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Impact of Climate Change and the Human Activities on Land Degradation in Arid and Semi-Arid Region

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Abstract

Climate change 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 are strongly affected by climatic variability.

The objectives of this research is to analyse the climate change and climate variability in the Butana area north - eastern part of Sudan, during the period 1941-2004 and to study the interaction between land degradation, climatic change and the human activities through the analysis of the vegetative cover and soil degradation.

To explore the climate variability and climate change in terms of rainfall for the period from 1941 to 2004, the monthly and annual time series for four weather stations (ElGadaref, Halfa, WadMedani and Shambat) across the Butana area were analysed. The trend of the rainfall at WadMedani and Shambat shows significant decline, while that of Halfa and ElGadaref does not show a significant decrease or increase. To study the effect of the high variability of the rainfall, meteorological stations surrounding the Butana area were used, to show the approximate location of the 100, 300, and 500 mm isohyets. Average of 30 years 1941-1970 as a wet period and 1971-2000 as a dry period was calculated. The result 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.

The relationship between 8 km^2 AVHRR/NDVI and rainfall data (1981-2003) was tested in the Butana area. The result shows that there is strong relationship between the peak NDVI and cumulative July/August rainfall.

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. To study the spatial trend of the human activities, the period from 1982 to 2001 was divided into four equal intervals of years (1982-1986, 1987-1991, 1992-1996, and 1997-2001). From the result it can be noticed 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 has become 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 as shown in the periods 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. During the period of 1997-2001 the area experienced drought in 2000 and the human effect has again become severe but with less extend than during the period 1982-1991.

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 had severe degradation.

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

The challenge in evaluating and monitoring land degradation 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 whether the climate factors have significance role in deterioration occurring in the vegetation cover and soil in the area.

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. 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 vegetation in arid and semi-arid in Sudan were exposed to extreme conditions and must survive drought, which can stretch over several years with little or no rain at all. In arid and 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.

Vegetative production in arid and semi-arid regions is closely related to the long-term average precipitation (Rutherford, 1980) and inter-annual rainfall variability (Le Houérou *et al*., 1988). The Normalized Difference Vegetation Index (NDVI) is one of the most widely used indices for vegetation monitoring (Tucker, 1979). The NDVI has been empirically shown to relate strongly to green vegetation cover and biomass using ground-based studies involving spectral radiometers (Beck *et al*., 1990).

Material and Methods

Study area

The Butana area north-eastern part of the Sudan was selected to represent the arid and semi-arid region. The boundary of the study area was adjusted 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 area (Figure 1)

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, were acquired to cover the period from 13 July 1981 to 31 December 2003.

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.

Data Analysis

Interpretation of rainfall data

The Inverse Distance Weighting (IDW) method was used to create a rainfall surface for the area. The IDW algorithm is a moving average interpolator that is usually applied to highly variable data.

Identification of rainfall and human activities impact on the vegetation cover

The residual trends method (RESTREND) was used to predict annual production based on rainfall (Wessels, 2005), 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 human activities.

Results and Discussion

Time series analysis of the rainfall data

The time series analysis conducted using long-term annual rainfall for the four stations bordering the study area. The result shows that there has been a gradual decrease in the annual rainfall during the period of 1940 to 2004 for Shambat and Wad Medani and from 1970 to 2004 for Halfa (Figure 2). 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 rainfall of Wad Medani and Shambat decline significantly, while for Halfa and El Gadaref the trend does not significantly decline or increase .

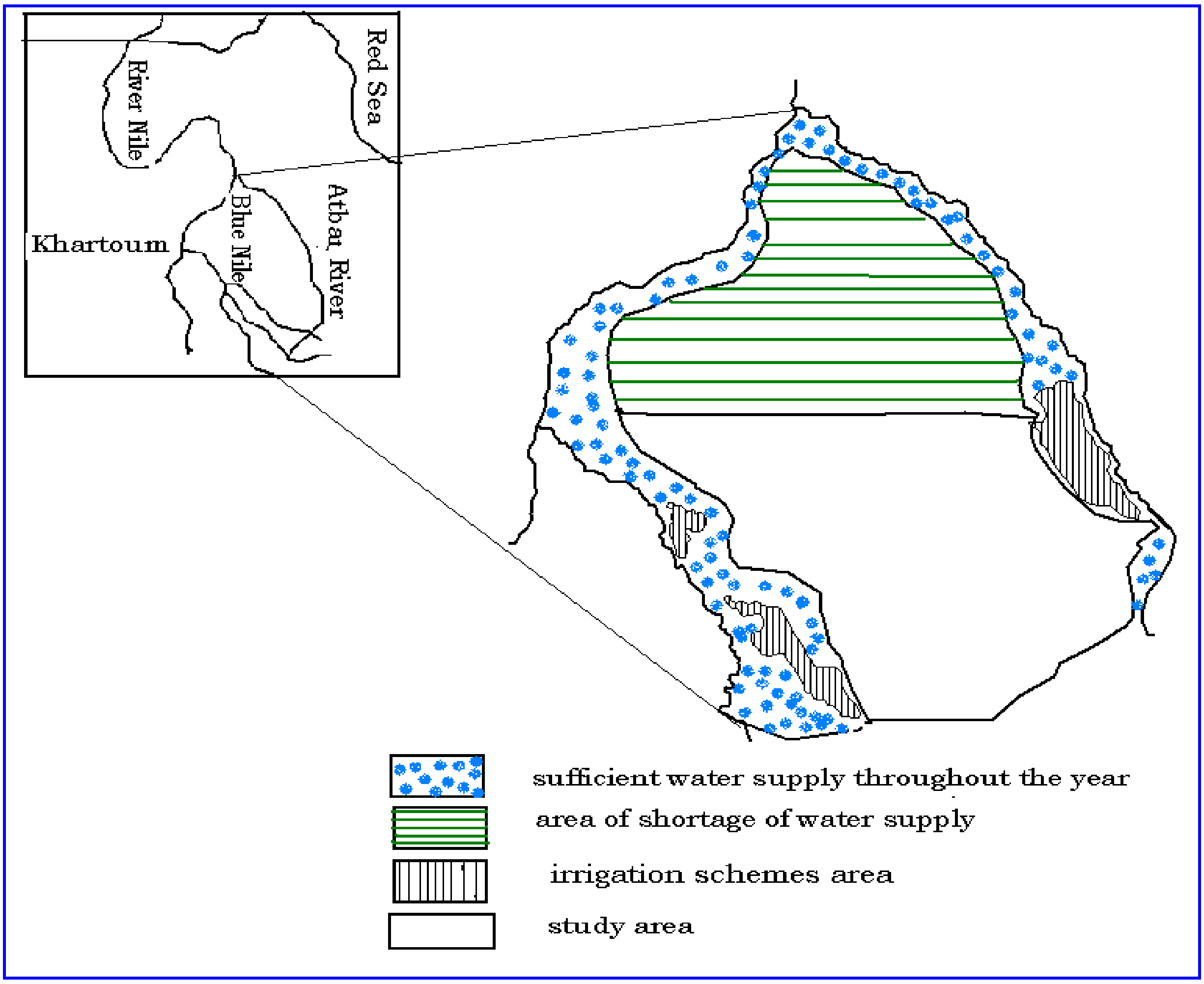


Figure 1 Map showing the boundary of the study area

To study the effect of the high variability of the rainfall, the calculation of 30 year averages of 1941-1970 as a wet period and 1971-2000 as a dry period. The seven meteorological stations surrounding the area were used to show the approximate location of the 100, 300, and 500 mm isohyets. Figure 3 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.

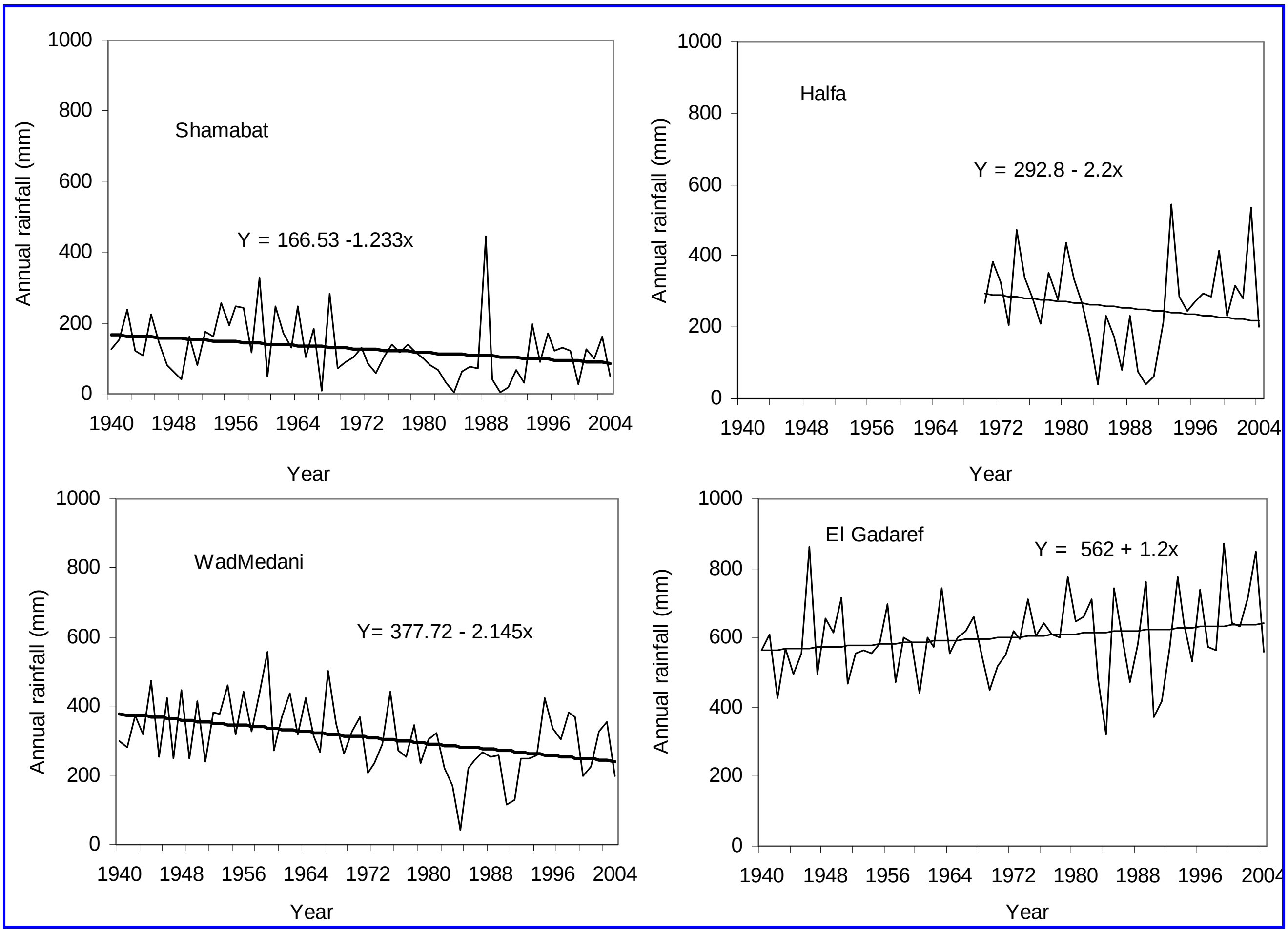


Figure 2 Annual rainfall for each of the four weather stations in the area together with the trend line and equation

Identification of rainfall impact on the vegetation cover

The study area was divided into four zones (grassland, patchy land, a extensive vegetation cover area and rainfed mechanized agricultural area) according to the percentage of occurrence of maximum NDVI (NDVI$_{max}$) throughout the year for the period from 1981-2003

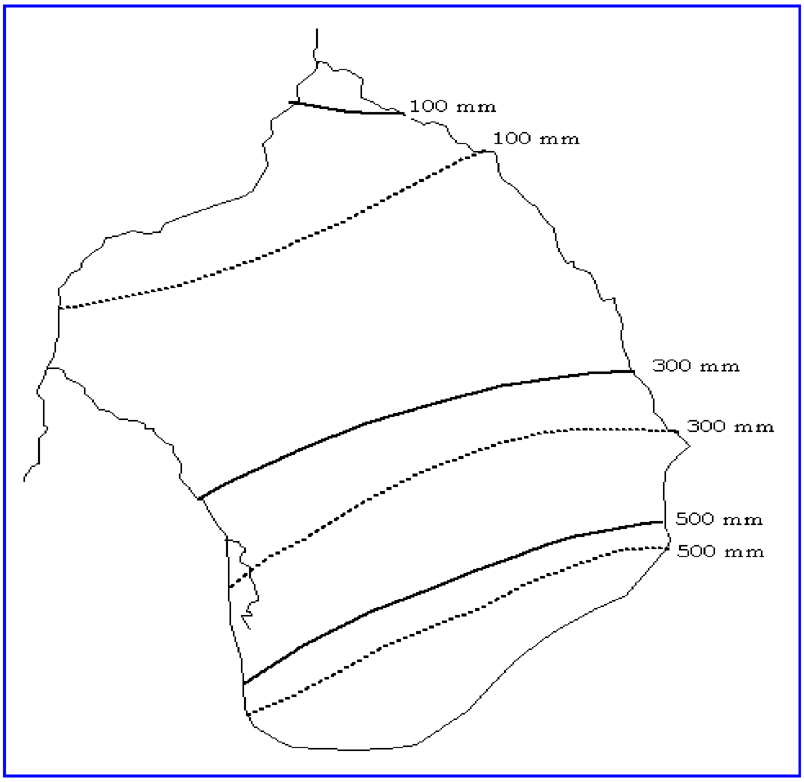


Figure 3 Rainfall isohyets for 1941-1970 average (———) and 1971-2000 (············) for the study area

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 using the linear correlation. Table 1 shows that the peak NDVI had a strong correlation with cumulative rainfall amount for July and August. 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 The peak NDVI had a stronger relation with the July/August rainfall during the drought years (1984, 1990, 2000), 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 1 Linear correlation coefficients (r) between various rainfall amounts and peak or accumulative NDVI in study 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

Identification the impact of human activities on the vegetation cover

There is a strong correlation between the peak NDVI and the cumulative rainfall for July and August for all the four zones (Figure 4) 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). The performance of the prediction model was tested for the four zones using the statistical Willmott tests between the observed and predicted NDVI.

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 (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 5), meaning that the rainfall is the determining factor for the vegetation growth in the Butana area.

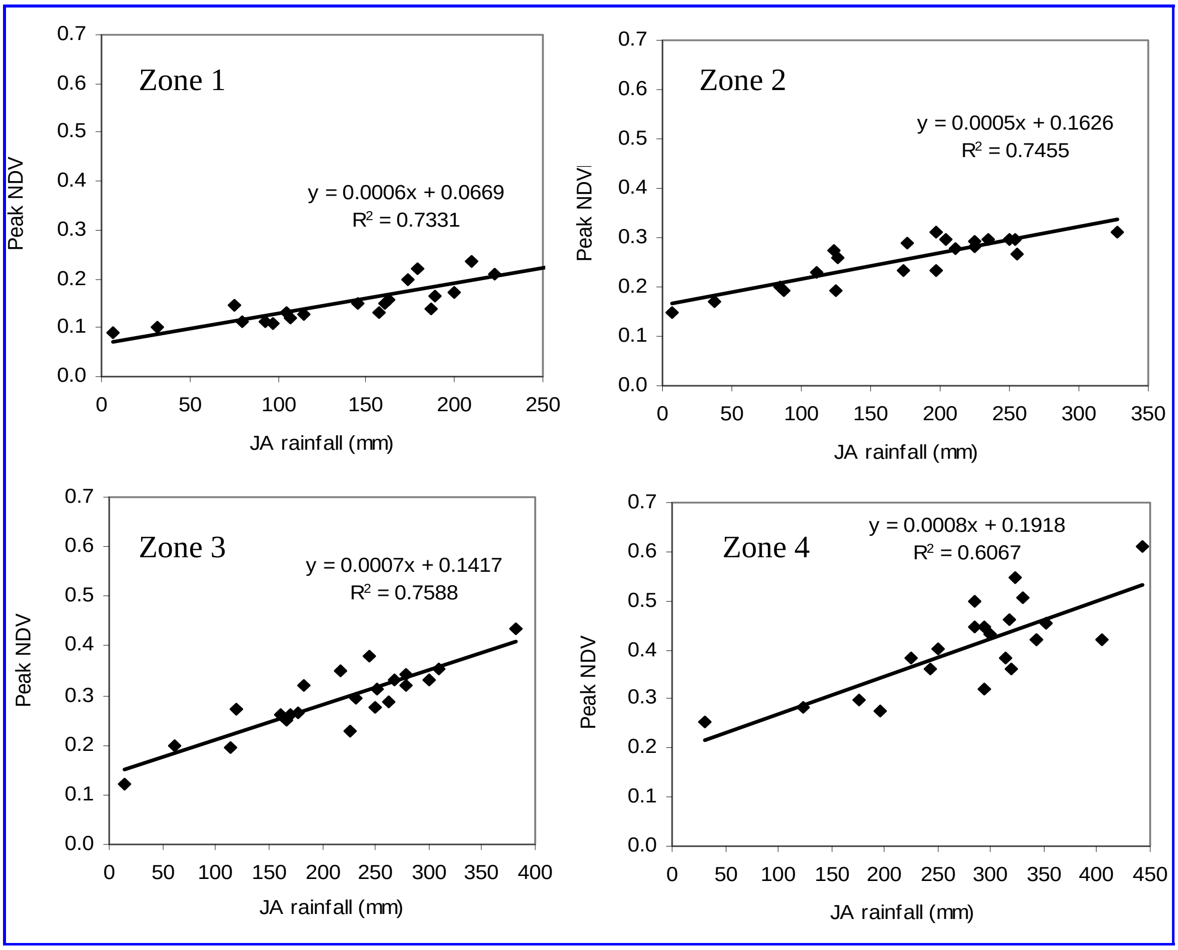


Figure 4 Linear regression of peak NDVI versus July/August rainfall for four zones in the Butana area

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 6 it can be noted that the residual effect of the human activities was severe in zones 1 and 2 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 1992-1996 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).

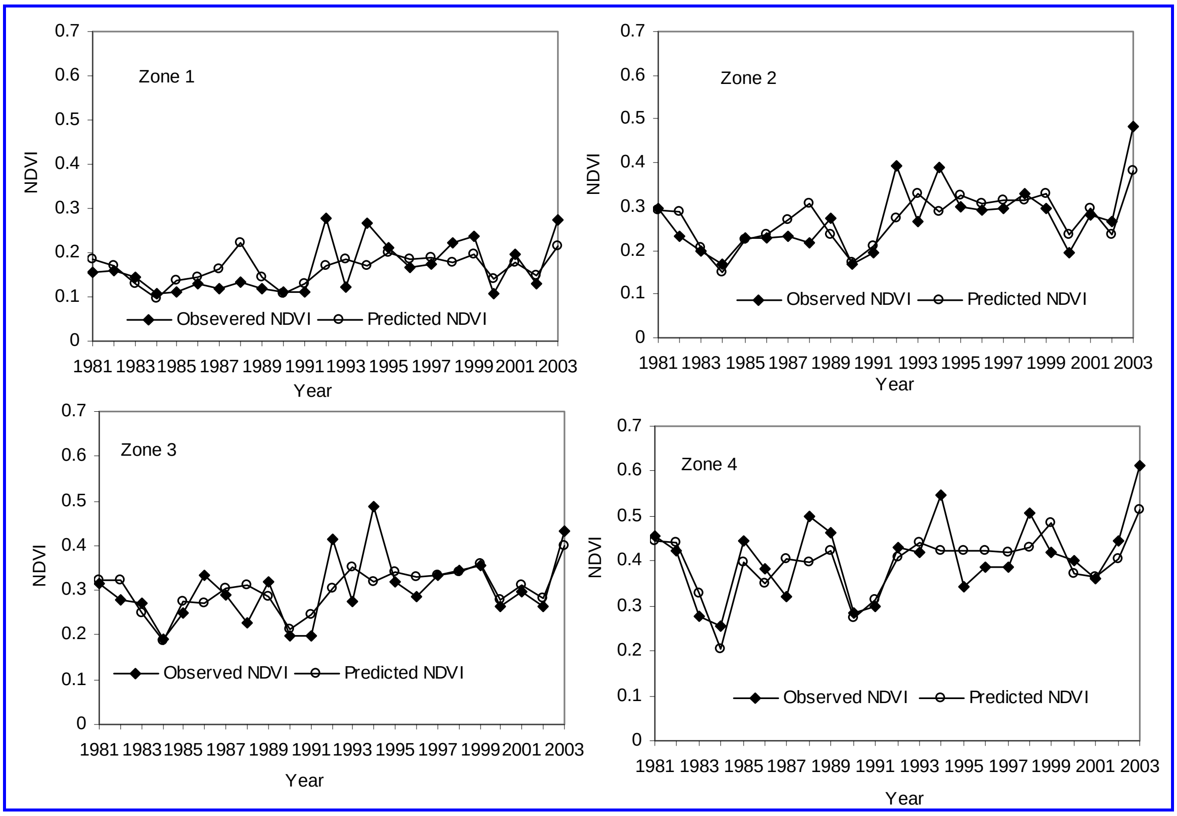


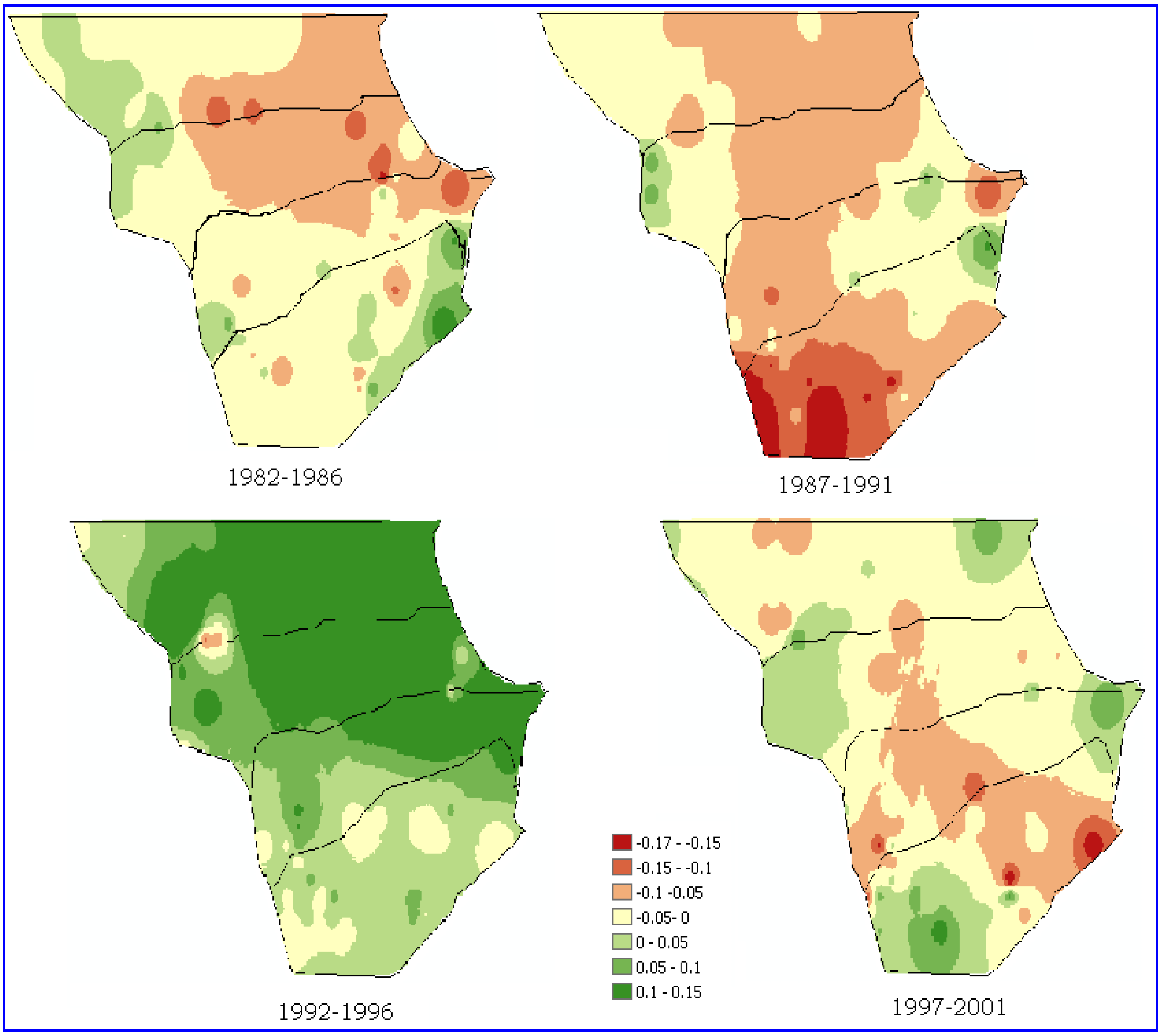
Figure 5 The observed and predicted peak NDVI for the four zones

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 2 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 2 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



1982-1986

1987-1991

1992-1996

1997-2001

Figure 6 Residual effects of the human activities in the Butana area from 1982-2001 in 5 year steps

Conclusion

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 result show that there is a strong correlation between the peak NDVI with the cumulative rainfall for July and August. 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 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 was higher than the observed peak NDVI from 1984 to 1989. This supports the conclusion of an increasing trend of the NDVI after the Sahelian drought. 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. 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 planners and decision makers is to understand the interaction between the vegetation growth and the climate in the 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.

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