Causes and Impact of Desertification in the Butana Area of Sudan

by

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Declaration

I declare that this thesis herby submitted for the Doctor of Philosophy degree at the University of the Free State is my own independent work and has not previously been submitted by me at another university / faculty. I further more cede copyright of the thesis in favour of the University of the Free State

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Abstract

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Desertification is one of the most serious environmental and socio-economic problems of our time. Desertification describes circumstances of land degradation in arid, semi-arid and dry sub-humid regions resulting from the climate variation and human activities. The fundamental goal of this thesis was to monitor the extend and severity of the land degradation and examine climate variability and change in the Butana area of north-eastern Sudan.

To explore the climate variability and climate change in terms of rainfall, temperature and the aridity index for the period from 1941 to 2004, the monthly and annual time series for four weather stations (El Gadaref, Halfa, Wad Medani and Shambat) across the Butana area were analysed. The trend of the rainfall at Wad Medani and Shambat shows significant decline, while that of Halfa and El Gadaref does not show a significant decrease or increase. The Cumulative Rainfall Departure (CRD) was used to detect the periods of abrupt changes in the rainfall series. A significant decrease in the annual rainfall was observed at Shambat ($p = 0.00135$) and Wad Medani ($p = 0.0005$) from 1968 to 1987, there after the rainfall amount is close to the long-term mean. In El Gadaref there was a decline in the annual rainfall from 1971 to 1974 ($p = 0.35$) but it was not significant, with a recovery from 1975 to 1982 to a value higher than the long-term mean, followed by another downward turn from 1983 to 1994. In Halfa there was a significant decrease ($p = 0.0304$) from 1982 to 1993. The trends of maximum and minimum temperature were examined for the summer (March-May), autumn (June-October) and winter (November-February) seasons for the four weather stations. At Halfa and Shambat the trend of maximum and minimum summer and winter temperature was increasing but

not significant, while in Wad Medani there was a significant increase for summer and winter minimum temperatures. El Gadaref station showed a significant increase in maximum and minimum temperature (p = 0.00005, p = 0.00016) respectively. The minimum autumn temperature for Halfa increased significantly, while this was the case for both the minimum and maximum autumn temperature at Shambat and Wad Medani. This significant increase in temperature, associated with autumn, is partly due to dry conditions observed during the late 1960s.

The relationship between 8 km^2 AVHRR/NDVI and rainfall data (1981-2003) was tested in the Butana area. The relationship was strong between the peak NDVI (end of August through the beginning of September) and cumulative July/August rainfall, but weak relationships resulted when annual rainfall and cumulative NDVI were used. The Departure Average Vegetation method showed that the area had a high percentage of departure, reaching about 40% of the long-term average during the drought years and the NDVI recovered during the following year if the rainfall was above average. There were increased trends in NDVI in the study area during the period from 1992 to 2003, despite some years during this period having higher departure although that departure was less than for the period 1981-1991. To monitor the impact of human activities on land degradation it is essential to remove the effects of rainfall on vegetation cover. Using the Residual Trend Method the differences between the observed peak NDVI and the peak NDVI predicted by the rainfall was calculated for each pixel. This method identified degraded areas that exhibit negative trends in NDVI. The human impact is more clear in the northern part.

Satellite imagery provides an opportunity to undertake routine natural resource monitoring for mapping land degradation over a large area such as Butana over a long time period. This facilitates efficient decision making for resource management. Five classes of land use were achieved using unsupervised classification, whereafter an image difference technique was applied for 1987-1996 and 1987-2000. This analysis showed that the bare soil and eroded land increased by 3-7% while the vegetated area decreased by 3-6%. Also when comparing the aerial photographs (1960s and 1980s) for Shareif

Baraket, Kamlin and El Maseid with Landsat images (2000) severe degradation of the vegetation cover was visible at all the three sites.
The Moving Standard Deviation Index (MSDI) is calculated by performing a 3×3 moving standard deviation window across the band 3 Landsat images (1987, 2000). MSDI proved to be a powerful indicator of landscape condition for the study area. The MSDI increased considerably from 1987 to 2000, especially for Sufeiya, Sobagh and Banat areas, which are referred to as severely degraded sites in the literature. The Bare Soil Index (BSI) supports the finding from the MSDI. The BSI for the degraded sites Sufeiya, Sobagh and Banat increased from 0-8 in 1987 to 32-40 in 2000. The image difference of the BSI indicated that the index increased by about 14-43 over the 13 years.

A Microsoft Excel macro was used to write the algorithms for a decision support tool relating the factors that trigger and propagate desertification in arid and semi-arid areas. This was named "Tashur". Rainfall, aridity index and NDVI were used to evaluate the condition of the landscape. If these three parameters alone were not sufficient to make a decision, then soil and human activity parameters need to be consulted for more reliable decision making. This simple and concise decision support tool is expected to provide guidelines to planners and decision makers.

Different ecosystems in the Butana area are subjected to various forms of site degradation. The desertification has led to sand encroachment and to accelerated development of dunes and also increased the water erosion in the northern part of the area. The area has also been subjected to a vegetation cover transformation. Pastures have deteriorated seriously in quality and quantity, but in many parts the degradation is still reversible if land use and water point sites are organized.

Opsomming

Oorsake en Impak van Verwoestyning in die Butana-gebied van Soedan

deur

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Verwoestyning is een van die ernstigste omgewings- en sosio-ekonomiese probleme van ons tyd. Verwoestyning beskryf omstandighede van land-degradasie in ariede, semi-ariede en droë sub-humiede streke wat voortspruit uit klimaatsveranderings en menslike aktiwiteite. Die fundamentele doel van hierdie verhandeling was om die graad en omvang van die land-degradasie te monitor en om klimaatsveranderlikheid en -verandering in die Butana-gebied van noordoos Soedan te ondersoek.

Die klimaatsveranderlikheid en –verandering ten opsigte van reënval, temperatuur en ariditeitsindeks is ondersoek vir die tydperk wat strek van 1941 tot 2004 deur die maandelikse en jaarlikse tydreeks van vier weerstasies (El Gadaref, Halfa, Wad Medani en Shambat) regoor die Butana-gebied te ontleed. Die neiging vir reënval by Wad Medani en Shambat dui betekenisvolle afname, terwyl dié van Halfa en El Gadaref geen noemenswaardige afname of toename toon nie. Die Kumulatiewe Reënvalafwyking (KRA) was gebruik om die tydperke van skielike veranderinge in die reënval tydreeks uit te wys. ʼn Beduidende toename in die jaarlikse reënval was by Shambat ($p = 0.00135$) en Wad Medani ($p = 0.0005$) waargeneem van 1968 tot 1987, waarna die reënval na aan die lang-termyn gemiddeld is. In El Gadaref was daar ʼn afname in die jaarlikse reënval van 1971 tot 1974 ($p = 0.35$), maar dit was nie betekenisvol nie, met ʼn herstel van 1975 tot 1982 na ʼn waarde hoër as die lang-termyn gemiddeld, gevolg deur ʼn verdere afwaartse neiging tussen 1983 en 1994. In Halfa was daar ʼn beduidende afname ($p = 0.0304$) van 1982 tot 1993. Die neigings van maksimum en minimum temperature is ondersoek vir die somer- (Maart-Mei), herfs- (Junie-Oktober) en winterseisoene (November-Februarie) vir die vier weerstasies. By Halfa en Shambat was daar ʼn nie-betekenisvolle maar stygende neiging in die maksimum en minimum somer- en wintertemperature, terwyl ʼn betekenisvolle toename wel in Wad Medani waargeneem is. El Gadaref het ʼn betekenisvolle toename in maksimum en minimum temperature (p = 0.00005, p = 0.00016) respektiewelik, getoon. Die minimum herfstemperature vir Halfa het beduidend toegeneem, terwyl dit die geval vir beide die minimum en maksimum herfstemperature by Shambat en Wad Medani was. Hierdie beduidende styging in temperature wat met herfs geassosieer word, is deels te wyte aan droë toestande wat gedurende die laat 1960s voorgekom het.

Die verwantskap tussen 8 km^2 AVHRR/NDVI en reënvaldata (1981-2003) is getoets in die Butana-gebied. Die verwantskap was sterk tussen die piek-NDVI (einde van Augustus tot begin September) en kumulatiewe Julie/Augustus reënval, maar swak wanneer jaarlikse reënval en kumulatiewe NDVI gebruik is. Die Afwyking Gemiddelde Plantegroei Metode het getoon dat die gebied ʼn hoë afwykingspersentasie het wat sowat 40% van die lang-termyn gemiddeld gedurende die droogtejare bereik en dat die NDVI gedurende die volgende jaar herstel het wanneer die reënval bo-gemiddeld was. Daar was stygende neigings in NDVI in die studiegebied gedurende die tydperk wat strek van 1992 tot 2003 al was daar sommige jare in hierdie tydperk wat hoër afwykings getoon het en hoewel daardie afwyking minder was as wat gedurende 1981-1991 waargeneem is. Om die impak van menslike aktiwiteite op land-degradasie te monitor, is dit noodsaaklik om die invloede van reënval op plantegroeibedekkings te verwyder. Deur gebruik te maak van die Residuele Neigingsmetode is die verskille tussen die waargenome piek-NDVI en die reënvalgebaseerde piek-NDVI bereken vir elke beeldelement. Hierdie metode het gedegradeerde areas uitgewys wat negatiewe neigings in NDVI het. Die menslike impak is duideliker in die noordelike deel te bespeur.

Satellietbeelde verskaf die geleentheid om roetine monitering van natuurlike hulpbronne vir die kartering van land-degradasie oor ʼn groot gebied soos Butana oor ʼn lang tydperk te ondergaan. Dit bewerkstellig effektiewe besluitneming vir hulpbronbestuur. Vyf klasse van landgebruik is met behulp van onbegeleide klassifikasie daargestel, waarna ʼn

beeldverskiltegniek vir 1987-1996 en 1987-2000 toegepas is. Die ontleding het getoon dat die kaal en geërodeerde grond met 3-7% toegeneem het, terwyl di plantegroeibedekte area afgeneem het met 3-6%. Wanneer die lugfotos (1960s en 1980s) vir Shareif Baraket, Kamlin en El Maseid met Landsatbeelde (2000) vergelyk is, is daar gevind dat ernstige degradasie van die plantegroeibedekking in die drie lokaliteite voorgekom het.

Die Bewegende Standaardafwykingsindeks (BSAI) is bereken deur ’n 3×3 standaardafwyking venster oor die band 3 Landsatbeeld (1987, 2000) te beweeg. BSAI het geblyk om ’n kragtige indikator van landskaptoestand vir die studiegebied te wees. Die BSAI het aansienlik toegeneem van 1987 tot 2000, veral vir Sufeiya, Sobagh en Banat-areas, waarna as ernstig gedegradeerde plekke in die literatuur verwys word. Die Kaalgrondindeks (KGI) ondersteun die bevindinge van die BSAI. Die KGI vir die gedegradeerde Sufeiya, Sobagh en Banat het toegeneem van 0-8 in 1987 tot 32-40 in 2000. Die beeldverskil van die KGI het getoon dat die indeks met sowat 14-43 toegeneem het oor die 13-jaar tydperk.

’n Microsoft Excel makro, genaamd ‘Tasahur’, is ingespan om die algoritmes te skryf vir die besluitneming ondersteuningshulpmiddel wat die faktore wat tot verwoestyning in ariede en semi-ariede gebiede aanleiding gee, in berekening bring. Reënval, ariditeitsindeks en NDVI is gebruik om die toestand van die landskap te evalueer. Indien hierdie drie parameters alleen nie voldoende is om ’n besluit te neem nie, moet grond en menslike aktiwiteitparameters geraadpleeg word om meer betroubare besluite te neem. Daar word verwag dat hierdie eenvoudige en bondige makro ’n reeks norme aan beplanners en besluitnemers sal bied.

In die Butana-gebied is daar verskeie ekosisteme wat aan verskillende vorme van degradasie onderwerp word. Die verwoestyning het gelei tot sandkruip en versnelde duinontwikkeling asook verhoogde watererosie in die noordelike deel van die gebied. Die gebied is ook onderwerp aan ’n transformasie in die plantegroeibedekking. Weivelde het ernstig agteruit gegaan in terme van kwaliteit en kwantiteit, maar in baie dele is die degradasie steeds omkeerbaar indien landgebruik en waterpunte georganiseer word.

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γ	Psychrometric constant (kPa $^{o}C^{-1}$)
Δ	Slope of vapour pressure curve at mean air temperature (kPa $^{o}C^{-1}$)
μ	Attenuation coefficient
β	Standardized regression coefficient
AI	Aridity Index
a	Intercept or estimated value when x = zero
b	Slope of line or average change in Y per unit of time (eq.2.3)
b	Exponent (divergence into k-dimensional space; b = k -1)
BSI	Bare Soil Index
c	Smoothing parameter
C	Long-term average rainfall (mm)
C	Cyclic variation
CDF	Cumulative Distribution Function
CRD	Cumulative Rainfall Departure
DST	Decision Support Tool
e_a	Actual vapour pressure (kPa)
e_s	Saturation vapour pressure (kPa)
$e_s - e_a$	Saturation vapour pressure deficit (kPa)
ET_o	Reference evapotranspiration (mm d^{-1})
FCC	False Colour Composite
F_i	Relative frequency of occurrence for the classes of CDF
G	Soil heat flux density (MJ m^{-2} d^{-1})
GCM	General Circulation Model
HAI	Human Activities Impact
i	Data point
i	i^{th} month (equation 2.1, 2.6)
j	Interpolation point
MSDI	Moving Standard Deviation Index
n	No of pixel per block (9)
n	Sample number (total number of rainfall data points)
N	Von Neumann’s ratio
NDVI	Normalized Difference Vegetation Index
NIR	Near infrared reflectance
NPP	Net Primary Production
p	significance levels
PET	Amount of potential evapotranspiration (mm).
Red	Visible red reflectance
r_{ij}	Distance between points i and j
R_n	Net radiation at the crop surface (MJ m^{-2} d^{-1})
RMSE	Root mean square error
RMSEs	Systematic RMSE
RMSEu	Unsystematic RMSE
S	Seasonal variation
SE	Standard error of the mean

S_b	Estimated standard error of the regression coefficient:
SPI	Standard Precipitation Index
T	Mean daily air temperature at 2 m height (ºC)
Tr	Return period (equation 2.8)
Ty	Trend values of the variable Y
u_2	Wind speed at 2 m height (m s^{-1})
w_{ij}	Weight of the data point and interpolated data
x	The point of time
X_{AI}	Aridity Index (monthly or season or annual)
X_{BSI}	Bare Soil Index (for at least two periods)
X_{HAI}	Human Activities Impact
X_{MSDI}	Moving Standard Deviation Index (for at least two periods)
X_{NDVI}	Normalized Difference Vegetation Index (daily or monthly or seasonal)
X_{rain}	Rainfall variable (monthly or annual rainfall)
Y	Rainfall amount (mm)
$\overline{Y}$	Average of the Y
z_i	Data point for the monthly rainfall amount
Z_j	Weight average computed at j

Chapter 1

General Introduction

1.1 Background

Drylands cover about 5.2 billion hectares, a third of the land area of the globe (UNEP, 1992a). Roughly one fifth of the world population live in these areas. Drylands have been defined by FAO on the basis of the length of the growing season, as zones which fall between 1-74 and 75-199 growing days to represent the arid and semi-arid drylands respectively (FAO, 1978). They are also characterized by low, erratic and highly inconsistent rainfall levels, receiving between 100 to 600 mm rainfall annually. The main feature of “dryness” is the negative water balance between the annual rainfall (supply) and the evaporative demand.

Many of the world’s drylands are grazing rangelands. All rangelands are characterized by the need to manage and cope with erratic events that constrain opportunities for development. Traditional nomadic pastoralism fully exploits these characteristics, typically by moving from one area to another in response to seasonal conditions. These forms of use were more economically efficient and less ecologically damaging than the sedentary systems that characterize the other landscapes (Squires and Sidahmed, 1998). Ecosystems in drylands around the world appear to be undergoing various processes of degradation commonly described as desertification (Hillel and Rosenzweig, 2002). One should be able to differentiate between true climatic desert areas, which have always been deserts (at least during known historic times) and deserts resulting from land degradation that have been caused by different factors, and are concerned with the creep of desert-like conditions into these areas.

Desertification has been with us for over a thousand years, although it went unrecognized for a very long time. It only became well known in the 1930s, when parts of the Great Plains in the United States turned into the "Dust Bowl" as a result of drought and poor farming practices, although the term itself was not used until almost 1950 (Dregne, 2000). During the "Dust Bowl" period, millions of people were forced to abandon their farms and livelihoods. Greatly improved methods of agriculture, land and water management in the Great Plains have prevented that disaster from recurring, but desertification presently affects millions of people on almost every continent. It is now recognized that desertification is one of the central problems in sustainable development of the dryland ecosystems. Rainfall variability both in time and space, coupled with inherent ecological fragility of the drylands weakens the resilience of the ecosystem and its ability to return to its original conditions.

1.1.1 Desertification: Concepts and definitions

Desertification is a single word used to cover a wide variety of effects involving the actual and potential biological productivity of an ecosystem in the arid, semi-arid and dry sub-humid regions (Hillel and Rosenzweig, 2002). Le Houérou (1977) used the term ‘desertization’ to define the extension of typical desert landscapes and landforms to areas where they did not previously occur in the recent past. This process most often takes places in arid zones bordering the deserts with average annual rainfall of 100 to 200 mm. The word ‘desertification’ is used to describe degradation of various types and forms of vegetation, including sub-humid and humid forest areas. It gained popularity following the severe drought that afflicted the Sahalien regions in Africa from the late 1960s to 1970s and again in the 1980s. During the period from 1958 to 1975 the mean annual rainfall diminished by nearly 50%, and the boundary between the Sahara and the Sahel shifted southward by nearly 100 km (Lamprey, 1975).

The United Nations Conference on Desertification (UNCOD) held in Nairobi in 1977 defined ‘desertification’ as “the diminution or destruction of the biological potential of land that can lead ultimately to desert-like conditions under combined pressure of adverse and fluctuating climate and excessive exploitation”.

Mainguet (1994) characterized desertification as the “ultimate step of land degradation to irreversible sterile land”. UNCED (1992) defined desertification as “land degradation in arid and semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities”. FAO (1993) also defined desertification as “the sum of geological, climate, biological and human factors which lead to the degradation of the physical, chemical and biological potential of lands in arid and semi-arid zones, and endanger biodiversity and the survival of human communities”.

According to the definitions listed above, desertification appears as land degradation in arid, semi-arid and dry sub-humid climates, whatever the cause, but land degradation can occur under all sort of climates. Land degradation includes salinity, waterlogging and faulty irrigation practices, although it is common in drylands in developing countries, but it is by no means restricted to these countries. Saline land occupies 106 km^2 (Dudal and Purnell, 1986) while 0·1% of the 2·4 x 106 km^2 of land under irrigation is annually being lost due to secondary salinity, sodicity and waterlogging. (Kovda, 1980, 1983). The United Nations Environment Programme (UNEP) has estimated that the area prone to desertification worldwide is approximately 38 million km^2 of which 6.9 million km^2 (19%) are in sub-Saharan Africa (Nana-Sinkam, 1995).

Desertification includes not only soil erosion but also potentially genetic erosion of the plant, animals and microorganisms that form the living elements of the dryland environments. When a dryland plant, animal or soil microorganism species adapted to dry condition is lost, it is very likely that it is lost forever (El Wakeel, 2004). Because there are so few species and genes well adapted to the drier areas, the percent loss of species is greater. The severe effects are remarkably seen in reduction of the biodiversity, range, forest and wildlife ecosystems.

Desertification is recognized globally as a complex problem. It includes the interaction of biological, ecological and socio-economic dimensions and it is of international concern owing to its widespread occurrence and to the interconnection of economies. Therefore, an integrated approach is necessary to link ecosystem goods and services such as food, water, biodiversity, forest products and above all human factors. Desertification is generally viewed as an advanced stage of the land degradation. This has been defined as a reduction of biological productivity of a dryland ecosystem (rangelands, pastures, rainfed and irrigated croplands), resulting from natural, chemical, physical or hydrological processes. These processes may include erosion and deposition by wind and water, salt accumulation in soil, surface runoff, reduction of amount or diversity of natural vegetation, decline in the ability of the soil to transmit and store the nutrients and water necessary for plant growth (Williams and Balling, 1996). The impact of desertification in arid and semi-arid regions is normally very severe due to the fragile nature of these lands. Charney *et al*. (1975, 1977) suggested that the drought and dynamics of deserts in the Sahara can be controlled by a biogeophysical feedback mechanism. The biological feedbacks play an important role in desertification worldwide (Schlesinger *et al*., 1990). Deforestation and the resulting hydrological changes of land surface affect regional and even global climates (Shukla and Mintz, 1982; Shukla et al., 1990, Wright *et al*., 1992). Some General Circulation Models (GCMs) suggest that future global warming will mostly likely exacerbate the degradation of semi-arid grasslands on a large scale in North America and Asia (Manabe and Wetherald, 1986). Le Houérou (1996) stated that desertification is irreversible in shallow soils, receiving rainfall of less than 200mm. However where the bulk density is low, the soil has good tilth and is deep enough, vegetation recovery is possible, even in areas receiving as little as 60 to 80 mm of average annual rainfall. The key elements related to desertification are drought, vegetation cover and carrying capacity of land, as well as soil degradation and water resources. The role of the social factor is also important (Hillel and Rosenzweig, 2002).

1.1.2 Drought

Droughts are unique in that unlike floods, earthquakes, or hurricanes; during which violent events of relatively short duration occur, droughts are like a cancer on the land that seems to have no recognized beginning (Mather, 1985). Droughts covering a few hundred square kilometres do exist but these are usually of limited duration and modest severity. It is more common for droughts to cover relatively vast areas, a significant proportion of a continent or sub-continent approaching millions of square kilometres (Mather, 1985). Drought is a creeping phenomenon making an accurate prediction of either its onset or end a difficult task. (Wilhite and Glantz, 1985). Tannehill (1947) noted: “We have no good definition of drought. We may say truthfully that we scarcely know a drought when we see one. We welcome the first clear day after a rainy spell. Rainless days continue for a time and we are pleased to have a long spell of such fine weather. It keeps on and we are a little worried. A few days more and we are really in trouble. The first rainless day in a spell of fine weather contributes as much to the drought as the last, but no one knows how serious it will be until the last dry day is gone and the rains have come again, we are not sure about it until the crops have withered and died". The definition of the drought can be categorised broadly as either conceptual or operational (Wilhite and Glantz, 1985). The encyclopaedia of Climate and Weather (Schneider, 1996) defines drought as "an extended period - a season, a year, or several years - of deficient rainfall relative to the statistical multi-year mean for a region". Operational definitions attempt to identify the onset, severity and termination of drought episodes. Drought is frequently defined according to disciplinary perspective. Subrahmanyam (1967) has identified six types of drought: meteorological, climatological, atmospheric, agricultural, hydrological and water-management. Many others have also included economic or socio-economic drought. According to Wilhite and Glantz (1985) four commonly used definitions of drought are as follows:

Meteorological drought is defined as a period when rainfall is significantly less than the long-term average or some designed percentages, or less than some fixed value (Linsley *et al*., 1982; Downer *et al*., 1967).

Agricultural or ecological drought is defined as "a deficit of rainfall with respect to the long-term mean, affecting a large area for one or several seasons or years, that drastically reduce primary production in natural ecosystems and rainfed agriculture" (WMO, 1975).

Hydrological drought is the natural occurring phenomenon that exists when precipitation has been significantly below normal recorded levels causing a hydrological imbalance (Linsley *et al*., 1982).

Socio-economic drought occurs when water supply is insufficient to meet water consumption for human activities such as agricultural activities, industry, urban supply, irrigation etc. (Heathcote, 1974; Gibbs, 1975).

Drought and dry spells occurred in West Africa between 1968 and 1973. It has been estimated that during this period the drought directly affected 6 million of the region's inhabitants and 25 million cattle, leading to an estimated 100,000 human deaths and up to 40% loss of cattle. In addition before cattle perished, large areas were denuded of vegetation due to excessively large numbers of cattle surviving on a dwindling vegetation resource (especially around watering points). There was also a breakdown of traditional grazing patterns due to construction of deep wells and pressure created by cultivators seeking more land to farm in the north especially during the preceding 15 year period of above average rainfall conditions (Glantz, 1977a).

1.2 Motivation

Hare and Ogallo (1993) estimate that over 400 million people are severely at risk as a direct result of the various processes of dryland degradation, and a further 700 million are either less severely affected or are at risk from the indirect repercussions of such degradation. UNEP (1992a, b) estimated that roughly 70% of all agriculturally used drylands are degraded to some degree, especially in terms of their soils and plant cover, and up to 4 million hectares of rainfed croplands are being lost each year in the world's drylands, chiefly as result of accelerated soil erosion and increasing urban growth.

Desertification is considered the most serious environmental problem facing Sudan, which lies within the zone where the risks of desertification are high. The area that is threatened by desertification hazard lies between latitudes 13^o and 18^o N extending across the country from east to west covering a total area of 65 million ha. According to Kassas (1991) the vegetation belt in Sudan has moved southwards by 150 km in 20 years (1970-1990). Most of the rainfed cropping land between 15^o and 17^o N was lost due to movement of the sand from the Libyan Desert (DECARP, 1976a). According to Sudan National Council for Research, the area classified as a semi-desert region (100 to 300 mm) in the country between 14^o N and 16^o N and occupying 350,000 km^2 has now become a desert (Lewis, 1975).

Many of the drylands of Sudan constitute important production and biodiversity-rich areas. Most of the important crops in Sudan, such as sorghum and millet have originated in the drylands. There are also other important species that provide vegetable oils, medicine, resins, waxes and other commercial products. It has been reported that the traditional and indigenous crop varieties and cultivars, which constitute the staple food of people in dry regions, are being threatened (El Wakeel, 2004). The survival of local pearl millet strains especially late maturing ones from western Sudan has been particularly adversely affected (Abuel Gasim, 1999). Sorghum types, local groundnut landraces, roselle and cowpea varieties are also badly affected by desertification accelerated climatic changes in those parts of the country.

Drylands provide critical habitats for wildlife including large mammals and migratory birds, which can be endangered by elements of nature and/or human activities. In the northern parts of Sudan, serious river bank erosion 'haddam' is associated with moving sands that are constricting the Nile course in the Dongola and Affads areas (Mohamed, 1999). The western, central and eastern parts of the country are plagued with recurrent droughts and desertification. The southern part of the country is not immune to desertification and already many locations are experiencing a variable degree of degradation (Ayoub, 1998a). Nevertheless, Sudan has a good chance of combating desertification when compared to some other Sahelian countries, as it has vast areas within its savannah belt that have not yet been degraded (WRI, 2003). However, these areas are increasingly threatened, as migration from the northern desertified belt intensifies human and animal pressure on those ecosystems.

Since time immemorial the Butana in the north eastern part of Sudan has been know to have excellent pastures (DHV consultants, 1989; Akhtar, 1994). The region has the best grazing land in Sudan. The grasses are palatable with high nutritional value for animals. Thus many nomadic tribes from adjacent as well as far away regions, use its grazing land during and after the rainy season.

Pastoral nomadism in the Butana is undergoing a rapid change in nature, strategy and pattern of mobility. This change is due to the expansion in agricultural development schemes in the Butana (Abu Sin, 1970) and changes in the vegetation cover and the availability of water points. Akhtar and Mensching (1993) reported that desertification has become one of the most serious environmental and socio-economic problems in the Butana area. The excessive human pressure on the inherently fragile natural resources, due to the abolishment of traditional land use rights, and harsh climatic conditions have resulted in severe processes of desertification. The arid loamy soil of the Butana area with an area of 8 million hectare is experiencing severe erosion (Shepherd, 1985; Akhtar and Mensching, 1993).

Therefore, literature in Sudan is full of information on causes and impact of desertification especially literature from the 1970s, concerned particularly with the areas of western Sudan (north of Kordofan). Among such studies and publications are those of Rapp (1974), Lamprey (1975), Mensching and Ibrahim (1976), DECARP (1976a, b), Hammer-Digeres (1977), Eckholm (1977), Ibrahim (1978), Baumer and Tahara (1979) and Rapp and Hellden (1979). Other studies such as those of Hellden (1988), Hussein (1991) and Kassas (1991) were carried out in the 1980s and 1990s. However, the research effort or remedial studies directly addressing desertification in the Butana area have been fragmented.

Therefore this study has used an integrational approach to study the causes and impact of desertification in the Butana area. The major focus of this research is on climate change and climate variability and its interaction with desertification. It also makes an initial contribution towards developing a decision support tool to monitor the progress of the land degradation in arid and semi-arid regions.

1.3 Description of the Study Area

1.3.1 Sudan

Sudan is the largest country in Africa (8.5% of Africa) and the country has a population of about 37 million people of which almost half are under the age of 15 years (CIA, 2004). However, the country is one of the worlds poorest as the GPD/capita is only $1360 (Hinderson, 2004). During 1984 and 1985 the country was stricken by a severe famine. The country is rich in natural resources such as oil, gold and chrome (Hinderson, 2004), but agriculture is the most important sector and employs nearly 80% of the workforce. Along the Nile, sorghum, groundnut, wheat and cotton are grown on large irrigation schemes (Grove, 1998), but the arable land actually covers only a small part of the country with pastoralism and rainfed cultivation dominating the agricultural sector.

The climate of Sudan varies from continental in the northern parts, through savannah in the centre, to equatorial in its southern most parts. Rainfall varies from 20 mm/year in the north to some 1600 mm/year in the far south. Average annual rainfall is 436 mm (Elagib and Mansell, 2000). High temperatures and a high radiation load conspire to produce a large atmospheric demand for moisture and annual potential evapotranspiration generally exceeds 2000 mm (Rockström, 1997). Water used in Sudan is derived almost exclusively from surface water resources, with groundwater only being used in very limited areas, and then mainly as a domestic water supply.

1.3.2 The Butana area

The word Butana is derived from the Arabic word ‘buton’, meaning belly in English. It refers to the region between the main Nile, Blue Nile and the river Atbar with the Khartoum, El Gadaref and Kassala railways as the southern boundary. It covers approximately 120,000 km^2, lying between latitude 13^o 50' and 17^o 50' N and longitude 32^o 40' and 36^o 00' E. It excludes the narrow strip of land along the eastern bank of the Blue Nile and western bank of River Atbar which are irrigated areas (Abu Sin, 1970; Elhassan, 1981). Figure 1.1 shows the location of the Butana area, which is roughly kidney shaped.

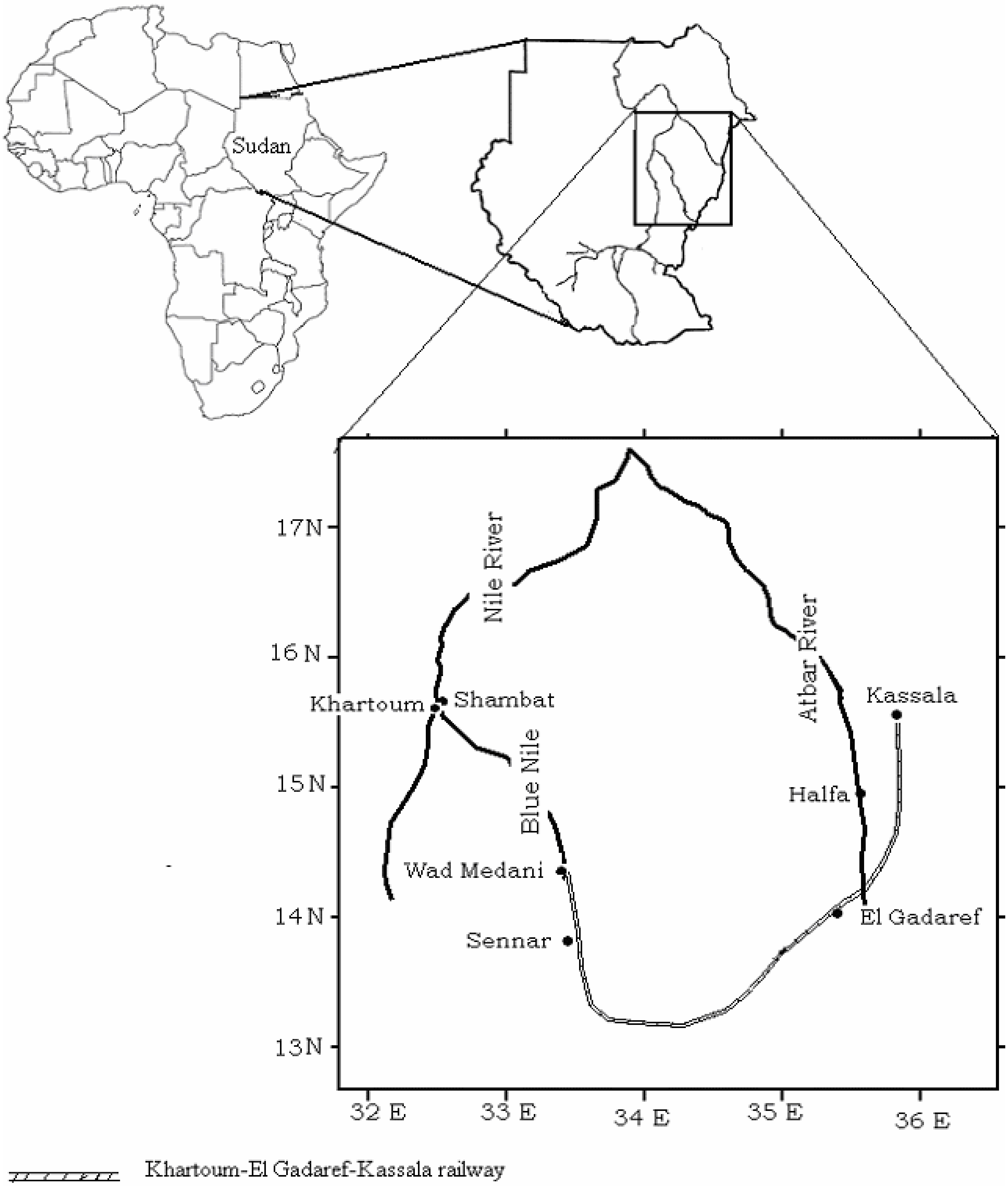


Figure 1.1 Map showing the location of the Butana area of Sudan and weather stations used in the climate analysis

1.3.2.1 Climate

The Butana lies in the belt of regular oscillation of the inter-tropical convergence zone (ITCZ) with a tropical continental climate. According to Köppen's classification (Mustoe, 2004) world climate classification the Butana lies in Bshw, which refers to an area where evaporation exceeds precipitation and is a hot steppe desert. The Butana can be classified as sub-desert, as 9 - 11 months of drought occur according to Abu Sin (1970).

Temperature is high all year around, the highest temperatures being in April above 40^{o} C and in October around 36^{o} C. January is the coolest month with the maximum temperature being 17^{o} C. The trend of annual temperature change is a drop in July and August as result of high humid and cloud cover. Then temperature begins to rise through September and October towards November with the retreating ITCZ and a declining cloud cover. Then it drops to a minimum with the advance of cool northerly winds through December, January and February (Van der Kevie, 1976).

Rainfall is the most important single determining factor in the climate of the Butana because the temperature is high all year around. The rainfall determines the vegetative life cycle and annual vegetative cover, land use and thus human occupation. It shows a substantial variation in incidence, amount, time received and annual distribution. Most of the rains are from convectional storm clouds. The rainfall variability is greater as one moves towards the north or north east. The annual rainfall in Butana ranges between 75 mm in the north to above 600 mm in the southern part (Oliver, 1965). The Butana is characterized by low relative humidity especially in winter reaching its minimum in April and its maximum in August, varying between 16% - 77%. The open nature of the area and free movement of the air accelerates evaporation, whether from the surface or sub-soil (Rath, 1936, Oliver, 1965).

1.3.2.2 Geology

The geology of the Butana consists of the following main features as distinguished by Andrew (1948) and Delany (1955): Basement complex in the middle and to the south east; Nubian formation in the west and north, the central region is a basement complex with flat surface; with only a few rocky hills breaking the monotony of the plains. The central part is a clay plain with numerous water resources. Most of these water courses form their own deltas and do not drain into nearby rivers. At the deltas of these water courses or 'khors' the people normally cultivate sorghum crops (Elhassan, 1981).

1.3.2.3 Soil

The variation in the rainfall, together with variations in relief, drainage and parent materials produce clear local differences in the Butana soil. The top soil is a mid-brown grey friable clay with round quartz pebbles and stone fragments. The cracks are not wide but medium in size and are more abundant in the soil under grass. The soil is a medium to fine textured light clay, sandy clay or silty clay which contains more than 40% expanding clay (Hunting Technical Services, 1966; Khalil, 1986).

1.3.2.4 Vegetation

The occurrence and distribution of vegetation in the Butana is generally determined by amount and distribution of the rainfall but topography and soil texture also play an important role in a detailed description of the distribution within areas receiving the similar amounts of the rainfall (Abu Sin, 1970).

There are three main types of the natural vegetation in the Butana. The Acacia trees that form the major perennial type, including *Acacia tertilus*, *Acacia Seyal* and *Acacia mellifera*. The shrubs are the second perennial type of vegetation in the Butana, including bushy grasses scattered all over the region. The third type includes the annual grasses and herbs. Grasses include *Schoenefeldia gracilis* (Gabash), *Sorghum Purpureo Sericeum* (Adar) and *Sehima ischaemoids*, while herbs include *Ipemea cardiosepala* (Hantut), *Ipomea Cordofana* (Taber) and *Blepharis edulis* (Siha). These herbaceous plants are dominant during the wet season, but after the rainy season they wither and disappear and only a few species can be seen during the dry season. During the rainy season the low areas which are covered by water for a long time will become less vegetated due to the spoilage of seeds. The climax vegetation in the Butana, is *Blepharis edulis* 'Siha'

(Harrison, 1955), where herbs were abundant and often occupied large areas as pure stands.

1.4 Objectives

This study aims to quantify the causes of desertification and the impact on vegetative cover, soil and socio-economic aspects. The specific objectives are:-

(1) To analyse the climate variability and climate change in the Butana area during the period 1941-2004.

(2) To study the interaction between desertification, climatic variability and climate change through the analysis of the vegetative cover and soil degradation.

(3) To quantify and analyze the extent of the area affected by desertification in the Butana area.

(4) To develop a decision support tool to evaluate the degree of desertification in arid and semi-arid regions.

1.5 Organization of the Chapters

This thesis discusses four major topics, namely climate, vegetation cover, soil parameters and the socio-economic aspects of the Butana area. The diversity of topics necessitated the sub-division of the thesis into independent chapters. Each chapter therefore contains a review of literature and methods together with results and discussion on that specific topic.

Chapter 2

Analysis of Climatic Variability and Climate Change

2.1 Introduction

Climate affects man in a multitude of ways and is probably the most important of all geographic factors. It is an important control over the distribution of plant and animal life and consequently largely determines the industries and activities of man, the foods produced in any area, and the material available for shelter and clothing. Climate may act as barrier to the migration of humans, animals and plant life, and it markedly affects man's health and energy levels.

Climate variability means the fluctuation between the normally experienced climate conditions and a different, but recurrent, set of the climate conditions over a given region of the world (IPCC, 1998) and also refers to a shift in climate, occurring as a result of natural and/or human interference (Wigley, 1999). Climate variability and climate change have gone on throughout time; but has now become a pressing issue on the world's agenda.

Climate variation may be divided into three types 1) Internal variability 2) Natural externally forced variability 3) Anthropogenic externally forced variability (Wigley, 1999). The important example of internal variability is the El Niño/Southern Oscillation (ENSO) phenomenon. ENSO arises from the interaction between the ocean and atmosphere in the tropical Pacific ocean and has clear regional consequences over a much wider area, especially in extreme events (flood, drought) (Ropekewski and Halpert, 1987).

2.1.1 Anthropogenic factors and variability

The contribution of the anthropogenic factors to the change in the natural climate is not negligible (Hare, 1993), and there is now strong evidence for a human influence on the global climate. This effect will continue for the foreseeable future due to continued emissions of carbon dioxide (CO_2) and other greenhouse gases from burning of fossil fuels as well as other sources (Howden, 2003).

The relation between climate variability and vegetation cover is based on the "biophysical feedback theory" (Glantz, 1977b, Otterman, 1981), which is an interaction between the biosphere and the atmosphere. The large-scale change in land-use characteristics resulting from drought as well as from over-cultivation, overgrazing and deforestation can generate climate change on a local and regional scale (Eltahir and Bars 1993, 1994). When Zheng and Eltahir (1997) used a simulation model to study the response of West Africa monsoon to desertification and deforestation they found that the impact of deforestation is more serious than desertification. This result upholds the notion about the role of the Equatorial forest (Elsayem, 1986) and the evaporation of the soil water from the neighbouring Bahr El Ghazal basin (Eltahir, 1989) in promoting rainfall in central Sudan, but this should be the subject of a different detailed a study.

Destruction of the permanent vegetation cover increases surface albedo, thus reducing the surface absorption of solar energy. Albedo may rise from about 25% for a well vegetated area to 35% or more for a bare, bright, sandy soil (Hillel and Rosenzweig, 2002). Reduction or destruction of the vegetation cover accelerates surface runoff due to less interception and infiltration of rain water. In this case, soil water levels are likely to decrease, resulting in more energy being available to heat the air and the soil (sensible heat) than to evaporate water (latent heat). This increase in temperature levels would lead to a cycle of drying. The cloud cover may be reduced as less moisture is returned to the atmosphere via evaporation, inevitably causing substantial reduction in the opportunity for rainfall (Elagib and Mansell, 2000). Hoffmann and Jackson (2000) concluded that conversion of tropical savannah to grassland reduced precipitation by approximately 10% in four of the five savannah regions under study. This is associated with an increase in the frequency of dry periods within the wet season and an increased in mean surface air temperature of 0.5° C.

2.1.2 Climate variability in Africa

Climate variability and climate change contribute to the vulnerability via economic loss, hunger, famine and relocation in Africa. The African Sahel provides the most dramatic example worldwide of climate variability that has been directly and quantitatively measured. Precipitation is much more variable in both time and space than other climate factors. The year-to-year variability is a dominant characteristic of the rainfall record and this variability becomes more pronounced if a smaller region is examined (Wigley, 1999). Precipitation varies in a number of its characteristics from total annual precipitation through precipitation seasonality to variability in characteristics of storms (duration, temporal, spacing, total storm precipitation) and variability in the intensity of instantaneous and daily precipitation (Mulligan, 1998).

African rainfall has changed substantially over the last 60 years; this change has been notable as rainfall during 1961-1990 declined by up to 30% compared with 1931-1960 (Sivakumar *et al*., 2005). Nicholson *et al*. (2000) concluded that a long-term change in rainfall has occurred in the semi-arid and sub-humid zones of West Africa, the rainfall during the 30 years (1968-1997) has averaged some 15-40% lower than during the period 1931-1960. Averages over 30 year intervals, showed that the annual rainfall in the Sahelian region fell by between 20-30% between 1930s and 1950s and the decades post 1960s (Hulme, 2001). Kidson (1977) suggested that the low rainfall was associated with a weaker meridional circulation and warmer temperatures over much of Africa. Newell and Kidson (1984) link the Sahelian rainfall variability to a modulation of the general circulation. Haile (1988) linked the drought in Ethiopia with ENSO and Sea Surface Temperature (SST) anomalies in the southern Atlantic and India Oceans combined with anthropogenic activities.

Statistical analysis by Attia and Abulhoda (1992) shows that ENSO episodes are negatively teleconnected with flooding of Blue Nile and Atbar Rivers that originate in Ethiopia due to reduced total rainfall in the Ethiopian highlands. Eltahir (1996) used two extensive data sets describing SST of the Pacific Ocean, and the flow of water in the Nile River. The analysis suggests that 25% of the natural variability in the annual flow of the

Nile is associated with El Niño oscillations. The primary natural forcing factors are linked to the change in solar output and they conclude that an ENSO event effects flows of the Nile River (El Niño indicates a drought in the highland of Ethiopia). Nicholson (1999) discussed the hypothesized role of surface-atmosphere interaction in the interannual variability of the Sahel rainfall. The Butana area of Sudan looked like a desert in 1991 due to low rainfall while the same area was covered by extensive pasture in 1992 due to high rainfall received during that year (Akhtar 1994), showing direct effect of rainfall variability on vegetative cover.

Climate variability has been, and continues to be, the principal source of fluctuations in global food and production in the arid and semi-arid tropical countries of the developing world. In conjunction with other physical, social and political-economic factors, many African countries have experienced severe drought and higher flood frequently in the 20th century. Extensive droughts have afflicted Africa, with serious episodes namely 1965-1966, 1972-1974, 1981-1984, 1986-1987, 1991-1992 and 1994-1995 (WMO, 1995). The aggregate impact of drought on the economies of Africa can be large; for example 8-9% of GDP in Zimbabwe and Zambia in 1992 (Benson and Clay, 1998).

A small change in variability has a stronger effect than the small change in the mean of the climate factors (Wigley 1985). Elagib and Mansell (2000) reported that the mean annual temperatures in Sudan have increased significantly by 0.076° – 0.2° C per decade specifically in the central and the southern regions. They also concluded that the inter-annual variability of the rainfall ranged from 13.8-122.9%.

The main objective of this chapter is to study the climate variability and climate change in the Butana area, by examining trends and seasonal components in the time series data of the climatic factors (rainfall, temperature), evapotranspiration and the aridity index in the recent decades (1940-2004) on monthly and annual bases.

2.2 Material and Methods

2.2.1 Data

Four Stations (Shambat, Halfa, Wad Medani and El Gadaref) were selected on the basis of reasonably long records for the monthly data and in locations to represent as many of climate zones in Butana area as possible. The climate data was obtained from the Sudan Meteorological Authority (SMA). Appendix A lists the locations of the stations, the duration of datasets, while Figure 1.1 shows these locations on the map of Sudan. These stations are classified by Elagib and Mansell (2000) and Van der Kevie (1976) as follows Shambat, Halfa and Wad Medani are arid, and El Gadaref is semi-arid. Meteorological observations, such as temperature and rainfall, sunshine duration, wind speed and relative humidity are readily available unlike solar radiation and evapotranspiration. Individual missing data for a given month were filled in from the neighboring values, as described by Qureshi and Khan (1994), taking the average of the three preceding and the three following years records for that specific month.

2.2.2 Data analysis

To achieve the objective of this chapter the following analyse will be conducted:

2.2.2.1 Homogeneity test

Reliable rainfall records are usually very important in making useful decisions for the many applications of climatology and hydrology. A rainfall record can be considered homogeneous when a sequence of monthly or annual rainfall amounts is stationary (Buishand, 1981) or evolutionary (Priestley, 1965). Stationarity means that the statistical properties of the rainfall amount do not change with time (Thompson, 1984).

The rainfall records over a long period of time may reflect non-uniform conditions (non-homogeneity). This could be due to a change in the observation site, or changes in the instrumentation or the location of the rain gauge with respect to obstructions such as trees, buildings, and/or the frequency of the observation. The observer also plays an important role in generation of the uncertain errors of the observation and error caused by low intensity rainfall below the resolution of the instrument are also common (Serrano, 1997). Non-homogeneity can lead to serious bias in the analysis of the rainfall data i.e. slippage of mean, trend or some oscillation that may lead to misinterpretations of the climate being studied (Buishand, 1977). Therefore this is the first test to assertion if one can use this dataset.

Various methods of evaluating the inhomogenity of monthly or annual rainfall totals were described by Conrad and Pollak (1950); WMO (1966); Buishand (1981, 1982); Thompson (1984) and Potter (1981). Bücher and Dessens (1991) used the bivariate test to check homogeneity of an annual precipitation series from the north east United States and the inhomogenity in the time series of surface temperature in France. Vives and Jones (2005) also used bivariate test to detect any abrupt changes in Australian decadal rainfall. Most homogeneity testing techniques are primarily used to compare neighboring stations. The assumption was made that rainfall observations at a nearby station are similarly influenced by the same general climatic trend. The main constraint of this assumption is that the homogeneity of rainfall series at the neighboring rainfall stations might be doubtful or when there is no other close independent neighboring station which has long-term rainfall data for comparison purposes.

The Von Neumann's ratio (N) is one of the methods used to test the homogeneity in a data series. Von Neumann's ratio has used in homogeneity testing of rainfall from India, Indonesia and Surinam (Buishand, 1977):-

$$N = \frac{\sum_{i=1}^{N-1} (Y_i - Y_{i+1})^2}{\sum_{i=1}^{N} (Y_i - \bar{Y})^2} \tag{2.1}$$

where:

Y = amount of rainfall (mm)

$\bar{Y}$ = average of the Y_i s

i = i^{th} month

The Von Neumann's ratio tends to be smaller than one for a non-homogenous rainfall series with a jump in the mean. Also where there is more than one jump in the mean, the denominator tends to be larger resulting in values below one (Yevjevich and Jeng, 1969; Buishand, 1982).

2.2.2.2 Time series analysis

A time series analysis provides the basis for planning for future changes. The review of historical data over time provides the decision maker with a better understanding of what has happened in the past, and how estimates of the future values may be obtained. A time series is nothing more than the observed successive values of a variable or variables observed at a regular interval of time.

The basic components of time series dataset, each of which influence the forecast of future outcomes, are

a) secular trend (*Ty*)
b) seasonal variation (*S*)
c) cyclic variation (*C*)
d) random or irregular variation (*I*)

The time series model generally used is a multiplicative model (Hoshmand, 1997), which shows the relationship between each component and the original data (*Y*) of a time series as follows:-

$$Y = Ty * S * C * I \qquad (2.2)$$

The essence of time series analysis is to decompose the series into one or more of these four components. Fleming and Nellis (2000) state that for the decomposition method of a time series analysis, the principle which is followed is to focus on the measurement of each of four components in turn.

Measurement of the trend (Ty)

Trend is the long-term growth movement of a time series. The linear trend method simply involves the application of a simple, two-variable, regression technique:-

$$Ty = a + bx \tag{2.3}$$

where:
T_y = trend values of the variable Y
x = point in time
a = intercept or estimated value when x equal to zero
b = slope of line or average change in Y per unit of time

Measurement of the seasonal variation (S)

Seasonal variation refers to repetitive fluctuations that occur within a period of one year. Measurement of the seasonal variation leads first to calculation of a seasonal index which indicates the magnitude of seasonal effect, on the average. The ratio-to-moving average method can be used to compute a seasonal index (Makridakis *et al.* 1978, Fleming and Nellis, 2000). The method to calculate the season index is as follows:-

- Detrend the series, Y, by computing Y_y/T_y
- Average detrend values for the corresponding time period (quarters or months of each year).
- Scale the averages corresponding to each time period to ensure that they sum to 400 for quarterly data or 1200 for monthly data.

2.2.2.3 Evapotranspiration

Evapotranspiration (ET) is a major component of the water balance. Hasegawa and Kasubuchi (1993) rightly noted that ET has an effect on the water balance almost throughout the year. The evapotranspiration term includes both evaporation from the soil surface (soil evaporation) and from the plant canopy (transpiration). Allen *et al.* (1998) defined evaporation as the process whereby liquid water is converted to water vapour and removed from the evaporating surface. This evaporating surface could be a bare soil and/or a vegetative surface. One way of estimating ET is by the determination of reference evapotranspiration. Reference evapotranspiration (ET_o) is defined by Allen *et al.* (1998) as that which occurs from a hypothetical extensive surface of green, well-watered, actively growing grass of 0.12 m height, with a fixed surface resistance of 70 sm^{-1} and albedo of 0.23. The standard method for its computation from meteorological data is given by the FAO Penman-Monteith equation (Allen *et al.*, 1998):

$$ET_o = \frac{0.408\,\Delta(Rn - G)}{\Delta + \gamma(1 + 0.34u_2)} + \frac{\gamma u_2 (e_s - e_a)\,(900/(T + 273))}{\Delta + \gamma(1 + 0.34u_2)} \qquad (2.4)$$

where:
ET_o = reference evapotranspiration (mm d^{-1})
Δ = slope of vapour pressure curve at mean air temperature (kPa $^{o}C^{-1}$)
R_n = net radiation at the crop surface (MJ m^{-2} d^{-1})
G = soil heat flux density (MJ m^{-2} d^{-1})
γ = psychrometric constant (kPa $^{o}C^{-1}$)
T = mean daily air temperature at 2 m height (ºC)
u_2 = wind speed at 2 m height (m s^{-1})
e_s = saturation vapour pressure (kPa)
e_a = actual vapour pressure (kPa)
$e_s - e_a$ = saturation vapour pressure deficit (kPa)

2.2.2.4 Cumulative Rainfall Departure (CRD)

The abrupt changes in climate data do not show up well in a time series graph. Kraus (1955) pointed out that a valuable property of cumulative departure (residuals) is that any change in a time series is often immediately apparent from the resultant graph.

The cumulative departure is calculated by first determining the average of the whole period under consideration, and then the running total of the residuals is computed (Reynolds, 1956; Xu and van Tonder, 2001).

$$CRD_i = CRD_{i-1} + (R_i - C) \qquad (2.5)$$

where:
CRD = cumulative rainfall departure
i = i^{th} month
R = amount of rainfall (mm)
C = long-term average rainfall (mm)

2.2.2.5 Cumulative Distribution Function (CDF)

The CDF provides a reasonably good estimate of probabilities. The CDF was determined by ranking the data in ascending order and calculating their associated cumulative probability of non-exceeding (Anderson *et al*., 1977):-

$$CDF = \frac{1}{n+1} * 100 \quad (2.6)$$

where:
I = rank position
n = total number of rainfall data points in series

The return period is the inverse of the probability of exceedance (Serrano, 1997):-

$$T_r = \frac{1}{(1-F_i)} \quad (2.7)$$

where:
T_r = return period (year)
F_i = relative frequency of occurrence for the classes of CDF

To test the degree to which the cumulative distributions are statistically different, the Kolmogrov-Smirnov (K-S) two-sample test was applied (Steel *et al*., 1997; Langyintuo *et al*., 2002). According to the K-S test, two distribution functions are significantly difference if the maximum vertical deviation between them (D-Statistic) exceeds the critical level at the specified significance level as 0.05. For a specified significance level, the fitting is rejected if the computed D is equal to or greater than the critical value i.e. high D statistics and associated low *p*-values would offer evidence to reject the null hypothesis.

2.2.2.6 Aridity index (AI)

Aridity is the continuous occurrence of rainfall below an arbitrary but very low threshold. It should be noted that aridity can be considered on seasonal or monthly basis (Coughlan, 2003). Aridity differs from drought in that it refers to a ratio between rainfall and potential evapotranspiration. The degree of aridity is inversely related to the magnitude of this ratio, but drought is more or less related to aridity because arid regions experience frequent droughts.

Aridity is defined as the more or less repetitive climate condition, which is characterized by a lack of water (Perry, 1986). Since rainfall is the main source of water over land, it is taken to be the most indicative parameter of water shortage. Many aridity indices have been designed to delimit climate and vegetation of a location. In this study the UNEP aridity index (Hare, 1993) has been used in order to classify the aridity situation in the Butana area as follow:-

$$AI = \frac{P}{PET} \tag{2.8}$$

where:
P = precipitation amount (mm)
PET = amount of potential evapotranspiration (mm).

UNESCO (1977) as reported by Stewart and Robinson (1997) defined the bioclimatic zones based on the climate aridity index as given in Table 2.2.

Table 2.2 Bioclimatic zones defined according to the Aridity Index (Stewart and Robinson, 1997)

Bioclimatic zone	Aridity Index
Hyper-arid zone	<0.03
Arid zone	0.03 - <0.20
Semi-arid zone	0.2 - < 0.50
Sub-humid zone	0.5 - < 0.75
Humid zone	> 0.75

2.2.2.7 Standardized Precipitation Index to identify drought (SPI)

Researchers at Colorado State University (McKee *et al.*, 1993) designed the Standardized Precipitation Index (SPI) based only on precipitation. Its fundamental strength is that it can be calculated for a variety of time scales. The index has the advantages of being easily calculated, having modest data requirements, and being independent of the magnitude of mean rainfall and hence comparable over a range of climate zones (Agnew, 2000). In technical terms, SPI for a given historical precipitation record represents the number of standard deviations away from the mean for an equivalent normal distribution with a mean of zero and standard deviation of one (McKee *et al.*, 1993). Taking the difference between the precipitation data and the mean for that particular time scale, and then dividing by the standard deviation, gives the SPI. Positive SPI values indicate greater than median precipitation (wet condition), while negative values indicate less than median precipitation (i.e. drought) (Hayes, 2001). Hayes *et al.* (1999) stated that a drought event is defined as any time the SPI is continuously negative and reaches a magnitude where the SPI is –1 or lower. The drought event ends when the SPI again becomes positive. This indicates that SPI is helpful in monitoring the development and relief of a drought. Hayes *et al*. (1999) suggested the SPI classification scale given in Table 2.2.

Table 2.1 Classification scale for SPI values (Hayes *et al*., 1999)

SPI	Category
2.00 and above	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.00 to –1.49	Moderately dry
-1.50 to –1.99	Severely dry
-2.00 and less	Extremely dry

2.3 Results and Discussion

2.3.1 Test for homogeneity

When analysing the rainfall data of a considerable number of years one must be aware that the rainfall observations collected over a long period of time may (1) have been influenced by factors other than actual rainfall received (2) can reflect non-uniform conditions due to external or extenuating influences or factors. The results for Von Neumann's ratio for El Gadaref, Halfa, Shambat and Wad Medani stations are 2.01, 1.45, 2.02 and 1.45 respectively, all values > 1 which supports the fact that there is no evidence for non-homogeneity at the 5% level for these datasets.

2.3.2 Characteristics of the rainfall in Butana area

The rainfall data for Sudan is mostly available as monthly and total annual values. Figure 2.1 shows the mean monthly rainfall for the four stations used in this study. The monthly mean reaches its maximum in July and August for the all stations while the minimum (non zero) rainfall is in April and November at El Gadaref and Wad Medani, while Halfa received the minimum amount during April and Shambat during June and October. El Gadaref station is characterized by the highest annual rainfall (322-864 mm) followed by Wad Medani (41-556 mm) and Halfa (78-543 mm) while Shambat station receives the lowest annual rainfall (6-328 mm) during the period from 1940-2004 (Figure 2.2).

Shambat and Wad Medani stations have more years with annual rainfall below the median during the period 1968 – 1994 (Figure 2.3) and had wet years during the period of 1950s and beginning of 1960s. Trilsbach and Hulme (1984) highlighted the occurrence of distinct wet and dry periods in the Sahelian region; however they were random in nature. The work done by Perry (1986) on the structure of the wet season in central Sudan, demonstrated the virtual collapse of the previous pattern in the length, timing and reliability of the wet season from about 1960 onwards.

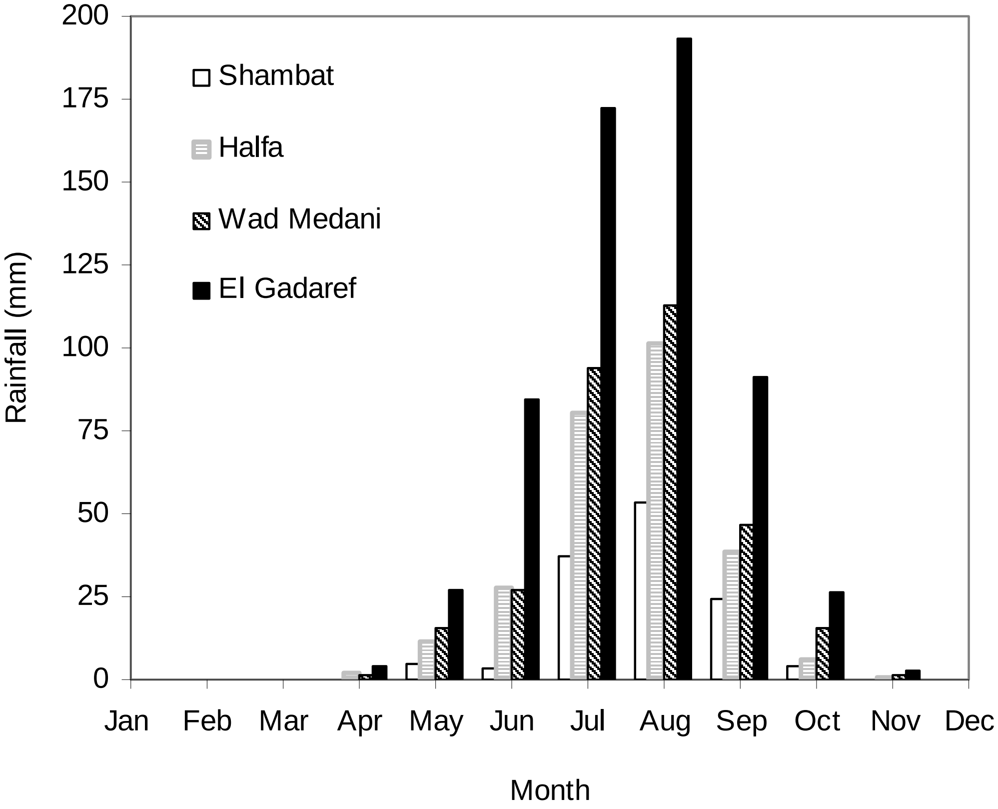


Figure 2.1 Mean monthly rainfall totals of the stations located in Butana area (Data from SMA)

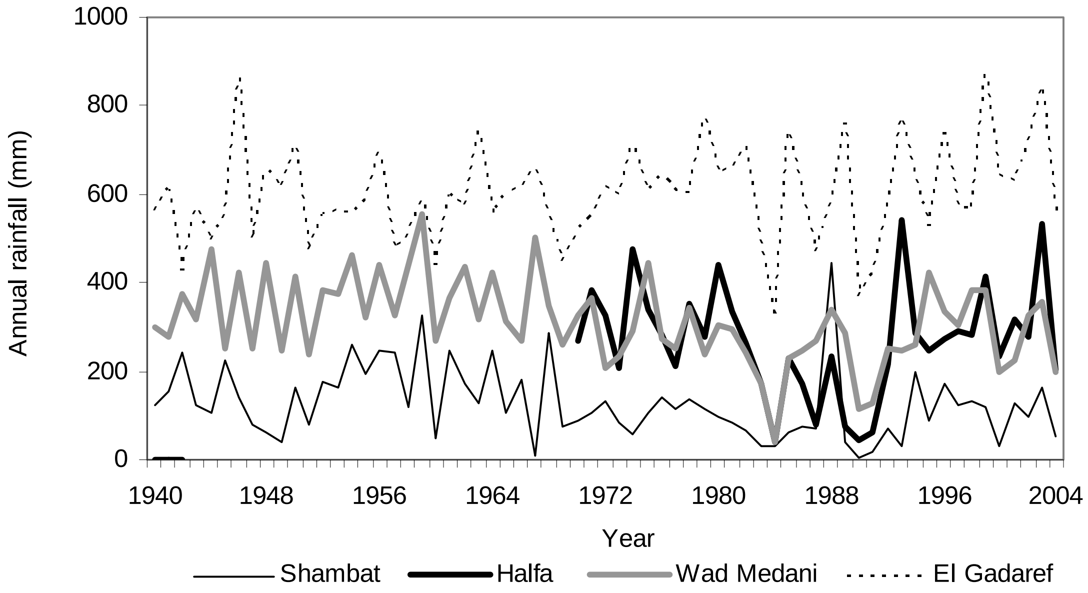


Figure 2.2 The annual total rainfall for the four stations, in Butana area (Data from SMA)

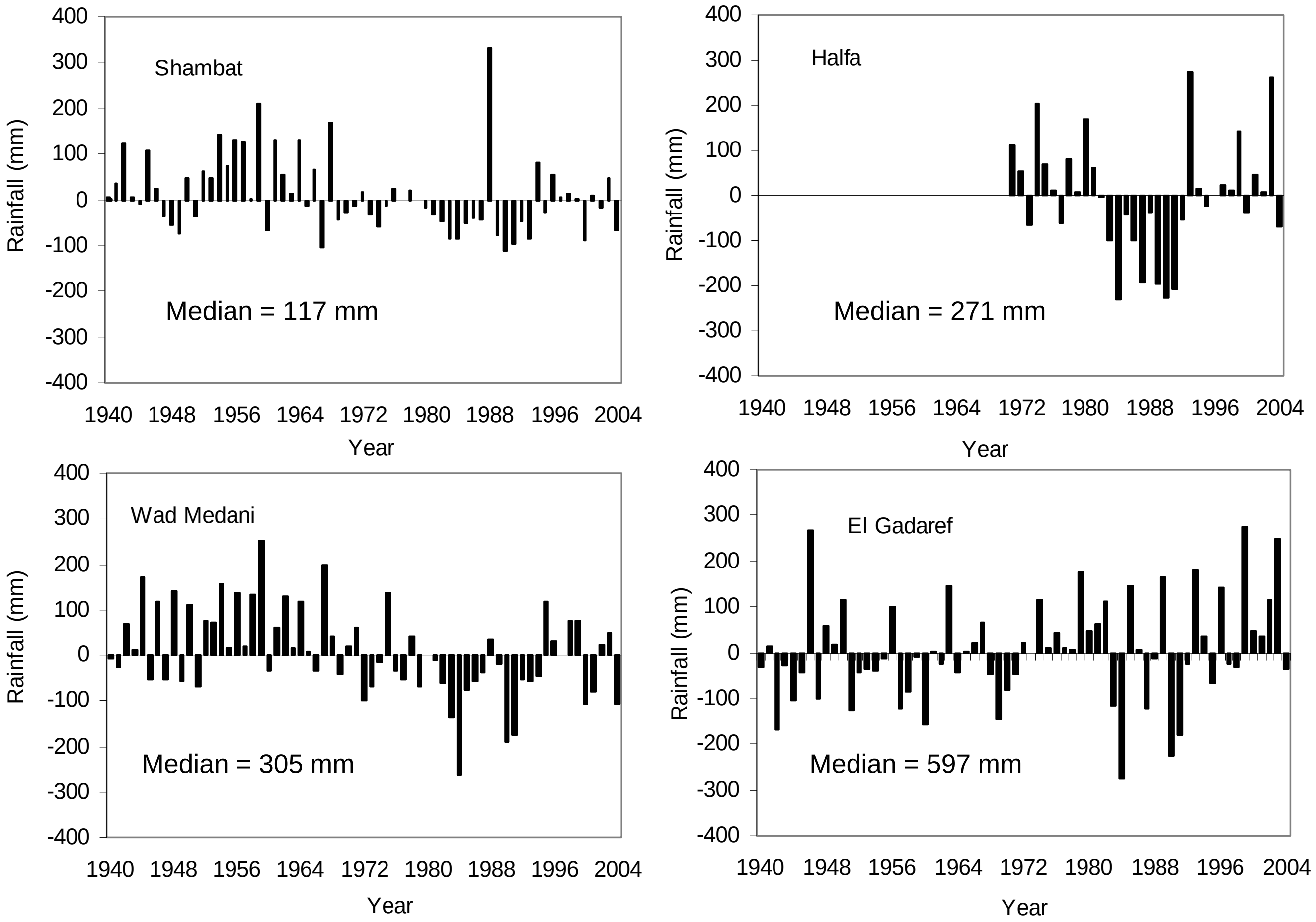


Figure 2.3 Deviation of the annual rainfall totals from the median values at the four weather stations located in Butana area (Data from SMA)

From the above results it is noticed that between 38% and 66% of the years from 1968 to 2004 are below the median for the four stations in the Butana area during the time in which the area was experiencing recurrent droughts. The result also shows that the northern part of the area receives lower rainfall while the southern part, represented by El Gadaref station is a semi-arid area receiving an annual rainfall amount ranging from 350 to 850 mm. The rainfall recovery noted in mid-1990s is still below the levels for the period prior to the mid-1960s (Figure 2.3). This slow recovery from the dry conditions is in line with the results and arguments for the Sahel (Nicholson, 1999; Nicholson *et al*., 2000), which suggest that the dry state would tend to persist longer than the wet state.

The variability of monthly rainfall, was expressed by a coefficient of variation (C_v) as [(standard deviation / mean) x 100]. To see whether the rainfall variability within each year has changed or not, the coefficient of variation of the monthly rainfall was calculated. Figure 2.4 shows that the variability has increased since the late 1960s for all four stations. Table 2.3 gives the result of the best-fit linear trend on the C_v for each of the four stations providing evidence of significant increasing variability for El Gadaref and Shambat. The significant change in variability is probably related to recent changes in the rainfall amount.

By comparing, Figure 2.1 and Figure 2.4 we find that the stations having lower mean rainfall have higher coefficient of variability. This finding agrees with Elagib and Mansell (2000) who pointed out that the year to year variability in annual rainfall in Sudan during 1961-1990, as measured by the coefficient of variability, ranges from 13.8% to 122.9% which increases with decreasing mean annual rainfall amount. From Figure 2.4 it could be noticed that the variability increase considerably during the period between 1971-2004.

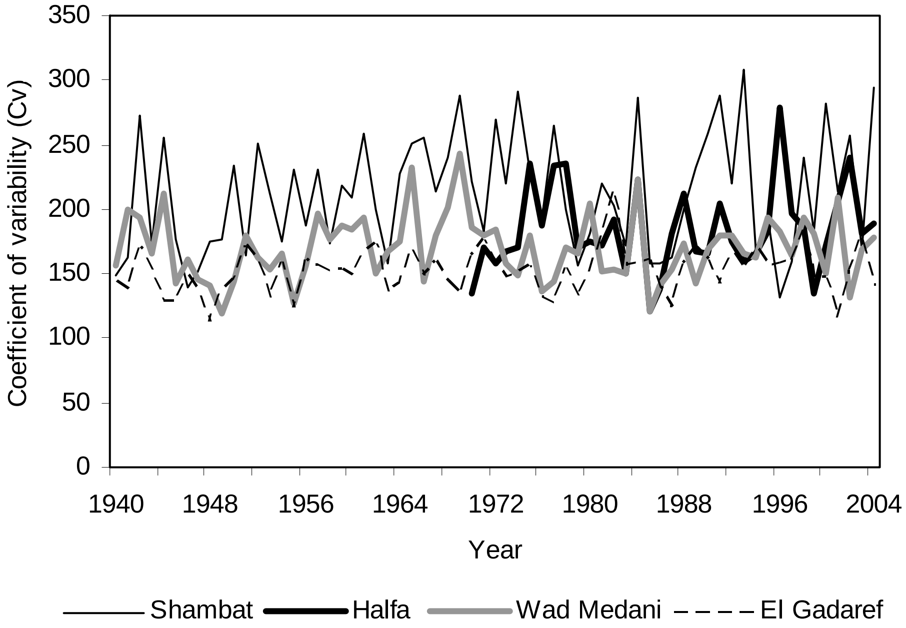


Figure 2.4 The coefficient of variability of the four stations in the Butana area

Table 2.3 Trends in inter–annual rainfall variability and their Significance levels ($p = 0.05$)

Station	Trend	p
Shambat	0.436	0.022*
Halfa	0.494	0.447^{ns}
Wad Medani	0.046	0.268^{ns}
El Gadaref	0.213	0.038*

ns = not significant (at $p = 0.05$); * = significant (at $p = 0.05$)

Figure 2.5 shows the cumulative probability of non-exceedence of the annual rainfall for the four weather stations as a cumulative distribution function (CDF). The probability of the total annual rainfall not-exceeding 350 mm is 0.98, 0.87, 0.7, and 0.05 for Shambat, Halfa, Wad Medani and El Gadaref respectively. This means that the return period to receive annual rainfall of less 350 mm is every year in El Gadaref and once every 50 years in Shambat, while in Wad Medani and Halfa it is once every 3 and 8 years respectively. Figure 2.5 also demonstrates that 75% of the time the annual rainfall do not exceeded 170, 325, 382, and 656 mm at Shambat, Halfa, Wad Medani, and El Gadaref respectively.

The Kolmogorov-Smirnov (K-S) test results as shown in Table 2.4, prove that the CDFs of the annual rainfall of the four stations are significantly different.

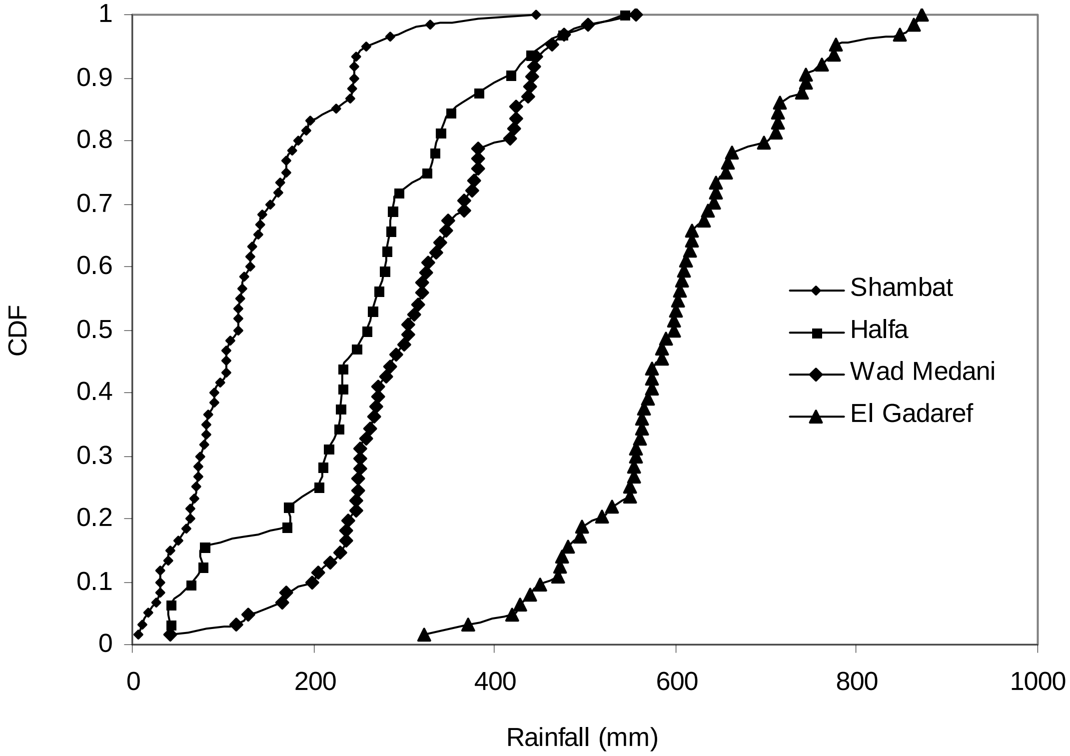


Figure 2.5 Probability of non-exceedence as a function of ranked annual rainfall for the four stations (data from 1940-2004)

Table 2.4 Kolmogorov-Smirnov (KS) test statistics, D, for comparing the CDFs of the annual rainfall

Station	Halfa		Wad Medani		El Gadaref	
	D	*p*	D	*p*	D	*p*
Shambat	0.614	0.000*	0.751	0.000*	0.967	0.000*
Halfa	-		0.295	0.047*	0.875	0.000*
Wad Medani	-		-	-	0.857	0.000*

* = significant (at $p = 0.05$)

Figure 2.5 and Table 2.4 prove that the rainfall amount in the Butana area is significantly different as one moves southward to areas that receives more rainfall as there is a clear difference between El Gadaref and Shambat. While comparing Wad Medani and Halfa the difference is also significantly, but to a lesser extent, as compared to El Gadaref (south) and Shambat (north), however this difference could only be due to the difference in the length of the record period (63 vs 34 years).

2.3.3 Time series analysis of the rainfall data

The time series analysis conducted using monthly and long-term annual rainfall for the four stations bordering the study area, show that there has been a gradual decrease in the monthly and annual rainfall during the period of 1940 to 2004 for Shambat and Wad Medani and from 1970 to 2004 for Halfa (Figure 2.6 and 2.7). While El Gadaref shows a gradual increase for both monthly and annual rainfall. The statistical analysis of the deviation from zero ($H_{o:}$ b = 0) proved that the trend for annual and monthly rainfall of Wad Medani and Shambat decline significantly, while for Halfa and El Gadaref the trend does not significantly decline or increase (Table 2.5).

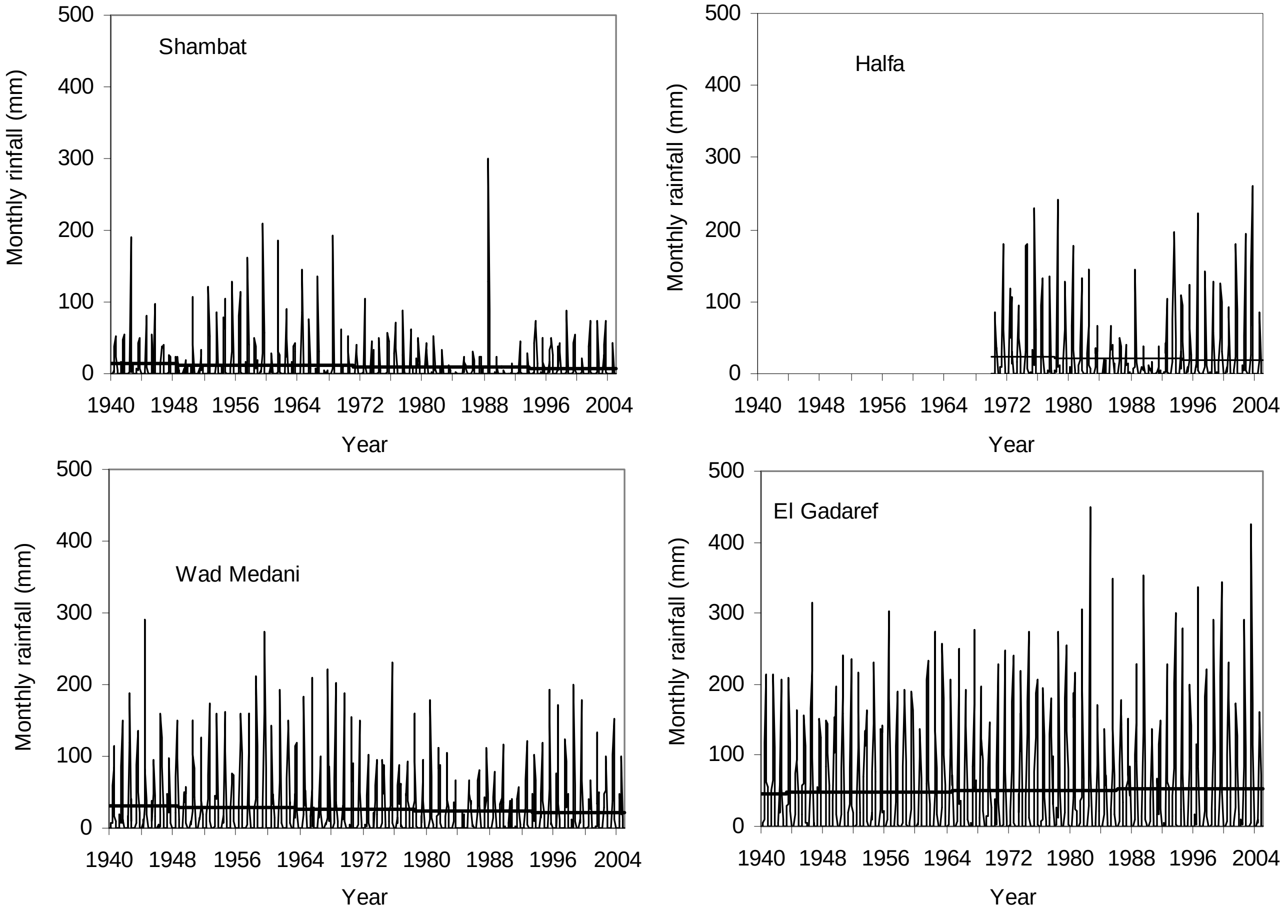


Figure 2.6 Monthly total rainfall for the four weather stations showing the trend line

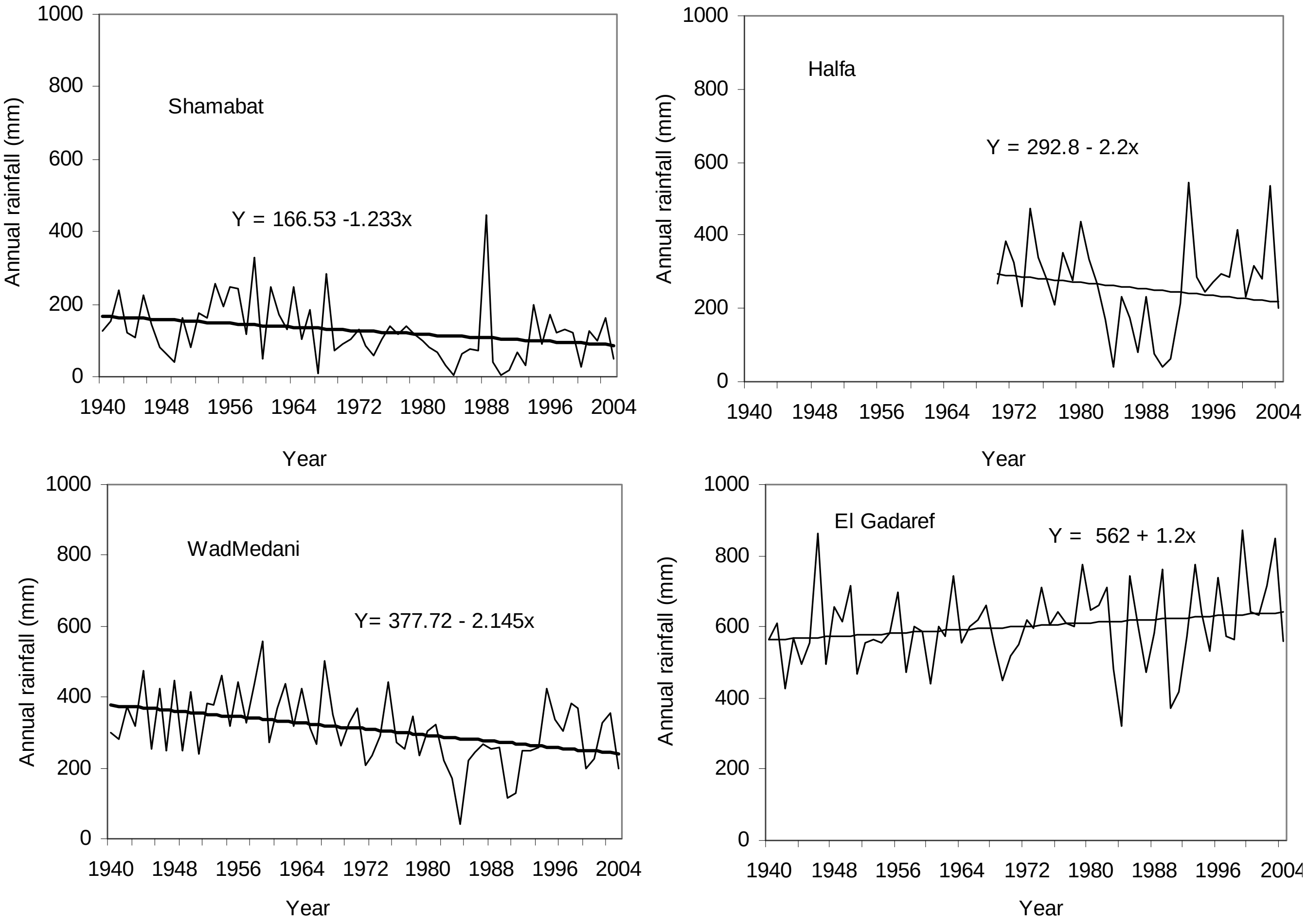


Figure 2.7 Annual rainfall for each of the four weather stations in the Butana area together with the trend line and equation

Table 2.5 The trend of the annual and monthly rainfall and their significant levels (*p* = 0.05)

Station	Annual rainfall		Monthly rainfall	
	Trend	*p*	Trend	*p*
Shambat	-1.23	0.025*	-0.009	0.028*
Halfa	-2.22	0.379^{ns}	-0.012	0.574^{ns}
Wad Medani	-2.15	0.002*	-0.016	0.044*
El Gadaref	1.21	0.101^{ns}	0.012	0.425^{ns}

ns = not significant; * = significant

Tarhule and Woo (1998) suggested that it is important to partition the entire period of the rainfall record into sub-periods that can represent distinct sectors divided according to changes in either the direction or the magnitude of the trend. In order to detect the periods of abrupt change, the method of cumulative departures from the long-term mean (Reynolds, 1956) has been adopted.

Figure 2.8 illustrates this analysis for the four stations; which clearly identify the step changes or jumps occurring in the annual rainfall. Data indicate that in Shambat and Wad Medani from 1968 to 1994 there was a decreasing trend of the annual rainfall. After this period the rainfall is close to the long-term mean. In El Gadaref there is a decrease during 1950s until the beginning of 1970s however this decrease recovered from 1975 to 1982 when the station received rainfall higher than the long-term mean (Figure 2.3), then there is another turning point during 1988 to 1994. While in Halfa there is decrease during 1982 to 1993. Using this approach, the statistical analysis of the sub-periods indicate that there are significant changes, that is, p = 0.0005; 0.00135 and 0.0304 for Wad Medani Shambat and Halfa respectively. But the change is not significant in El Gadaref with p = 0.35.

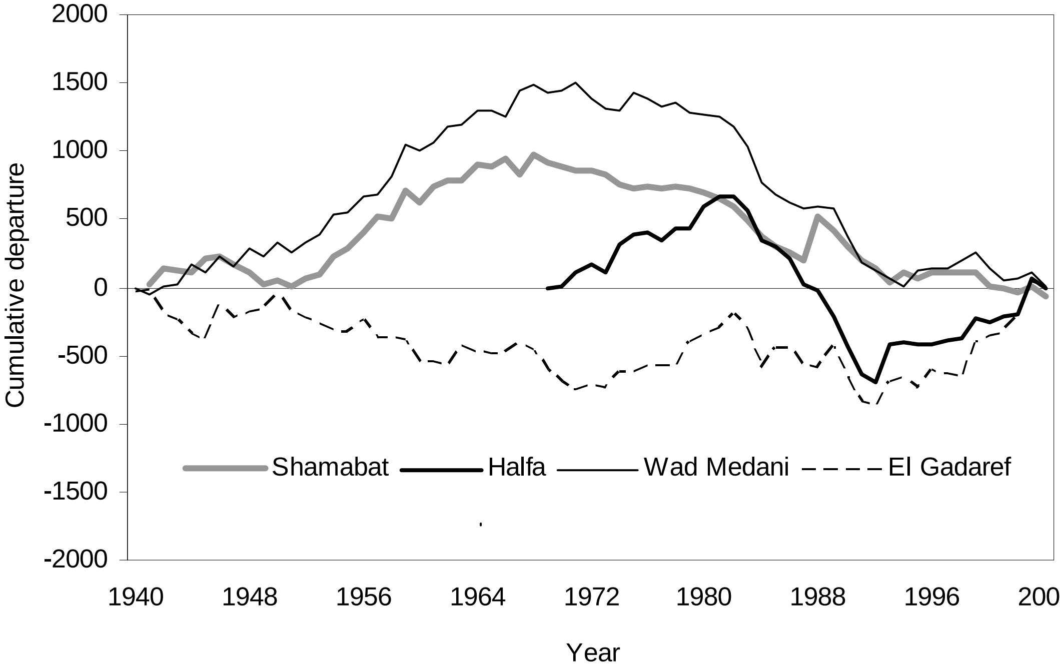


Figure 2.8 The cumulative departure from the long-term mean of the annual rainfall for the four stations in Butana area

The rainfall series for Shambat and Wad Medani from 1940 to 2004 showed a progressive decline since late 1960s. This result agrees with the investigation of annual rainfall series for the western and central Sudan by Eltahir (1989), who indicated that for a record period of 1928-86 the decline is significant and cannot be considered random.

The annual rainfall amount depends on the magnitude of the seasonal (monthly) effect on the average (seasonal index). The July and August rainfall make the highest contributions to the annual rainfall in Shambat, Halfa and El Gadaref, while June and July have the highest effect at Wad Medani (Figure 2.9). April, May and October have negative effects on the annual rainfall for El Gadaref, Shambat and Halfa (Figure 2.9). In Wad Medani, May has a low positive effect on rainfall while September and October have negative effects. The comparison between the observed monthly rainfall and the monthly rainfall predicted using seasonal variation index (Figure 2.10) showed that the fluctuation of the rainfall in Wad Medani is mainly due to a seasonal effect while in Shambat, Halfa and El Gadaref the seasonal variation has less of an effect.

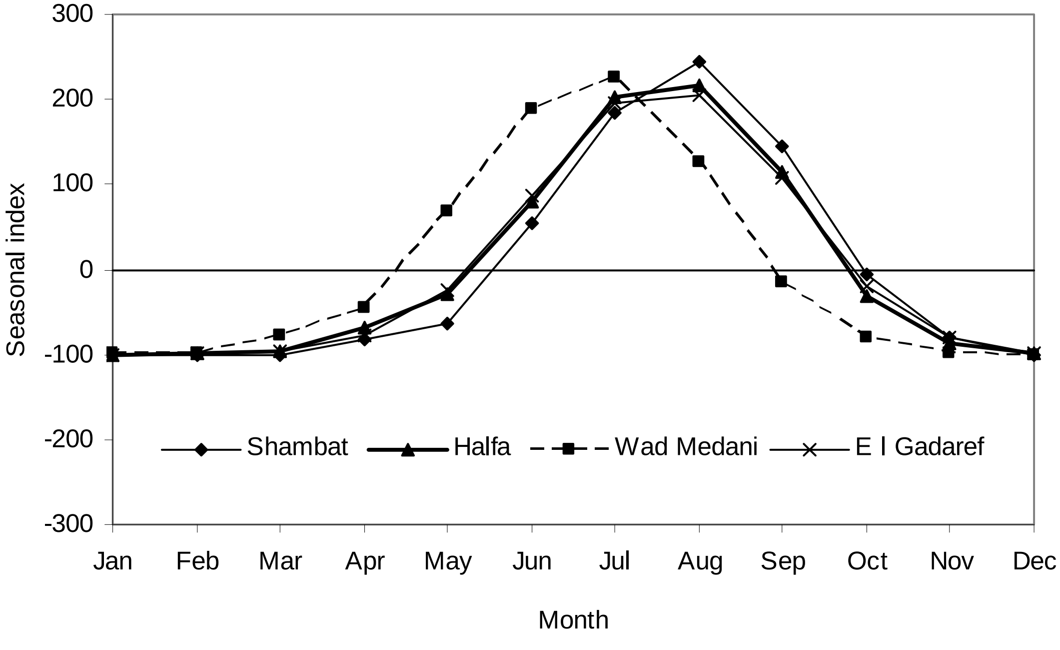


Figure 2.9 The seasonal index for Shambat, Halfa, Wad Medani and El Gadaref weather stations

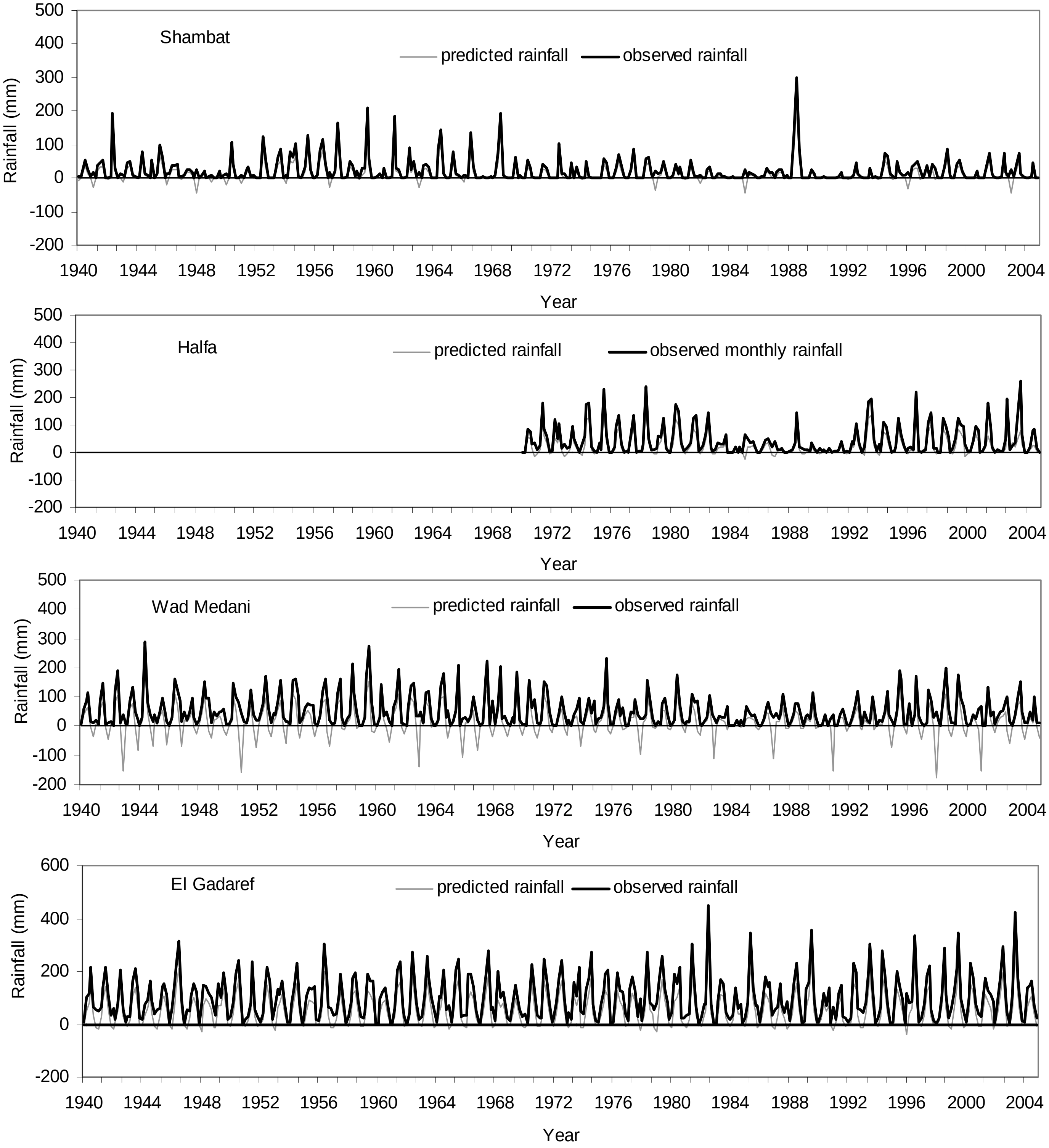


Figure 2.10 Observed rainfall and the rainfall predicted using the seasonal variation index for the four weather stations

2.3.4 Time series analysis of temperature data

The time series analysis for the air temperature shows that there is an increasing trend for both maximum and minimum temperature (Figure 2.11) but it is not statistically significant for Shambat and Halfa. Also the maximum temperature of Wad Medani is not significant, although this station had a significant increase in the minimum temperature. The El Gadaref station shows a significant increase in the both maximum and minimum temperature (Table 2.6).

For the four stations the trend of maximum and minimum temperature were examined separately for the summer (March-May), autumn (June-October) and winter (November-February) seasons. From Table 2.7 and 2.8 it can be noted that the trend is increasing for the maximum and minimum summer temperature for the all stations but the trend is only significant in El Gadaref for the maximum temperature and for the minimum temperature at Wad Medani. The trends of the maximum and minimum autumn temperature are increasing significantly for El Gadaref, Shambat and Wad Medani. However in Halfa the maximum autumn temperature is not statistically significant. Maximum winter temperature showed an increasing trend for Shambat, Halfa and El Gadaref, but this increase is significant only for El Gadaref, while Wad Medani had a slight decreasing trend. The minimum winter temperature showed a significant increasing trend for El Gadaref and Wad Medani, with the increase not being significant in Halfa, but Shambat had a significant decreasing trend.

Table 2.6 The trend of the annual maximum and minimum temperature and their significant levels ($p = 0.05$)

Station	Trend (Tmax)	p	Trend (Tmin)	p
Shambat	0.0018	0.0623^{ns}	0.0015	0.1183^{ns}
Halfa	0.0007	0.5559^{ns}	0.0027	0.0886^{ns}
Wad Medani	0.0008	0.0907^{ns}	0.0016	0.0097*
El Gadaref	0.0019	0.0001*	0.0015	0.0002*

ns = not significant; * = significant

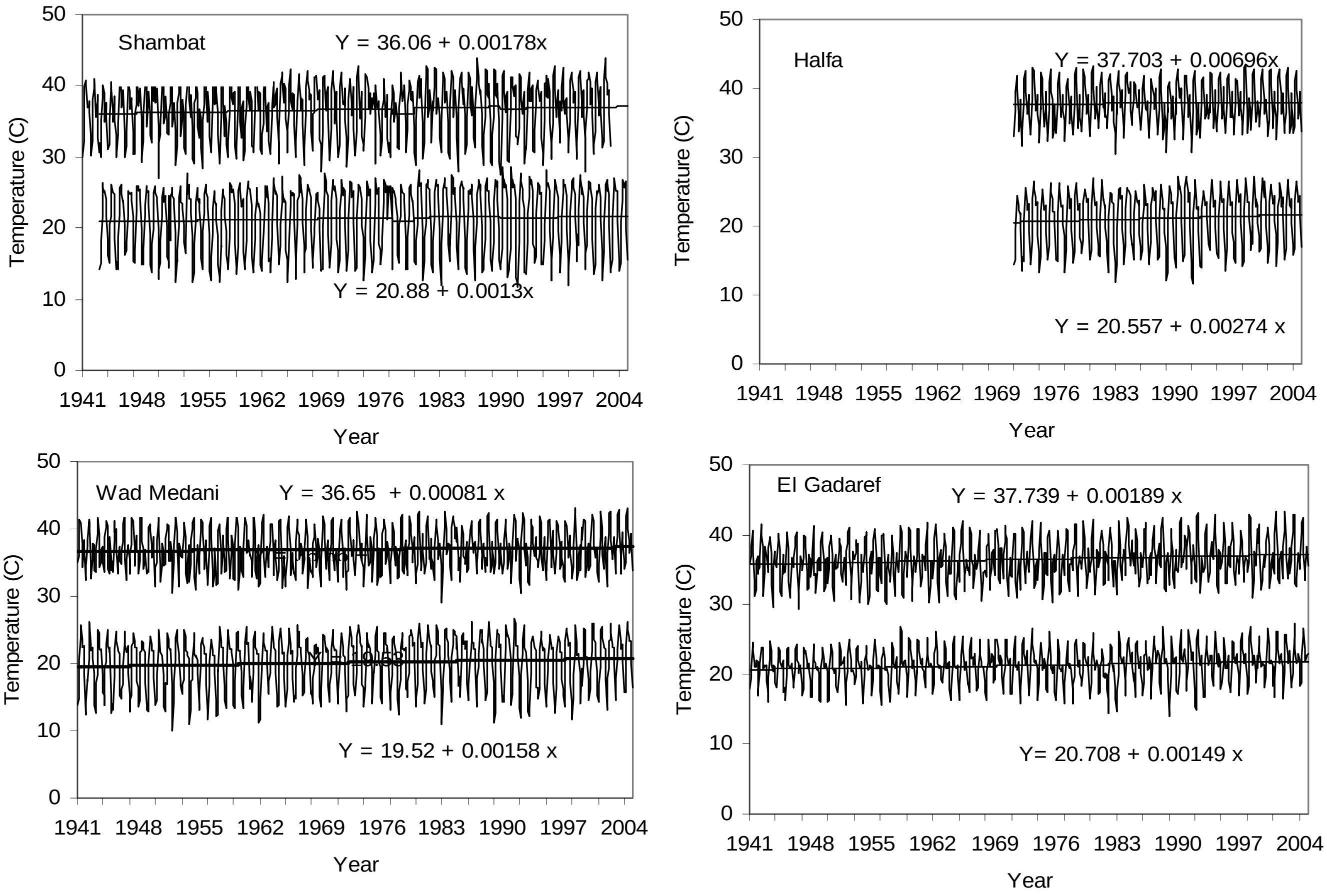


Figure 2.11 The trend of the minimum and maximum temperature for the four weather stations located in the Butana area

Table 2.7 Trend of maximum temperature and their significant levels

Station	Maximum Temperature					
	Summer		Autumn		Winter	
	Trend	*p*	Trend	*p*	Trend	*p*
Shambat	0.009	0.0851 ns	0.007	0.001*	0.001	0.866 ns
Halfa	0.005	0.4121 ns	0.001	0.973ns	0.005	0.292 ns
Wad Medani	0.004	0.0816 ns	0.004	0.006*	-0.008	0.625ns
El Gadaref	0.010	0.0001*	0.006	0.000*	0.003	0.009*

ns = not significant; * = significant (at *p* = 0.05)

Table 2.8 Trend of minimum temperature and their significant levels

	Minimum Temperature					
	Summer		Autumn		Winter	
Station	Trend	p	Trend	p	Trend	p
Shambat	0.004	0.495 ^{ns}	0.006	0.000*	-0.002	0.003*
Halfa	0.012	0.256 ^{ns}	0.006	0.004*	0.007	0.194 ^{ns}
Wad Medani	0.009	0.007*	0.003	0.002*	0.005	0.016*
El Gadaref	0.005	0.069 ^{ns}	0.004	0.002*	0.004	0.001*

ns = not significant; * = significant (at $p = 0.05$)

Thus warming conditions can be observed to characterize summer and autumn, with highest temperatures recorded mostly during the 1980s and 1990s. The slight falling trend of the winter time series was dominate in Wad Medani and Shambat. The lowest winter temperatures were also in 1980s and 1990s. A significant increase in the temperature is associated with the autumn season, which encountered dry conditions during the most recent period. These observations reinforce the conclusions of Wigley (1988) which indicate increased likelihood of extremes in a changing climate as well as Elagib and Mansell (2000) who showed most of the stations in Sudan have experienced warming conditions since 1966-1978.

2.3.5 Evapotranspiration

Halfa, Wad Medani and Shambat stations always had the highest potential evapotranspiration (ET_o) values during May and June, and the lowest values calculated during January and December (winter season). For El Gadaref station the highest values are in summer April and May with the lowest value during August and September, this being associated with the rainy season in the El Gadaref area (Figure 2.12). It can also be noticed that ET_o had an increasing trend from 1960s to mid-1980s, with high variability for the April, May, and June, while there is less variability in ET_o for December and January for all stations. This can be interpreted due to the warmer conditions during the summer season and the drought that effected the area from late 1960s.

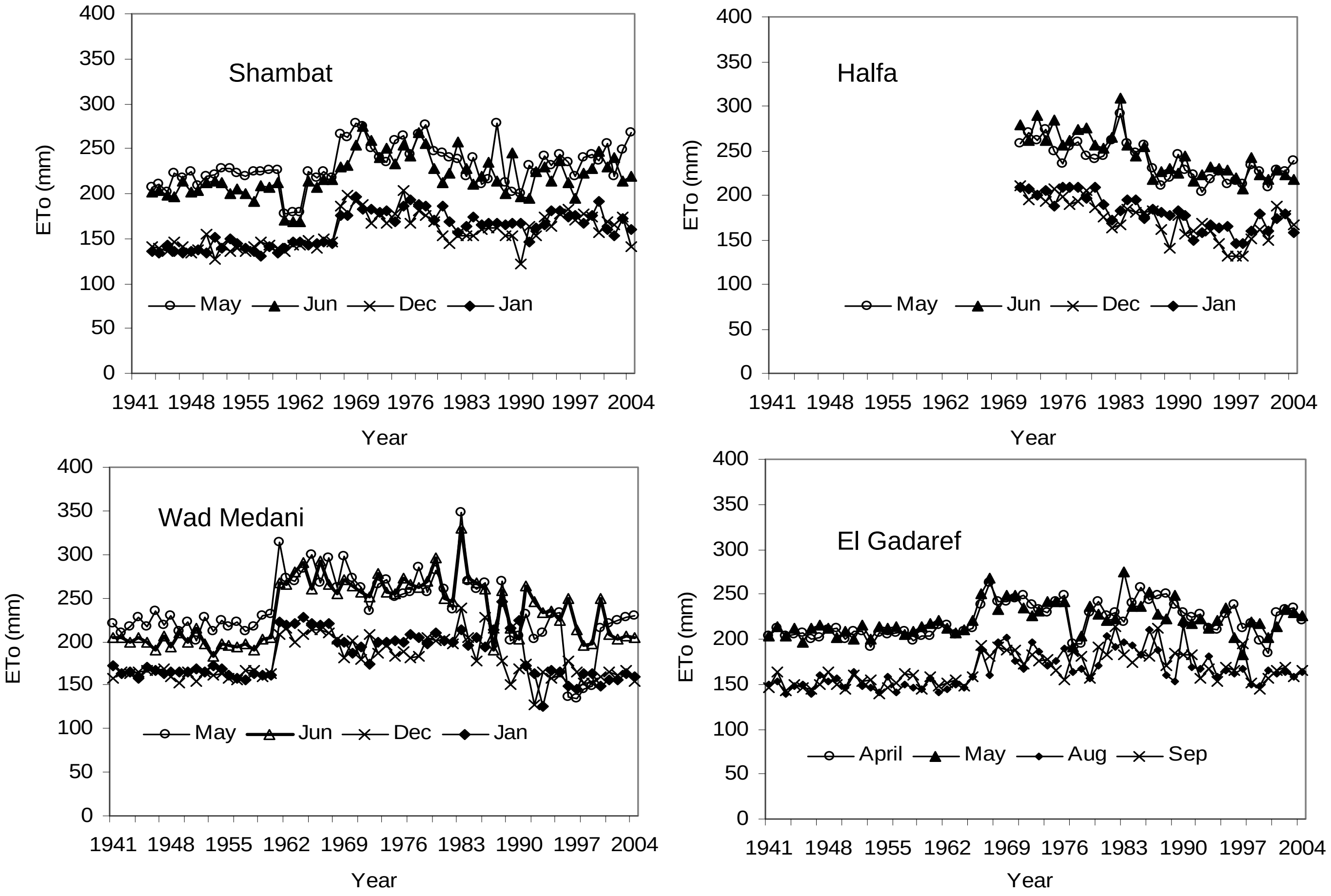


Figure 2.12 The highest and lowest values for the evapotranspiration for the four weather stations

When comparing the long-term mean of monthly ET_o, maximum and minimum temperature, and rainfall it was found that in El Gadaref the rainfall amount does exceed the ET_o during August (Figure 3.13) because during this month the maximum and minimum temperature had dropped to a minimum value. The timeline of monthly ET_o estimates were also compared with the monthly rainfall amount, to examine the moisture deficit in the Butana area (Figure 2.14). At El Gadaref the rainfall exceeded the ET_o during August about (21 times) 33% during the last 64 years. In Wad Medani, the August rainfall exceeds the ET_o about 11 times only (17%). While in Shambat and Halfa it is rare that rainfall exceeded the ET_o. There is a statistically significant increase in ET_o at El Gadaref and Shambat, while in the case of Wad Medani the trend shows an increase in ET_o but it is not significant. Halfa station shows a decrease in the ET_o which is significant (Table 2.9).

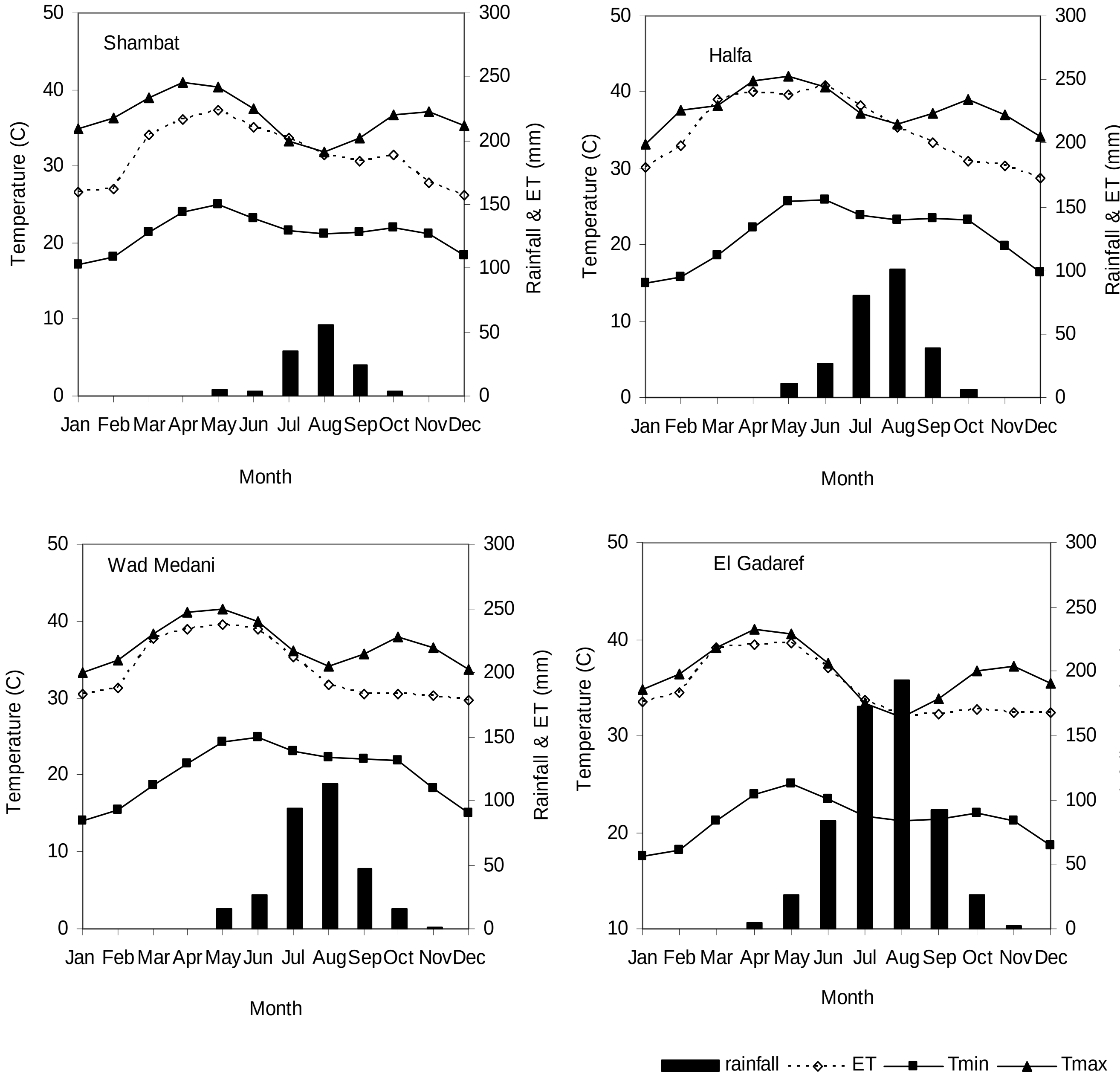


Figure 2.13 Long-term average of rainfall, ETo and maximum and minimum temperature for the four weather stations (Data from SMA)

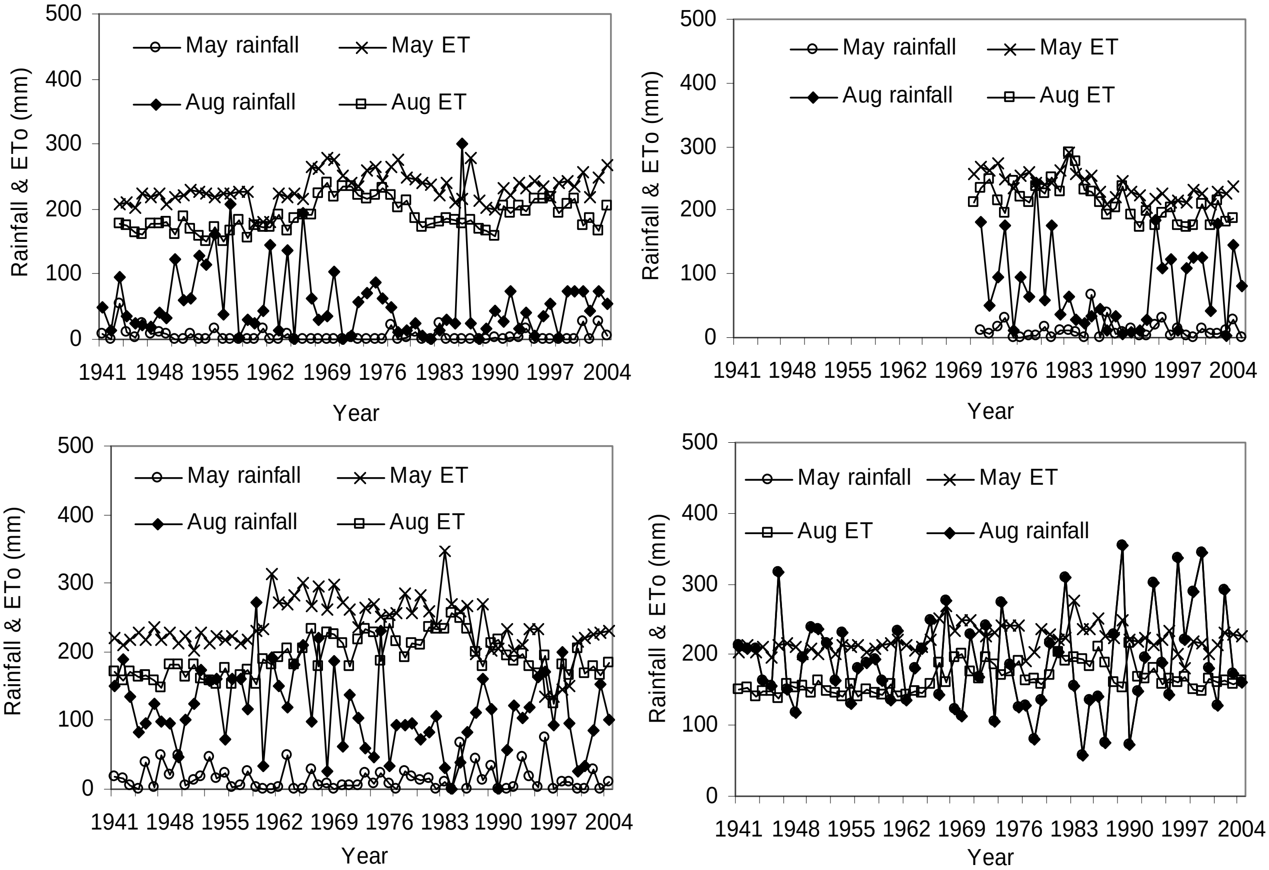


Figure 2.14 Monthly rainfall and monthly ET_o for the Shambat, Halfa, Wad Medani and El Gadaref respectively (Data from SMA)

Table 2.9 The trend of monthly ET_o and their significance levels ($p = 0.05$)

Station	Trend	*p* (0.05)
Shambat	0.0335	0.000*
Halfa	-0.138	0.00006*
Wad Medani	0.0028	0.648 ^{ns}
El Gadaref	0.0226	0.000024*

ns = significant; * = significant

2.3.6 Aridity index

Having demonstrated the changes in climatic conditions and patterns, it is useful to consider the possible changes in the aridity conditions also. According to the UNEP the highest aridity index values were obtained in July and August as during these months the area receives its highest rainfall. Minimum aridity index values were found during June and October, when the rainfall is low and evapotranspiration is high (Figure 2.15). The aridity index increased from late the 1960s to 2004 and this is mainly due to the increase in the variability of the rainfall during the same period see Figure 2.4.

From Figure 2.16 and Table 2.10 it can be concluded that the annual aridity index is increasing with time at Halfa and El Gadaref although they are not significant. There is a significant decreasing trend of the annual aridity index at Wad Medani and Shambat, indicating that there are intensifying arid conditions across the northern part of Butana area. The aridity index was considerably lower during the period between 1983 to 1991 when the area experienced severely dry years, namely 1984 and 1990. During the drought years the aridity index values for each of four sites moved to the next lower zones, which indicates the change in the climatic conditions of the area. There is an apparent tendency for a number of wet years to occur during the end of the study period (2001-2004).

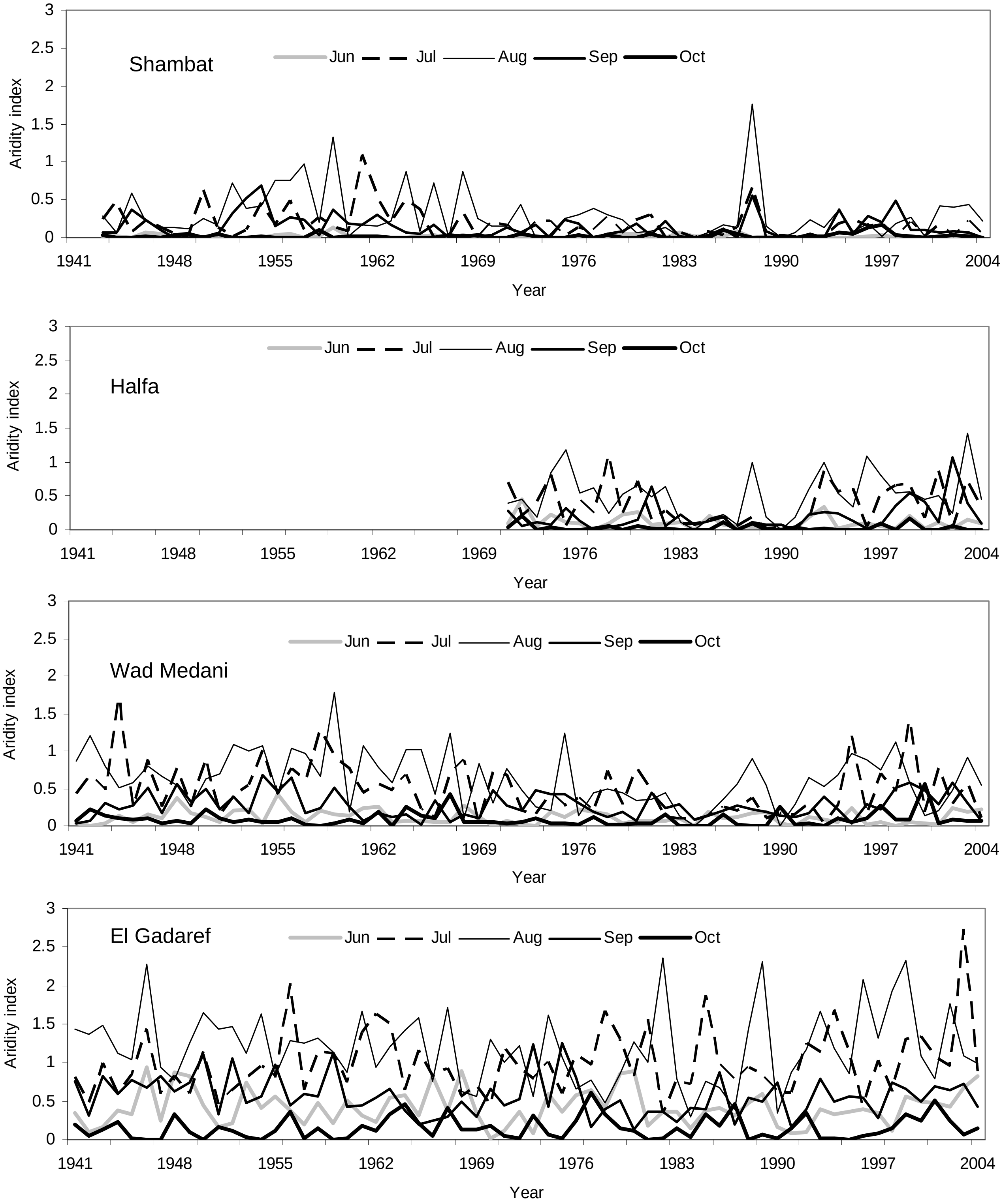


Figure 2.15 Aridity index for each month in the rainy season (June – October) for the four stations

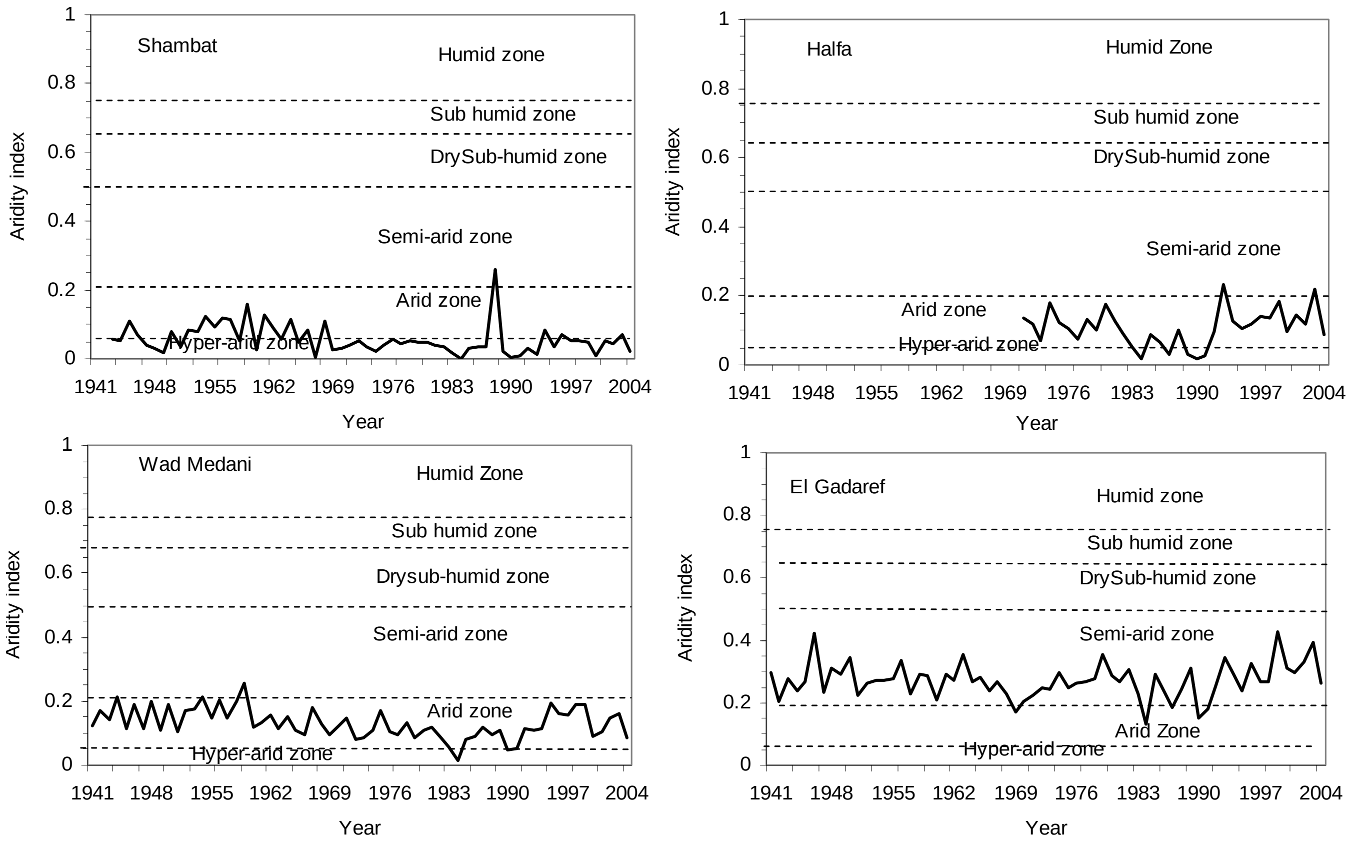


Figure 2.16 Trend of annual aridity index for the four stations located in Butana area

Table 2.10 The trend in annual aridity index and its significant level

Station	Trend	*p* (0.05)
Shambat	-0.0007	0.032*
Halfa	0.0008	0.390 ^{ns}
Wad Medani	-0.0009	0.003*
El Gadaref	0.0002	0.654 ^{ns}

ns= not significant; * = significant

2.3.7 Standardized Precipitation Index

The occurrence of drought is illustrated using SPI for the 6-month time scale (Figure 2.17) for all four stations, in decade steps, August has moderately wet to very wet conditions, while July is always moderately wet to near normal, as these two months received the highest rainfall during the rainy season.

Figure 2.18 illustrates the 12-month time scale SPI, where Wad Medani has experienced many moderately wet to very wet years during the beginning of the study period (before

1970s) and there are two extremely dry years namely 1984, 1990, and one severely dry 1991, while 1972, 1983, and 2000 were moderately dry. These 6 years out of 64 or 10% of the time, but it should be noted that these years all occur after 1972 until present in contrast with none occurring during the 30 years before 1972. In El Gadaref area 41 years out of 65 years (or 63%) are near normal, but the area has experienced extreme dry years in 1984, 1990, while 1942 and 1991 were severely dry. About 15% of study period is moderately wet for Halfa and Shambat, with 1984, 1990 and 1991 when it is moderately dry in Shambat and severely dry years in Halfa. Based on the above analysis of stations across Butana, SPI showed that throughout the Butana region the severe drought has occurred during 1984, 1990, 1991, while the drought during 1972, 1983 and 2000 affected only some parts of the area.

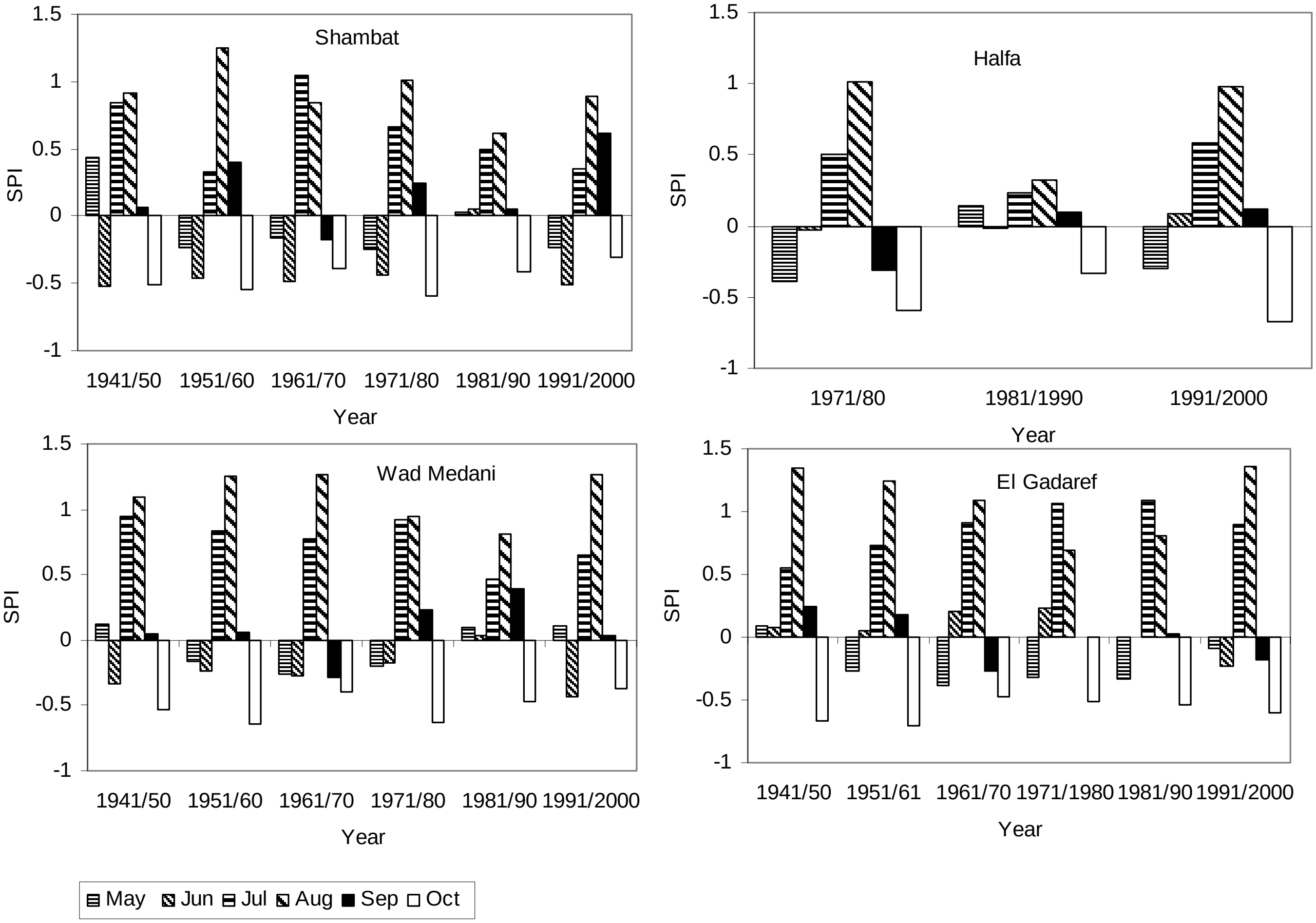


Figure 2.17 Ten years average of the standardized precipitation index for 6 months time scale (SPI)

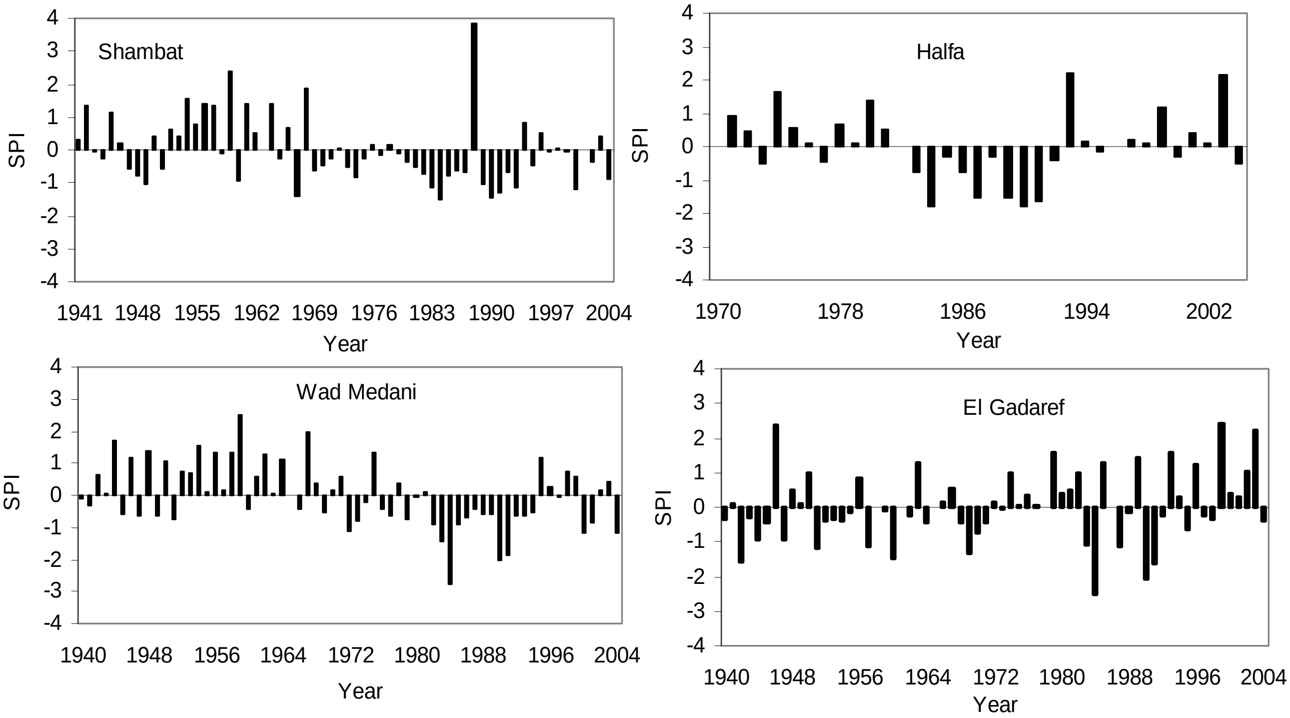


Figure 2.18 Annual Standardized Precipitation Index (SPI) for the four weather stations using 12-month time scale

2.4 Conclusions

With the long-time series of climate data inhomogeneity is commonly expected due to changes in instruments or observation practices. However, the Von Neumann's ratio proved that the monthly and annual rainfall data of El Gadaref, Halfa, Shambat and Wad Medani are homogenous and so can be used with confidence for further analysis.

The rainy season in Butana area starts in May and ends in October with the peak always occurring during August. The northern part of the area had experienced wet years during the 1950s and the beginning of the 1960s with rainfall below the median during the period 1968 to 1994. The El Gadaref data which represent the southern part of the area has the same number of years below and above the median, and received the highest amount compared to the rainfall of all the other stations.

The Kolmogrov-Smirnov test showed that the annual rainfall is significantly different for the four weather stations located in Butana area. The rainfall variability increase during the late 1960s to mid-1990s when the area consistently received rainfall lower than the long-term mean. There is significant increasing trend of the rainfall variability for Shambat and El Gadaref, while these increases are not significant for Halfa and Wad Medani. Shambat had the highest variability among the stations. This means that the variability increase with decreasing annual rainfall amount, as is common in arid and semi-arid areas in Africa.

The decomposition method of the time series analysis has shown that the trend of the monthly and annual rainfall decreases in Shambat, Wad Medani and Halfa. The statistical test for this decrease has shown that the decrease is only not significant for Halfa and this may be due to the short record period (1970-2004). The trend of the rainfall for El Gadaref shows an increase in rainfall but this increase is not significant. The significant decline in the amount of rainfall and increase in the variability of the annual rainfall at Wad Medani and Shambat which both represent the northern part of the Butana area gives evidence that there is a change in the rainfall pattern which cannot be considered random during the 60 years period between 1940 - 2004.

The trend in the temperatures at Shambat, Wad Medani and Halfa show an increase in both minimum and maximum temperatures but the statistical analysis indicates that the deviation from zero slope is not significant. A significant increase in the temperature is associated with the autumn season, which encountered dry conditions during the most recent years. El Gadaref station shows significant increase in both maximum and minimum temperature.

The evapotranspiration values for all the sites exceed the rainfall even during the rainy season except in El Gadaref where rainfall exceeds evapotranspiration only in August. This indicates there is always a water deficit in Butana area especially in the northern part. The increasing tendency of temperature and decline in the rainfall amount in the area accentuates the increasing evapotranspiration. Oliver (1965) mentioned that rainfall characteristics, such as length of rainy season, distribution and time of falls during the day, are important factors governing the evapotranspiration in Sudan. There are also indications of increase in the drought stress resulting from the deficiency of rainfall (supply) and increased evapotranspiration (demand). There was an increasing trend in the aridity index which represents the relation between the rainfall and potential evapotranspiration. This increase is not significant for Halfa and El Gadaref but there is a significant decreasing trend in Shambat and Wad Medani, showing that the northern part of Butana area has become more arid.

The Standardized Precipitation Index (SPI) was used to identify the occurrence of the drought periods during 1940 – 2004. There is moderate drought at El Gadaref during 1951 and 1957, in 1972 there was moderate drought at Shambat, Halfa and Wad Medani, while 1984 was severely dry in Halfa and extremely dry at Wad Medani and El Gadaref. In 1990 and 1991 there was a severe to extreme dry condition at El Gadaref, Halfa and Wad Medani, while Shambat was moderately dry. That means that the 1990s drought was the most severe and covered most of the area. The 2000 drought covered only the north western part of the Butana area which is represent by Shambat and Wad Medani, during the period between 1960s and 1990s the drought occurred most frequently in those areas. The SPI and Aridity index give evidence that the northern part of the Butana area has become drier since the 1960s Sahelian drought.

Chapter 3

Rainfall and the Impact of Human Activities on Vegetation Cover

3.1 Introduction

Climate variability has a large impact on the renewable natural resources, but the impact is not the same for every region; it will be stronger for regions with a delicate balance between climate and ecosystem including the Sahel and parts of the Mediterranean region. Vegetation as part of the ecosystem is very sensitive to climate variability. Both the growing season and the total amount of vegetation, together called the vegetation dynamics, are strongly affected by climatic variability (Roerink *et al*., 2003).

The Butana area is sparsely vegetated as a result of the low amount of rainfall. The vegetation is exposed to extreme conditions and must survive drought, which can stretch over several years with little or no rain at all (Akhtar and Mensching, 1993; Ayoub, 1998b). In semi-arid ecosystems with a single rainy season there is usually a short growth period followed by a long dry season with a great reduction in the amount of green plant material (Hinderson, 2004). Pflaumbaum (1994) reported that during the dry season of 1990 the climate induced a boundary shift of extended useable pasture in the Butana region southward by about 400 km.

Rainfall is the most important climatic factor in the Butana area. All people and their livestock depend on the amount of rainfall that falls to support the growth of the plants. They use the land as a grazing area and some of them cultivate the "wadis" or the seasonal water courses. The rainfall is characterized by its obvious seasonal variations. The wet season extends from June to September, when all the nomads converge on the Butana from different regions to graze the available pastures. October and November are periods when the livestock start to feed on the litter of the plants that are beginning to wither and vanish. In winter, December to February, the nomads are preparing to face the dry season from March to May, when they concentrate around the permanent water points, graze the little pasture in those areas, or migrate to irrigation schemes around the area to purchase fodder for their animals (Abu Sin, 1970; Elhassan, 1981; Holter, 1994a).

Remote sensing techniques have now become the single most effective method for land-cover and land-use data acquisition (Lillesand *et al*., 2004). Monitoring of vegetation by remote sensing techniques is an accepted and effective technique of resource assessment and it is commonly used in the quantitative description of vegetative growth (Menenti *et al*., 1993; Justice and Hiernaux, 1986). Satellite data are also increasingly used to relate vegetation indices to climatic parameters (Roerink *et al*., 2003; Hess *et al*., 1996). In this context, remote sensing can provide an indirect measure of vegetation growth through the calculation of vegetation indices. The Normalized Difference Vegetation Index (NDVI) is one of the most widely used indices for vegetation monitoring (Deering *et al*., 1975; Tucker, 1979).

3.1.1 Remote sensing

Remote sensing means measuring at a distance without physical contact. When the sun's electromagnetic energy reaches the earth's surface, it will be reflected, absorbed or transmitted. The radiation that is used to identify objects with different remote sensing techniques is either reflected or emitted energy (Lillesand *et al*., 2004). The proportions accounted for by each process depend upon the nature of the surface, wavelength of the energy and angle of illumination (Campbell, 2002). Remote sensing uses the knowledge that radiation intensity within different wavelengths is often typically emitted by different objects, thus giving different objects different spectral signatures (Figure 3.1). For example, at a certain wavelength, sand reflects more energy than green vegetation while at other wavelength it absorbs more (reflects less) energy. Therefore, these spectral signatures can be used to distinguish one object from another or to obtain information about shape, size and other physical and chemical properties (Campbell, 2002). When the radiation passes through the atmosphere it will be scattered by aerosols and clouds. This may lead to error in the data collected by remote sensing (Campbell, 2002).

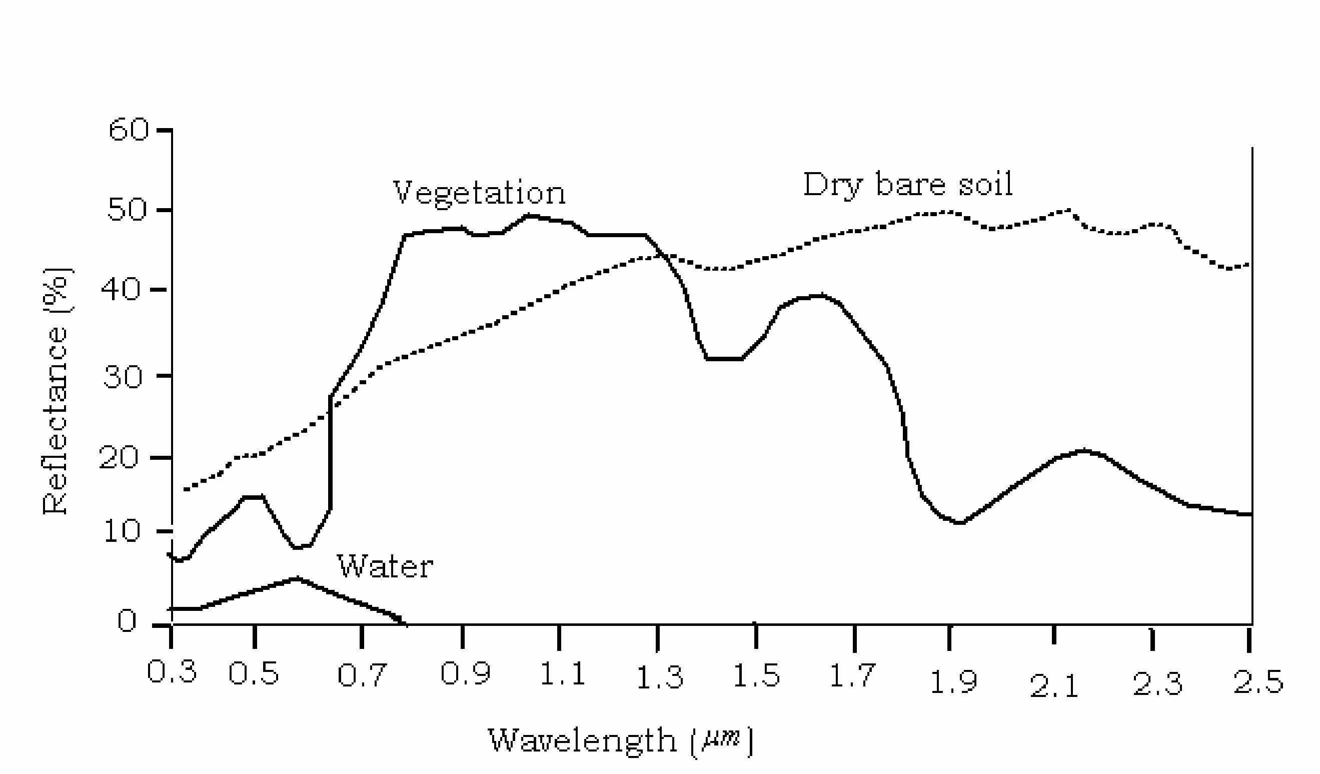


Figure 3.1 Spectral signatures for vegetation, dry bare soil and water (Tso & Mather, 2001)

Time series information about location and condition of vegetation of pasture areas is one of the key elements for effective management of pastoral (extensive) livestock. Remotely sensed data derived from satellites have successfully being utilized for decades in assessment of pastureland productivity, predicting biomass and monitoring the vegetation health status (Reeves *et al.*, 2001; Lillesand *et al.*, 2004) in temporal and spatial scales. It was also proved to be economically feasible to make routine measurements (Tueller, 1989). Many researchers have studied vegetation growth and its productivity in two different directions. One is to establish empirical relationships between spectral reflectance and biomass (Tucker *et al.*, 1983; Wylie *et al.*, 1995), the other is the use of spectral reflectance to estimate the amount of absorbed photosynthetically active radiation (Choudhury and Tucker, 1987) for ecosystem modeling. The first method is mainly used to estimate active growing biomass as the estimated biomass is well correlated with remotely sensed vegetation indices (Tucker *et al.*, 1983; Kennedy, 1989). However, this method does not take the existing dry mass into account (Reeves *et al.*, 2001). The second method is more successful for prediction of biomass, but it is based on regression models and depends on local environment parameters (Kennedy, 1989; Merrill *et al.*, 1993; Wylie *et al.*, 1995).

Many researchers use coarse to high resolution satellite and aerial images with a ground scale of 0.2 to 60 meters (Wylie *et al.*, 1995; Yool *et al.*, 1997; Weber, 2001) for pastureland assessment. High temporal resolution (for over 20 years), wide area coverage, availability and affordability make NOAA / AVHRR (National Oceanic and Atmospheric Administration / Advance Very High-Resolution Radiometer) satellite images very attractive for application in pasture assessment. However, the barriers to the use of high resolution data are the data availability and high cost of processing.

A few studies have taken place in the Butana area to estimate pastureland and vegetation dynamics from the remote sensing point of view. ElMobark (1991), Akhtar and Menching (1993), Akhtar (1994), Pflaumbaum (1994) and Eltayeb (1998) studied seasonal growth changes using satellite data, taking into account the soil background reflectance and percent vegetation cover.

3.1.2 The Normalized Difference Vegetation Index (NDVI)

Many natural surfaces are about equally as bright in the red and near-infrared part of the spectrum with the notable exception of green vegetation. Red light is strongly absorbed by photosynthetic pigments (chlorophyll) found in green leaves, while near-infrared radiation either passes through or is reflected by live leaf tissue, regardless of their color. This means that areas of bare soil that have little or no green plant material will appear similar in both the red and near-infrared wavelengths, while areas with green vegetation will appear bright in the near-infrared and very dark in the red part of the spectrum. By using these wavelengths, different vegetation indices can be produced. The NDVI is the most widely used vegetation index and many studies have demonstrated its ability to describe vegetative phenology.

NDVI is calculated from atmospherically corrected reflectance from the visible red (RED) and near infrared (NIR) channels as:-

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{3.1}$$

The resulting index value is sensitive to the presence of vegetation on the land surface and can be used to address issues of vegetation type, amount and condition. The NDVI values range from -1.0 to 1.0, where areas with vegetative cover have values greater than zero and negative values indicate non-vegetated surface features such as water, bare soil or the presence of clouds (Justice *et al.*, 1985).

The main advantages of the use of the NDVI for monitoring vegetation are:

i) the simplicity of the calculation;
ii) the high degree of correlation of the NDVI with a variety of vegetation parameters;
iii) the extensive area coverage and high temporal frequency of NOAA-AVHRR data (Hess *et al.*, 1996).

3.1.3 Relationship between rainfall and NDVI

Vegetative production in arid and semi-arid regions is closely related to the long-term average precipitation (Rosenzweig, 1968; Rutherford, 1980) and inter-annual rainfall variability (Le Houérou *et al.*, 1988). The NDVI has been empirically shown to relate strongly to green vegetation cover and biomass using ground-based studies involving spectral radiometers (Boutton and Tieszen, 1983; Tucker *et al.*, 1983; Huete and Jackson, 1987; Beck *et al.*, 1990).

Many studies in the Sahel zone (Tucker *et al.*, 1985; Hielkema *et al.*, 1986; Malo and Nicholson, 1990) indicate meaningful direct relationships between NDVI derived from NOAA/AVHRR satellites, rainfall and vegetation cover as well as biomass. However, when predictions of rainfall or vegetation are compared for different NDVI based studies, highly variable relationships are found (Hielkema *et al.*, 1986). These relationships vary in terms of their predictive strength (coefficient of determination), amount of error (standard error or standard deviation), slope and y-axis intercept. There are many reasons for the variable relationships, including the fact that the studies have been conducted over many different soil and vegetation types, biomass, cover and greenness ranges and at different times of the year. However, probably the most important reason is that NDVI is seriously disturbed radiometrically due to complex radioactive interactions between the atmosphere, sensor view angle and solar zenith angle (Van Dijk *et al.*, 1987), these factors then reduce the reliability of the NDVI.

Many studies appear limited in that they do not incorporate the fundamental variability of NDVI when predicting vegetation and rainfall variables. Some studies use statistical filters to smooth NDVI profiles (Van Dijk *et al.*, 1987), but filtering can not remove the fundamental radiometric disturbance (Viovy *et al.*, 1992). Also, many of these studies promote the use of NDVI as a sensitive tool for monitoring small changes in vegetation cover and biomass, although their results often indicate coefficient of determination values of less than 0.6 (Hellden and Eklundh, 1988; Nicholson *et al.*, 1990; Davenport and Nicholson, 1993). Although NDVI is recognized as being limited in its use (Lillesand *et al.*, 2004), it is still mostly used without appropriate consideration of the limitations. The implication is that if NDVI is to be used as a prediction tool for rainfall and/or vegetation, the fundamental error in NDVI needs to be incorporated in such predictions. Furthermore, these relationships need to be calibrated for each climatic zone (arid, semi-arid etc.) in different parts of the world. Relationships found in the semi-arid Sahel region are not necessarily applicable to the semi-arid parts of Botswana (Farrar *et al.*, 1994; Nicholson and Farrar, 1994) or East Africa (Nicholson *et al.*, 1990).

NDVI is known to lag behind rainfall by up to three months as the changes in vegetative cover are not detected by satellite immediately (Eklundh, 1996). The time lag differs between climatic zones, in dry regions it is usually shorter than in humid regions. The rapid response to rainfall in dry regions is interpreted to be due to the critical dryness of the vegetation. In dry regions, the dominant vegetation is usually annual/perennial grasses, which respond rapidly to rainfall (Tachiiri, 2003). The satellite observed peak of NDVI occurs at the same time as the peak of the delayed response of annuals and perennials to rainfall (Schmidt and Karnieli, 2000). NDVI is also known to be affected by the soil background signal particularly in arid and semi-arid areas (Huete *et al.*, 1994).

The NDVI has been used extensively to qualitatively infer changes in vegetation response to rainfall in seasonally arid regions (Lambin *et al.*, 1993). Malo and Nicholson (1990) studied the relationship between NDVI and rainfall in the semi-arid Sahel of Mali and Niger. They concluded that the monthly NDVI could best be explained by a linear correlation with monthly rainfall. The best correlations were achieved when the rainfall of the preceding two months was also included. Justice *et al.* (1991b) studied a similar region of Mali and Niger and compared mean decadal NDVI with rainfall estimates from cold cloud duration. They observed a lag between rainfall and NDVI of between 10 and 20 days. Similar observations were made in East Africa (Davenport and Nicholson, 1993). Hess *et al.* (1996) and Van Zyl *et al.* (2004) concluded that there is a strong log-linear correlation between NDVI and rainfall. Di *et al.* (1994) developed an analytical model to investigate the response of peak NDVI and total duration of NDVI to a rainfall event. They showed that the peak vegetation response to a precipitation event becomes more delayed toward the later stages of the growing season which could be interpreted together with phenological data specifically if the vegetation is already at the reproductive phase. The good correlation observed between rainfall and NDVI, particularly when cumulative rainfall during a preceding period is considered, suggests that a predictive model, based on rainfall alone, could be developed for a given vegetation community.

The spatial responses of NDVI to precipitation and temperature during 1989–1997 in Kansas, USA was examined by Wang *et al.* (2001) and he concluded that the average precipitation is a strong predictor of the major east–west NDVI gradient. And the deviation from average precipitation explained most of the year-to-year variation in spatial patterns. NDVI and precipitation co-varied in the same direction (both positive or both negative) for 60–95% of the total area. Richards and Poccard (1998) conclude that mean seasonal NDVI is in accordance with the mean seasonal rainfall over the majority of southern Africa, except over deserts. The predicted monthly NDVI, derived from climate-based regression equations and Fourier smoothing algorithms, shows good agreement with observed NDVI for several different years at a series of ecosystem test locations from around the globe Potter and Brooks (1998).

All the above mentioned research studies generally achieved good correlation between rainfall and NDVI. Rainfall has a dominant role in determining vegetation growth which makes the minor biomass trends imposed by human influences difficult to identify (Evans and Geerken, 2004; Wessels, 2005). In order to identify changes that are due to human activities the climatic impact must be identified and removed from the NDVI datasets. The objective of this chapter is to examine the relationship between the vegetative cover and the rainfall and to identify the role of the rainfall variability and human activities on the vegetative cover degradation in the study area by using the time series of 8-km AVHRR–NDVI data.

3.2 Material and Methods

3.2.1 Study area

The boundary of the study area was adjusted according to the map developed by Pflaumbaum (1994) to avoid the area with sufficient or deficient water supply throughout the year together with areas in irrigation schemes, which may distorting the relationship between NDVI and rainfall for the drylands (Figure 3.2).

3.2.2 NDVI data.

The images of 10-day NDVI data at an 8 by 8 km resolution, from the Advance Very High-Resolution Radiometer (AVHRR) sensor flown on the National Oceanic and Atmospheric Administration (NOAA) satellites series were acquired from Global Inventory Monitoring and Modeling Studies group (GIMMS) for the Butana area covering the period from 13 July 1981 to 31 December 2003.

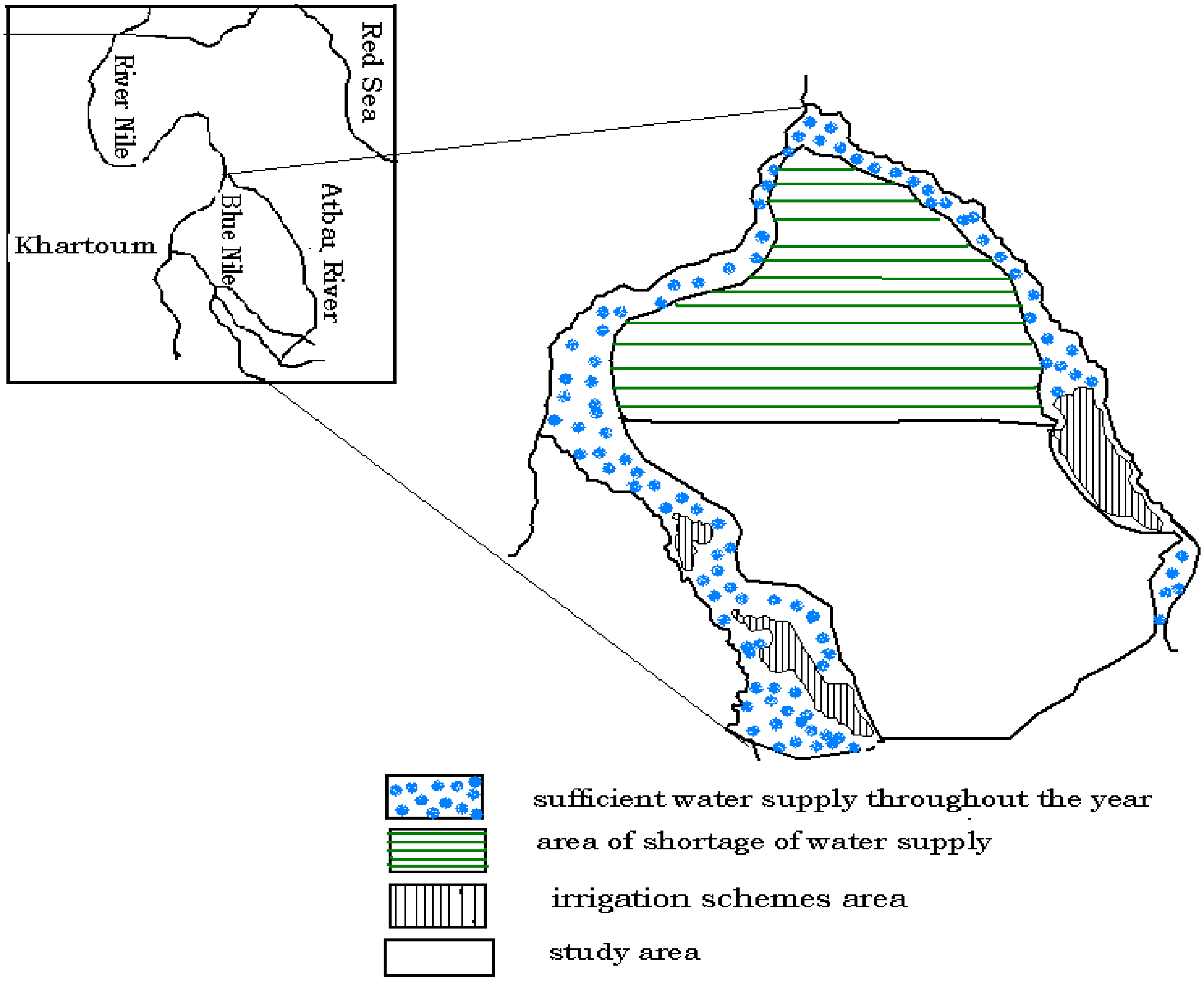


Figure 3.2 Map of the Butana area showing the boundary of the study area (Pflaumbaum, 1994)

3.2.3 *Rainfall data*

The rainfall data used in this analysis were the long-term monthly rainfall data for seven stations: Khartoum, Shambat, Wad Medani, Sennar, El Gadaref, Halfa, and Kassala from 1940 to 2000. The daily rainfall for four stations namely El Gadaref, Halfa, Shambat, and Wad Medani was also used from 1981 to 2004. This weather data was supplied by Sudan Meteorological Authority (Appendix A and Figure 1.1).

3.2.4 Data analysis

3.2.4.1 NDVI data processing

The GIMMS NDVI datasets were already corrected using solar zenith angle values from the AVHRR sensor for the period of 1981-2003 (Pinzon *et al.*, 2004, Tucker *et al.*, 2005). Preprocessing of this dataset involves corrections for sensor degradation, corrections for artifacts in NDVI due to satellite drift and corrections for stratospheric volcanic aerosols from volcanic eruptions in 1982 and 1991 (Slayback *et al.*, 2003).

The maximum value composite (MVC) of NDVI was calculated from a multi-temporal series of geometrically corrected and cloud screened NDVI images. On a pixel-by-pixel basis (picture element), each NDVI value is examined, and only the highest value over the specific period is retained for each pixel location by using Windisp 5.1 software. During the current study, MVC values were calculated from consecutive NDVI images over a 10-day period (10-day interval MVC). In addition the noisy pixels characterized by exceptionally high or low NDVI values identify by subtracting the original pixel value from a mean value was calculated by using 3x3 pixel matrix. The pixels having a difference of NDVI > 0.08 were considered as noise. Then this identified pixel was replaced by the average value calculated from the peripheral pixels of a 3x3 pixel neighborhood.

3.2.4.2 Departure from average vegetation greenness

Long-term time series image data provides an opportunity to quantitatively and qualitatively assess of the vegetation cover status in the past and present and to determine trends as well as being used to predict the ecosystem processes (Nemani and Running, 1997). An average of 23 years of NDVI data was computed for each image pixel and departure from its long-term average was then calculated for each year to evaluate a annual vegetation growth rate or greenness visually and statistically. The algorithm to produce the departure from average (Burgan *et al*., 1996) is:-

$$\text{Departure} = (\text{NDVI}_{cur} / \text{NDVI}_{avg}) * 100 \qquad (3.2)$$

where:

Departure = i^{th} pixel's departure value
NDVI_{cur} = current NDVI
NDVI_{avg} = long-term average NDVI
100 = a multiplier to scale the output for zero departure

Departure from average vegetation greenness can be applied for inter-annual assessment of vegetation cover status (Naidansuren, 2002). This temporally and spatially distributed information provides support to decision makers, planners, and agricultural managers and gives the opportunity to compare each year to the average of years in terms of vegetation growth, stress and productivity, resource allocation and pastureland overgrazing.

3.2.4.3 Interpretation of rainfall data

The Inverse Distance Weighting (IDW) method was used to create a rainfall surface for the Butana area. The IDW employs the Tobler's law by estimating unknown measurements as weighted averages over known measurements at neighboring points, giving the greatest weight to the nearest point (Burrough and McDonnel, 1998). The IDW algorithm is a moving average interpolator that is usually applied to highly variable data, and the general equation for the IDW method is:-

$$Z_j = \frac{\sum_{i=1}^{n} w_{ij} z_i}{\sum w_{ij}} \qquad (3.3)$$

where:

i = data point
j = interpolation point
w_{ij} = weight
z_i = data point of the monthly rainfall amount
Z_j = the weight average computed at j

The weight w_{ij} is

$$w_{ij} = \frac{1}{\left(r_{ij} + c\right)^b} \exp\left(-\mu r_{ij}\right) \qquad (3.4)$$

where:

r_{ij} = distance between points i and j

μ = attenuation coefficient

b = exponent (divergence into k-dimensional space; b = k -1)

c = smoothing parameter

Seven stations with monthly rainfall were used to create July, cumulative July/August and annual rainfall surfaces. While the daily rainfall for four stations (Shambat, Halfa, Wad Medani and El Gadaref) were summed for each 10 day period in accordance with the composite NDVI data periods and used to create 10 day rainfall surfaces.

3.2.4.4 Identification of rainfall and human activities impact on the vegetation cover

Evans and Geerken (2004) described a method that allows individual production-rainfall relationships to be developed for each pixel; after which negative trends in the production-rainfall relationship are used to facilitate the detection of potential human-induced effects. Analysis of the rainfall-production relationship for every pixel accommodates the effects of local variations in slope, soil and vegetation which all have a major influence on the nature of this relationship (Justice *et al*., 1991a). The residual trends method (RESTREND) uses the entire time-series to derive a production-rainfall relationship, which is then used to predict annual production based on rainfall (Wessels, 2005). Using the same time-series, it then identifies areas with negative trends in the difference between the observed and predicted production (residual=observed-predicted). Ideally the rainfall-production relationship should be derived from a time-series containing no degradation and a full range of rainfall conditions, after which trends in the residuals of an independent time-series could be used to detect reduction in production caused by factors other than rainfall, such as degradation. Unfortunately such an independent, non-degraded reference period does not exist, since degradation may have occurred at any time, from before the beginning to the end of the satellite record (i.e. 1981 to present). However, several different rainfall accumulation periods and lag times were tested in order to find the best correlation with NDVI, using a linear regression method. The best correlation was then used to calculate the residual trend, in order to remove the effect of rainfall.

3.3 Results and Discussion

3.3.1 General Characteristic of vegetation cover in Butana area of Sudan

According to the percentage of occurrence of maximum NDVI ($NDVI_{max}$) throughout the year for the period from 1981-2003 (Figure 3.3) the study area was divided into four zones, which represent grassland, patchy land, a extensive vegetation cover area and rainfed mechanized agricultural area respectively (Figure 3.4). This division differs from Holter (1994b) who divided the area into five different zones only according to the vegetation cover. The difference is that the extensive woody vegetation and extensive plant cover area in the Holter map (Holter, 1994b) is consider as one zone in this study. This is due to deterioration that occurred in the woody vegetation area during the drought years and also due to the extensive use of the trees for fuel as well as an expansion of the rainfed mechanized agricultural production area.

From personal communication with experts and the herders from the Butana area it is suggested that the usual peak vegetative growth occurs sometime between the end of August and the beginning of September. This coincides with the peaks shown in Figure 3.3. This result gives evidence that the $NDVI_{max}$ can be used to study the vegetation cover in the Butana area. Figure 3.5 shows that the peak NDVI and the cumulative NDVI are correlated ($r^2 = 0.5675$) to each other. Therefore the peak NDVI can be assumed to be representative of the total green biomass production in a given year.

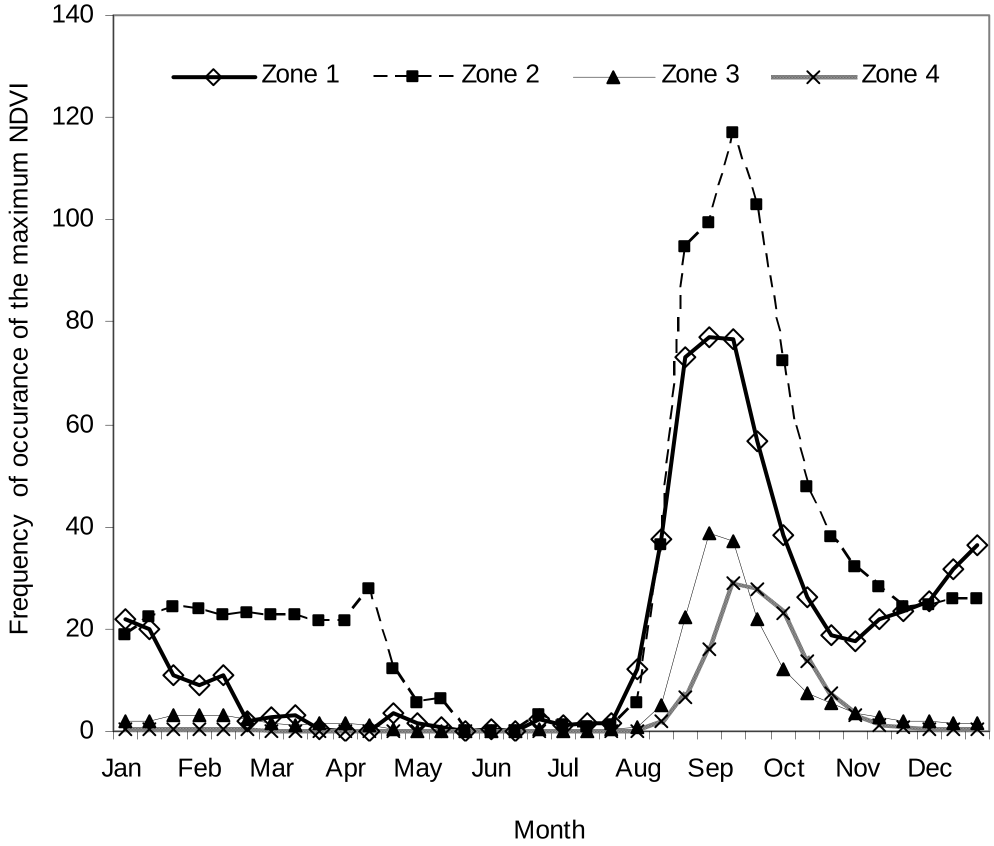


Figure 3.3 Percentage of occurrence of the $NDVI_{max}$ throughout the year in the Butana area

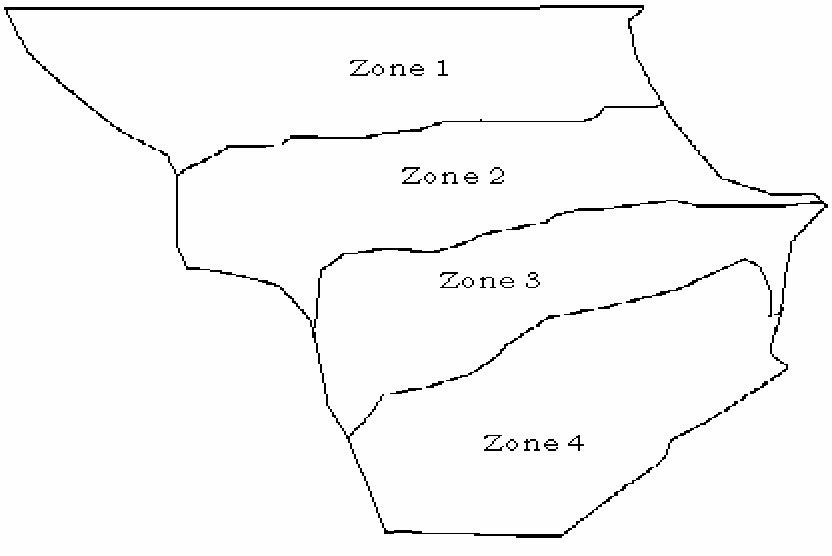


Figure 3.4 Map of the study area showing the four vegetation zones

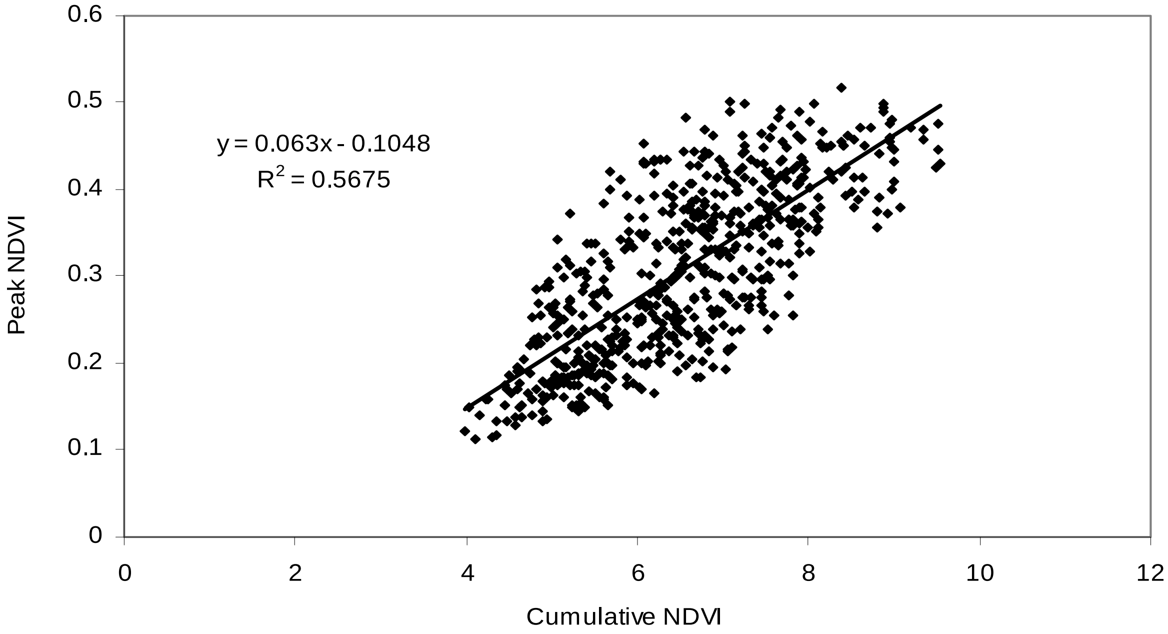


Figure 3.5 Correlation between cumulative NDVI and the peak NDVI in Butana area, Sudan (n = 979)

The inter-annual variability of peak NDVI was express as a coefficient of variation C_v [(standard deviation/mean) x 100]. Figure 3.6 shows that there is a high inter-annual variability of the green biomass in the area. Zones 1 and 4 had the same pattern of variation during the period from 1981 to 1991 but after this period the C_v for zone 1 increased. Zone 4 had the lowest C_v after 1984 since the area received rainfall higher than the long-term mean from 1985 to 1987 (see Figure 2.4), while zone 2 had the highest C_v. The noticeable changes in the inter-annual variability since 1984 are probably related to recent changes in quantity and distribution of the rainfall. Van Zyl *et al*. (2004) and Evans and Geerken (2004) concluded that the long-term trend graph of the $NDVI_{max}$ show the high variability of the NDVI but there was a strong correlation between rainfall and $NDVI_{max}$ in the central part of South Africa, and in the drylands of Syria.

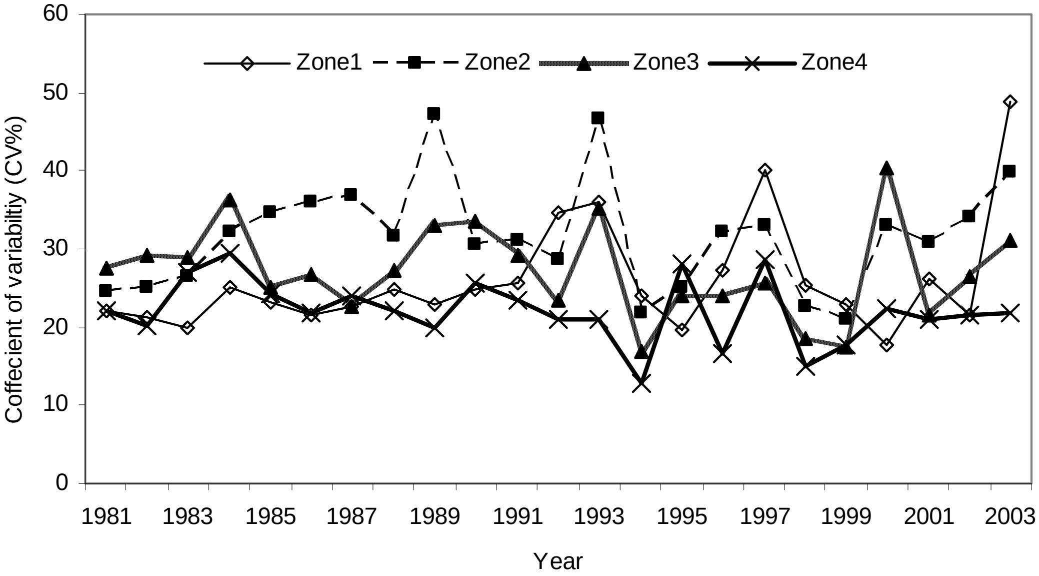


Figure 3.6 Inter-annual variability of the peak NDVI for the Butana area

The percentage of the pixels that had $NDVI_{max}$ less than the long-term average of the $NDVI_{max}$, was calculated by using 23 years of 10 day AVHRR $NDVI_{max}$ data for each pixel (n = 979). Figure 3.7 confirms that there is strong correlation between the percentage of the pixels that had $NDVI_{max}$ less than the long-term average and the cumulative rainfall over 10 day periods for each of the four zones in the area. The correlation is stronger in zone 4 and this may be due to the fact that the area is use for rainfed agriculture, namely for sorghum and sesame cropping which are both sensitive to the rainfall amount.

Figure 3.8 shows that there is higher percentage of the pixels with $NDVI_{max}$ less than long-term average during years with low rainfall namely 1984, 1990, 1991, 1993, 2000, and 2002. Zone 1 had a large response to the higher rainfall that can be interpreted to be due to the critical dryness of vegetation cover in zone 1 which is a dry region with the dominant vegetation being annual/perennial grasses, which respond to rainfall rapidly. The $NDVI_{max}$ of zones 2, 3 and 4 is more sensitive to drought conditions rather than the high rainfall. This result agreed with Van Zyl *et al*. (2004) and Tachiiri (2003) as they reported that the $NDVI_{max}$ it is more sensitive to drought than high rainfall.

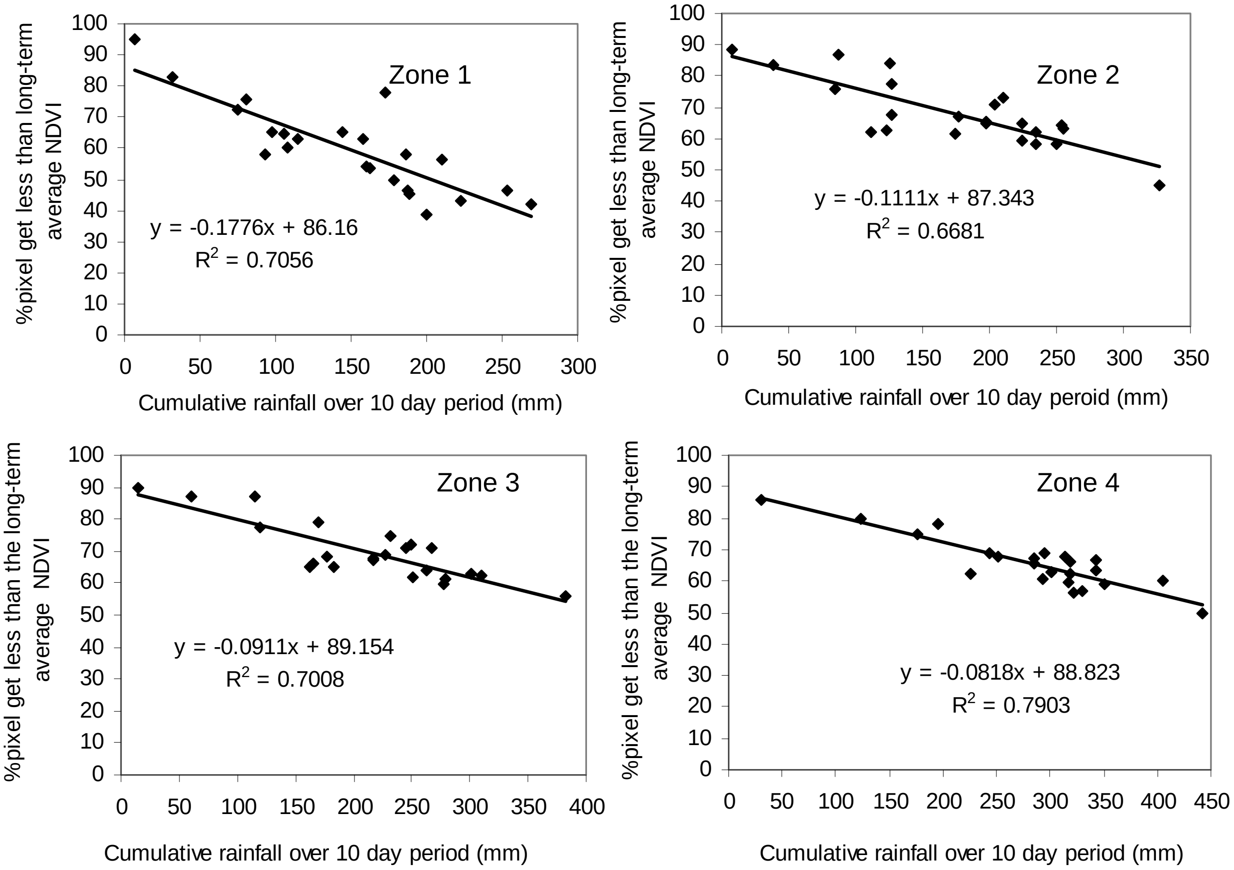


Figure 3.7 Relationship between percent of pixels with $\mathrm{NDVI}_{\max}$ less than long-term average versus the 10 day cumulative rainfall (mm) for zones 1, 2, 3 and 4 respectively

The departure from the long-term average of peak NDVI for each pixel was calculated using the departure average vegetation method. Figure 3.9 shows that the four zones had a high percentage of departure from long-term average which reached > 50% during the drought years. Figure 3.9 also shows increasing trends in NDVI during the period from 1992 to 2003, despite the fact that there are a few years with high departure but this departure is still less than that during the period from 1981 to 1991. This increase is significant for zone 1 and 2 ($p = 0.0159$ and $p = 0.03$), but not significant for zones 3 and 4 ($p = 0.06$ and $p = 0.052$).

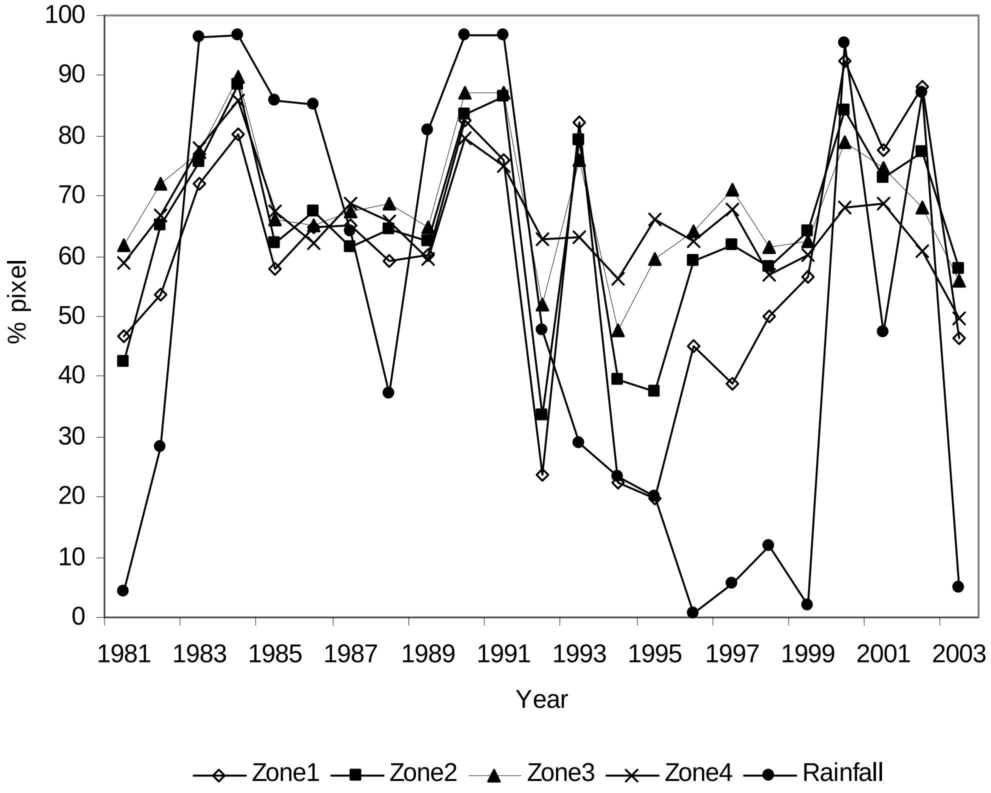


Figure 3.8 Percentage of pixels with NDVI_{max} less the long-term average and percent of pixels with rainfall amount less than long-term average

This result agrees with recent research that has shown significant increasing trends in NDVI for some Sahelian regions during the period of 1982-1999 (Eklundh and Olsson, 2003), which could be interpreted as a recovery from the Sahelian droughts of the 1970s and 1980s. While Sjöström (2004) concluded that the increasing trend of the AVHRR NDVI is not significant for the southern part of Kordofan-Sudan for the period from 1982-2002. Eklundh and Sjöström (2005) analysed vegetation changes in the Sahel by using sensor data from Landsat and NOAA. They derived results that support a conclusion that areas with a strong positive trend in AVHRR NDVI are greening. However, causes behind this greening are difficult to ascertain, as results show that increasing rainfall does not fully explain the observed trends.

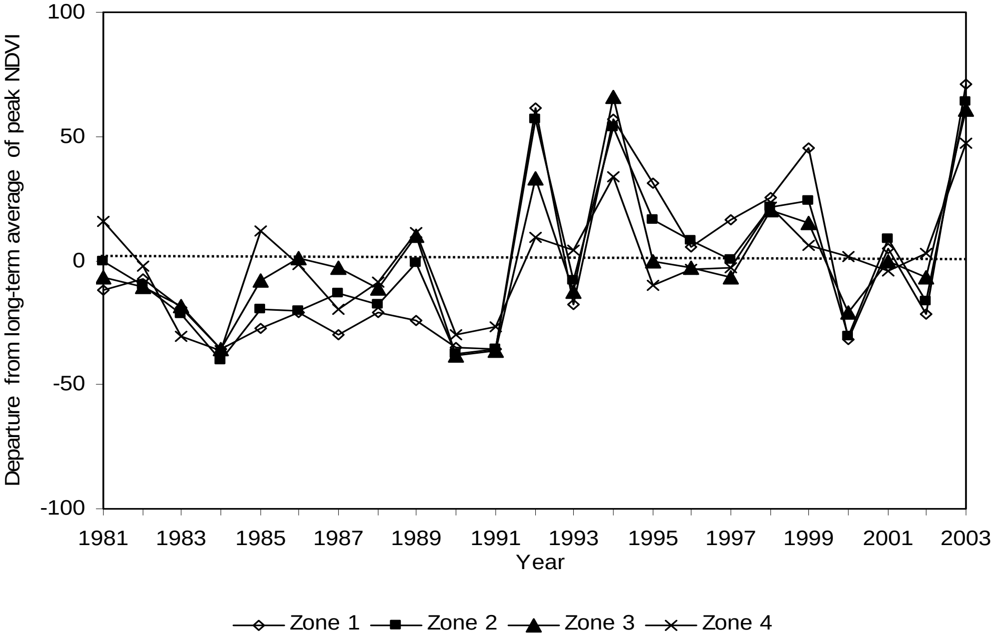


Figure 3.9 Departure from the long-term average of peak NDVI for the four zones in the study area

The spatial effect of the drought years on the vegetation cover was examined by calculating the departure of the peak NDVI from the long-term average of the peak NDVI for each pixel for the 1984, 1990 and 2000 as drought years and this was compared with the following years 1985, 1991 and 2001 representing the recovery periods. Figure 3.10 illustrates that the departure from the average was higher during the drought years. In 1984 zones 1, 2 and 4 were severely effected by drought and the departure ranged between 30-60%, while zone 3 was less affected especially in the central part. A similar deviation was seen during 1990, with less effect in a large area of zones 3 and 4. While in 2000 zones 1 and 2 were severely affected by drought and the departure ranged between 40-60% especially for the western part of these two zones, NVDI in zones 3 and 4 showed high value (15-45%).

By comparing Figure 3.10 with Figure 3.11 it is noted that the peak NDVI in 1985 was still below the long-term average for zone 1 and some parts of zones 2 and 3 (15-45%). Zone 4 and the area adjacent to the irrigated schemes in zones 2 and 3 showed improvement in the NDVI by about 30–75% of the long-term average, due to high rainfall after a drought year. The situation is different during 1991 as for zones 1, 2 and 3 the departure is still high especially for some parts (30-60%). The departure for zone 4 was not severe (15-30%). In 2001 the rainfall was above average, such that the four zones start to recover from the drought event, but some areas adjacent to the irrigated scheme still had high departure. This may be due to overexploitation by the nomads during the drought and following years. The above result showed that the AVHRR/NOAA NDVI can be use as an indicator for the drought events, and to study the degradation in the vegetative cover after drought years to monitoring the vegetation condition in Butana area.

The long-term departure of NDVI map (Figure 3.12) confirmed that the NDVI in zone 4 has improved, while in zones 1, 2, and 3 there is departure range from -30-30% during period from 1981 to 2003. Some parts in zones 1 and 2 had positive departure (30-45%) this means that these parts may not be severely affect by the drought conditions or that the vegetative cover started to recover. In general there was some improvement of the NDVI as mentioned by many authors in the Butana area.

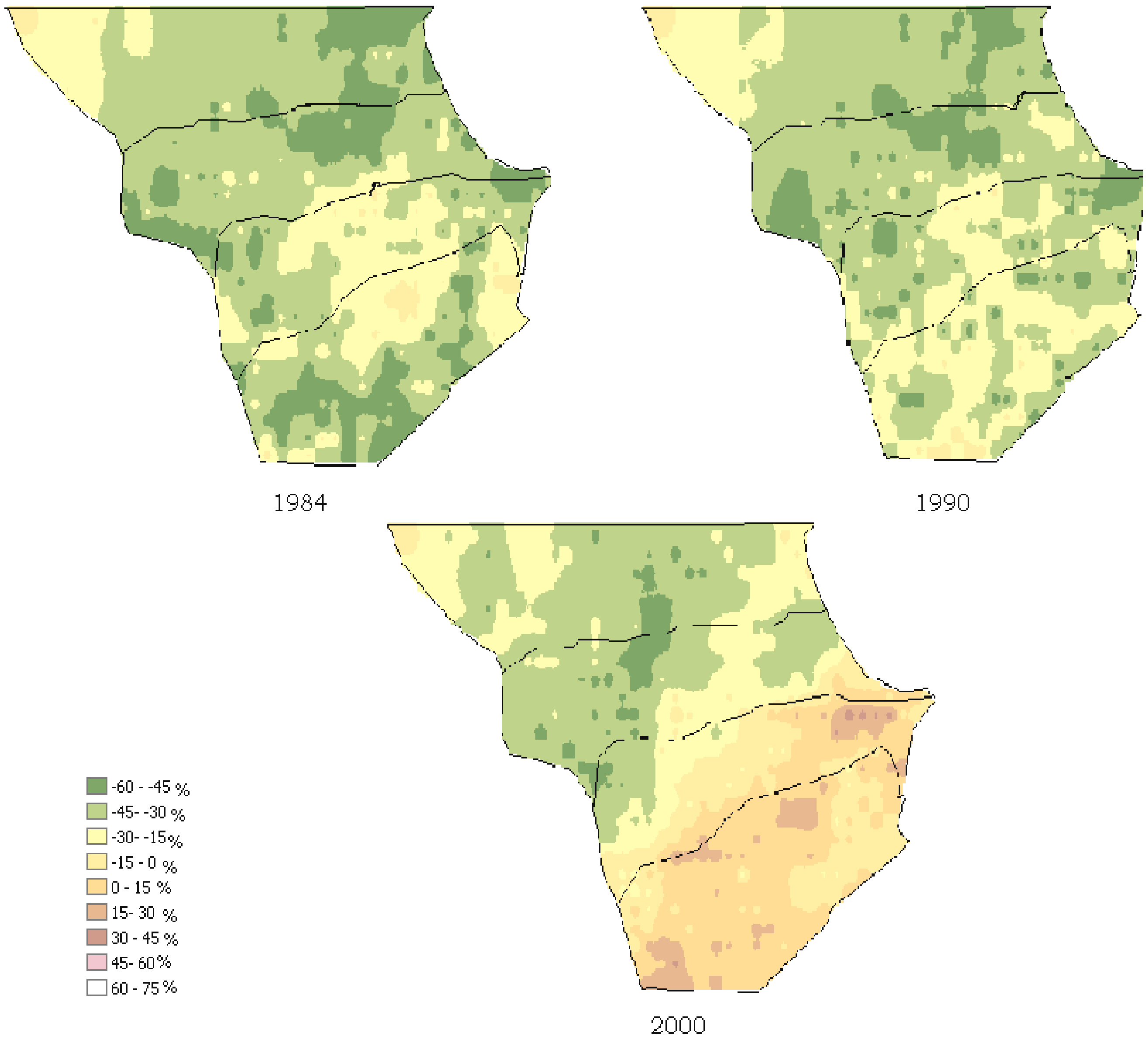


Figure 3.10 Departure from long-term average of peak NDVI for drought years (1984, 1990 and 2000)

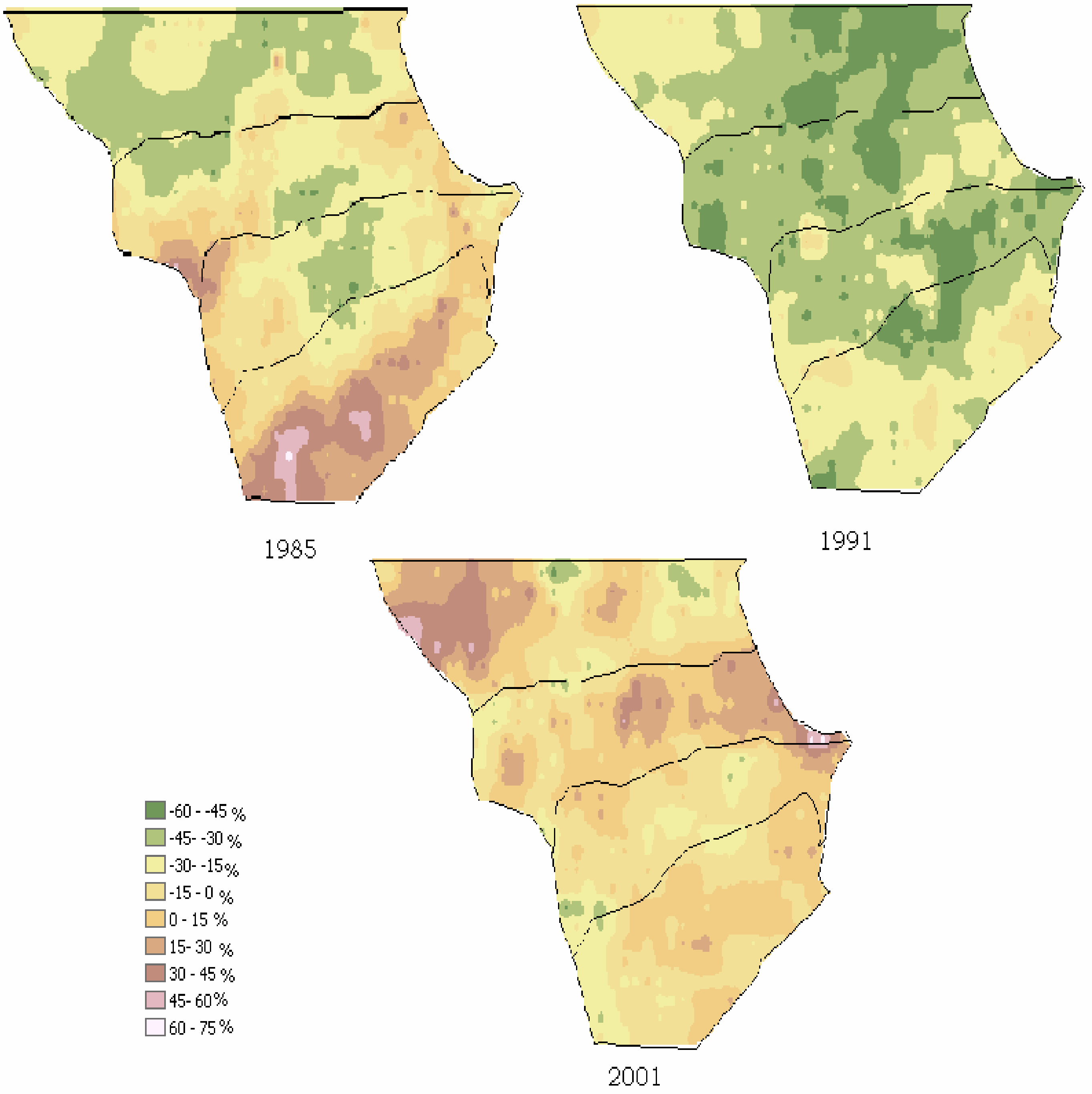


Figure 3.11 Departure from long-term average of peak NDVI for the study area for years following drought years (1985, 1991 and 2001)

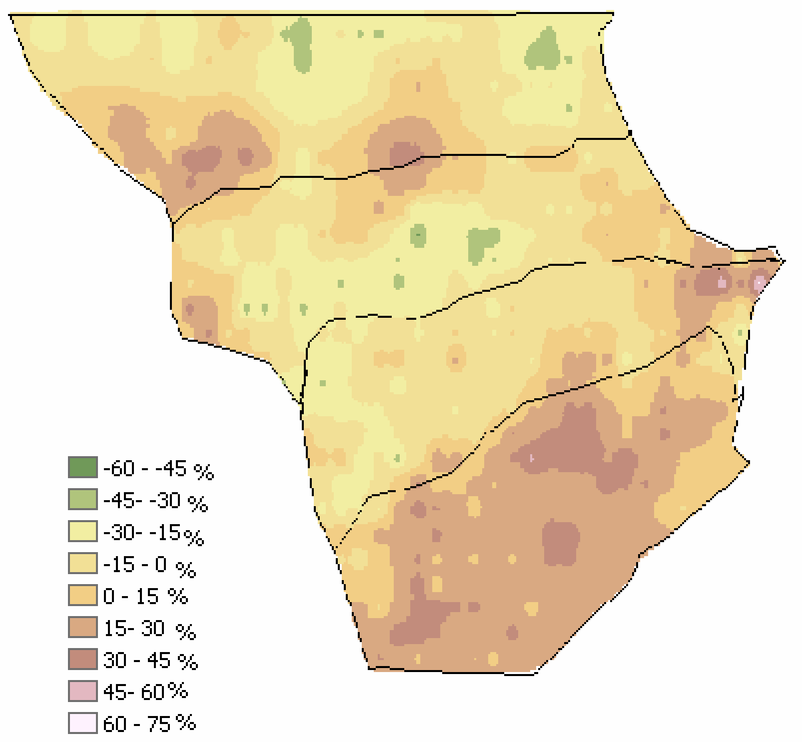


Figure 3.12 Long-term departure of peak NDVI for the period 1981-2003 for the study area

3.3.2 Identification of rainfall impact on the vegetation cover

Recent studies have shown that rainfall is the most important climate factor that has a direct effect on vegetation growth (Wang *et al.*, 2001; du Plessis, 1999; Hielkema *et al.*, 1986). Wang *et al.* (2001) relate the differences in NDVI/rainfall correlations to variation in the vegetation type and soil properties. The best correlated rainfall accumulation periods in terms of their length (accumulation time) and their position in time (time lag; time between end of accumulation time and the NDVI value it is correlated with), given by various authors are variable and depend on the locations of these studies. Result from previous studies show that it is important to test several different rainfall accumulation periods in order to find an optimum correlation with NDVI.

Hence, linear correlations were calculated for many combinations of rainfall accumulations and lag time, for each NDVI pixel in the study area. The peak NDVI (occurring at the end of August and the beginning of September) and NDVI$_{acc}$ versus the different rainfall accumulation and lag times ranging from June to October (10 day increment) as well as annual rainfall were investigated. Table 3.1 shows that the peak NDVI had a strong correlation with cumulative rainfall amount for July and August (r value range from 0.319 to 0.686). This means that the rainfall received in the month in which the peak NDVI occurs is by itself, poorly correlated with the magnitude of the peak NDVI. There is also a weak correlation between cumulative NDVI during the growing season and the annual rainfall (r = 0.258 to 0.412). The peak NDVI had a stronger relation with the July/August rainfall during the drought years (1984, 1990, 2000) r values range between 0.593-0.686, while in the wet years (1988, 1995, 2003) the relation is not as strong giving r values between 0.319-0.440. This confirmed that the peak NDVI is more sensitive to the drought years. Therefore linear regressions between the peak NDVI and the July/August rainfall were used to study the effect of the climate component on the NDVI in the Butana area.

Table 3.1 Linear correlation coefficients (r) between various rainfall amounts and peak or accumulative NDVI in Butana area for specific years

Year	August rainfall vs peak NDVI	July/August rainfall vs peak NDVI	Annual rainfall vs $NDVI_{acc}$
1984	0.497	0.593	0.159
1988	0.154	0.338	0.412
1990	0.409	0.604	0.151
1995	0.370	0.440	0.338
2000	0.656	0.686	0.257
2003	0.275	0.319	0.235

3.3.3 Identification the impact of human activities on the vegetation cover

Human and livestock population data is not readily available for the Butana area on a regular basis due to many factors. For example, in Sudan there have only been two livestock census (1957 and 1977) and after that all the livestock populations were estimated on the basis of the population growth rate of the animals. Data on nomadic population (e.g. number, whereabouts, migration pattern) are rarely collected and where available are rather doubtful. The nomads in the Butana area for cultural reasons refuse to give the actual number of animals they have because they think that something bad will happen to their herds when they give the actual number. Sometimes they give under-estimates so as to pay less taxes or other governmental payments (Holter, 1994a). Another reason is that the nomads in the area keep on moving to seek water and grazing fodder, which makes it difficult to track the population growth in a specific region during a specific period of time. All these reasons make the identification of human activities impact on the vegetation cover in the Butana area very difficult.

There is a strong correlation between the peak NDVI and the cumulative rainfall for July and August for all the four zones (Figure 3.13) which needs to be removed to allow rainfall trends to be distinguished from human-induced trends. The regression equation between the peak NDVI and July/August rainfall were used to predict a peak NDVI for each pixel (Archer, 2004; Evans and Geerken, 2004). The performance of the prediction model was tested for the four zones using the statistical Willmott tests between the observed and predicted NDVI. The following statistical parameters were calculated: Index of agreement (D-index), root mean square error (RMSE), systematic RMSE (RMSEs) and unsystematic RMSE (RMSEu). The relevance of these parameters can be explained as follows: RMSE provides information about the actual size of the error produced by the procedure. RMSEs indicates whether there is systematic over- or under-estimation by the procedure. RMSEu indicates the extend to which the error is unsystematic, and therefore indicates absence of any systematic fault in the procedure used. Hence it is important to know what fraction this value comprises of the total RMSE. D-index is a standardised and bounded index that measures the degree to which the predictions are error-free (Willmott, 1981). The number of pairs of observed and predicted values were compared, the observed and predicted means, and the total RMSE together with its unsystematic component expressed as % of RMSE, [(RMSEu/RMSE) x 100]. According to Willmott (1982) and Lourens (1985) the D-index in a good prediction procedure should approach 1.0, while the RMSEu should approach the total RMSE, i.e. as much of the error as possible must be unsystematic. As shown in Table 3.2, the RMSE ranged from 0.042 to 0.063, with an overall mean of 0.05. The D-index was generally close to 1. The mean RMSEu/RMSE was 75%, which means that the linear regression equation between peak NDVI and July/August rainfall can be used to predict the peak NDVI for the Butana area.

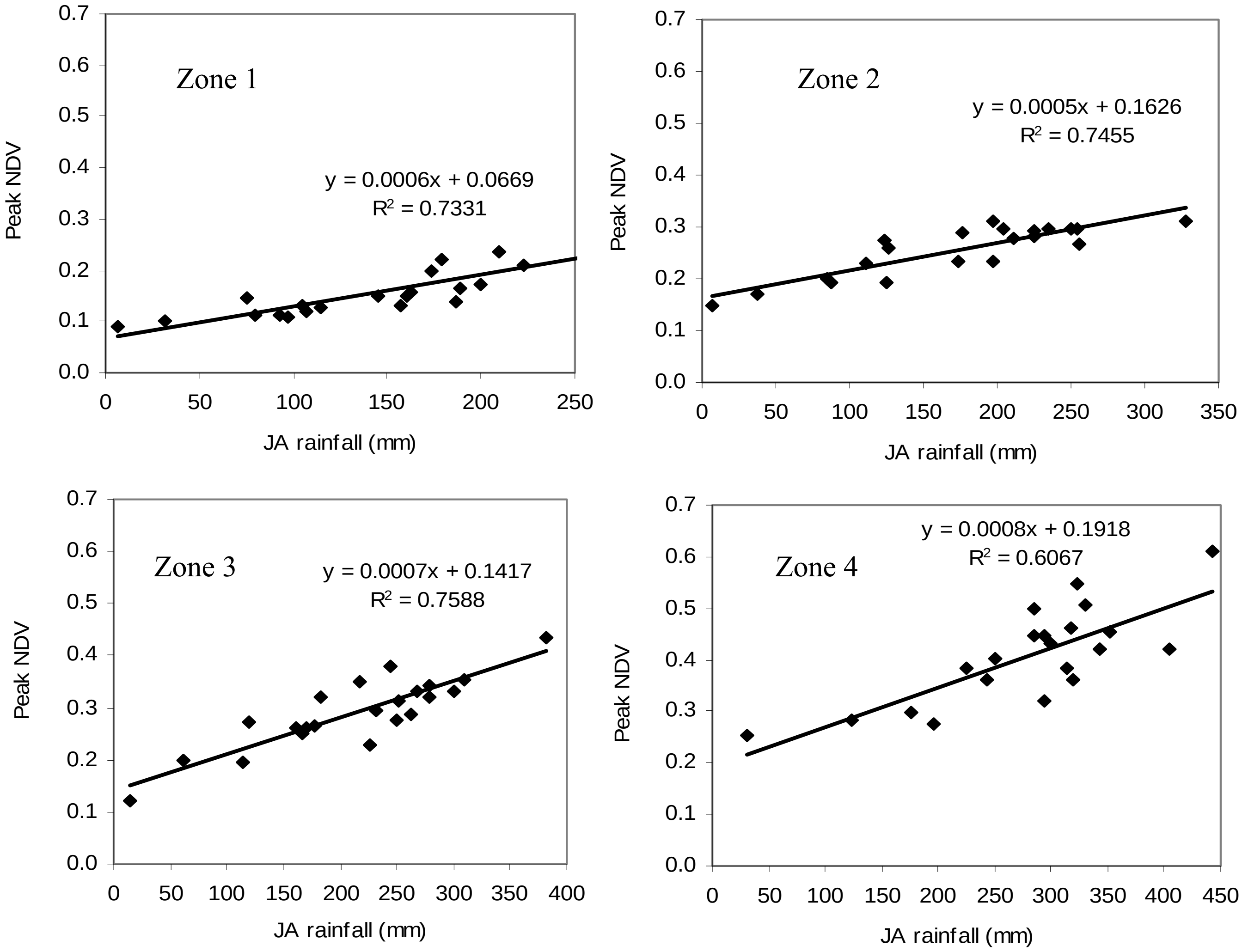


Figure 3.13 Linear regression of peak NDVI versus July/August rainfall for four zones in the Butana area

Table 3.2 Results of statistical test of model performance. RMSE = root mean square error, RMSEu = unsystematic RMSEs, D-index = Willmott's index of agreement

	Zone 1		Zone 2		Zone 3		Zone 4	
	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
Mean	0.165	0.168	0.272	0.268	0.298	0.306	0.407	0.411
Standard dev.	0.055	0.041	0.077	0.058	0.081	0.060	0.089	0.072
Std error of mean	0.011	0.009	0.016	0.012	0.017	0.013	0.018	0.015
RMSE	0.042		0.055		0.057		0.063	
RMSEs	0.028		0.036		0.039		0.038	
RMSEu	0.031		0.041		0.042		0.050	
R^2	0.58		0.66		0.61		0.62	
D-index	0.965		0.986		0.980		0.994	

To identify the effect of inter-annual variation in rainfall, the differences (Residual) between the observed peak NDVI and the predicted peak NDVI were calculated. Trends in these residuals over time may indicate changes in peak NDVI that were not due to the effect of rainfall in the current year and therefore may facilitate the identification of human impacts (Evans and Geerken, 2004; Geerken and Ilaiwi, 2004). The predicted peak NDVI is higher than the observed ones during the period between 1984 and 1989 for zone 1 and after that the observed NDVI was mostly higher than the predicted ones. While in zones 2, 3 and 4 there is no significant difference between the predicted and observed peak NDVI (Figure 3.14), meaning that the rainfall is the determining factor for the vegetation growth in the Butana area. Figure 3.15 shows the residual effect which indicates the human activities impact during the period from 1981 to 2003. It can be noticed that there is high variability of the residual for the four zones till 1995 and after this period the residual effect has become less variable. This may be interpreted that the human impact become less due to the fact that the area received more rainfall and vegetation cover started to recover.

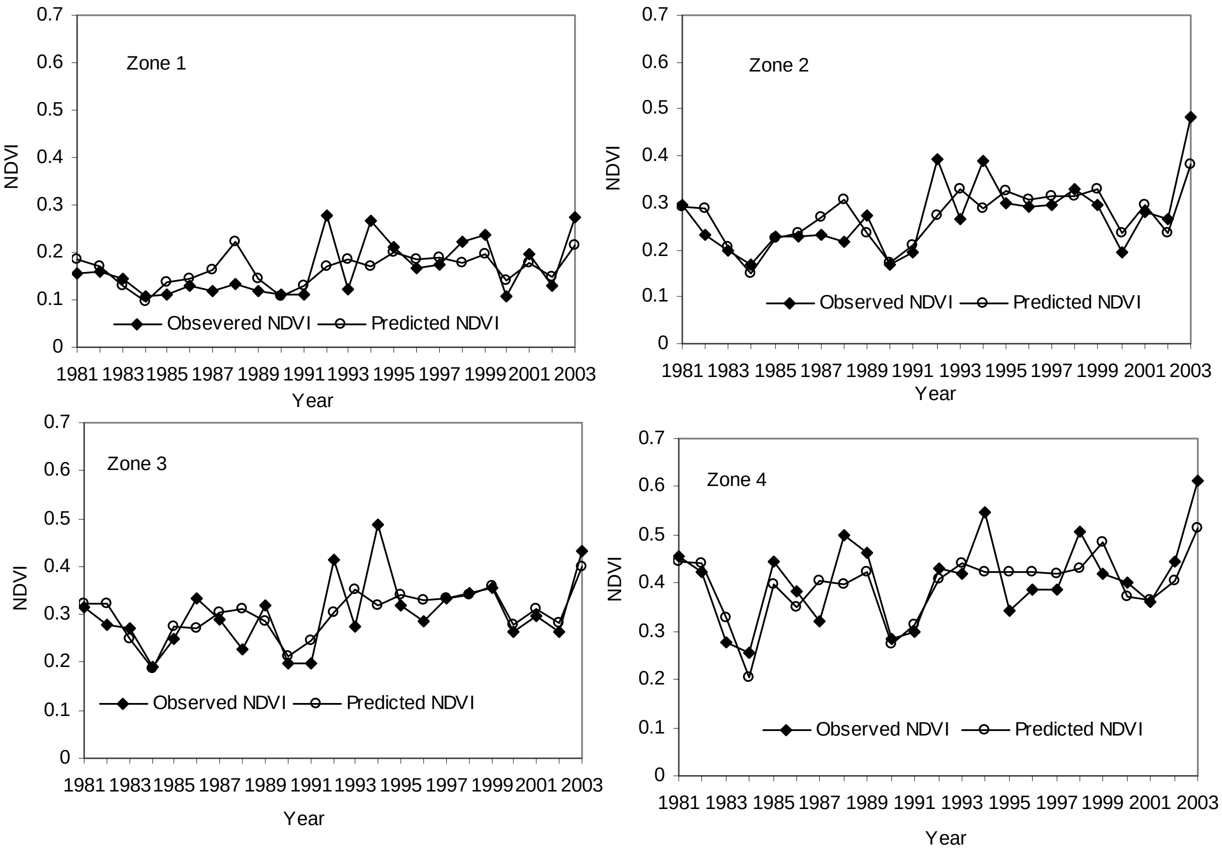


Figure 3.14 The observed and predicted peak NDVI for the four zones

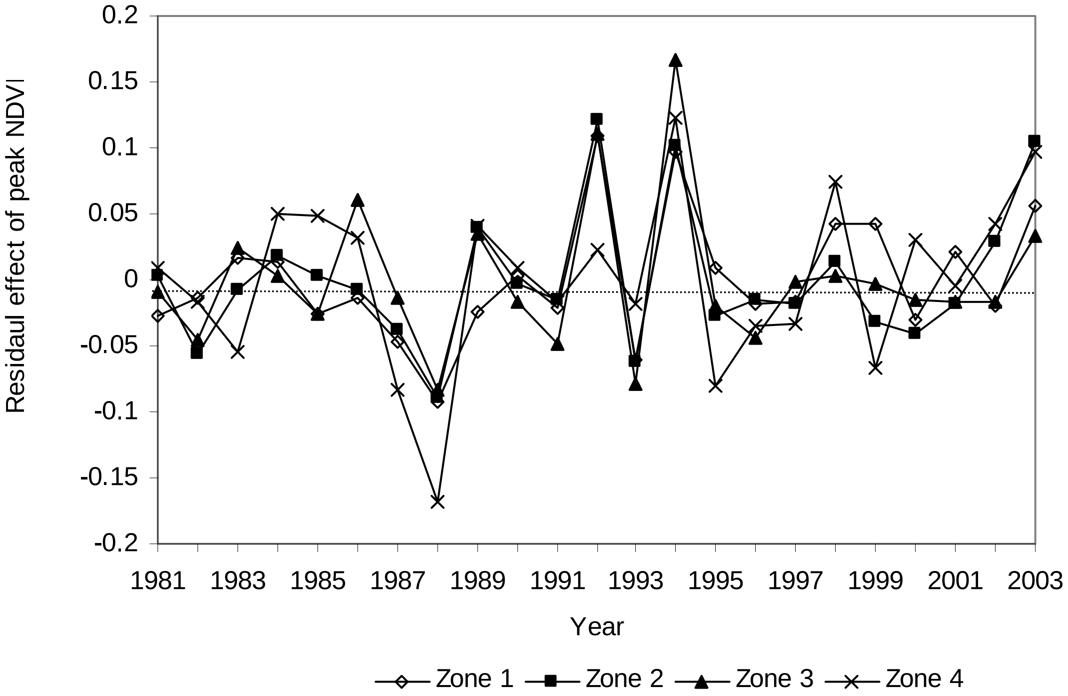


Figure 3.15 Residual effects of the human activities for the four zones in the study area

To study the spatial trend of the human activities, the period from 1982 to 2001 was divided into four equal intervals of five years (1982-1986, 1987-1991, 1992-1996, and 1997-2001). From Figure 3.15 and 3.16 it can be noted that the residual effect of the human activities was severe in zones 1 and 2 (-0.17 to -0.5) during 1982-1986, when the area was affected by severe drought. During 1987-1991 the area was affect by two consecutive drought years (1990-1991) which covered the whole of the Butana area, the effect of human activities became more severe in all of the four zones especially the area adjacent to the Rahad irrigation scheme and the rainfed agricultural area. This was due to the fact that the nomads concentrate in the areas where there is water and fodder available for their livestock. After this period the effect became less, because the nomads reacted flexibly to drought (additional fodder, purchase and transportation of water, moving herds of sheep by lorry to the irrigation scheme to eat the crop residue) (Kirk, 1994). This can be shown in the period 1992-1996 which indicate that the human impact has become less and there is an increase in the observed NDVI which can be interpreted as recovery from the drought years or may be due to the reductions that occurred in livestock numbers. Rahmanin (1994) mentioned that livestock in the area was reduced on average by one third after the extremely dry years of 1990-1991, primarily due to sales and not to death of the animals as is often assumed. During the period of 1997-2001 the area experienced drought in 2000 and the human effect has again became severe but was less widespread than during the period 1982-1991. Table 3.3 shows that the negative trend of the residual effect of human activities were significant for zones 2 and 4 for the period from 1982-1996 and the positive trends were significant for all four zones during 1992-1996 which indicate that the increase of the NDVI during this period.

Table 3.3 Significance levels of the residual effects of the human activities in the Butana area ($p = 0.05$)

Zones	1982-1986	1987-1991	1992-1996	1997-2001
Zone1	0.069	0.000*	0.049*	0.954
Zone 2	0.009*	0.055	0.004*	0.055
Zone 3	0.862	0.861	0.018*	0.582
Zone 4	0.001*	0.000**	0.002*	0.527

* = significant

Figure 3.17 shows the spatial trend of the residual for the period from 1981 to 2003. The human impact is high in zones 1, 2 and 3 especially in the area adjacent to Rahad irrigation scheme. This impact was not significant for zone 1 ($p = 0.38$) but significant for zones 2 and 3 ($p = 0.02$, $p = 0.035$). Pflaumbaum (1994) and Holter (1994a) reported that the crop residues being located mainly in the central Butana (zone 2 and 3) and the area was mostly occupied by the nomads during and after the rainy season, thus the human impact was more clear in this zone. While the zones in which there is rainfed agricultural production has no evidence for adverse long-term human impact.

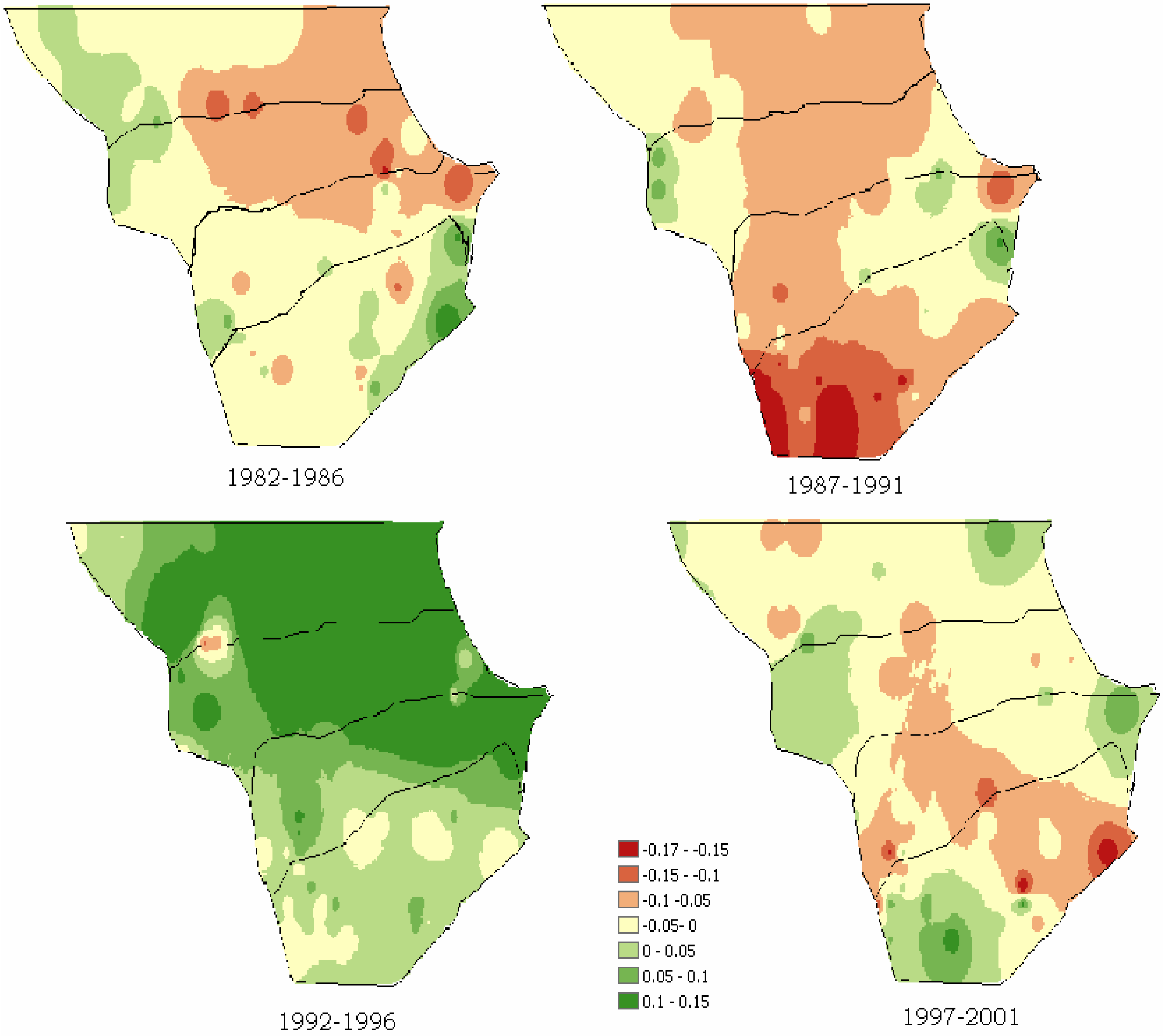


Figure 3.16 Residual effects of the human activities in the Butana area from 1982-2001 in 5 year steps

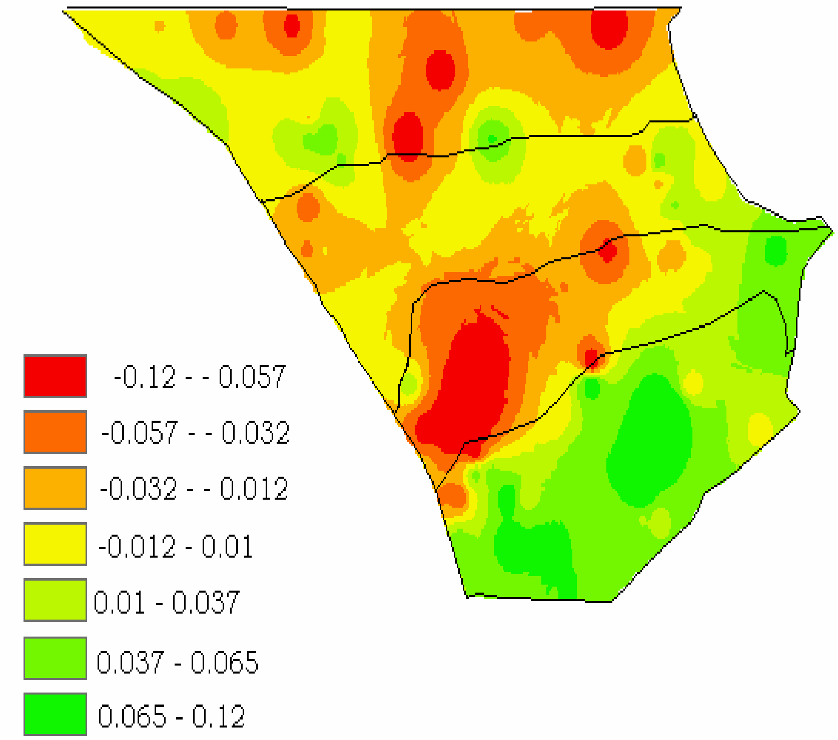


Figure 3.17 Long-term of residual effect of human activities for the period from 1981-2003 for study area

3.4 Conclusion

Broad scale time series NDVI images can be applied in conjunction with traditional methods for monitoring pastureland condition changes across time and space. It is useful especially where there is a lack of primary measurements of vegetation and pastureland conditions across large areas and where climate dependent nomadic livestock is a primary source of living like in the Butana area. The NOAA series satellite with AVHRR sensors (high resolution sensors) make vegetation indices like Normalized Difference Vegetation Index available to be used. Annual assessment of grass growth and biomass on a broad scale and its comparison to other years has practical meaning for correct allocation of pasture resources, pastureland conservation and justification of livestock numbers.

The NDVI series divided the Butana area into four vegetative zones, namely grassland, patchy land, extensive vegetation cover and rainfed mechanized agricultural area. The inter-annual variability of NDVI increased after 1984 when the area had experience the

Sahelian drought. Zone 1 is more sensitive to the higher rainfall rather than zones 2, 3 and 4 which had a lower response. This difference in response can be interpreted to be due to the critical dryness for vegetation in zone 1 which is a dry region where the dominant vegetation is annual/perennial grasses, which responds to rainfall rapidly. During the drought years, zones 1, 2 and 4 were severely effected while zone 3 was less effected, and the NDVI deviates from the long-term average by about 30-60%, but the vegetation can recover if wet years follow the drought year. Zones 3 and 4 showed significant increase in the NDVI after the drought years (20-40%).

There is a strong correlation between the peak NDVI, occurring during the end of August and at the beginning of September with the cumulative rainfall for July and August, while annual rainfall had a weak correlation with $NDVI_{acc}$. Peak NDVI is more sensitive to low rainfall than the higher rainfall amounts. The temporal trend of NDVI indicates an increase in the green vegetation after 1992, this trend is significant for zone 1 and 2 but not significant for zone 3 and 4, which indicates that the northern part of the Butana area has started to recovery from the Sahelian drought.

The residual effects indicate that the predicted peak NDVI, by using the regression equation of July/August rainfall, was higher than the observed peak NDVI from 1984 to 1989. After this period the observed NDVI was mostly higher than those predicted for zone 1. This supports the conclusion of an increasing trend of the NDVI after the Sahelian drought. There is no significant difference between the observed and predicted NDVI of zones 2, 3 and 4. The human activities impact on the vegetation cover was more clear after drought years, but in general this impact was severe for zone 1 and 2 during the 1984 drought. There is significant impact of human activities for the whole area during 1987-1991 when the area experiences another severe drought and the nomads started to congregate in the area near the irrigation schemes and rainfed agricultural areas from where they can get supplementary fodder and water during a drought. After 1991 the vegetation started to recover and the nomads reacted flexibly to the harsh condition in the area by purchasing additional fodder and moving the herds of livestock to the areas near to the irrigation schemes.

The challenge facing the nomads, planners and decision makers is to understand the interaction between the vegetation growth and the climate in the Butana area. The drying conditions should be carefully monitored over the coming years and decades. This could allow one to establish evidence as to whether the rainfall changes have a significant impact on vegetative cover in the area and hence sustainability of the nomad life style.

Chapter 4

Environmental Degradation of the Natural Resources

4.1 Introduction

Environmental degradation refers to the diminishment of a local ecosystem or the biosphere as a whole due to human activity or the climate factors. Environmental degradation occurs when nature's resources (such as trees, plants and other habitat, earth, water, air) are being consumed faster than nature can replenish them (WRI, 1996; Squires, 1998a; Ehrlich *et al*., 2000).

The land degradation of arid and semi-arid lands, often termed desertification in its irreversible form, due to human impact and/or climatic change has been much debated since the mid 1970s. It is believed to be one of the most serious global environmental problems of our time (Dregne *et al*., 1991; UNCED, 1992; Reynolds and Stafford Smith, 2002). Desertification means land degradation in arid, semi-arid and dry sub-humid areas resulting from a variety of factors including climate variation and human activities (UNCED, 1992). Degradation processes include erosion, compaction and surface sealing, acidification, declining soil organic matter, soil fertility depletion, biological degradation and soil pollution (Lal and Stewart 1990). Land degradation describes circumstances of reduced biological productivity (UNCCD, 1994; Reynolds and Stafford Smith, 2002). Most types of degradation result in a loss of plant available water capacity, the most important factor affecting soil productivity in many soils. Deterioration of natural vegetation is the prime indicator of land degradation. Vegetative indicators are characterized by a visible degradation of the natural plant cover up to the point of complete destruction. Vast areas entirely cleared of natural vegetation show an irreversible loss of the natural regeneration of the tree, shrub or herbage cover. A change in the composition of the species can be a further indicator (Akhtar and Mensching, 1993).

Williams and Balling (1996) define land degradation in drylands as a "reduction of biological productivity of dryland ecosystems, including rangeland, pastures and rainfed and irrigated croplands, as a result of an acceleration of certain natural physical, chemical and hydrological processes, including erosion and deposition by wind and water, salt accumulation in soils, and groundwater and surface runoff, a reduction in the amount or diversity of natural vegetation, and a decline in the ability of soils to transmit and store water for plant growth". This comprehensive definition was adopted in the analysis of this chapter.

The key soil characteristics that affect plant growth are nutrient content, water holding capacity, organic matter content, soil reaction (acidity), topsoil depth, salinity, and soil biomass. Changes over time in these characteristics constitute "degradation" or "improvement" (Lal and Stewart, 1990). An important criterion of soil degradation (itself a major component of land and ecosystem degradation) is the loss of the soil organic matter. Compared to soils in more humid regions, those in arid regions tend to be inherently poor in organic matter content, owing to relatively sparse natural vegetative cover and to the rapid rate of decomposition due to relatively high temperatures (Hillel and Rosenzweig, 2002). Plant residues over the surface protect the soil from the direct erosive impact of raindrops and from deflation by wind and help to conserve soil water by minimizing evaporation. When the natural vegetative cover is removed, there follows a rapid processes of organic matter decomposition and depletion. Accelerated erosion also removes the layer of the topsoil that is richest in organic matter, consequently, the destabilized soil tends to form a surface crust that further inhibits infiltration. Water losses by both runoff and evaporation increase. Moreover, the soil looses an important source of nutrients (Hillel and Rosenzweig, 2002). Surface soil not protected by permanent vegetation becomes subject to erosion by water and wind, crusting by raindrop splash and trampling by animals, salinization by evaporation, and water logging in topographic depressions since water is no longer extracted by permanent vegetation (Le Houérou, 1995, 1996). The most widespread cause of land degradation in drylands is water erosion, followed by wind erosion, chemical degradation (three quarters from nutrient loss, the rest from salinization), and physical degradation. Overgrazing accounted for half of all degradation, followed by agricultural activities, deforestation and over-exploitation (Le Houérou, 1996).

Water erosion is a serious form of land degradation that leads to desertification throughout the world. Vast areas were permanently ruined by water erosion (Fadul *et al.*, 1999). These areas have been rendered virtually useless because they have been stripped of topsoil or riddled with gullies. Ellison (1947) defined soil erosion as a process of detachment and transportation of soil material by erosive agents. The detachment of soil particles and runoff are linked to the intensity and duration of rainfall, as well as the slope and roughness of the landscape. Soil properties, plant cover and cultivation practices also play an important role in water erosion. Gully and stream pattern are controlled by a combination of hydrology, geology, geomorphology and man-made factors (Heede, 1976; Wollman and Miller, 1960). Mainguet (1999) has stated that water erosion is a natural mechanism of topography shaping, which when accelerated by human activities and water action causes land deterioration.

Key components in semi-arid ecosystem degradation processes are increased surface albedo (reflectance of solar radiation) and increased generation of dust, both of which are consequences of the exposure of the bare soil as dry ground following removal of the original vegetative cover (Hillel and Rosenzweig, 2002). The albedo of a bare soil depends on the organic matter content and the mineral composition of the topsoil. It also depends on the moisture content of the soil surface. A moist soil is generally less reflective (i.e. darker) than a dry soil (Hillel, 1998).

Livestock pressure under pastoralism is dynamic and would change mostly with the availability of pastures and drinking water. Warren and Khogali (1992) and Hanan *et al.* (1991) state that grazing has caused much less damage to the Sahelain rangelands than drought and desiccation, and that severe damage is caused more by physical than human factors. Ayoub (1998b) added that the exceptions were the limited areas where livestock population was high (e.g. in settlements and around watering centres). Hanan *et al.* (1991) report that the animals grazing vegetation has both positive and negative effects.

The growth of many savannah species is stimulated by moderate grazing (Pearson, 1965; Edroma, 1981).

In Sudan there is a total of about 170 million hectare of agricultural land, pasture, forest and woodland, but nearly 75 million hectare (45%) have been severely or very severely degraded by various factors:- wind and water erosion, overgrazing, cutting wood and expansion of the rainfed agriculture (Ayoub, 1998a). Water erosion is a key problem affecting productivity and conditions in the Butana area. Complete surveys have not been carried out so the severity of the problem is not know but it has been estimated that 8 million hectare of the area used for grazing has suffered substantial or severe erosion (Ayoub, 1998a; Akhtar and Mensching, 1993; Shepherd, 1985).

Environment degradation has long been regarded as a problem in the Butana area (Akhtar and Mensching, 1993; Ayoub, 1998a; Holter, 1994a; Elhassan, 1981; Fadul *et al.*, 1999) but little is known of its true extent. The Butana area has been pointed out as an example of severe land degradation. The area is identified as a zone of high risk for further desertification in the UNEP map of desertification risk (UNEP, 1992b).

It has been noted by Pickup and Chewings (1994) that it is in wet periods that desertification can best be detected. During wet periods reductions in the Net Primary Production (NPP) owing to desertification are separable from reductions that are caused simply by drought.

4.1.1 The role of remote sensing in land degradation

Monitoring of land degradation over large areas is difficult (Grainger and Bradley, 1998), resulting in a lack of reliable data that has even caused questions to be raised about the existence of land degradation (Thomas and Middleton, 1994). However, Dregne (1983) argued that without convincing data the level of commitment to programmes to combat desertification will remain low. By combining image analysis with Geographical Information Systems (GIS) models that take into account both environmental and human impacts, the ability to monitor land degradation will be extended (Burrough, 1986). This will however not remove all technical obstacles nor remove uncertainty (Grainger and Bradley, 1998). GIS and remote sensing play an important role in the linkage and analysis of soils, physiography, climate, vegetation and land use data, in particular for detection (direct or indirect), extrapolation and interpretation, as well as area calculation and monitoring. More specifically, GIS and/or remote sensing have been used in assessment of different kinds of soils degradation and conservation; to map temporal and spatial changes in landcover and landuse; and to identify areas of degradation (van Lynden and Mantel, 2001).

Rangelands are often too extensive, heterogonous and inaccessible to effectively make an inventory or to be monitored by ground surveys (Wessman *et al*., 1995). The ground survey method involves intensive measurement of soil or plant community properties (Foran *et al*., 1986). These techniques are either too slow or too expensive for use at more than a few points in the landscape yet many locations must be surveyed to represent the highly diverse landscapes (Tanser, 1997). Less intensive techniques such as aerial photograph interpretation can provide better coverage but with far less accuracy (Pickup and Chewings, 1994). Furthermore, these techniques are not sufficiently repeatable. Therefore, they are of little use in monitoring change over time. In particular, subjective assessments of land degradation during droughts indicate a far worse situation than if the assessment is made shortly after good rains (Freidal *et al*., 1990).

New possibilities for developing detailed maps of degraded land were introduced by using remote sensing data. The possibility to use the aerial photographs for soil mapping has been known for a long time (Goosen, 1967). They were used to support conventional geomorphological methods (Strömquist, 1990), and also for direct identification of sheet, rills and gully erosion (Frazier *et al*., 1983; Strömquist *et al*., 1985). Aerial photographs from different time periods allow the study of erosion dynamics, mainly the growth of rills and gullies (Alam and Harris, 1987). Pickup and Nelson (1984) concluded that a radiance measurement based on the band 4/6-5/6 MSS data space may be used to categorized eroding, stable and depositional surfaces in the arid lands of central Australia. Fulajtar (2001) studied the erosion distribution of agricultural land in Slovakia using aerial photographs and SPOT PAN image.

Satellite remote sensing offers a possible solution to the need to survey all corners of the globe with repeated, ongoing ground observation (Ray, 1995). Remote sensing should provide a powerful adjunct to ground observations by extrapolating observations made at a single point in a given region and providing survey data to aid in targeting ground observation. Remote sensing supported by verifications on the ground are very important for a better perception of the extent as well as the processes of degradation.

4.2.1 LandSat

The Landsat program is the longest running enterprise for acquisition of imagery of the earth from space. The first Landsat satellite was launched in 1972; the most recent, Landsat 7 was launched on April 15, 1999. The instruments on the Landsat satellite have acquired millions of images. The images, archived in the United States and at Landsat receiving stations around world, are a unique resource for global change research and applications in agriculture, geology, forestry, regional planning, education and national security (Lillesand *et al.*, 2004)

Five different types of sensors have been included in various combinations on the Landsat missions. These are the Return Beam Vidican (RBV), the Multispectral Scanner (MSS), the Thematic Mapper (TM), the Enhanced Thematic Mapper (ETM) and the Enhanced Thematic Mapper Plus (ETM^+). These sensors were launched into repetitive, circular, sun-synchronous and near-polar orbits (Lillesand *et al.*, 2004).

4.2.2 LandSat Thematic Mapper

Landsat 4 and 5 carrying the Thematic Mapper (TM) sensor were launched in 1982 and 1984 respectively. The TM sensor is an upgrade of the MSS sub-system on which efforts where made to incorporate improvements into a new instrument. The TM instrument is thus based on the same technical principal as the MSS but with a more complex design as it provides finer spatial resolution, improved geometric reliability, greater radiometric detail and more detailed spectral information. The MSS has only four broadly defined spectral regions whereas the TM has seven spectral bands, customized to record radiation of interest to specific scientific investigations (Campbell, 2002).

4.2.3 LandSat Enhanced Thematic Mapper Plus

The Landsat Enhanced Thematic Mapper Plus (ETM^+) sensor, launched in 1999, is a further development of the TM sensor. The Landsat 7 ETM^+ sensor offers several enhancements over the Landsat 4 and 5 Thematic Mapper sensors, including increased spectral information content, improved geodetic accuracy, reduced noise, reliable calibration, and the addition of a panchromatic band and improved spatial resolution of the thermal band (Masek *et al.*, 2001).

4.2.4 Image correction procedures

Raw digital images contain geometric distortions that are so significant that they cannot directly be used as map base without subsequent processing. The sources of these distortions range from variations in altitude, latitude and velocity of the sensor platform, to factors such as panoramic distortion, earth curvature, atmospheric refraction, relief displacement, and nonlinearities in the sweep of the a sensor's Instantaneous Field of View (IFOV) (Lillesand *et al.*, 2004). The intent of geometric correction is to compensate for the distortions introduced by these factors so that the corrected image will have the highest geometric integrity of a map.

As with geometric correction, the type of radiometric applied to any given digital image data set varies widely among sensors. The radiance measured by any given system over an object is influenced by the factors such as changes in scene illumination, atmospheric conditions, viewing geometry, and instrument response characteristics (Lillesand *et al.* 2004). Some of these such as viewing geometry variations are reduced in the case of satellite image acquisition as opposed to airborne data collection. It is often necessary to generate mosaics of images taken at different times or to study the changes in reflectance of ground features at different times or locations. In such applications it is necessary to apply a sun elevation correction and earth-sun distance correction.

4.2.5 Multi-spectral techniques

Classification of digital imagery involves grouping together pixels on the basis of similar spatial reflectance values in order to identify the areas or information of interest (Harrison and Jupp, 1990; Lillesand *et al.*, 2004; Richards and Jia, 1999; Tueller, 1989). Classification is achieved by two basic methodologies. These are supervised, unsupervised or a mixture of both. Tueller (1989) states that on rangeland unsupervised classification appears to produce the most accurate results. O'Neill (1989) found that in the heterogeneous areas of high variability unsupervised classification was far more accurate than a supervised approach but that a combination of both produced the best results.

4.2.5.1 Unsupervised classification

Unsupervised classification involves algorithms that examine the unknown pixels in an image and aggregate them into a number of classes based on the natural groupings or clusters present in the image value. The basic premise is that values within a given cover type should be close together in the measurement space, whereas data in different classes should be comparatively well separated.

4.2.5.2 Supervised classification

A supervised classification consists of three basic steps: (1) In the training stage, the analyst identifies representative training areas and develops a numerical description of the spectral attributes of each land cover type of the interest in the scene. (2) In the classification stage each pixel in the image data set is categorized into a land cover class it most closely resembles. If the pixel is insufficiently similar to any training dataset, it is usually labelled 'unknown'. The category label assigned to each pixel in this process is then recorded in the corresponding cell of an interpreted data set as an output image. Thus, the multi-dimensional image matrix is used to develop a corresponding matrix of interpreted land cover category types. (3) After the entire dataset has been categorized, the results are presented in the output stage.

In this chapter aerial photographs and Landsat images were combined together with the GIS techniques to evaluate and map the extend of the land degradation in the Butana area during the period from the mid 1960s to 2000. Some indices were also examined to assess the landscape condition in the area.

4.3 Material and Methods

4.3.1 Data collection and data analysis

The boundary of the Butana area was adjusted according the availability of the aerial photographs and Landsat images. Figure 4.1 shows the study area and the Landsat scenes and aerial photographs sites. To fulfil the objective of this chapter an ample amount of data were needed to monitor and map the land degradation over extensive, remote areas. Hence the primary sources of the data were panchromatic, black and white aerial photographs and Landsat images. The multi-dates Landsat images were obtained from the National Remote Sensing Unit, University of Khartoum, Sudan and the Regional Centre for Mapping of Resources for Development, Nairobi, Kenya. The aerial photographs were obtained from the Agricultural Research Corporation, Wad Medani, Sudan and Sudan National Survey Authority, Khartoum, Sudan. The aerial photographs covered part of El Maseid, Kamlin and Shareif Baraket areas (Figure 4.1). Landsat images dates are presented in Table 4.1. Limited field collection of data has been carried out. Auxiliary sources of information include topographic maps (scale 1:250,000).

The image processing tool used in this chapter is ERDAS IMAGINE 8.5, and ArcMap 9.1 software, therefore the methods used in obtaining multi-spectral classifications will be taken from ERDAS.

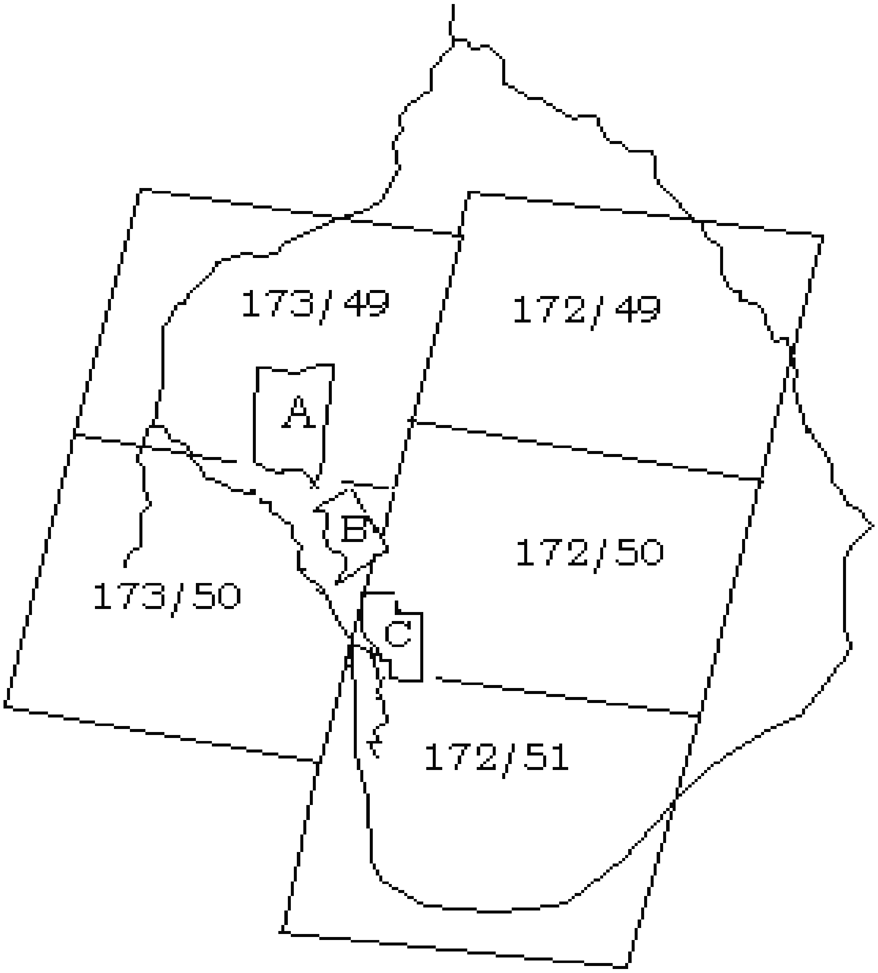


Figure 4.1 Map of the study area showing the Landsat scenes (path/row) in World Reference System 2 (WRS2) and aerial photographs for A) El Maseid, B) Kamlin and C) Shareif Baraket sites.

Table 4.1 Acquisition dates and position in WRS2 for the Landsat data

Scene ID (P/R)	Acquisition Date
173/49	3/10/1987; 24/12/2000
173/50	30/10/1987; 06/11/2000
172/49	27/10/1987; 3/10/1996; 30/10/2000
172/50	30/10/1987; 3/10/1996; 30/10/2000
172/51	27/10/1987; 3/10/1996; 13/11/1999

4.3.2 Interpretation of aerial photographs

The aerial photographs were analyzed with both pocket and mirror stereoscopes (Buringh, 1993). The main criteria used to distinguish the miscellaneous, dissected land use were topography, drainage pattern, grey tone, vegetation cover and land use (parceling).

4.3.3 Geometric correction of Landsat data

The Landsat data covering the same area from the different dates were geometrically corrected to each other in order to cut out areas of interest and get the same size and exactly the same area. Every pixel in the Landsat TM data from 1987 was converted to the projection of the Landsat ETM+ data from 1999. The reason that the TMs were corrected to the ETM+s is that the field data collected (training areas) during the field survey (March-August 2005) corresponded better to the ETM+s that were taken more recently. Finally subsets of areas that surround the study areas were cut out.

4.3.4 False Colour Composite (FCC)

Bands 2, 3 and 4 which represent the green, red and infrared respectively, were used to develop False Colour Composite (FCC) image. The colours assigned to each of the bands are in the same order blue, green and red. This combination of colours gives various shades or tones of red for the healthy chlorophyll-rich vegetation in an FCC image. The richness of red colour is dependent on the vigour as well as on the size of leaves (ElMobark, 1991).

4.3.5 Image classification

An unsupervised classification is performed using the ERDAS Imagine ISODATA algorithm. ISODATA stands for "Iterative Self-Organizing Data Analysis Technique." It is iterative in that it repeatedly performs an entire classification (outputting a thematic raster layer) and recalculates statistics. "Self-Organizing" refers to the way in which it locates the clusters that are inherent in the data. The ISODATA clustering method uses the minimum spectral distance formula to form clusters. It begins with either arbitrary cluster means or means of an existing signature set, and each time the clustering repeats, the means of these clusters are shifted. The new cluster means are used for the next iteration. The ISODATA utility repeats the clustering of the image until either:

a maximum number of iterations has been performed, or
a maximum percentage of unchanged pixels has been reached
between two iterations.

The output file will have a grey scale colour scheme if the initial cluster means are arbitrary. If the initial cluster means are from an existing signature set, then the output file will use the colours of this signature set (ERDAS 8.5 Manual).

4.3.6 A landscape pattern index to monitor degradation

4.3.6.1 Moving Standard Deviation Index (MSDI)

The redistribution of matter and nutrients across heterogeneous landscapes is not well documented. However, recent work in semi-arid rangelands (Miles and Johnson, 1990; Pickup, 1985; Schlesinger *et al.*, 1990; Tongway, 1990) has shown that land degradation may result in increased runoff and increased soil and water redistribution within an area. This leads to changes in the distribution pattern of vegetation cover of different types and not necessarily a reduction in biomass. Biomass may be relocated in the roots and woody plants which are less desirable for the nomads. This leads to an increase in landscape heterogeneity or variability, with the nutrients and moisture being concentrated in small run-on or deposition areas supporting an increasingly dense cover of unpalatable grass and shrubs. The rest of the landscape maintains a cover which is sparser than that existing before degradation occurred (Tanser, 1997). The heterogeneity of soil resources leads to further localization of the soil resources under canopies. In the barren area soil fertility is lost by erosion and gaseous emission. This leads to desertification of formerly productive areas (Schlesinger *et al.*, 1990).

The underlying assumption of the heterogeneity index is that a healthy landscape is less variable than a degraded landscape (Tanser, 1997). Degraded arid zone landscapes can be highly patterned due to extensive erosional activity. The vegetation change is often spatially variable because of the redistribution of water and sediment (Freidel *et al.*, 1993). When an increase in spatial heterogeneity is observed the landscape has moved from a state of equilibrium to non-equilibrium and can be said to have become 'dysfunctional' (Ludwig and Tongway, 1997). Moving standard deviation images were calculated by passing a 3x3 moving filter across the image (Baker and Cai, 1992; Tanser, 1997; Tanser and Palmer, 1999). The moving window calculates the standard deviations for nine pixels and assigns that value to the middle pixel. The standard deviation is then placed into a new map at the same location as the target pixel. The window is then moved to the right one pixel (and then down one row at the end of the row) and the process is repeated. The standard deviation is calculated according to the following formula:-

$$\sigma = \frac{\sqrt{X_{ij}{}^2 - \frac{(\sum X_{ij})^2}{n}}}{n} \tag{4.1}$$

where:
X_{ij} = Digital numbers
n = No. of pixel per block (9)

4.3.6.2 Bare Soil Index (BSI)

The bare soil areas, fallow lands and vegetation with marked background response are enhanced using this index. The BSI was used for mapping bare soil and thus differentiating it from vegetation cover. It is a normalized index separating two vegetation with different background viz completely bare, sparse canopy and dense canopy. BSI has been calculated using equation 4.2 (Jamalabad and Abkar, 2004; Pretorius and Bezuidenhout 1994; Wessels, 2001):-

$$BSI = \frac{(B_5 + B_3) - (B_4 + B_1)}{(B_5 + B_3) + (B_4 + B_1)} * 100 + 100 \qquad (4.2)$$

where

B_1, B_3, B_4, B_5 is band 1, 3, 4, 5 respectively.

4.4 Results and Discussion

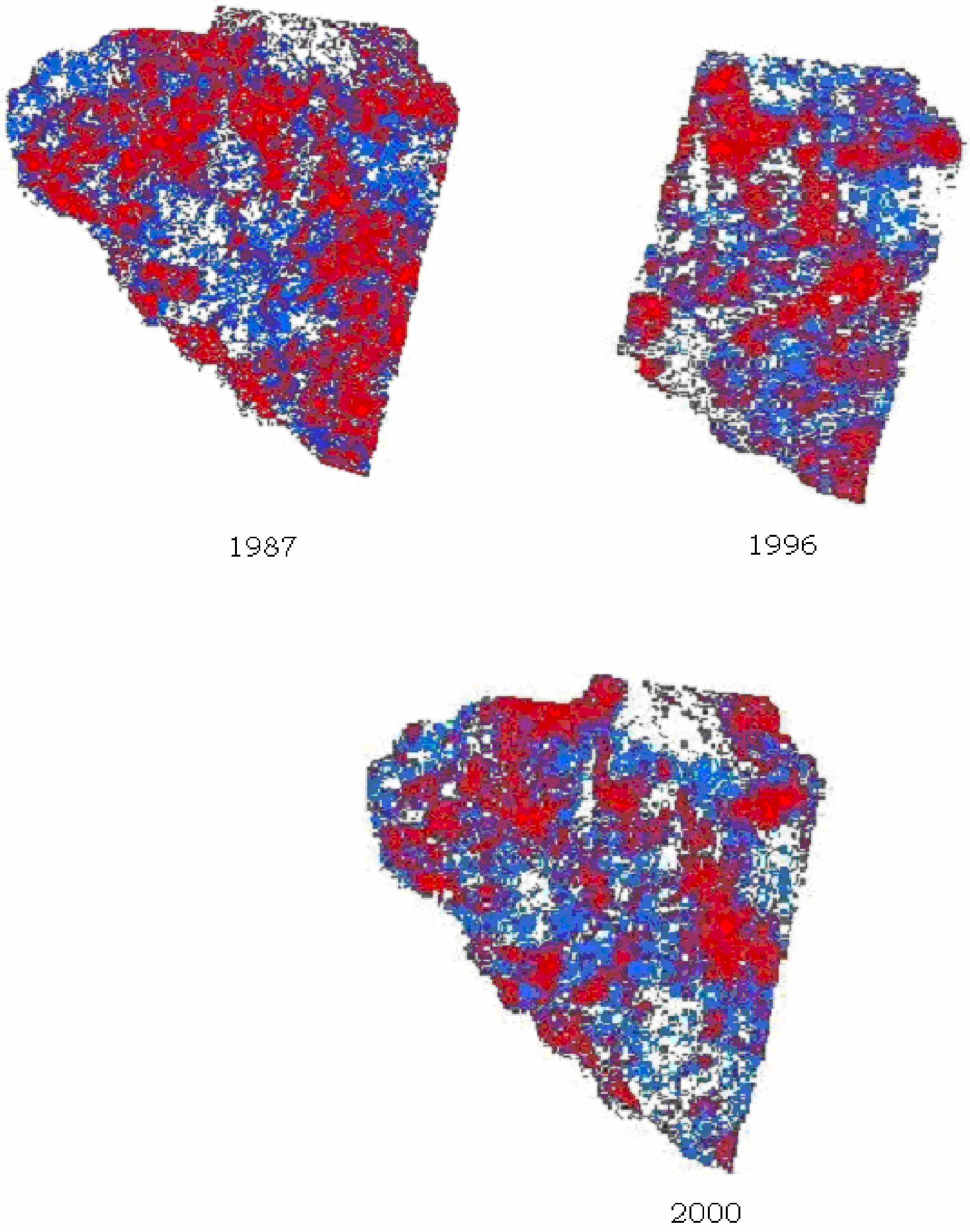
The Landsat data contains an enormous amount of information. The image processing and classification techniques are dealing mainly with the categorization of these data depending on the spectral information in that data.

4.4.1 False Colour Composite

Bands 2, 3 and 4 were used to created False Colour Composite (FCC) for 1987 and 2000 for scenes (173/49, 173/50 and 172/49, 172/50, 172/51) and 1996 for scenes (1972/49, 172/50, 172/51). Figure 4.2 shows the result of the FCC mosaic image where the red colour represent the healthy vegetation in the irrigated schemes (Rahad, ElGuiened and New Half), rainfed agricultural production area and dense vegetation cover. Bare lands are represented by white colours and the blue colour represents different soil conditions and soil types, mainly according to soil water content.

4.4.2 Unsupervised classification

The unsupervised classification of bands 2, 3 and 4 produced a good result for land use classification in the area. Five classes that were mapped using the unsupervised classification agreed strongly with those produced by the FCC. Figure 4.3 shows the different classes of land use in the Butana area. The parcels containing vegetation in the irrigated schemes, rainfed and dense vegetation area were classified on the three different dates.



1987

1996

2000

Figure 4.2 False Colour Composite for 1987, 1996 and 1999 respectively developed from Landsat data

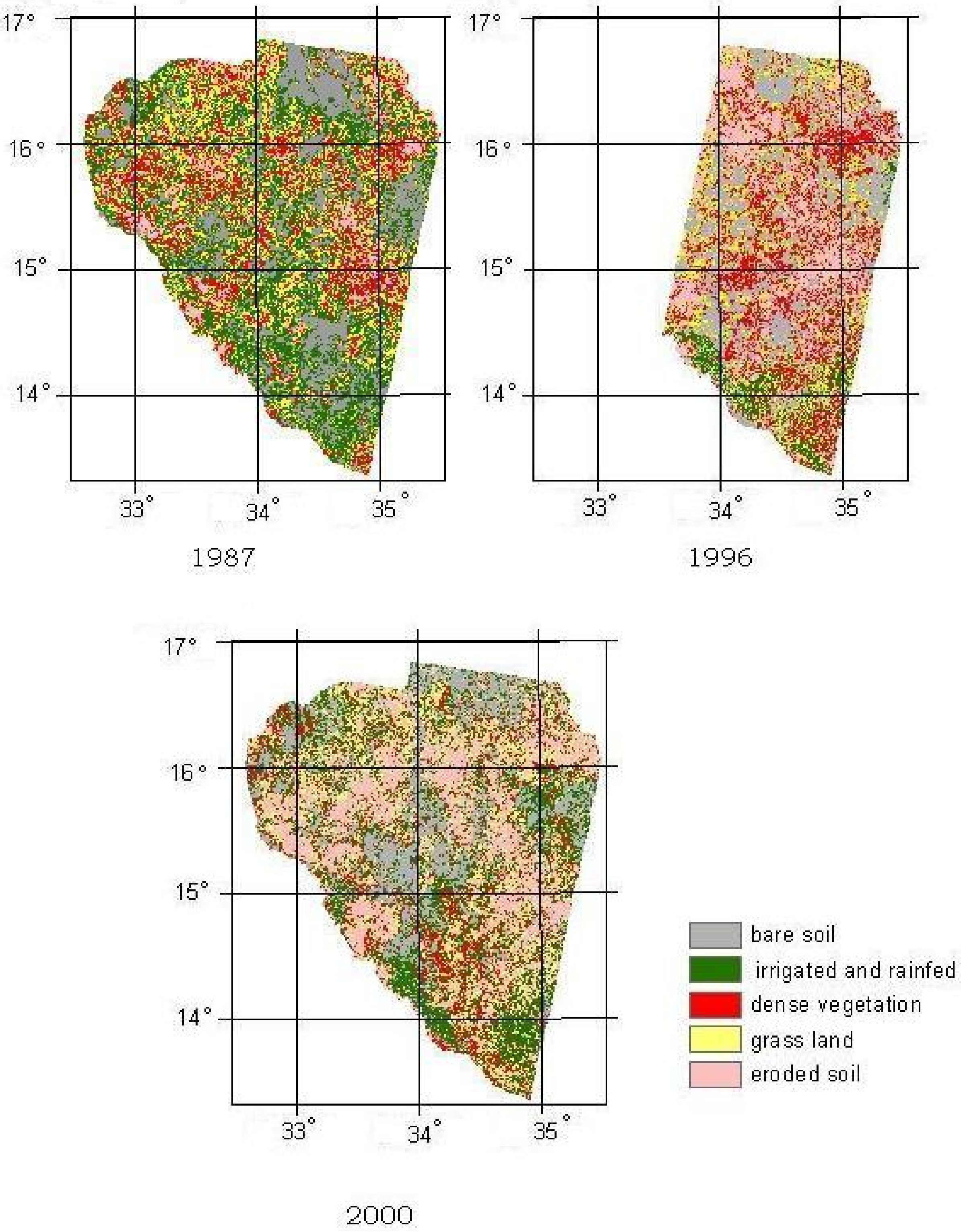


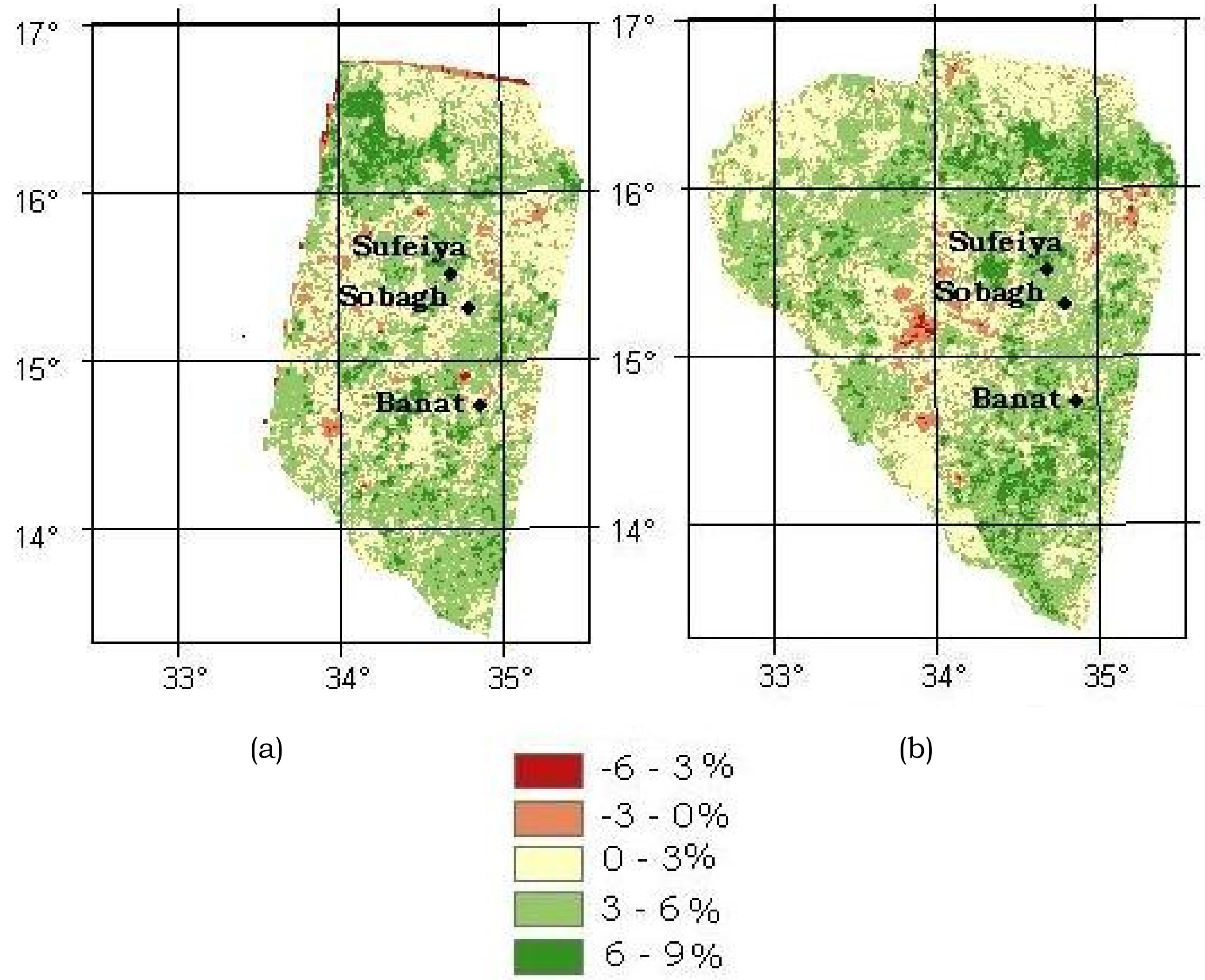
Figure 4.3 Land use classes of the study area for 1987, 1996 and 2000 respectively from unsupervised classification method using Landsat data

Akhtar and Mensching (1993) classified the Butana area into seven classes based on the Landsat MSS 1986 and Landsat TM 1991. In Akhtar and Mensching's classification the irrigated and rainfed agricultural areas were considered as two classes, while in this study the two were combined into one class, and that was due to fact that the irrigated schemes and rainfed agricultural areas had the same crops during the rainy season (Sorghum, groundnut, sesame) and so would be difficult to distinguish from each other.

The visual comparison of classes on the three dates indicates that the bare (Figure 4.3) and eroded soil increased from 1987 to 2000. The eroded soil was associated with a high reflectance. Pickup and Nelson (1984) reported that the most severe erosion is associated with high reflectance of Landsat MSS bands.

To study the differences in the land use and land cover between the different dates of the Landsat images, the image difference techniques in GIS software (ArcMap 9.1) were used and the results are shown in Figure 4.4. Based on the comparison between image classification and image difference results, it could be noticed that the eroded and bare soil increased by about 1 - 3% during the period from 1987 to 1996, and by about 3 - 7% during the period between 1987 and 2000. While the vegetation cover decrease by about 3 - 6% for the same period. Figure 4.4 also illustrates that the degradation of the vegetation cover around Sufeiya, Sobagh and Banat areas was increased as mentioned by many authors, while that on the irrigation schemes has remained stable.

To study the effect of the high variability of the rainfall on this degradation, the calculation of 30 year averages with 1941-1970 as a wet period and 1971-2000 as a dry period. The seven meteorological stations surrounding the Butana area were used to show the approximate location of the 100, 300, and 500 mm isohyets. Figure 4.5 shows that the isohyets shifted toward the south by about 89, 46, 23 km for the 100, 300, and 500 mm isohyets respectively between the two 30 year periods. This led to a shift in the vegetation belt towards the south. Pflaumbaum (1994) concluded that the climate induced a boundary shift of extended useable pasture in the Butana area by about 400 km southward.



(a) (b)

Figure 4.4 Image differences for the study area for (a) 1987-1996 and (b) 1987-2000 respectively.

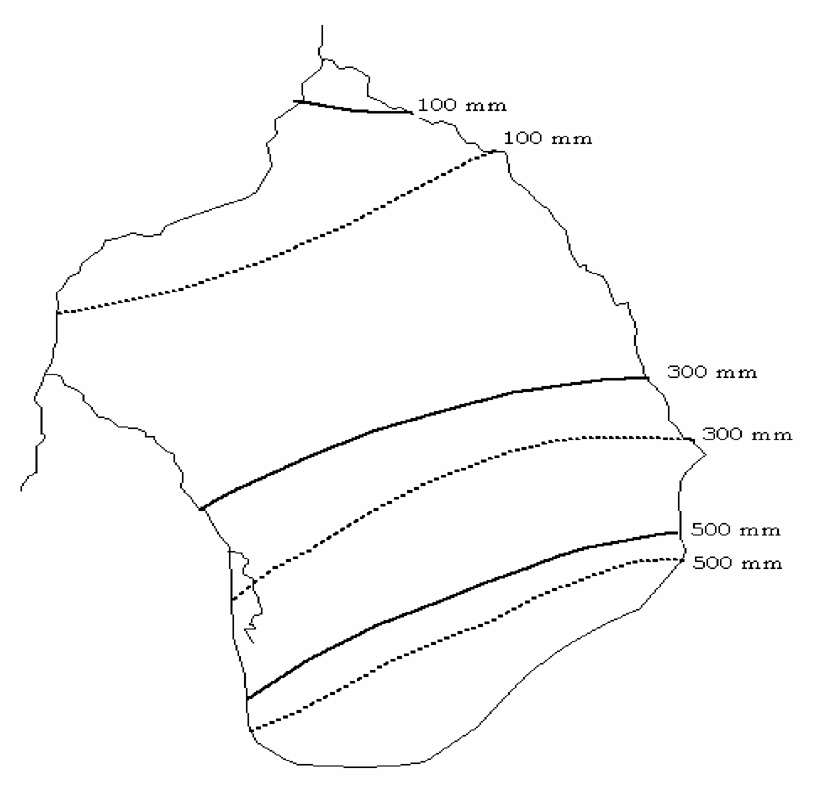


Figure 4.5 Rainfall isohyets for 1941-1970 average (———) and 1971-2000 (···········) for the study area (data from SMA)

4.4.3 *Aerial photographs*

Maps for El Maseid (1964, 1984), Kamlin (1965, 1984) and Shareif Baraket (1966) areas were produced using grey tone, drainage pattern, vegetation cover and land use. These maps were overlaid with the Landsat image for 2000. Figures 4.6 a and b show that during the 1960s there is active rainfed agriculture and dense trees in the Kamlin area, while in 1984 the rainfed agriculture was abandoned completely or partially and the dense trees had disappeared. When these maps are overlaid with Landsat 2000 it can be noticed that the eroded and bare soil area has increased considerably and there are some areas covered with grass which may be an indication of bush encroachment. For example at the Kamlin site the dense vegetation area (V1) during 1965 (block 33° 15' to 33° 19' E and 15° 11' to 15° 15' N) has became eroded soil by 2000 although the progression of the degradation can not be seen as this section is not on the 1984 aerial photograph. And the active rainfed agriculture during 1965 (block 33° 13' to 33° 17' E and 15° 0' to 15° 3' N) is completely abandoned in (R4) 1984, while in 2000 has became eroded soil with sparely scatter grasslands.

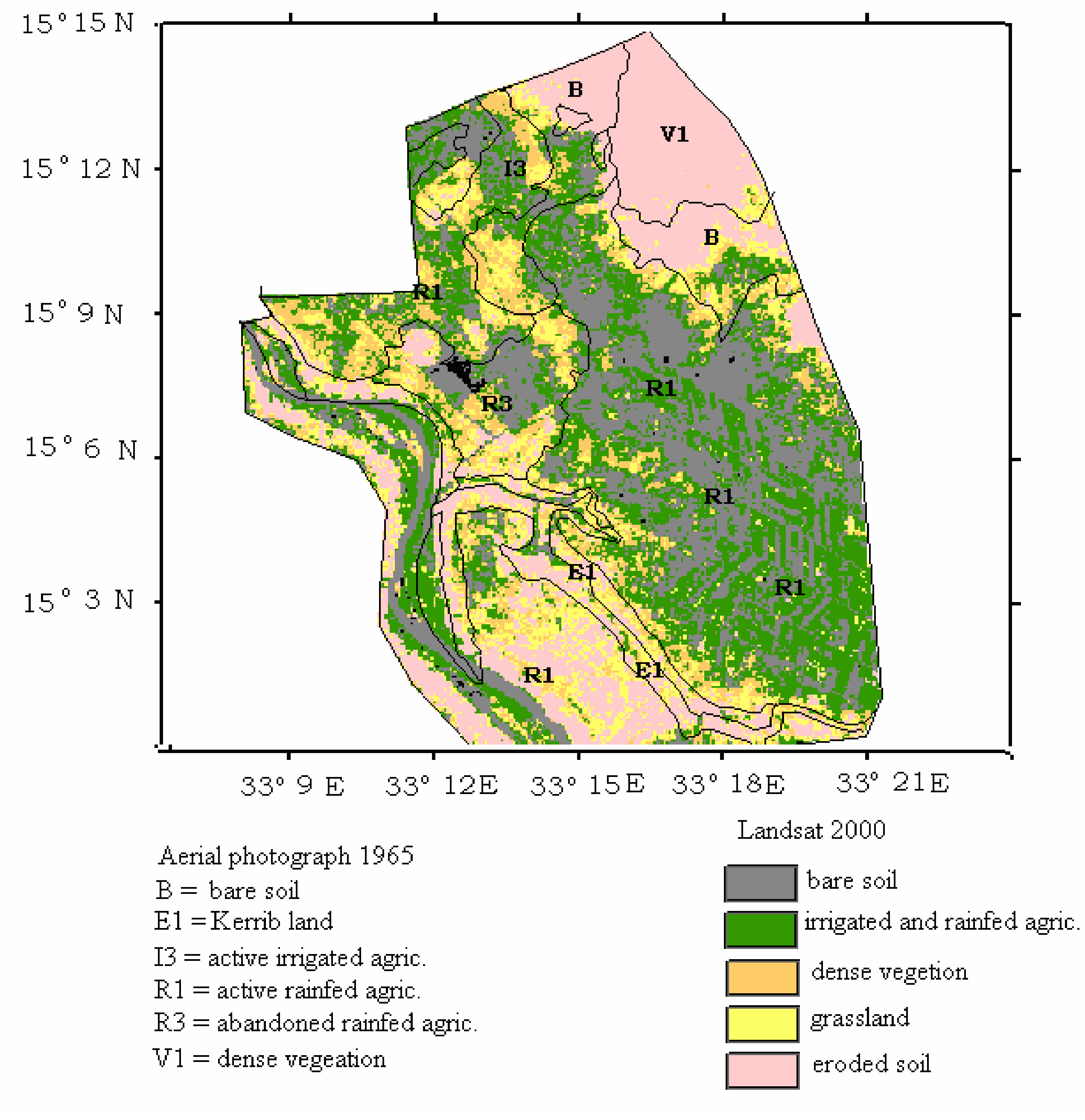


Figure 4.6a Map made from the overlay of the 1965 aerial photos and Landsat image (2000) for Kamlin area

(Kerrib land: sloping lands, severely dissected and eroded between the clay plain and the alluvial plain (Masdar, 1991)).

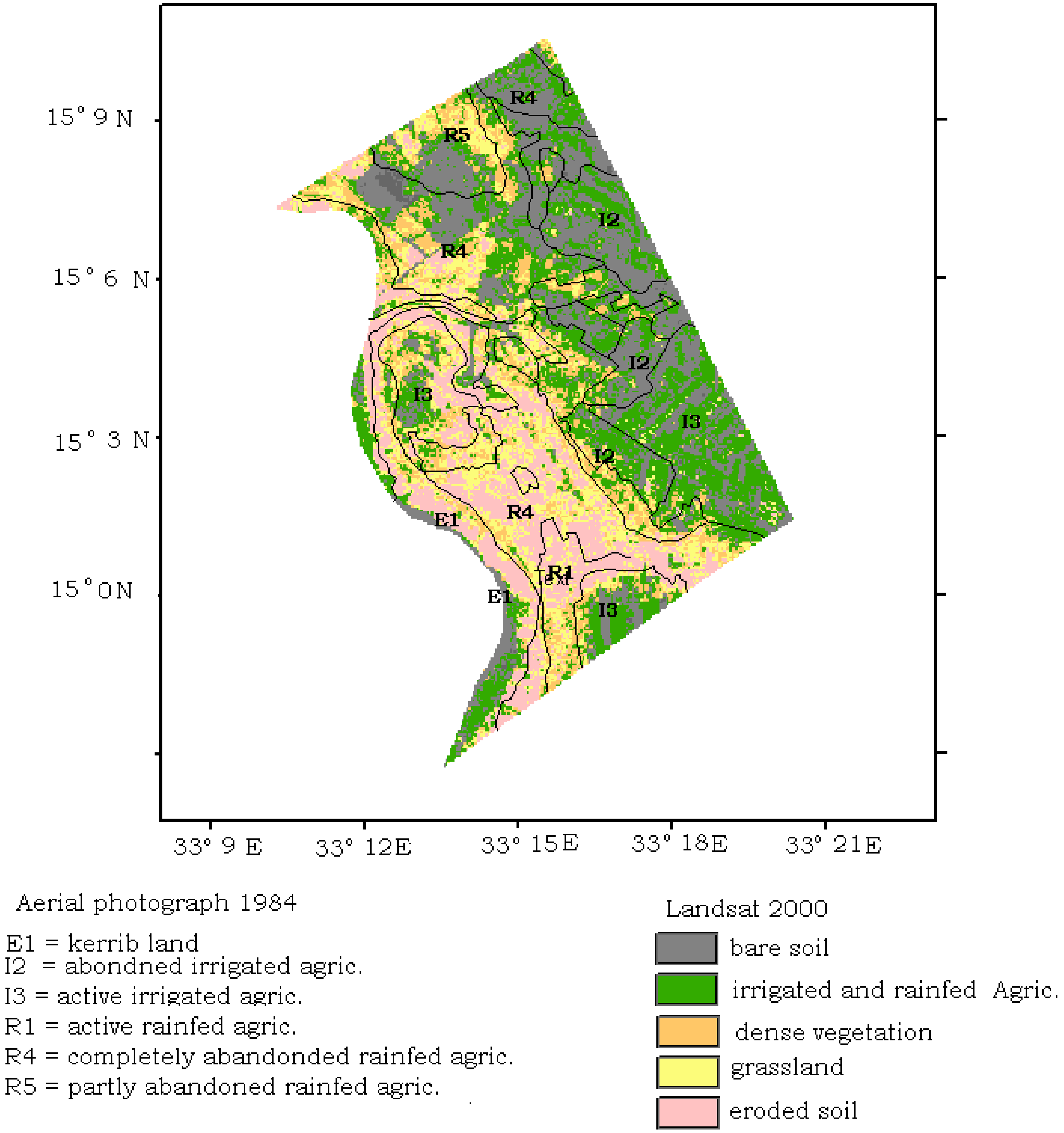


Figure 4.6b Map from the overlay of the 1984 aerial photograph and Landsat (2000) for Kamlin site

For El Maseid site when comparing the maps of 1960 and 1984 with Landsat 2000 (Figure 4.6 c and d) it can be noticed that the active rainfed agriculture areas (R1) (block

32^{o} 55' to 32^{o} 58' E and 15^{o} 19' to 15^{o} 21' N) change to scattered trees and rainfed agriculture (V2) and trees in depressional area (V3) in 1984. In 2000 the Landsat image shows this area to be predominantly eroded soil with some grassland on the edge. This then area has change from active production to become an eroded area in 35 years. While the rainfed agriculture (R1) and dense vegetation (V1) area in block 32^{o} 58' to 33^{o} 3' E and 15^{o} 17' to 15^{o} 20' N during 1960 and 1984 were completely eroded in the east by 2000 and only had small patches of irrigated areas in the west interspersed bare soil and some grassland. This show decrease productivity from this area and increase degradation with time.

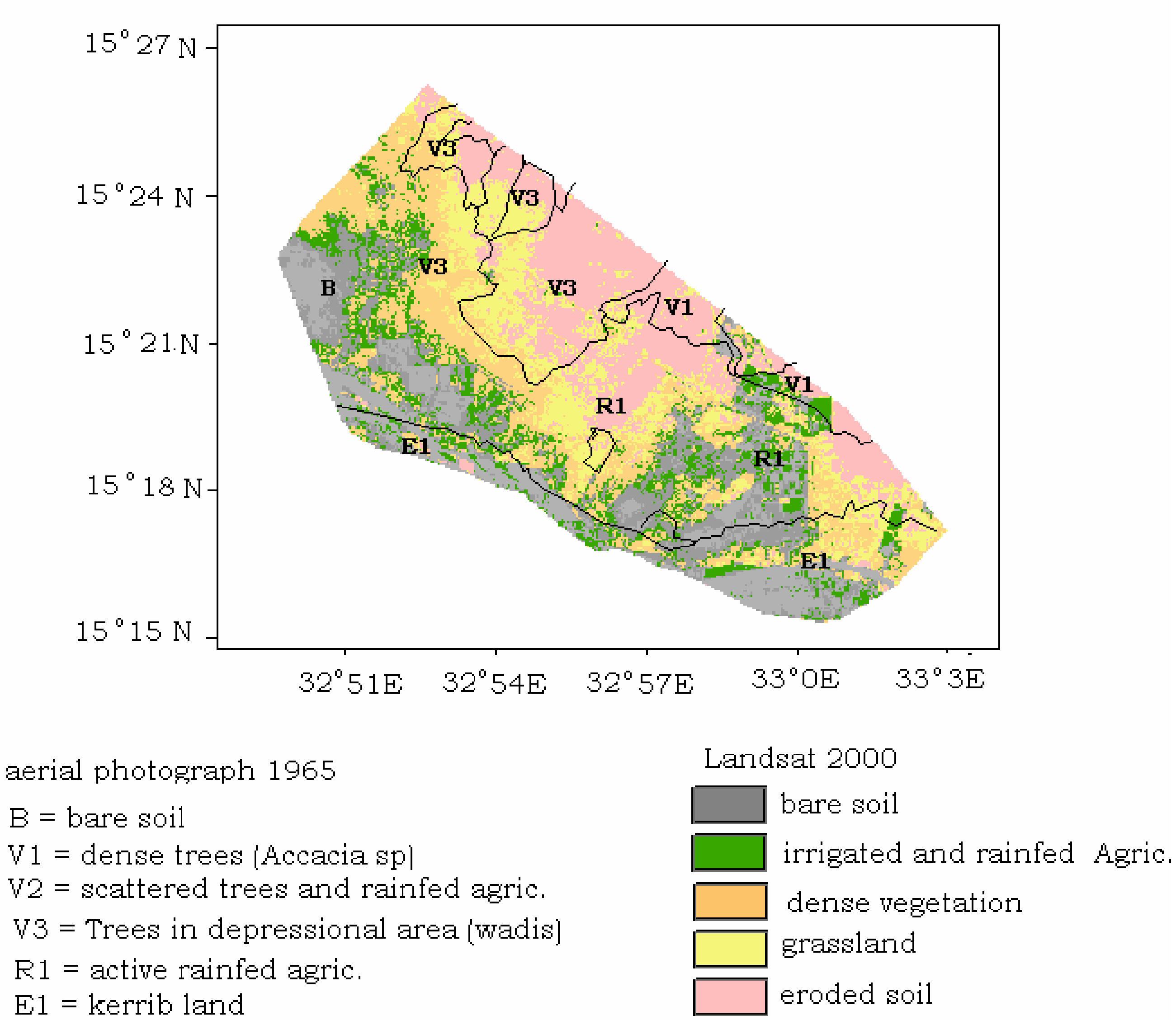


Figure 4.6c Map from the overlay of the 1965 aerial photos and Landsat image (2000) for El Maseid area

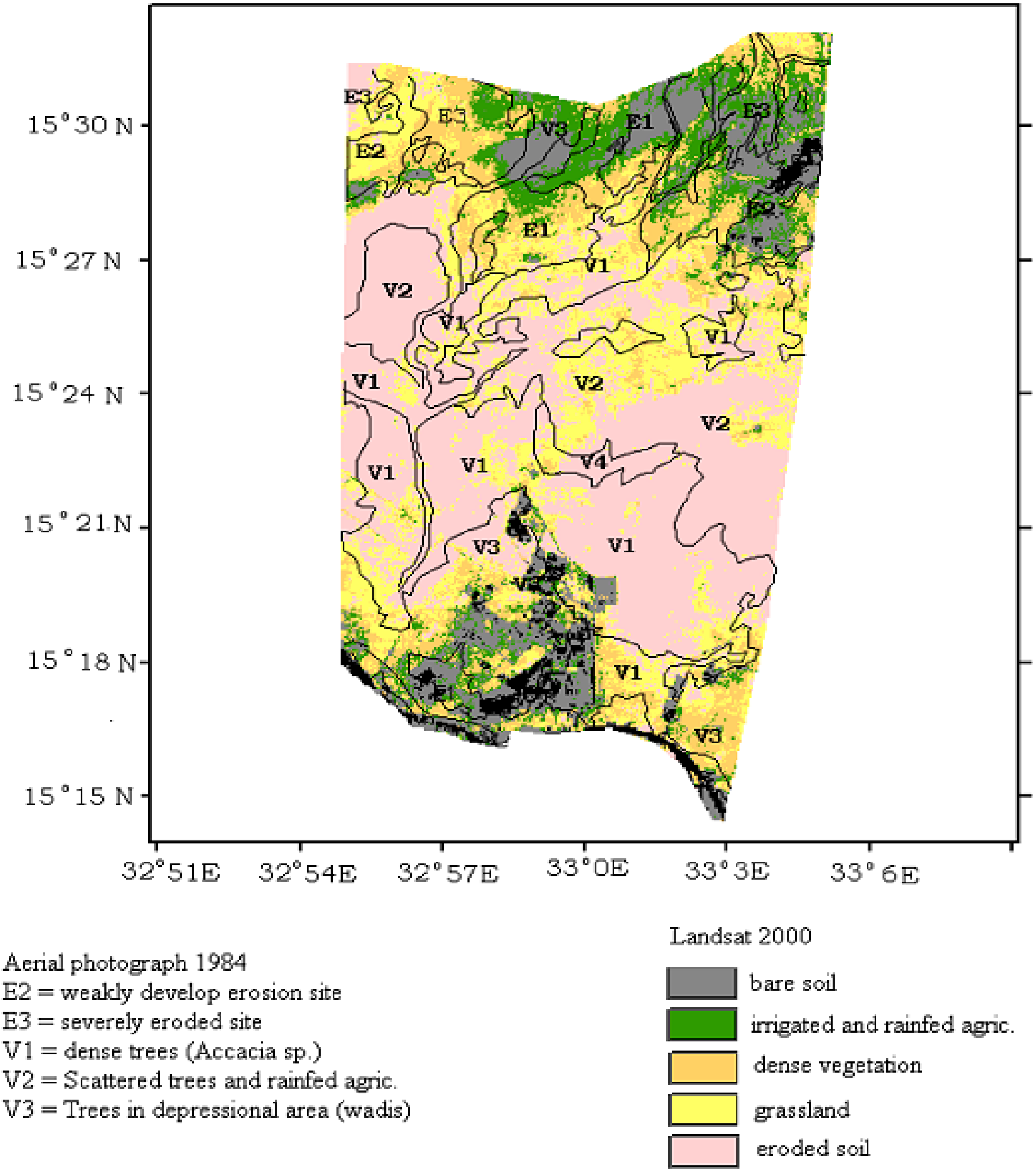


Figure 4.6d Map from overlay of the 1984 aerial photograph and Landsat image (2000) for El Maseid area

The Shareif Baraket site (Figure 4.6e) shows considerably change in the landscape pattern. For example the rainfed agriculture area (R1) during 1960 changes to dense vegetation in some parts and to eroded soil in other parts in 2000. While the area cover by dense trees (V1) and grass (V5) in 1965 has by 2000 has become eroded soil. While all the vegetative cover has vanished except for small areas adjacent to the Nile river bank or the wadis and there it is scattered grassland which was not recognised in 1965 maps.

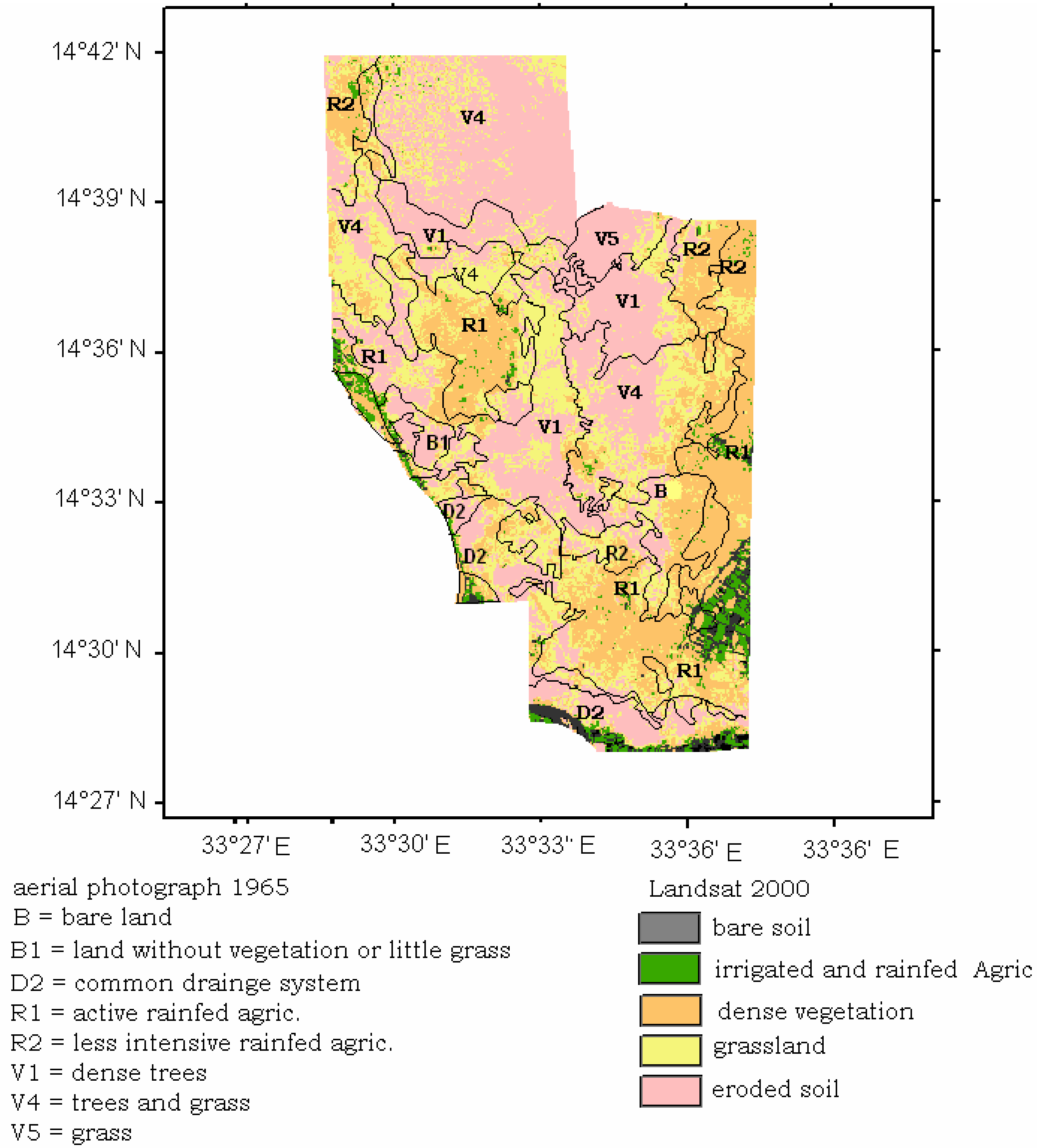


Figure 4.6e Map from the overlay of the 1965 aerial photographs and Landsat image (2000) for Shareif Baraket

From the Landsat image and aerial photograph results it can be seen that soil erosion by water and wind is a serious problem in the Butana area. Plate 4.1 and 4.2 shows the sand encroachment around Banat and ElKhatow villages. Water erosion leads to washouts in some villages around ElKhatwa and Shakia Mekkia during the rainfall season (August 2005) (plate 4.3).

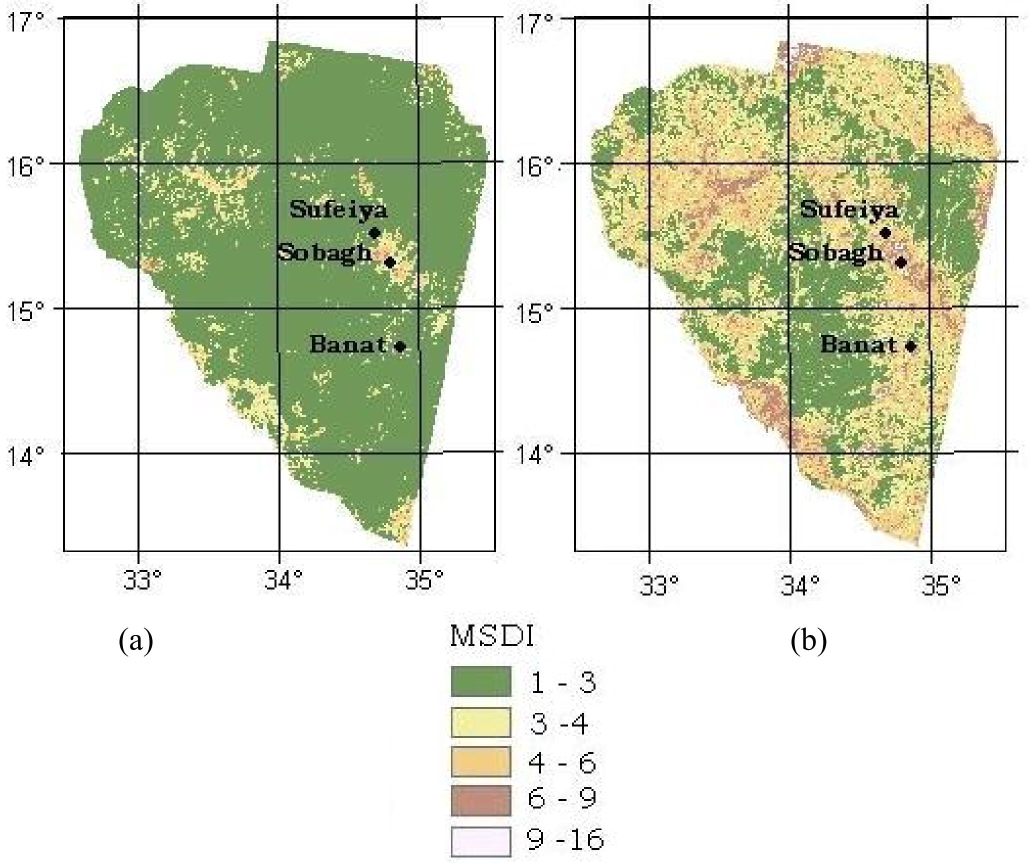
Plate 4.1 Wind erosion around ElKhatow (photo courtesy S. Walker, August 2005)

Plate 4.2 Wind erosion around Banat area (photo courtesy M. Elhag, May 2005)

Plate 4.3 Houses in Shakia Mekkia village that were completed washed away by water erosion after a rain event in August 2005 (photo courtesy S. Walker, August 2005)

4.4.4 Moving Standard Deviation Index

The MSDI shows that the degraded site in the area exhibits the highest MSDI values. While un-degraded areas are shown by low MSDI values (Figure 4.7). It can be noted that the areas which have been severely eroded with little or no vegetation show high MSDI values. Areas severely degraded as mentioned by many authors (Akhtar and Mensching, 1993; Ayoub, 1998a, Elhassan, 1981) around Banat, Sufeiya and Sobagh also show high MSDI. In 1987 the study area shows lower MSDI values, compared to 2000. The image difference for MSDI (Figure 4.8) shows that most of the areas have exhibited large changes in MSDI during the last 13 years. The MSDI image difference indicates that the degraded areas were increased considerably between 1987 and 2000 especially around Banat, Sufeiya and Sobagh (Figure 4.8).



(a) (b)

Figure 4.7 Moving Standard Deviation Index (MSDI) for the study area for (a) 1987 and (b) 2000 respectively calculated from Landsat data

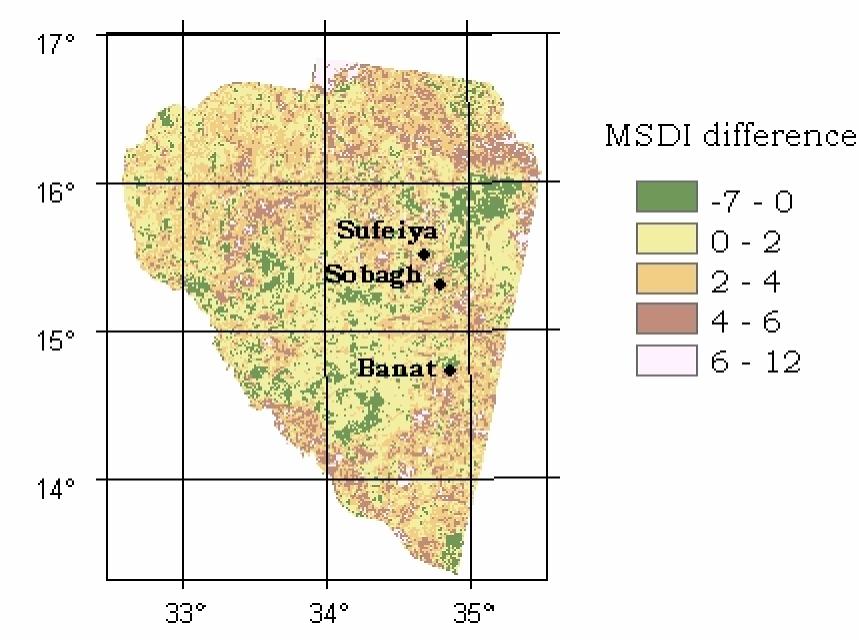
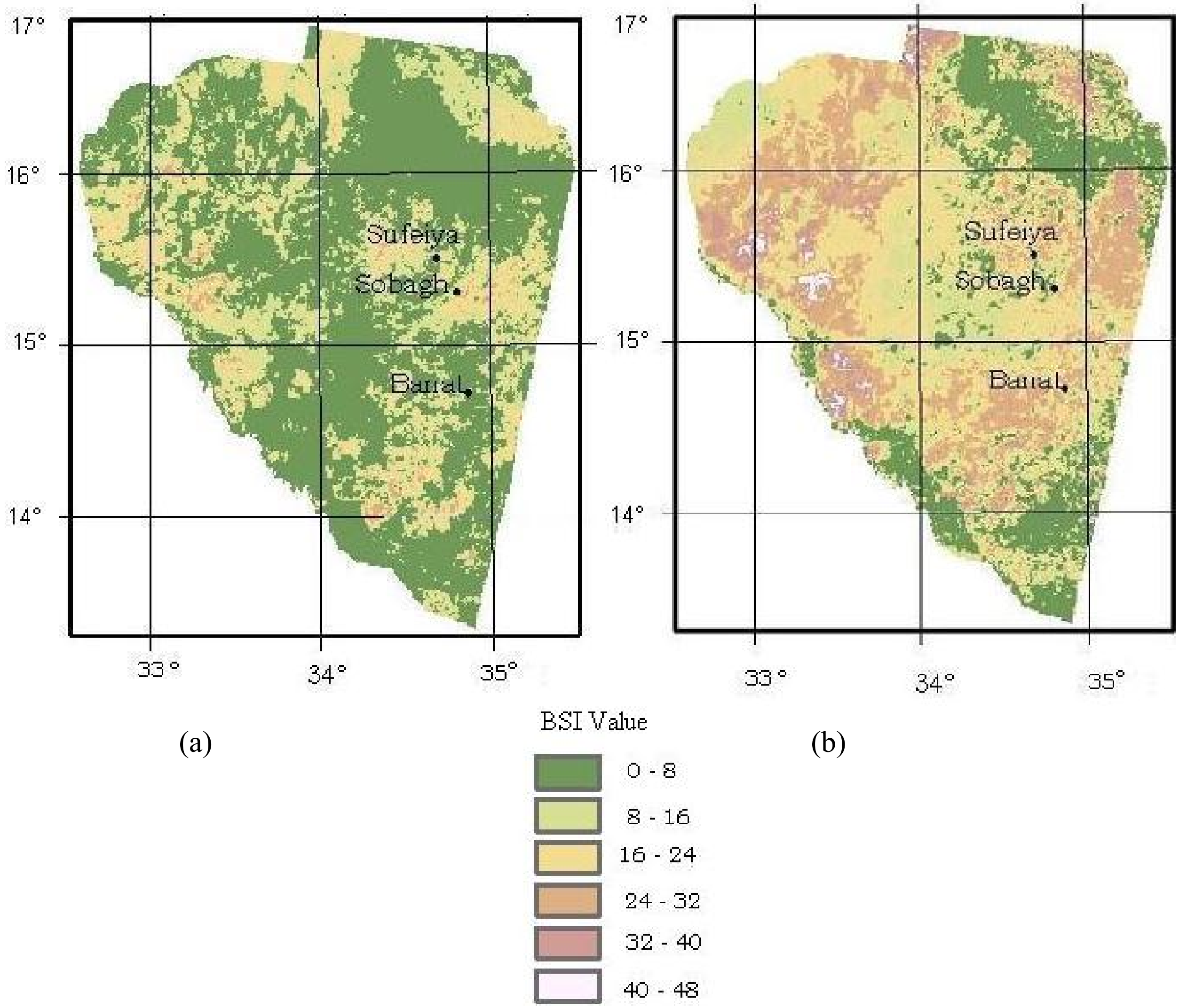


Figure 4.8 Image difference of MSDI (1987-1999) for the study area

4.4.5 Bare Soil Index

The BSI was calculated to identify areas affected by soil degradation and to independently confirm the result obtained from the MSDI analysis. The BSI highlights areas that were potentially affected by erosion, possibly requiring intervention to counteract severe degradation. Degraded areas could be identified in a short period of time using satellite imagery. This is unlike conventional field surveys that take much more time for the completion of degradation assessments. By the time when surveys are completed, degradation could have reached severe stages. Figure 4.9 indicates large degraded areas; which would have taken too much time to be identified using only physical observations. The BSI image was merged with the land cover classes in order to differentiate between cultivated areas and bare soil. This helped to avoid misinterpretation of cultivated lands to degraded classes. Figure 4.9 illustrates that in 1987 most of the study area had a low BSI expect for a few sites where the index at a medium level, while in 2000 the BSI is low in the irrigation schemes (south western and north eastern part) and rainfed agriculture areas (south part), but most of the area exhibits the highest BSI values. By comparison of the MSDI and BSI images it can be noticed that the degraded areas exhibit high values for the both indices, which can be interpreted that the degraded area is more heterogeneity and their more bare land rather than the undegraded area.

To study the change in the bare land, the image difference between the 1987 and 2000 BSI images was calculated using the image difference technique (ArcMap 9.1 software). Figure 4.10 indicates that the bare soil in the irrigated scheme remains constant (-6 to 8). While in the west and central part of the study area the bare soil increased by about 14-43%. It can be noticed that the bare soil increased by about 22-43% around Banat, as illustrated in plate 4.2 the area has been severely affected by wind erosion.



(a)

(b)

Figure 4.9 Bare Soil Index (BSI) for the study area for a) 1987 and b) 2000 respectively

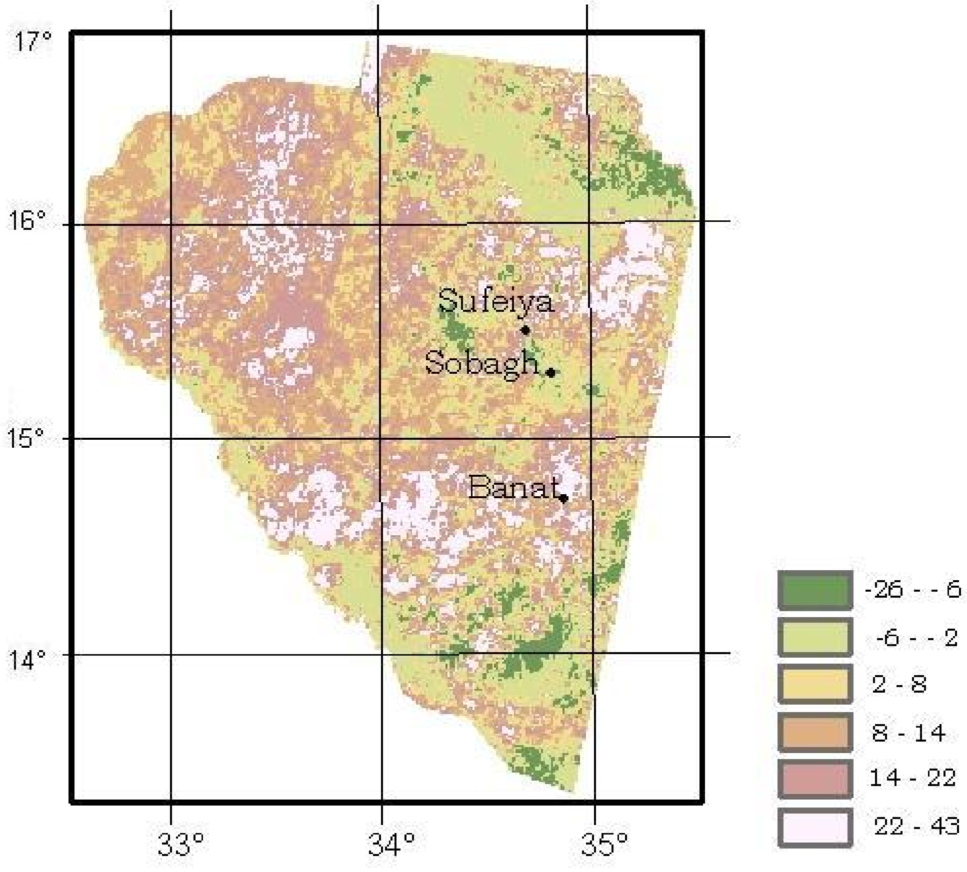


Figure 4.10 Image difference of the BSI (1987-2000) for study area

4.5 Conclusion

The extensive spatial coverage, regular temporal coverage and reasonable cost of satellite imagery provides an opportunity to undertake routine natural resource monitoring. This can then contribute to efficient decision making in natural resource management. In order to monitor and map the land degradation over a large area like the Butana area and over a long time period, multi-dates of both aerial photographs and Landsat images were used.

Five classes of land use and vegetation cover were achieved using unsupervised classification. This result confirmed the findings by O'Nell, (1989) and Tueller (1989) who propose that in heterogeneous areas of high variability an unsupervised classification is more accurate than a supervised classification. From the land use classes it can be noticed that the bare and eroded land has increased over the last 13 years. This result was confirmed when applying image differences for 1987-1996 and 1987-2000 which give evidence that the bare soil and eroded land increased by about 3-7% while the vegetative area decreased by about 3-6%. When comparing the aerial photographs (1960s and 1980s) for Shareif Baraket, Kamlin and El Maseid with Landsat images for 2000 severe degraded patches have replaced the vegetative cover in the some of the specific parts at all three sites.

Miles and Johnson (1990), Pickup (1985), Pickup and Nelson (1984) suggest that any process that leads to an increasing heterogeneity of the soil resources in space and time is likely to lead to the degradation of a landscape. Based on the above findings the Moving Standard Deviation Index (MSDI) was used to examine the heterogeneity of landscape in the Butana area. The MSDI proved to be powerful indicator of landscape condition for the study area. The MSDI increased from 1987 to 2000 considerably especially in Sufeiya, Sobagh and Banat areas, as mentioned by many researchers as sites that have shown severe degradation.

The extent of degradation affecting natural resources can be monitored using the Bare Soil Index (BSI). The BSI image for 1987 and 2000 support the finding from the MSDI. The BSI for the degraded sites Sufeiya, Sobagh and Banat increase from 0-8 at 1987 to 32-40 at 2000. The image difference of the BSI indicated that the index increased by about 14-43 over the last 13 years.

From the all results obtained above it can be noticed that the different ecosystems in the Butana area are subject to various forms of site degradation. The desertification has led to sand encroachment and to accelerated development of dunes and also increased the water erosion in the northern part of the area. Pastures have deteriorated seriously in quality and quantity. But in many parts the degradation is still reversible if organized land use and water points could be introduced.

Chapter 5

Perceptions of the Pastoralists on Environmental Degradation

5.1 Introduction

Life in the Butana area – an area with annually changing conditions of rainfall and pastures - has always been a challenge for nomadic pastoralists. They have developed ways of reacting to these changes, and also of surviving during droughts - a principal strategy being their mobility. Livestock not only constitutes the main livelihood of the pastoralists, but also represents the main component of the gross domestic product (GDP) of the economy of the country. Due to the harsh climate of the drylands, where conventional cropping agriculture is difficult without supplementary irrigation, pastoralism has evolved as a means to convert the rangeland forage resources into milk, meat, hides and skins through livestock production (EARO, 2002). In time, however, this form of agriculture has come under increasing pressure from the influence of droughts and environmental degradation.

Livestock production in pastoral areas is affected by numerous problems of which environmental degradation is prominent. The problem is often better understood by the pastoralists than the policy makers, development planners and researchers. Environmental degradation is a world scenario for which pastoralists are often held responsible. Current indicators are still inadequate to assess relationships between climate, vegetation and livestock, preventing the establishment of development oriented policies that must reverse the unabated process of rangeland degradation (Raynaut *et al*., 1997). The lack of understanding of the relationship between the environment and pastoralists and ignorance regarding the perception of the pastoralists and their outlook on life, may also contribute to the misunderstanding of the pastoral production system and the priorities and needs of the pastoralists (EARO, 2002; Amaha, 2003).

In addressing the problem of rangeland degradation, the primary focus used to be on biodiversity, rainfall and soil erosion without due concern for the pastoralists (Mortimore,

2005) or their perception of the problem (Sandford, 1983; Ellis and Swift, 1988). This approach was mainly due to the biased perception that pastoral production systems are fundamentally ecologically unsustainable (Lamprey, 1983; Sinclair and Fryxell, 1985). A root cause of this biased view is that environmental changes, rangeland degradation and pastoral perceptions of the problem are not fully understood and documented. Contradicting reports will have a negative impact on the planning and implementation of development projects. Therefore, further studies that might lead to better understanding of the current status of rangelands in the Butana area was imperative.

The open-grazing system is practiced in the Butana area, which entails the communal use of the natural grassland by any number of the tribes. The number of the animals which normally graze on the rangeland is not controlled by anybody. The nomads compete for good grass in the limited area that belongs to all of them. Since the grazing lands are tribally owned, no one is allowed to utilized a pasture region exclusively for his flocks and herds.

Pastoral nomadism in the Butana area has been undergoing a rapid changes in the nature of the pastures, as well as strategy and pattern of mobility (Abu Sin, 1990, Akhtar and Mensching, 1993). This change is basically due to climate factors and the expansion in the agricultural development schemes in the Butana area, where two schemes were established, New Halfa 202,345 ha and Rahad 121,407 ha, (Elhassan, 1981). These schemes have reduced the area available for natural pasture lands and forced many nomads to settle in one place. Even though such schemes caused a reduction in the natural pastures, they have provided the nomads with supplementary fodder from crop residues following the cropping seasons.

A field study in the Butana area during the period between 1970 and 1980 (Abu Sin, 1990) showed that there was a rapidly growing tendency towards a different strategy or combination of the four major types of animals in the region, camels, cattle, goats and sheep. Elhassan (1981) reported that 68% of the stock keepers said they felt the shortage of the pasture and the degradation in the rangeland was due to the recent invasion by other tribes. The nomads in the Butana area cut trees to build houses and animal enclosures or to use for firewood. They also use the green branches or the whole tree to feed their animals. The expansions of the rainfed agriculture in the Butana area from the south and the irrigated schemes have also reduced the area of the natural pastures.

5.1.1 Qualitative data collection techniques

Qualitative information relating to socio-economic, environmental changes and rangeland degradation has become an important tool in understanding the overall perception of the pastoral communities regarding their livelihoods under expanding aridity and changing circumstances. This may help to understanding how people perceive environmental changes and how they explain it and react to the challenges encountered.

Qualitative methodology refers in the broadest sense to research that produces a rich descriptive dataset: people's own written or spoken words and observable behavior (Taylor and Bogdan, 1984). Qualitative research is inductive, where researchers develop concepts, insights, and understanding from patterns in the data, rather than collecting data to assess preconceived models or hypotheses or theories. In qualitative studies, researchers follow a flexible research design. Often they begin their studies with only vaguely formulated research questions (Rist, 1977).

In participant observation studies researchers try to convey a sense of "being there" and experiencing the setting first-hand. Qualitative research should provide a "thick descriptive" view of social life (Geertze, 1983). Emerson (1983) writes "thick descriptions present an up-close detailed context and meaning of events and scenes that are relevant to those involved". The researcher must also provide sufficient details about how their studies were conducted (Castenada, 1976).

Qualitative data can be defined as numeric observations that denote the presence or absence of a characteristic or membership to a particular category. Quantitative observations, by contrast, involve measuring the degree to which a feature is present. To score a qualitative observation, researchers must decide whether the object of study has a given characteristic or belongs to a particular category. If this information is recorded numerically, these “qualitative data” can be used to calculate percentages, frequencies, chi-squares or other statistics. Qualitative data may therefore be analyzed using quantitative techniques. This adds to the usefulness and acceptability of this research methodology. An alternative definition includes textual or visual data that have been derived from interviews, observations, documents or records. Qualitative data collected from respondents are generated by intensive, often repeated, encounters with a small number of people in their natural environment (Chung, 2000).

Patton (1990) states that qualitative data focus on the everyday life of individuals, groups, and organizations. Researchers ask respondents to describe “normal” (rather than contrived or experimental) situations or institutions. Qualitative records contain descriptions of “situations, events, people, interactions, and observed behaviors; direct quotations from people about their experiences, attitudes, and beliefs; and excerpts of passages from documents, correspondence, records and case histories”. The resulting data may be coded for themes and interpreted qualitatively or they may be coded and translated into quantitative data that is analyzed statistically (Boyatzis, 1998). This then leads to a detailed formulation or description of the current situation in the area.

The objective of this chapter is to gain a better understanding of the indicators of environmental degradation of the rangelands and to document the perception of the pastoralists in the Butana area. The main reason for interviewing the people in the area was to establish a relationship between the climate factors, satellite data and the qualitative vegetation history of the area. It was also used to establish the environmental history of the area before and after droughts of the early seventies until today.

5.2 Material and Methods

5.2.1 Survey technique

A field survey was conducted during the period from March to August 2005, by visits to a number of villages and livestock watering points, which are sites used by nomads during the dry period, in the Butana area (Figure 5.1). All field trips were accomplished before the peak rainy season (mid-August), in order to avoid difficulties of travel, particularly in the southern area of the Butana. Questionnaires and open discussions were used at randomly selected villages. This was in an attempt to cover as many villages as possible in order to get a broad view about the current perception of the nomads concerning the change in the vegetative cover and climate factors.

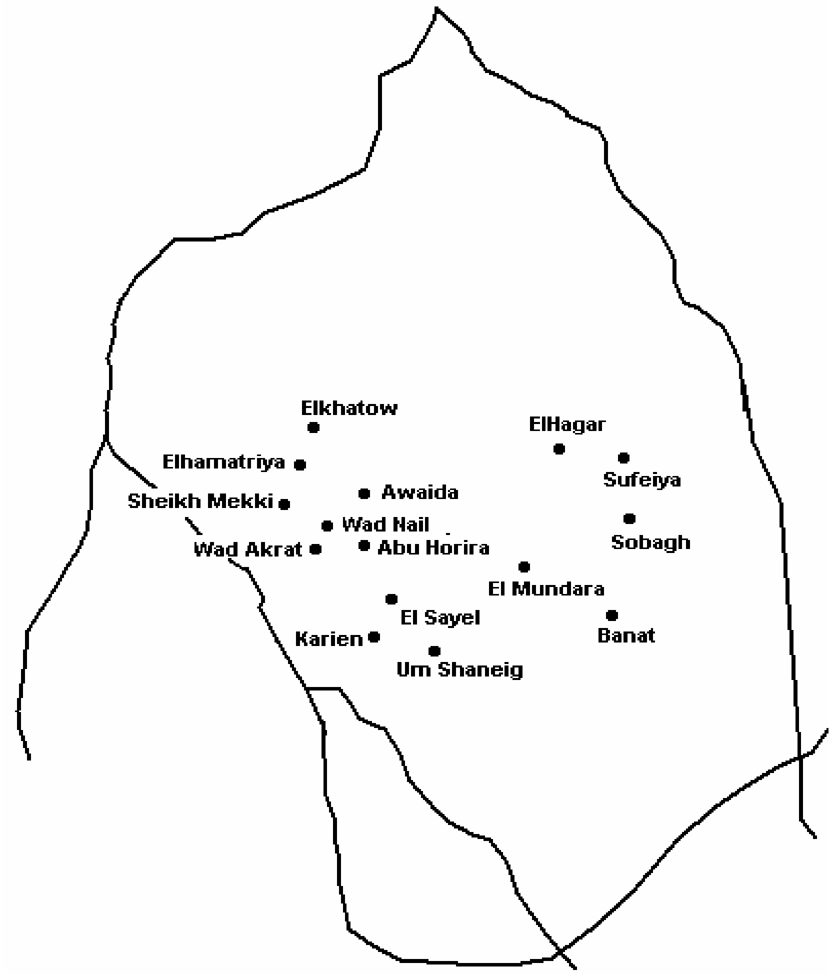


Figure 5.1 Map of Butana area showing names of the villages visited during the field survey (March-August 2005)

5.2.2 Selection of the respondents

For each village, a list of household owners was obtained from the local administrative offices and village leaders. The age group of 30-70 years was selected in order to use their indigenous knowledge acquired through experience as a reference. The aim was to assess and analyze the nature and magnitude of changes perceived to have occurred in their environment over a 60 years period between 1944 and 2004. Fundamental criteria for their selection were the representation of different rangeland vegetation types; livestock herd structures as well as availability of sufficient numbers of elderly pastoralists for interviewing as well as access to transportation for researchers.

5.2.3 Period of the study

The impact of environmental degradation over a 60 years time period was assessed by identifying the year 1969 as a reference to split the 60 year period in two periods for comparison purposes: 1944-1969 and after 1969 (1970-2004). The reference year (1969) was chosen due to the fact that this year represents the date before the start of Saheilain drought (Nicholson *et al*., 2000; Hulme, 2001).

5.2.4 Interview Method

Depending on the type of survey different kinds of interview methods can be used (Hinderson, 2004). The interviewer determines how controlled the interview and the respondents answers will be. For the interviews in this study the semi-structured interview technique, based on a questionnaire, was used. This is a controlled and well prepared method since it is based on an interview guide. The interviewer knows what information is important, but still lets the respondents openly answer the questions based on the semi-structure questionnaires as described by Berg (1998).

The interviews were performed as group interviews. This was done in a relaxed environment to allow maximum information flow without being restricted by the questionnaires. Group interviews stimulate interaction between people and usually generate more consensuses of ideas compared to individual interviews (Berg, 1998). It also requires less time than interviewing the same number of people individually. But in some cases individual interviews were also conducted with the key informants. The interviews covered the following areas:

1. Land use
2. Vegetation cover
3. Livestock

4. Climate change (rainfall and wind storms)
5. Availability of the pastures and water.

Questions concerned the changes in the land use and dominance and composition of vegetation cover, the extent of the vegetation-free surfaces, changes in the rain and wind storm occurrence and availability of water and fodder during two periods pre-1969 and from 1970 to date. The questions that were used to guide the interviews are shown in Appendix B. In most cases the interviews were supplemented by visits to representative areas to help the respondents explain what they were describing. The number of respondents ranged between 3 to 15 person in each group.

5.2.5 Data analysis

The data were analyzed using descriptive statistics such as percentages, which were calculated using the Statistical Package for Social Sciences (SPSS 8.00).

5.3 Results and Discussion

Fifty interviews with village leaders and nomadic pastoralists were carried out as group discussions. An additional number of individual communications were also done with a number of the village leaders and local administrative officers. The respondents were either groups of people or individuals, most of them 30-75 years old, capable of reconstructing the environmental history of the area, as villagers perceive it. The results from the interviews were divided in to six main categories:

1. Changes in land use
2. Degradation of vegetation cover
3. Species composition and quality of the plant species for livestock feed
4. Causes of vegetation cover changes
5. Climate factors
6. Availability of the fodder and water.

5.3.1 Changes in land use

According to the respondents in the villages, there has not been much of a change in land use in the area between pre-1969 and now, except that part of the area was cleared for establishment of the two irrigation schemes (New Halfa and Rahad). From Table 5.1 it can be shown that the agriculture area was increased resulting in a decrease in fallow land available for grazing.

Table 5.1 Land use and percentage of respondents during pre-1969 and 1969–2004

Type of land use	%Respondents	
	Pre-1969	1970-2004
Agriculture & pasture	32%	38%
Agriculture, pasture & forest	12%	16%
Agriculture, pasture, forest & fallow	31%	18%
Agriculture, pasture & fallow	17%	10%
Pasture & forest	4%	7%
Agriculture	4%	11%

5.3.2 Pastoral perceptions on vegetation cover degradation

The respondents pointed out that the amount of vegetation has decreased since the 1973/74 drought, and a change to different species composition has been noticed, in the direction of decreased quality for livestock. Most of villagers (97%) mentioned that until 1975 there were no vegetation-free surfaces, and the whole area was covered by different types of grass, shrubs or dense trees. While after the 1970s drought there are many areas without vegetation (76% of respondents). Some respondents mentioned that there were some areas without vegetation cover even during the rainy season particularly around Elkhatow and Sheikh Mekki villages. While some areas like Sobagh were the most deteriorated with 100% bare land.

Sheikh Mohamed leader of the Elhamatriya village mentioned that there were dense forests around his village during 1956 when he was ten years old. It was easy for the small children to get lost in those forests, he said this condition continue until the late 1960s. But the situation changed after 1974 when the area experienced a severe drought.

While in 1988 the rainfall had recovered but without major beneficial effect to the vegetative cover. He mentioned that after the disappearance of the Acacia spp. the sand encroachment began. During the field trip (May 2005) to Elhamatriya village only a few scattered Acacia trees (Plate 5.1) were seen around the village which is the remains of the dense Acacia forest at that was present in 1960s.

Plate 5.1 Vegetation cover around Elhamatriya village during field survey (photo courtesy M. Elhag, May 2005)

A nomad pastoralist mentioned that the change in vegetation cover includes change in plant type, density, disappearance of palatable species as new plants species invade the area. From Table 5.2 it can be concluded that the vegetation cover in the Butana area has changed completely. This result agreed with the finding by Elhassan (1981) when he concluded that 100% of the nomads in the central Butana believed that the land in the past was covered by plants throughout the year.

Table 5.2 Change in vegetation cover and percentage of respondent during the period from 1969 to 2004

Type of change	%Respondents
vegetation type, density, some species disappear	7%
vegetation type, density, some species disappear and new plant species	53%
vegetation type, density, new plant species	5%
new plant species only	3%
vegetation density only changed	3%
vegetation type only changed	11%
vegetation type, some species disappear	13%
some species disappear only	5%

5.3.3 Pastoral perceptions of changes in plant species composition and quality

Perennials, which characterised the pastures in the Butana area, only a few decades ago, have declined. The main perennial *Blepharis edulis* (Siha) was a very important dry season grazing plant. It was defined by Harrison (1955) as climax vegetation of the Butana area and was found where there were no water resources. It was a more palatable grazing plant for camels and sheep during the wet and dry season but it has disappeared and can now only be recorded at remote sites. This result was also reported by Akhtar and Mensching (1993). While the other well known species, such as the shrubs *Crotalaria senegalensis* (Sufari) and *Ipomoea cordovana* and the grass *Schoenefeldia gracilis* (Gebash), which is dominant in the northern part and the most popular grasses in the area, (Taber) have also decreased. The nomads reported that new species have invaded the area like *Aristida* spp. (Gau), *Cymbopogon procera* (Usher) and *Cymbopogon nervatus*, (Nal) and these plants now occupied large areas as pure stands around the El Mundara area. The spread of *Urochloa trichopus* (Taffa) and *Ocimum basilicum* (Rehan) also indicates an alarming ecological degradation of the Butana vegetation cover (Table 5.3).

Some of respondents (65%) mentioned that some of the new species don’t seem to be grazed during the early growth stages, and some grasses were not palatable or have low nutritional value like “Nal”. While 27% of respondents said it could be used, 8% of respondents believed that the animals would only graze the new species if there was no other alternative. From these results it can be concluded that the vegetation composition in the Butana area has undergone rapid and complete changes during the Sahelian drought periods.

Table 5.3 Vegetation cover composition and dominance and percentage of respondents agreeing with each statement for each time period during the pre-1969 and 1970-2004

Plant type	%Respondents pre-1969	%Respondents 1970-2004
Gebash	20%	39%
Hantot	17%	14%
Taber	13%	9%
Siha	14%	-
Hantot, Taber & Siha	24%	11%
Nal, Gubein & other grasses	12%	27%

* pre-1969:
Gebash + Hantot + Siha + Taber = 88% , other grass 12%
Hantot + Taber + Siha = 24%
* 1970 – 2004:
Gebash + Hantot + Taber + Siha = 73%, other grass = 27%
Hantot + Taber + Siha = 11%

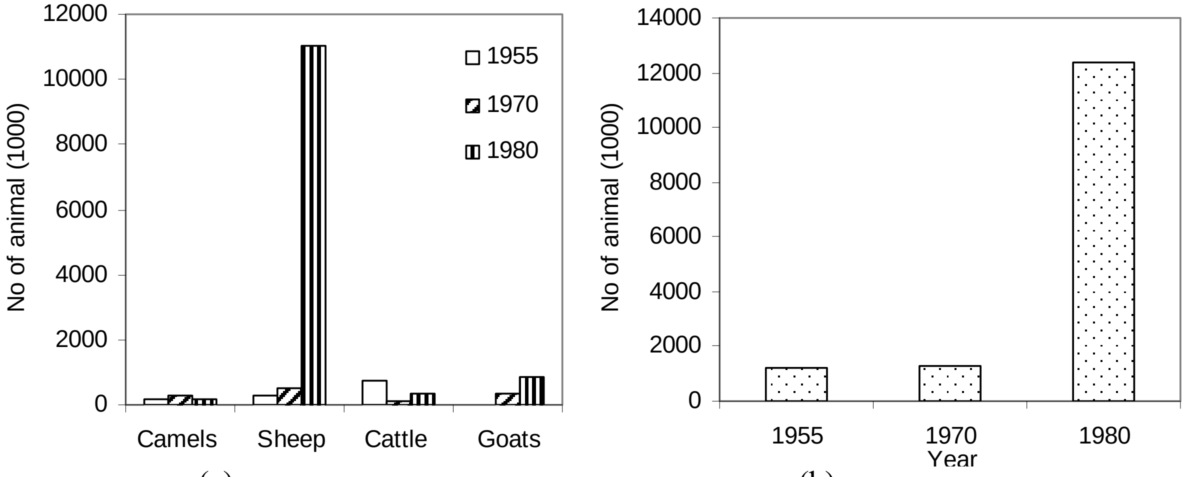
5.3.4 Pastoral perceptions of causes of the vegetation changes

Most of the respondents agreed that the drought and the variability of the rainfall events as well as the amount of rain received during early 1970s and 1980s was the main reason for deterioration pasture condition and shifting of the adequate palatable vegetation cover southwards. About 60% of respondents mentioned the rainfall variability and drought as the main reason for vegetation cover changes. While 13% of respondents reported that the main reasons were drought, rainfall variability, expansion in the agricultural activities and overgrazing. Only 4% of respondents believed that overgrazing is the main reason for the vegetation degradation in the area (Table 5.4).

Table 5.4 Reasons behind the change during period 1970-2004 in vegetation cover and percentage of respondent

Reason for change 1970-2004	% Respondents
drought, rainfall variability & overgrazing	4%
drought & overgrazing	4%
drought, expand agric. & soil degradation	4%
drought & expand agric.	4%
rainfall variability & overgrazing	4%
rainfall variability & expand agric.	3%
drought, rainfall variability, overgrazing & expand agric.	13%
drought & rainfall variability	17%
rainfall variability only	20%
drought only	23%
overgrazing only	4%

Elhassan (1981) reported that the livestock (mainly sheep) numbers increased by more than 100% during the period from 1955 to 1980 (Figure 5.2a and 5.2b), which means that overstocking could have had a negative impact on the vegetation cover in the Butana area. The nomads in the areas were not aware of the effect of overstocking on the vegetation cover because most of them consider the number of the animal from the social prestige point of view. Animal husbandry still seemed to guarantee a secure subsistence for life and it is difficult for nomads to believed that overstock could create a serious problem. The respondents reported that keeping animals for prestige has weaken with time, mainly due to droughts and environmental changes.



(a) (b)

Figure 5.2 (a) The increase of animal population by type of animal (b) total number of animal population in the Butana area during the period 1955 – 1980 (from Elhassan, 1981).

5.3.5 Pastoral perceptions about climate factors changes

Table 5.5 shows that the peoples perception is that the number of the rainfall events decreased considerably during the period of 1970-2005. The respondents mentioned that during the 1960s they received more than 12 rainfall events per season on average, while during recent years the number ranged between 2 to 10 rainfall events per season. Most of the respondents mentioned that the rainfall amount received per season is considerably less than in the past. This decline in the number of rainfall events and amount was associated with the increased number of the windstorms from 1-3 to 5-7 windstorms on average during a rainy season (Table 5.6). During personal communication with Sheikh Ali Babaker, leader of Elkhatow village, he mentioned that during the last 25 years the rainfall is below average and sometimes the northern part of the Butana area did not receive any rain throughout the rainy season. The perceptions of the nomads in the Butana about the climate change and climate variability can't be checked scientifically because pre-1969 daily rainfall data was not available.

Table 5.5 Respondents opinions (%) regarding the number of rainfall events per season for each of the two periods (pre-1969 and 1970 – 2004)

No. of rainfall events pre-1969	%Respondents	No. of rainfall events 1970-2004	%Respondents
7	26%	2-4	38%
10	20%	5-10	32%
12	17%	20	8%
30	12%	less than 1969	22%
more	25%		

Table 5.6 Respondents perception of number of windstorms occurring in each of the two periods (pre-1969 and 1970 – 2004)

No. of windstorm pre-1969	%Respondents	No. of windstorm 1970-2004	%Respondents
1-3	41%	2-4	12%
4-7	27%	5-7	32%
more than 7	9%	10-13	20%
less than now	23%	More than pre-1969	33%
		less than pre-1969	3%

5.3.6 Pastoral perceptions on availability of pastures and water

The Butana area with annually changing conditions of rainfall and pastures has always been a challenge for nomadic pastoralists. They have developed ways of reacting to these changes, also of surviving during droughts, with a principal strategy being their mobility. The availability of fodder and water are the main physical limitation to keeping livestock in the area. When the drought of 1984 struck, the nomads suffered great losses of animals and were forced to leave the natural pastures in the Butana. They moved to the agricultural schemes of Rahad and New Halfa and the rainfed agricultural cropping area in Ghadambaliy. The respondents mentioned that before the drought years they only searched for fodder and water within a range of 10 to 50 km but in recent years the distance ranged from 100 to150 km (Table 5.7). Elhassan (1981) reported that there were palatable plants around the villages in the central Butana area during the period between 1950 and 1970 in both wet and dry seasons. But this situation changed during the 1980s and the nomads had to travel greater distances in the rainy season; the maximum distances are covered by camel owners, and shorter distances by cattle owners.

Table 5.7 Percentage of respondents indicating the various distances traveled for pastures and water pre-1969 and 2004

distance (km)	% respondents pre-1969	distance (km)	% respondents 1970-2004
1-10	28%	1-10	9%
11-50	40%	11-50	18%
51 –100	19%	51-100	42%
101-160	13%	101-185	31%

Hafirs are machine-dug or hand-dug reservoirs on the clay soil, filled by rain or runoff water (Plate 5.2) to provide the nomads with enough water during and after the rainy season. All the hafirs were constructed in areas that contained pastures that had not been utilized before. But now these areas have been overgrazed and there is no sign of any Siha round them. Most of respondents (64%) prefer hafirs which are dug by government rather than the surface wells which belong to local inhabitants, as the people owning the wells could easy prevent the other nomads from taking water. The other reason to prefer “Hafirs” is that the water is easily available. The water in the hafirs is at the surface compared with wells which are deeper and it takes a long time and a lot of work to fill small tank. 24% of the respondents prefer to use water in wadis during rainy season when it is readily available.

Hafirs may lead to deterioration of soil and vegetation cover due to overstocking in the small area surrounding the water points. When any hafir is dry, most of the nomads move to a nearby one and this leads to a high concentration of animals. The people usually avoid the hafirs that keep water for a longer time after the rainy season because this stagnant water causes disease that can spread easily among the animals.

Plate 5.2 Hafir with store of rainfall water during the field survey to ElKhatow village (photo courtesy S. Walker, August 2005)

5.4 Conclusions

In this chapter, the elderly nomads in the Butana have explained that the pastures system has been faced by different constraints since the late 1960s. Environmental degradation has increased in terms of intensity and magnitude (coverage in area). The pasture degradation has become the main factor influencing the vegetation ecology and the production system as well as being a threat to the sustainability of the livelihoods of the nomads in the Butana area.

The different ecosystems in the Butana area are subject to various forms of site degradation around hafirs and other water points. Vegetative cover in the area is undergoing particularly rapid change in terms of the vegetation composition and dominant , some species which were known as climax vegetation (e.g. Siha) in the area have now complete disappeared. The area was invaded by unpalatable or low nutritional value grass like “Nal”. The removal of the forests in the area has led to sand encroachment which has accelerated the development of dunes rendering large area unproductive.

The deterioration of the vegetation cover forces the nomads to move long distances to searched for fodder and water. Also the nomads responded to these environmental changes by migrating to nearby schemes, so as to feed their animals on crop residues and purchase fodder for their animals from cultivation areas. The nomads mentioned that the there was a change in the climate factors especially the number of rainfall events and windstorms per rainy season, however it is not possible to check as the daily rainfall data is not available from SMA.

The results from the interviews are in agreement with the satellite images results of the land degradation in chapter 4 of this study concerning of the bare land and the deterioration of the vegetation cover.

Chapter 6

A Decision Support Tool for Desertification Severity in Arid and Semi-Arid Regions

6.1 Introduction

Desertification encompasses a wide range of processes of physical and biological nature, although many studies use the term in a narrower sense, often influenced by the author's discipline. Thus the geomorphologists may focus on erosion processes, soil scientists on physical and chemical properties, ecologists on productivity of natural vegetation and botanists on changes in species composition and loss of biodiversity. This implies that land degradation may be seen to have taken place in the view of a geomorphologist, yet not with the eyes of botanists or vice versa (Ramussen *et al*., 2001). Warren (1998) has further pointed out the need to view land degradation in its economic, social and cultural context. Erosion may not, in certain cases where soils are deep, have significant economic impacts in the short to medium term, but probably these areas are in the minority as many areas around the world will be severely affected by soil erosion.

Land degradation has been taken seriously in three ways: its extent and the proportion of the global population affected; the international environmental policy responses; and its inter-relationship with other global environmental issues such as biodiversity. The relationships between land degradation and two other main global environmental change components, biodiversity and climate change, should be more fully exploited for effective monitoring of the degradation problem (Gisladottir and Stocking, 2005). Knowing the extent and severity of the land degradation is important as decisions are made by policy makers, resource managers as well as local communities and nomads for effective control of the land degradation (Gisladottir and Stocking, 2005). At present there is no easy way for these decision makers to access the information available from scientific research and so many of the decision are made with inadequate and incomplete dataset. This should not be the case, as there are many highly sophisticated methods that could be used to analysed the data. The aim here is to make it easier for decision makers at various levels to access the data and use it to make an informed decision.

6.1.1 Decision analysis: Definition and approaches

Decision analysis is defined as a logical process of discrimination and then choice (Barnard, 1938). There are three defined stages in decision analysis:-

(1) the sequence of restructuring a problem (establishing a context), allocating probabilities and making a choice from among alternative courses of action. Structuring the decision situation is a form of system diagnosis or situation description.

(2) a rule of decision analysis is that all uncertainties can be represented through appropriate use of probabilities, which express their future behavior.

(3) systematically presenting the choices, chances and consequences associated with a particular decision, in which the best choice often either becomes obvious (*i.e.* one choice has much better outcomes than all the others), or is marginal (*i.e.* little difference between the projected outcomes) (Diga, 2005).

Hayman (2004) calls such a sequence of approaches to the uncertain a 'decision support system' (DSS) or 'decision support tool' (DST). Goodwin and Write (1991) emphasized the term 'analysis' which involves going deeper into the smaller parts, while synthesis is the process of putting the decisions and problem situation back together as a whole, but with new understanding, to enable the user to apply it to different situations.

Hochman (1995) described a DST as any structured method of using data, information or knowledge to help people reach objective management decisions. Arinze (1992) noted a trend for the term DSS to be applied to problem solving rather than the specific technology of computers. For instance, Nykanen *et al.* (1991) defined DST as "the exploitation of the extended human mind and computer related technologies to creatively improve decisions that really matter". For the purposes of this study, a DST is understood to be a computer based, interactive system which offers both data analysis and decision making procedures, and is designed to support a specific set of decisions (Sage, 1991). According to Sprague (1980), a DST has always had its greatest value in uncertain environments dealing with missing information or data such as a climate dataset. Much of the success of decision analyses has been attributed to the 'divide and conquer' orientation in the sense of using diagrams such as decision trees to disaggregate or analyse a decision problem (Keeny, 1982). Setting boundaries for a particular problem consistent with time and other resources available is therefore vital. The promise of DST is as a means of organizing data into information or knowledge that can be readily used or applied to address a specific problem. According to Gaffney (1996) decision analysis is what one has to do when situations become difficult to manage, and one cannot logic all the possibilities in one's mind.

DSS software has been developed in a number of disciplines to facilitate efficient allocation of resources. These tools are especially useful for management of resources derived from complex systems, such as rangeland, where the response to human intervention may be difficult to predict. Squires (1998b) mentioned that a DSS software could empower land managers to readily estimate the ecological and economic implications of a wide range of alternative management strategies if it was designed to do that.

The broad concept of the a DSS or DST was original developed as a tool which helps in solving problems by using and integrating whatever approaches are appropriate to that specific problem (Squires, 1998b). By using many inputs and relationships, they offer a mechanism for improving the objectivity of the decision making, especially where complex interactions (e.g. environment) are involved, as is the case with desertification. The spatially extensive nature of the arid and semi-arid lands, coupled with the temporal and spatial variability of rainfall, complicate any analysis and/or planning for economically sustainable management and development. Therefore there is need for a easily applicable tool to address this spatio-temporal variability (Ellis and Coughenour, 1998) and integrate the available information before using certain predetermined criteria to classify the current situation.

6.1.2 Decision support tool for monitoring desertification

DSTs with computer-based decision tools are useful especially for resources derived from complex systems, such as rangelands. A number of global integrated assessment models have addressed issues relating to desertification at various different scales and details. These models have emphasized biophysical variables such as climate, soil and land cover aspects that determine land degradation, while generally neglecting the human dimensions of the problem (Gisladottir and Stocking, 2005; Okin, 2002), as those empirical relationships are more difficult to develop and test.

The challenge is to bring local and scientific knowledge systems together into a single accessible and structured database. This would provide land users and managers as well as scientists with more opportunities to inform and stimulate each other to making improved assessment of the situation and a common basis to work from, for sound decision making. If land use planners, managers and land users are to be encouraged to become formally involved in the monitoring and adaptive management process, they also require access to user friendly tools, which provide them with a view on the current status of the situation (Squires, 1998b). The DSS framework would provide an opportunity for the inclusion of software to support land planners and managers in assessing and interpreting the condition of their land. The most important part of the DST paradigm is the focus on the end-user (Stuth and Stafford Smith, 1993) and the aim of developing a simple user friendly tool that can address some of the question they are faced with.

During recent decades, a variety of assessment methodologies have been used to interrogate and investigate important environmental problems such as climate change and land degradation. Some assessments have focused on synthesis through extensive reviews at country level of the current understanding of the information available, for example the Intergovernmental Panel on Climate Change (IPCC) assessment. Others have employed models to quantify the processes and key interactions in the environment e.g. the IMAGE model (Alcamo *et al*. 1998), which developed scenarios with comprehensive projections of future developments. These scenarios warned policy makers that outcomes could be worse if developments continued as currently projected. Most of the assessment models have relied on identifying cause-effect pathways that describe the environmental issue being considered (Leemans and Kleidon, 2001) and then a process type stepwise model has been developed. Okin (2002) developed a unified land degradation model, which concentrates on factors that trigger land degradation, such as human activity in drylands or climate change and factors that propagate land degradation such as wind and water erosion in arid and semi-arid regions, such as are found in the northern Mediterranean region, South Africa, the United States and Australia. One of the most widely used models to described land degradation processes is the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978; Mongkolsawat *et al*., 1994; Angima *et al*., 2003). Desertification monitoring could be improved by correcting vegetation data acquired by remote sensing techniques for environmental variability.

Schlesinger and Pilmanis (1998) concluded that as an area becomes desertified, it takes on an increasingly arid character. This finding tends to support the view that increasing aridity is associated with the increasing dominance of abiotic transport process primarily wind and water erosion over biotic processes (human interactions and climate change). This fact becomes increasingly relevant when the effect of climate change on the world’s drylands is considered together with future extreme events. Studies in the Kalahari indicate that a decrease in the ratio of precipitation to potential evapotranspiration associated with drought reduces vegetation cover and, thus has a major effect on the mobility of linear dunes (Lancaster, 1988). Although biotic processes are important, wind and water erosion appear to be the principal drivers of land degradation. Thus, the vegetation-erosion interactions are a vital part of the system that need to form the backbone of a biophysical framework for understanding key mechanisms that drive land degradation (Okin, 2002).

The largest obstacle in developing an integrated biophysical view of land degradation in the drylands is the fact that scientific communities in different regions tend to focus on different process. In South Africa for example, research is dominated by ecologists, who tend to concentrate on biological dynamics. In the Mediterranean region research projects are dominated by earth scientists who tend to concentrate on abiotic factors (Okin, 2002). In Sudan, research is dominated by soil scientists, who focus on the soil erosion by both wind and water (Ayoub, 1998a). In order to make progress, all of these aspects need to be integrated into a holistic view of the degradation processes.

There are two major processes which are intertwined as they contribute to land degradation. However, they can be partially separated if one consider their influence as initiating or triggering factors (namely drought, rainfall variability, overstocking and overgrazing, plough marginal areas) compared to propagating factors (wind and water erosion, waterlogging and salanization). These must be considered separately because in many cases the processes that allow land degradation to persist, once it has begun, are not necessarily the same as the initiating processes. When considering water erosion, for example, rainfall variability may create the initial circumstances in which gully erosion occurs but once started, erosion can become a self-sustaining process.

The biophysical degradation is often viewed as a suite of phenomena that disrupts patchiness, either by increasing the heterogeneity of the patchiness (Schlesinger and Gramenopoulos, 1996) or removing patches altogether (Okin *et al*., 2001). Brown *et al*. (1997) have shown that shrub encroachment can occur in the absence of grazing as a result of increased winter rainfall that favors C_3 shrubs over C_4 grasses or can eliminate bare patches altogether (Okin *et al*., 2001). Both human and climate factors can trigger patch disruption and any process that destroys patches (decreases vegetation cover) or increases the heterogeneity (bush and unpalatable grass encroachment) of the landscape patchiness which will make soils vulnerable to abiotic transport.

The purpose of this chapter is to describe the development of a decision support tool (DST) for assessment of the desertification severity in arid and semi-arid regions, by integrating biophysical and social parameters (both human and livestock population). It is based on the interaction between vegetation and climate factors, highlighting the role of climate change and climate variability in land degradation. The DST developed is to be used to raise the awareness of the planners and policy makers in the arid and semi-arid regions concerning the impact of the desertification. Lindner *et al*. (2002) mentioned that amongst the policy makers in most developed countries there is a tendency to be concerned only about specific impacts that have clear social and economics consequences (e.g. unemployment, imbalance trade) but they do not seem concerned about the long-term effects of what will happen in 100 years time.

6.2 Material and Methods

6.2.1 The elements of a decision support tool

The elements of the DST are:

(i) A time scale, t = 0, 1, 2,....., in appropriate units such as month or season or year;

(ii) An input set X which includes

X_{rain} = rainfall variable (monthly or annual rainfall);
X_{AI} = Aridity Index (monthly or seasonal or annual);
X_{NDVI} = Normalized Difference Vegetation Index (daily or monthly or seasonal);
X_{BSI} = Bare Soil Index (for at least two time intervals);
X_{MSDI} = Moving Standard Deviation Index (for at least two time intervals)
X_{HAI} = Human Activities Impact (time series of the residual effect)

6.2.2 Input data

6.2.2.1 Aridity index

The main reason to include the aridity index in this DST is the fact that according to the General Circulation Model (GCMs) predictions, the atmospheric CO_2 concentrations will be increased and this condition will tend to make drylands hotter and drier due to increased evaporation (Rind, 1990). This will increase the frequency of droughts, which is likely to trigger landscape changes. Increased aridity tends to increase the wind and water erosion (Schlesinger and Pilmanis, 1998). The aridity index used here is calculated using the UNDP aridity index (Hare, 1993) (see Chapter 2).

6.2.2.2 Trend of time series data of rainfall, Aridity Index and NDVI

The trend of time series of monthly or annual rainfall, Aridity Index and the NDVI data were calculated using the Linear Trend Method, which simply involves the application of a simple, two-variable, regression technique (see Chapter 2).

6.2.2.3 Testing the significant of the trend in time series data

The hypothesis test or confidence interval estimation was used for testing the estimated regression coefficient which differs from zero ($b = 0$). If this hypothesis is rejected at any appropriate level ($H_0 = b = 0$), then it is generally accepted that a significant linear trend is present (Woodward and Gray, 1993; Hoshmand, 1997). This procedure involves a two-tailed test in which the test statistic is:-

$$t = \frac{b - \beta}{S_b} \tag{6.1}$$

where:

b = regression coefficient, or slope of regression line

β = standardized regression coefficient

S_b = estimated standard error of the regression coefficient computed as follows:

$$S_b = \frac{S_{xy}}{\sqrt{\sum X^2 - n\bar{X}^2}} \tag{6.2}$$

$$S_{xy} = \sqrt{\frac{\sum Y^2 - a\left(\sum Y\right) - b\left(\sum XY\right)}{n-2}} \tag{6.3}$$

where:

Y = dependent variable

X = independent variable

a = regression constant, or Y intercept

n = sample size

6.2.2.4 Soil Data

The available soil data from soil analysis at different dates can be used to detect the changes in the soil properties. There are so many soil parameters that can be used to monitor soil deterioration for example soil texture, soil structure, pH, organic matter (carbon content), soil depth and many other soil factors according to the interest of the researchers. If the detailed georeference soil analysis data from routine soil sample analysis is not available, the Landsat images can be use to detect the changes in the soil properties as was the case in this study. The Moving Standard Deviation Index (MSDI) and Bare Soil Index (BSI) were used to monitor the heterogeneity and free vegetation surface (see Chapter 4) or another index or indictor that can be generated from the satellite images could be used to study the heterogeneity of the landscape and the bare soil percentage. In this DST we try to give the user the choice of the type of data according to the availability of the data, but the idea was to monitor the difference between two values of an index over a given period of time.

6.2.2.5 Human and livestock population data

Monitoring and evaluating the Human Activities Impact (HAI) on the land degradation process in arid and semi-arid regions is very difficulty, due to a lack of updated population and livestock data. This is also complicated by the fact that there is a strong relation between the rainfall and vegetation growth in this region. To monitor this effect, the Residual Trend Method was used in this decision support tool (see chapter 3).

6.3 Decision support tool structure

The basic structure of the decision support tool is summarized in Figure 6.1. Marcos under Microsoft Excel 2003 was used to develop the DST. The time series data of monthly or annual rainfall, Aridity Index and NDVI were used as the inputs for the first part of the analysis. The name “Tashur” was selected for this DST, as it means “desertification” in the Arabic language. “Tashur” was designed to operate in arid and semi-arid regions, as it is envisioned to be applied to landscapes incorporating the point domain of the selected area. The flowchart (Figure 6.1) explains the steps that follow to evaluate the landscape condition in the selected area.

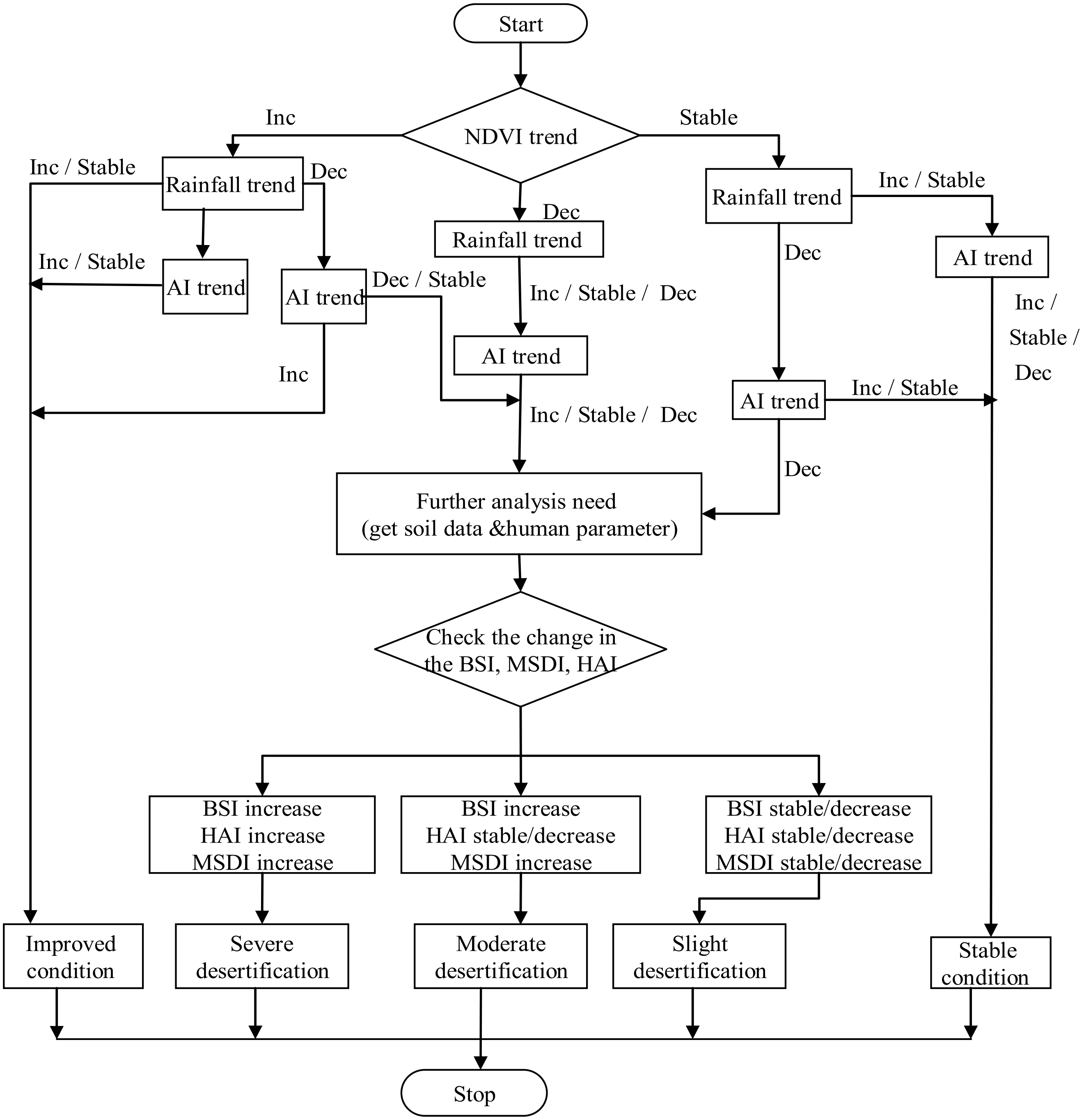


Figure 6.1 Flowchart shown the structure of the "Tashur" decision support tool

* Inc = Increase; Dec = Decrease

The first parameter to be considered is NDVI trend over a selected time period. The left hand side part of the Figure 6.1 shows that if there is an increasing trend in the NDVI and the trend of the two other factors are also increasing or stable then “Tashur” will display “*Improved condition*” which means that the landscape condition has improved and there is no any sign of degradation. The middle part of the flowchart shows, for instance if the trend of the NDVI was decreasing whatever the trend of the other two factors ‘“Tashur” display “*Further analysis needed*”. These analyses include the soil and human activities impact parameters. The soil parameters could be MSDI and BSI from the Landsat images or the data from routine soil analysis. From these parameters three decision combinations were used. The first box shows that if bare soil, heterogeneity of the landscape (MSDI) values and the human activities impact were increased then “Tashur” will display “*Severe desertification*”. The middle box highlights that if the soil indices increased but the human impact is stable or decreasing there is “*Moderate desertification*”. The right hand side box shows that if the soil indices and human impact were decreasing or stable then there is “*Slight desertification*”. The same steps are followed when the NDVI trend is stable and the trend of the rainfall and Aridity Index is decreasing then “Tashur” display “*Further analysis needed*”

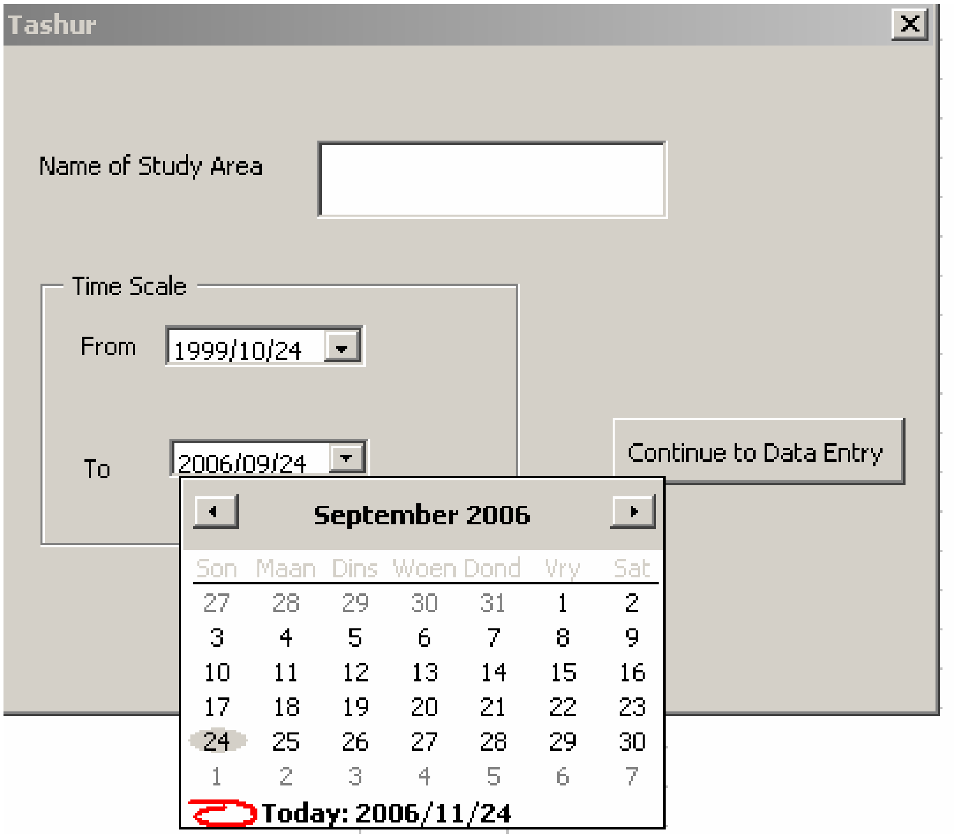
The right hand side part of the DST highlights different conditions under which “Tashur” will display a “*stable condition*”. Under these conditions the trend of the vegetation parameter (NDVI) is always stable, while the trend of the two other parameters (rainfall and aridity index) may increase or remain stable resulting in an overall stable condition.

6.4 Results and Discussion

This DST called “Tashur” was developed to help the planners (agriculturist, foresters and landscape planners) and decision makers in arid and semi-arid regions to assess the landscape conditions and to monitor and map the extend of the land degradation. This can help for better management and planning of the natural resources in these regions.

6.4.1 *Pilot example for "Tashur"*

The interface in Figure 6.2 shows the first step of the DST which requires that one insert the name of the site and time scale. Then the trends of the NDVI, rainfall and aridity index are computed (Figure 6.3). If the result from the first calculation is not enough to display the decision, then the DST continues to compute the other parameters. The BSI and MSDI values for at least two time interval (previous and present values) so that the difference can be calculated by subtracting the two values. Then the rainfall and the NDVI were used to compute the residual effect of the Human Activities Impact (HAI) (Figure 6.4) (see appendix C).



Name of Study Area

From 1999/10/24

To 2006/09/24

September 2006

Son	Maan	Dins	Woen	Dond	Vry	Sat
27	28	29	30	31	1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
1	2	3	4	5	6	7

Today: 2006/11/24

Figure 6.2 The first step in which the name of the site and time scale are inserted

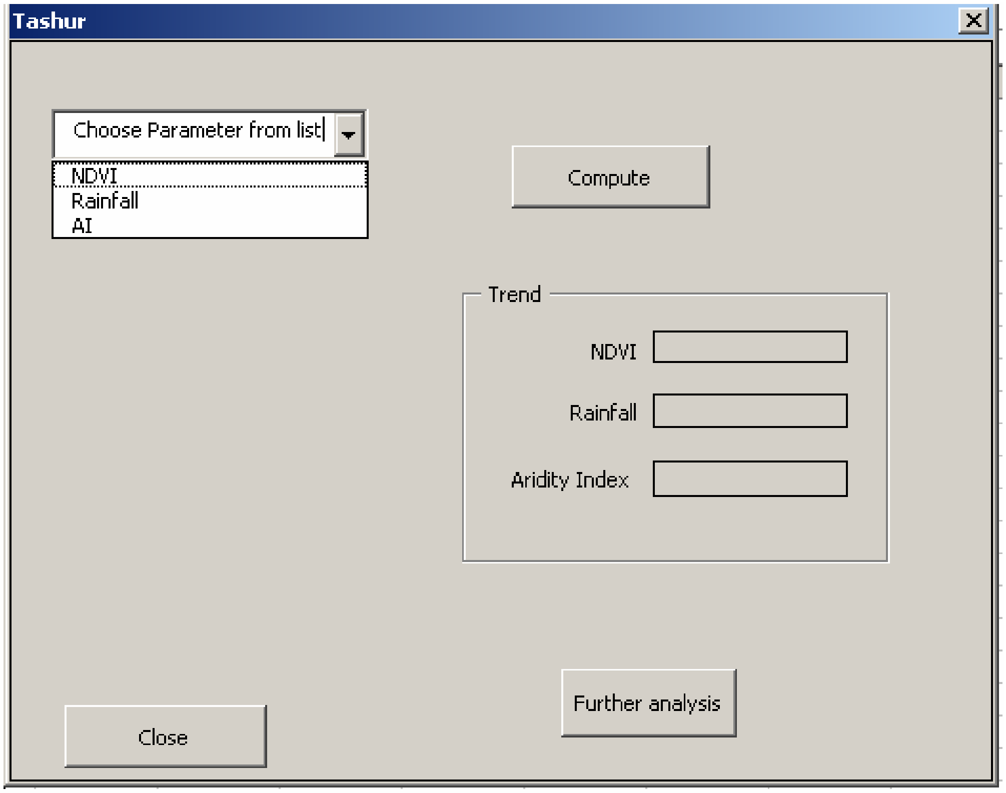


Figure 6.3 The second step in which the NDVI, rainfall and Aridity Index trends are computed

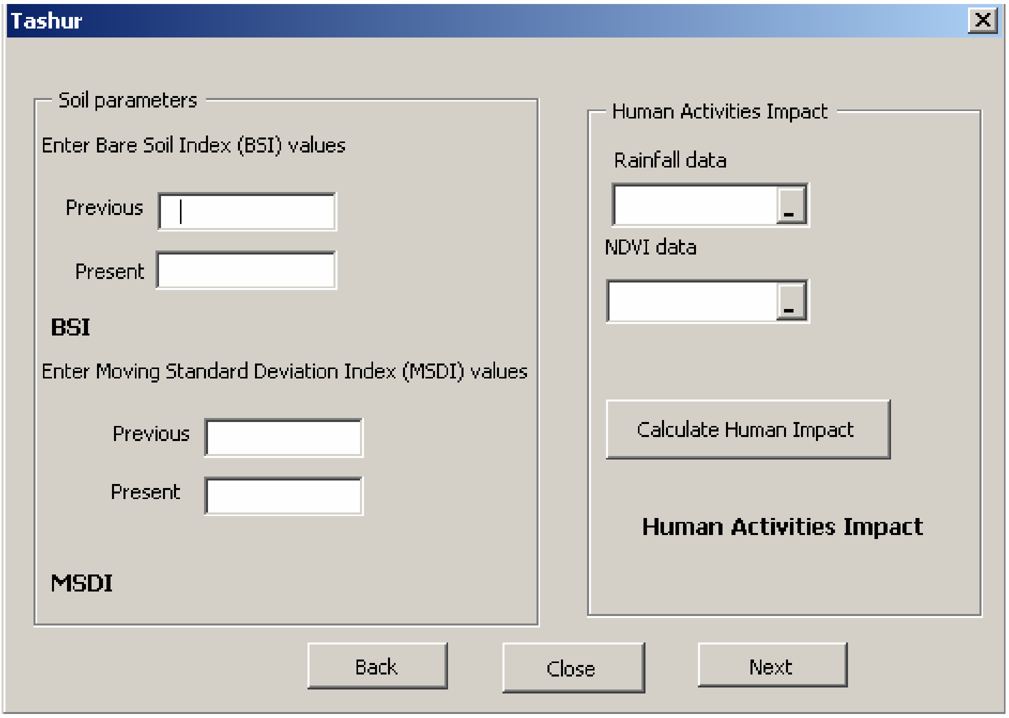
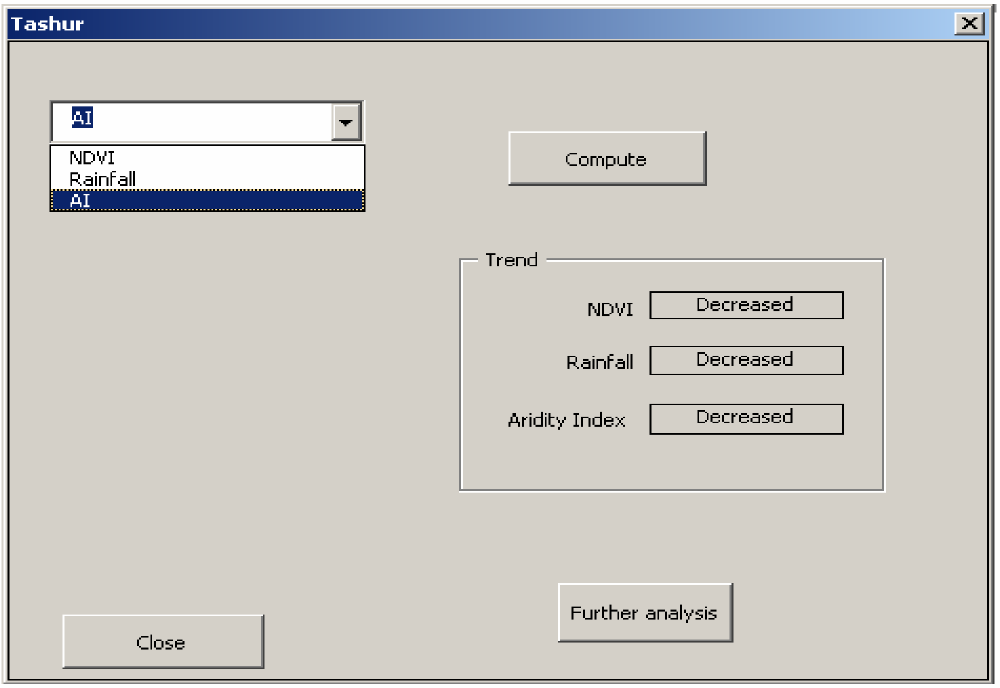


Figure 6.4 Computation of the human activities impact and the soil parameters

6.4.2 Verification of the "Tashur" DST

Three sites were selected to validate "Tashur" which represent two grazing areas (Sufeiya and Sobagh) and one irrigated site (Rahad irrigation scheme). Maximum monthly NDVI, monthly rainfall and AI covering the period between 13 July 1981 to 31 December 2003, together with the MSDI and BSI for 1987 and 2000 were used as input data.

Figure 6.5 shows the first result following the calculation of the trend of the NDVI, rainfall and Aridity Index for the Sufeiya site, the DST display "decreased" trend for each of the three parameters. In this case the first calculation alone was not sufficient to evaluate the landscape condition and more analysis will be needed for making a decision. Therefore, in order for "Tashur" to declare the decision, both MSDI and BSI differences and Human Activities Impact (HAI) were computed (Figure 6.6). The residual effect of the human activities and MSDI and BSI values had increased, then "Tashur" will display "*Severe desertification*" at Sufeiya site during the period between 1981 to 2003 (Figure 6.7). The same result was obtained for the Sobagh site, such that this agrees with the results obtained in chapter 3, 4 and 5 of this thesis. While the evaluation of the landscape condition for the irrigated site showed that there is "Slight *desertification*".



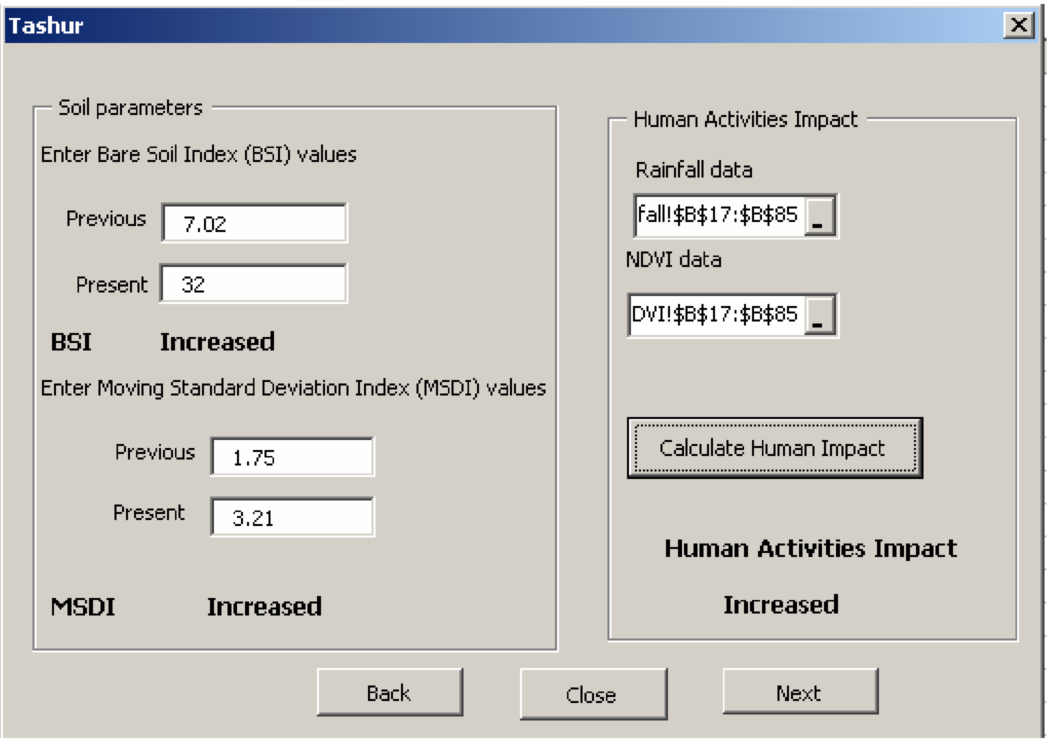
Trend

NDVI: Decreased

Rainfall: Decreased

Aridity Index: Decreased

Figure 6.5 The trend analysis of NDVI, rainfall and AI for Sufeiya site



Enter Bare Soil Index (BSI) values

Previous 7.02

Present 32

BSI **Increased**

Enter Moving Standard Deviation Index (MSDI) values

Previous 1.75

Present 3.21

MSDI **Increased**

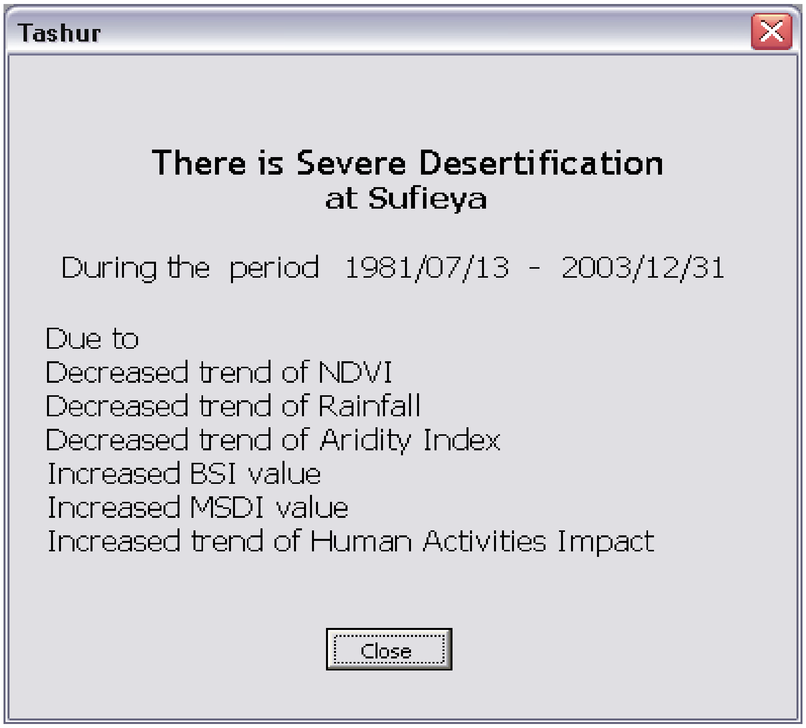
Rainfall data fall!$B$17:$B$85

NDVI data DVI!$B$17:$B$85

Human Activities Impact

Increased

Figure 6.6 Computation of the human activities impact, BSI and MSDI for Sufeiya site



There is Severe Desertification at Sufieya

During the period 1981/07/13 - 2003/12/31

Due to
Decreased trend of NDVI
Decreased trend of Rainfall
Decreased trend of Aridity Index
Increased BSI value
Increased MSDI value
Increased trend of Human Activities Impact

Figure 6.7 The decision display by Tashur for the Sufeiya site

6.5 Conclusions

This chapter has discussed the benefits and use of a decision support tool in monitoring the land degradation in general and described the principle grounds on which “Tashur” was developed and the steps used in its development for possible application in arid and semi-arid regions.

The vast majority of DST developments for rangeland is occurring in technologically advanced countries of the world, especially in United State, Europe and Australia. Yet most of the grazing land lies elsewhere. Decision support systems have considerable potential as they allow natural resources mangers and planners to critically compare and evaluate the landscape conditions. The rangeland degradation problem has a spatial dimension. This has been reflected in the increased interest in remote sensing and GIS in the developing of a DST that can monitor the extend and severity of the land degradation.

The results from combined decision options show that the condition of the landscapes can be evaluate by using the climate parameters and vegetation cover index as trigger factors and soil parameters and human activities impact as propagation factors. For instance, if the trigger factors display increased trend, then “Tashur” evaluates the landscape condition as “*improved*” and that is due mainly to an increase in the vegetation cover in the area. There are also cases when the trigger factor alone is not sufficient for the decision, to be made, when more inputs are required. For instance, when the vegetation cover index realizes a decreasing trend, regardless of what the other two factors have shown, then further analysis must be conducted to combine the trigger and propagation factors in order for “Tashur” to declare the level of desertification or severity of the condition.

However, this has challenges with the recognition of the existing knowledge with nomads, extension workers, scientists and others, and the availability of the wide range of the data (observation and remote sensing data) to combine all these sources of information in this simple and briefly constructed DST that can easy be used by the planners and manager to evaluate the severity of the land degradation.

Chapter 7

Conclusions and Recommendations

7.1 Conclusions

Desertification has now become a pressing issue on the world stage since the Sahelian drought started at the late 1960s. Desertification appears as land degradation under arid, semi-arid and dry sub-humid climates, whatever the causes, but land degradation can occur under a wide range of climates. Current indicators are still inadequate to assess relationships between climate, vegetation and human activities, preventing the establishment of development oriented policies that can begin to reverse the unabated process of rangeland degradation. The lack of understanding of the relationship between the environment and pastoralists and ignorance regarding the perception of the pastoralists may also contribute to the misunderstanding of the rangeland production system and the priority needs of the pastoralists.

The primary objective of this study was to investigate whether there is land degradation in the Butana area of Sudan. It also covers the extend and the causes of this problem using the field observed and remote sensing data. These enable several theories and indices of the land degradation to be tested and quantified.

The large amount of data available for this study was effectively employed for monitoring and mapping the prevailing conditions in the Butana area of Sudan. The hypothesis that the ground observed and remote sensing data can be used to achieve reliable characterization of the extend and severity of the land degradation proved to be correct.

A time series analysis of the climate data, that was restricted to the period 1940–2004, shows an important piece of evidence of some changes and much variability of the climatic factors that were examined, in most parts of the Butana area, but specifically in the northern part. The northern part of the area had experienced wet years during the

1950s and in the beginning of the 1960s but with rainfall below the median during the period from the late 1960s up until 1994. El Gadaref which represents the southern part of the area has a stable pattern of rainfall. The trend of monthly and annual rainfall (1940-2004) significantly decreased in Shambat and Wad Medani while the decrease was not significant at Halfa in the east although this may be due to the fact that the data were only available from 1970-2004. There was an increasing trend for the rainfall for El Gadaref but it is not statistically significant.

Mean annual temperatures have increased significantly by 0.02 – 0.12° C per decade. Warming conditions did not characterize all seasons: at Wad Medani, Shambat and Halfa the autumn and winter minimum temperatures increased significantly. The warmest period extended from the 1980s to the early 1990s. It is not possible at this stage to ascribe these rising trends to the global greenhouse effect, or to ascertain continued increasing temperatures in the future. The increase in wet-season temperatures could be traced back to the decline in rainfall amounts experienced during the same period. The change in temperature observed in the Butana area could be partly a consequence of local climatic and/or human forces, such as changes in rainfall pattern (with periodic droughts). El Gadaref station shows significant increase in maximum and minimum temperature.
The annual trend of the aridity showed only a slight increase at Halfa and El Gadaref, while the trend for Shambat and Wad Medani significantly decreased. Therefore, the northern part of Butana area has become more arid, as implied by a decrease in the aridity index.

The drought during the 1960s and 1970s affected only the northern part of the area while in 1980s and 1990s the drought conditions covered the whole of the Butana area. The Standard Precipitation Index (SPI) and Aridity Index gave evidence that the northern part of the Butana area become drier since the Sahelian drought started. The 100, 300, and 500 mm isohyets shift toward the south by about 89, 46, 23 km for each isohyets respectively during the period from 1950s to 2004. This led to a shift of the vegetation cover towards the south.

Broad scale time series analysis of Normalized Difference Vegetation Index (NDVI) data was applied in conjunction with traditional methods for monitoring changes in pastureland condition across time and space. This is useful particularly where there is a lack of primary measurements of vegetation and rangeland conditions over large area and where climate dependent nomadic livestock is a primary source of living. According to the NDVI series from July 1981 to December 2003, the Butana area was divided into four vegetation zones (grassland, patchy bushes, extensive plant cover and rainfed cropping area). Normally the grassland area is more sensitive to the higher rainfall rather than the patchy land, extensive plant cover and rainfed cropping area. The NDVI deviate from long-term average by about 30-60%, during the drought years but the vegetation could recover when wet years followed the drought ones, as for the 1984 drought which was followed by high rainfall during 1985.

The residual effect which used to discriminate the human activities impact from the climate effects and it indicates that the predicted NDVI was higher than the observed NDVI from 1984 to 1989. After this period the observed NDVI was significantly increasing for zones 1 and 2 (northern section), but not significant for zones 3 and 4 (southern section). This agreed with the recent research that has shown significant increasing trends in NDVI for the Sahel region during the period of 1982-1999 (Eklundh & Olsson, 2003). These observations could indicate that the amount of vegetation in the region is increasing and there is a steady recovery from the Sahelian droughts. The impact of human activities on the vegetation cover in the Butana area was clearer following the drought years, but in general this effect was not severe for zones 1, 3 and 4. However zone 2 had significant impact of human activities and this was due to the drought in 1984 when the nomads started to use this area intensively. This area is close to the irrigation schemes and rainfed cropping areas from where they can get supplementary fodder and water.

Five vegetation classes of land use were identified using unsupervised classification for Landsat images. This result confirmed the findings by O’Nell (1989) and Tueller (1989) who propose that in heterogeneous areas of high variability an unsupervised classification is more accurate than a supervised classification but the combination of both produces the best results. From the land use classes it can be noticed that the bare and eroded soil in the area was increased within the last 13 years by about 3-7%, while vegetated area decreased by about 3-6%. Also from a comparison the aerial photographs (1960s and 1980s) for Shareif Baraket, Kamlin and El Maseid areas together with the Landsat image (2000) severe degradation of the vegetation cover was observed at all three sites.

The Moving Standard Deviation Index (MSDI) and Bare Soil Index (BSI) proved to be very powerful and sensitive indicators of the landscape condition in the Butana area. The result confirmed the hypotheses of several authors (Miles and Johnson, 1990; Pickup, 1985; Pickup and Nelson, 1984) that suggest that any process that leads to an increasing heterogeneity of the soil resources in space and time is likely to lead to the degradation of a landscape. The value of the MSDI showed considerably increase from 1987 to 2000, especially for Sufeiya, Sobagh and Banat areas, which are mentioned by many authors as severe degraded sites. BSI can be used together with MSDI for monitoring the extent of degradation that affects natural resources. The BSI for the degraded sites Sufeiya, Sobagh and Banat increase from 0-8 in 1987 to 32-40 in 2000. The image differences of the BSI indicated that the index increased by about 14 to > 40 over the last 13 years (1987-2000).

Results from the combination of the observed climate data and remote sensing data with the perceptions of the nomads indicated that the people in the area have a good awareness about the degradation processes in the area. But most of the villagers were of the opinion that causes of the land degradation were linked mainly with the droughts of the eighties, they do not consider their activities as a cause. It is difficult for the nomads to consider their livestock to be a cause of the problem because that means that they would need to reduce the livestock population to reduce the overstocking and prevent overgrazing.

A decision support tool was developed to understand the interaction between climate factors (rainfall and aridity index) and vegetation cover (NDVI) as trigger factors and soil and human parameters as propagation factors of land degradation. “Tashur” is the name given to this DST which means “desertification” in the Arabic language. The results from a run of “Tashur” show that a better evaluation of land degradation can be made by combining all the factors that may lead to any change in the landscape condition. Three sites were selected to validate “Tashur” and the results obtained reported that two sites were severely degraded. This DST “Tashur” can be used in evaluation and monitoring of the severity of land degradation. It can help to apply some control techniques that may reduce and help to implement controls against the land degradation by mapping the severity of the degradation in arid and semi-arid regions in the Butana area. This will help the decision maker to where they should concentrate their efforts and finances, so that if an area has suddenly be noted to have shifted from one land use type to another. Then the resource managers need to mount an extensive ground truthing survey to check if this is actually the true picture. They also need to institute a publicity campaign mangiest the nomads and others in the area to begin some positive activities that can halt the degradation cycle. “Tashur also can help to identify areas that have already improved where the nomads can obtain more fodder for grazing and relive the areas that are suffering from heavy grazing pressure.

Finally it could be concluded that the different ecosystems in the Butana area were subject to various forms of site degradation. The desertification has led to sand encroachment and to accelerated development of dunes and also increased the water erosion in the northern and western part of the area. Also the area is subject to a vegetation cover transformation. Although pastures have deteriorated seriously in quality and quantity, in many parts the degradation is still reversible if organized land use and water points sites selection can be implement.

7.2 Recommendations

The challenge in evaluating and monitoring desertification in the Butana area is to understand the interaction between the vegetation cover and the climate factors. The drying and the warming conditions should be carefully monitored over the coming years and decades. This would allow one to establish evidence as to whether the climate factors have a significance role in deterioration occurring in the vegetation cover and soil in the area.

Any program aimed to understand the limits on land degradation in the Butana area must take several interconnected elements into account like climate factors, social aspect of the nomads, livestock numbers and the land use strategies (expansion of the irrigated, rainfed areas and consumption rate of the trees per year). In this regard, a focus needs to be made on the following research aspects:-

1) Intensive research will be required to develop a methodology for evaluation of the natural resources and to classify the Butana area according to temporal and spatial variability of the climate factors, which requires one to increase the number of the weather stations to obtain a representative cover over all the climate zones in the area. Together with this are needs to develop complete natural resources databases with Metadata about the area.
2) To combine the newly emerging technologies including the remote sensing data with ground observed data and nomads perceptions to monitor and evaluate the landscape condition in the area.
3) To expand the use of the decision support tools in the spatial sense so as to apply it not only for a point domain to plan for sustainable development in the whole area.
4) To conduct more detailed studies to evaluate the severity of the wind and water erosion to determine the propagation factors of this problem and then incorporate results into “Tashur”.
5) To examine some techniques that can help in the control and mitigation of the ongoing land degradation in the area.
6) To promote collaboration between the Sudanese and international scientists, planners and the policy makers in all different aspects concerning land degradation and climate change and climate variability that will be needed for above tasks.

Finally, it is recommended that more Agrometeorogical extension work in the form information and education will be needed to raise the awareness of the people in the Butana area about the severity and the sequences as well as the consequences of the land degradation and climate change.

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Appendices

Appendix A Details of the locations of the weather stations used in this study (Sudan Meteorological Authority)

Station	Latitude (°N)	Longitude (°E)	Altitude (m)	Period of data reported				
				Rainfall (mm)	Temperature (Co)	Wind Speed (m/sec)	Sunshine (hr)	Relative Humidity (%)
Khartoum	15.6	32.55	380	1903-2004	-	-	-	-
Shambat	15.6	32.5	380	1941-2004	1940-2004	1961-2004	1961-2004	1959-2004
Wad Medani	14.4	33.48	405	1941-2004	1941-2004	1961-2004	1947-2004	1957-2004
Halfa	14.5	36.38	500	1970-2004	1971-2004	1971-2004	1970-2004	1970-2004
Sennar	13.56	33.47	450	1907-2004	-	-	-	-
Kassala	15.47	36.4	500	1940-2004	-	-	-	-
El Gadaref	14.03	35.4	600	1941-2004	1941-2004	1966-2004	1966-2004	1966-2004

Appendix B The Questionnaire for the Nomads in the Butana area during the period between March – August 2005

Interviews were performed in 15 villages, with between 3 and 15 respondents present during each of the interviews. When a question was raised the group discussed it and gave an answer. The basic questions used in the interview were as follows:-

1- What are the Names, Ages, Village name, Education level, and occupation of the respondents?

2- Is there a change in the land use of the area between pre-1969 and from 1970 to 2005?

3- Have you noticed any changes in the vegetation pattern around the village compared to the time before the drought (density and type)?

4- Has the number of trees changed during this time?

5- Has the amount of grass changed?

6- Has the amount of vegetation that animals like to graze changed since the drought started?

7- What was the most suitable plant species in the past for the grazing?
    a- in the rainy season
    b- in the dry season.

8- What is most suitable plant species at present?
    a- in the rainy season
    b- in the dry season

9- Have you noticed any changes in the rain since the drought (amount and number of rainfall event per season)?

10- Have you noticed any changes in the frequency of wind storms between the two periods (number of storm)?

11- Are you growing crops (name the crops)

12- How does the area planted now compare to that before the drought?

13- How many hours do you go searching for fodder and water (before 1969 and 1969-2004)?

14- What are the names of the new plant species in the area?

15- Are the new plant species palatable or not?

16- Is the number of the trees more in the recent years or pre-1969?

17- What you think are the reason behind the change of the trees stands?

18- Was there any area without vegetation cover in the period pre-1969?

19- Is there any area without vegetation cover now?

20- What do you think, from the following, is the main reason for the removal of the vegetation cover? (can be more than one answer)

  a- drought
  b- rainfall variability
  c- overgrazing
  d- agricultural expansion
  e- soil change
  f- other reason (mention it)

21 How many kilometers do you go searching for good fodder (compare the two periods).

22 Do you think the open grazing under the present situation is causing the degradation of the vegetation cover?

23 hy do the nomads drive their animals to the irrigated schemes?

24 round which type of water points do you prefer to stay

  a Hafier
  b Wells
  c Wadis

Appendix C User Manual for Tashur 1.1

Tashur is a decision support tool (DST) which uses available data to determine the desertification status in a given area of consideration. The data required to run Tashur are:-

1- NDVI (maximum NDVI at 10 days interval or on a monthly basis)
2- rainfall (daily or monthly rainfall amount)
3- aridity index (AI) calculated by using UNEP aridity index (precipitation/potential evapotranspiration)
4- soil indices (calculated from the Landsat image)
    a) Bare Soil Index
    b) Moving Standard Deviation Index (MSDI)

This DST primarily requires NDVI, rainfall land aridity index data to be provided by the user in Microsoft-Excel sheet provided in the workbook of Tashur. The sheet for each parameter is labeled accordingly and the data for each parameter and must be copied into the respective sheet. Once the required datasets are on the spread sheets, the user can proceed to the analysis for the trend in the data on hand by clicking on the button "**Show Decision Support Form**". This button can be accessed from each sheet on the workbook. When you clicking on this button, the program will display a form which prompts the user to provide the **place name** and the **period** for which data is provided on the sheet. For the program to proceed, these input values **must** be provided. Click the button "**Continue to Data Entry**" which then displays a form for analysis of the trend of NDVI, rainfall and AI. In this form there is a combo-box which provides a drop-down list from which a user can choose one parameter at a time. Choosing a parameter from this list will display two RefEdit boxes that enable the user to select X and Y values on spread sheet for the parameter to be considered. Having provided the X and Y data, pressing the "**Compute**" button on the form which will give the trend analysis result which is a choice of 3 options:- Increased, Decreased or Stable. This procedure needs to be done for all three parameters before one can proceed to a final decision or for further analysis.

Depending on the trend analysis results found for the three parameters, the program will show either the final decision form or a further analysis form. On the analysis form, the user will be prompted to provide two soil parameter values: bare soil index (BSI) and moving standard deviation index (MSDI). The beginning and end values for these two indices must be typed in. Furthermore, for human activities impact analysis, data for rainfall and NDVI must be given in the same way as described for the primary analysis. Having provided the required data, pressing the “**Calculate Human Impact**” button to provide the trend analysis result of the human activity impact. Clicking the “**Next**” button will reveal the final decision form. This decision form will present the final decision with summary of the results for the parameters used for decision making.