.79	9.63	4	8
33	161	4	Acacia negrii Pichi-Sermolli.	8.86	2.20	6.00	28.29	38.50	4	8
33	162	1	Lycium shawii Roem. et Sch.	9.38	0.99	3.00	7.07	0.69	4	8
33	162	2	Kleinia odora (Forssk.) DC.	4.45	1.30	4.00	12.57	0.70	4	8
33	162	3	Lycium shawii Roem. et Sch.	8.00	1.00	3.00	7.07	0.69	4	8
33	162	4	Lycium shawii Roem. et Sch.	8.20	1.08	4.00	12.57	0.70	4	8
33	163	1	Kleinia odora (Forssk.) DC.	6.00	1.20	4.00	12.57	0.64	5	6
33	163	2	Kleinia odora (Forssk.) DC.	4.70	0.80	6.00	28.29	0.79	5	6
33	163	3	Kleinia odora (Forssk.) DC.	5.15	0.75	4.00	12.57	0.64	5	6
33	163	4	Kleinia odora (Forssk.) DC.	5.20	0.90	4.00	12.57	0.85	5	6
33	164	1	Kleinia odora (Forssk.) DC.	3.90	0.92	3.00	7.07	0.50	3	9
33	164	2	Kleinia odora (Forssk.) DC.	6.56	0.80	4.00	12.57	0.70	3	9
33	164	3	Kleinia odora (Forssk.) DC.	8.98	0.74	3.50	9.63	0.54	3	9
33	164	4	Kleinia odora (Forssk.) DC.	3.30	0.85	4.00	12.57	0.69	3	9
33	165	1	Kleinia odora (Forssk.) DC.	4.50	0.75	3.00	7.07	0.65	3	9
33	165	2	Lycium shawii Roem. et Sch.	9.20	1.20	3.00	7.07	0.70	3	9
33	165	3	Kleinia odora (Forssk.) DC.	8.10	0.78	4.00	12.57	0.69	3	9
33	165	4	Kleinia odora (Forssk.) DC.	2.00	0.55	4.00	12.57	0.69	3	9
34	166	1	Acacia negrii Pichi-Sermolli.	8.53	4.30	15.00	176.79	63.64	4	8
34	166	2	Acacia negrii Pichi-Sermolli.	5.75	4.70	15.00	176.79	95.07	4	8
34	166	3	Acacia negrii Pichi-Sermolli.	5.00	0.70	6.00	28.29	0.79	4	8
34	166	4	Acacia negrii Pichi-Sermolli.	10.00	2.50	7.00	38.50	7.07	4	8
34	167	1	Lycium shawii Roem. et Sch.	8.09	0.55	4.00	12.57	0.64	4	8
34	167	2	Acacia negrii Pichi-Sermolli.	1.50	3.27	17.00	227.07	15.91	4	8
34	167	3	Lycium shawii Roem. et Sch.	3.00	0.50	3.00	7.07	0.39	4	8

34	167	4	Lycium shawii Roem. et Sch.	10.00	0.59	3.00	7.07	0.50	4	8
34	168	1	Lycium shawii Roem. et Sch.	8.50	0.62	4.00	12.57	0.65	3	7
34	168	2	Acacia negrii Pichi-Sermolli.	3.00	5.17	19.00	283.64	38.50	3	7
34	168	3	Lycium shawii Roem. et Sch.	9.00	5.20	18.00	254.57	28.29	3	7
34	168	4	Acacia negrii Pichi-Sermolli.	7.00	0.70	3.00	7.07	0.50	3	7
34	169	1	Acacia negrii Pichi-Sermolli.	2.15	4.85	11.00	95.07	23.77	5	7
34	169	2	Lycium shawii Roem. et Sch.	1.10	0.60	4.00	12.57	0.65	5	7
34	169	3	Lycium shawii Roem. et Sch.	9.10	0.90	5.00	19.64	0.72	5	7
34	169	4	Acacia negrii Pichi-Sermolli.	7.80	3.55	11.00	95.07	28.58	5	7
34	170	1	Adenium obesum (Forssk.) Roem & Schultz.	3.08	0.71	18.00	254.57	0.50	4	6
34	170	2	Adenium obesum (Forssk.) Roem & Schultz.	6.78	1.06	16.00	201.14	0.69	4	6
34	170	3	Acacia negrii Pichi-Sermolli.	7.13	2.58	15.50	188.77	9.09	4	6
34	170	4	Acacia negrii Pichi-Sermolli.	8.60	1.81	11.20	98.56	7.07	4	6
35	171	1	Acacia negrii Pichi-Sermolli.	2.50	5.60	8.50	56.77	12.57	3	7
35	171	2	Acacia negrii Pichi-Sermolli.	5.55	0.75	4.00	12.57	0.64	3	7
35	171	3	Acacia negrii Pichi-Sermolli.	8.50	0.60	4.00	12.57	0.39	3	7
35	171	4	Acacia negrii Pichi-Sermolli.	8.50	1.35	3.50	9.63	0.98	3	7
35	172	1	Lycium shawii Roem. et Sch.	7.76	1.04	5.00	19.64	0.79	3	7
35	172	2	Acacia negrii Pichi-Sermolli.	3.20	1.90	9.00	63.64	19.64	3	7
35	172	3	Acacia negrii Pichi-Sermolli.	8.18	1.50	11.20	98.56	17.62	3	7
35	172	4	Lycium shawii Roem. et Sch.	9.00	0.75	4.00	12.57	0.65	3	7
35	173	1	Lycium shawii Roem. et Sch.	7.78	0.69	3.50	9.63	0.64	3	8
35	173	2	Lycium shawii Roem. et Sch.	6.00	0.65	3.00	7.07	0.65	3	8
35	173	3	Lycium shawii Roem. et Sch.	4.00	0.50	3.00	7.07	0.56	3	8
35	173	4	Lycium shawii Roem. et Sch.	5.50	0.60	4.00	12.57	0.65	3	8
35	174	1	Lycium shawii Roem. et Sch.	9.50	1.10	5.00	19.64	0.64	3	8
35	174	2	Lycium shawii Roem. et Sch.	8.00	0.59	4.00	12.57	0.50	3	8
35	174	3	Lycium shawii Roem. et Sch.	9.75	0.98	3.00	7.07	0.54	3	8
35	174	4	Lycium shawii Roem. et Sch.	9.00	1.20	6.00	28.29	0.65	3	8
35	175	1	Lycium shawii Roem. et Sch.	8.10	0.90	4.50	14.13	0.72	4	9
35	175	2	Acacia negrii Pichi-Sermolli.	4.50	2.54	12.00	113.14	19.64	4	9
35	175	3	Lycium shawii Roem. et Sch.	9.00	0.80	4.00	12.57	0.65	4	9
35	175	4	Acacia negrii Pichi-Sermolli.	6.75	1.89	11.10	96.81	1.50	4	9
36	176	1	Lycium shawii Roem. et Sch.	10.00	0.60	7.00	38.50	0.50	4	8
36	176	2	Lycium shawii Roem. et Sch.	4.50	0.69	7.00	38.50	0.64	4	8
36	176	3	Acacia gerradii Benth.	8.00	2.92	14.00	154.00	15.91	4	8
36	176	4	Acacia gerradii Benth.	4.50	2.24	4.00	12.57	7.07	4	8
36	177	1	Acacia gerradii Benth.	9.86	3.60	10.00	78.57	23.77	4	7
36	177	2	Acacia gerradii Benth.	10.00	1.75	4.00	12.57	3.14	4	7
36	177	3	Acacia gerradii Benth.	9.95	4.30	12.00	113.14	50.29	4	7
36	177	4	Acacia gerradii Benth.	8.88	1.57	4.00	12.57	2.14	4	7
36	178	1	Acacia gerradii Benth.	9.64	0.92	4.50	15.91	0.76	3	7
36	178	2	Kleinia odora (Forssk.) DC.	8.00	0.78	3.00	7.07	0.50	3	7
36	178	3	Kleinia odora (Forssk.) DC.	7.57	0.90	4.00	12.57	0.64	3	7
36	178	4	Kleinia odora (Forssk.) DC.	8.09	0.67	3.50	9.63	0.54	3	7
36	179	1	Kleinia odora (Forssk.) DC.	9.30	0.71	2.50	4.91	0.53	3	9
36	179	2	Lycium shawii Roem. et Sch.	9.00	0.72	3.00	7.07	0.65	3	9
36	179	3	Kleinia odora (Forssk.) DC.	7.85	0.84	6.00	28.29	0.64	3	9
36	179	4	Lycium shawii Roem. et Sch.	10.00	0.81	4.00	12.57	0.73	3	9
36	180	1	Acacia gerradii Benth.	8.95	1.08	4.00	12.57	3.14	3	10
36	180	2	Acacia gerradii Benth.	2.08	2.20	10.00	78.57	4.91	3	10
36	180	3	Kleinia odora (Forssk.) DC.	1.95	0.65	3.00	7.07	0.50	3	10

36	180	4	Kleinia odora (Forssk.) DC.	7.22	0.59	3.00	7.07	0.53	3	10
37	181	1	Lycium shawii Roem. et Sch.	1.00	0.56	3.00	7.07	0.50	3	7
37	181	2	Acacia gerradii Benth.	5.00	3.20	6.00	28.29	9.63	3	7
37	181	3	Acacia gerradii Benth.	5.20	1.60	6.00	28.29	9.63	3	7
37	181	4	Acacia gerradii Benth.	3.49	0.85	4.00	12.57	0.98	3	7
37	182	1	Acacia gerradii Benth.	9.53	1.72	7.50	44.20	3.14	3	8
37	182	2	Acacia gerradii Benth.	9.77	1.35	5.50	23.77	1.54	3	8
37	182	3	Acacia gerradii Benth.	9.20	1.40	4.00	12.57	1.76	3	8
37	182	4	Acacia gerradii Benth.	7.10	0.93	3.50	9.63	0.54	3	8
37	183	1	Acacia gerradii Benth.	9.50	0.90	7.50	44.20	2.55	3	8
37	183	2	Acacia gerradii Benth.	10.00	0.85	6.00	28.29	1.54	3	8
37	183	3	Lycium shawii Roem. et Sch.	10.00	0.65	4.00	12.57	0.76	3	8
37	183	4	Calotropis procera (Ait.) Ait.f.	10.00	1.50	6.00	28.29	1.54	3	8
37	184	1	Lycium shawii Roem. et Sch.	6.00	0.63	3.00	7.07	0.64	3	8
37	184	2	Lycium shawii Roem. et Sch.	4.33	0.79	6.00	28.29	0.65	3	8
37	184	3	Lycium shawii Roem. et Sch.	8.72	0.58	3.00	7.07	0.50	3	8
37	184	4	Lycium shawii Roem. et Sch.	9.77	0.61	2.50	4.91	0.54	3	8
37	185	1	Acacia gerradii Benth.	8.83	0.91	3.50	9.63	0.79	3	4
37	185	2	Acacia gerradii Benth.	7.38	1.80	7.50	44.20	1.77	3	4
37	185	3	Lycium shawii Roem. et Sch.	9.93	0.97	3.00	7.07	0.88	3	4
37	185	4	Acacia gerradii Benth.	9.35	0.83	4.00	12.57	0.79	3	4
38	186	1	Lycium shawii Roem. et Sch.	5.50	0.56	3.00	7.07	0.50	5	5
38	186	2	Lycium shawii Roem. et Sch.	5.10	0.65	4.00	12.57	0.79	5	5
38	186	3	Acacia gerradii Benth.	8.12	0.89	6.00	28.29	0.79	5	5
38	186	4	Lycium shawii Roem. et Sch.	6.10	0.63	4.00	12.57	0.50	5	5
38	187	1	Lycium shawii Roem. et Sch.	9.33	0.67	2.50	4.91	0.58	3	5
38	187	2	Acacia gerradii Benth.	8.17	0.81	3.50	9.63	0.61	3	5
38	187	3	Lycium shawii Roem. et Sch.	7.81	0.51	2.50	4.91	0.50	3	5
38	187	4	Lycium shawii Roem. et Sch.	4.30	0.56	3.00	7.07	0.50	3	5
38	188	1	Lycium shawii Roem. et Sch.	9.80	0.62	4.00	12.57	0.65	5	6
38	188	2	Lycium shawii Roem. et Sch.	7.99	0.71	4.00	12.57	0.70	5	6
38	188	3	Kleinia odora (Forssk.) DC.	9.70	0.56	4.00	12.57	0.50	5	6
38	188	4	Lycium shawii Roem. et Sch.	2.50	0.72	6.00	28.29	0.79	5	6
38	189	1	Lycium shawii Roem. et Sch.	8.50	0.92	4.00	12.57	0.65	5	4
38	189	2	Kleinia odora (Forssk.) DC.	3.00	0.60	6.00	28.29	0.65	5	4
38	189	3	Leptadenia pyrotechnica (Forssk.) Decne.	4.45	1.90	6.00	28.29	1.54	5	4
38	189	4	Leptadenia pyrotechnica (Forssk.) Decne.	8.89	1.23	5.00	19.64	0.97	5	4
38	190	1	Reseda sphenocleoidis Deflers.,	10.00	0.72	3.00	7.07	0.65	4	5
38	190	2	Reseda sphenocleoidis Deflers.,	9.18	0.59	2.50	4.91	0.50	4	5
38	190	3	Kleinia odora (Forssk.) DC.	9.08	0.82	4.00	12.57	0.64	4	5
38	190	4	Reseda sphenocleoidis Deflers.,	8.09	0.74	3.00	7.07	0.50	4	5
39	191	1	Lycium shawii Roem. et Sch.	4.35	0.82	3.00	7.07	0.65	4	6
39	191	2	Acacia gerradii Benth.	8.10	1.80	4.00	12.57	3.13	4	6
39	191	3	Acacia gerradii Benth.	9.60	0.67	3.00	7.07	0.64	4	6
39	191	4	Acacia gerradii Benth.	10.00	2.15	7.00	38.50	12.57	4	6
39	192	1	Lycium shawii Roem. et Sch.	9.72	0.90	5.50	23.77	3.14	3	3
39	192	2	Lycium shawii Roem. et Sch.	9.80	1.10	6.00	28.29	9.63	3	3
39	192	3	Lycium shawii Roem. et Sch.	7.98	0.76	4.00	12.57	2.82	3	3
39	192	4	Lycium shawii Roem. et Sch.	8.50	0.92	4.00	12.57	0.74	3	3
39	193	1	Lycium shawii Roem. et Sch.	10.00	0.71	3.00	7.07	0.50	4	4
39	193	2	Lycium shawii Roem. et Sch.	8.90	1.15	4.00	12.57	0.74	4	4
39	193	3	Lycium shawii Roem. et Sch.	10.00	0.60	3.00	7.07	0.65	4	4

39	193	4	Kleinia odora (Forssk.) DC.	7.20	0.70	4.00	12.57	0.50	4	4
39	194	1	Lycium barbarum L.	6.30	0.53	3.00	7.07	0.50	5	5
39	194	2	Lycium barbarum L.	7.60	0.49	2.50	4.91	0.54	5	5
39	194	3	Lycium barbarum L.	2.50	0.72	4.00	12.57	0.65	5	5
39	194	4	Lycium shawii Roem. et Sch.	8.76	0.51	3.00	7.07	0.57	5	5
39	195	1	Periploca aphylla Decne.	10.00	1.23	6.00	28.29	1.13	4	4
39	195	2	Lycium barbarum L.	4.30	0.56	3.00	7.07	0.65	4	4
39	195	3	Periploca aphylla Decne.	8.90	1.00	5.50	23.77	0.88	4	4
39	195	4	Lycium shawii Roem. et Sch.	5.50	0.81	4.00	12.57	1.03	4	4
40	196	1	Lycium shawii Roem. et Sch.	2.50	0.57	3.00	7.07	0.50	5	7
40	196	2	Acacia gerradii Benth.	10.00	2.80	7.00	38.50	12.57	5	7
40	196	3	Lycium shawii Roem. et Sch.	2.70	1.85	6.00	28.29	12.57	5	7
40	196	4	Lycium barbarum L.	1.00	0.55	3.00	7.07	0.50	5	7
40	197	1	Kleinia odora (Forssk.) DC.	10.00	0.65	4.00	12.57	0.65	5	8
40	197	2	Kleinia odora (Forssk.) DC.	10.00	0.50	3.00	7.07	0.64	5	8
40	197	3	Acacia gerradii Benth.	10.00	2.60	6.00	28.29	5.89	5	8
40	197	4	Acacia gerradii Benth.	6.20	1.50	6.00	28.29	3.14	5	8
40	198	1	Kleinia odora (Forssk.) DC.	5.50	0.75	6.00	28.29	1.13	4	5
40	198	2	Lycium barbarum L.	2.00	0.54	4.00	12.57	0.76	4	5
40	198	3	Lycium barbarum L.	4.20	0.65	4.00	12.57	0.67	4	5
40	198	4	Kleinia odora (Forssk.) DC.	6.00	0.96	6.00	28.29	1.13	4	5
40	199	1	Lycium barbarum L.	9.10	0.50	3.00	7.07	0.50	3	6
40	199	2	Lycium barbarum L.	7.34	0.58	3.50	9.63	0.54	3	6
40	199	3	Lycium barbarum L.	6.30	0.52	3.00	7.07	0.50	3	6
40	199	4	Kleinia odora (Forssk.) DC.	8.00	0.72	4.00	12.57	0.65	3	6
40	200	1	Kleinia odora (Forssk.) DC.	8.10	0.65	4.00	12.57	1.13	5	8
40	200	2	Lycium barbarum L.	5.00	0.58	3.00	7.07	0.76	5	8
40	200	3	Lycium barbarum L.	4.08	0.50	4.00	12.57	0.65	5	8
40	200	4	Lycium barbarum L.	6.50	0.60	4.00	12.57	0.76	5	8
41	201	1	Lycium shawii Roem. et Sch.	7.00	0.90	4.00	12.57	3.14	4	4
41	201	2	Lycium shawii Roem. et Sch.	6.00	0.78	4.00	12.57	2.01	4	4
41	201	3	Acacia gerradii Benth.	9.50	1.45	6.00	28.29	1.13	4	4
41	201	4	Lycium barbarum L.	4.50	0.53	3.00	7.07	0.65	4	4
41	202	1	Kleinia odora (Forssk.) DC.	10.00	0.94	5.00	19.64	0.84	2	2
41	202	2	Kleinia odora (Forssk.) DC.	6.00	0.75	4.00	12.57	0.74	2	2
41	202	3	Kleinia odora (Forssk.) DC.	6.52	0.95	6.00	28.29	3.14	2	2
41	202	4	Kleinia odora (Forssk.) DC.	7.00	0.80	4.00	12.57	1.13	2	2
41	203	1	Lycium barbarum L.	5.56	0.54	4.00	12.57	0.50	3	3
41	203	2	Kleinia odora (Forssk.) DC.	4.00	0.93	6.00	28.29	0.79	3	3
41	203	3	Kleinia odora (Forssk.) DC.	10.00	0.72	4.00	12.57	0.65	3	3
41	203	4	Lycium shawii Roem. et Sch.	5.00	0.52	3.00	7.07	0.50	3	3
41	204	1	Lycium barbarum L.	2.00	0.50	3.00	7.07	0.50	4	4
41	204	2	Lycium barbarum L.	9.60	0.53	3.00	7.07	0.50	4	4
41	204	3	Lycium shawii Roem. et Sch.	5.30	1.17	6.00	28.29	0.75	4	4
41	204	4	Kleinia odora (Forssk.) DC.	3.08	0.73	6.00	28.29	0.65	4	4
41	205	1	Lycium barbarum L.	0.80	0.50	3.00	7.07	0.65	3	3
41	205	2	Lycium barbarum L.	10.00	0.50	3.00	7.07	0.50	3	3
41	205	3	Kleinia odora (Forssk.) DC.	8.00	0.78	4.00	12.57	0.64	3	3
41	205	4	Lycium barbarum L.	0.50	0.52	3.00	7.07	0.50	3	3
42	206	1	Lycium barbarum L.	2.50	0.53	4.00	12.57	0.50	7	9
42	206	2	Leptadenia pyrotechnica (Forssk.) Decne.	2.10	1.20	6.00	28.29	2.33	7	9
42	206	3	Sageretia thea (Osb.) M.C. Johnst.	9.00	0.65	4.00	12.57	0.50	7	9

42	206	4	Kleinia odora (Forssk.) DC.	2.09	1.10	6.00	28.29	1.77	7	9
42	207	1	Lycium shawii Roem. et Sch.	9.90	0.90	4.00	12.57	1.13	7	7
42	207	2	Lycium shawii Roem. et Sch.	9.53	1.05	3.00	7.07	1.13	7	7
42	207	3	Lycium shawii Roem. et Sch.	7.30	1.60	6.00	28.29	0.75	7	7
42	207	4	Lycium shawii Roem. et Sch.	1.00	1.20	4.00	12.57	0.65	7	7
42	208	1	Lycium shawii Roem. et Sch.	3.60	2.03	7.00	38.50	1.54	6	7
42	208	2	Lycium shawii Roem. et Sch.	3.30	1.20	6.00	28.29	0.79	6	7
42	208	3	Lycium shawii Roem. et Sch.	5.00	2.45	8.00	50.29	2.01	6	7
42	208	4	Lycium shawii Roem. et Sch.	4.52	0.95	4.00	12.57	0.79	6	7
42	209	1	Kleinia odora (Forssk.) DC.	5.00	0.83	6.00	28.29	1.54	5	5
42	209	2	Kleinia odora (Forssk.) DC.	3.00	0.87	6.00	28.29	1.54	5	5
42	209	3	Acacia gerradii Benth.	2.80	2.50	12.00	113.14	4.13	5	5
42	209	4	Lycium barbarum L.	5.50	0.67	4.00	12.57	0.79	5	5
42	210	1	Lycium barbarum L.	9.48	0.69	4.00	12.57	0.64	3	4
42	210	2	Kleinia odora (Forssk.) DC.	3.10	0.52	3.00	7.07	0.50	3	4
42	210	3	Lycium barbarum L.	10.00	0.50	3.00	7.07	0.54	3	4
42	210	4	Kleinia odora (Forssk.) DC.	6.08	0.65	4.00	12.57	0.54	3	4
43	211	1	Acacia gerradii Benth.	3.80	3.60	16.50	213.91	38.50	4	3
43	211	2	Kleinia odora (Forssk.) DC.	3.10	0.50	4.00	12.57	0.54	4	3
43	211	3	Acacia gerradii Benth.	7.90	1.45	10.00	78.57	0.79	4	3
43	211	4	Lycium shawii Roem. et Sch.	4.00	0.90	6.00	28.29	1.77	4	3
43	212	1	Lycium shawii Roem. et Sch.	10.00	0.78	6.00	28.29	0.79	3	2
43	212	2	Kleinia odora (Forssk.) DC.	3.50	1.14	7.00	38.50	3.14	3	2
43	212	3	Acacia gerradii Benth.	5.70	0.60	4.00	12.57	0.65	3	2
43	212	4	Lycium barbarum L.	9.00	0.55	3.00	7.07	0.54	3	2
43	213	1	Kleinia odora (Forssk.) DC.	8.79	0.88	4.00	12.57	1.96	3	2
43	213	2	Lycium shawii Roem. et Sch.	7.00	0.70	4.00	12.57	0.79	3	2
43	213	3	Acacia gerradii Benth.	10.00	1.00	6.00	28.29	2.01	3	2
43	213	4	Kleinia odora (Forssk.) DC.	5.50	1.00	4.00	12.57	2.00	3	2
43	214	1	Kleinia odora (Forssk.) DC.	6.00	0.93	5.50	23.77	3.14	3	1
43	214	2	Lycium shawii Roem. et Sch.	10.00	1.00	7.00	38.50	4.91	3	1
43	214	3	Acacia gerradii Benth.	8.64	0.68	3.50	9.63	0.54	3	1
43	214	4	Acacia gerradii Benth.	3.50	0.78	6.00	28.29	0.64	3	1
43	215	1	Kleinia odora (Forssk.) DC.	8.90	0.98	6.00	28.29	2.01	2	2
43	215	2	Lycium shawii Roem. et Sch.	5.00	0.50	3.00	7.07	0.50	2	2
43	215	3	Kleinia odora (Forssk.) DC.	8.50	0.72	4.00	12.57	0.64	2	2
43	215	4	Kleinia odora (Forssk.) DC.	9.57	0.82	4.50	15.91	0.68	2	2
44	216	1	Lycium shawii Roem. et Sch.	9.11	0.58	4.70	17.36	0.56	4	4
44	216	2	Lycium shawii Roem. et Sch.	1.50	0.72	4.00	12.57	0.79	4	4
44	216	3	Acacia gerradii Benth.	8.00	4.00	26.00	531.14	63.64	4	4
44	216	4	Lycium shawii Roem. et Sch.	4.30	0.87	7.00	38.50	1.13	4	4
44	217	1	Acacia gerradii Benth.	3.00	2.50	15.00	176.79	50.29	4	4
44	217	2	Lycium shawii Roem. et Sch.	9.50	0.54	4.00	12.57	0.65	4	4
44	217	3	Lycium shawii Roem. et Sch.	10.00	0.80	3.50	9.63	0.79	4	4
44	217	4	Lycium shawii Roem. et Sch.	4.00	0.70	6.00	28.29	0.79	4	4
44	218	1	Lycium shawii Roem. et Sch.	6.00	1.13	6.00	28.29	1.13	4	3
44	218	2	Lycium shawii Roem. et Sch.	5.50	0.79	4.00	12.57	0.79	4	3
44	218	3	Lycium shawii Roem. et Sch.	7.10	0.79	3.50	9.63	0.79	4	3
44	218	4	Lycium shawii Roem. et Sch.	8.20	0.94	4.00	12.57	0.94	4	3
44	219	1	Lycium shawii Roem. et Sch.	2.00	0.50	3.00	7.07	0.54	3	2
44	219	2	Lycium shawii Roem. et Sch.	4.50	0.50	3.00	7.07	0.50	3	2
44	219	3	Lycium shawii Roem. et Sch.	7.98	0.51	2.50	4.91	0.46	3	2

44	219	4	Lycium shawii Roem. et Sch.	6.10	1.50	7.00	38.50	3.14	3	2
44	220	1	Lycium shawii Roem. et Sch.	9.87	0.71	5.50	23.77	0.76	2	2
44	220	2	Lycium shawii Roem. et Sch.	10.00	0.83	7.00	38.50	1.13	2	2
44	220	3	Lycium shawii Roem. et Sch.	10.00	0.89	6.00	28.29	0.79	2	2
44	220	4	Lycium shawii Roem. et Sch.	9.50	1.40	7.00	38.50	3.14	2	2
45	221	1	Acacia gerradii Benth.	6.20	5.60	26.00	531.14	38.50	4	2
45	221	2	Acacia gerradii Benth.	6.00	3.10	12.00	113.14	12.57	4	2
45	221	3	Acacia gerradii Benth.	9.68	1.12	8.60	58.11	0.91	4	2
45	221	4	Acacia gerradii Benth.	3.05	4.60	20.00	314.29	12.57	4	2
45	222	1	Lycium shawii Roem. et Sch.	4.30	0.73	4.00	12.57	0.55	4	2
45	222	2	Lycium shawii Roem. et Sch.	9.00	1.57	6.00	28.29	3.80	4	2
45	222	3	Acacia gerradii Benth.	3.00	0.50	3.00	7.07	0.54	4	2
45	222	4	Acacia gerradii Benth.	5.27	1.72	7.00	38.50	8.25	4	2
45	223	1	Acacia gerradii Benth.	10.00	0.78	4.00	12.57	0.79	3	1
45	223	2	Acacia gerradii Benth.	8.76	0.60	5.00	19.64	0.46	3	1
45	223	3	Lycium shawii Roem. et Sch.	9.98	1.40	7.00	38.50	1.13	3	1
45	223	4	Lycium shawii Roem. et Sch.	7.50	1.92	7.00	38.50	9.63	3	1
45	224	1	Acacia gerradii Benth.	9.50	0.50	3.00	7.07	0.50	3	1
45	224	2	Lycium shawii Roem. et Sch.	5.00	0.54	3.50	9.63	0.50	3	1
45	224	3	Acacia gerradii Benth.	9.87	0.72	3.50	9.63	0.46	3	1
45	224	4	Lycium shawii Roem. et Sch.	10.00	1.10	4.00	12.57	0.79	3	1
45	225	1	Kleinia odora (Forssk.) DC.	4.25	0.78	4.00	12.57	0.79	2	2
45	225	2	Kleinia odora (Forssk.) DC.	8.50	0.85	6.00	28.29	1.13	2	2
45	225	3	Kleinia odora (Forssk.) DC.	9.55	0.76	3.50	9.63	0.64	2	2
45	225	4	Kleinia odora (Forssk.) DC.	9.86	0.61	3.00	7.07	0.58	2	2
46	226	1	Acacia gerradii Benth.	6.00	6.15	14.00	154.00	12.57	4	3
46	226	2	Acacia gerradii Benth.	7.00	1.50	6.00	28.29	3.14	4	3
46	226	3	Ziziphus spina-christi (L.) Willd.	5.00	5.50	34.00	908.29	56.57	4	3
46	226	4	Lycium shawii Roem. et Sch.	2.20	0.67	3.50	9.63	1.13	4	3
46	227	1	Acacia gerradii Benth.	5.20	5.30	22.00	380.29	38.50	3	2
46	227	2	Acacia gerradii Benth.	3.50	5.00	20.00	314.29	56.77	3	2
46	227	3	Lycium shawii Roem. et Sch.	9.00	0.75	6.00	28.29	1.13	3	2
46	227	4	Lycium shawii Roem. et Sch.	5.50	0.65	3.50	9.63	0.79	3	2
46	228	1	Kleinia odora (Forssk.) DC.	5.50	0.71	4.00	12.57	0.79	3	3
46	228	2	Lycium shawii Roem. et Sch.	6.00	0.67	3.50	9.63	0.54	3	3
46	228	3	Acacia arabica (Lam.) Willd.	4.50	2.66	24.00	452.57	7.07	3	3
46	228	4	Lycium shawii Roem. et Sch.	4.20	1.48	7.00	38.50	1.13	3	3
46	229	1	Lycium shawii Roem. et Sch.	3.50	0.50	3.50	9.63	0.60	3	2
46	229	2	Lycium shawii Roem. et Sch.	6.20	0.67	3.00	7.07	0.50	3	2
46	229	3	Lycium shawii Roem. et Sch.	8.25	0.44	3.00	7.07	0.54	3	2
46	229	4	Lycium shawii Roem. et Sch.	9.30	0.45	3.50	4.91	0.48	3	2
46	230	1	Lycium shawii Roem. et Sch.	6.10	0.72	3.50	9.63	0.65	3	3
46	230	2	Acacia arabica (Lam.) Willd.	10.00	6.65	32.00	804.57	15.91	3	3
46	230	3	Lycium shawii Roem. et Sch.	4.50	2.50	6.00	28.29	1.18	3	3
46	230	4	Acacia arabica (Lam.) Willd.	8.20	5.70	20.00	314.29	19.64	3	3
47	231	1	Lycium shawii Roem. et Sch.	9.89	0.95	3.50	9.63	0.79	4	1
47	231	2	Acacia arabica (Lam.) Willd.	5.50	4.20	7.00	38.50	63.64	4	1
47	231	3	Acacia arabica (Lam.) Willd.	7.20	5.23	8.00	50.29	12.57	4	1
47	231	4	Lycium shawii Roem. et Sch.	10.00	1.60	6.00	28.29	3.41	4	1
47	232	1	Acacia arabica (Lam.) Willd.	10.00	1.00	4.00	12.57	0.79	3	3
47	232	2	Acacia arabica (Lam.) Willd.	6.20	2.10	6.00	28.29	50.29	3	3
47	232	3	Lycium shawii Roem. et Sch.	8.50	0.50	3.00	7.07	0.64	3	3

47	232	4	Acacia arabica (Lam.) Willd.	6.32	0.91	3.50	9.96	0.71	3	3
47	233	1	Lycium shawii Roem. et Sch.	2.60	1.48	6.00	28.29	1.40	3	3
47	233	2	Acacia arabica (Lam.) Willd.	3.60	2.00	7.00	38.50	3.14	3	3
47	233	3	Acacia arabica (Lam.) Willd.	4.50	3.10	7.00	38.50	4.12	3	3
47	233	4	Rhamnus disperma Ehrenb.	9.00	1.60	20.00	314.29	7.07	3	3
47	234	1	Lycium shawii Roem. et Sch.	7.18	0.63	4.00	12.57	0.44	3	3
47	234	2	Lycium shawii Roem. et Sch.	6.12	0.50	3.00	7.07	0.50	3	3
47	234	3	Acacia arabica (Lam.) Willd.	6.00	2.50	7.00	38.50	7.07	3	3
47	234	4	Lycium shawii Roem. et Sch.	5.10	1.10	4.00	12.57	0.79	3	3
47	235	1	Acacia arabica (Lam.) Willd.	7.50	1.00	7.00	38.50	2.14	3	2
47	235	2	Lycium shawii Roem. et Sch.	8.91	0.59	5.00	19.64	0.54	3	2
47	235	3	Lycium shawii Roem. et Sch.	9.00	0.92	6.00	28.29	1.29	3	2
47	235	4	Acacia arabica (Lam.) Willd.	4.50	1.62	7.00	38.50	3.14	3	2
48	236	1	Acacia gerradii Benth.	8.20	1.95	6.00	28.29	9.63	3	2
48	236	2	Lycium shawii Roem. et Sch.	1.98	0.90	4.00	12.57	1.13	3	2
48	236	3	Lycium shawii Roem. et Sch.	4.20	1.20	6.00	28.29	1.13	3	2
48	236	4	Lycium shawii Roem. et Sch.	8.00	1.40	7.00	38.50	1.54	3	2
48	237	1	Acacia arabica (Lam.) Willd.	7.00	2.60	18.00	254.57	15.91	3	1
48	237	2	Acacia arabica (Lam.) Willd.	7.50	2.20	10.00	78.57	12.57	3	1
48	237	3	Acacia arabica (Lam.) Willd.	6.30	3.10	10.00	78.57	19.64	3	1
48	237	4	Acacia arabica (Lam.) Willd.	9.35	2.12	8.00	50.57	11.64	3	1
48	238	1	Acacia arabica (Lam.) Willd.	5.60	2.40	22.00	380.29	12.57	3	3
48	238	2	Acacia arabica (Lam.) Willd.	5.40	1.20	7.00	38.50	1.13	3	3
48	238	3	Acacia arabica (Lam.) Willd.	8.50	2.30	8.00	50.29	3.14	3	3
48	238	4	Acacia arabica (Lam.) Willd.	10.00	1.40	8.00	50.29	1.13	3	3
48	239	1	Lycium shawii Roem. et Sch.	4.00	1.60	4.00	12.57	1.13	3	2
48	239	2	Acacia arabica (Lam.) Willd.	6.20	1.70	7.00	38.50	3.14	3	2
48	239	3	Acacia arabica (Lam.) Willd.	9.22	0.82	3.50	9.63	3.14	3	2
48	239	4	Acacia arabica (Lam.) Willd.	9.40	0.73	3.00	7.07	0.76	3	2
48	240	1	Acacia arabica (Lam.) Willd.	5.00	3.00	4.00	12.57	12.57	3	2
48	240	2	Acacia arabica (Lam.) Willd.	6.00	2.50	6.00	28.29	12.57	3	2
48	240	3	Acacia arabica (Lam.) Willd.	7.50	2.30	6.00	28.29	9.63	3	2
48	240	4	Rhamnus disperma Ehrenb.	7.20	2.00	20.00	314.29	12.57	3	2
49	241	1	Acacia arabica (Lam.) Willd.	9.53	0.97	3.50	9.63	1.13	3	2
49	241	2	Acacia arabica (Lam.) Willd.	9.57	1.67	12.00	113.14	12.57	3	2
49	241	3	Acacia arabica (Lam.) Willd.	3.60	1.48	7.50	44.20	3.80	3	2
49	241	4	Acacia arabica (Lam.) Willd.	4.35	0.66	4.00	12.57	0.65	3	2
49	242	1	Acacia arabica (Lam.) Willd.	9.00	2.30	6.00	28.29	1.13	2	2
49	242	2	Acacia arabica (Lam.) Willd.	8.13	1.10	6.00	28.29	1.09	2	2
49	242	3	Acacia arabica (Lam.) Willd.	9.45	0.92	5.00	19.64	0.79	2	2
49	242	4	Acacia arabica (Lam.) Willd.	7.12	0.70	4.00	12.29	0.64	2	2
49	243	1	Acacia arabica (Lam.) Willd.	6.83	1.53	6.00	28.29	3.80	3	2
49	243	2	Acacia arabica (Lam.) Willd.	9.10	1.48	6.00	28.29	3.14	3	2
49	243	3	Acacia arabica (Lam.) Willd.	9.70	0.95	3.50	9.63	0.84	3	2
49	243	4	Acacia arabica (Lam.) Willd.	5.10	0.92	4.00	12.57	1.13	3	2
49	244	1	Acacia arabica (Lam.) Willd.	3.60	0.92	6.00	28.29	1.13	3	1
49	244	2	Acacia arabica (Lam.) Willd.	10.00	1.33	7.00	38.50	3.14	3	1
49	244	3	Acacia arabica (Lam.) Willd.	9.80	1.22	6.00	28.29	3.14	3	1
49	244	4	Acacia arabica (Lam.) Willd.	8.77	1.50	4.80	18.10	2.13	3	1
49	245	1	Acacia arabica (Lam.) Willd.	9.83	0.67	3.50	9.63	0.65	2	2
49	245	2	Acacia arabica (Lam.) Willd.	8.80	1.08	6.00	28.29	1.12	2	2
49	245	3	Acacia arabica (Lam.) Willd.	8.21	0.98	4.00	12.57	0.82	2	2

49	245	4	Acacia arabica (Lam.) Willd.	9.96	1.25	4.00	12.57	0.79	2	2
50	246	1	Acacia arabica (Lam.) Willd.	9.00	0.59	2.50	4.91	0.47	3	1
50	246	2	Acacia arabica (Lam.) Willd.	5.00	0.50	3.00	7.07	0.50	3	1
50	246	3	Acacia arabica (Lam.) Willd.	7.05	1.09	6.00	28.29	2.01	3	1
50	246	4	Acacia arabica (Lam.) Willd.	8.68	0.90	4.00	12.57	0.79	3	1
50	247	1	Acacia arabica (Lam.) Willd.	9.83	1.50	6.00	28.29	3.14	3	1
50	247	2	Acacia arabica (Lam.) Willd.	10.00	1.27	7.00	38.50	3.80	3	1
50	247	3	Acacia arabica (Lam.) Willd.	7.92	0.98	4.80	18.10	1.22	3	1
50	247	4	Acacia arabica (Lam.) Willd.	8.60	1.80	7.00	38.50	3.80	3	1
50	248	1	Acacia arabica (Lam.) Willd.	9.87	0.81	6.00	28.29	2.24	3	2
50	248	2	Acacia arabica (Lam.) Willd.	5.60	1.24	7.00	38.50	3.14	3	2
50	248	3	Acacia arabica (Lam.) Willd.	10.00	1.00	7.00	38.50	3.14	3	2
50	248	4	Acacia arabica (Lam.) Willd.	8.71	0.79	4.90	18.87	1.78	3	2
50	249	1	Acacia arabica (Lam.) Willd.	4.93	1.33	3.50	9.63	0.79	3	2
50	249	2	Acacia arabica (Lam.) Willd.	4.31	1.62	6.00	28.29	3.14	3	2
50	249	3	Acacia arabica (Lam.) Willd.	3.20	0.80	3.00	7.07	0.50	3	2
50	249	4	Acacia arabica (Lam.) Willd.	6.70	1.29	4.00	12.57	1.13	3	2
50	250	1	Acacia arabica (Lam.) Willd.	9.20	1.19	4.00	12.57	1.13	4	3
50	250	2	Acacia arabica (Lam.) Willd.	8.38	1.20	6.00	28.29	1.13	4	3
50	250	3	Acacia arabica (Lam.) Willd.	8.17	1.00	4.00	12.57	0.98	4	3
50	250	4	Acacia arabica (Lam.) Willd.	7.70	0.91	3.50	9.63	0.64	4	3
51	251	1	Acacia arabica (Lam.) Willd.	5.21	0.82	3.50	9.63	0.79	4	2
51	251	2	Acacia arabica (Lam.) Willd.	7.72	0.50	3.00	7.07	0.54	4	2
51	251	3	Acacia arabica (Lam.) Willd.	9.80	0.95	4.00	12.57	0.86	4	2
51	251	4	Acacia arabica (Lam.) Willd.	8.87	0.65	2.50	4.61	0.54	4	2
51	252	1	Acacia arabica (Lam.) Willd.	8.00	1.57	6.00	28.29	3.14	3	2
51	252	2	Acacia arabica (Lam.) Willd.	9.59	0.71	3.50	9.63	0.50	3	2
51	252	3	Acacia arabica (Lam.) Willd.	4.22	1.00	3.50	9.63	0.79	3	2
51	252	4	Acacia arabica (Lam.) Willd.	4.50	1.15	4.00	12.57	1.13	3	2
51	253	1	Acacia arabica (Lam.) Willd.	6.20	1.47	5.00	19.64	3.34	3	2
51	253	2	Acacia arabica (Lam.) Willd.	8.00	1.67	6.00	28.29	3.80	3	2
51	253	3	Acacia arabica (Lam.) Willd.	9.08	1.06	3.50	9.63	0.79	3	2
51	253	4	Acacia arabica (Lam.) Willd.	8.50	0.88	2.50	4.91	0.60	3	2
51	254	1	Acacia arabica (Lam.) Willd.	2.20	0.50	3.00	7.07	0.50	3	1
51	254	2	Acacia arabica (Lam.) Willd.	2.51	1.25	4.00	12.57	3.14	3	1
51	254	3	Acacia arabica (Lam.) Willd.	1.23	0.50	3.00	7.07	0.50	3	1
51	254	4	Acacia arabica (Lam.) Willd.	1.27	0.85	3.50	9.63	0.65	3	1
51	255	1	Acacia arabica (Lam.) Willd.	5.05	1.00	4.00	12.57	0.65	3	2
51	255	2	Acacia arabica (Lam.) Willd.	4.60	0.87	3.50	9.63	0.60	3	2
51	255	3	Acacia arabica (Lam.) Willd.	2.30	1.23	4.00	12.57	0.79	3	2
51	255	4	Acacia arabica (Lam.) Willd.	2.10	1.38	6.00	28.29	0.95	3	2
52	256	1	Acacia arabica (Lam.) Willd.	4.15	0.52	3.00	7.07	0.50	4	2
52	256	2	Acacia arabica (Lam.) Willd.	5.63	1.83	19.00	283.64	3.25	4	2
52	256	3	Acacia arabica (Lam.) Willd.	3.08	1.10	4.00	12.57	1.25	4	2
52	256	4	Lycium shawii Roem. et Sch.	7.00	2.06	7.00	38.50	3.14	4	2
52	257	1	Acacia arabica (Lam.) Willd.	9.80	0.92	4.00	12.57	0.68	3	1
52	257	2	Acacia arabica (Lam.) Willd.	9.31	1.13	6.00	28.29	0.89	3	1
52	257	3	Acacia arabica (Lam.) Willd.	5.10	1.30	7.00	38.50	1.89	3	1
52	257	4	Acacia arabica (Lam.) Willd.	4.20	2.33	19.00	283.64	4.91	3	1
52	258	1	Acacia arabica (Lam.) Willd.	9.00	0.72	3.00	7.07	0.64	3	2
52	258	2	Acacia arabica (Lam.) Willd.	8.89	0.44	2.50	4.91	0.54	3	2
52	258	3	Acacia arabica (Lam.) Willd.	9.19	1.13	6.00	28.29	1.13	3	2

52	258	4	Acacia arabica (Lam.) Willd.	3.30	0.50	3.50	9.63	0.65	3	2
52	259	1	Acacia arabica (Lam.) Willd.	10.00	1.17	6.00	28.29	1.13	3	2
52	259	2	Acacia arabica (Lam.) Willd.	9.90	0.83	3.00	7.07	0.73	3	2
52	259	3	Acacia arabica (Lam.) Willd.	9.00	0.49	2.50	4.91	0.64	3	2
52	259	4	Acacia arabica (Lam.) Willd.	8.20	0.67	4.00	12.57	1.32	3	2
52	260	1	Lycium shawii Roem. et Sch.	3.80	0.50	4.00	12.57	0.64	2	1
52	260	2	Acacia arabica (Lam.) Willd.	8.97	0.98	3.00	7.07	0.54	2	1
52	260	3	Lycium shawii Roem. et Sch.	6.40	0.74	4.00	12.57	0.64	2	1
52	260	4	Lycium shawii Roem. et Sch.	9.00	0.60	3.50	9.63	0.60	2	1
53	261	1	Acacia arabica (Lam.) Willd.	9.98	0.88	3.50	9.63	0.62	3	2
53	261	2	Acacia arabica (Lam.) Willd.	4.00	2.05	4.00	12.57	1.13	3	2
53	261	3	Acacia arabica (Lam.) Willd.	4.33	2.08	6.00	28.29	3.14	3	2
53	261	4	Acacia arabica (Lam.) Willd.	7.30	2.50	7.00	38.50	12.57	3	2
53	262	1	Acacia arabica (Lam.) Willd.	9.70	0.85	6.00	28.29	1.13	3	1
53	262	2	Rhamnus disperma Ehrenb.	9.61	0.50	4.00	12.57	0.46	3	1
53	262	3	Rhamnus disperma Ehrenb.	5.15	1.56	7.00	38.50	3.84	3	1
53	262	4	Acacia arabica (Lam.) Willd.	4.00	0.50	3.00	7.07	0.64	3	1
53	263	1	Acacia arabica (Lam.) Willd.	6.00	0.50	3.00	7.07	0.54	3	1
53	263	2	Acacia arabica (Lam.) Willd.	10.00	0.68	3.50	9.63	0.60	3	1
53	263	3	Acacia arabica (Lam.) Willd.	3.10	1.15	4.00	12.57	1.13	3	1
53	263	4	Acacia arabica (Lam.) Willd.	4.04	1.90	7.00	38.50	3.84	3	1
53	264	1	Acacia arabica (Lam.) Willd.	2.72	0.50	3.00	7.07	0.65	3	1
53	264	2	Acacia arabica (Lam.) Willd.	9.80	0.41	2.50	4.91	0.39	3	1
53	264	3	Acacia arabica (Lam.) Willd.	4.60	0.53	3.00	7.07	0.64	3	1
53	264	4	Acacia arabica (Lam.) Willd.	4.65	0.50	3.00	7.07	0.50	3	1
53	265	1	Acacia arabica (Lam.) Willd.	8.35	1.12	3.00	7.07	0.79	3	1
53	265	2	Acacia arabica (Lam.) Willd.	5.35	0.50	3.50	9.63	0.54	3	1
53	265	3	Acacia arabica (Lam.) Willd.	9.89	0.41	2.50	4.91	0.43	3	1
53	265	4	Acacia arabica (Lam.) Willd.	7.11	0.49	2.50	4.91	0.50	3	1
54	266	1	Acacia arabica (Lam.) Willd.	2.35	1.27	4.00	12.57	1.84	3	1
54	266	2	Lycium shawii Roem. et Sch.	3.40	1.53	4.00	12.57	3.14	3	1
54	266	3	Acacia arabica (Lam.) Willd.	7.00	2.65	4.50	15.91	4.84	3	1
54	266	4	Lycium shawii Roem. et Sch.	10.00	0.40	2.50	4.91	0.39	3	1
54	267	1	Acacia arabica (Lam.) Willd.	9.70	0.48	2.50	4.91	0.44	3	1
54	267	2	Acacia arabica (Lam.) Willd.	5.56	0.58	3.00	7.07	0.65	3	1
54	267	3	Acacia arabica (Lam.) Willd.	5.68	1.30	6.00	28.29	3.14	3	1
54	267	4	Acacia arabica (Lam.) Willd.	5.75	0.50	3.00	7.07	0.50	3	1
54	268	1	Acacia arabica (Lam.) Willd.	4.30	3.29	5.00	19.64	7.07	3	1
54	268	2	Acacia arabica (Lam.) Willd.	9.00	2.72	4.00	12.57	7.07	3	1
54	268	3	Acacia arabica (Lam.) Willd.	10.00	0.80	4.00	12.57	1.13	3	1
54	268	4	Acacia arabica (Lam.) Willd.	8.92	0.77	3.50	9.63	0.92	3	1
54	269	1	Acacia arabica (Lam.) Willd.	7.00	2.05	13.00	132.79	7.07	3	1
54	269	2	Acacia arabica (Lam.) Willd.	2.80	2.10	12.00	113.14	5.89	3	1
54	269	3	Acacia arabica (Lam.) Willd.	9.89	0.78	7.00	38.50	2.14	3	1
54	269	4	Acacia arabica (Lam.) Willd.	8.00	1.15	5.00	19.64	3.14	3	1
54	270	1	Lycium shawii Roem. et Sch.	8.55	0.80	3.50	9.63	0.64	2	1
54	270	2	Acacia arabica (Lam.) Willd.	9.20	0.89	4.00	12.57	0.79	2	1
54	270	3	Lycium shawii Roem. et Sch.	9.20	0.72	3.00	7.07	0.64	2	1
54	270	4	Lycium shawii Roem. et Sch.	9.77	0.65	2.50	4.91	0.50	2	1
55	271	1	Acacia arabica (Lam.) Willd.	3.00	0.54	3.00	7.07	0.64	4	2
55	271	2	Acacia arabica (Lam.) Willd.	3.30	0.79	3.50	9.63	0.63	4	2
55	271	3	Calotropis procera (Ait.) Ait.f.	6.00	4.00	9.50	70.91	3.84	4	2

55	271	4	Acacia arabica (Lam.) Willd.	3.00	3.50	14.00	154.00	19.64	4	2
55	272	1	Acacia arabica (Lam.) Willd.	4.37	4.30	16.00	201.14	19.64	3	1
55	272	2	Acacia arabica (Lam.) Willd.	3.56	1.56	7.00	38.50	3.14	3	1
55	272	3	Acacia arabica (Lam.) Willd.	0.67	0.59	3.00	7.07	0.54	3	1
55	272	4	Acacia arabica (Lam.) Willd.	9.33	0.54	2.50	4.91	0.50	3	1
55	273	1	Calotropis procera (Ait.) Ait.f.	9.78	1.19	3.80	11.35	0.67	3	2
55	273	2	Acacia arabica (Lam.) Willd.	6.20	2.60	12.00	113.14	9.63	3	2
55	273	3	Acacia arabica (Lam.) Willd.	10.00	0.50	3.00	7.07	0.50	3	2
55	273	4	Calotropis procera (Ait.) Ait.f.	9.95	0.80	3.50	9.63	0.54	3	2
55	274	1	Acacia arabica (Lam.) Willd.	4.25	0.72	3.50	9.63	0.64	3	1
55	274	2	Acacia arabica (Lam.) Willd.	8.63	0.70	3.00	7.07	0.60	3	1
55	274	3	Acacia arabica (Lam.) Willd.	10.00	1.20	4.00	12.57	0.79	3	1
55	274	4	Tephrosia apollinia (Del.) Link.	8.90	0.70	2.50	4.91	0.52	3	1
55	275	1	Lagonychium farctum (Banks & Sol.) Bober.	2.23	0.50	3.50	9.63	0.54	3	2
55	275	2	Lagonychium farctum (Banks & Sol.) Bober.	5.60	0.68	4.00	12.57	0.64	3	2
55	275	3	Acacia arabica (Lam.) Willd.	10.00	1.30	6.00	28.29	0.79	3	2
55	275	4	Lycium shawii Roem. et Sch.	9.80	1.40	7.00	38.50	1.13	3	2
56	276	1	Acacia arabica (Lam.) Willd.	7.87	1.11	7.00	38.50	3.14	2	1
56	276	2	Acacia arabica (Lam.) Willd.	5.60	3.10	12.00	113.14	4.87	2	1
56	276	3	Acacia arabica (Lam.) Willd.	9.69	0.92	6.00	28.29	1.14	2	1
56	276	4	Acacia arabica (Lam.) Willd.	6.90	4.38	16.00	201.14	15.91	2	1
56	277	1	Acacia arabica (Lam.) Willd.	6.11	1.35	8.00	50.29	3.14	3	1
56	277	2	Acacia arabica (Lam.) Willd.	9.01	0.80	8.00	50.29	0.79	3	1
56	277	3	Acacia arabica (Lam.) Willd.	9.00	3.36	20.00	314.29	7.07	3	1
56	277	4	Acacia arabica (Lam.) Willd.	9.21	0.67	2.50	4.91	0.57	3	1
56	278	1	Acacia arabica (Lam.) Willd.	1.70	0.50	3.00	7.07	0.67	3	1
56	278	2	Acacia arabica (Lam.) Willd.	8.59	3.60	24.00	452.57	28.29	3	1
56	278	3	Acacia arabica (Lam.) Willd.	7.40	1.86	10.00	78.57	3.14	3	1
56	278	4	Acacia arabica (Lam.) Willd.	9.38	0.80	2.50	4.91	0.54	3	1
56	279	1	Acacia arabica (Lam.) Willd.	3.20	0.50	3.00	7.07	0.52	2	1
56	279	2	Acacia arabica (Lam.) Willd.	7.98	0.50	2.50	4.91	0.50	2	1
56	279	3	Acacia arabica (Lam.) Willd.	2.00	3.00	6.23	30.50	12.57	2	1
56	279	4	Acacia arabica (Lam.) Willd.	8.32	0.50	2.50	4.91	0.53	2	1
56	280	1	Acacia arabica (Lam.) Willd.	8.71	0.50	3.00	7.07	0.68	2	1
56	280	2	Acacia arabica (Lam.) Willd.	10.00	0.72	3.50	9.63	0.64	2	1
56	280	3	Acacia arabica (Lam.) Willd.	1.00	1.20	3.50	9.63	0.60	2	1
56	280	4	Acacia arabica (Lam.) Willd.	9.50	0.51	3.00	7.07	0.54	2	1
57	281	1	Acacia arabica (Lam.) Willd.	2.65	1.28	6.00	28.29	1.13	4	3
57	281	2	Rumex nervosus Vahl.	2.00	0.50	3.50	9.63	0.65	4	3
57	281	3	Acacia arabica (Lam.) Willd.	7.41	7.25	36.00	1018.29	50.29	4	3
57	281	4	Acacia arabica (Lam.) Willd.	2.80	0.75	4.00	12.57	0.79	4	3
57	282	1	Lycium shawii Roem. et Sch.	2.00	0.55	4.00	12.57	0.68	3	3
57	282	2	Acacia arabica (Lam.) Willd.	4.10	1.60	8.50	56.77	3.14	3	3
57	282	3	Acacia arabica (Lam.) Willd.	3.50	3.21	22.00	380.29	12.57	3	3
57	282	4	Acacia arabica (Lam.) Willd.	2.90	2.30	15.00	176.79	7.07	3	3
57	283	1	Acacia arabica (Lam.) Willd.	6.00	0.50	3.00	7.07	0.69	3	2
57	283	2	Acacia arabica (Lam.) Willd.	9.80	1.21	7.00	38.50	2.14	3	2
57	283	3	Acacia arabica (Lam.) Willd.	8.90	0.50	3.50	9.63	0.54	3	2
57	283	4	Acacia arabica (Lam.) Willd.	9.00	2.10	8.80	60.85	3.14	3	2
57	284	1	Acacia arabica (Lam.) Willd.	10.00	2.10	6.00	28.29	12.57	3	1
57	284	2	Acacia arabica (Lam.) Willd.	5.40	0.50	3.00	7.07	0.56	3	1
57	284	3	Acacia arabica (Lam.) Willd.	5.00	1.10	3.50	9.63	0.64	3	1

57	284	4	Acacia arabica (Lam.) Willd.	4.15	0.80	4.00	12.57	0.79	3	1
57	285	1	Lagonychium farctum (Banks & Sol.) Bober.	8.10	0.60	3.50	9.63	0.58	3	2
57	285	2	Lagonychium farctum (Banks & Sol.) Bober.	4.00	0.52	3.50	9.63	0.54	3	2
57	285	3	Acacia arabica (Lam.) Willd.	8.39	1.15	4.00	12.57	0.98	3	2
57	285	4	Acacia arabica (Lam.) Willd.	9.93	0.86	4.00	12.57	0.87	3	2
58	286	1	Acacia arabica (Lam.) Willd.	4.00	1.65	13.00	132.79	12.57	3	2
58	286	2	Acacia arabica (Lam.) Willd.	3.00	2.30	18.00	254.57	7.07	3	2
58	286	3	Acacia arabica (Lam.) Willd.	7.70	0.92	8.70	59.47	1.13	3	2
58	286	4	Acacia arabica (Lam.) Willd.	3.10	1.60	15.00	176.79	1.77	3	2
58	287	1	Acacia arabica (Lam.) Willd.	9.00	0.84	6.00	28.29	1.46	2	1
58	287	2	Acacia arabica (Lam.) Willd.	4.20	0.80	6.00	28.29	1.46	2	1
58	287	3	Acacia arabica (Lam.) Willd.	4.00	0.72	4.00	12.57	1.00	2	1
58	287	4	Acacia arabica (Lam.) Willd.	8.98	0.68	3.50	9.63	0.87	2	1
58	288	1	Acacia arabica (Lam.) Willd.	9.00	1.13	5.00	19.64	3.14	3	1
58	288	2	Acacia arabica (Lam.) Willd.	5.00	1.50	4.80	18.10	3.14	3	1
58	288	3	Acacia arabica (Lam.) Willd.	8.90	0.98	4.80	18.10	1.12	3	1
58	288	4	Acacia arabica (Lam.) Willd.	7.72	1.78	7.00	38.50	1.13	3	1
58	289	1	Acacia arabica (Lam.) Willd.	10.00	2.43	5.00	19.64	3.83	3	1
58	289	2	Acacia arabica (Lam.) Willd.	2.16	1.21	4.00	12.57	1.13	3	1
58	289	3	Acacia arabica (Lam.) Willd.	7.86	1.12	3.50	9.63	0.89	3	1
58	289	4	Acacia arabica (Lam.) Willd.	10.00	0.58	3.50	9.63	0.52	3	1
58	290	1	Acacia arabica (Lam.) Willd.	5.20	1.09	5.00	19.64	1.13	3	1
58	290	2	Acacia arabica (Lam.) Willd.	9.55	0.80	4.30	14.53	1.13	3	1
58	290	3	Acacia arabica (Lam.) Willd.	9.95	0.79	4.00	12.57	0.64	3	1
58	290	4	Acacia arabica (Lam.) Willd.	2.15	0.51	3.00	7.07	0.54	3	1
59	291	1	Acacia arabica (Lam.) Willd.	4.10	2.78	23.00	415.64	7.07	3	2
59	291	2	Acacia arabica (Lam.) Willd.	9.84	1.05	7.00	38.50	1.84	3	2
59	291	3	Acacia arabica (Lam.) Willd.	6.00	3.00	30.00	707.14	12.57	3	2
59	291	4	Acacia arabica (Lam.) Willd.	5.35	2.35	10.00	78.57	3.14	3	2
59	292	1	Acacia arabica (Lam.) Willd.	4.22	2.00	7.00	38.50	7.07	3	2
59	292	2	Acacia arabica (Lam.) Willd.	4.00	0.50	3.00	7.07	0.50	3	2
59	292	3	Acacia arabica (Lam.) Willd.	9.97	0.56	3.50	9.63	0.54	3	2
59	292	4	Acacia arabica (Lam.) Willd.	5.15	0.71	3.50	9.63	0.65	3	2
59	293	1	Acacia arabica (Lam.) Willd.	9.78	0.71	4.00	12.57	0.79	2	1
59	293	2	Acacia arabica (Lam.) Willd.	6.80	1.33	7.50	44.20	2.01	2	1
59	293	3	Acacia arabica (Lam.) Willd.	6.50	0.67	7.00	38.50	0.79	2	1
59	293	4	Acacia arabica (Lam.) Willd.	6.00	0.65	5.00	19.64	0.64	2	1
59	294	1	Acacia arabica (Lam.) Willd.	9.90	0.77	3.50	9.63	0.60	2	1
59	294	2	Acacia arabica (Lam.) Willd.	6.32	0.58	3.00	7.07	0.54	2	1
59	294	3	Acacia arabica (Lam.) Willd.	9.80	0.50	3.00	7.07	0.64	2	1
59	294	4	Acacia arabica (Lam.) Willd.	9.50	0.53	3.00	7.07	0.60	2	1
59	295	1	Acacia arabica (Lam.) Willd.	9.80	1.15	5.00	19.64	0.79	2	1
59	295	2	Acacia arabica (Lam.) Willd.	8.60	1.00	4.00	12.57	0.72	2	1
59	295	3	Acacia arabica (Lam.) Willd.	9.86	0.73	3.50	9.63	0.60	2	1
59	295	4	Acacia arabica (Lam.) Willd.	7.25	0.66	3.00	7.07	0.54	2	1
60	296	1	Lycium shawii Roem. et Sch.	7.00	3.35	10.00	78.57	9.63	3	2
60	296	2	Acacia arabica (Lam.) Willd.	3.12	1.50	9.00	63.64	4.91	3	2
60	296	3	Acacia arabica (Lam.) Willd.	7.00	1.40	7.00	38.50	4.91	3	2
60	296	4	Acacia arabica (Lam.) Willd.	9.22	0.93	5.70	25.53	1.34	3	2
60	297	1	Acacia arabica (Lam.) Willd.	6.20	0.83	4.00	12.57	0.79	3	2
60	297	2	Acacia arabica (Lam.) Willd.	4.05	2.45	22.00	380.29	7.07	3	2
60	297	3	Acacia arabica (Lam.) Willd.	3.25	1.00	5.00	19.64	1.77	3	2

60	297	4	Acacia arabica (Lam.) Willd.	4.25	1.38	7.00	38.50	3.14	3	2
60	298	1	Acacia arabica (Lam.) Willd.	4.85	1.57	12.00	113.14	1.77	2	1
60	298	2	Acacia arabica (Lam.) Willd.	8.90	0.82	7.00	38.50	1.23	2	1
60	298	3	Acacia arabica (Lam.) Willd.	9.72	1.05	11.20	98.56	1.62	2	1
60	298	4	Acacia arabica (Lam.) Willd.	5.00	0.91	6.00	28.29	0.79	2	1
60	299	1	Acacia arabica (Lam.) Willd.	6.00	1.08	5.00	19.64	1.54	2	1
60	299	2	Acacia arabica (Lam.) Willd.	8.50	1.27	7.00	38.50	1.77	2	1
60	299	3	Acacia arabica (Lam.) Willd.	10.00	2.15	10.00	78.57	7.07	2	1
60	299	4	Acacia arabica (Lam.) Willd.	10.00	0.77	4.00	12.57	0.64	2	1
60	300	1	Acacia arabica (Lam.) Willd.	2.20	0.75	5.00	19.64	0.79	2	1
60	300	2	Acacia arabica (Lam.) Willd.	4.45	0.93	5.00	19.64	0.79	2	1
60	300	3	Acacia arabica (Lam.) Willd.	8.98	0.87	4.80	18.10	0.64	2	1
60	300	4	Acacia arabica (Lam.) Willd.	1.50	0.70	4.00	12.57	0.64	2	1

APPENDIX THREE

Questions to Be Answered By Shepherds and Owners of Livestock in the Research Area

Date ______
Location ______
Interview number ______

1- Do you own these animals?
- -Yes ______
- -No ______

If your answer to question 1 is No, what is the relationship between you and the owner?
- -Tenant ______
- -Partner ______
- -Relative ______
- -Other (specify) --- ______

2- What kind of animals and how many do you have?
- -Sheep ______
- -Goat ______
- -Camel ______
- -Donkey ______
- -Other (specify) --- ______

3- What is the purpose(s) of breeding these livestock?
- -For personal domestic use ______
- -For personal use and market demand ______
- -Suitability of land and / or crops ______

4- Does your income depend only on livestock breeding or do you have another source of income?
- -Depends only on livestock breeding ______
- -Depends on another income source ______
- -Depends on both ______

5- Are the pastures in your current area sufficient for feeding your animals or do you have to move them to other areas?
- -The pastures are sufficient for the animals(go to question 9) ______
- -Not sufficient, and I move them to other areas ______

6- In which direction do you usually move your animals, and how long do you stay there?
- -Toward the north (-------- months, -------- days) ______
- -Toward the south (-------- months, -------- days) ______
- -Toward the east (-------- months, -------- days) ______
- -Toward the west (-------- months, -------- days) ______

7- What is/are the reason(s) for movement?
-To look for new pastures ______
-To look for water ______
-Both the above ______
-Other (specify) -- ______

8- In which season do you move to the new grazing land?
-In summer ______
-In autumn ______
-In winter ______
-In spring ______

9- What kind(s) of vegetation do your animals depend on for grazing?
-Trees ______
-Shrubs ______
-Weeds ______
-Herbs ______

10- What kind(s) of water source(s) do you use for your animals?
-Wells ______
-Water remaining after rainfall ______
-Springs ______
-Water transported by cars ______
-Other (specify) -- ______

11- Do you know, what is the effect of livestock on vegetation and soil?
-Yes ______
-No (go to question 13) ______

12- What kind(s) of effect do livestock have on vegetation and soil?
-Increasing of soil fertility ______
-Crumbling and exposure of soil ______
-Crumbling of vegetation ______
-Over-grazing (fatigue of grazing) ______

13- What do you think are the reason(s) for deterioration of grazing in your current area?
-Decreasing of rain and increasing of temperature ______
-Increasing of livestock ______
-Weakness of planning for exploitation of the postures ______
-Concentration close to the resources of water ______
-Over-grazing ______
-Governmental support to the Bedouins ______
-Increasing of Bedouin movement ______
-Wood-cutting ______
-Unwatered agriculture ______
-Weakness of traditional hema system
-Movement of weeds and herbs

14- Do try try to avoid over-grazing?
- -Yes ______
- -No ______

15- How do you avoid over-grazing?
- -Have fewer animals in the dry periods ______
- -Move to new grazing land ______
- -Other (specify) --- ______

16- What can be done to conserve vegetation and soil?
- -Protect soil and vegetation against fire and pollution ______
- -Stop wood-cutting ______
- -Stop over-grazing ______
- -Other (specify) -- ______

Thank you very much for your assistance and co-operation.

APPENDIX FOUR

Soil Data

Soil Data

Location: Upper Wadi Bishah.
Researcher: Al-Qahtani
Date of analysis: 1 October to 20 November 1996
Texture class represented as follows:
1= sandy clay loam 2= sandy loam/sandy clay 3= loam 4= sandy loam
5= loam sandy/sandy loam 6= loamy sand 7= sand loamy sand 8= sand

Transect NO	sample NO	soil depth C	sand %	silt %	clay %	texture class	Moisture %	Soil pH	EC	OM	OC	CaCO3	N	P	K
1	1	50	88	10	2	8	0.54	8.2	1.49	0.236	0.137	2.33	98.28	9	202
1	2	26	82	16	2	6	0.74	8.5	0.19	0.236	0.137	2.33	189	4	156
1	3	18	82	14	4	6	0.79	8.5	0.16	0.304	0.173	2.72	158.76	2	77.1
1	4	30	84	12	4	6	0.9	8.6	0.15	0.169	0.098	3.1	143.64	3	97.6
1	5	18	90	8	2	8	0.58	8.5	0.16	0.236	0.137	2.33	181.44	2	87.3
2	6	50	94	4	2	8	0.67	8.6	0.11	0.103	0.0597	2.33	120.96	4	112
2	7	50	88	10	2	8	0.84	8.7	0.14	0.103	0.0597	2.72	113.4	3	143
2	8	30	92	6	2	8	0.66	8.8	0.12	0.103	0.098	2.72	105.84	3	132
2	9	18	80	18	2	6	1.99	8.7	0.19	0.169	0.098	19.01	143.64	9	103
2	10	20	90	8	2	8	1.79	8.7	0.14	0.169	0.0597	7.76	136.08	3	87.9
3	11	50	90	6	4	8	0.63	7.8	7.38	0.103	0.0597	8.92	105.84	2	122
3	12	50	82	14	4	6	0.7	8.3	1.06	0.103	0.0197	3.1	151.2	2	309
3	13	45	90	6	4	8	0.61	8.7	0.28	0.0342	0.0197	2.33	143.64	2	171
3	14	19	90	6	4	8	0.66	8.5	0.14	0.304	0.176	2.33	151.64	5	124
3	15	15	92	6	2	8	0.36	8.6	0.15	0.503	0.291	2.33	181.44	5	170
4	16	50	96	2	2	8	0.33	8.7	0.1	0.013	0.0075	1.94	113.4	2	108
4	17	41	88	8	4	8	0.48	8.6	0.15	0.236	0.137	2.33	143.64	4	188
4	18	23	86	10	4	6	0.83	8.5	0.23	0.304	0.176	2.33	173.88	4	92.7
4	19	20	76	18	6	5	1.12	8.6	0.23	0.304	0.176	4.27	143.64	3	80.1
4	20	15	82	14	4	6	0.9	8.5	0.17	0.2025	0.117	2.72	143.64	3	79.5
5	21	50	70	20	10	4	1.59	8.2	0.2	0.304	0.176	1.94	272.16	2	239
5	22	50	44	42	14	3	3.17	3.9	0.42	0.844	0.489	3.88	468.72	1	33.8
5	23	16	70	22	8	4	2.26	7.9	0.17	1.52	0.881	1.94	476.28	3	71.6
5	24	15	70	28	2	4	2.27	8.2	0.16	0.776	0.45	1.55	718.2	1	32.2
5	25	21	56	38	6	4	3.43	8.1	0.19	0.574	0.332	1.94	831.6	2	66.8
6	26	50	84	12	4	6	2.29	7.5	0.76	2.64	1.531	1.94	234.36	20	544
6	27	50	76	20	4	6	2.81	7.5	0.7	1.49	0.864	1.94	771.12	18	860
6	28	26	78	16	6	6	1.64	7.5	1.19	0.913	0.529	1.94	385.12	7	376
6	29	20	72	22	6	4	1.69	8.4	0.12	1.352	0.784	2.72	393.12	2	78.9
6	30	14	74	22	4	5	1.51	8.4	0.16	1.42	0.823	5.04	405.24	1	48.4
7	31	30	70	24	6	4	1.14	7.8	0.18	1.554	0.901	1.94	710.64	63	920
7	32	28	72	22	6	4	2.45	8	0.14	2.03	1.177	2.33	612.36	46	36
7	33	16	80	16	4	6	2.72	7.7	0.18	2.096	1.215	1.94	650.16	46	38.1
7	34	15	72	20	8	4	2.01	7.6	0.21	2.163	1.238	1.94	827.82	49	58.6
7	35	13	78	18	4	6	3.3	7.6	0.21	2.352	1.354	1.94	733.32	42	50
8	36	30	74	22	4	5	2.87	7.6	0.15	2.352	0.784	1.94	801.36	33	23.1
8	37	20	76	20	4	6	3.61	7.7	0.13	3.72	2.157	1.94	3379.32	47	38.8
8	38	13	76	20	4	6	3.27	7.7	1.39	4.374	2.536	2.72	1512	46	236
8	39	17	78	16	6	6	2.01	8.1	0.27	4.596	2.665	2.33	1512	216	49.6
8	40	20	80	18	2	6	2.22	7.8	0.15	3.244	1.88	1.94	937.44	42	33.5

9	41	50	72	20	8	4	2.53	8.1	0.15	1.893	1.097	1.94	498.96	37	36.4
9	42	30	82	16	2	6	2.16	8	0.1	1.49	0.864	1.94	536.76	49	46.4
9	43	25	36	32	32	3	4.64	7.3	0.19	3.515	2.038	1.94	703.08	36	21.8
9	44	40	82	12	6	6	2.72	8	0.14	3.65	2.117	1.55	725.76	49	20.4
9	45	28	84	12	4	6	2.7	8.1	0.21	0.88	0.51	1.94	907.2	112	40.4
10	46	50	80	14	6	6	1.62	8	0.11	4.87	2.82	1.94	166.32	39	29.6
10	47	25	70	20	10	4	3.18	8	0.25	5.205	3.018	1.55	143.64	139	55.1
10	48	16	68	20	12	4	5.21	7.1	0.18	4.33	2.511	1.55	937.44	36	31.9
10	49	10	70	20	10	4	3.16	7.5	0.21	5.34	2.98	1.55	1323	142	50.3
10	50	20	70	20	10	4	6.72	7.4	0.17	3.38	1.96	1.55	748.44	29	30.8
11	51	30	82	12	6	6	2.93	7.6	0.19	3.096	1.795	1.94	1126.44	160	27.6
11	52	25	78	16	6	6	3.23	7.5	0.21	2.49	1.44	1.55	559.44	147	43.2
11	53	20	64	28	8	4	3.65	7.5	0.14	3.836	2.224	1.55	1043.28	66	24.5
11	54	13	62	28	10	4	4.7	7.6	0.13	4.038	2.342	1.55	1436.4	43	18.9
11	55	14	76	14	10	4	4.07	7.4	0.3	9.69	5.62	1.55	3890.72	56	203
12	56	19	64	28	8	4	2.62	7.6	0.13	2.56	1.484	1.55	801.36	36	22.8
12	57	27	68	26	6	4	3.23	8.3	0.17	0.875	0.507	6.98	680.4	51	16.1
12	58	15	82	12	6	6	2.23	8	0.21	1.28	0.742	2.33	960.12	156	37.3
12	59	20	62	26	12	4	3.61	7.9	0.11	2.288	1.327	1.55	786.24	55	16.1
12	60	20	64	28	8	4	3.25	7.8	0.18	3.3	1.91	1.55	1134	56	39.1
13	61	35	70	24	6	4	3.06	7.7	0.16	2.086	1.209	1.55	665.28	79	267
13	62	29	82	16	2	6	3.92	8.1	0.17	1.88	1.09	1.55	642.6	46	31.5
13	63	28	60	34	6	4	2.31	8.2	0.08	1.28	0.742	1.94	1353.74	11	11.2
13	64	20	76	18	6	5	2.97	8.1	0.16	0.942	0.546	1.94	627.84	12	41.2
13	65	20	80	16	4	6	4.67	7.9	0.2	2.422	1.404	1.94	801.36	2	27.8
14	66	50	90	8	2	8	0.78	8.1	0.11	0.673	0.39	1.94	355.32	11	98.3
14	67	50	90	8	2	8	0.91	8.2	0.14	0.74	0.429	1.55	241.92	4	102
14	68	40	84	12	4	6	1.72	8.1	0.15	0.673	0.391	1.94	355.32	5	69.6
14	69	40	90	8	2	8	1.98	8	0.16	1.278	0.741	1.94	514.08	5	63.6
14	70	30	64	30	6	4	2.56	8.4	0.19	0.706	0.409	2.33	355.32	2	39.8
15	71	50	74	20	6	4	3.66	8.3	0.49	0.875	0.5075	10.86	158.76	49	37
15	72	50	78	16	6	6	2.04	8.5	0.3	0.74	0.429	2.72	234.36	65	60.9
15	73	50	86	10	4	6	1.28	8.4	0.34	0.404	0.234	1.94	128.52	8	68.4
15	74	40	90	8	2	8	0.66	8.5	0.11	0.706	0.409	1.94	249.48	7	71.5
15	75	35	82	12	6	6	1.5	8.6	0.17	0.538	0.312	1.33	294.84	54	122
16	76	35	66	22	12	4	2.88	8	0.2	2.652	1.538	1.16	1738.8	75	292
16	77	38	72	18	10	4	2.17	8.1	0.18	2.78	1.612	1.16	1837.08	97	30.6
16	78	20	76	16	8	4	3.4	8	0.18	2.312	1.34	1.6	990.36	37	31.8
16	79	16	74	16	10	4	3.4	8	0.15	2.924	1.695	1.16	1179.36	93	55
16	80	22	78	18	4	6	3.37	7.6	0.13	2.574	1.492	1.55	1186.92	51	29.7
17	81	50	72	20	8	4	3.23	7.8	0.12	2.188	1.222	1.16	967.69	34	142
17	82	29	72	22	6	4	5.02	7.8	0.13	2.516	1.459	1.16	1141.56	48	32.2
17	83	34	76	16	8	4	4.43	7.8	0.18	2.516	1.459	1.55	831.6	55	48
17	84	40	80	14	6	6	2.79	7.9	0.1	1.43	0.829	1.16	559.44	55	84.3
17	85	24	80	12	8	6	3.63	8	0.12	1.77	1.0266	1.16	687.96	63	57
18	86	50	80	16	4	6	1.95	8.3	0.18	1.292	0.749	1.94	491.4	62	47.8
18	87	28	84	12	4	6	3.16	8.1	0.12	0.816	0.473	1.55	453.6	107	32.8
18	88	25	88	10	2	8	4.68	8	0.12	2.244	1.301	1.55	937.44	37	34.8
18	89	19	90	8	2	8	3.88	8	0.13	1.43	0.829	1.55	498.96	35	33.3
18	90	22	86	12	2	8	3.35	7.9	0.13	1.292	0.794	1.55	1375.92	67	35.8
19	91	44	58	36	6	4	3.11	7.9	0.14	0.884	0.512	1.16	461.16	25	166
19	92	23	80	16	4	6	3.18	8	0.16	2.142	1.242	1.16	703.08	54	34.2

19	93	20	76	18	6	5	4.01	8.1	0.14	1.972	1.143	1.16	498.96	26	49.5
19	94	20	84	12	4	6	4.43	8.4	0.23	1.623	0.946	3.49	763.56	38	25.5
19	95	19	86	12	2	7	3.02	7.8	0.26	1.43	0.829	1.16	801.36	30	52.2
20	96	50	50	24	26	1	6.54	7.9	0.66	1.904	1.104	1.16	846.72	65	183
20	97	43	70	20	10	4	9.79	7.8	0.27	4.62	2.679	1.16	1708.56	72	79.6
20	98	35	58	22	20	2	10.8	7.2	0.48	6.26	3.63	1.16	2162.16	115	44.2
20	99	22	66	20	14	4	8.41	7.8	0.34	5.91	3.42	1.16	1776.6	123	148
20	100	19	64	16	20	2	10.3	7.4	0.43	3.26	1.89	1.16	1239.84	62	36.2
21	101	35	88	8	4	8	1.43	8.1	0.15	1.02	0.591	1.55	1065.96	106	255
21	102	23	88	10	2	8	2.43	8.1	0.16	0.952	0.552	1.55	151.2	33	72.4
21	103	20	82	12	6	6	1.94	8	0.17	1.632	0.946	1.55	143.64	38	109
21	104	18	78	16	6	5	2.1	8.4	0.24	0.952	0.552	1.94	69.66	41	60
21	105	18	88	10	2	8	2.53	8.3	0.19	0.816	0.473	1.16	81.65	27	20.3
22	106	33	70	24	6	4	4.95	7.8	0.15	3.196	1.853	1.55	317.36	39	57.2
22	107	25	72	20	8	4	4.3	7.8	0.16	3.47	1.981	1.55	839.16	61	37.9
22	108	20	78	16	6	6	4.08	7.6	0.17	2.52	1.462	1.55	385.56	49	40
22	109	22	78	18	4	6	4.83	7.6	0.19	3.47	2.1	1.55	786.24	61	47.9
22	110	10	78	18	4	6	3.88	7.7	0.18	4.76	2.76	1.55	725.76	66	39.2
23	111	50	56	22	22	1	6.6	7.8	0.24	2.584	1.498	1.55	771.12	86	106
23	112	45	66	28	6	4	5.16	7.7	0.08	3.54	2.053	1.55	362.88	42	16.4
23	113	40	72	22	6	4	7.42	7.7	0.17	2.652	1.538	1.55	582.12	55	21.7
23	114	31	76	20	4	6	5.13	7.6	0.13	2.312	1.282	1.55	665.28	37	41.5
23	115	18	82	12	6	6	5.82	7.8	0.18	2.72	1.577	1.55	710.64	35	27.3
24	116	23	84	12	4	6	9.98	7.8	0.3	5.372	3.115	1.55	975.24	184	56
24	117	27	70	20	10	4	7.45	7.9	0.25	2.924	1.695	1.55	385.56	30	95.5
24	118	16	78	18	4	6	5.03	7.7	0.27	5.3	3.074	1.55	559.44	105	65.4
24	119	16	84	10	6	6	3.52	7.5	0.2	2.56	1.537	1.55	272.16	42	75.4
24	120	18	84	12	4	6	3.04	7.7	0.26	0.476	0.276	1.55	1058.4	85	80.8
25	121	24	50	36	14	3	5.57	7.5	0.24	2.584	1.498	1.55	1323	43	72.3
25	122	22	54	36	10	4	6.67	7.8	0.21	2.72	1.577	1.55	816.48	65	159
25	123	15	74	20	6	4	2.27	7.6	0.18	2.176	1.262	1.55	997.92	33	50.1
25	124	20	72	22	6	4	2.96	7.5	0.2	3.196	1.853	1.15	597.24	57	57.1
25	125	18	70	22	8	4	4.72	7.6	0.22	4.35	2.52	1.55	1353.24	43	55.1
26	126	35	76	18	6	5	2.06	8.1	0.12	0.612	0.354	1.94	98.28	45	69.5
26	127	26	76	18	6	4	2.01	7.8	0.07	1.564	0.907	1.55	105.84	30	225
26	128	25	82	14	4	6	1.05	8.1	0.07	0.814	0.472	1.55	68.04	37	24.5
26	129	13	94	4	2	8	2.17	7.8	0.06	0.92	0.533	1.55	60.48	40	33.7
26	130	25	86	12	2	7	2.17	8	0.05	0.983	0.57	1.55	45.36	42	11.5
27	131	35	86	8	6	6	2.8	7.9	0.12	0.644	0.37	1.55	151.2	45	137
27	132	33	64	12	24	1	10.4	8.4	0.3	1.254	0.727	2.72	257.04	58	96.7
27	133	13	82	14	4	6	1.3	7.9	0.1	1.118	0.648	1.55	30.24	54	116
27	134	11	80	14	6	6	1.79	8.1	0.15	0.983	0.57	1.55	211.68	44	140
27	135	10	82	12	6	6	2.64	8.7	0.16	0.92	0.534	1.55	45.36	58	81.6
28	136	50	90	6	4	8	1.01	8.4	0.11	0.305	0.177	1.94	60.48	80	105
28	137	46	82	12	6	6	2.98	8.5	0.16	0.305	0.177	1.94	37.8	79	139
28	138	28	68	16	16	4	5.57	8.2	0.22	1.32	0.765	1.55	113.4	55	64
28	139	20	76	10	14	4	4.48	7.8	0.14	1.254	0.727	1.94	400.68	50	97.8
28	140	19	76	10	14	4	5.16	7.8	0.28	0.915	0.53	1.94	143.64	38	32.6
29	141	50	66	16	18	4	8	7.8	0.46	0.44	0.255	12.42	37.8	34	276
29	142	20	86	8	6	6	2.21	8.5	0.25	0.915	0.53	1.55	45.36	45	111
29	143	25	86	8	6	6	2.19	8.2	0.12	0.847	0.491	1.55	143.64	47	77.9
29	144	23	90	6	4	8	2.18	8.3	0.1	0.847	0.491	1.55	461.16	49	111

29	145	13	88	6	6	7	1.38	8.2	0.23	1.356	0.786	1.94	325.8	44	167
30	146	22	82	12	6	6	2.11	8.5	0.3	0.576	0.334	1.94	347.76	54	338
30	147	19	90	6	4	8	1.33	8.5	0.09	0.508	0.295	1.55	60.76	49	32.3
30	148	15	84	8	8	6	2.09	8.5	0.19	0.779	0.451	1.94	385.56	47	147
30	149	18	84	6	10	6	1.84	7.9	0.14	1.424	0.824	1.55	257.04	55	168
30	150	25	88	4	8	6	2.32	7.8	0.11	0.915	0.53	1.94	483.84	41	80.7
31	151	50	62	30	8	4	10.3	8.3	0.41	0.8078	0.468	2.72	257.04	48	32.9
31	152	50	68	28	4	4	6.35	8.4	0.31	0.602	0.349	3.1	143.64	50	81
31	153	50	78	14	8	5	5.66	8.3	0.25	0.535	0.31	1.55	294.84	44	92.7
31	154	45	86	10	4	6	3.66	8.2	0.18	0.602	0.349	1.55	430.92	45	177
31	155	29	84	14	2	6	9.33	8.2	0.31	1.34	0.777	2.33	438.48	23	120
32	156	50	62	24	14	4	10.8	8.3	0.42	0.669	0.388	5.04	604.8	33	185
32	157	43	64	24	12	4	9.36	7.9	2.24	1.14	0.661	3.88	687.96	37	269
32	158	17	70	22	8	4	6.17	8.2	0.23	0.94	0.545	1.55	287.28	47	202
32	159	35	90	8	2	8	5.68	8.4	0.24	0.669	0.388	2.72	249.48	56	239
32	160	23	74	22	4	5	7.36	8.3	0.33	1.404	0.814	2.33	589.76	45	166
33	161	50	82	14	4	6	1.75	7.9	0.73	1.404	0.814	2.72	158.76	48	221
33	162	38	84	10	6	6	0.98	8.5	0.15	0.401	0.232	1.55	151.2	61	141
33	163	43	82	12	6	6	1.39	8.2	0.12	0.468	0.271	1.94	189	38	127
33	164	30	88	10	2	8	0.65	8.4	0.12	0.502	0.291	1.94	68.04	51	54.1
33	165	22	84	10	6	6	1.38	8.3	0.21	0.669	0.388	1.94	45.36	45	43.5
34	166	50	90	6	4	8	0.97	7.9	0.19	0.802	0.465	1.94	151.2	52	122
34	167	50	84	10	6	6	1.21	8.2	0.26	0.401	0.232	3.88	45.36	68	163
34	168	30	84	8	8	6	1.21	8.2	0.3	0.134	0.0777	2.33	45.36	103	178
34	169	20	82	10	8	6	1.89	8.2	0.18	0.401	0.232	4.27	83.16	66	199
34	170	27	84	12	4	6	1.28	8.3	0.19	0.334	0.193	2.33	90.72	49	55.2
35	171	45	96	2	2	8	1.64	9	0.11	0.27	0.156	2.33	75.6	42	52.1
35	172	20	86	10	4	6	2.1	8.7	0.11	0.468	0.27	4.27	52.92	58	100
35	173	24	74	14	12	4	3.25	8.7	0.2	0.535	0.31	4.27	68.04	42	320
35	174	19	84	10	6	6	2.53	8.7	0.12	0.535	0.31	3.49	68.04	53	132
35	175	15	86	10	4	6	2.46	8.4	0.12	0.501	0.29	1.94	37.8	53	139
36	176	50	74	16	10	4	1.74	6.8	7.16	0.401	0.232	1.94	37.8	70	94.9
36	177	45	82	14	4	6	2.93	8.7	0.18	0.401	0.232	3.1	166.32	54	78.2
36	178	50	92	6	2	8	1.28	8	0.96	0.2007	0.116	2.33	680.4	55	53.2
36	179	45	94	4	2	8	1.54	9.4	0.14	0.134	0.0777	1.55	37.8	51	23.1
36	180	50	80	14	6	6	2.4	9.1	0.14	0.334	0.193	3.94	37.8	70	134
37	181	50	90	6	4	8	0.85	8.5	0.2	0.401	0.232	2.72	45.36	74	67.9
37	182	50	90	6	4	8	0.9	8.5	0.1	0.296	0.155	1.55	45.36	44	70.8
37	183	50	90	6	4	8	1.03	8.5	0.13	0.401	0.232	1.94	98.28	51	75.6
37	184	50	86	8	6	6	1.85	8.6	0.08	0.334	0.193	2.33	189	56	175
37	185	15	78	16	6	6	2.6	8.7	0.09	0.401	0.232	2.33	831.6	47	61.9
38	186	22	90	6	4	8	9.08	8.2	0.09	0.535	0.31	2.72	15.12	65	167
38	187	20	84	10	6	6	1.5	8.1	0.64	0.635	0.368	1.55	22.68	54	129
38	188	21	86	8	6	6	1.72	8.9	0.09	0.334	0.193	2.33	302.4	82	78.8
38	189	15	88	8	4	8	2.85	8.7	0.12	0.535	0.31	3.1	52.92	67	78.8
38	190	14	88	8	4	8	1.72	8.6	0.27	0.334	0.193	2.72	60.48	88	80
39	191	50	80	14	6	6	3.5	8.9	0.2	0.267	0.155	2.33	204.12	57	27.6
39	192	35	94	2	4	8	1.06	8.6	0.33	0.2007	0.116	1.94	37.8	61	78.3
39	193	25	78	18	4	6	1.32	8.5	0.23	0.334	0.193	1.94	37.8	47	116
39	194	20	82	14	4	6	1.21	8.4	0.08	0.669	0.388	1.55	52.92	47	64.3
39	195	30	50	40	10	8	1.47	8.7	0.14	0.401	0.232	1.55	309.96	50	42.1
40	196	50	90	8	2	8	1.15	8.7	0.13	0.401	0.232	2.33	7.56	55	89.1

40	197	45	90	8	2	8	0.73	8.4	1.45	0.267	0.155	2.33	90.72	50	68.4
40	198	30	82	12	6	6	2.99	8.1	0.48	0.535	0.31	3.1	30.24	47	133
40	199	35	86	12	2	7	2.71	8.8	0.13	0.2007	0.116	3.49	45.36	56	53.7
40	200	25	84	12	4	6	2.08	8.7	0.09	0.401	0.232	1.94	37.8	54	91.9
41	201	50	92	6	2	8	1.72	8.6	0.16	0.269	0.155	2.72	22.68	52	123
41	202	50	86	12	2	7	1.14	7.8	3.81	0.201	0.116	0.72	26.46	56	37.9
41	203	40	80	14	6	6	1.35	8.6	0.11	0.471	0.273	3.1	68.04	55	117
41	204	42	82	12	6	6	1.36	8.7	0.17	0.201	0.116	2.33	151.2	44	124
41	205	45	86	10	4	6	1.5	8.8	0.1	0.201	0.116	3.88	22.68	49	62.7
42	206	45	78	18	4	6	1.73	8.6	0.13	0.336	0.195	2.72	26.64	54	58.6
42	207	50	86	12	2	7	0.72	8.4	0.62	0.269	0.156	2.33	309.96	67	256
42	208	22	84	12	4	6	1.1	8.8	0.14	0.336	0.195	3.1	52.92	53	114
42	209	23	82	12	6	6	1.16	8.5	0.1	0.437	0.253	3.49	68.04	52	112
42	210	20	82	14	4	6	1.12	8.4	0.38	0.235	0.136	3.88	15.12	61	102
43	211	50	86	10	4	6	0.89	8.4	0.14	0.201	0.116	1.94	52.92	44	178
43	212	50	86	8	6	6	1.33	8.4	0.08	0.201	0.116	1.55	60.84	32	94.2
43	213	50	70	18	12	6	1.56	7.8	2.89	0.302	0.175	3.1	41.58	47	71.6
43	214	40	70	14	16	4	3.69	8.7	0.11	0.437	0.253	3.1	113.4	54	117
43	215	21	76	16	8	4	1.83	8.9	0.07	0.269	0.156	2.33	41.58	60	119
44	216	15	86	8	6	6	0.99	8.9	0.1	0.201	0.116	2.33	37.8	58	134
44	217	50	86	8	6	6	1.44	8.7	0.05	0.135	0.078	1.94	57.6	45	94.1
44	218	45	86	8	6	6	1.34	8.6	0.07	0.168	0.097	1.55	41.58	60	58.3
44	219	16	82	8	10	6	1.52	8.7	0.09	0.37	0.214	1.94	196.56	43	117
44	220	15	82	6	12	6	1.5	8.6	0.15	0.336	0.195	2.72	75.6	35	170
45	221	50	90	4	6	8	1.12	8.4	0.1	0.0673	0.039	3.88	309.76	46	77.1
45	222	50	88	6	6	7	1.27	8.7	0.09	0.134	0.0777	1.55	83.16	40	79.4
45	223	50	82	10	8	6	1.28	8.5	0.2	0.134	0.0777	3.49	90.72	52	144
45	224	40	82	10	8	6	2.28	8.7	0.1	0.269	0.156	1.94	60.48	39	68.7
45	225	15	92	4	4	8	1.27	8.7	0.12	0.135	0.0783	2.33	68.41	33	78.2
46	226	50	92	6	2	8	0.47	8.5	0.08	0.265	0.154	1.94	45.36	41	94.5
46	227	50	92	6	2	8	0.57	8.5	0.09	0.398	0.23	1.55	41.58	43	148
46	228	26	88	8	4	8	0.76	8.5	0.09	0.265	0.154	1.55	41.58	40	140
46	229	23	86	12	2	7	1.27	8.7	0.11	0.398	0.23	1.55	45.36	35	95.9
46	230	15	90	6	4	8	0.61	8.6	0.1	0.464	0.269	1.55	41.58	46	92.8
47	231	50	76	14	10	4	4.02	7.5	24.9	1.326	0.769	15.52	37.8	47	321
47	232	50	88	8	4	8	1.2	8.9	0.13	0.265	0.156	2.33	272.16	44	187
47	233	28	94	4	2	8	0.38	9.1	0.07	0.199	0.115	1.94	378	52	65
47	234	30	92	6	2	8	1.32	9.1	0.1	0.199	0.115	1.55	37.8	43	161
47	235	30	96	2	2	8	0.47	8.7	0.19	0.133	0.077	2.33	60.48	33	104
48	236	35	84	10	6	6	2.59	7.7	5.61	0.398	0.23	3.49	181.44	38	145
48	237	40	90	6	4	8	1.14	9	0.08	0.199	0.115	2.33	257.04	46	188
48	238	20	94	4	2	8	1.87	9	0.09	0.199	0.115	1.55	143.64	49	33.4
48	239	35	92	6	2	8	2.89	8.6	0.08	0.133	0.077	1.94	181.44	43	116
48	240	40	96	4	0	8	1.18	8.8	0.14	0.199	0.115	1.94	269.72	32	42.1
49	241	50	76	18	6	5	1.07	8.5	0.12	0.199	0.115	1.55	241.92	53	169
49	242	48	72	22	6	4	1.44	8.2	0.87	0.248	0.23	5.43	105.84	41	580
49	243	25	86	12	2	7	0.76	8.6	0.1	0.199	0.115	1.94	45.36	60	134
49	244	16	82	14	4	6	1.13	8.6	0.1	0.133	0.077	2.72	98.28	48	123
49	245	28	62	34	4	4	0.64	8.6	0.12	0.133	0.077	3.88	90.72	40	175
50	246	50	86	10	4	6	1	8.6	0.11	0.133	0.077	2.33	204.12	51	115
50	247	50	64	28	8	4	1.43	8.2	0.67	0.265	0.154	4.27	332.64	49	441
50	248	35	78	18	4	6	1	8.8	0.11	0.166	0.096	3.49	52.92	46	97.2

50	249	20	78	20	2	6	1.25	8.6	0.15	0.269	0.154	7.76	60.48	42	113
50	250	26	60	36	4	6	1.09	8.6	0.13	0.331	0.18	10.09	45.36	38	150
51	251	50	88	10	2	8	0.6	8.6	0.09	0.2019	0.117	3.1	37.8	36	142
51	252	50	94	4	2	8	0.47	8.8	0.07	0.2019	0.117	2.33	52.92	46	87
51	253	50	82	14	4	6	0.96	7.7	2.81	0.296	0.156	3.88	41.58	45	354
51	254	18	92	6	2	8	1.71	8.6	0.1	0.583	0.312	3.1	60.48	55	85.3
51	255	15	92	6	2	8	1.35	8.7	0.1	0.606	0.315	2.33	37.8	40	112
52	256	50	76	18	6	5	1.41	8.4	0.09	0.471	0.273	1.16	52.92	58	134
52	257	50	72	20	8	4	1.39	8.4	0.39	0.2019	0.117	2.33	41.58	53	134
52	258	50	78	14	8	5	1.79	8.6	0.14	0.2019	0.117	2.72	37.8	52	151
52	259	35	70	22	8	4	0.59	7.9	1.28	0.235	0.136	2.72	52.92	48	324
52	260	14	84	10	6	6	1.27	8.7	0.16	0.269	0.156	7.76	158.76	45	90.7
53	261	50	74	16	10	6	1.98	8.6	0.22	0.269	0.312	1.55	41.58	50	2.92
53	262	35	86	8	6	6	0.83	8.8	0.1	0.588	0.176	3.49	30.24	43	271
53	263	23	76	16	8	4	1.6	8.7	0.12	0.303	0.195	4.27	181.44	46	192
53	264	17	88	8	4	8	1.41	8.7	0.08	0.337	0.156	3.1	22.68	36	96.1
53	265	13	78	16	6	6	1.33	8.7	0.09	0.296	0.117	9.7	52.92	45	70.7
54	266	50	90	6	4	8	0.5	8.7	0.1	0.2019	0.193	1.94	83.16	52	216
54	267	50	72	18	10	4	0.82	8.7	0.12	0.337	0.243	3.49	45.36	46	297
54	268	30	72	18	10	4	1.26	8.5	0.15	0.404	0.243	10.86	45.36	46	195
54	269	23	70	22	8	4	1.21	8.6	0.15	0.337	0.195	15.13	79.38	56	96.8
54	270	17	78	16	6	6	0.94	8.5	0.14	0.2019	0.117	12.03	83.16	48	83
55	271	50	88	4	8	6	0.46	8.6	0.05	0.2019	0.177	3.1	39.69	60	81.8
55	272	40	84	8	8	6	0.72	8.6	0.13	0.269	0.156	8.92	22.68	62	281
55	273	18	78	12	10	4	1.11	8.6	0.09	0.337	0.195	8.15	52.92	56	97.7
55	274	20	80	10	10	5	1.22	8.6	0.1	0.269	0.156	8.54	60.48	57	90.5
55	275	14	90	2	8	6	0.52	8.6	0.08	0.2019	0.117	2.72	37.8	58	71.2
56	276	50	78	12	10	4	0.83	8.6	0.1	0.337	0.195	13.58	37.8	57	115
56	277	50	90	2	8	6	0.55	8.7	0.05	0.606	0.351	3.88	30.24	41	108
56	278	32	90	2	8	6	0.45	8.6	0.07	0.2019	0.117	2.33	37.8	49	127
56	279	19	92	2	6	8	0.47	8.4	0.08	0.235	0.136	2.33	79.38	60	128
56	280	16	90	2	8	6	0.52	8.6	0.07	0.2019	0.117	1.94	30.24	56	93.1
57	281	50	94	0	6	8	0.45	8.7	0.06	0.2019	0.119	2.33	45.36	60	79.9
57	282	50	94	0	6	8	0.3	8.9	0.06	0.2019	0.117	1.94	52.92	54	119
57	283	23	86	4	10	6	0.82	8.6	0.09	0.269	0.156	2.33	52.92	57	108
57	284	35	88	2	10	6	0.74	8.7	0.07	0.0673	0.039	1.55	52.92	51	105
57	285	15	78	12	10	4	0.9	8.6	0.16	0.2019	0.117	8.54	37.8	57	44.6
58	286	50	86	8	6	6	0.95	8.6	0.21	0.269	0.156	2.33	52.92	69	132
58	287	50	84	8	8	6	0.97	8.7	0.33	0.2019	0.117	3.1	22.68	54	344
58	288	30	84	12	4	6	0.9	8.6	0.27	0.235	0.136	2.72	22.68	59	238
58	289	14	86	12	2	7	0.65	8.7	0.17	0.337	0.195	5.04	45.36	73	153
58	290	25	92	6	2	8	0.6	8.7	0.12	0.135	0.078	1.94	37.8	75	105
59	291	50	80	14	6	6	1.16	8.8	0.15	0.337	0.195	2.72	45.36	52	168
59	292	22	76	16	8	4	0.96	8.5	0.39	0.269	0.156	3.1	45.36	49	410
59	293	18	84	12	4	6	1.53	8.7	0.16	0.2019	0.117	3.49	52.92	62	145
59	294	20	80	14	6	6	1.78	8.6	0.21	0.337	0.195	10.48	75.6	52	142
59	295	15	74	20	6	4	1.12	8.7	0.19	0.2019	0.177	13.58	37.8	69	178
60	296	50	92	4	4	8	0.62	8.8	0.1	0.269	0.156	1.94	52.92	52	166
60	297	50	94	4	2	8	0.85	8.9	0.05	0.337	0.195	1.94	15.12	63	125
60	298	14	86	8	6	6	0.95	8.6	0.09	0.135	0.078	3.1	37.8	49	157
60	299	25	76	18	6	5	1.32	8.6	0.15	0.2019	0.117	7.37	37.8	65	130
60	300	17	78	12	10	4	2.29	8.6	0.15	0.0673	0.0392	14.36	45.36	69	112