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A Geographic Analysis Of Vegetation Deterioration In The Tabuk Area, Saudi Arabia

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A GEOGRAPHIC ANALYSIS OF VEGETATION DETERIORATION IN THE TABUK AREA, SAUDI ARABIA

A Dissertation

Presented to

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Doctor of Philosophy

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by

Khalid M. Al-Harbi

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APPROVAL SHEET

The dissertation of Khalid M. Al-Harbi, Contribution to the School of Graduate Studies, Indiana State University, Series III, Number 865, under the title *A Geographic Analysis of Vegetation Deterioration in the Tabuk Area, Saudi Arabia* is approved as partial fulfillment for the Doctor of Philosophy Degree.

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ABSTRACT

Vegetation deterioration has received an increasing amount of attention in the last few decades. It is considered a main indicator of land degradation processes. The Tabuk area, located in the northwest region of Saudi Arabia, has experienced vegetation deterioration as the major facet of land degradation processes. The study utilized Landsat-5 TM data, professional agricultural reports, and topographic maps, supported with intensive fieldwork to monitor vegetation deterioration and its causes and consequences.

The data used in this study has been analyzed using remotely sensed methods by pre-processing data, visual interpretation, and Normalized Differences Vegetation Index (NDVI). Climatic analysis also applied, especially to explain the variations in temperature and rainfall. Human impact analysis provided an environmental evaluation of overgrazing, woodcutting, and conservation. Statistical analysis assisted in obtaining simple statistics for the thirty vegetation samples and led to advanced analysis using T test and point biserial coefficient. Geographic Information Systems (GIS) was used in displaying TM images for obtaining scale and producing images as JEPG files.

The study came to the following findings and observations: Landsat-5 TM data has limited use in detecting vegetation deterioration in arid lands due to low spatial resolution. NDVI did show vegetation differences between 1988 and 1999. Climatic analysis demonstrated that the area is characterized by stressful arid conditions and a

paucity of rainfall over the entire area. Overgrazing and woodcutting have impacted several sites. Statistical analysis has quantified differences in vegetation and the relationship between NDVI and vegetation cover, human impact, and conservation.

In conclusion, NDVI assisted in analyzing major differences in vegetation and was useful in evaluating degradation in arid lands. Along with NDVI, human impact and climatic analyses are shown to be indicators of land degradation processes within this study area.

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INTRODUCTION

Desertification has received a great amount of attention in the past few decades since many countries in the world have suffered its effects and consequences. Indicators of desertification fall into three major groups depending upon three criteria: first, monitoring scales that include global, regional, and national/local indicators; secondly, the types of variables that include physical, biological or agricultural, and social indicators; and the last, land-use, which is divided into drylands, irrigated lands, rainfed croplands, pastoral lands, mining areas, and recreational lands (Mabbutt, 1986).

Desertification responds to both long-term climatic conditions and human impact. High temperature, low humidity, and high values of evapotranspiration, as well as the impact of overgrazing and woodcutting have contributed to the reduction of biological productivity and the spread of arid zones. The combination of human activities and the occasional series of dry years has led to vegetation reduction in arid environments (Goudie, 1986).

Desert vegetation may adapt to various environmental stresses. Plant adaptation to aridity includes morphological and physiological mechanisms. Examples include roots that reach down to 80 m, waxy leaf coatings, changing solar orientation of the leaves, and delayed seed germination (Heathcote, 1983). These adaptations assist researchers in distinguishing desert vegetation.

Desert vegetation presents an example of the conflicting presence of vegetation during water availability. The more water available, the more surviving and flourishing the vegetation. As a result, water is a dominant factor for vegetation survival in different areas.

Walter (1984) explains the productivity of desert vegetation by describing the varying productivity during drought times, when lower transpiration and photosynthesis lead to a reduction of active surface and vegetation production. He also mentions that woody plants in the desert bear large numbers of dead branches, which indicate past years of drought. In contrast, the reproduction process of seeds takes place after a good rain-year or after several successive good years.

According to Kassas (1966), desert vegetation is a habitat with ever-changing aspects. The seasonal aspects are the apparent expression of the phenological diversity of the plants and the seasonal rhythm of the climate. Seasonal changes involve soil microorganisms, animals that hibernate during the winter, and the effect on vegetation of wild animal grazing. The annual fluctuation of weather and climate also causes fluctuation in plant growth. Desert vegetation may manifest successional progression via the accumulation of soft material and the gradual building up of the soil surface; this may be attributed to water or wind transportation. The changes begin with succulent plants on shallow soils, non-succulent perennials on desert grasslands, and finally, a climax scrubland.

Vegetation and human impact in desert environments are two important topics that have received great attention in recent decades. Observing, monitoring and analyzing desert vegetation and its dynamics become essential tools for research in biological, environmental, and geographical research because natural vegetation is a major component and a fundamental element in any desert ecosystem.

Humans have played a major role in changing vegetation and its environment in arid lands in which grazing, woodcutting, and burning can deteriorate and damage the biological productivity resulting in degraded areas. Light grazing increases the productivity of wild pastures by spreading species seeds through animal defecation. Also, grazing can increase species diversity by opening the grass community and creating more niches. However, heavy grazing may cause deflation processes and accelerate soil deterioration or may kill plants and /or reduce the level of photosynthesis (Goudie, 1986).

Woodcutting one of the destructive impacts on desert vegetation may contribute to nonequilibrium processes in desert lands. Woodcutting in densely vegetated environments may be less harmful to those lands than woodcutting in desert environments, which experience drought, have limited resources, and require long-term periods for renewing vegetation cover. On the other hand, according to Batanounty (1983), the disturbance of habitat-supporting vegetation, dominated by *Acacia ehrenbergiana*, by cutting the trees and shrubs engenders invasion of this habitat by *Calotropis procera* that is neither used for fuel nor for grazing.

Numerous applied studies have been published in the field of environmental change. Young (1994), for example, mentions the importance of monitoring environment change issues. Indeed the investigation for any environmental issues like vegetation and its dynamics in desert lands continues to pose questions lacking simple answers. Nevertheless, there is a need for environmental studies in desert lands to help in understanding desert environmental phenomena change and their resulting effects on the landscape.

Change detection of land use, range conditions, desertification, changes in forest cover, regional evapotranspiration differences, soil moisture conditions, and other physical and biological processes are examples which may spatially and temporally occur within ecosystems (Mouat et al. 1993).

Vegetation deterioration is an important and dynamic indicator of desertification in arid regions. The method used to detect vegetation dynamics is a procedure for monitoring vegetation change during a specific period of time (Hellawell, 1991). A successful monitoring program requires five parts. First, the purpose or the aim of monitoring needs to be identified. Second, the method or how this aim can be achieved is determined. Third, the analysis or how often the data will be collected is decided. Fourth, the interpretation or what the data might mean is identified. Fifth, the time required for the study is determined (Usher, 1991). Monitoring vegetation change by satellite has become a scientific tool for a variety of research purposes. The Landsat satellite carries on board a Thematic Mapper (TM) sensor. The TM sensor is a mechanical scanning device with improved spectral, spatial, and radiometric characteristics and has one good advantage in that it acquires, scans, and obtains data in one direction only (Richards, 1993). Images obtained by a TM sensor have both an increase in the number of spectral bands and an improvement in spatial resolution, with a ground resolution of 30 m. TM has seven spectral bands. Band 1: 0.45-0.52 μm (blue) may be used for mapping and cultural feature identification. Band 2: 0.52-0.60 μm (green) is used to measure green reflectance of vegetation and vegetation discrimination and to identify cultural features. Band 3: 0.63-0.69 μm (red) is used for sensing a chlorophyll observation region, for plant species differentiation, and for cultural feature identification. Band 4: 0.76-0.90 μm (near infrared) is used for determining vegetation type, vigor, and biomass content, for delineating water bodies, and for soil moisture discrimination. Band 5: 1.55-1.75 μm (mid infrared) is used for vegetation moisture content, for soil moisture content and for differentiation of snow from clouds. Band 6: 10.4- 12.5 μm (thermal infrared) is more useful for vegetation stress analysis, soil moisture discrimination, and thermal mapping application. Band 7: 2.08-2.35 μm (mid infrared) is more applicable in discrimination of minerals and rock types and is sensitive to vegetation moisture content (Lillesand and Kiefer, 1994).

TM sensor is increasingly used as a data source for multiple environmental studies. It can provide reliable data for studying small geographic areas, for presenting the classification of various phenomena, and for understanding the processes associated with environmental factors.

This study is mainly focused on discussing, analyzing and evaluating vegetation deterioration processes in the Tabuk area, Saudi Arabia; an area that has experienced environmental destruction and much vegetal loss. Theoretically, the study utilizes several previous studies, especially those including identification and measurement of vegetation dynamics. In addition, it has adopted multiple techniques that effectively applied a NDVI equation and statistical techniques to examine different physical and human variables.

Methodologically, the study utilized remote sensing (spectral analysis, NDVI equation); climatic analysis (temperature and rainfall); disturbance measurement (overgrazing, woodcutting, and conservation) and statistical analysis (T test and point biserial coefficient).

The study fundamentally demonstrates that TM data is a limited source in studying vegetation in arid environments due to low spatial resolution, because multiple vegetation sites in the study area do not appear on the images.

Study Area

- Location

The Tabuk area is located in the northwest region of Saudi Arabia (Figure 1-1). Tabuk's history dates back to 500 B.C. It was known by the name of Taboo when it was the capital of Al-Ayaneyean (Saudi Ministry of Information, 1992). There are different studies confirming the Tabuk area as the land of Madyan and Dadan, both mentioned in the Holy books (Saudi Ministry of Information, 1992).

Tabuk is a transit point for trade caravans passing from south to north and vice versa. It has resumed its role as a town combining a glorious past with modern achievements. Tabuk lies roughly between latitudes 24° 30′ and 30° 00′ north, and longitudes 34° 45′ and 40° 00′ east. The study area used for this research is located between latitudes 27° 30′ and 29° 00′ north, and longitudes 35° 30′ and 37° 30′ east.

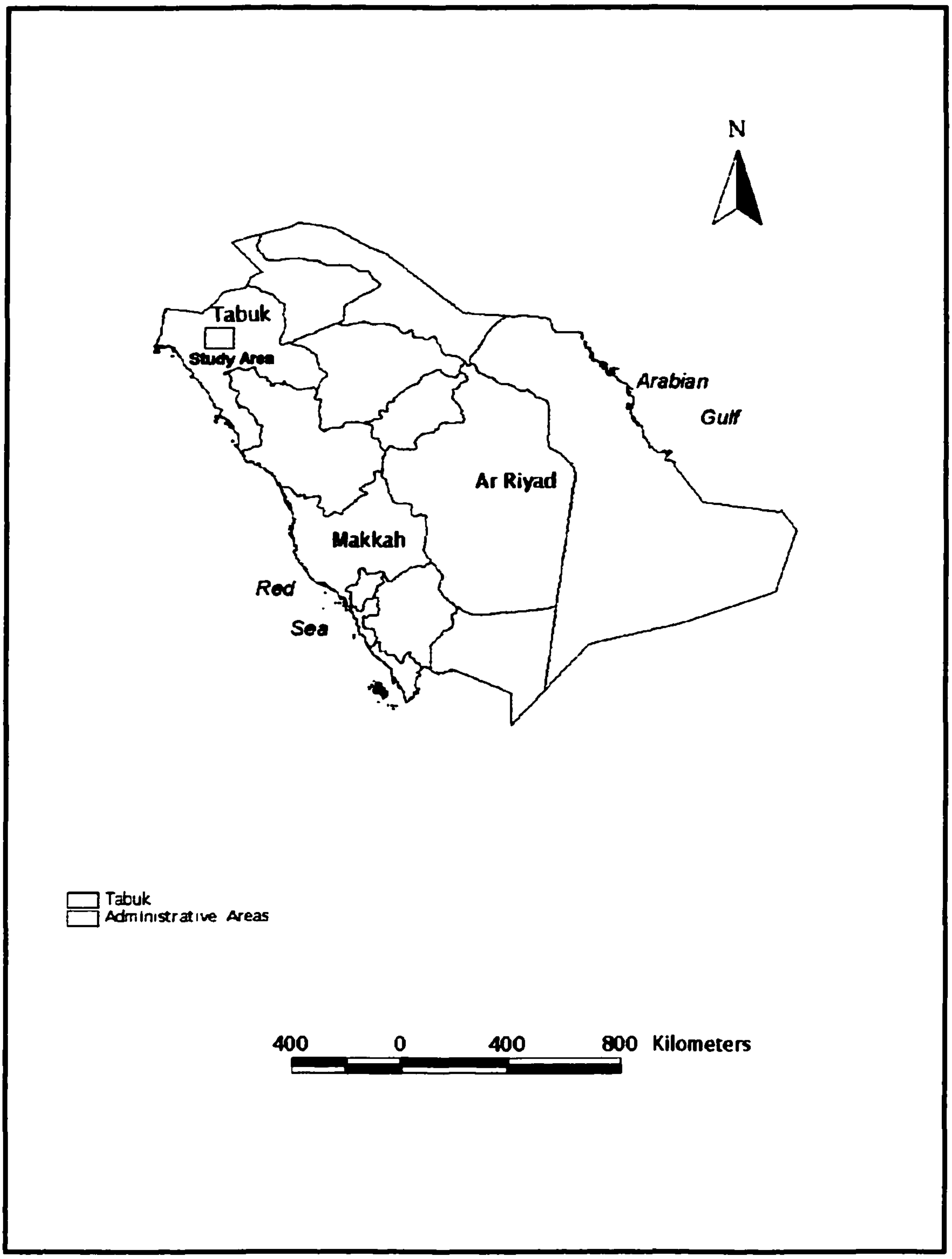

Figure 1-1. Location of the Study Area (Source: www.esri.com, 2001)

- Geology

The Tabuk area is underlain by both igneous rock and sedimentary formations. There are numerous basinforms related to different geomorphic processes. In particular, the study area has a combination of sandy, rocky, and silty soils that are affected by runoff.

There is a mix of geologic formations that are related to different geologic periods. Faults have vertically and horizontally crossed the study area. According to US Geologic Survey, 1963, Geologic Map of Saudi Arabia plates: 200-A and 204-A (Figure1-2), there are the following geologic formations:

1. Precambrian outcrops include granite formations that are red and coarse-grained. This granite is found, especially in the mountains located on the eastern edge of the Gulf of Aqaba, where it is crossed with a basalt formation in some areas and a greenstone formation in others.
2. Silurian and Devonian periods resulted in a Tabuk formation that consists of light-brown sandstone and white limestone. The Tabuk formation from upper layer to the base is fine sandstone, with silty sandstone to shaly siltstone.
3. During the Tertiary period a sandstone formation developed in the east and a granite formation which extends to the north of Al-Hisma.
4. Quaternary period deposits of terrace alluvium that includes gravel and sand, was deposited along the east coast of the Aqaba Gulf and a gravel formation comprised of quartz gravel along with various limestone formations is located around Tabuk and to its north.

5. Olivine Basalt formation has a local name "Al-Harrah." this formation was formed in the Tertiary and Quaternary periods and shows a mix of thin lava fields and underlying rocks located especially in the southern part of the study area.

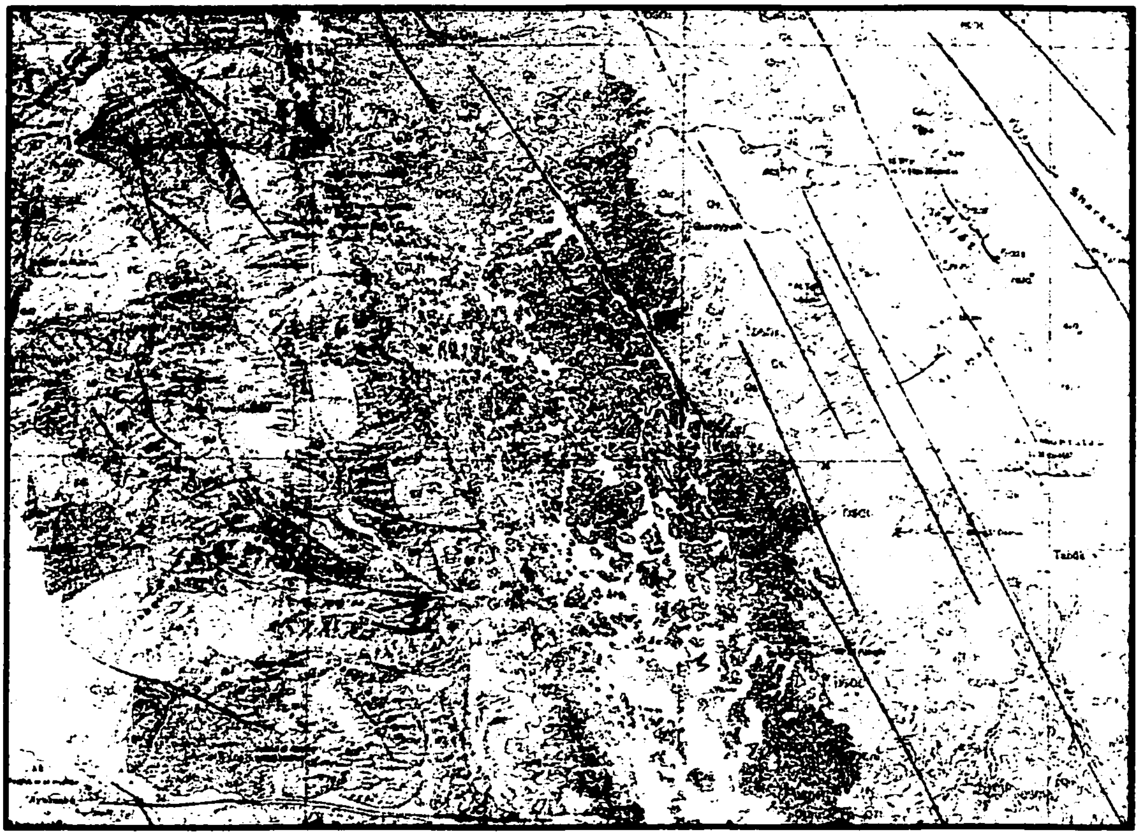

Figure 1-2. Geologic Map of the Study Area
(Source: USGS 1:500,000 Geologic Maps)

- Topography

The Tabuk area is a wide plateau with an average elevation of 800 m above sea level (Saudi Aerial Survey Department, 1984). It consists of a complexity of stream systems and variations in elevation levels, which can be divided into two different subareas (Figures 1-3a and 1-3b).

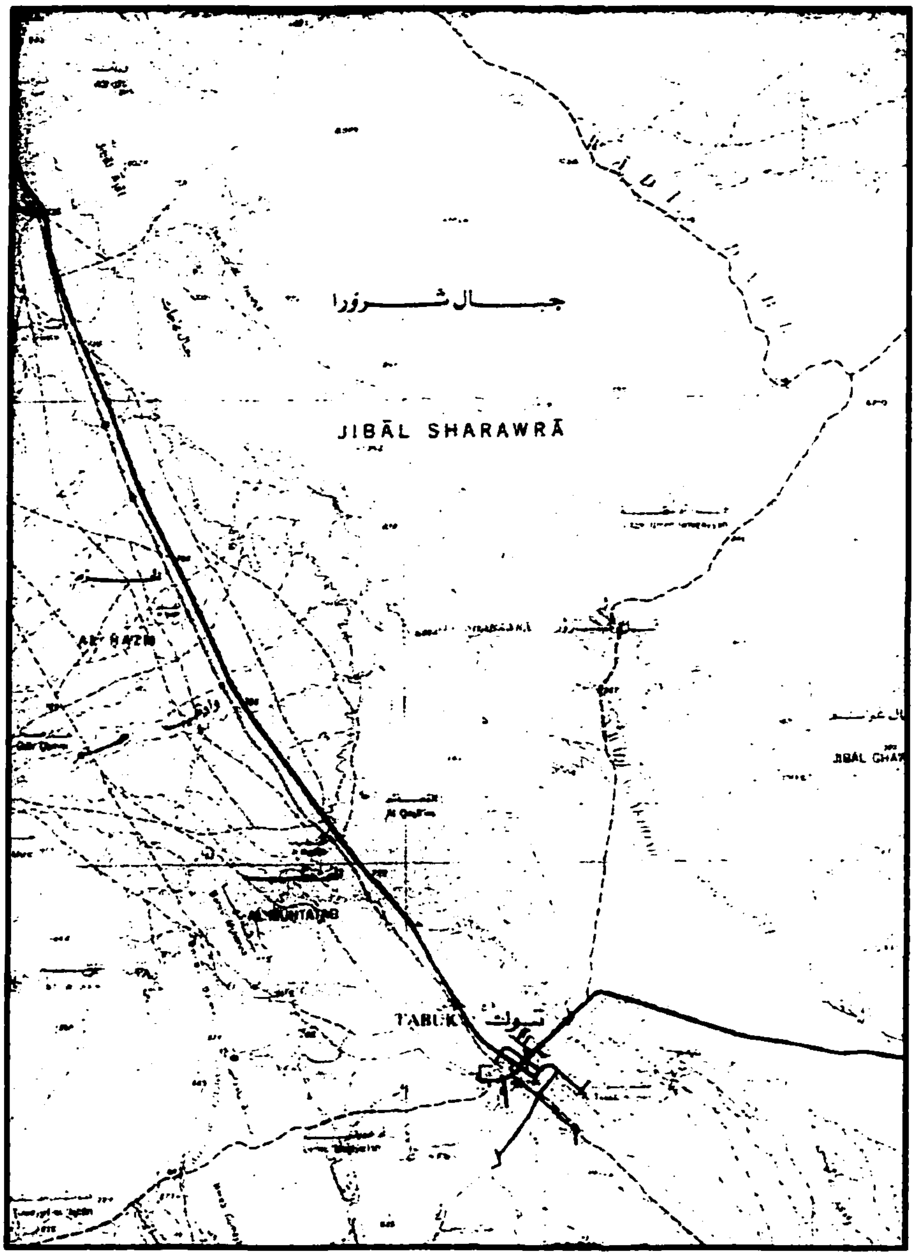

Figure 1-3a. The Eastern Part of the Study Area
(Source: Saudi Aerial Survey Department, 1984)

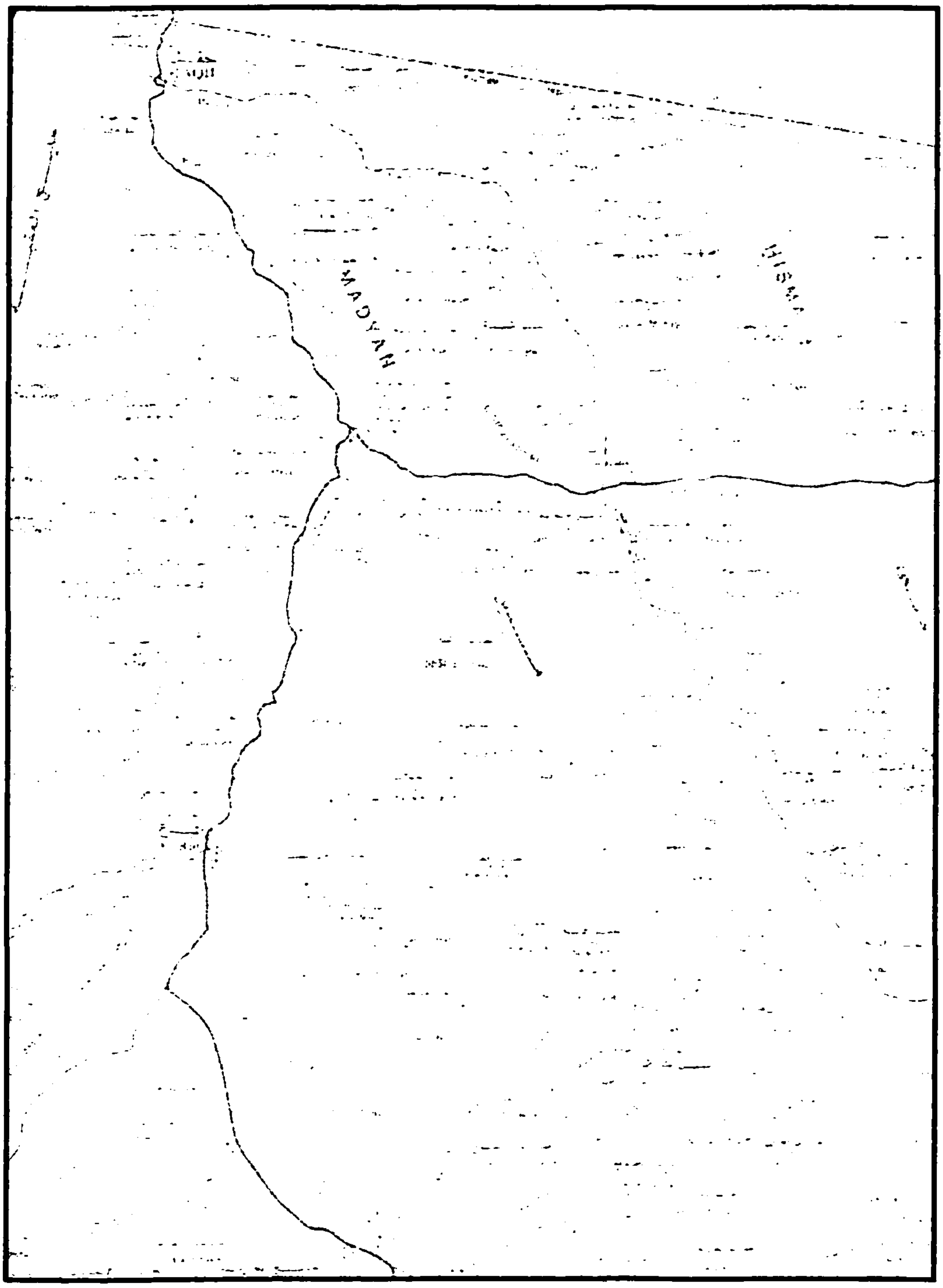

Figure 1-3b. The Western Part of the Study Area (Source: Saudi Aerial Survey Department, 1984)

- Climatology

The study area is affected by the Mediterranean climate. It is subjected yearly to Mediterranean Sea effects, especially the depressions that cause winter rainfall (Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to1994, 1999). The area is subjected also to Indian depressions that produce the northern tradewinds, contributing to increased temperatures in the summer. Figure 1-4 shows the minimum values of temperatures as lowest from December to March with values between 4.1-9.4° C. A rapid increase in temperature starts in April and continues through September. In November, the temperature begins to decrease as the winter season approaches. However, the average temperatures in January have low values of 17.6° C while 38.7° C and higher values are recorded in August.

Figure 1-5 graphically presents maximum relative humidity increases in the winter season, with an average value of 100 percent in both December and January, and shows a decreasing trend toward the summer season, with an average value of 58 percent in July.

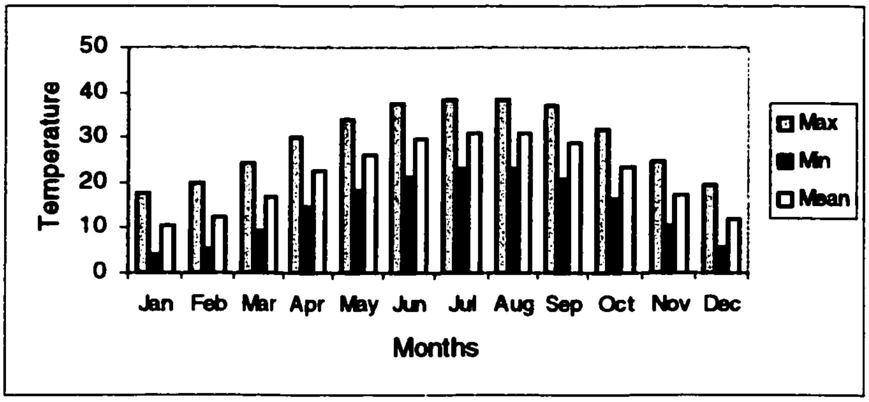

Figure 1- 4. The Average of Temperature Variations Between 1985-1994 (Source: Saudi Ministry of Defense and Aviation, Tabuk Meteorological Report, 1985 to 1994)

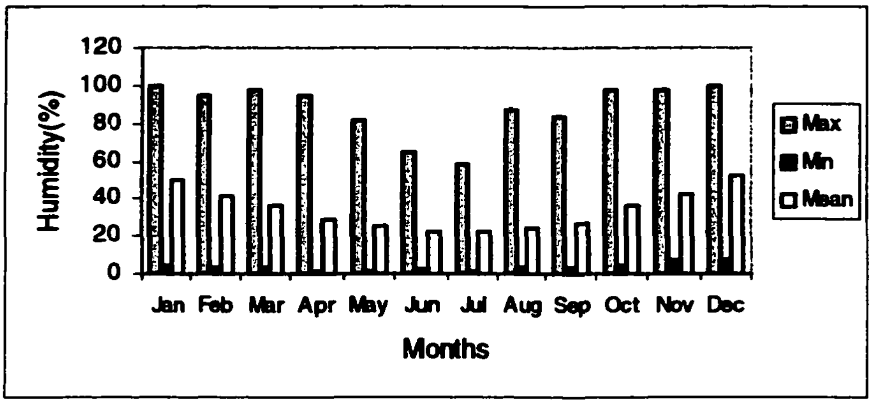

Figure 1-5. The Relative Humidity in the Study Area
(Source: Saudi Ministry of Defense and Aviation, Tabuk Meteorological Report, 1985 to 1994)

Rainfall in the study area as the main factor of vegetation change will be discussed in further detail in Chapter Four. Generally, according to the meteorological data for 1985-1994, rainfall is extremely variable. The Tabuk area is located in an arid region and moist maritime air masses are blocked from the Mediterranean Sea. Precipitation is a little higher in December with an average value 11.5 mm and 0 value for the summer season (Figure1-6).

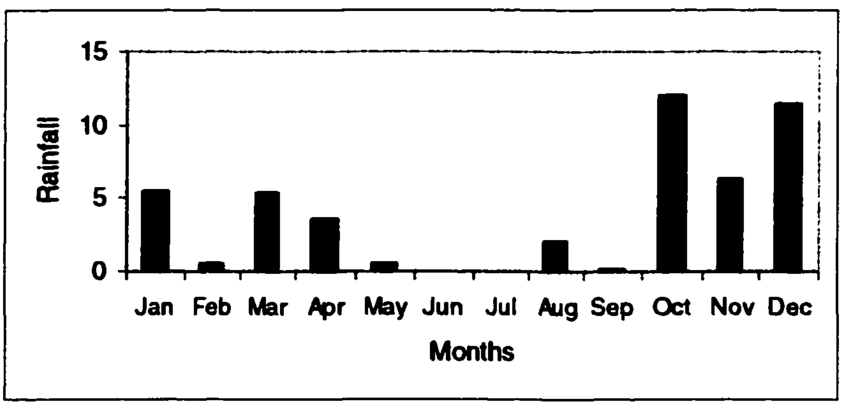

Figure 1-6. The Average Precipitation in the Study Area
(Source: Saudi Ministry of Defense and Aviation, Tabuk Meteorological Report, 1985 to 1994)

- Natural Vegetation

The growing season of most desert vegetation is restricted to a short term during the rainfall period that contributes to moisture availability in the upper layer of the soil. Most of the germination of seeds in desert environments occurs after a rainfall period (Went, 1979). However, the bulk of their new vegetation is immediately removed by herbivores. The growth and yield of desert vegetation are restricted by low precipitation, frequent droughts, intense radiation, and poor soil conditions such as inadequate moisture, high infiltration rates and low organic carbon (Gupta, 1979).

Biologically, desert plants can be classified into two major groups. First, ephemerals, which germinate after a rainfall during the dry season. The second category includes the perennials, which maintain some photosynthesis during the dry season and need water and energy for biological processes. This group of plants has adapted to arid environments (Gupta, 1979).

Vegetation in the Tabuk area has a luxurious appearance. The area has different sub-areas, each one characterized by special geographic attributes causing vegetation variations. Rocky areas have an abundance of *Delonix elata*. On the other hand, *Rhus triparita* and *Ficus palmat* grow among the boulders. The higher slopes are characterized by vegetation in the form of *Gymnocarpos decandrum*. Also, *Moringa peregrina* may be seen on slopes accompanied by *Ferula sinaica* on north-facing slopes (The Saudi Ministry of Agriculture and Water, 1999) (Table 1-1).

Table 1-1. Vegetation Types in the Study Area

Site	Scientific Name	Local Name
1- Wadi Al Baqqar	Hammada elegans	Remth
	Haloxylon persicum	Algatha
	Genista	Retam
	Euphorbia retusa	Gazalah
	Citrulls colocynthis	Hanthal
	Acacia raddiana	Talh
	Stipa capensis	Samghah
	Plan tago spp.	Rablah
	Fagonia cretica	Shwakah
	Zilla spinosa	Sallah
	Salsola verniculata	Rothah
2- Wadi Al Akhdar	Zygophyllum Simplex	Garmal
	Hyoscyamus muticus	Bang
	Tamarix passrinoides	Tarfah
	Atriplex leucoclada	Raghal
3- Up Valleys	Calotropis procera	Oshar
	Leptadenia pyrotechnica	Markh
	Cucumis prophetarum	Shara
	Citrullus colocynthis	Hanthal
	Cassica italica	Ashreq
	Aerva javanica	Arwah
	Acacia tortilis	Samour
	Hammada elegans	Remth
	Lycium shawii	Awsag
	Panicum turgidum	Thumam
	Rhazya stricta	Harmal
	Hyphaena thebaica	Nakheel aldoom
Coastal areas	Capparis decidua	Tandab
	Suaeda monoica	Swad
	Zygophyllum simplex	Garmal
	Zygophyllum coccineum	Haram

(Source: Saudi Ministry of Agriculture and Water 1999. Natural Vegetation of Saudi Arabia)

Acacia trees are one of the most common types of vegetation in the Tabuk area. This type of vegetation is able to survive the stress associated with high temperatures and low moisture conditions. Acacia, as a desert plant, is highly resistant to extreme weather variations and may be an adaptive vegetal response to rainfall deficiency, dry soil, and low moisture content (Plate 1-1).

Desert vegetation in the study area shows a progressive succession, with some sites increasing in vegetative diversity and biomass over time. The biological development of desert vegetation has taken place periodically (annually and seasonally) in the study area. This process, caused by a year of much rainfall, can lead to increased soil moisture retention and is the main factor of increasing vegetation cover in the study area (Plate 1-2).

Plate 1-1. Acacia Trees of the Study Area

Plate 1-2. Progressive Succession in the Study Area

Retrogressive succession change commonly has been noticed in the study area. Unfortunately, the area has suffered from extremely arid conditions over the past several years (Plate 1-3).

Fieldwork in the study area shows that three types of natural vegetation are found there. First are the desert shrubs distributed throughout the area and more common shrub types found in valleys and highly sloped mountains. Second are the grasses that grow after a rainfall season. Third are the mixes of shrubs and grasses (Figure1-7).

- Water Resources

In one new report published by the Tabuk Agriculture and Water Department (1998), geologic studies in this area reveal that the Tabuk area has a huge amount of ground water stored in aquifers. This untapped groundwater source enabled people to start massive agricultural projects in the last two decades. Geologically, the area has two major aquifers. The first is the Al-sag Aquifer, the largest aquifer in Saudi Arabia. Water is located between 550-750 meters below the ground surface. Secondly, the Tabuk aquifer the Tabuk Aquifer consists of sandstone layers, and water can be found in depths ranging between 400-450 meters. Advanced technology is employed to monitor groundwater well levels (Figure 1-8).

Plate 1-3. Retrogressive Succession in the Study Area

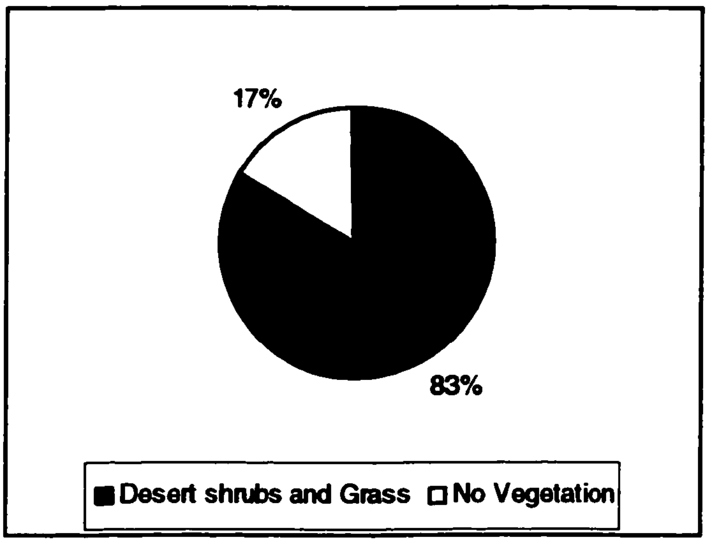

Figure 1-7. Vegetation Types of the Thirty Sites in the Study Area
(Source: Fieldwork Conducted by Students at Tabuk Teachers College, April 2001)

The Tabuk Agriculture and Water Department works on the following guidelines: (1) monitor digging procedures, (2) solve the technical problems that may occur during the search processes for water, and (3) publish reliable information about water resources for the entire area.

The "drinking water project" of the Tabuk Agriculture and Water Department is directed by a highly trained and competent work team. This sub-department monitors thirty-two drinking projects that distribute water to the entire Tabuk area. Also, fifty-eight villages are supplied water from wells operated by those directing the "drinking water project."

- Agriculture

Agriculture has been enhanced in recent years by adopting planned integrated agricultural projects designed to make the kingdom of Saudi Arabia self-sufficient and to transform Saudi Arabia into a modern country (Saudi Ministry of Information, 1992). The Tabuk area now is one of the important agricultural areas in Saudi Arabia. The area has contributed to Saudi food security by producing wheat, other basic cereals, fruits, and vegetables. Developing agriculture in the Tabuk area will contribute greatly to food provisioning in Saudi Arabia for future generations (Figures 1-9a and 1-9b).

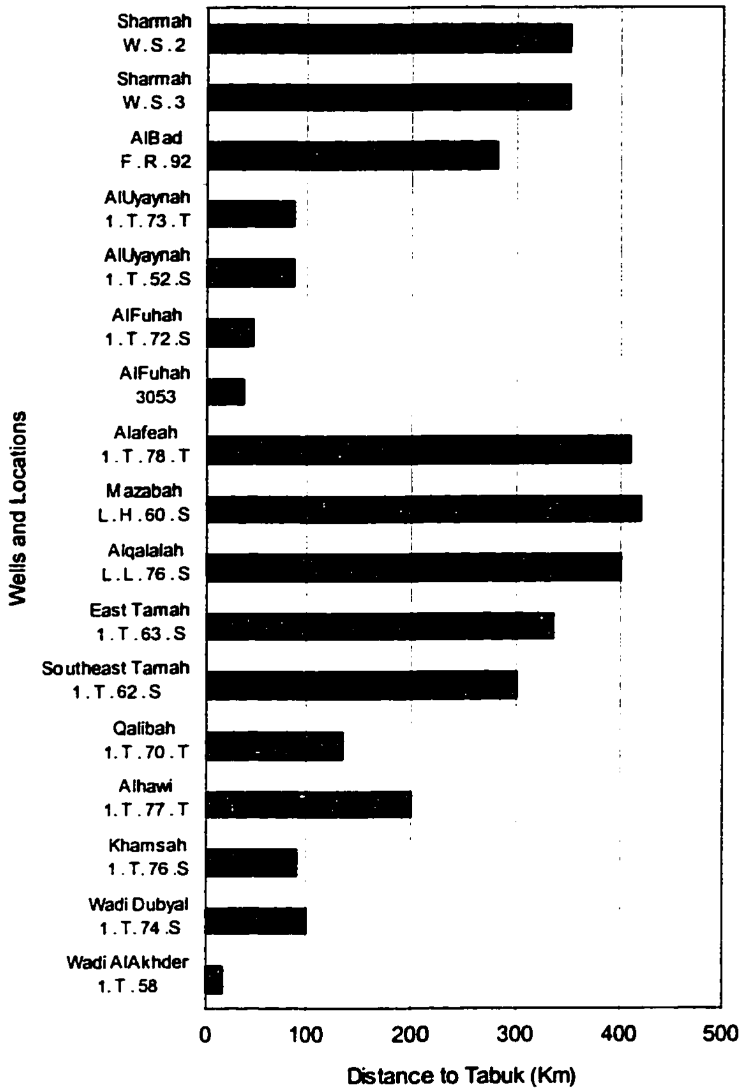

Figure 1-8. Spatial Variation of Wells in the Study Area (Source: Saudi Ministry of Agriculture and Water, 1996, A Comprehensive Report for Tabuk Agriculture and Water)

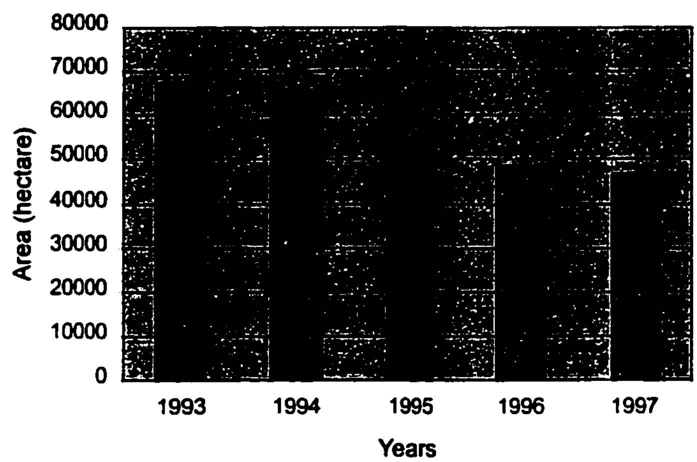

Figure 1-9a. The Estimated Agricultural Areas in the Study Area
(Source: Saudi Ministry of Agriculture and Water 1998 Statistical Yearbook)

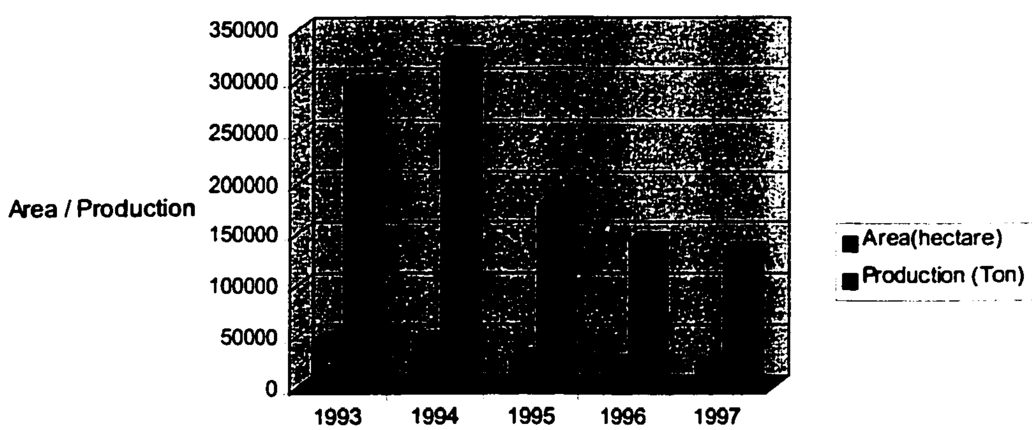

Figure 1-9b. The Estimated Agricultural Areas and Production in the Study Area
(Source: Saudi Ministry of Agriculture and Water 1998 Statistical Yearbook)

- Transportation

The Tabuk area is "the gate" to the northwestern part of Saudi Arabia. For this reason and according to a special report published by the Saudi Ministry of Transportation (1997), it has received great attention from the government in the transportation field. Several projects have been completed to connect widely distributed sub-areas. The availability of a good network of roads in the Tabuk area is an important factor in the government's plan to improve and develop the entire area in different but economically linked sectors (Figure1-10).

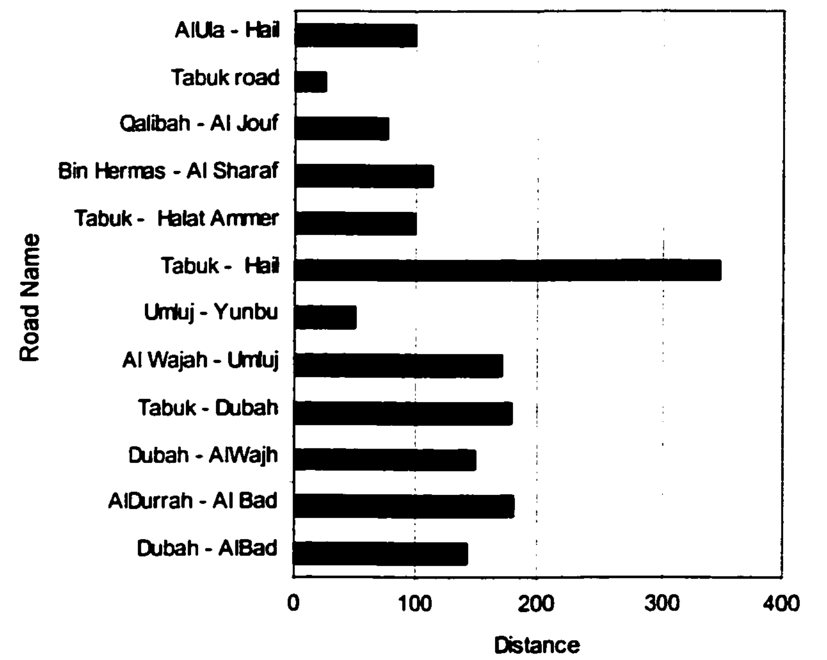

Figure 1-10. The Network of Roads in the Study Area
(Source: Saudi Ministry of Transportation, Tabuk Roads Network 1997)

<u>Statement of the Problem</u>

Deterioration of vegetation cover is considered the most important indicator of desertification in arid lands (Dregne, 1983). The purpose of this study is to assess vegetation deterioration as a principal cause and consequence of desertification, using Landsat-5 TM data, climatic records and supported by field observations in the Tabuk area of Saudi Arabia. These results will be used to consider the potential roles of increased aridity, overgrazing, and excessive woodcutting as possible desertification causes. Plates 1-4, 1-5 and 1-6 illustrate each of these modifications and the ramifications of physical and human factors.

Plate 1-4. Arid Conditions Prevalent in the Study Area

Plate 1-5. Overgrazing by Animals in the Study Area

Plate 1-6. Selling Firewood in the Study Area

Research Objectives

a) To investigate vegetation deterioration as a degradation indicator in the study area

b) To locate sites of vegetation deterioration

c) To discuss the causes of vegetation deterioration

d) To test the relationship between Normalized Difference Vegetation Index NDVI and presence/absence of vegetation cover, and disturbance

e) To outline the conservation work currently being done in the study area

f) To suggest future research to be conducted in the study area

Null Hypotheses

In order to investigate the research problem, the following hypotheses are offered in this study:

(a) There are no significant differences in Normalized Difference Vegetation Index (NDVI) images between 1988 and 1999.

(b) There is no significant correlation between NDVI and the presence/ absence of vegetation cover.

(c) There is no significant correlation between NDVI and the presence/absence of disturbance (overgrazing and woodcutting).

(d) There is no similarity in rainfall for the entire study area.

To examine these hypotheses, the following questions need to be considered:

- Can Landsat TM data be effectively used to detect vegetation deterioration in this study area?
- Does the Normalized Difference Vegetation Index (NDVI) accurately represent the deterioration in vegetation cover?

Organization of the Study

The Table of Contents reveals the topics that are covered. This dissertation falls into five main chapters, references, and appendices. Chapter One deals largely with a general introduction focused upon the vegetation changes in desert environments, the study area, the statement of problem, hypotheses, and a definition of terms. Chapter Two introduces the theoretical background and a basic understanding of previous studies that have been done involving desert vegetation, remote sensing applications, and the monitoring of vegetation changes. Chapter Three presents the data that has been obtained and the methodology. Chapter Four mainly discusses the analytical methods, including remote sensing, climatic analysis, the measuring of human impact, statistical analysis, and the major findings and observations. Chapter Five includes the conclusion, recommendations, and future research.

Definition of Terms

Analysis of correlation: product-moment or Pearson's Correlation Coefficient (r) that describes the correspondence of two variables together (Shaw and Wheeler, 1985).

Aquifer: a rock, such as chalk or sandstone that holds and supplies large amounts of water (Illustrated Dictionary of Geography, 1988).

Descriptive statistics: represent numbers used to describe the general magnitude of all observations in a data set (Shaw and Wheeler, 1985).

Desertification: refers to the process of deterioration in an ecosystem that can be measured by calculating reduced productivity of biomass, the diversity of the macro fauna and flora, accelerated soil erosion, and possible increases in hazards for human societies (Dregne, 1983).

Ephemeral: vegetation types that germinate after a significant rainfall during a dry season.

False color composite: a remote sensing term referring to the resemblance of different bands to make different plates for visual identification of geographic features.

Geographic coordinates: the latitude and longitude coordinate system (Clarke, 1999).

Geometric correction: a remote sensing preprocess applied to digital data to remove possible distortion caused by latitude, altitude, and velocity of the sensor platform (Lillesand and Kiefer, 1994).

Geographic Information Systems (GIS): a set of computer tools for analyzing spatial data (Clarke, 1999, p.314).

Normalized Differences Vegetation Index (NDVI): may be expressed as (TM 4-TM)/(TM 4 + TM 3) and is used to develop a greenness index. In arid lands, it is well correlated with parameters, including leaf area index, green leaf biomass, and vegetation cover (Nicholson and Tucker, 1998).

Perennials: one type of vegetation which maintains some photosynthesis during a dry season and needs water and energy for biological processes. This group of plants has adapted to arid environments (Gupta, 1979).

Pixel: The smallest unit of resolution on a display, often used to display one grid cell at the highest display resolution (Clarke, 1999).

Plant succession: is a directional change in the species composition or structure of a community over time (Barbour et al. 1999).

Point biserial coefficient: a useful measure to examine the relationship between two variables on a nominal scale (Shaw and Wheeler, 1985).

Progressive succession: indicates the possibility of growing natural vegetation, starting from grasses to woody. There is usually an increase in diversity and biomass over time, with the habitat becoming more moist (Barbour et al. 1999).

Retrogressive succession: occurs, with the destruction of the surface soils and the removal of the products by exceptional torrents or storms. It results in a decrease in diversity and biomass, often with the habitat becoming either more wet or dry (Barbour et al. 1999).

Standard deviation: is a statistical measurement that may be used to measure how closely the values of a data set cluster around the mean (Mann, 1998).

Statistical Package for Social Sciences (SPSS*)*: is a statistical computer program used to display, manipulate, analyze, and interpret a given data set. (Mann, 1998).

Thematic mapper sensor: is a highly advanced sensor on board Landsats, incorporating a number of spectral, radiometric, and geometric design improvements relative to MSS (Lillesand and Kiefer, 1994).

T-test: is used to determine the differences between two samples obtained from the same population. A T-test is commonly used to accept or reject the null hypothesis, which assumes H = Y + X no difference between the means of the two samples (Shaw and Wheeler, 1985).

UTM (Universal Transverse Mercator): a standardized coordinate system based on the metric system and a division of the earth into sixty 6 degrees-wide zones. Both civilian and military versions exist (Clarke, 1999).

Chapter 2

REVIEW OF RELATED LITERATURE

Desertification: Definition and Processes

The term *desertification* may refer to different aspects such as degradation of grazing lands, destruction of vegetation cover, wind erosion, or moving sand dunes, turning productive land into a waste land, resulting in degradation of vegetation and soil resources. In general, desertification is the impoverishment of terrestrial ecosystems under the impact of humans. It is the process of deterioration in these ecosystems, which can be measured by reduced productivity of plants, alteration in the biomass, and the diversity of the micro and macro fauna and flora (Dregne, 1983).

According to Dregne, desertification processes may be classified into the following: (1) Degradation of vegetation cover, which varies from sparse to non-existent plant cover in arid lands. The plants in these lands may be damaged and usually need a much longer time to recover than in wetter lands. (2) Water and wind erosion, which work in combination in arid lands. Water and wind erosion can contribute in degrading land from vegetation and vice versa. Disturbing vegetation cover can lead to increases in erosion and runoff processes. The severity of water and wind erosion may be determined by estimating the loss of soil in the case of wind erosion or the amount of deposition that has taken place. (3) Salinization is a process, which can occur by giving too much water during irrigation or by using saline irrigation that causes accumulated salt layers on the topsoil. (4) Soil compaction, which commonly occurs in arid lands by the pounding of livestock hooves on the soil, refers to the dispersion and packing effect of raindrops striking the soil. (5) Overgrazing which can contribute to removing native perennial and annual plants, thus allowing the possible invasion of harmful shrubs or grass plants or the formation of massive gullies and sands dunes. (6) Extensive woodcutting, a common human practice that impacts on woody plant species in arid lands, is done to provide firewood, building materials, and or "bush fencing" to protect livestock. Excessive removal of woody plants assists in increasing wind and water erosion and runoff. (7) Fire has two possible effects: it can assist in controlling the spread of invasive harmful shrubs or grasses or can be destructive by initially increasing soil erosion and denudation of the land via raindrop impact. (8) Dry land cropping, a communal activity in arid lands, initially requires the removal of vegetative cover by grazing, and may accelerate wind erosion or cause soil compaction.

Desertification as a dynamic phenomenon causes the destruction of environmental components and leads to a lower carrying capacity for animals and people, a reduction in crop production potential, an increase in environmental deterioration, an increase in flooding potential of low lying lands, and a reduced capacity to support human life.

Desert Vegetation and Vegetation Monitoring in Saudi Arabia

Fieldwork is the main source of reliable geographic data. Several vegetation studies have been done of desert vegetation in Saudi Arabia. In particular, two major studies have observed this region's desert vegetation and its dynamics, and as result techniques have been developed to monitor desert vegetation for range development.

The Saudi Ministry of Agriculture and Water (1999) published a new edition of *The Natural Vegetation of Saudi Arabia*, which includes plant communities, seed plants, and a comparison between Arabic and scientific names of vegetation species. The Arabian Peninsula shares its flora with the African continent in the west and southwest and with the Asian continent in the northeast, east, and southeast. In addition, the vegetation communities in the northwest region (Tabuk area) have the same vegetative characteristics as the Mediterranean region. In general, vegetated areas of Saudi Arabia are described as the "Sahara Zone" except in the southwest (Asir Region), which is characterized by evergreen mixed forest as well as bushland vegetation.

Natural vegetation in Saudi Arabia can be classified into three major groups: mountain vegetation, arid vegetation, and coastal vegetation (Badi, 1997). These natural types are subject to modification by forest development, such as urban extension and woodcutting, as well as drought conditions.

Another study published by the Saudi Ministry of Agriculture and Water (1994) sheds light on desertification and its effects. The Ministry of Agriculture and Water has many projects to protect areas suffering from woodcutting or overgrazing by establishing pastoral enclosures for range monitoring.

The Saudi Ministry of Agriculture and Water has published a study (1978), which discusses vegetation characteristics of selected sites in Saudi Arabia. In chapter two of this study, the Tabuk area has been presented as an arid site with a rainfall average around 75 mm/year. This study shows different sites in the Tabuk area as having deteriorated environmentally (Figure 2-1).

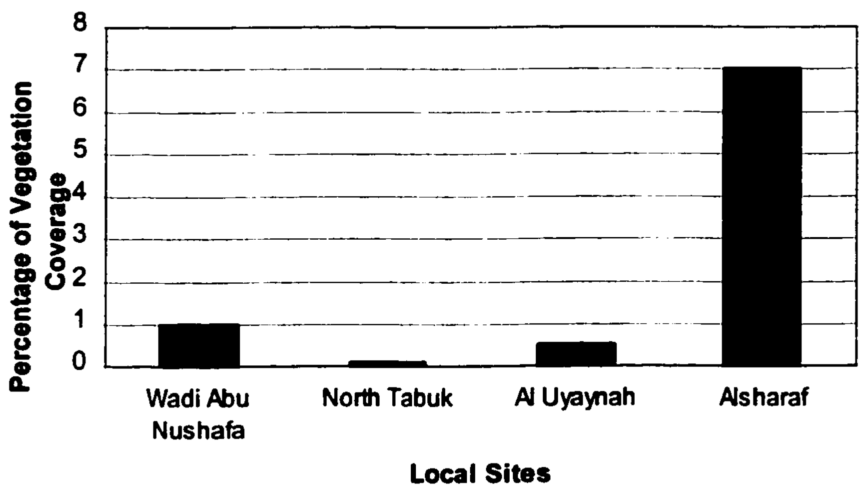

Figure 2-1. The Percentage of Vegetation Coverage in Selected Sites in the Study Area (Source: Saudi Ministry of Agriculture and Water, 1978)

This study came to the following conclusions: (1) establish reserved sites for monitoring vegetation growth and measuring monthly rainfall; (2) evaluate soils and their characteristics in the sites that have good chances to be suitable sites for growing natural vegetation; (3) prohibit overgrazing and woodcutting in northwest Tabuk to protect vegetation from deterioration; and (4) suggest doing several environmental studies to evaluate vegetation growth and how it will be developed.

The Department of Economic Studies and Statistics at the Saudi Ministry of Agriculture and Water (1998) has published the *Agriculture Statistical Yearbook*. This eleven-volume report presents the efforts of the Ministry of Agriculture and Water in dealing with pastoral and forest environments in Saudi Arabia. Also, the report shows a list of pastoral areas of various sizes for all Saudi regions. The Tabuk area is one of the important sites; it has twelve pasture sites, eighty-two dikes in several sites for reserving runoff, and one enclosure.

The Saudi Ministry of Agriculture and Water (1994) has recognized the importance of the development and protection of natural vegetation in Saudi Arabia, focusing on the deterioration of vegetation, especially in those areas that have been impacted by overgrazing, woodcutting, sand movement, water depletion, and drought conditions. The environmental efforts of the Ministry in the field of development include vegetation monitoring for those areas and the establishment of Forest and Range departments.

In the Tabuk area there are various species of desert vegetation. The area has different sub-areas, each one characterized by special geographic attributes that cause variations in vegetation types. Rocky areas have an abundance of *Delonix elata*. On the other hand, *Rhus triparita* and *Ficus palmata* are presently growing among the boulders. The higher slopes are characterized by *Gymnocarpos decandrum*, along with *Moringa peregrina*. The slopes between 600-1000 m have *Lycium shawii*, accompanied by *Ferula sinaica* on north-facing slopes.

Tabuk's Agriculture Department (1983) suggested different sites to grow pastoral seeds in order to develop the rangeland areas in the Tabuk area. In this particular task, there was a team that consisted of experts and specialists in range development, an agricultural engineer, and two drivers. The team had visited the following sites: Wadi Albaqqar, located approximately 20 km southwest of Tabuk city, received much attention for developing rangelands. Wadi Alkhnbara, located 112 km northwest of Tabuk city, occupies 50 square km of land impacted by overgrazing. Wadi Alhesma, located in the center of Tabuk region, has a topographic advantage to grow pastoral seeds because it has physical characteristics that may assist to renew vegetation cover. Wadi Almagrah, located west of the Tabuk area, has two important vegetation communities: *Hammada elegans* and *Acacia tortilis*. Wadi Alkhwah also is one of the important sites because it has a variety of vegetation communities such as *Acacia tortilis*, *Hammada elegans*, and *Genista*. In addition, there are other sites in different parts of the Tabuk area. Each site has a variety of vegetation communities, and is being considered for agricultural development and pastoral improvement. Vegetation monitoring is necessary for environmental and economic purposes, requiring systematic groundwork and in-depth data analysis. Recently, many studies have been published in the field of vegetation monitoring in Saudi Arabia; those studies were concerned initially with recognizing environmental factors that were affecting range areas.

A project regarding evaluation of human and physical resources of Al Hammad basin, located in the northern part of Saudi Arabia, was conducted by the Arabic Center for Arid Environment Studies (1983). This project concentrated on selecting twenty-seven sites of vegetated areas, and each site was surveyed during three seasons: spring 1980, autumn 1980, and spring 1982. The intensive fieldwork in this part of Al Hammad identified the following important desert plants: *Haloxylon salicornicum*, *Calligonum comosum*, *Ammodondrom persicum*, *Achilla fragantissima*, *Artemisia herba-alba*, *Farseti aegypatia*, *Aristida plamosa*, and *Traganum nudatum*. In addition, all of the sites of vegetated areas were impacted by wind erosion and were characterized by less vegetation productivity.

An applied project was carried out to monitor range areas in the Al Jouf area of Saudi Arabia (Figure 2-2). This project was conducted by Heemstra and Hassan (1990). They identified Saudi Arabia as the largest grazing area in the Near East region. Out of a total land area of 2.25 million square kilometers, more that 69.9 percent can be classified as rangeland. This percentage is even higher in the northern part of the kingdom, where grazing is the largest single land use type and where a considerable part of the population is engaged in extensive livestock production. Their objective of this work was to provide reliable information about range trends. The study area was divided into the following units:

1. The sand dunes of different sizes and patterns. The vegetation types in this unit are *Calligonum comosum*, *Haloxylon persicum*, *Artemisia monosperma*, and other abundant annuals such as *Eremobium aegypatiacum* and *Plantago boissieri*.
2. The Hammad area has dwarf-shrub vegetation such as *Salsola Tetrandra*, S. *Tetrandra*, S. *chaudharyi*, with other types such as *Elegans*, *Spinosus*, and *Achillea*.
3. Al Harra, a volcanic massif with rocks of basalt loamy depressions and wadis, is dominated by *Astragalus*, *Spinosus*, and *Zilla spinosa*.
4. Al Widyan, a complex of valleys, has vegetation such as *Artemisia*, *Astragalus*, and *Pituranthos* being impacted by overgrazing.
5. El Shama, a plain with soil of shallow sand, has vegetation that is undergoing heavy grazing.

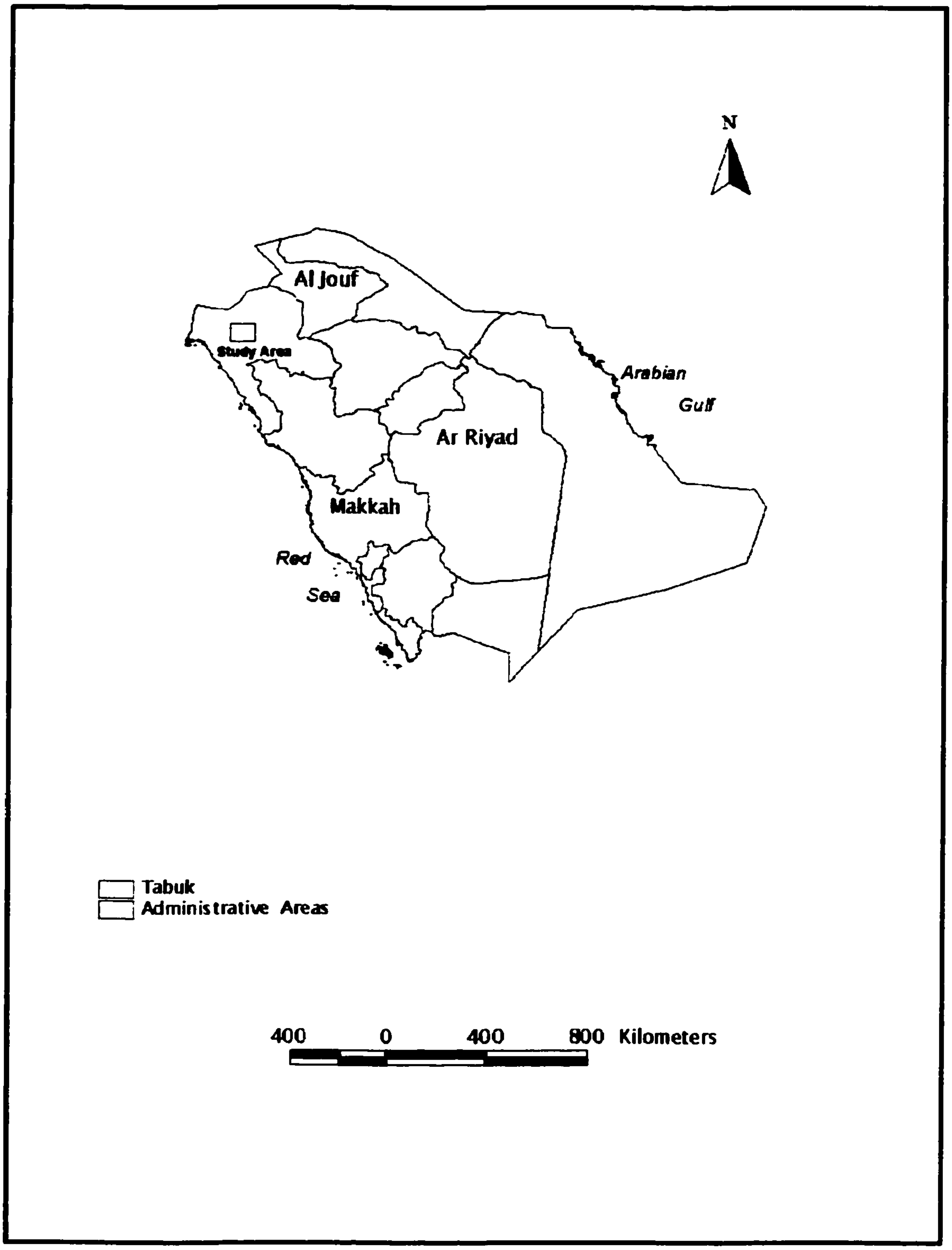

Figure 2-2. Location of Al Jouf Area
(Source: www.esri.com, 2001)

The most important part of this project was its methodology that combined different techniques. The measuring of plant frequency, plant density, and plant cover was the essence of this study. Each field site consisted of two clusters of three transect lines, one cluster inside (120 m by120 m) and one on the open range. Each transect line was 50 m long with one line pointing north, and metal bars were used to mark the center and end points of each line. They compared data statistically for each site in the study area by using Chi square test for the plant frequency, a T test for the species density, and a paired T test for the percentage cover. The project came to the following conclusions: abundance of annual vegetation is more related to rainfall; plant frequency and plant cover are used as indicators of climatic conditions; and overgrazing has affected annual vegetation amounts in the study area.

Mirreh and Daraan (1986) evaluated the productivity of different range sites in the Al Jouf region of Saudi Arabia. Nine sites were selected according to geomorphologic, topographic, and soil factors in the study area. They focused on measuring the total dry matter yield for each site and examined the relationship between forage yield and precipitation. Then Mirreh and Daraan (1987) chose the same nine sites in the Al Jouf region of Saudi Arabia to further investigate the effects of protection and grazing pressure on desert rangelands. The study showed that the region had deteriorated and that range protection from the animal's overgrazing can be used as a tool in range recovery and improvement.

Mirreh's (1991) report concentrated on studying the effects of early to late grazing on vegetation and sheep growth in the Wadi Tamriat area in the northern part of Saudi Arabia. The research divided the study area into three pastures, with each pasture divided into three permanent transects. Two pastures were adjacent and similar, and a small enclosure was established in one of the pastures. This report indicated that sheep grazing behavior has affected plant species in the study area, because sheep prefer to graze on young seedlings and strip off all accessible leaves in the summer. This behavior contributes to destroying plant carbohydrate reserves, especially in low rainfall years.

Desert Vegetation and Human Impact

Castillo et al. (1997) conducted experimental research to evaluate runoff and soil loss in response to vegetation removal. They chose two 5m wide by 15 m long runoff plots, D and N, installed on a 23 percent slope. Vegetation was removed by clipping from Plot D and the changes in runoff and soil loss were compared with the undisturbed Plot N. Monitoring procedures were applied annually from 1989 to1993 to measure and describe precipitation, surface runoff, soil loss, and sediment concentrations. This study had the following results: vegetation removal caused an increase in surface runoff in Plot D, and vegetation removal produced a soil loss about 2.25 times greater in Plot D than in Plot N during the five year period.

Batanouny (1983) conducted research on the human impact on desert vegetation. In his research, he identified several impacts, primarily cutting or uprooting of ligneous species for firewood and overgrazing, which leads to degradation. These processes may be controlled by the establishment of range reserves to protect such areas from human intrusion. In addition, several medicinal plants are being depleted in the Middle East environment, and construction activities (such as pipeline establishment and intensive motorized transport) have contributed to the removal of plants and an increase of erosion.

This study shows different examples such as the destruction of the *Maerua Crassifolia* tree by camel grazing and the large rangelands destroyed each year by the rooting and grubbing of desert shrubs.

The causes of degradation of the natural environment in the central, eastern, and northern parts of Saudi Arabia were studied by Alwelaie (1985). He defines the causes of degradation as drought, agricultural activities, woodcutting, water wastage, aeolian processes, hunting, and overgrazing. Also, he presents the influences of the deterioration of vegetation, namely through drought, governmental subsidies, Bedouin's mobility, overgrazing, dry farming, tree cutting and wood collecting, and the clearing of herbs and grasses.

Al-Haratani (1997) evaluated the impact of modernization on nomads and their use of rangeland resources in northern Saudi Arabia. His approach consisted of interviews with nomads in this region, a socio-economic study of the region's lifestyle, and a range capability assessment. The application of Monte Carlo simulations of four different grazing intensity scenarios and twelve different levels of government subsidies demonstrated that lower grazing intensities assist in the combating of desertification of rangelands in this region.

Ishaque (1996) studied the ecology of the *Acacia* species in the Chihuahuan Desert rangeland in New Mexico. The objective of this study was to monitor the growing behavior of the *Acacia* for two seasons. He wanted to observe these species and measure the chemical composition of plant leaves and pods, seed germination, root and shoot growth rates, and weight for spring and summer seasons. The result was a summary of how the growth and density of the species relate to rainfall levels.

The effects of sheep grazing on a shadscale plant community at the Desert Experimental Range in southwestern Utah were measured by Alzerreca (1996). The study area was divided into two major areas: one that had been grazed, and one that was ungrazed. His fieldwork reveals information such as total species cover, annuals, shrub survival, seedling recruitment, plant succession, and plant spatial relationships. Also, he utilized precipitation records and distribution that contributed to dividing the study area into several subareas. He found that there were differences between the two areas. The results showed that the pastures and grasses increased over the two-season monitoring period in the ungrazed area and decreased in vegetation cover in the grazed area. Ultimately, the study showed that grazing leads to lower vegetation production and biomass.

Miller (1999) used a combined methodology that consists of aerial photo interpretation, GIS analysis, drought analysis, and human impact (fire and grazing) analysis. This methodology involved monitoring the vegetation change of a selected small area located in southwestern New Mexico. Aerial photography was obtained and digitally entered into GIS software for classifying, analyzing, and evaluating the nine classes (categories) of vegetation communities. In addition, the drought analysis of the precipitation data was analyzed. Fire and overgrazing data was obtained from the USDA and was subjected statistically to evaluating their role in vegetation change. This study presented and employed different geotechniques to study and discuss vegetation change.

Turner (1990) selected an area located in the Sonora Desert to monitor vegetation change. He used well conceived methodology to study this phenomenon. Three major permanent plots were established, and two photogrammetric plots were selected to examine the growth behavior of the two major types of desert vegetation that dominated in the study area. The Palmer Drought Severity Index (PDSI), integrating moisture and temperature conditions over periods of time, was examined by calculating average conditions of moisture and temperature values over a given time and then expressing the observed values from long term averages. The study presented these detailed findings: using photographs as a source of information may help in detecting vegetation change and drought conditions were the cause of vegetation change over the last few decades. Long-term monitoring should be useful in showing the major differences of vegetation cover over time periods.

Mabbutt (1986) classified desertification indicators into three major groups depending upon three criteria: First, monitoring scale that includes global, regional, and national/local indicators. Secondly, types of variables that include physical, biological or agricultural, and social indicators. And thirdly, land-use which is divided into drylands, irrigation, rainfed cropping, pastoralism, mining, and recreation lands. A good advantage of this study is emphasizing the importance of using Landsat imagery in evaluating arid lands and monitoring vegetation variations during the dry season. Also, the study has focused on pastoralism and firewood gathering as the two major social indicators that can be agents of desertification. This study provides a good explanation of several physical/human factors that work in combination for the degradation of vegetation cover.

The objective of Balling and Robert's study (1998) was to evaluate the climatic impact on desert vegetation at fourteen stations in the Sonora Desert. They analyzed the monthly precipitation and the May maximum temperature data to determine the spatial and temporal trends that may be associated with vegetation or albedo variations in the study area. A standardized coefficient of skewness and kurtosis for testing normality in the May maximum temperature data was applied, and it showed that there are no significant departures from normal in any of the May maximum temperatures. A principal component analysis was also conducted in this study to identify any station with any large deviations away from the regional pattern. Two stations had less than 10 percent shared variance compared with other stations, and these two stations were dropped from the data analysis. The study indicates that the Mexican landscape has been overgrazed, has more bare soil, and has higher values of albedo compared to areas in Arizona.

Remote Sensing Studies

Many studies have been published in the field of environmental monitoring, using multiple types of remotely sensed data. These studies apply a variety of analytical techniques, including Image Enhancement, Unsupervised Classification, Normalized Difference Vegetation Index, and Ratio Vegetation Index.

- Image Enhancement

Mas (1999) tested six change detection procedures using Landsat Multi Spectral Scanner (MSS) images for detecting areas in the region of Terminos Lagoon, Mexico. Visual interpretation, image differencing, vegetation index differencing and principal component analysis were applied to each technique reveals little significant difference. Also, unsupervised classification was used in this study and carried out the eight bands of the multidate image in order to classify the images into 35 clusters. The resulting images were examined to determine if the land cover would correspond to clusters for both dates.

Allum and Dreisinger (1996) studied vegetation change near Inco's Sudbury mining in Canada. The aim of this work was to produce a map showing areas of vegetation loss and areas of no change in vegetation. The authors obtained July Landsat data from 1973 and 1980. For later projects, July Landsat scenes from 1976, 1979, 1980, and 1983 were processed using an unsupervised classification procedure that was supported by an intensive study of available aerial photography and by visual inspection of Landsat scenes. Maps were created from the Landsat images using cartographic procedures that showed major differences in vegetation cover.

Another researcher, Salami (1999), focused on a three-step methodology in his study: photo interpretation, digital image processing, and integration of aerial and spatial data. The study was an attempt to use Landsat Thematic Mapper (TM) data for monitoring and assessing vegetation dynamics using an unsupervised classification in a selected area of Nigeria. Salami, using three channels of TM data (2, 4, 5), made specific observations that were related to vegetation change ratios and to vegetation dynamics and factor relationships.

Mouat et al. (1993) focused on reviewing use of change detection methods for various applications. He presented different studies that have been published into five broad categories: visual interpretation, difference images and rationed images, classification, transformed data sets (albedo difference images), and regression analysis. This study shows how the application of a NDVI equation can be used for multiple purposes, and presents the albedo difference images for monitoring arid environments. These researches successfully used principal component analysis for land-cover change detection.

- Normalized Difference Vegetation Index

Millington et al. (1994) used the NOAA-AVHRR sensor to study vegetation patterns in Tunisia and Pakistan. They examined the relationship between the AVHRR-Normalized Differences Vegetation Index (NDVI expressed as [NIR-RED]/[NIR+RED] and moisture availability by using data obtained from two different locations (Tunisia and Pakistan). They applied a new approach of monitoring, mapping, and quantifying changes in dryland vegetation cover. This study shows that there is a positive relationship between the AVHRR-NDVI and rainfall records. It focuses on the relationship between AVHRR data and transpiration rates that may be used as an indicator of vegetation growth behavior. The authors explain how they created land cover maps from multi-temporal AVHRR imagery and classified the country of Pakistan into four classes of land, depending on environmental standards such as rainfall, soil, climate, and river discharge.

Using TM data, the Sohi study (1999) reveals landscape change in the Abu Dhabi Emirate, United Arab Emirates. Univariate image differencing was applied by subtracting a pixel digital number (DN) on one date from the corresponding pixel DN on the second date. This technique provides locational information on areas for spectral change and shows the major differences for both areas on two different dates. The NDVI equation used in this study demonstrates its usefulness in detecting agricultural areas. Nevertheless, it was not able to detect the new urban areas. Post- classification was also utilized and presented as a good method to illustrate the nature of change. Unsupervised classification was applied and contributed to clearly showing the major classes of land-cover.

In their study, Choudhury and Tucker (1997) used AVHRR data collected from 1982-1984 and Scanning Multi-Channel Microwave Radiometer data (Nimbus-7 satellite) from 1979-1985 to present the seasonal interannual vegetation variation on three large deserts: the Kalahari (Africa) and the Great Victoria, and Great Sandy deserts (Australia). The results indicate that the NDVI values measured from the two Australian deserts were alike and had acceptable values for evaluating and determining the aridity of the deserts. On the other hand, the Kalahari Desert presented a higher NDVI value that associated with the higher mean annual precipitation.

Achard et al. (1988) presented a methodology to monitor the seasonal dynamics of plant communities in the area between the forest and the savanna in West Africa. They classified vegetation types by using NOAA-AVHRR LAC, SPOT, and TM images. The study suggests that monitoring seasonal characteristics using both SPOT and Landsat TM data is sufficient to produce automated classification on a large scale.

By combining variables from fieldwork measurement with NOAA-AVHRR data, Paltridge and Barber (1988) developed a technique for monitoring grassland dryness and fire potential in Australia. They divided the study area into four locations, each one containing various mixtures of pasture and crop. At each location, fifteen sites were chosen for measuring the total green biomass of each site. This study used a NDVI equation that served to measure the differences in vegetation cover, and it contributed to more details about the distribution of vegetation patterns of November 1985 and January 1986. These researchers conclude that the NDVI equation should be acceptable as a biophysical indicator in monitoring vegetation patterns and vegetation movement.

Lambin and Ehrlich (1997) studied land-cover change in Sub-Sahara Africa. They hypothesized that land-cover change is a result of the following causes: a long-term natural change in climate conditions; geomorphologic and ecological processes; human impact on vegetation cover; interannual climatic variability; and/or human-induced climate change. The study uses a continental scale for obtaining data by using NOAA-AVHRR to assist in measuring two biophysical indicators. These indicators are NDVI and land surface "skin" brightness temperatures that are derived from thermal channels of AVHRR. They demonstrate that climatic conditions and human impact are two major factors in changing vegetation cover.

Prince and Tucker (1986) investigated the relationship between NDVI results and the herbaceous vegetation in three selected sites of Eastern Botswana rangeland. NOAA-AVHRR data were obtained in order to select three 12 km ×12 km study sites. Also, Landsat MSS data for September and November, 1983 and January and March, 1984 were obtained to identify 4 ha sites in the middle of each site. This project utilized three successive methods, including field measurements, Landsat MSS interpolation of the field measurements, and AVHRR data processing techniques. The authors applied multiple linear regression to analyze the variation in NDVI values.

The major objective of the study done by Chavez, David, and Mackinnon (1994) was to detect vegetation change in an arid to semi-arid desert in the southwestern United States, using multi-temporal Landsat MSS data for April and July, 1992 and February, 1981-1984 and GEOS Visible Infrared Spin-Scan Radiometer (VISSR) data for April and July, 1992. These researchers discuss technical processes involved in radiometric calibration. They conclude that the calibrated visible band is better than

NDVI images for monitoring vegetation change because soil in the arid to semi-arid environment supporting most of the vegetation has a high reflectance in both the visible and near-infrared spectral bands. NDVI values will change much, because when the near-infrared reflectance for the soil is high and the vegetation also has a high reflectance, the changes in brightness value for the near-infrared band will be minimal.

Peters and Eve (1995) utilized NOAA-AVHRR to monitor desert plant communities in the Chihuahuan Desert of southern New Mexico. They applied the NDVI equation that classified the area into three classes: desert area, non-desert area, and lake. Moreover, the study uses an unsupervised classification technique to isolate areas not in the study's objective, including agricultural areas and riparian vegetation. This technique helped to delineate the area into four classes: barren/sparse, shrub, grass/shrub, and grass. The study recommends a methodology for identifying desert plant communities using satellite monitoring, which could be applied to large regional-scale areas. However, the authors also conclude that small areas need to be evaluated, using parameters such as rainfall effectiveness and local precipitation patterns.

Kennedy (1989) monitored the phenology of Tunisian grazing lands. The study applied a NDVI equation to satellite data obtained from the Advanced Very High Resolution Radiometer (AVHRR) of NOAA-9 for different seasonal dates. The study was supported by fieldwork that covered 22 selected study sites located within different types of grazing lands along a north-south transect. The NDVI application proved to be a good equation for monitoring vegetation cover and accurately estimating the value of above-ground green biomass. In this particular study, the low NDVI values (0-0.2) correspond to areas of low photosynthesis activity and low percentage vegetation cover and thus low biomass. High values of NDVI (0.2-0.5) represent high biomass and photosynthesis activity. NDVI evaluations can assist in deciding whether the study area is dry or not.

Another study monitoring vegetation change was conducted by Pickup, Chewings, and Nelson (1993). Their study used vegetation change as an indicator in arid rangeland to monitor and identify the processes of land degradation using MSS data. It illustrated the development of a vegetation index such as NDVI by using MSS band 4 and band 5. Moreover, ground-based radiometer data were used to examine how the index responds to "pure" targets, representing a wide range of soil, rock, and vegetation types from Australia's arid zone.

Tripathy, Ghosh, and Shah (1996) discussed a monitoring approach that involves indicators of desertification processes in semi-arid lands using multi-temporal satellite data from Landsat-4 MSS. Several equations were computed in this study. First, the albedo image in the wavelength range 0.28-6.00 μm was computed; then for vegetation analysis and change, an NDVI equation was computed. Finally, the authors used the Universal Soil Loss Equation (USLE) to estimate the rate of soil erosion. They successfully classified desertification indicators into geologic and soil indicators, meteorological and hydrologic indicators, and biological and statistical indicators with emphasis on the severity of the desertification phenomenon.

Hill et al. (1999) developed an NDVI using Landsat TM and NOAA-AVHRR data when classifying pastureland cover in eastern Australia. TM data were used to divide the study area into six potential pasture growth levels by using three different channels of TM data: those in green (0.52-0.60 μm), red (0.63-0.69 μm), and near infrared (0.76-0.90 μm) with high-resolution imagery.

Researcher Henebry (1993) utilized a nine-year data set of Landsat TM data for land use analysis of the Konza Prairie Research Natural Area (KPRNA), located about 10 km south of Manhattan, Kansas. Each image was processed using NDVI. Two locations were tested in this study. They were accurately characterized by burn status, grazing, soil type, and slopes.

Jadhav, Kimothi and Kandya (1993) analyzed the causes of grassland change for Banni, Kachchu in India. The grassland of the study area had been affected by expanding agriculture and overstocking of domestic animals. The study presents an interesting methodology for monitoring that combined multi-temporal satellite images, surveys of India's topographical map data, and digital image analysis.

Edwards et al. (1997) used remotely sensed data to map and monitor sparse vegetation in the eastern desert regions of Jordan that was used extensively for grazing. The study area is located predominately in an arid climate with a mean annual rainfall of between 200 mm in the north and 50 mm in the south. Intensive fieldwork was carried out on two different seasons of 1996. By using Landsat TM imagery, they defined large homogenous vegetated sites and then calculated percentage of vegetation cover, biomass, plant dimensions, density and spacing, soil moisture, soil type and area, and ground radiometric properties. Also, the study focuses on using a NDVI equation as an acceptable and successful application in arid lands. Jansinski's model, a computer program written in C, is used to calculate red and near infrared reflectance for different vegetation covers and soil reflectance. This model is a hybrid model using a physical modeling approach to interpret the information of red/near infrared feature space derived from a single multispectral satellite image.

A study of the environmental impact of desertification by using remote sensing and land-based information systems was done by Ghosh (1993). The study had three major objectives: (1) to investigate the nature of desertification of the region; (2) to estimate land degradation due to human activities; and (3) to apply GIS technology for decision-making. The Landsat TM data was radiometically corrected. A color composite with principal component analysis was useful for mapping sediments and delineating densely vegetated sites. Principal component analysis contributed to analyzing the characteristics of different degraded lands of different degrees of severity. NDVI was also applied in this study. This equation assisted in delineating the boundaries of degraded lands and demonstrated a good application of remote sensing in finding and evaluating where vegetation exists. Geographic Information Systems (GIS) technology was used in this study. Each map for each created site in the study area had four classes, and a numerical value was assigned for each class. The values ranged from 1 through 9, where 1 designates poor for desertification and 9, good for desertification. By subjecting those maps to GIS analysis, the results showed three major degrees of desertification in these sites: (1) good lands, (2) low desertification, and (3) high desertification.

Nicholson and Tucker (1998) briefly reviewed the historical background and the meteorological aspects of desertification in West Africa. They examined a scenario of desertification in this area: advancing desert, increasing albedo, and a decline in biological productivity. Their study used NDVI values that had been obtained from previous studies and calculated. Those values were used to demonstrate desert change.

Also, they used data extracted from a surface albedo data set that was calculated from METEOSAT B2 data with a resolution of 30 km.

Hellden (1987) wrote a report on the use of remote sensing and GIS analysis for community forests, land uses, and soil erosion assessment in Ethiopia employing NDVI. This report includes a multipurpose monitoring and planning approach for integrating natural resources. The study evaluates an area that was affected by intensive agriculture, soil erosion, and fairly poor woody biomass resources. The TM sensor was used for monitoring small areas in the study field, especially to detect and evaluate eroded areas.

In their study, Alwashe and Bokhari (1993) researched vegetation change in Al Madina, Saudi Arabia, by using TM data. The study shows that monitoring becomes a necessity, especially for environments that have been affected by drought conditions. The study focuses on image processing of TM data for vegetation reconnaissance. It helped to distinguish between two different areas: that of natural vegetation and cultivated fields. Also, Alwashe and Bokhari applied Ratio Vegetation Index and merged three layers of images into one TM coverage. They suggest that annual bi-monthly TM data during one year is required to assess the natural variations of vegetation in a Saudi Arabian environment.

Hall (1998) utilized TM data as a useful methodology to monitor and measure changes in the Nevada desert. Forty sites were selected in central Nevada using Landsat Thematic Mapper data, and Ratio Index was measured. Multiple linear regression and canonical correlation analyses were applied to determine and predict the percent cover of each vegetation type in the study area. In this study, an ordination analysis was applied to separate the field sites into fourteen groups. Those groups then were categorized into six major groups that showed differences from one to another.

Summary

Previous studies have used several techniques in assessing desert vegetation quantity and quality. Their findings and observations can be classified into three major groups that are closely related to this proposal research topic. First, the Saudi Ministry of Agriculture and Water, the Al Jouf Range and Animals Development Research Center technically have been conducting intensive fieldwork for monitoring vegetation changes and evaluating several sites that may have been utilized physically for range development. These studies include classification of vegetation in desert environments and the environmental influences that could intensively affect such vegetation communities. The studies have yet to assess remote sensing techniques that may be useful in Saudi Arabia's environment, a large area impacted climatically by drought and physically by humans.

Secondly, the studies ecologically and geographically have evaluated vegetation and human impact in desert environments. These studies show the impact of precipitation and overgrazing on desert vegetation, as well as good techniques for dividing a study area into subsets, depending upon several environmental criteria. In this proposal research, there will be a geographic evaluation of environmental factors that are responsible for the deterioration of vegetation cover. This evaluation will be supported with the identification of primary physical and human influences.

Thirdly, remotely sensed studies provide a variety of remote sensing techniques for analyzing, evaluating, and monitoring vegetation dynamics. These studies have used NDVI for detecting and mapping vegetation and its dynamics, and this equation has been utilized in semi-to-arid lands. NDVI applications contributed not only to show differences between two particular images, but also to assist in measuring human impact such as grazing and woodcutting in the world.

The use of NDVI has major problems, such as the effect of soil background on detecting processes for sparse desert vegetation. NDVI was adopted in multiple studies as a biological indicator, which helped in delineating desert boundaries and assisted in measuring desert movement from dry to sub-humid areas.

NDVI also was utilized as a pre-classification step, especially as a basic image for more advanced remotely sensed application. A NDVI image can be used to provide data about soil types and to classify a significant area into different degradation levels. It is a useful image to be integrated with other data sets by using geographic information systems for environmental assessment.

Chapter 3

DATA AND METHODS

The data and methods section provides detailed insights into how the data were obtained and scientifically analyzed. This study employs several analytical methods to assist in displaying, analyzing, and interpreting the data. Figure 3-1 presents the analytical procedures that fundamentally were used as a combined method, and the manner in which each procedure helped in achieving the research objectives.

In the following section, more explanation is provided for the division of the analytical methods utilized in this study.

Data Sources

1. Landsat-5 TM Data

Landsat-5 TM data were subjected to radiometrically corrected, systematically geocoded and two dimension resampling processed. The Landsat-5 TM scenes for April, 1988 and April, 1999 of the study area were acquired from the Space Research Institute, King Abdulaziz City for Sciences and Technology, Riyadh, Saudi Arabia. The study area lies between latitudes 27°, 30′ and 29°, 00′ north, and longitudes 35°, 30′ and 37°, 30′ east (Path 173, Row 40). TM bands 1, 2, 3, 4, 5,and 7 were utilized in this investigation (Figures 3-2a and 3-2b).

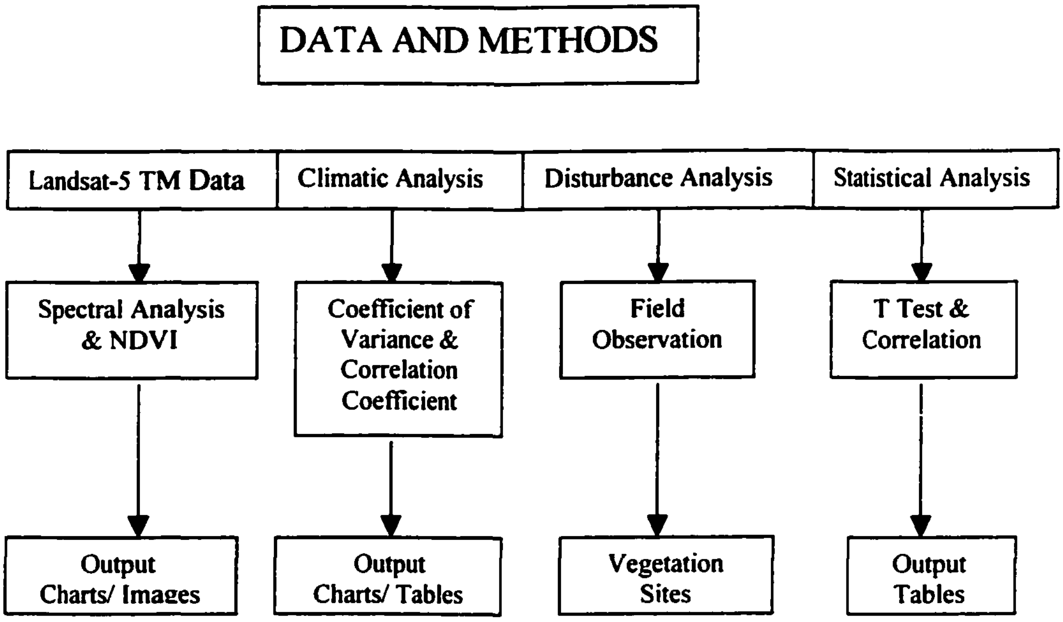

Figure 3-1. System Flow Chart

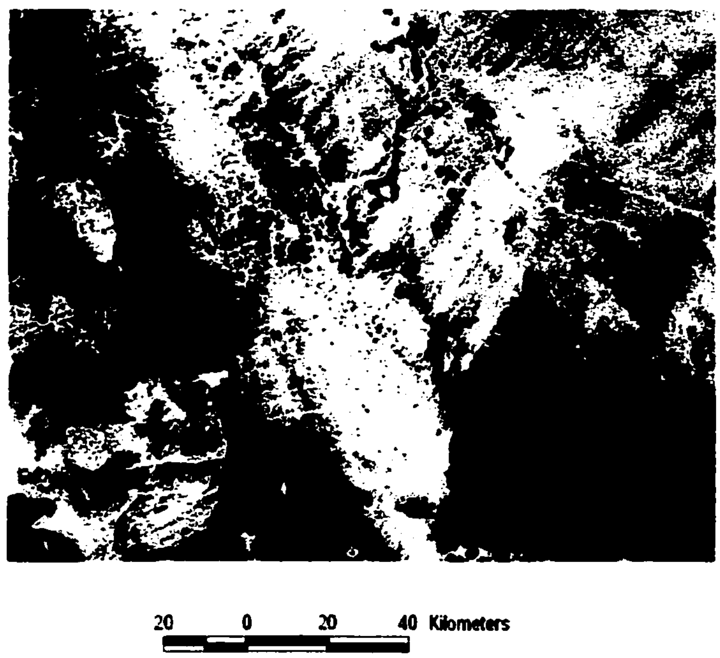

Figure 3-2a. Thematic Mapper Scene for the Study Area (April 3, 1988)
(TM 4, TM 3 and TM 2)
(Source: Saudi Space Research Institute, 2000)

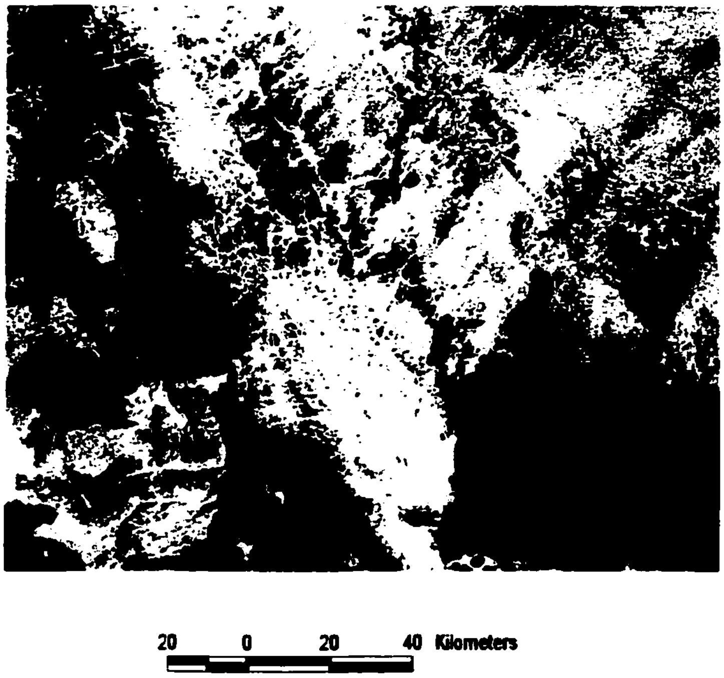

Figure 3-2b. Thematic Mapper Scene for the Study Area (April 18, 1999)
(TM 4, TM 3 and TM 2)
(Source: Saudi Space Research Institute, 2000)

2. Sites Selection

Thirty vegetation sites were chosen in the study area (Figure 3-3). These sites belong to two specific areas: first, the western area which includes Aynonah and Sharmah villages, and the eastern area which covers the vast region surrounding Tabuk City. Visual interpretation of the TM images for 1999 supporting with ground truth has clearly helped to delineate those sites.

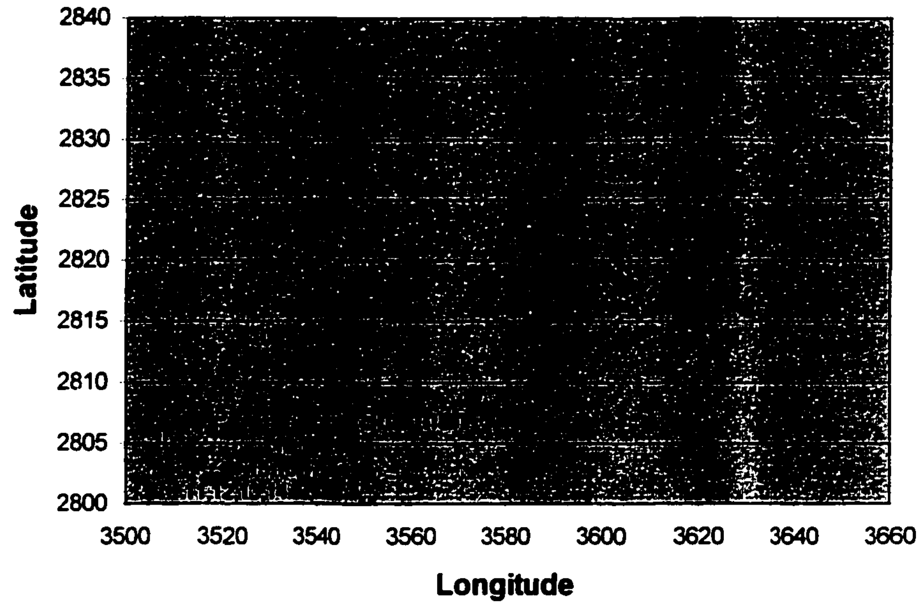

Figure 3-3. The Geographic Coordinates of the Vegetation Sites (Source: Topographic Maps, 1:250000 scale, of the Study Area).

3. Ground Truth

A ground survey was required in this study for two major reasons. First, it was needed to collect vegetation samples and secondly, to observe and collect qualitative data about the presence or absence of vegetation type, disturbance (overgrazing and woodcutting), and conservation. The empirical procedure for collecting the fieldwork data was conducted by observing each site individually, and assigned 1 for existence of vegetation, disturbance, and conservation or 0 for none. Fieldwork was done on April 18, 2001 approximately two years after the TM image was acquired on April 18, 1999. Thirty vegetation sites were analyzed and showed significant differences in vegetation in the study area. Topographic maps at a scale of 1:250,000 were used to define the exact location of each site. The vegetation sites or spectral pixels are defined by using the following procedure: (1) Using manual interpretation, select 30 sites, which show vegetation change. (2) Identify the geographic coordinates (longitude and latitude) for each site using topographic maps and searching for the nearest adjacent known points in the field. (3) Convert each geographic coordinate to UTM by using a program on the web site: (http:// www.globalserv.net/nac/). (4) Identify the UTM coordinates for each site from TM images. (5) Then coregister each selected site on the ground with the same site in the image. And (6) perform image enhancement that includes spectral bands 2,3,4,5, and 7 and NDVI values for 1999 for each site. Table 3-1 lists all sites and characteristics: latitudes and longitudes, vegetation cover, disturbance, and conservation, in which the last three elements are assigned as 1 for presence and 0 for none.

4. Topographic Maps

Several topographic maps (1:250,000 scale) that cover the study area were used in this study. Those maps are available in the Military Survey Agency Library, Riyadh, Saudi Arabia: sheet NH 36-12, sheet NH 37-9, sheet NH 36-16, sheet NH 37-13, sheet NG 36-4, sheet NG 37-1, sheet NH 37-14, and sheet NG 37-2.

5. Tabuk Agriculture and Water Department Reports

Pertinent reports that cover the water wells distribution, pastoral sites, and some field surveys for vegetation types and their distribution were read, analyzed, critically reviewed, and insights used in the study.

Table 3-1. The Geographic Characteristics of the Vegetation Sites.

Site	Longitude	Latitude	Vegetation	Disturbance	Conservation
1	35°13'	28°07'	0	0	0
2	35°14'	28°07'	0	0	0
3	35°15'	28°07'	1	1	0
4	35°16'	28°07'	1	1	0
5	35°17'	28°08'	1	1	0
6	35°18'	28°09'	1	1	1
7	35°19'	28°10'	1	1	0
8	35°20'	28°11'	1	1	0
9	35°21'	28°12'	1	1	0
10	35°22'	28°13'	1	1	0
11	35°17'	28°02'	1	1	0
12	35°18'	28°02'	1	1	0
13	35°19'	28°02'	1	1	0
14	35°20'	28°02'	1	1	0
15	35°21'	28°03'	1	1	0
16	35°22'	28°03'	1	1	0
17	35°23'	28°03'	1	1	0
18	35°24'	28°04'	1	1	0
19	35°25'	28°04'	1	1	0
20	35°26'	28°04'	1	1	0
21	36°15'	28°17'	0	0	0
22	36°29'	28°16'	1	1	0
23	36°37'	28°36'	1	1	0
24	36°46'	28°13'	0	0	0
25	36°52'	28°32'	1	1	1
26	36°07'	28°27'	1	1	1
27	36°17'	28°17'	1	1	0
28	36°24'	28°23'	0	0	0
29	36°39'	28°30'	1	1	1
30	36°30'	28°32'	1	1	1

(Source: Topographic Maps, 1:250000 scale, of the Study Area and the Fieldwork Conducted by Students at Tabuk Teachers College, April 2001)

6. Geographic Books and Periodicals

Multiple theoretical and applied studies have been done in the field of monitoring vegetation change and desert vegetation. Those studies have provided a background in analyzing and interpreting multiple environmental facets in the study area.

Data Analysis

Several analytical methods are employed in the research project. These are:

1. Preprocessing TM Data

1-1. Geometric Correction

The Landsat-5 TM scenes of 1988 and 1999 have been geometrically corrected using twenty-four ground control points by utilizing the following topographic maps: NG 36-4, NH 36-16, NG 37-1, and NH 37-13 of the Saudi Aerial Survey Department, Riyadh. They were used to locate multiple known ground control points.

1-2. False Color Composite

The two images were displayed using the FCC to recognize and present differences in vegetation cover in the study area. False color composites of bands 2,3, and 4 contributed in determining the major differences in vegetation cover in 1988 compared with 1999.

2. Normalized Difference Vegetation Index (NDVI)

NDVI (TM 4-TM 3)/(TM 4+TM 3) is used as a greenness index because in arid lands, it correlates well with such parameters as leaf area index, green leaf biomass, and vegetation cover (Nicholson and Tucker, 1998). NDVI assists in image classification by separating vegetated from nonvegetated areas; by distinguishing between different types and densities of vegetation; and by monitoring seasonal variations in vegetation vigor, abundance, and distribution (Campbell, 1996). The NDVI equation was applied on both images of 1988 and 1999. Figures 3-4a and 3-4b show the two NDVI images by which the main vegetation differences can be recognized. Gray color indicates high in band 3 and low in band 4, which means less to no vegetation in those areas. White color indicates high in band 4 and low in band 3, and currently presents vast areas of agriculture.

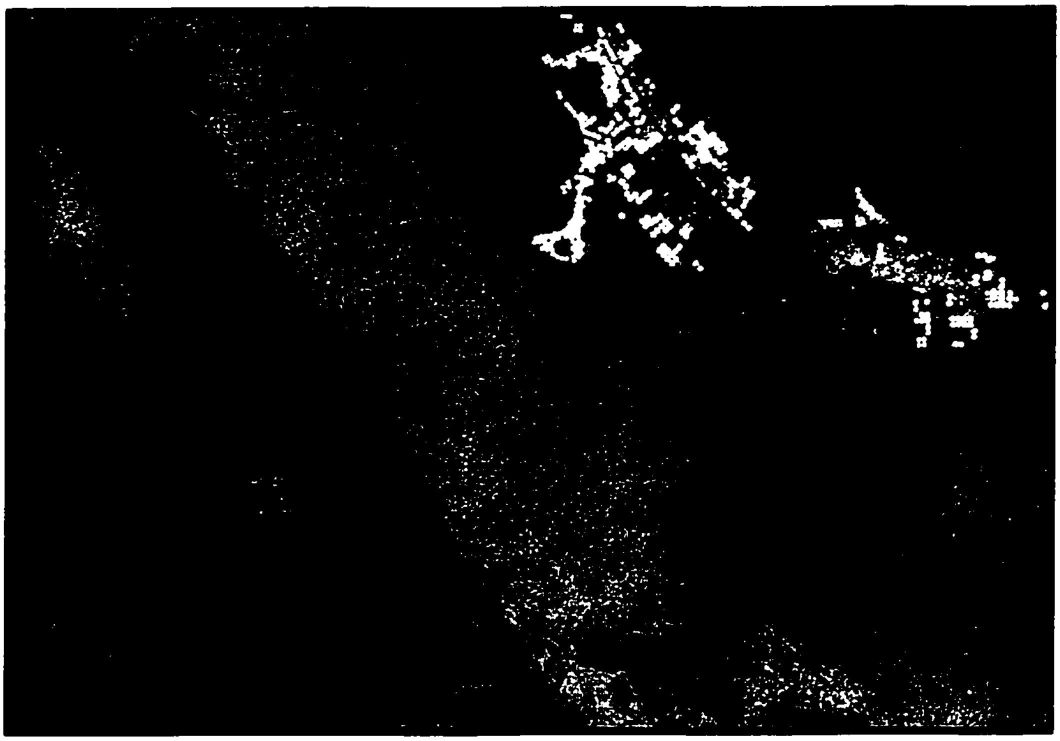

Figure 3-4a. NDVI Image-1988 for the Study Area

3. Climatic Analysis

Temperature and precipitation have the greatest climatic influences on vegetation change or vegetation distribution. The climatic record for the Tabuk area covers the maximum and minimum temperatures and the monthly rainfall of the past twenty years

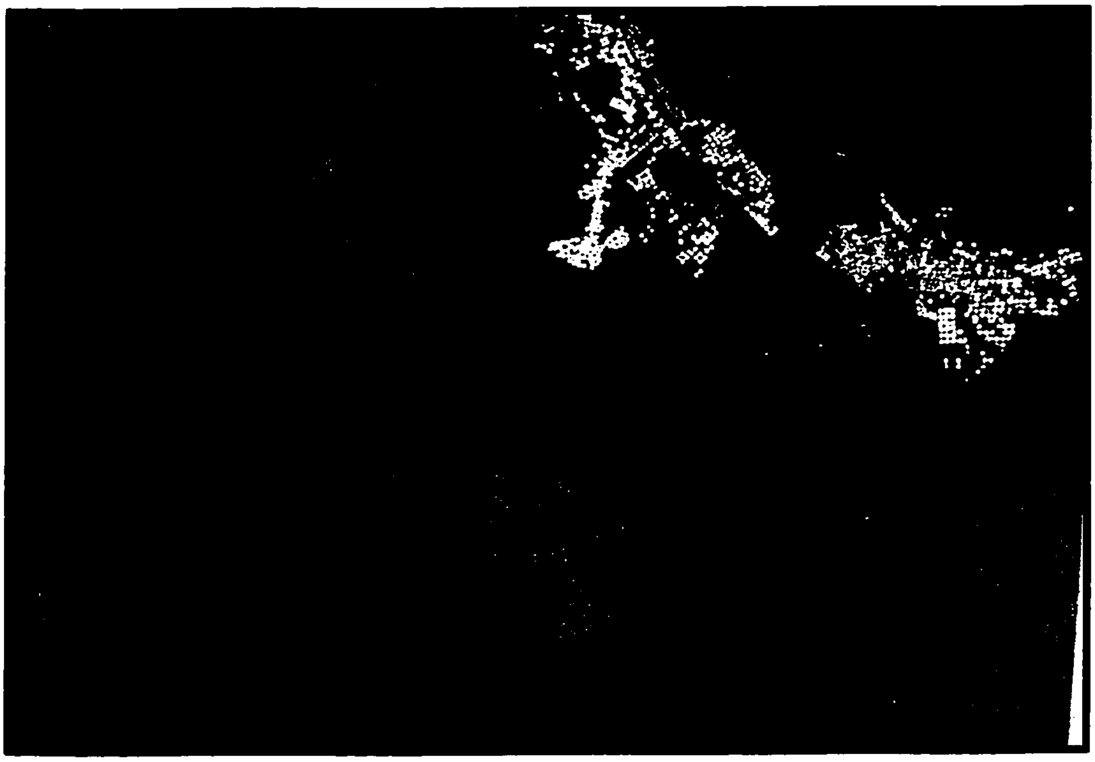

Figure 3-4b. NDVI Image-1999 for the Study Area

(1975-1994) and evaporation of the past nine years (1976-1984) for the study area(Appendix B). These data were presented as tables and graphs in order to assist in analyzing and explaining the vegetation variations. Also, climatic analysis indicated whether or not a similarity of rainfall deficiency in the study area existed.

Particularly, in this part of the analysis, two major statistical techniques were used. First, the coefficient of variance was applied, using the following formula:

$$CV = \frac{\sigma}{\mu}$$

Where σ is the standard deviation and μ is the mean of the data set (Mann, 1998). This equation reveals the relative variability of the rainfall data and the many differences of rainfall values. Second, the Coefficient of Correlation was applied on the rainfall data of the Tabuk station and the Tama station, using the SPSS software to investigate whether or not the study area had similar rainfall.

4. Disturbance Analysis

Disturbance (overgrazing and woodcutting) has received great attention in this investigation. The main objective of the fieldwork was focused on gathering nominal data from the thirty vegetation sites about the presence or absence of three major elements: vegetation, disturbance, and conservation. Fieldwork was conducted by the students of the Department of Social Studies at Tabuk Teachers College, with assistance from two faculty members.

As previously explained, Point Biserial Correlation Coefficient is mainly used to examine the relationship between NDVI and vegetation cover, and disturbance. In addition, an interview with the specialist working at the Tabuk Agriculture and Water Department helped to investigate multiple issues dealing with vegetation and human impact or disturbance in the study area (Appendix A).

5. Statistical Analysis for Remote Sensing and Fieldwork Data

Statistics are used to display, and analyze the remote sensing data. The remote sensing data of this study consist of the thirty vegetation sites in which each site represents spectral values of bands 2, 3, 4, 5, and 7 and NDVI for 1988 and 1999. The objective of using these statistics in this particular research is to provide the descriptive analyses to identify the general magnitude of all observations in a data set (Shaw and

Wheeler, 1985). The mean or average was the statistical measure used in this study. The standard deviation, also an important measurement, can be used to measure how closely the values of a data set are near the mean (Mann, 1998). In addition, the minimum, maximum, and range are a group of measurements that help in describing the data set. A second objective is to examine the differences between 1988 and 1999 for NDVI by using a T-test to determine the differences between two samples that were obtained from the same population. A T-test commonly is used to accept or reject the null hypothesis. A third objective is to find the relationship between NDVI and the presence or absence of vegetation cover and disturbance by using a Point Biserial Correlation Coefficient formula.

$$r_b = \frac{\bar{Y}_1 - \bar{Y}_0}{s_Y} \sqrt{\left[\frac{N_1 N_0}{N(N-1)} \right]} \qquad \hat{s}_Y = \sqrt{\left[\frac{N \Sigma Y^2 - (\Sigma Y)^2}{N(N-1)} \right]}$$

This formula is more applicable for measuring the relationship between two variables, where (Y) represents NDVI-1999 values for all sites and X represents the presence or absence of vegetation and disturbance for each site. NDVI-1999 values are divided into two major groups depending on the variable of (X): the site with vegetation and disturbance (X = 1) and those without (X = 0). And the two major groups need to be calculated (Y_0 and Y_1) together with the standard deviation $^S y$. N_0 = number of observations with X value of 0 and N_1 = number of observations with X value of 1 (Shaw and Wheeler, 1985). The formula computations for the correlation between NDVI-1999 and the variables of vegetation cover and disturbance (see Appendix D).

6. Geographic Information Systems (GIS)

GIS, as a tool for displaying and analyzing geographic data, was used in this study for two objectives: First, it enabled the creation of the Saudi Arabia map, which shows the location of the Tabuk area. Secondly, GIS was used to display the image data. The image file for multiple subset images was added as themes and displayed for obtaining the scale. JPEG image extension, a standard technique for storing images, was the main file extension used in this study.

Chapter 4

DISCUSSION AND RESULTS

Vegetation deterioration in the study area was the subject of investigation, using multiple analytical methods to detect, analyze, and measure different facets of the deterioration and then to identify the processes behind environmental deterioration. As mentioned earlier, digital image, climatic, disturbance, and statistical analyses are discussed in this chapter.

The Use of Remote Sensing Analysis in DetectingVegetation Deterioration

Remote sensing applications were used to detect the location of vegetation deterioration in the study area. There are two main techniques applied in this study. First, manual interpretation of false color composite images allowed for initial recognition of the multiple variations of vegetation. Manual interpretation also assisted in obtaining the representative spectral signature values for the thirty vegetation sites. Second, NDVI, used mainly as a biological indicator for the vegetation sites, was used to identify the vegetation differences for all sites.

- Spectral Signature

Spectral signature values for bands 2, 3, 4, 5, and 7 at each site were obtained and used to indicate variation in vegetation amount and health for all thirty vegetation sites (see Appendix C). Spectrally, the vegetation status of 1988 revealed more greenness than existed in 1999. Figure 4-1 presents nearly equal spectral values for band 2 for the thirty vegetation sites, which is related to chlorophyll absorption. Band 3 expresses a lower value for 1988 and a higher one for 1999. Band 4 has higher reflectance for 1988 but has a slightly lower value for 1999, due to dense vegetation which increases the spectral reflectance. Spectral reflectance variations for both bands 5 and 7 may be explained by differences in moisture content. On one hand, the 1988 value represents much higher moisture content in plants and much thicker plant species, which appears as lower reflectance for both bands 5 and 7. On the other hand, the 1999 value appears to show less vegetation, which graphically appears as higher reflectance for both bands 5 and 7.

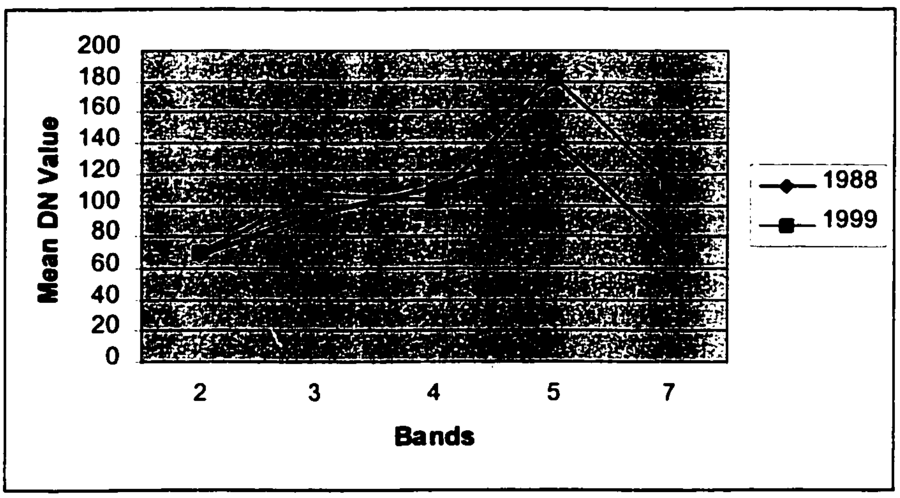

Figure 4-1. The Average Spectral Reflectance by TM Bands of the Thirty Vegetation Sites from 1988 and 1999.

Spectrally, the thirty vegetation sites belong to two major areas within the study area. The western part, which includes Aynonah and Sharmah as the main two sites, has distinct vegetation differences. The eastern part occupies a vast area surrounding Tabuk City. The thirty vegetation sites show qualitative variation in vegetation, and they have been subjected to individual analysis.

1. Aynonah

In 1988, the Aynonah area site represented an example of vegetation deterioration that characterizes this site. Figure 4-2 compares April 1988 with April 1999. The image of 1988 shows vegetation concentrated around the village (Aynonah), but vegetation does not appear in the 1999 image.

Figure 4-3 shows the great difference in reflectance values for bands 5 and 7, explained by decreases in the moisture content and thickness of plants in 1999 compared to 1988. In contrast, similar average values exist for band 2 for both 1988 and 1999, yet there is not much difference between the average reflectance for band 4. This finding demonstrates that variation in natural vegetation exists but reflectance is not enough for identifying unique differences.

2. Sharmah

The Sharmah area presents slight differences in vegetation quality compared to Aynonah. Figure 4-4 shows differences in the amount of vegetation delineated that can be recognized between 1988 and 1999; these differences are due to water depletion and woodcutting in this specific site (An Interview with a Specialist, 2000).

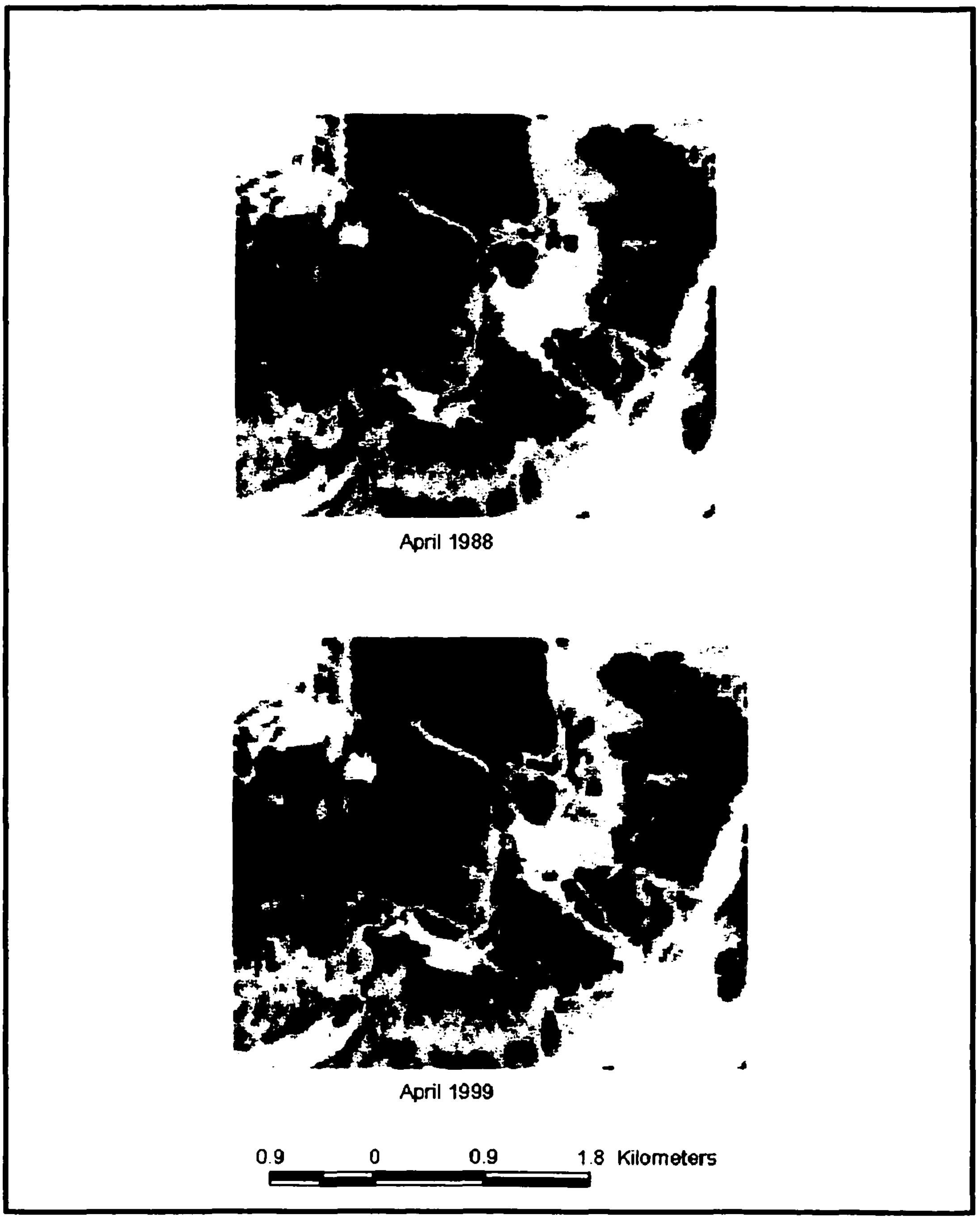

Figure 4-2. Vegetation Variations of the Aynonah Area

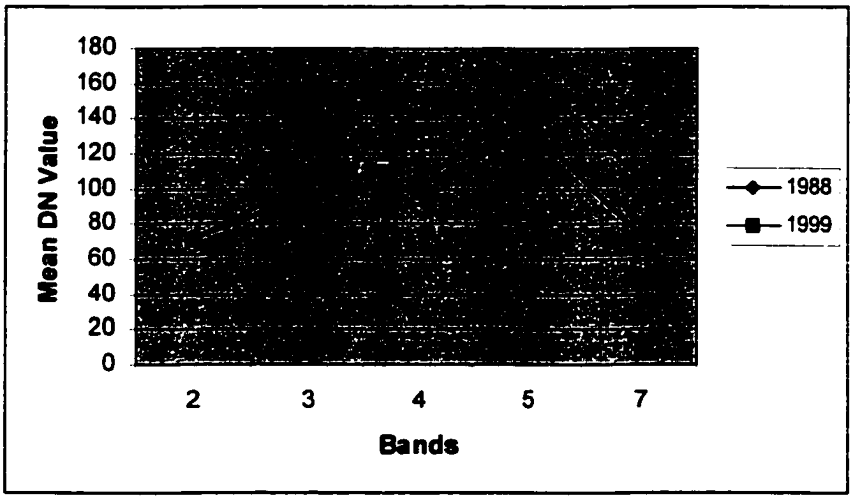

Figure 4-3. The Average Spectral Reflectance from Ten Vegetation Sites Representative of the Aynonah Area

Figure 4-5 shows differences between TM bands for both 1988 and 1999. This figure presents similarities in bands 2 and 3 with a slight increase in band 4 reflectance especially. Band 4 is the main spectral indicator of greenness.

3. The Area Surrounding Tabuk City

The area surrounding Tabuk City is the second site where variations in vegetation can be visually observed by looking at Figure 4-6. This area was chosen because it has been selected by Saudi Ministry of Agriculture and Water as possible rangeland in the future. Wheat fields shown in red color mainly occupy large areas. Several sites of natural vegetation have disappeared due to the TM data's inability to identify those sites. In Figure 4-7 the average spectral reflectance of multiple vegetation sites is shown by high spectral values in band 3 and low values in band 4 for 1999. On the other hand, the low spectral value of band 3 and high spectral value of band 4 for

1988 can be noted. The data visually presented vegetation variation according to color composites of bands 2, 3, and 4.

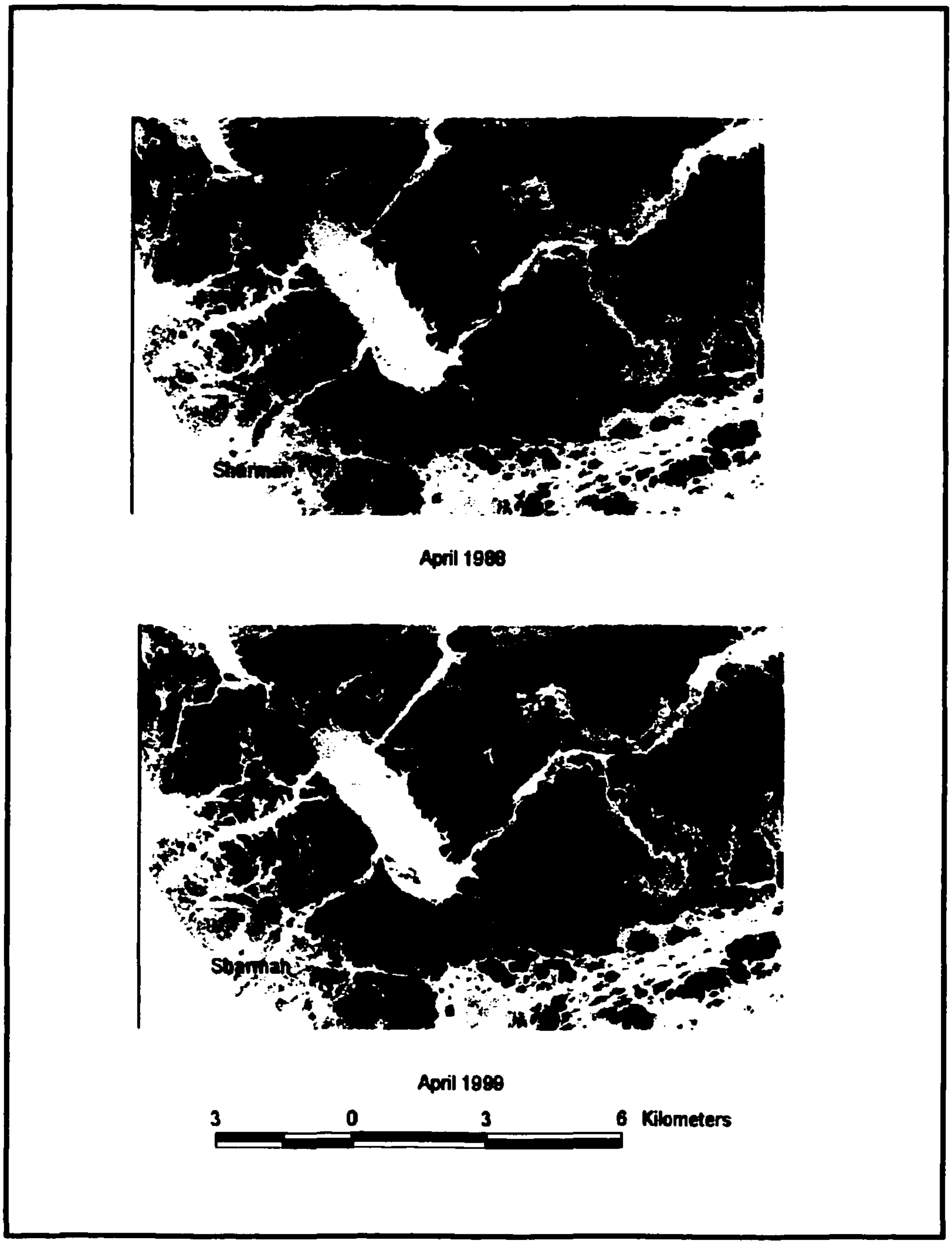

Figure 4-4. Vegetation Deterioration in the Sharmah Area

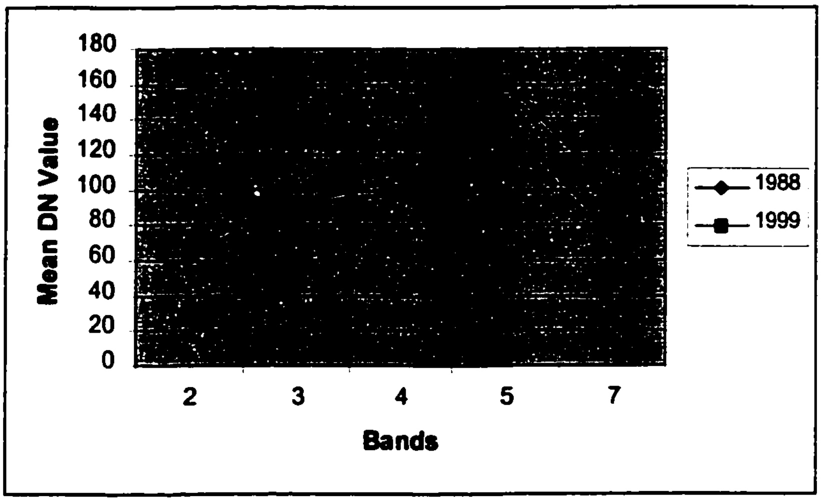

Figure 4-5. The Average Spectral Reflectance from Ten Vegetation Sites Representative of the Sharmah Area

- Normalized Difference Vegetation Index Analysis

NDVI was applied in this study. The two images from 1988 and 1999 were subjected to NDVI equation analysis. A NDVI equation has technically contributed to understanding major variations in vegetation change. Figure 4-8 shows red, cyan, and white dots on the image indicating wheat fields, the most common agricultural activity in the study area. The number of fields increased during that decade, which has resulted in more rapid reduction of natural vegetation in the study area (An Interview with a Specialist, 2000).

Figure 4-9 includes spectral NDVI values for each of the thirty vegetation sites. The graph mainly reveals that the vegetation manifested more greenness and was flourishing in 1988 compared to 1999, when low NDVI values were shown, especially for Site 2 (a unique situation). These low NDVI values may be due to lower biological productivity.

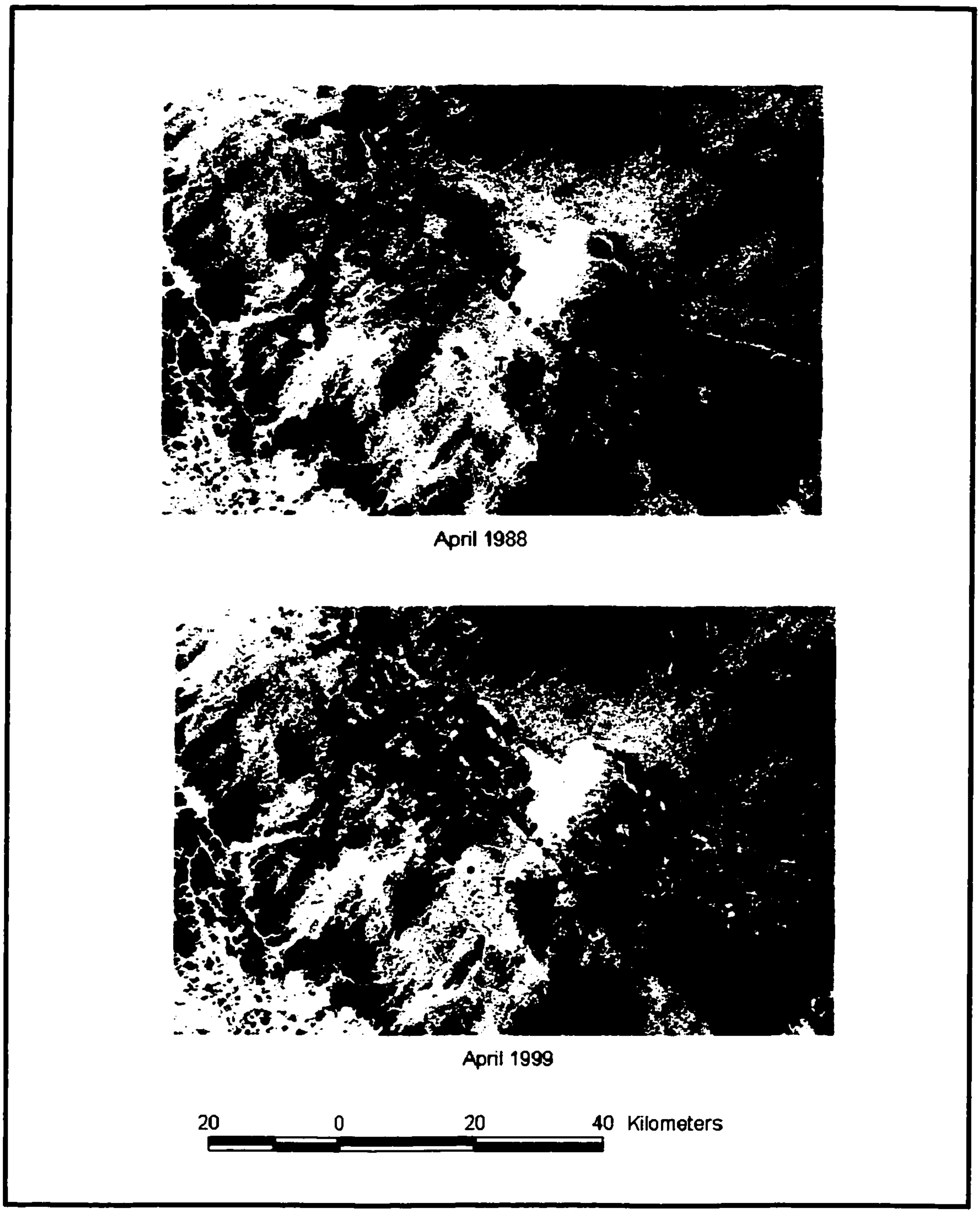

Figure 4-6. Significant Changes in the Area Surrounding Tabuk

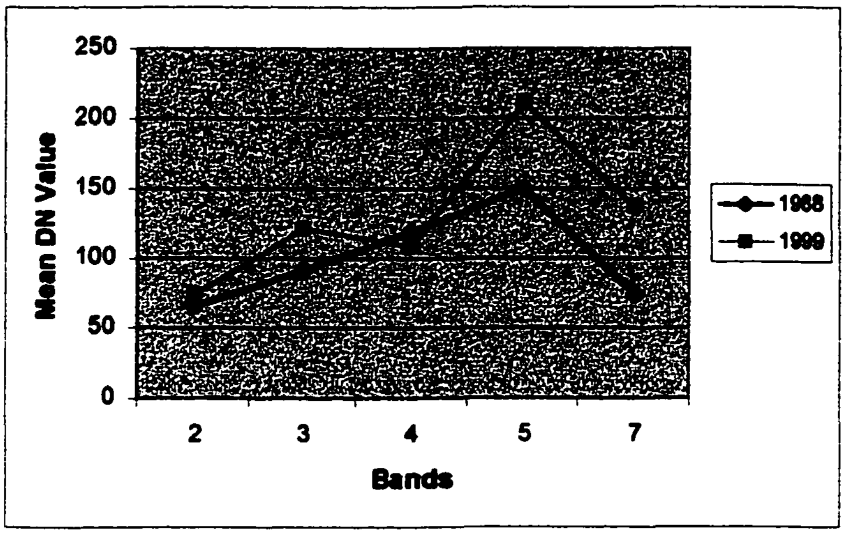

Figure 4-7. The Average Spectral Reflectance from Ten Vegetation Sites Representative of the Tabuk Area

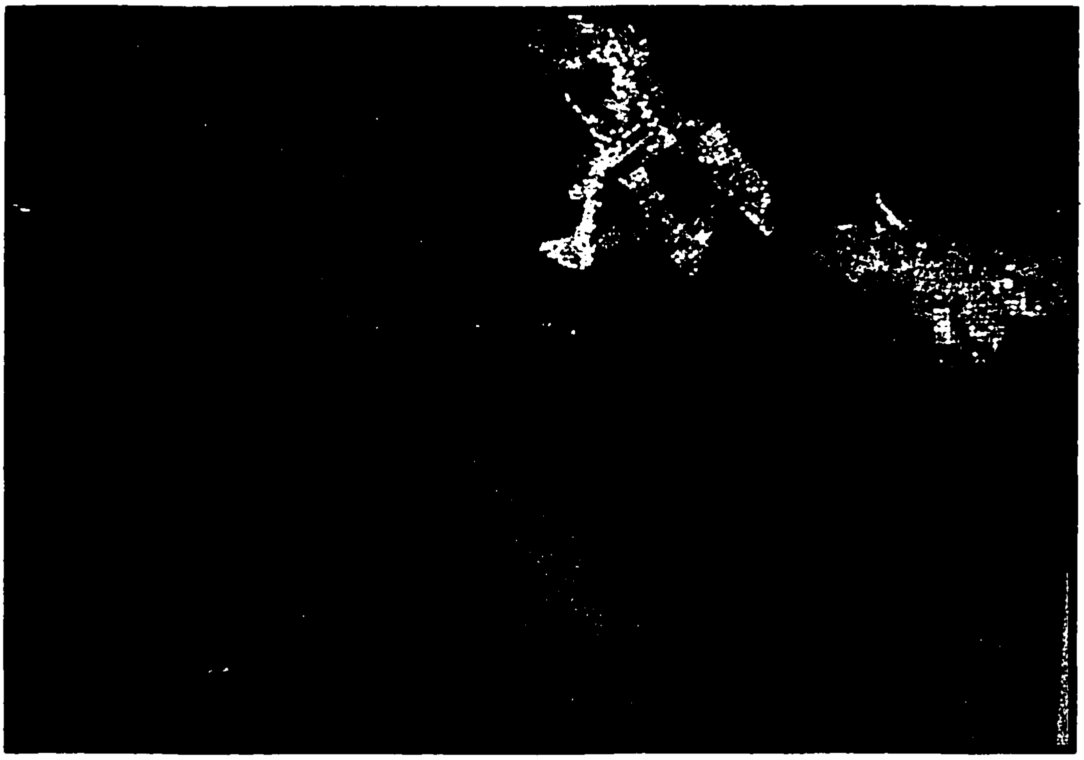

Figure 4-8. Merged Images of NDVI 1988 and 1999
(Red for decrease, cyan for increase, and white for no change)

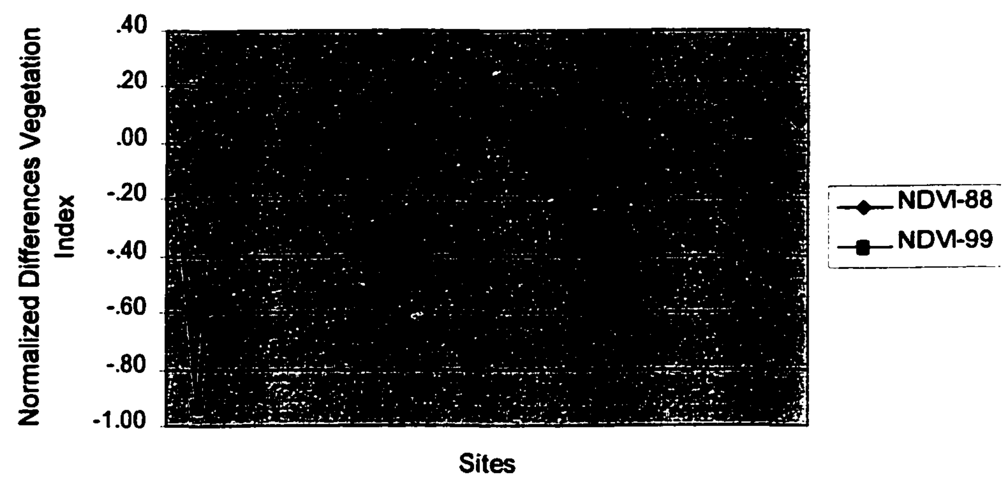

Figure 4-9. Average NDVI Values for All Thirty Vegetation Sites

Elevation and soil type are considered in understanding how the NVDI equation can be changed from one site to another. The data were obtained from geologic and topographic maps of the study area. The maps covered all sites and were significantly utilized in this analysis.

Sites 1, 3, and 4 show alluvial formation dominates low elevations (ranging between 50 and 150 m above sea level). There was no vegetation on site 1, with an NDVI value of – 0.14, and sparse vegetation in site 3, with an NDVI value of –0.09. Site 2 is located on sandy soil and exposed granite outcrops, which may assist in decreasing the NDVI value. Site 5 has a high NDVI value of 0.22, at an elevation ranging between 200-400 m above sea level. Here increasing vegetation leads to another increase in NDVI values. Site 6 has sparse vegetation and a NDVI value of – 0.04, that may be caused by the granite outcrop formation. This outcrop may assist in increasing the red band. Site 7 has a high value of NDVI which sand and silt formation dominates and allows retention of soil moisture in moist years. Sites 8, 9, and 10 have sparse vegetation and the NVDI values are low which may be due to exposed granite formation that spectrally can increase the red band value. Sites 12 and 13 have sparse vegetation and spectrally show a high value in the red band, a low value in near infrared, and low NDVI values that may be caused by brown and red sand formations. Sites 11, 17, and 18 show high NDVI values because sandstone and alluvial formations dominate those sites making them more susceptible for arid vegetation growth. Site 14, Wadi Uthayll, located in south Tabuk City, and sites 15 and 16 have sparse vegetation and high NDVI values. Alluvial deposits at these sites assist in vegetal growth. Site 19 shows a -0.07 value of NDVI due to bare soil that consists of limestone and gravel formation, especially in the upstream of Wadi Al Akhder. Site 20 consists of silty soil causing sparse vegetation growth that can lead to an increased NDVI value. Sites 21 and 24 have no vegetation due to sand movement in the former and gravel formation in the latter. Sites 22 and 23 are characterized by sparse vegetation due to silt formation that assists in retaining soil moisture availability for longer periods of time. Sites 27, 28, 29, and 30 present arid vegetation, thus showing a high value in red band, and a low value in near infrared band with NDVI values ranging between –0.06 and -0.11. Site 28 has no vegetation due to domination of the gravel formation.

From insights gained through site examination, the following points were made:

1. False color composite images are essentially the first step in applying remote sensing analysis. For both 1988 and 1999, false color composite images of bands 2, 3, and 4

were used to identify vegetation change and to assist in obtaining background reflectance information about the natural vegetation.

2. Normalized Difference Vegetation Index (NDVI) contributed in delimiting and depicting multiple vegetation sites in the Tabuk area. The thirty sites were chosen in two different locations within the entire study area. NDVI assisted in showing the vegetation differences, according to differences in NDVI values which ranged between –. 05 to .30 for 1988 and -. 93 to .22 for 1999.

The Climatic Analysis of Temperature and Rainfall

The entire Tabuk region investigated here currently has two climatic stations. First, Tabuk station, that has complete climatic data, is located in Tabuk City. The second station at Tayma has complete data covering the winter season. Complete climatic data covers the past twenty years and includes maximum and minimum temperatures and annual rainfall. The available climatic data can be used as representative statistics for the entire region.

The climatic data are graphically presented and climatically discussed in order to show the major temporal characteristics of temperature and rainfall of the Tabuk area. This study also is attempting to determine the role of local climate in changing the landscape of the Tabuk region.

- The Maximum Monthly Temperature

Analysis of the maximum monthly temperature shows that there are major variations, especially in comparing each month with the same month in different years, or presenting the differences in temperature of all months for one year. January is the peak month of the winter season in the study area. For all twenty years (1975-1994) (Appendix B), the maximum value ranged between 28.5° C in 1989 and 14.3° C in 1992. The range was 14.2° C with the standard deviation of 3.09° C. On the other hand, July readings show the maximum temperature and ranged between 42.1° C in 1980, and 36.3° C in 1994. A range of 5.8° C with a standard deviation of 1.43° C indicates that all values for the month of July are close to the mean.

The climatic record for the study area indicates a similarity in the maximum winter temperatures for December, January, and February. Fluctuations in temperature ranged between 15 to 30° C. January readings show an increase in maximum temperatures only for 1989 and 1990. February records show a reading of over 20° C for almost all years except the period 1990 to 1994. An interesting point in this analysis is that December and January have the same start-point and end-point of maximum monthly temperatures for 1975 and 1994 (Figures 4-10a and 4-10b).

The summer season in the study area, as one would expect, recorded much higher temperature values than the winter season. June, July, and August are the summer months, and they are much hotter and drier than all other months in the twenty-year period. Dry conditions may be caused by the domination of a high-pressure belt that impacts Saudi Arabia (Saudi Ministry of Defiance and Aviation, Tabuk Meteorological Report, 1975-1994. (Figures 4-11a and 4-11b).

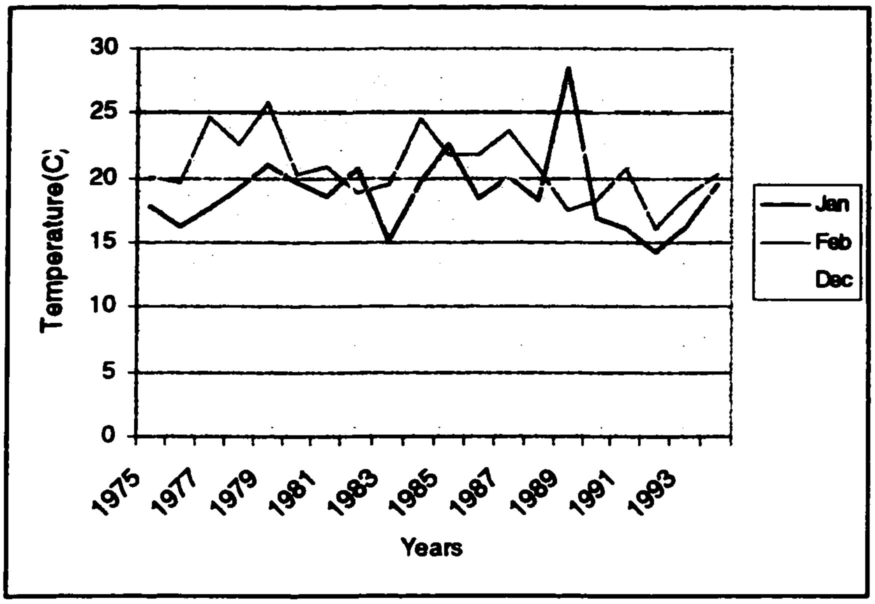

Figure 4-10a. The Maximum Temperatures for Jan, Feb, and Dec. (°C) (Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to 1994)

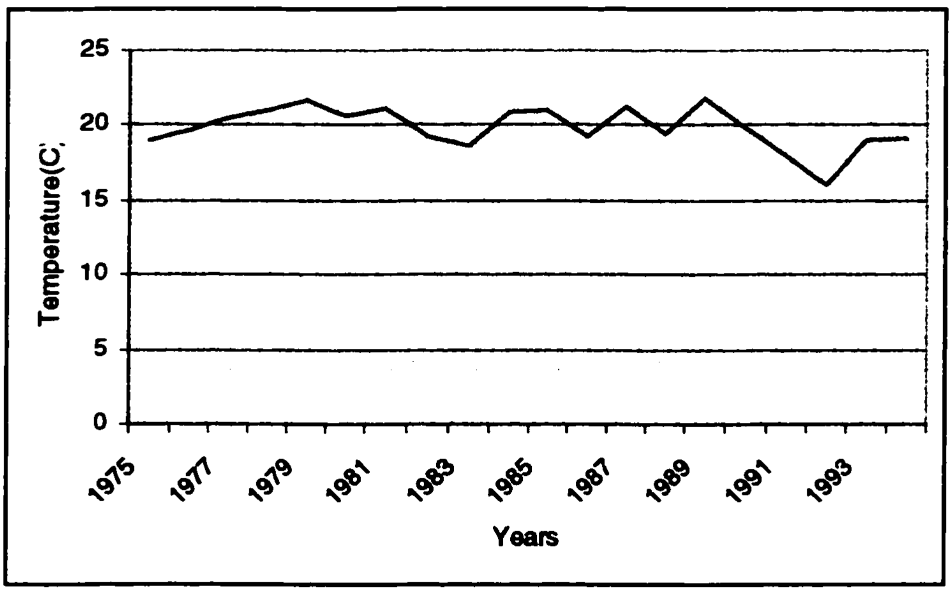

Figure 4-10b. The Average Maximum Winter Temperature (°C) (Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to 1994)

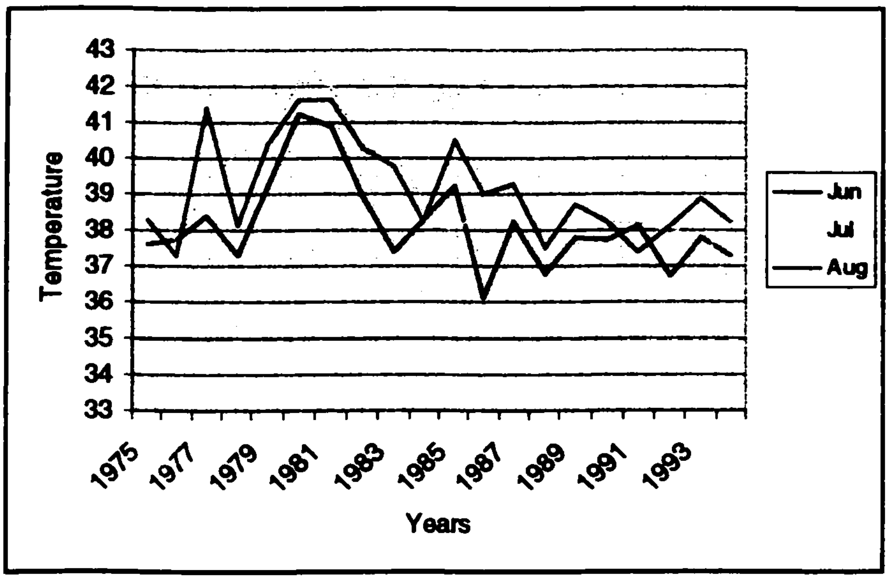

Figure 4-11a. The Maximum Temperatures for June, July, and Aug. (°C)
(Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to 1994)

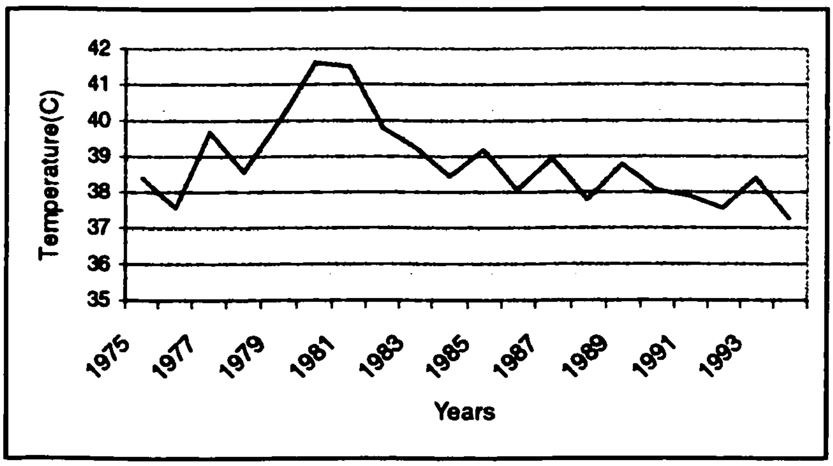

Figure 4-11b. The Average Maximum Summer Temperature (°C)
(Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to 1994)

- **The Minimum Temperature**

January experienced the lowest temperatures in the study area over the past twenty years. The minimum temperature varied between 1.1° C to 8.5° C, a range of 7.4 °C. The mean is 3.64° C with a standard deviation of 1.89° C. However, July is the peak month of the summer season in the study area. It has a small range, between 19.6 to 23.8° C, a range of 4.2 °C with a standard deviation of 1.14° C (Figure 4-13a).

Climatic data graphically shows great fluctuations in winter temperatures. The year 1989 was considered a unique event, because it had the highest maximum and the highest minimum in January than other months (Figures 4-12a and 4-12b).

The minimum summer temperatures presented a similar pattern in fluctuations of temperature values. Both July and August had a majority of values over twenty degrees (°C), while June had values less than twenty degrees (Figures 4-13a and 4-13b).

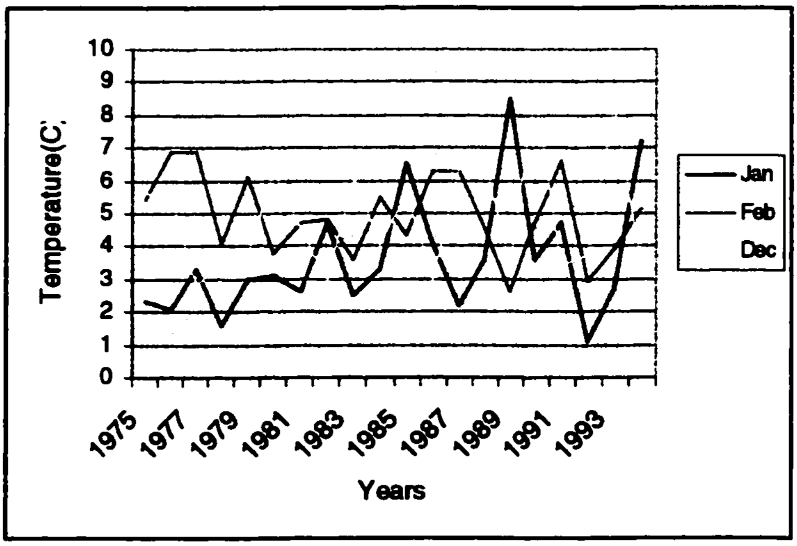

Figure 4-12a. The Minimum Temperatures for Jan, Feb, and Dec. (°C)
(Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to 1994)

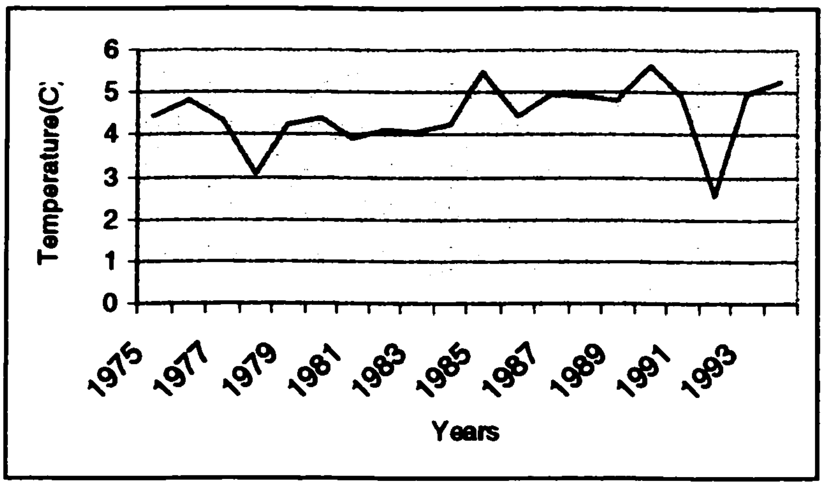

Figure 4-12b. The Average Minimum Winter Temperature (°C)
(Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to1994)

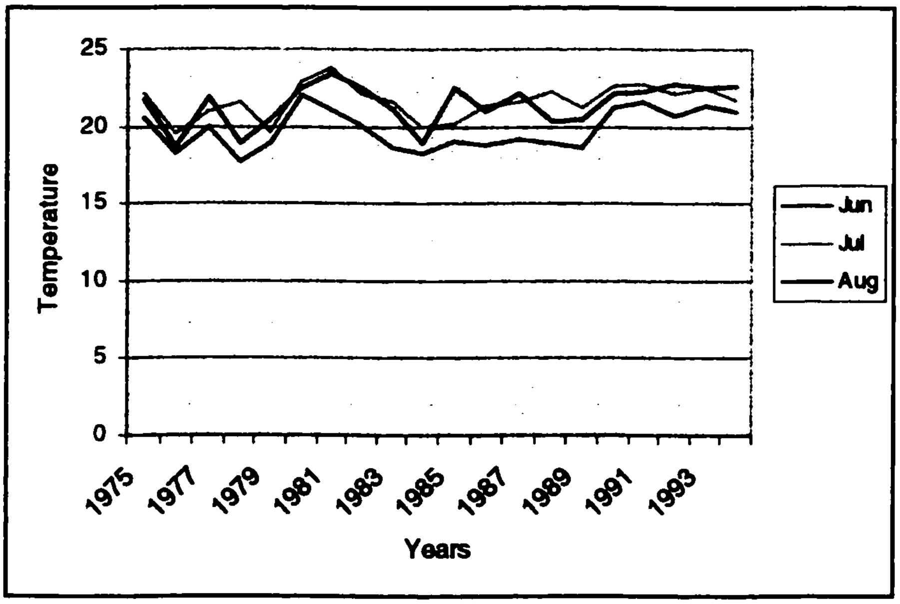

Figure 4-13a. The Minimum Temperatures for June, July, and Aug. (°C)
(Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to1994)

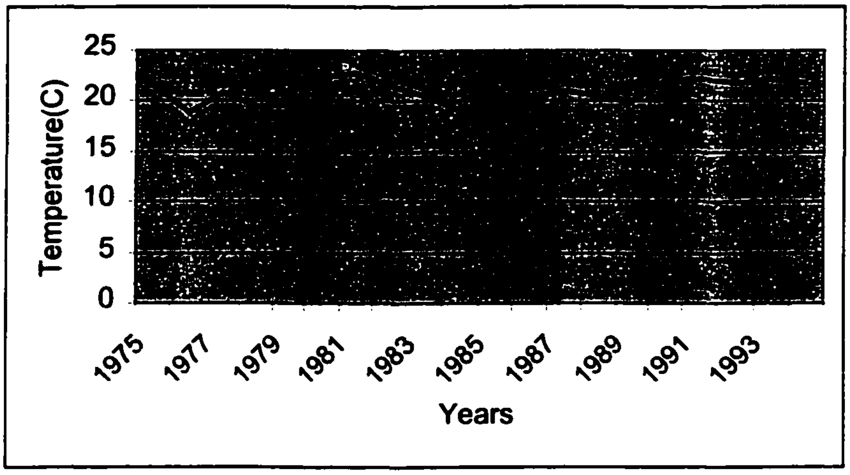

Figure 4-13b. The Average Minimum Summer Temperature (°C)
(Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to 1994)

The comparison between average winter maximum and average winter minimum temperatures shows a small range due to low solar radiation in this season--a major climatic characteristic of this study area. However, the summer season shows large differences between the average summer maximum and the average summer minimum temperatures. Another characteristic of the Tabuk area's arid environment is caused by the Indian cyclones that annually affect all of Saudi Arabia in this season (Figures 4-14a and 4-14b).

- Rainfall Analysis

Lack of detailed climatic data from multiple stations throughout the study area was one of the major problems in this particular analysis. The Tabuk area suffers from acute rainfall deficiency. No rain was received during the entire summer season. The period from October to April is the wettest season and the season in which most rainfall occurs (Plate 4-1).

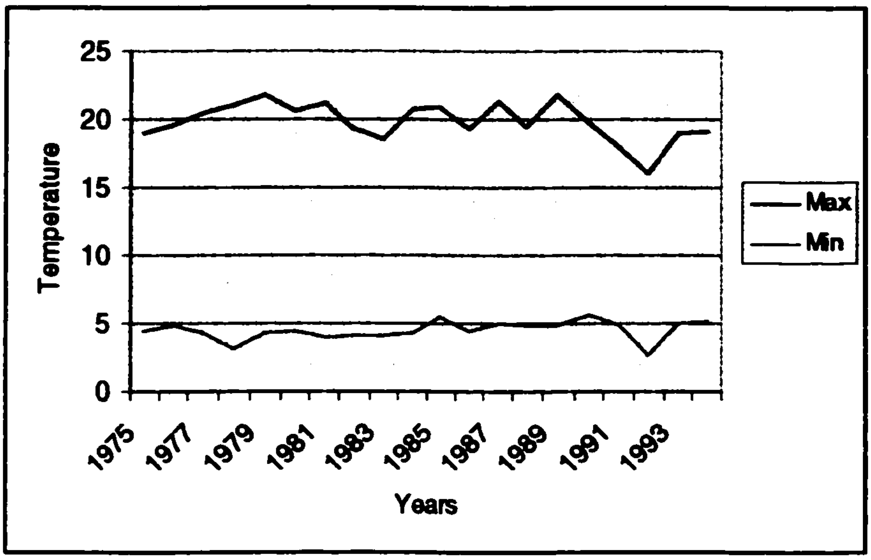

Figure 4-14a. The Average Winter Maximum and Minimum Temperatures (°C) (Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to 1994)

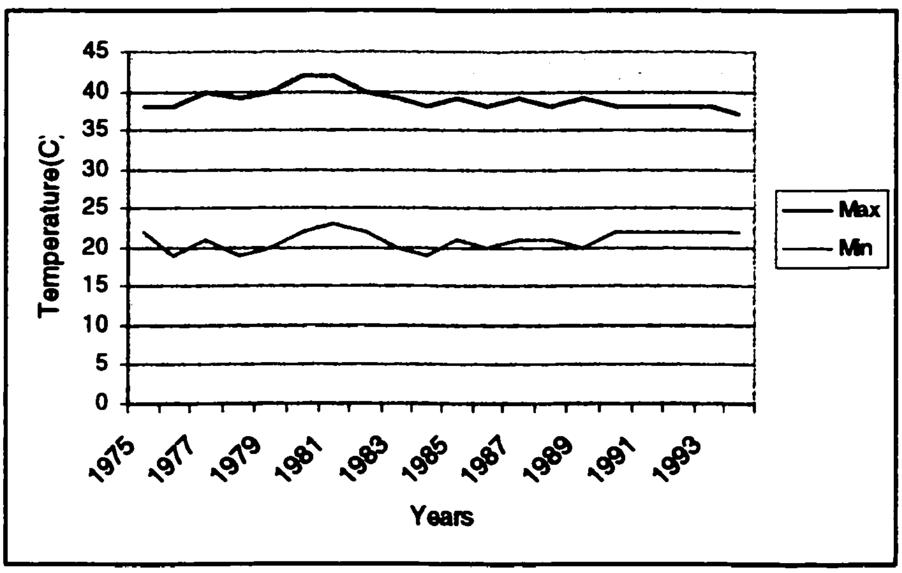

Figure 4-14b. The Average Summer Maximum and Minimum Temperatures (°C) (Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to 1994)

Plate 4-1. Retention of Rainfall in the Study Area

Statistically, January has been observed as the month with highest rainfall values (36.2 mm). Both June and July recorded a 0 mm value for the entire twenty years. An anomaly, August of 1992 received 20 mm in rainfall.

The winter season is the most important period of rainfall availability for biomass development and vegetal growth in the study area. For example, January showed two peaks of rainfall (Figure 4-15a). February 1975 recorded a high value and December 1985 also showed a high receipt of rainfall (Figures 4-15a, 4-15b, and 4-15c).

Rainfall data of the study area has been subjected to graphic analysis in order to present four major statistics: the mean, the Coefficient of Variation, the Coefficient of Correlation, and the total annual rainfall.

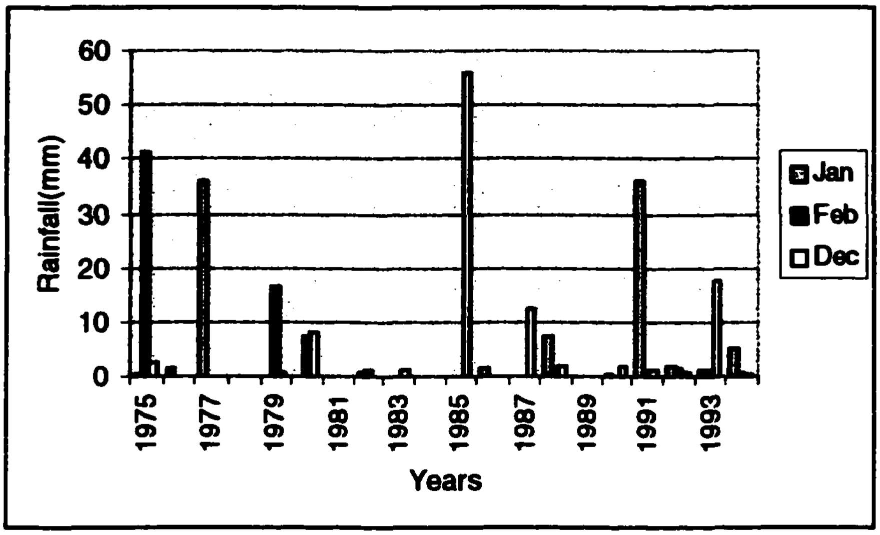

Figure 4-15a. The Winter Rainfall in the Study Area
(Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to 1994)

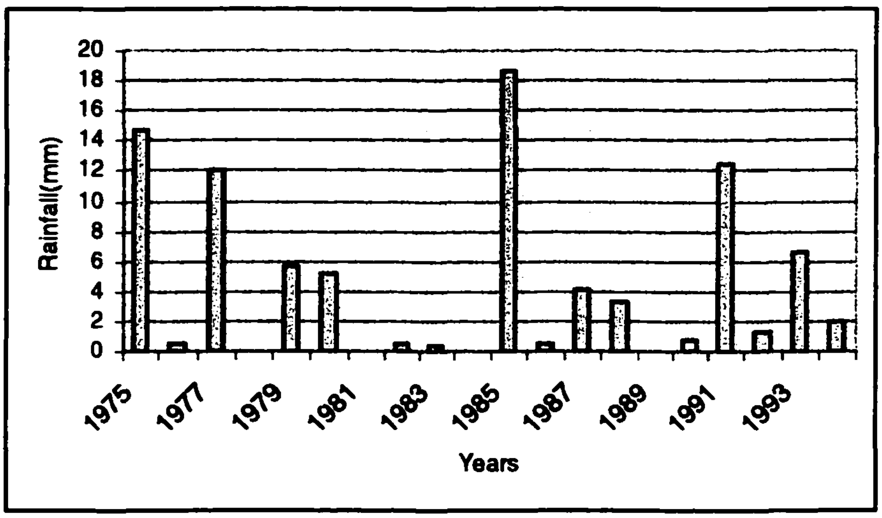

Figure 4-15b. The Average Winter Rainfall in the Study Area
(Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to 1994)

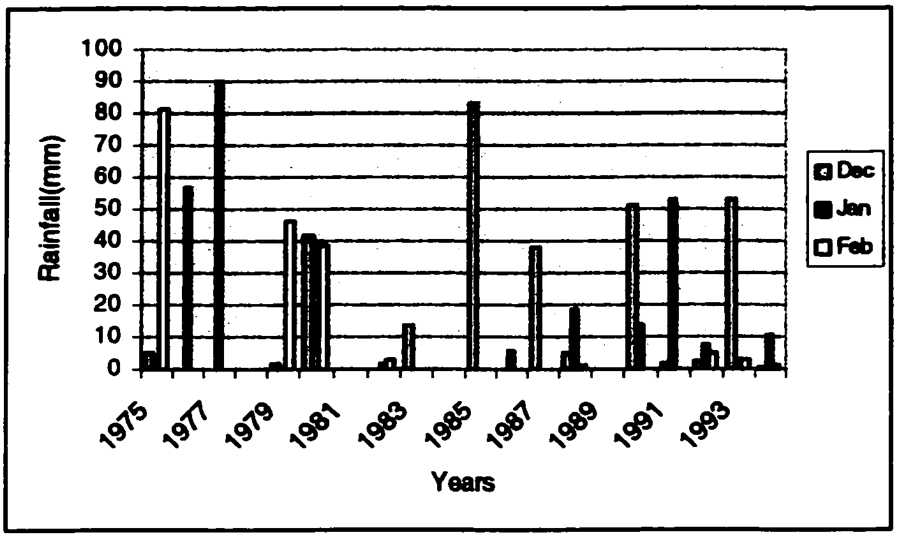

Figure 4-15c. The Winter Rainfall Percentage in the Study Area
(Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to1994)

- Mean Annual Rainfall

There is a variation in mean annual rainfall in the study area among the years studied. Records show high values in 1985 and 1991 with a mean of 6 mm, and 0 mm for 1976, 1978, and 1990. Generally, the mean is low and great fluctuations in rainfall are characteristic of the study area (Figure 4-16).

- Coefficient of Variation

Coefficient of Variation is one of the important statistical procedures that may assist in measuring how much monthly or yearly variation in temperature or rainfall exists in the study area. In this case, it was used to measure the variability in the rainfall data of the study area. The result ranged between 0 mm to 400 mm. Relative variability of annual rainfall is higher for the following years: 1975, 1977, 1985, 1989, and 1992, which means those years presented major variability in rainfall for all months (Figure 4-17).

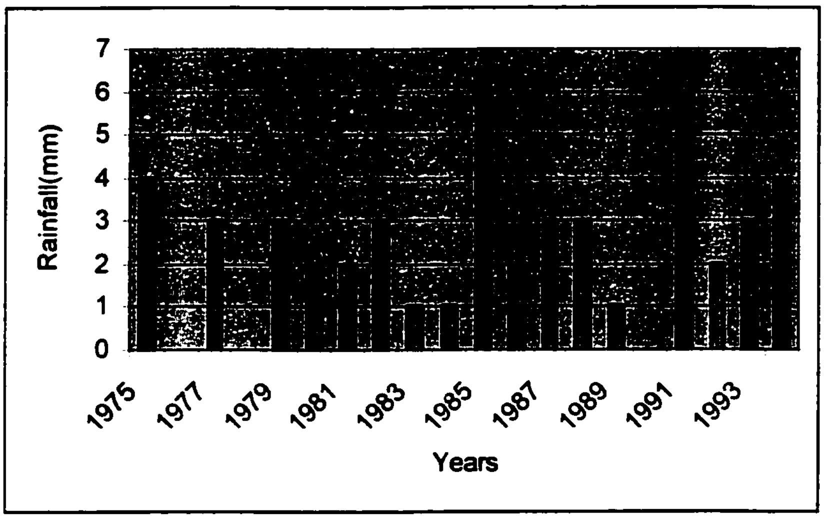

Figure 4-16. Mean Annual Rainfall in the Study Area
(Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to 1994)

- Correlation of Rainfall

Another climatic station is located in the southeast area of the Tabuk region. Tayma, as mentioned previously, has incomplete climatic data except the rainfall data that covers the winter season from 1975 to 1990 (Table 4-1). The rainfall data of the Tabuk area and the Tayma area were examined statistically and the Coefficient of Correlation was calculated.

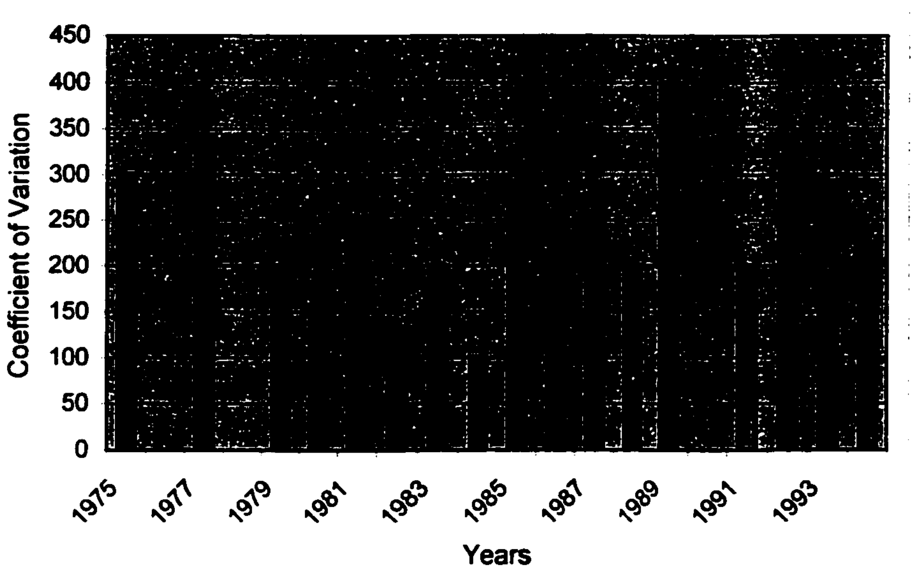

Figure 4-17. Coefficient of Variation of Annual Rainfall in the Study Area (Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to 1994)

The results of this analysis (Table 4-2) show high correlation between the two places, which have similar rainfall patterns during the winter season. However, the summer season received no rainfall. Climatically, the results demonstrate that the study area has received only winter rainfall.

- Total Annual Rainfall

The total annual rainfall showed an increase above the norm occurring once in four or five years. Also, total annual rainfall is an excellent indicator of whether or not the year experienced an acute rainfall deficiency (less than 80 mm). For the past twenty years some rainfall has been recorded in the study area with the exception of 1978. In

1978 drought conditions exacerbated an already acute and unstable water balance (Figure 4-18).

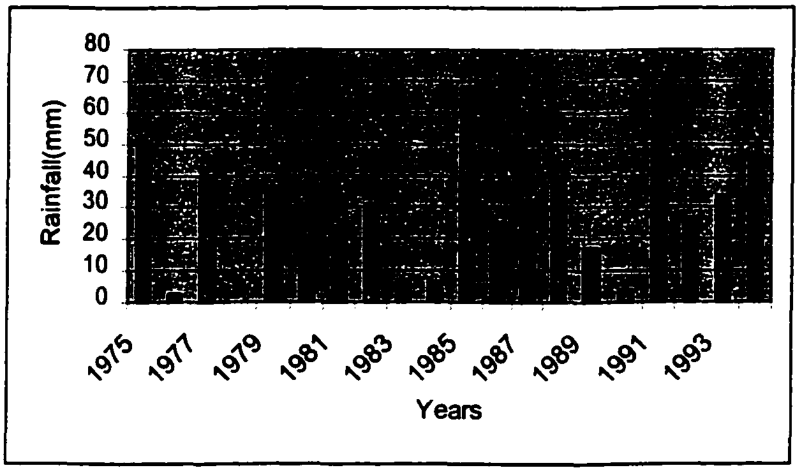

Figure 4-18. Total Annual Rainfall in the Study Area
(Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to 1994)

Table 4-1. The Comparison of Winter Rainfall (mm) Across the Study Area

	Tabuk			Tayma		
Years	**Dec**	**Jan**	**Feb**	**Dec**	**Jan**	**Feb**
1975	2.7	0.5	41.1	0	2	16.5
1976	0	1.6	0	0.2	0	0
1977	0	36	0	3	60	0
1978	0	0	0	0	0	8
1979	0.6	0	16.4	0.4	0	3
1980	8	0	7.4	17	0	9
1981	0	0	0	1	0	0
1982	0	0.6	1	0	12	6
1983	1	0	0	0	1	0.2
1984	0	0	0	0	0	0
1985	56	0	0	68	8	0
1986	0	1.4	0	0	1	0.4
1987	12.4	0	0	0	0	0
1988	2	7.4	0.4	0	0	0
1989	0	0	0	7	0	0
1990	1.9	0.5	0	0	2	0

(Source: Saudi Ministry of Agriculture and Water, Tabuk Meteorological Report, 1975 to 1994)

Table 4-2. Simple Correlation of Winter Rainfall

Variable	Tayma-Dec	Tayma-Jan	Tayma-Feb
Tabuk-Dec	0.95		
Tabuk-Jan		0.94	
Tabuk-Feb			0.82

(Source: The Statistical Analysis of Winter Data Rainfall Using SPSS)

Finally, this study was helpful in understanding the multiple facets of variations in maximum and minimum temperatures for both the winter and summer seasons. The study particularly focused on the comparison between the maximum and minimum temperatures in relationship to the yearly climatic variations in Saudi Arabia.

Rainfall was considered as the main factor in dealing with understanding whether or not the study area has suffered an above or below normal receipt of atmospheric moisture. Rainfall deficiency may be related to desert vegetation deterioration. Initially, climatic analysis of rainfall showed that the study area has climatic characteristics of an extreme arid environment. Nevertheless, the study area has the advantage of rainfall occurring in the winter season, which increases moisture effectiveness and the availability of existing vegetation to maximize the life-supporting impact of small amounts of water. However, the summer season receives little rainfall and this assists in increasing vegetal stress from May to September.

Rainfall is a major factor in delineating the boundaries of vegetation regions, especially in hot arid climatic realms. The Tabuk area has the typical arid environment, characterized by low rainfall that may cause temporary and long-term deterioration in the natural landscape. The main reason that existing vegetation in the Tabuk area thrives is ability of the soil to store the limited winter rainfall and to make the moisture available in the critical hot and arid summer season. Rainfall, prior to the 1988 Landsat TM image, was much higher or above normal, compared to the past three years, which means that the vegetation might have been greener due to wet conditions. On the other hand, the rainfall data for the period between 1995 and 1999 indicates that the Tabuk area has been subjected to limited rainfall (Saudi Ministry of Agriculture and Water, 1995-1999). This situation contributed to much accelerated vegetation deterioration.

Disturbance Analysis

Grazing and woodcutting are two major factors contributing to increasing the deterioration of vegetation cover of the Tabuk's ecosystem (An Interview with a Specialist, 2000). Also, burning can be considered slightly as an impacting factor within this region. In the following section, the two main factors are significantly discussed and qualitatively assessed.

- Grazing

Grazing is one of the most important factors contributing to changes in the vegetation cover. Grazing in the Tabuk area has been concentrated in specific sites which for this region has more than average vegetation and is near water sources such as a well

(An Interview with a Specialist, 2000). The major finding of the grazing analysis done for the research project is that grazing is more active today than in 1988.

Most people in the Tabuk area are classified as Bedouins. Livestock is considered to be their most important source of income. Therefore, the Bedouins move from one site to another looking for grasses, especially after a rainy season. Plate 4-2 shows sheep grazing in the Tabuk area. Sheep are one of the common domestic animals impacting the study area. Grazing sheep contribute greatly to removal of temporary vegetation (grass) that grows after a rainy season.

Grazing usually leads to the deterioration of vegetation cover in almost all sites. Overgrazing and lack of animal feed has become a problem for the Bedouins. They typically can not afford to purchase forage for their sheep from agricultural feed companies because these companies offer forage at too high a price (An Interview with a Specialist, 2000). On the other hand, there are no fees charged for the Bedouins to graze their animals throughout the study area. Therefore, they have no motivation to cease overgrazing.

There are no significant sites appropriate for grazing. However, overgrazing is most critical at sites close to a well or water source (An Interview with a Specialist, 2000). Water wells provide water for field crops and animals (Plate 4-3).

Plate 4-2. General View of Grazing Sheep in the Study Area

- Woodcutting

Woodcutting has negative and destructive impact on desert vegetation. It contributes much to the natural environmental degradation processes in desert lands.

Woodcutting in dense vegetation environments may be less devastating for those lands than woodcutting in desert environments that suffer drought, have limited moisture and energy resources, and long-term periods required for renewing vegetation cover. On the other hand, according to Batanounty (1983), *the disturbance of the habitat supporting* vegetation dominated by Acacia ehrenbergiana by cutting the trees and shrubs engenders invasion of this habitat by Calotropis procera that is neither used for fuel nor for grazing. For this study, there exists a difference between wood collecting and woodcutting. The first term is related to the collection process of trees that may be uprooted by severe runoff or die and then are collected. The second term, woodcutting, refers to a traditional occupation that tends to destroy vegetation by using power saws for commercial or local uses.

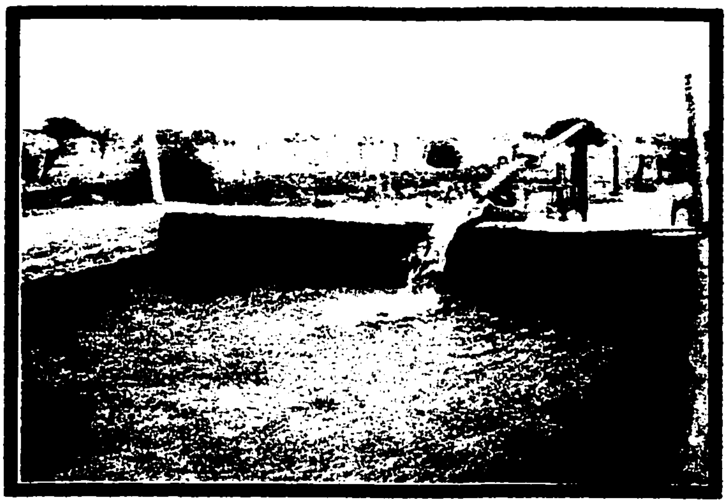

Plate 4-3 Wells as Common Water Sources in the Study Area

There are three purposes for woodcutting activity in the Tabuk area. First, a group of people cut and collect wood to sell as a small business. Plate 4-4 shows a pickup truck waiting to carry wood. Secondly, people may cut trees to use as fuel. Thirdly, people who can not afford to buy electric stoves may cut trees for personal use. The demand for fuel and for more cut wood has increased, especially in the beginning of the winter season.

Plate 4-4. Firewood in the Study Area

According to a specialist working in the Tabuk Agriculture and Water Department (2000), the places throughout Tabuk that have experienced increased woodcutting are where the Bedouins live. Woodcutting activity is more common in areas that are located far from Tabuk City.

The practice of woodcutting has been accelerated in recent years (An Interview with a Specialist, 2000). This trend was investigated by the Tabuk Agricultural and Water Department to protect the natural vegetation of the study area. For this practice to be contained, a governmental decision was declared in 1999, which included stopping woodcutting activities and prohibiting transportation of wood. To support activities that reduce enumerated degradation, the government has encouraged those involved in the wood fuel industry to import wood to Saudi Arabia without additional customs duties for the next five years. This policy may assist in protecting vegetation that would have been used for fuel.

Detailed fieldwork for thirty sites shows that twenty-six sites have experienced an impact from overgrazing and woodcutting. Only four sites show no evidence of this impact but mainly show high NDVI values for 1999 compared to 1988 (Figure 4-19).

- Conservation

The Tabuk Agriculture and Water Department published a report (1998), which contains procedures to be applied for protecting natural vegetation (forest or pastures) used as a source of food and medicine. In this particular report, the Tabuk Agriculture Department was developing different pasture sites (Table 4-3), which were planted with grass seeds to increase the natural vegetation. Also, in order to improve the pastures, several dikes had been built in the Tabuk area for retaining runoff in the winter season and for increasing water availability. The water contributes to germinating grass cover immediately after a rainfall event.

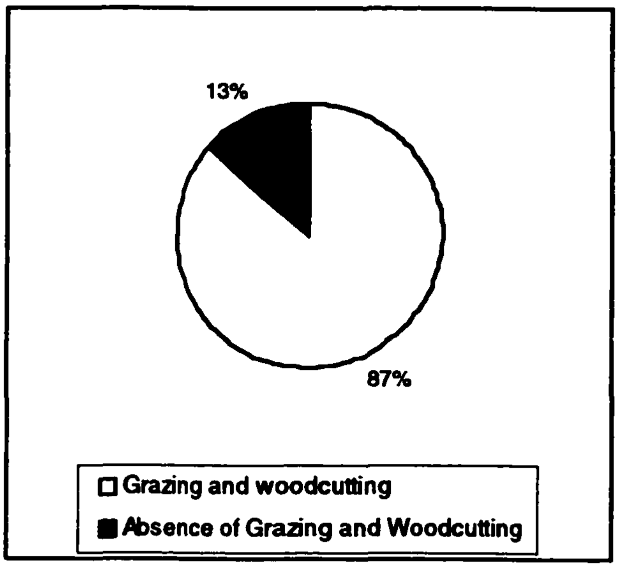

Figure 4-19. Disturbance Types in the Study Area
(Source: Tabuk Teachers College, April 2001)

Agricultural specialist of the Tabuk Agriculture and Water Department (2000) have researched and outlined procedures for protecting and maintaining the natural vegetation in Saudi Arabia. These procedures include: (1) plant grass in deteriorated grazing lands; (2) construct contour dikes for redistributing rainfall; (3) protect deteriorated sites by constructing enclosures; (4) encourage research in the field by growing new pastoral species; and (5) construct signs to halt woodcutting or overgrazing.

Table 4-3. Planting of Pastures with Grass Seed

Location Name	Area in 1/10 of Hectare	Date of work
Al Akhder/ Al Baqqar	2546	1982/1983
Al Akhder/ Al Baqqar	2553	1983/1984
Al Khanbarah/ Al Qalibah	1962	1984/1985
Umm Regabah	1600	1985/1986
Al Kalbah	1500	1988/1989

(Source: Saudi Ministry of Agriculture and Water, 1998. A Comprehensive Report of Tabuk Agriculture and Water)

The enhancement and enrichment of vegetation cover in the Tabuk area can occur if the following suggestions are implemented. The media should be used to advise people of the importance of protecting the vegetation in the Tabuk area. Forest or grassy sites must be reserved for tourism purposes. New species of plants such as *Atriplex*, can be planted for improving the pastoral lands in the Tabuk area. Forage for cattle should be imported and offered at low prices to the Bedouins.

The Tabuk area has been subjected to intensive field surveys to help in identifying different sites that suffer from the overuse of woodcutting and grazing. One of the initial steps to protect the vegetation environment of the Tabuk region is to construct signs prohibiting woodcutting and grazing in particular areas that have deteriorated from human impact (Plate 4-5).

Fieldwork conducted by the author demonstrates that the entire study area has not received proper attention in the task of conserving natural vegetation. Figure 4-20 shows that twenty-five of the thirty sites have no form of protection nor sign of conservation of the vegetation. In four sites dikes have been constructed and only one site has a warning sign for protection.

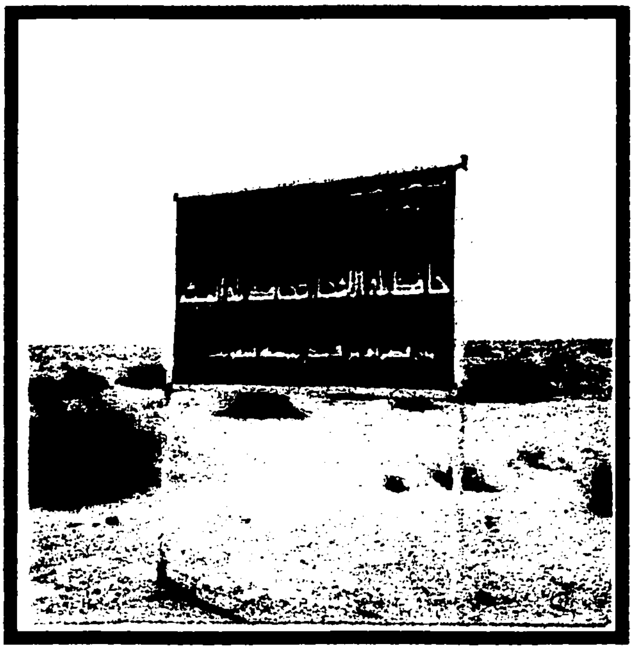

Plate 4-5. Warning Sign for Protecting Vegetation in the Study Area

The Use of Statistical Analysis in Analyzing Remote Sensing and Fieldwork Data

This section is basically focused on presenting some statistical indicators, which are important in showing the differences of spectral reflectance, NDVI values, and field observations through the use of descriptive statistics, T test, and point biserial coefficients.

- Descriptive Statistics

Descriptive statistics helped evaluate the maximum, minimum, range, mean, and the standard deviation for all bands and NDVI values. These statistics can be used to understand the magnitude of each variable in relation to the whole data set.

Table 4-4 presents general statistics characteristics needed to understand the nature of the data set. The two main statistical measurements are the mean and the standard deviation. The mean of all bands and NDVI values for 1988 suggests that the study area has been characterized by bare soil (high band 3) and sparse vegetation (high band 4). The standard deviation shows the values for the data set as near the mean for band 2 and are a little high for bands 3, 4, and 7. The exception is band 5, which shows a high value of 23.5 due to much variability in band 5 for each site. In 1999, the means for each band suggest that the study area has high values for band 3 due to the possible dominance of dry soil and low values for band 4, which indicates a possible slight decrease in band 3 vegetation reflectance. Also band 3-99 has a high standard deviation (21.84) when compared to 1988 data, and high standard deviations in both bands 5 and 7 in 1999. These figures may indicate lower soil moisture and vegetation moisture content.

- Two-Tailed T Test Analysis

Two-Tailed T test was used to examine the differences in NDVI between 1988 and 1999 for all thirty vegetation sites. The analysis of the T test shows that there is a difference between the NDVI-88 and the NDVI-99. The T test value is 3.510 and the critical value at the 0.25 level is 1.699. As the observed value is greater than the critical value, then the null hypothesis of NDVI must be rejected (Table 4-5). On the other hand, the correlation between the NDVI-88 and the NDVI-99 is the low value of 0.15, which means that there is no significant relationship between the two variables.

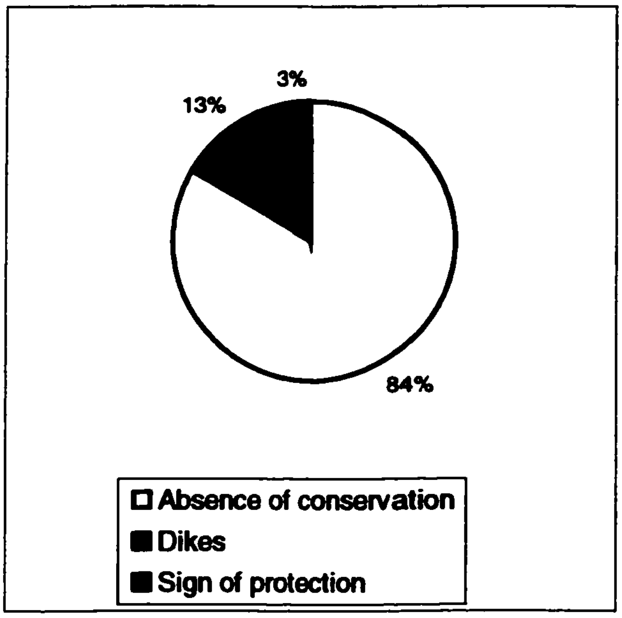

Figure 4-20. The Conservation Types in the Study Area
(Source: Tabuk Teachers College, April 2001)

Table 4-4. The General Statistics Characteristics of Remote Sensing Data

Variable	Maximum	Minimum	Range	Mean	Standard Deviation
Band 2-88	82	51	31	68.9	6.7
Band 3-88	117	65	52	93.9	11.88
Band 4-88	133	94	39	110.8	10.87
Band 5-88	200	93	107	141.9	23.5
Band 7-88	103	39	64	74.5	14.94
NDVI-88	0.3	-0.05	0.35	8.40E-02	7.77E-02
Band 2-99	89	53	36	69.9	9.04
Band 3-99	167	66	101	107.2	21.84
Band 4-99	144	89	55	103.1	10.77
Band 5-99	255	111	144	181.87	38.16
Band 7-99	210	57	153	114.37	32.76
NDVI-99	0.22	-0.93	1.15	-4.11E-02	0.1914

Table 4-5. Result of T Test Analysis on NDVI in the Study Area

Time period	Calculated T Test	Degree of Freedom	Critical Values
NDVI-88-NDVI-99	3.51	29	2.045

The T test assists in showing that there is a difference between the NDVI-88 and the NDVI-99. The results mean that each date has a special vegetation status and that a change has occurred over the last decade. The correlation between two variables can contribute to examining whether both variables are related or not. The correlation between the NDVI-88 and the NDVI-99 shows that there is a weak relationship.

- The Point Biserial Correlation Coefficient

The Point Biserial Correlation Coefficient was also applied to measure the relationship between NDVI and the presence or absence of vegetation cover and disturbance (overgrazing and woodcutting) (Table 4.6).

Table 4-6. Point Biserial Correlation Coefficient

Variable	Vegetation	Disturbance
NDVI	0.52	0.52

Statistical analysis provided indicators which can be used to interpret how differences in vegetation cover are occurring in the study area. The descriptive statistics of the remotely sensed data indicate vegetation differences between 1988 and 1999 primarily by comparing bands 3 and 4 for all selected vegetation sites.

The NDVI values were effectively subjected to T-test analysis and supported other data which asserted that vegetation differences have been occurring in the study area.

Point Biserial Correlation Coefficient was used in examining the correlation between NDVI values and vegetation and disturbance. It helped in determining the magnitude of correlation and understanding how NDVI can be used as an important predictor for vegetation existence.

Results

The analytical methods that were used in this study led to further investigation and aided in finding and observing multiple facets of the vegetation deterioration problem. The major findings and observations are as follows:

Remote Sensing Findings

1. The Landsat Thematic Mapper data (TM) was demonstrated as a useful and reliable data source in multiple applications of the remote sensing field compared with, for example, the Multi Spectral Scanner (MSS), and especially to improve spatial resolution and reduce mixed pixels. Although Landsat (TM) had good applications for several planning, developing, and improving studies designed to inventory the environmental landscape, it had limited application in studying the vegetation of this arid environment.
2. Remote sensing application in the Tabuk area had another limitation in that spectral reflectance of sparsely desert vegetation is greatly affected by soil conditions.

3. In some cases, similarity of spectral reflectance of the soil and dry vegetation samples was one of the main technical problems. This was due to vast areas of dry soil that distort the true vegetation spectral reflectance in the study area.
4. Several important vegetation sites had been identified in the field and considered as possible areas for developing and improving rangeland. Unfortunately, they did not appear on the images due to low spatial resolution.
5. False color composite was the first step in the remote sensing analysis. This technique was utilized to display 1988 and 1999 images of the study area. False color composite images of bands 2, 3, and 4 contributed in identifying differences in vegetation.
6. Spectral analysis assisted in presenting differences among the thirty vegetation sites that represent the majority of the study area. Spectral analysis showed that sparse vegetation occurred in 1988, compared with 1999.
7. Aynonah is one of the major sites that displayed differences in vegetation through analysis of the spectral reflectance of multiple vegetation sites. It presented a unique situation of a mix of natural vegetation and agriculture.
8. Sharmah is the second site and it showed differences in vegetation pattern between 1988 and 1999 due to environmental causes, including the depletion of ground water sources as a result of excessive water use.
9. The significant area surrounding Tabuk City also was considered an important sub-area, because it is used more for grazing. Recently the Tabuk Agriculture and Water Department suggested that this area be one of the main sites for developing rangeland.

10. Normalized Difference Vegetation Index (NDVI) contributed in delimiting multiple vegetation sites in the Tabuk area. The thirty vegetation sites were chosen from within the entire study area to show the three major categories: decrease, increase, or no change of vegetation cover. The NDVI values ranged between –0.05 to 0.30 for 1988 and -0.93 to 0.22 for 1999. The two major values for each year indicated that the range of 1988 showed little vegetation for the multiple vegetation sites, and less or no vegetation for 1999.
11. NDVI, considered a biological indicator, effectively identified areas of vegetation deterioration for multiple vegetation sites.
12. NDVI was not only utilized as a biological indicator but also as a basic map for advanced remotely sensed applications. For example, NDVI can be used in the analysis of a significant area for locating areas of major degradation.
13. Geologic structure is one of the important factors that can help in understanding how NDVI values can be changed due to geologic structure.

Climatic Analysis Findings

14. The climatic records of the study area over twenty years revealed significant fluctuations in the temperature values. These fluctuations were one indicator of arid land climatic characteristics. The summer season in the study area recorded high values of temperature when compared to the winter season. June, July, and August were designated as the summer months, and were characterized by much hotter and drier conditions. July was the peak month of the summer season, which had a

minimum range between 19.6 to 23.8°C. January had the lowest temperatures in the study area over the past twenty years, ranging between 1.1°C to 8.5°C.

15. Rainfall was one of the important factors in analyzing and explaining vegetation variation in the study area. The Tabuk area experiences acute rainfall deficiency, especially for the period that covers May, June, July, August, and September. There was no rainfall during these months due to atmosphere conditions that dominated the study area. The wet season, which extends from October to April, had the highest recorded amount of rainfall. Statistically, January had been observed as having the highest value of rainfall at 36.2 mm. Both June and July recorded 0 mm for the twenty years. An anomaly, August received 20 mm in 1992 and September 1.7 mm in 1994.
16. The 1995-1999 period has been considered as the period of no rainfall in the study area.
17. The Coefficient of Variation indicated the relative variability of annual rainfall is higher for 1975, 1977, 1985, 1989 and 1992, and these years have showed great variability in rainfall for all months.
18. The Correlation of Coefficient was used to examine the correlation of the winter months between the Tabuk station and the Tama station and the results were as follows: The correlation between Tabuk-December and Tayma-December was 0.95; between Tabuk-January and Tayma-January, it was 0.94; and the correlation between Tabuk-February and Tayma-February was 0.82. These numerical results prove that there is a similarity of rainfall in the study area.

Disturbance Analysis Findings

19. Research shows that the entire study area has experienced vegetation deterioration. The combination of rainfall deficiency and human impact (grazing and woodcutting) has increased the deterioration process and led to more vegetation destruction in the study area.
20. The most active season of overgrazing was the period following the rainfall season, when vegetation growth is greatest.
21. There are no specific sites assigned for grazing. However, sites where grass or shrubs are growing will be more susceptible to intensive grazing.
22. Intensive woodcutting work in the study area has caused decision-makers in the Tabuk Agriculture and Water Department to adopt a strong administrative policy to discourage people from woodcutting in the area.
23. Fieldwork indicates that grazing and woodcutting affected twenty-six vegetation sites and four sites show no effects of grazing and woodcutting.
24. Burning, as an indicator of vegetation destruction, has had a negative effect on vegetation in the study area. Although some trees have been burned in the area, this impact has had only a slight effect overall on vegetation cover and no effect on the thirty vegetation sites.
25. Conservation activity in the study area received little direction and little attention in this time period. Fieldwork showed that on the majority of vegetation sites there were no conservation activities, and only four sites showed any evidence of past conservation activities. There, dikes had been established to retain runoff for increasing soil moisture, thus allowing vegetation to thrive on additional moisture for

a more extended period of time. Also, on one site a warning sign designed to protect the vegetation was placed.

Statistical Analysis Findings

26. Statistical analysis showed several findings. The descriptive statistics of the remote sensing data have contributed in showing spectral NDVI values as indicators of vegetation status, since band 3 is low and band 4 is high for 1988 and vice versa for 1999.
27. The other indicator was the TwoTailed T test, which was applied between NDVI-88 and NDVI-99. It showed that there was a difference between the two periods at a significant level (0.025).
28. The Point Biserial Coefficient was applied to examine the relationship between the NDVI and the presence or absence of the two following factors: vegetation and disturbance (grazing and woodcutting). This analysis showed the following relationships to NDVI: 0.54 for vegetation cover, which was more significant, and 0.54 for disturbance (grazing and woodcutting).

Chapter 5

CONCLUSIONS

Summary

The Tabuk area has the unique spatial location of being at the north gate of Saudi Arabia. Several geographic factors have played a major role in forming the environmental ensemble of the Tabuk area. By using multiple geographic techniques in describing, analyzing, and interpreting the data, this study significantly reveals that deterioration of vegetation has been occurring there. This vegetation deterioration has been caused by several processes; each process has received considerable attention in this research.

This study clearly demonstrates that vegetation deterioration is one of the main desertification indicators in arid environments. A combined methodology, consisting of remote sensing methods, climatic analysis, disturbance analysis, fieldwork, and statistical analysis was adopted for this study.

Vegetation in the study area was inventoried and analyzed using remotely sensed analyses with spectral reflectance and Normalized Difference Vegetation Index (NDVI) techniques. Remote sensing application was done for thirty vegetation sites that show differences in vegetation from 1988 to 1999.

Spectral reflectance analysis initially was an important step in presenting multiple facets of vegetation variation specifically using data acquired from the main bands 3 and 4. Overall, the averages of bands for the thirty vegetation samples indicate that an environmental change has been occurring and this change impacting the majority of vegetation sites.

NDVI, as a biological indicator, numerically demonstrates the possibility of obtaining values that can be used to classify images into three main categories: increase, decrease, and no change. Generally, NDVI showed twenty-six sites had deteriorated, and only four sites had been improved somewhat environmentally.

Rainfall variability was the main vegetal impacting factor in the study area. Two statistical techniques were used to measure its variability and similarity. Coefficient of Variance was applied and showed a range between 0 to 400, which indicates high differences among the data values. Correlation Coefficient was used to examine the similarity of rainfall, using rainfall data from two main climatic stations, Tabuk and Tamah. The winter rainfall data (the only data available) were used, and the analysis shows high correlation: 0.95 for December between the two stations, 0.94 for January, and 0.82 for February.

Disturbance analysis theoretically assisted in determining how overgrazing and woodcutting in the study area could cause deterioration of vegetation and empirically helped in identifying how many sites had been impacted. Grazing has been considered the main occupation that provides a moderate income for the local people. It was noted that overgrazing occurred after the rainfall season when increasingly more edible species of grass were available for the livestock. Woodcutting was a destructive activity causing vegetation deterioration, especially the shrub types that can prevent the accelerating processes of wind and water erosion.

The Tabuk area overall has not received much attention from the public sector in the field of conservation. Multiple rangeland sites have never been subjected to conservation work there.

Statistical analysis demonstrated that a difference exists between 1988 and 1999 in NDVI, and this was supported by using the Two Tailed Test. Also, the Point Biserial Correlation Coefficient was valuable in examining the relationship between the NDVI values of the thirty vegetation sites associated with nominal data of the presence or absence of vegetation cover and disturbance (overgrazing and woodcutting).

Recommendations

In order to protect and develop vegetation in the study area, some recommendations should be adopted theoretically and applied empirically. They are:

- Establish climatic stations over the entire study area to provide more detailed climatic data.
- Prohibit woodcutting, the predominant human impact, currently influencing and accelerating degradation processes such as water erosion.
- Conserve what exists and enhance the vegetal cover at sites. Several vegetation sites should receive special attention, especially in the field of improving and developing conservation efforts to re-grow the vegetation cover.
- Educate the public in the value of conservation efforts. The Tabuk Agriculture and Water Department should institute and finance an educational week, including

programs about the environmental role of vegetation and how physical and human deterioration processes remove vegetation cover and cause environmental destruction in the entire region.

- Monitor environmental change monthly using remote sensing techniques and supported with intensive fieldwork. The focus should be on evaluating the degradation processes, their indicators and consequences in the entire study area, and selecting solution to mitigate the site problem.
- Create an environmental database using remote sensing and geographic information systems (GIS). The database should consider and evaluate all environmental factors which affect the biosystem of the study area. This database would be useful in manipulating and analyzing several problems, including knowledge of the variations of vegetation, soil, and microclimates there.
- Establish a water conservation and collection agency or department. The Tabuk Agriculture and Water Department has worked seriously on improving some vegetation sites by establishing a sub-department, which studies where to build dikes to help the environment. This procedure has helped to develop many grazing sites. This work should be expanded as it contributes to collecting runoff that might be lost through evaporation and infiltration.
- Research in great detail the delicate components of the biophysical environment. National and international researchers should be encouraged to study the multiple facets of Tabuk's environment. Several topics that can be the main titles for advanced projects in cooperation with national and international research centers are climatic change, desertification, and agricultural and urban development.

- Fund an inter-agency and inter-governmental environmental protection and enhancement center. There is a need to establish a professional environmental center, which can be coordinated with governmental sectors and different universities in Saudi Arabia to solve the various environmental problems.

Future Research

Several environmental topics deserve more investigation and advanced research in the study area. These topics are as follows:

- Monitor agricultural change in the Tabuk area of Saudi Arabia using TM data.
- Map all critical aspects that impact desertification and urban sprawl in the region surrounding Tabuk City, Saudi Arabia using Landsat TM data.
- Study desertification processes in the Central Tabuk area of Saudi Arabia employing Landsat TM data and Geographic Information Systems.
- Use Landsat TM data in monitoring drought conditions in the Tabuk area of Saudi Arabia.
- Employ topographic maps and Landsat TM data to create three dimensional images of Tabuk City, Saudi Arabia.
- Analyze wind erosion activity and wind speed in the Tabuk area of Saudi Arabia.
- Evaluate the impact of conservation processes on developing Wadi El-Fajer in the Tabuk area of Saudi Arabia.
- Develop an environmental assessment inventory of the natural vegetation in Wadi Al-Baqqar in the Tabuk area of Saudi Arabia.

- Apply Geographic Information Systems and Global Positioning Systems in classifying vegetation species and their characteristics in the Tabuk area of Saudi Arabia.
- Utilize Global Positioning Systems and Geographic Information Systems in classifying vegetation species and their characteristics in the Tabuk area of Saudi Arabia.
- Research a cost-benefit ratio of grazing and an environmental evaluation of grazing behavior in the Tabuk area.
- Provide local governmental agencies and regional university scholars funds for an environmental assessment of woodcutting activities in Tabuk area (including its monetary return to local economies).

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APPENDICES

A: Letter and Interview Questions

Dear Sir

The purpose of this survey is to collect fieldwork data that will be used specially for research purposes. One of the most important sources of my research data relating to my dissertation topic involves measuring vegetation deterioration in the Tabuk area. With your help, I hope to answer several questions pertaining to this issue. I am asking you to help me in answering these questions that will fit my research needs and will contribute in reaching good results. These questions are included.

Sincerely

Khalid M Alharbi

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Geography, Geology and Anthropology Dept
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Interview Questions

1- Has vegetation quantity and quality deteriorated between April 1988 and April 1999. In your opinion, what do you think are the primary causes of this deterioration?

2- Has the Tabuk area experienced overgrazing?

3- If there is overgrazing in Tabuk area, in which sites is this phenomenon predominately located?

4- Is the Tabuk area experiencing extensive woodcutting?

5- If there is extensive woodcutting in Tabuk area, which sites have woodcutting problem?

6- Do you think the woodcutting has contributed in the deterioration of vegetation cover in Tabuk area? Why?

7- What plans do you have in combating desertification in Tabuk area?

8- What is the optimal environmental program for vegetation cover development in Tabuk area

B: Climatic Data

1. Maximum Temperature 1975-1994

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1975	17.8	20.1	24.5	29.4	33.9	37.6	39.3	38.3	38.1	31.7	26.1	19.2
1976	16.2	19.6	23.8	29.9	33.5	37.7	37.6	37.3	36.1	32.9	25.4	23
1977	17.6	24.8	25.8	28.6	33.1	38.4	39.2	41.4	37.5	33.5	24.9	18.9
1978	19.1	22.6	25.1	32	36.9	37.3	40.2	38.1	36.5	32.9	22.1	21.3
1979	21	25.8	28.2	35.7	36.2	39.2	40.4	40.4	40.1	32.3	27.4	18.2
1980	19.7	20.3	28.4	32.8	38.1	41.2	42.1	41.6	39.8	35.2	28.1	21.9
1981	18.6	20.9	27.4	32.1	36.3	40.9	42	41.6	40.5	36	24.9	24
1982	20.7	18.8	23	32.6	34	38.9	40.1	40.3	39.7	32.8	22.1	18.1
1983	15.1	19.5	23.9	29.9	34.9	37.4	40.4	39.8	37.7	32.8	28.9	21.2
1984	19.6	24.6	27.8	31.9	36.2	38.3	38.8	38.2	38	32.4	32.1	18.3
1985	22.6	21.8	27.4	31.4	35.2	39.2	37.8	40.5	36.7	29.6	25.6	18.4
1986	18.4	21.8	24.7	29.4	30.7	36.1	39	39	37.9	32	21.8	17.7
1987	20.1	23.7	23.4	29.3	34.6	38.2	39.4	39.3	37.5	31.1	26.3	20.1
1988	18.2	20.7	25.8	30.8	36	36.8	39.1	37.5	36.8	30	23.4	19.4
1989	28.5	17.5	35.2	33.9	36.3	37.8	39.8	38.7	37.4	31.2	34.3	19.3
1990	16.8	18.3	23.4	30.1	34.1	37.7	38.2	38.2	36.4	33.1	27.8	24.1
1991	16.1	20.7	24.9	32.3	34.6	38.1	38.2	37.4	36.6	31.4	26.7	17.1
1992	14.3	16.1	21.9	28.8	33.1	36.7	37.9	38.1	36.4	33.1	24.3	17.6
1993	16.3	18.6	23.7	30.2	33.2	37.8	38.4	38.9	37.1	31.5	25.5	22.2
1994	19.5	20.2	24	31.2	34.7	37.3	36.3	38.2	35.9	32.5	22.8	17.6

2. Minimum Temperature 1975-1994

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1975	2.3	5.4	8.4	14.4	16.8	20.6	22.2	21.7	20.5	14.3	9.5	5.6
1976	2.1	6.9	7.2	11.2	15.5	18.2	19.6	18.6	17.3	14.3	7.3	5.5
1977	3.3	6.9	7.5	10.3	15	19.9	21	21.9	18.3	13.1	5.1	2.8
1978	1.6	4.1	6.3	11.8	16.1	17.7	21.6	18.9	15.9	12.6	4.3	3.5
1979	3	6.1	8.7	15.5	16.8	18.9	19.7	20.5	19.9	12.7	9.9	3.7
1980	3.1	3.8	10.5	13.1	17.8	22	22.9	22.5	19.7	15.5	11	6.3
1981	2.6	4.7	9	13.7	17	21.1	23.8	23.5	20.9	15.9	6.1	4.5
1982	4.7	4.8	6	14.7	17.2	20.1	22.1	22.6	19.9	14.8	6.8	2.9
1983	2.5	3.6	6.3	11.5	16.6	18.7	21.6	21.1	18.8	12.2	9.7	6.1
1984	3.3	5.5	10.7	12.6	15.5	18.3	19.9	18.9	18.3	14.3	8.3	4
1985	6.5	4.3	9.1	13.9	16.9	19.1	20.2	22.5	17.6	12.6	11.4	5.6
1986	4.1	6.3	9.4	14.4	14.4	18.8	21.4	21	20.1	14.8	6.8	2.9
1987	2.2	6.3	7.2	10.4	15.8	19.2	21.6	22.1	18.1	15.1	8	6.4
1988	3.6	4.6	8.4	12.3	16.8	18.9	22.3	20.4	17.7	13.7	7.4	6.6
1989	8.5	2.6	16	14.7	18.1	18.6	21.2	20.5	18.4	21.1	9.3	3.4
1990	3.6	4.7	7.9	14.1	17.1	21.2	22.7	22.2	19.8	17.1	11.9	8.6
1991	4.7	6.6	11.2	16.5	18.5	21.6	22.8	22.3	20.6	16.5	10.9	3.4
1992	1.1	2.9	7.3	12.9	17.3	20.7	22.1	22.8	20	16	10.2	3.7
1993	2.7	3.9	8.5	13.6	18.4	21.4	22.6	22.6	20.3	17.1	10.8	8.3
1994	7.2	5.1	8.9	15.7	18.3	21	21.8	22.7	21.1	18.3	10.4	3.4

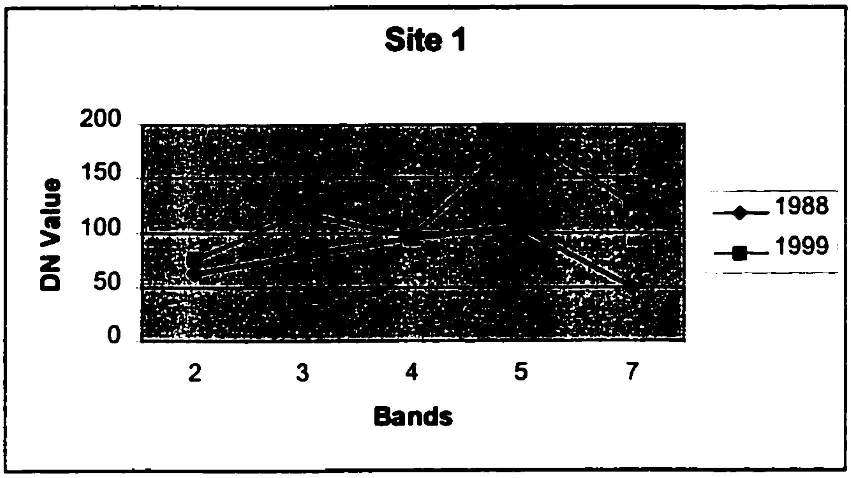
3. Rainfall (mm) 1975-1994

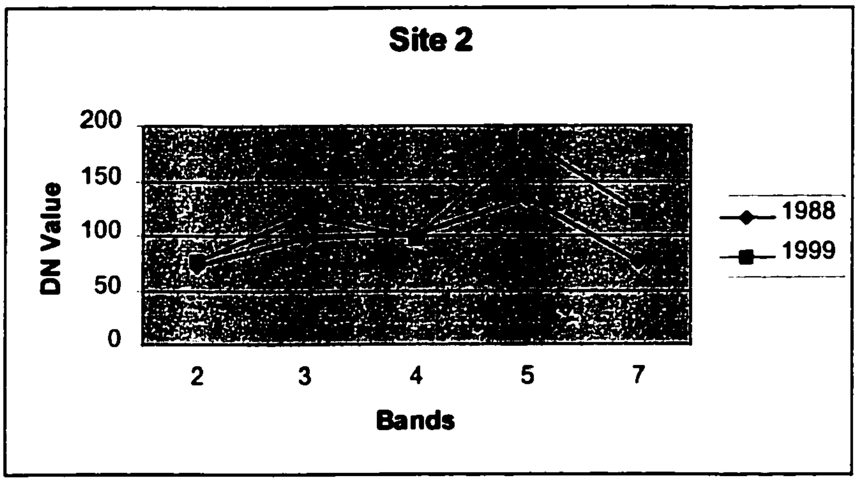
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1975	0.5	41.1	0	6.3	0	0	0	0	0	0	0	2.7	50.6
1976	1.6	0	0	0	0.2	0	0	0	0	0	1	0	2.8
1977	36	0	3	1	0	0	0	0	0	0	0	0	40
1978	0	0	0	0	0	0	0	0	0	0	0	0	0
1979	0	16.4	0	7.6	0	0	0	0	0	10.6	0.4	0.6	35.6
1980	0	7.4	0	0	0	0	0	0	0	0	3.6	8	19
1981	0	0	7.8	6.6	0	0	0	0	0	9.4	0	0	23.8
1982	0.6	1	0	13	6	0	0	0	0	2	8	0	30.6
1983	0	0	6	0	0	0	0	0	0	0	0	1	7
1984	0	0	1.6	0	0	0	0	0	0	2.4	2.6	0	6.6
1985	0	0	0	9	0.8	0	0	0	0	0	2	56	67.8
1986	1.4	0	13.6	5.6	0	0	0	0	0	0.6	3.8	0	25
1987	0	0	0	0	0	0	0	0	0	20	0	12.4	32.4
1988	7.4	0.4	1.6	8.4	1	0	0	0	0	19.2	0	2	40
1989	0	0	4	1	0	0	0	0	0	0	12	0	17
1990	0.5	0	0	0.4	0	0	0	0	0	0.9	0	1.9	3.7
1991	36.2	0.2	24.2	0	0	0	0	0	0	6	0	1.1	67.7
1992	2	1.4	0	0	0	0	0	20	0	0	2.4	0.7	26.5
1993	1.1	1.1	0	4.5	0.3	0	0	0	0	8.9	0	17.7	33.6
1994	5	0.6	0	0	1.3	0	0	0	1.7	24.4	13.3	0.2	46.5
Total	92.3	69.6	61.8	63.4	9.6	0	0	20	1.7	104.4	49.1	104.3	

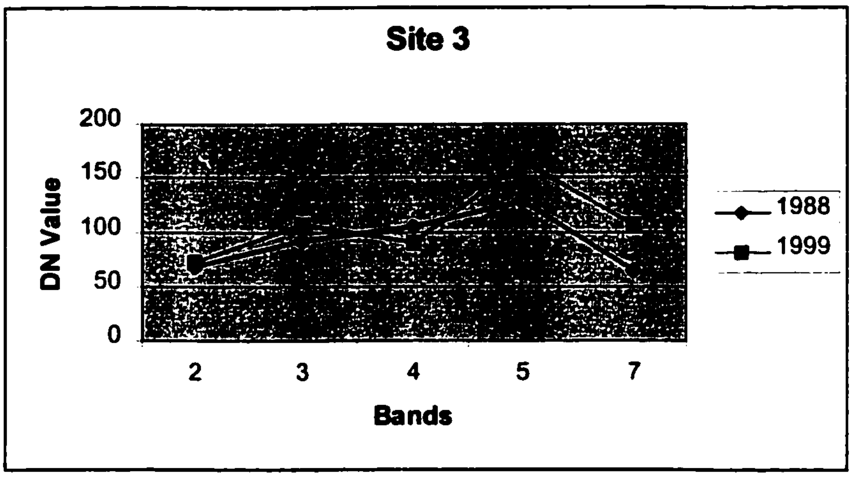
4. Evaporation (mm) 1976-1984

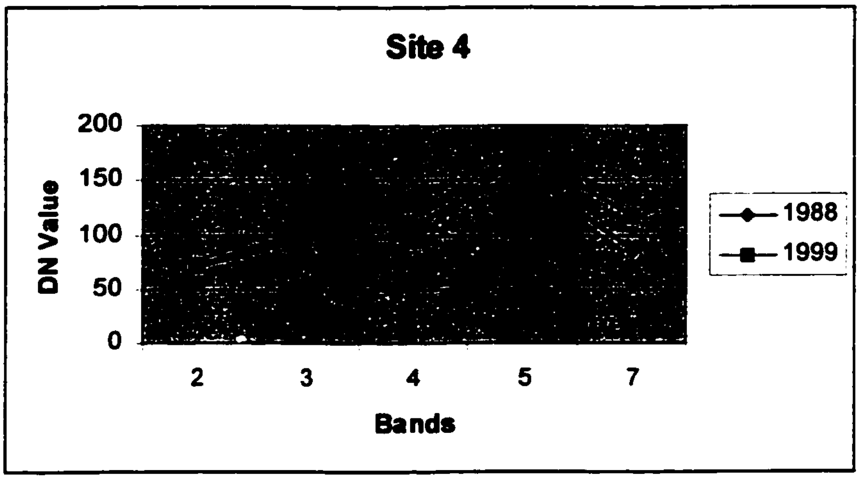
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1976	5	9.9	11	12.7	14.8	13.1	11	9.2	9	5.8	5	5
1977	4	5.7	7.7	12	11.3	12.6	10.9	14	14	9.4	6	6
1978	5	6.1	8.4	10.6	12	13.1	14.3	13	12	8.1	7	6
1979	6	6.7	6.6	9.7	9.5	11.7	12.7	13	12	7.3	6	5
1980	4	4.5	7.8	10.4	11.5	12.4	12.5	11	9.7	9.7	5	4
1981	4	4.7	6.2	8.5	9.7	9.8	9.4	8.9	7.7	6.4	5	4
1982	3	5.1	6.4	8.5	10.1	11.1	13.6	8.9	6.4	5	4	3
1983	3	4.5	6.1	9.3	9.7	10.6	9.8	8.7	7	5.9	4	4
1984	4	5.7	6.3	8.5	8.1	9.1	8.3	8.9	7	5.2	4	3

C: Remotely Sensed Data for the Thirty vegetation Sites





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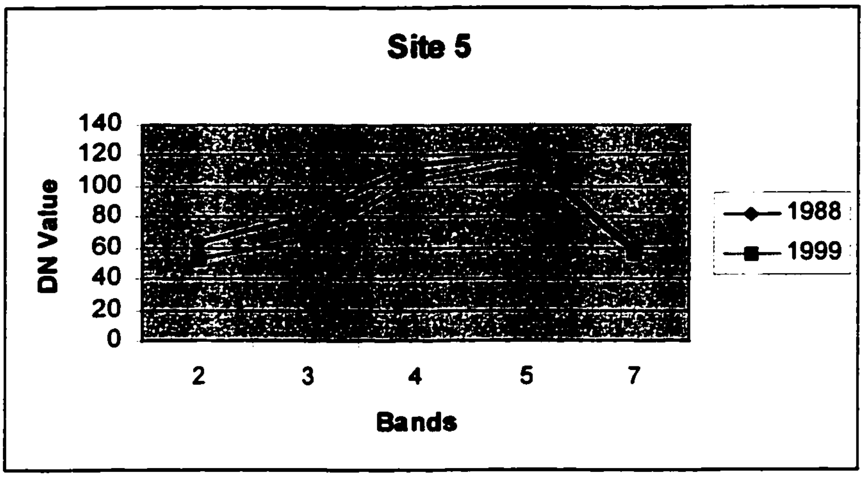
1999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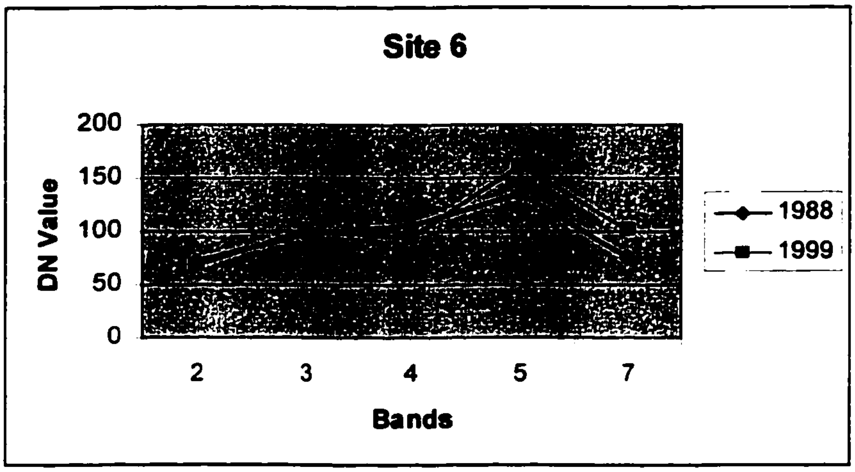
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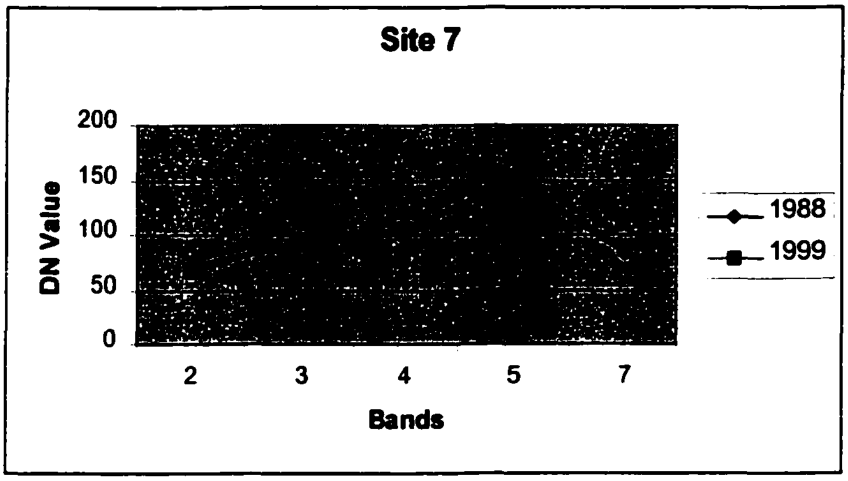
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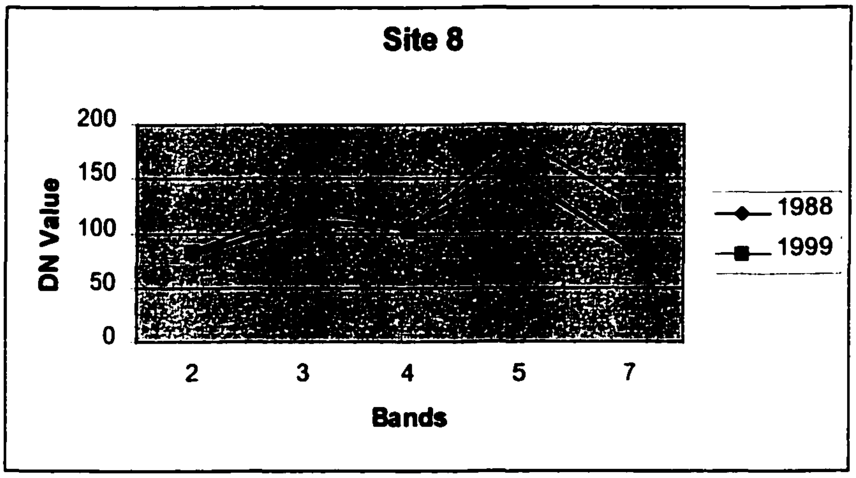
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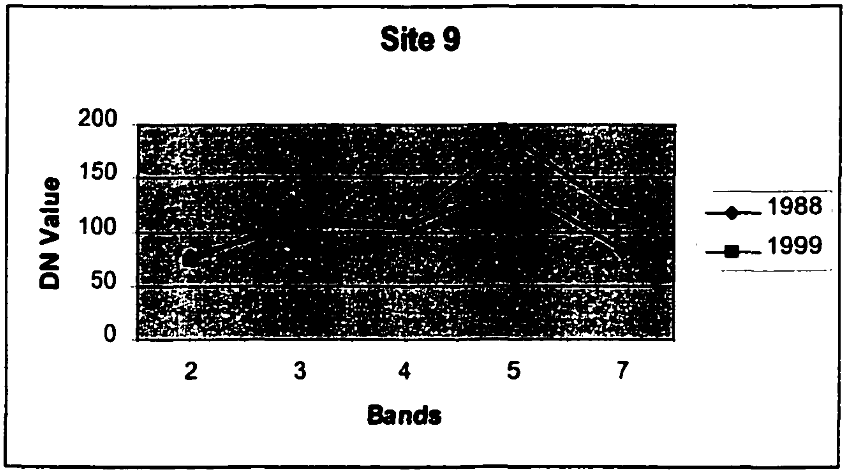
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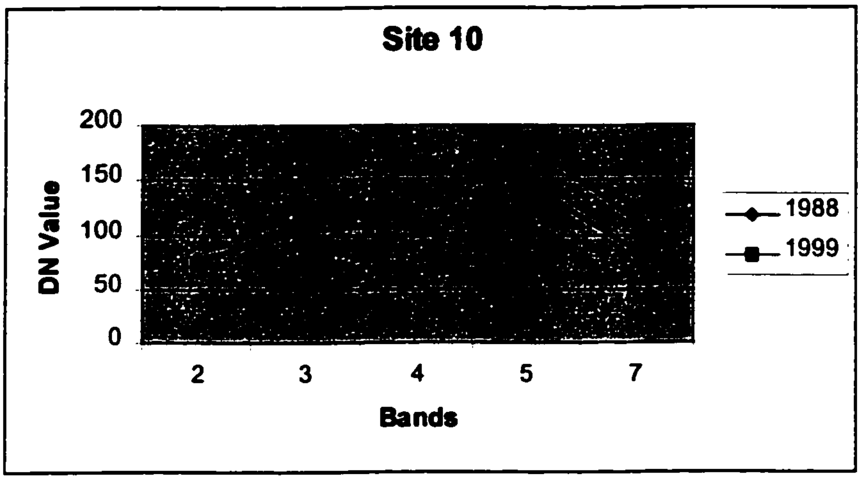
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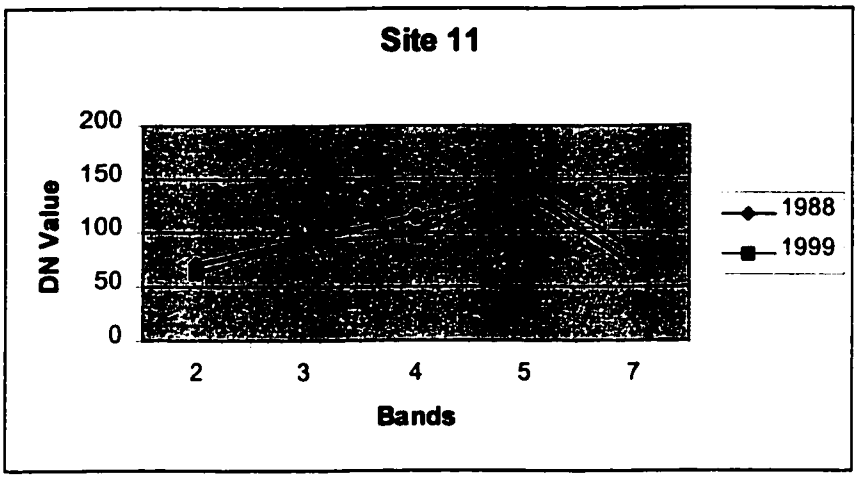
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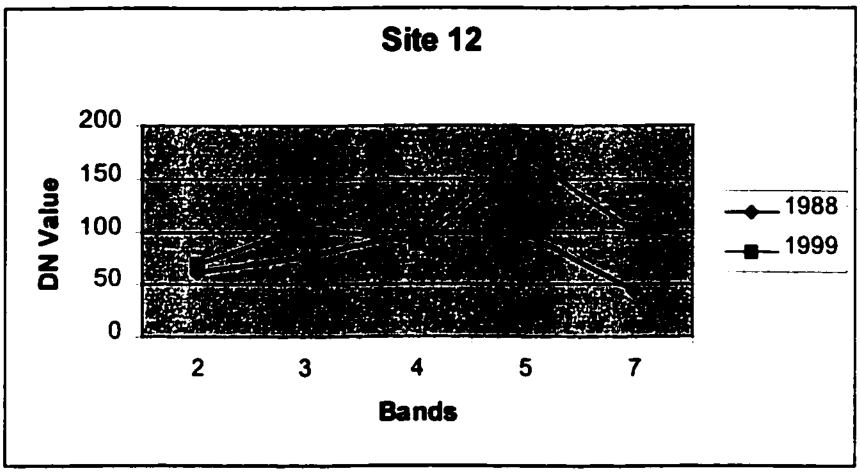
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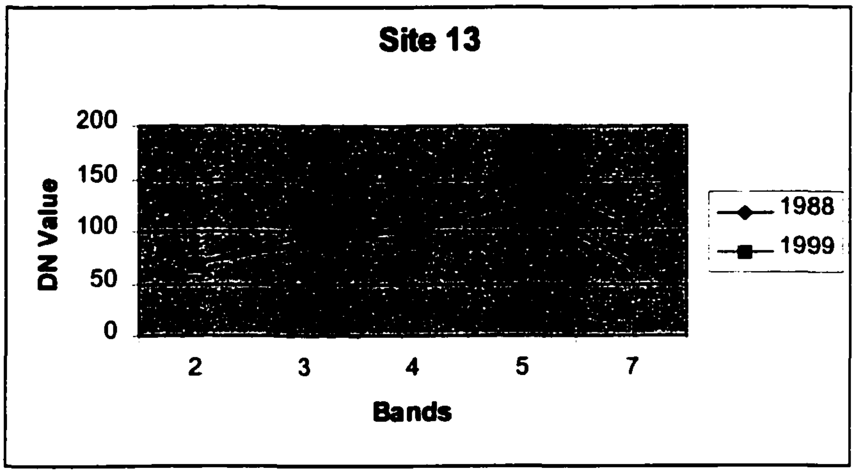
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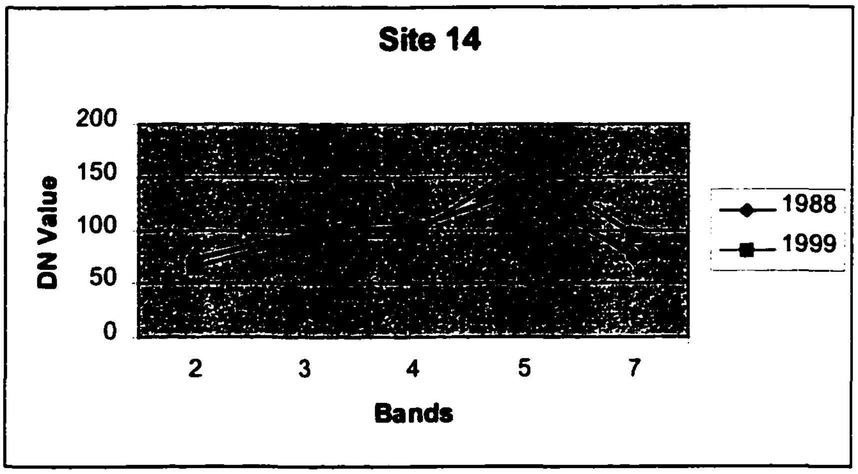
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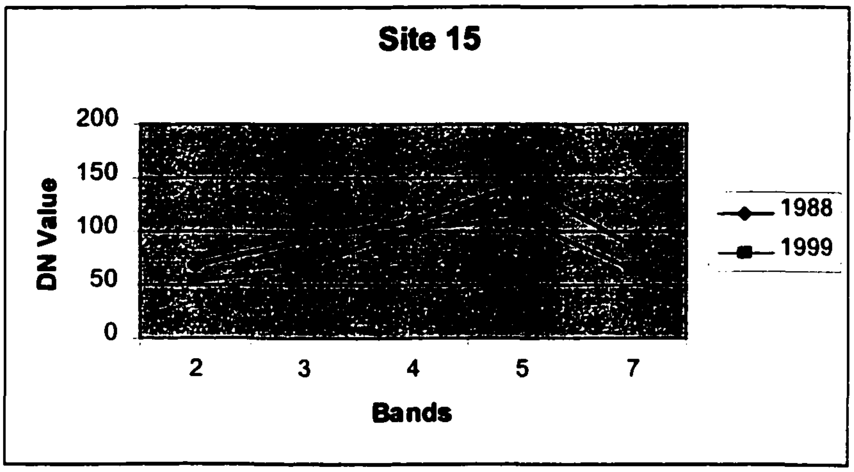
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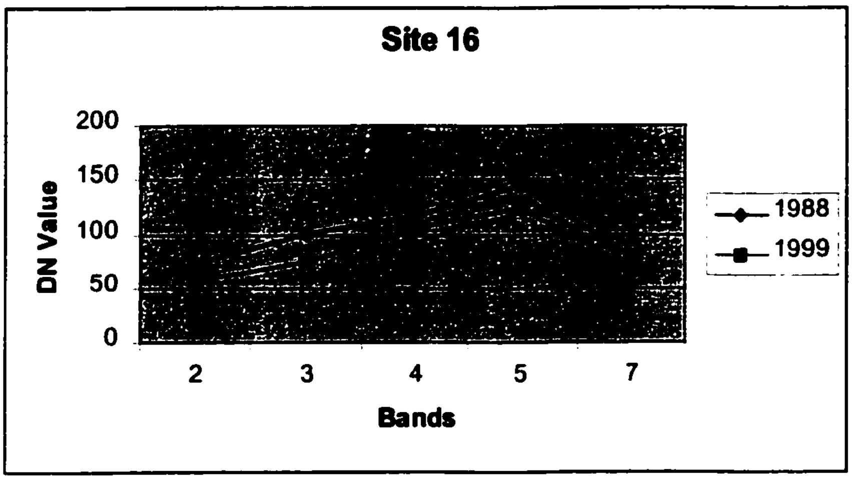
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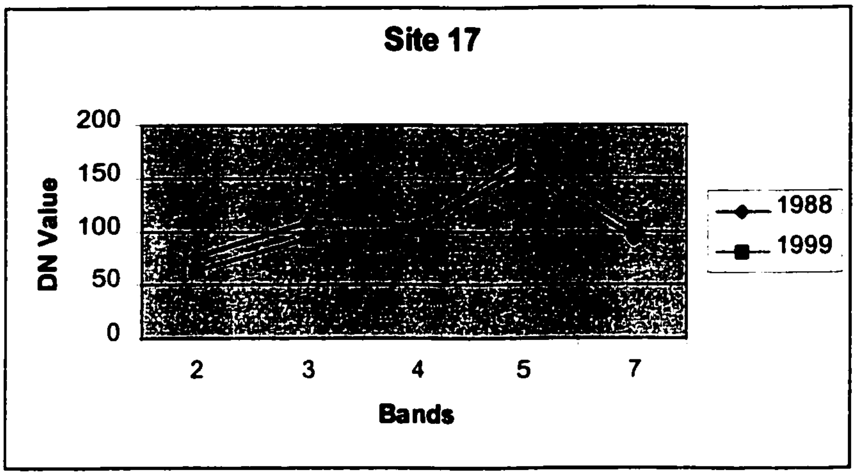
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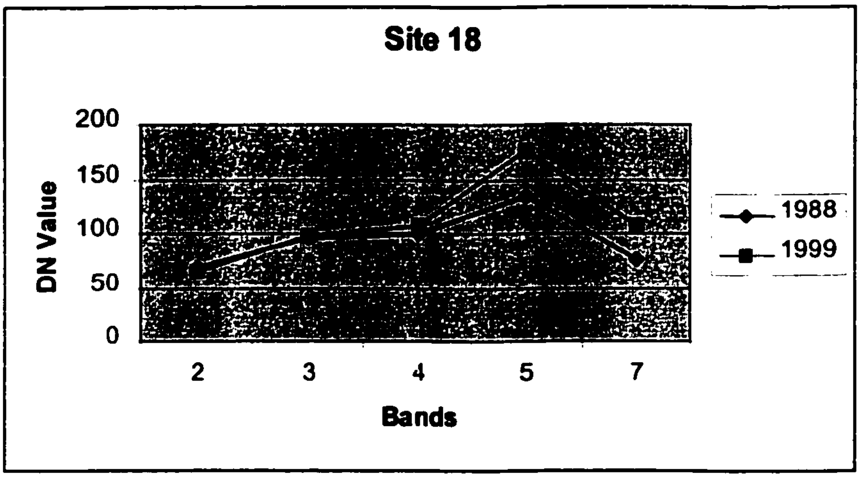
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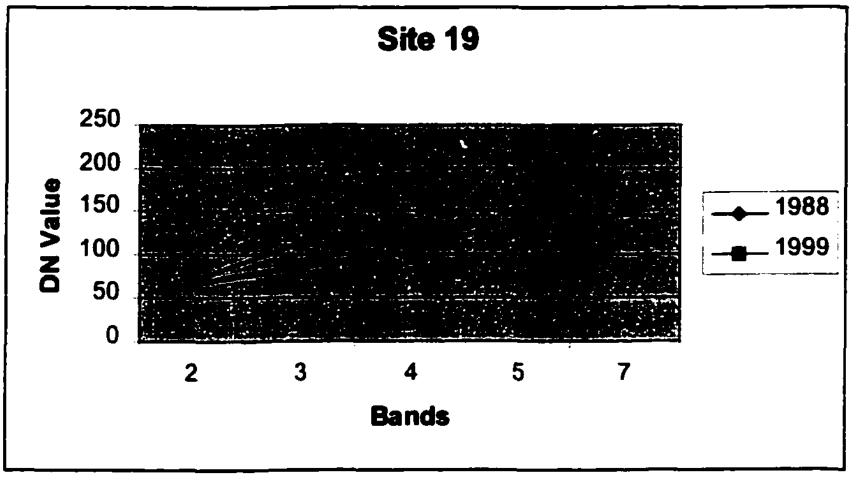
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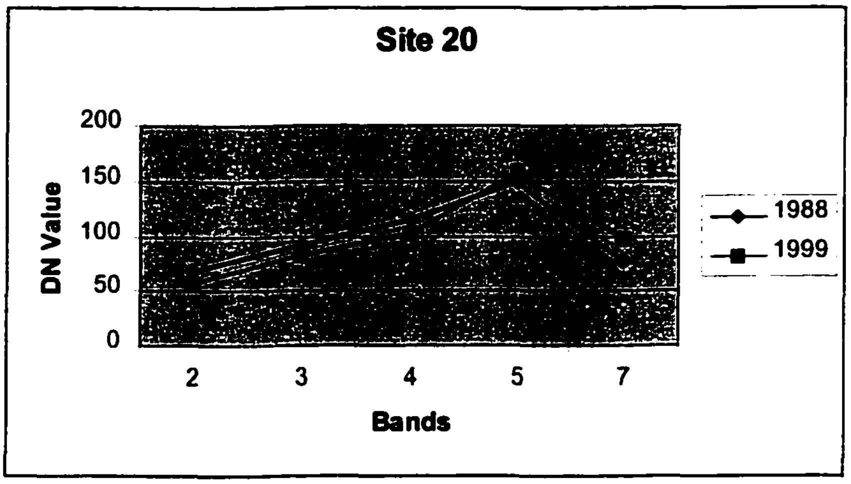
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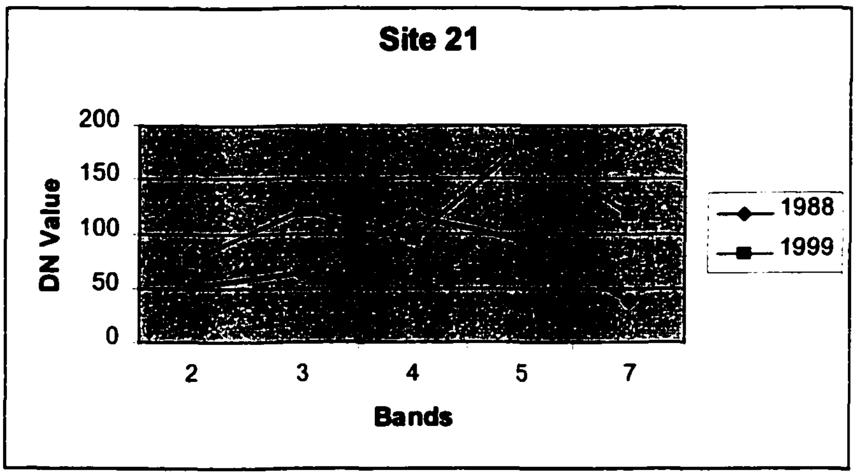
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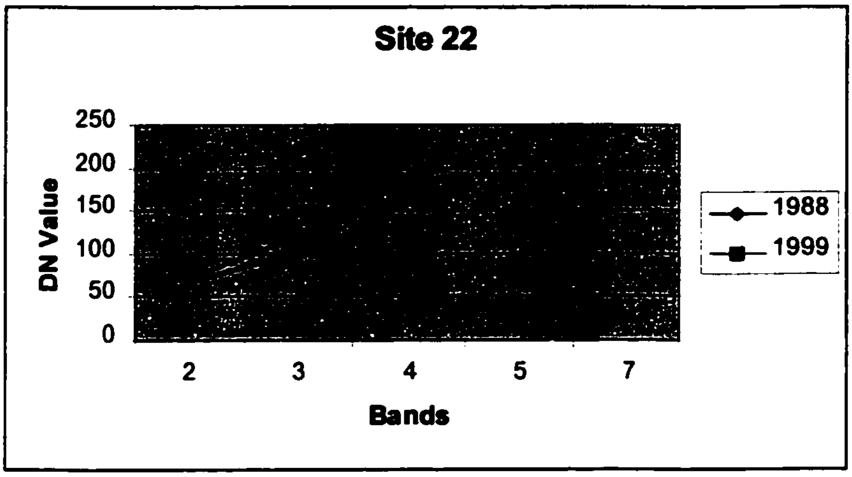
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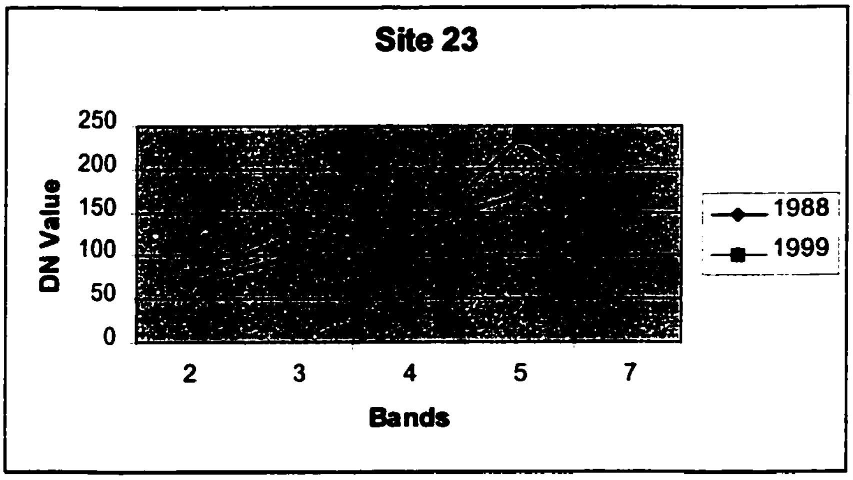
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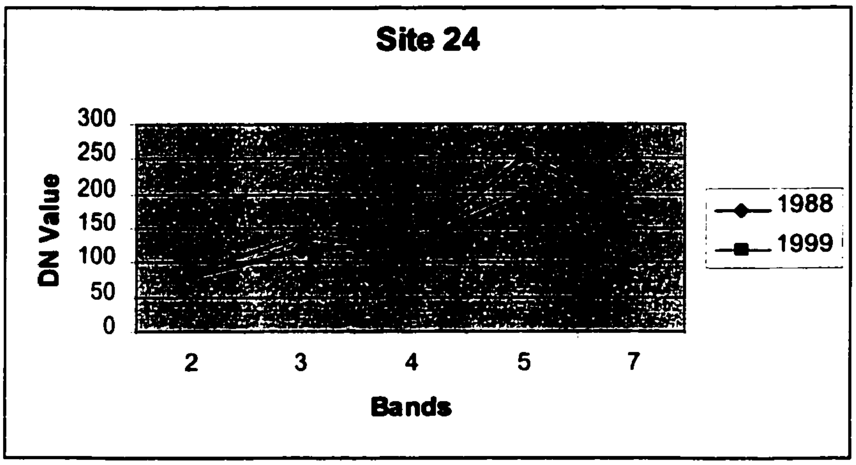
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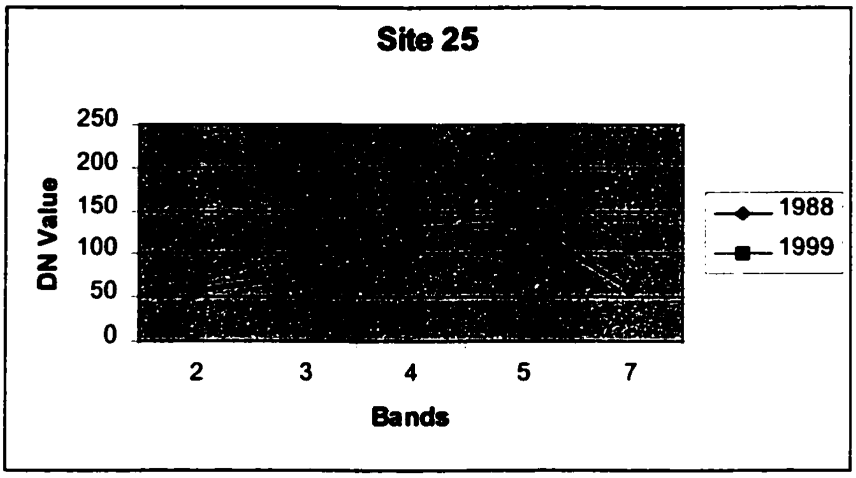
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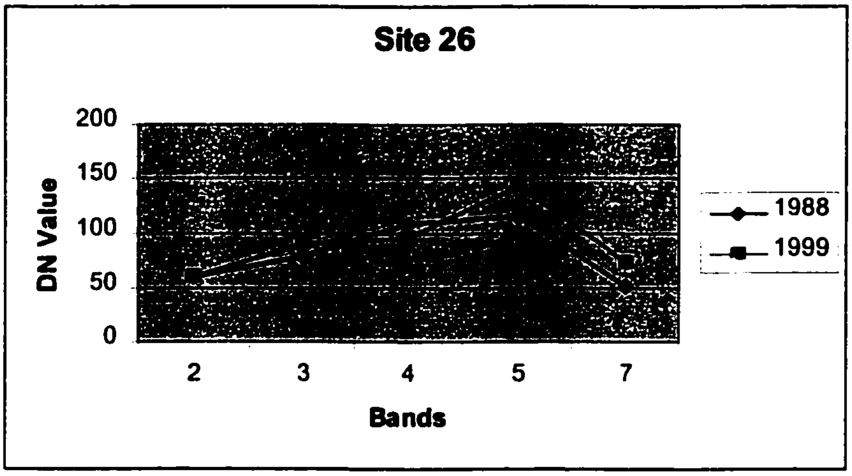
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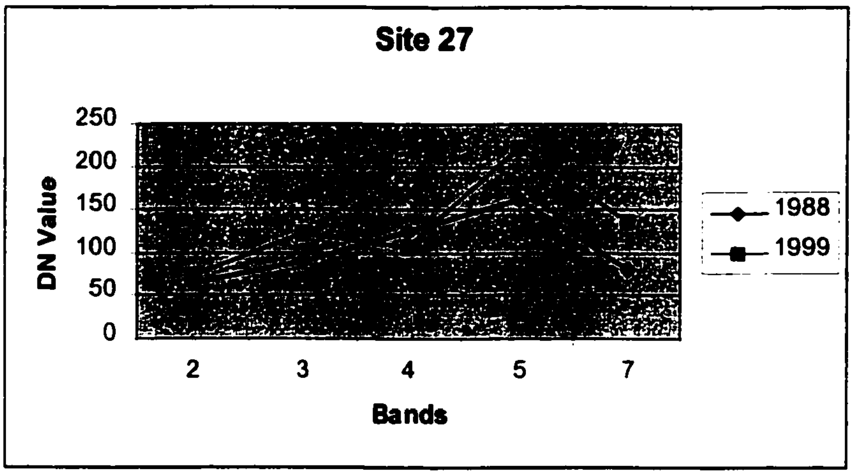
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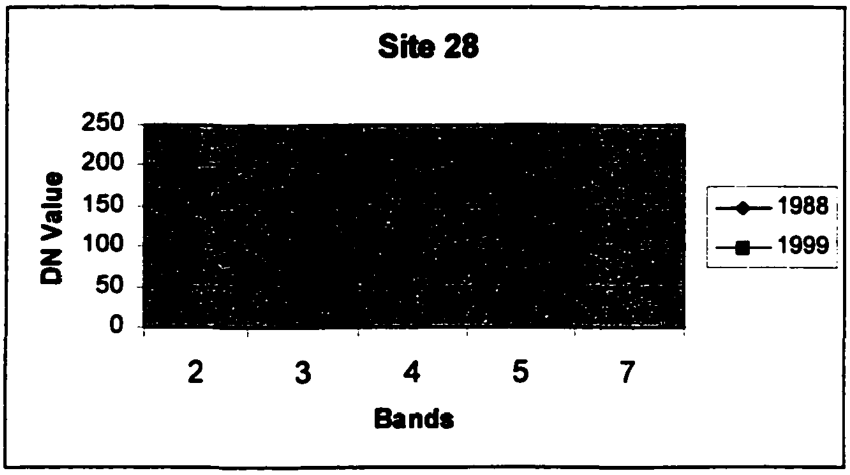
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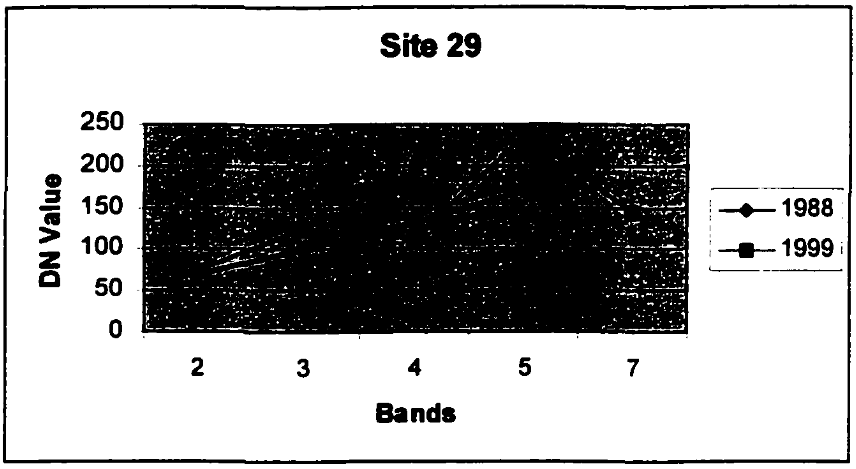
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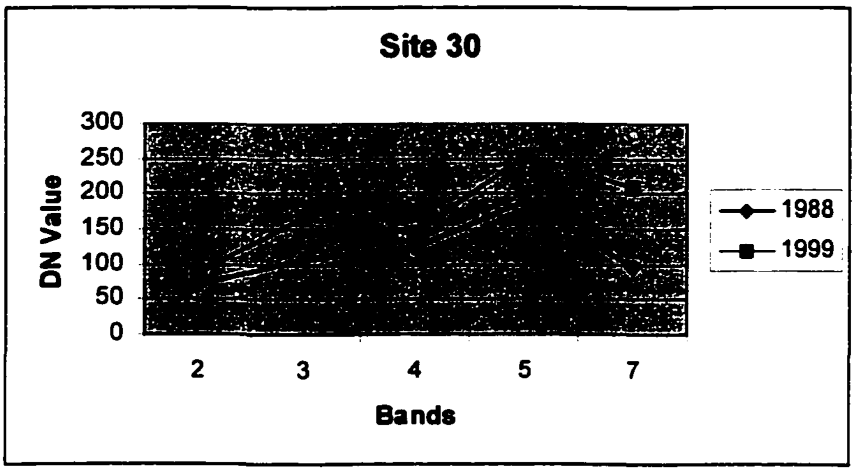
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Bands
1988
1999

D. Point Biserial Correlation Coefficient Output between NDVI and Presence/Absence Vegetation, and Disturbance

Site	NDVI-99	Vegetation	Disturbance
1	-0.14	0	0
2	-0.93	0	0
3	-0.09	1	1
4	-0.05	1	1
5	0.22	1	1
6	-0.04	1	1
7	0.06	1	1
8	-0.09	1	1
9	-0.01	1	1
10	-0.04	1	1
11	0.05	1	1
12	-0.08	1	1
13	-0.04	1	1
14	0.01	1	1
15	0.21	1	1
16	0.18	1	1
17	0.04	1	1
18	0.04	1	1
19	-0.07	1	1
20	0.11	1	1
21	-0.12	0	0
22	-0.06	1	1
23	-0.06	1	1
24	-0.07	0	0
25	0.0	1	1
26	0.03	1	1
27	-0.07	1	1
28	-0.11	0	0
29	-0.06	1	1
30	-0.07	1	1

Formula Computation:

- The Correlation Between NDVI and Vegetation

$$^{s}y = \sqrt{\frac{30\,(0.98) - (-1.96)^{2}}{30\,(30-1)}}$$

$$^{s}y = \sqrt{\frac{29.4 - 3.84}{870}}$$

$$^{s}y = \sqrt{0.029} = 0.17$$