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

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Abstract

This research was initiated with the objective of analyzing the climate change and climate variability in the Butana area, north - eastern part of Sudan, during the period 1940-2004 and to study the interaction between land degradation, climate 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 1940 to 2004, the annual time series for 4 weather stations (ElGadaref, Halfa, WadMedani and Shambat) across the Butana area, were analyzed, The trend of the rainfall at WadMedani and Shambat showed a significant declination, while that of Halfa and ElGadaref did not show a significant change.

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 the degraded areas that exhibit negative trends in NDVI. From the results, it was noticed that the residual effect of the human activities are severe in zones 1 and 2 (-0.17 to -0.5) during 1982-1986, during severe drought. After this period the effect became less during the period of 1992-1996. This indicated a decrease of the human impact and an increase in the observed NDVI. These findings could be interpreted as recovery from the drought years or might be due to the reductions that occurred in livestock numbers. During the period of 1997-2001 the area experienced a drought in 2000 and the human influence increased but still relatively less than during the period 1982-1991.

Key words: Climate change, Human impact, land degradation, RESTREND, Sudan

1. INTRODUCTION

Climate variability has a large impact on the renewable natural resources, but the impact is not the same for every region. It is clear 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 are called the vegetation dynamics which are strongly affected by the climatic variability (Roerink et al., 2003).

The vegetation in arid and semi-arid regions of the Sudan were exposed to extreme conditions. They must survive drought that could 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).

2. MATERIAL AND METHODS

2.1. 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 (This might distort the relationship between NDVI and rainfall for the area.), (Figure 1)

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

2.3. Rainfall Data

The rainfall data, used in this study, were the long-term monthly rainfall data for 7 weather stations (i.e. Khartoum, Sennar, Kassala, Shambat, Wad Medani, El Gadaref, Halfa) from 1940 to 2004. The daily rainfall for 4 stations (i.e. El Gadaref, Halfa, Shambat, and Wad Medani) was also used from 1981 to 2004.

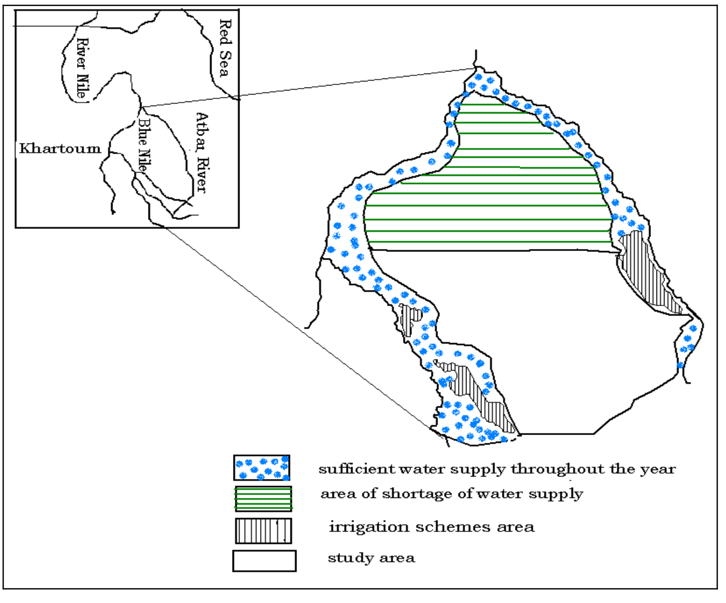

Figure1: Adjusted boundary of the study area

3. DATA ANALYSIS

3.1 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 Burrough and McDonnel, 1998). 7 stations, with monthly rainfall, were used to create July, cumulative July/August and annual rainfall surfaces. While the daily rainfall, for 4 stations (Shambat, Halfa, WadMedani and ElGadaref), were summed for each 10 day period in accordance with the composite NDVI data periods and were used to create 10 day rainfall surfaces.

3.2 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 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 that, 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.

4. RESULTS AND DISCUSSIONS

4.1 Time Series Analysis of the Rainfall Data

The time series analysis was conducted, using long-term annual rainfall, for the 4 stations bordering the study area. The result showed 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 showed a gradual increase for the monthly and annual rainfall. The statistical analysis of the deviation from zero (Ho: b = 0) proved that the trend for annual rainfall of Wad Medani and Shambat would decline significantly, while for Halfa and El Gadaref the trend did not indicate a significant change.

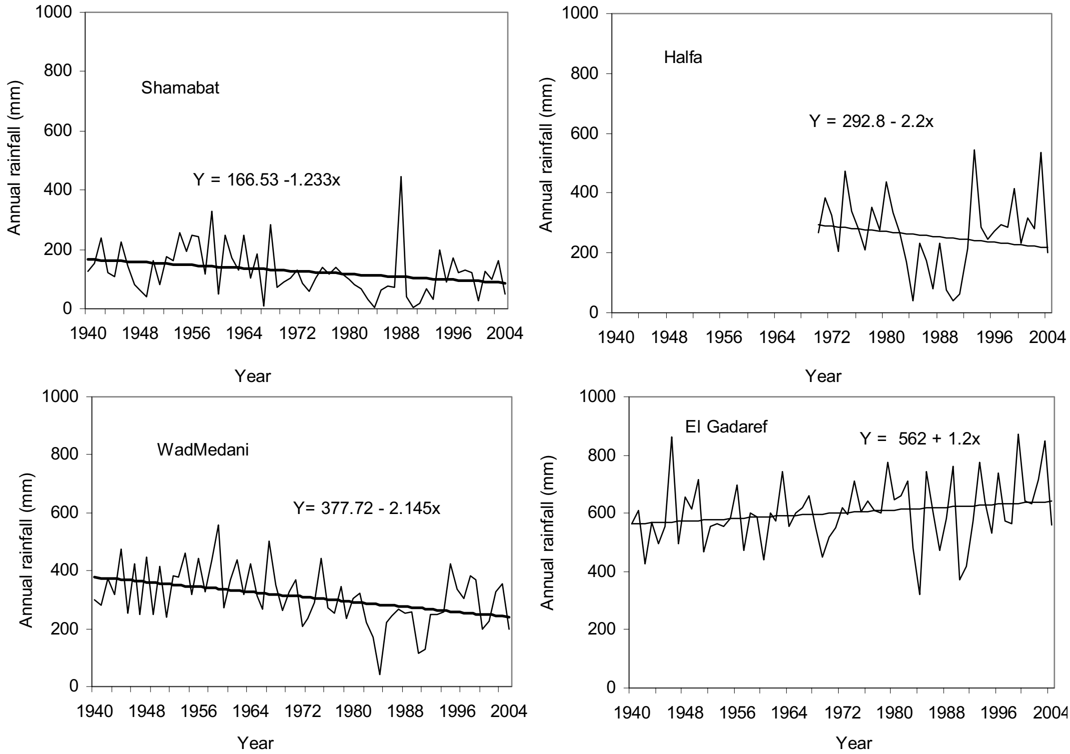

Figure 2: Annual rainfall for each of the 4 weather stations in the area together with the trend line and equation

To study the effect of the high variability of the rainfall, the calculation of 30 year averages of 1940-1970 as a wet period and 1971-2000 as a dry period was executed. The 7 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.

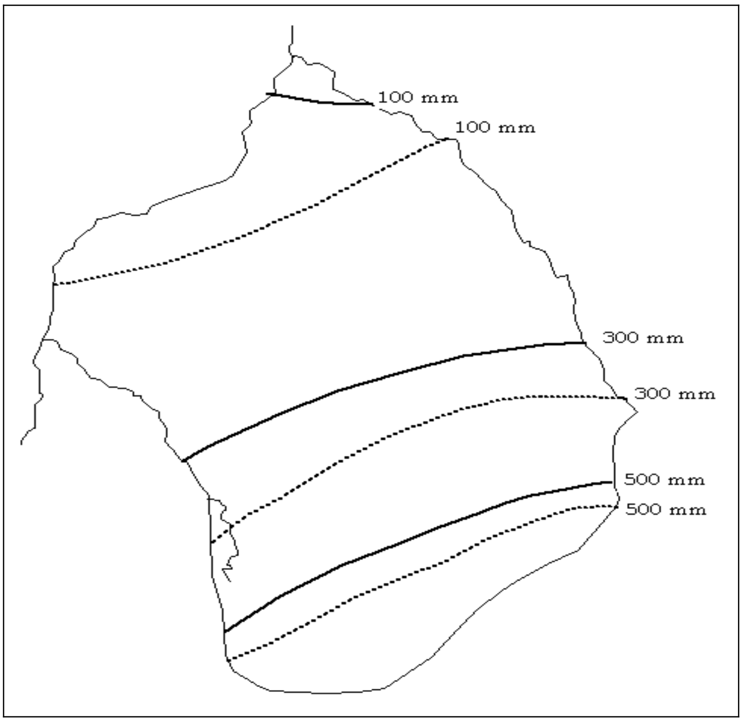

Figure 3: Rainfall isohyets for 1940-1970 average (———) and 1971-2000 (···········) for the study area

4.2 Identification of Rainfall Impact on the Vegetation Cover

The study area was divided into four zones according to the percentage of occurrence of maximum NDVI (NDVImax) throughout the year for the period from 1981-2003 (grassland, patchy land, an extensive vegetation cover area and rain-fed mechanized agricultural area).

The peak NDVI (occurring at the end of August and the beginning of September) and NDVIacc 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 poorly correlated with the magnitude of the peak NDVI. There is also a weak correlation between the 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 the study area for specific years

Year	August rainfall vs peak NDVI	July/August rainfall vs peak NDVI	Annual rainfall vs NDVIacc
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

4.3 Identification of 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 4 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 4 zones using the statistical Willmott tests between the observed and predicted NDVI.

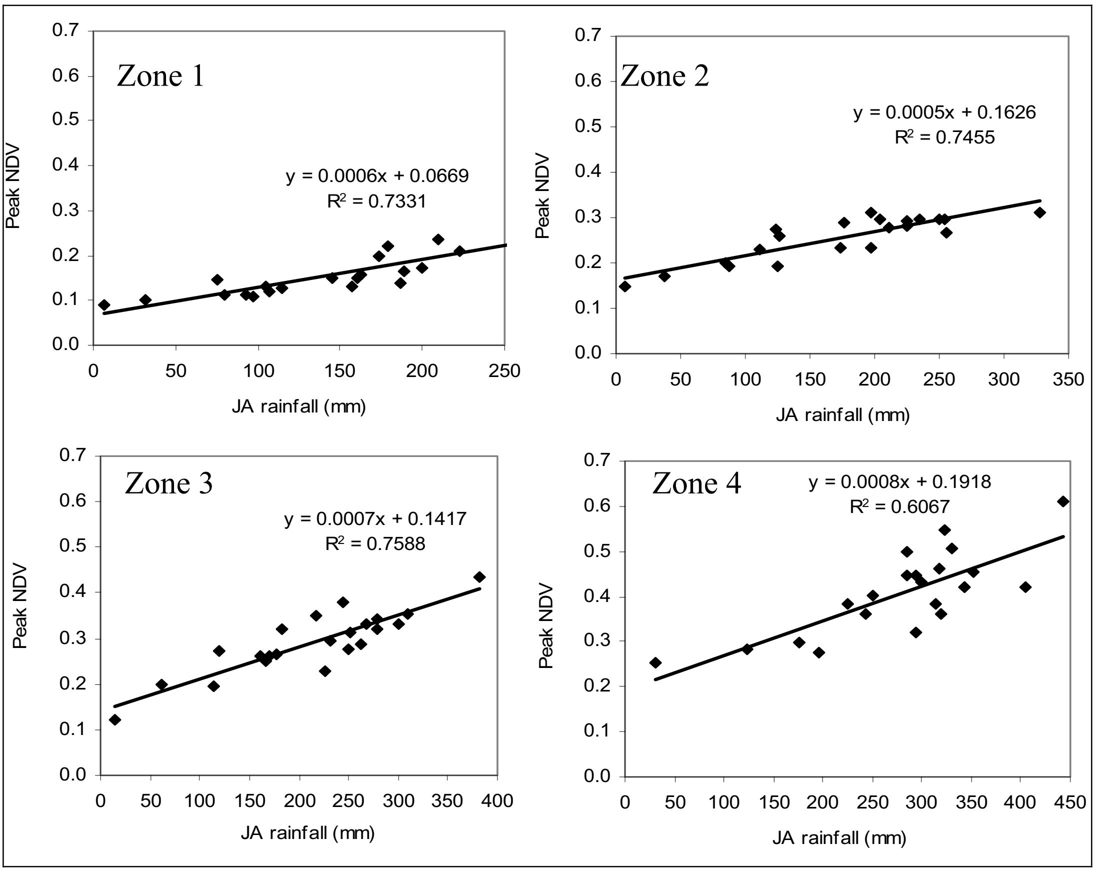

Figure 4: Linear regression of peak NDVI versus July/August rainfall for 4 zones in the Butana area

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 indicated changes in peak NDVI that were not due to the effect of rainfall in the current year. This might 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 was no significant difference between the predicted and observed peak NDVI (Figure 5). This means that the rainfall is the determining factor for the vegetation growth in the Butana area.

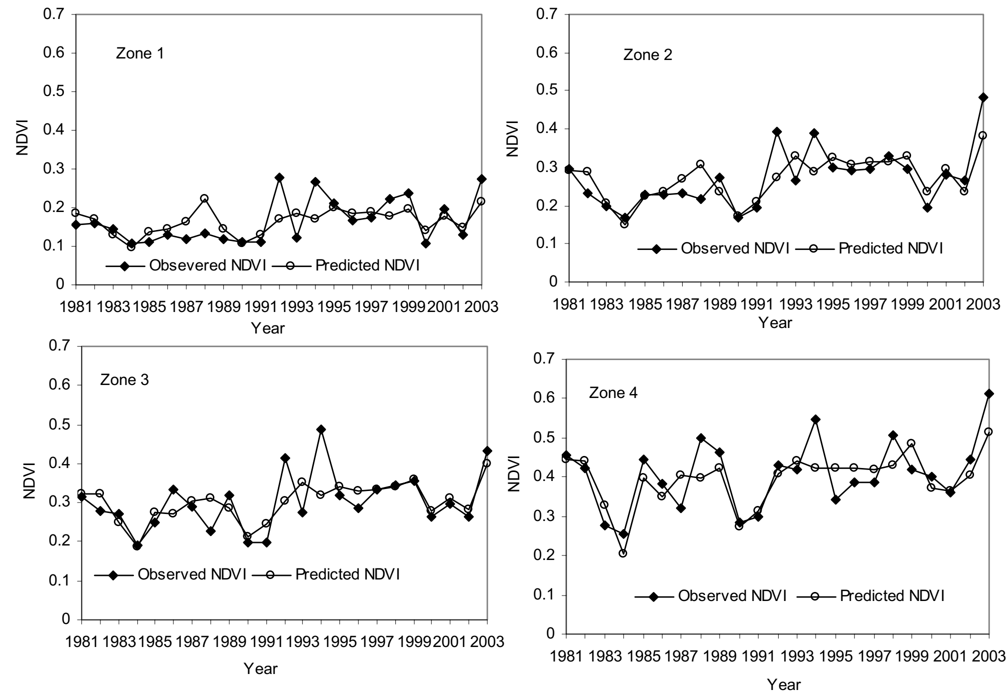

Figure 5: The observed and predicted peak NDVI for the 4 zones

To study the spatial trend of the human activities, the period from 1982 to 2001 was divided into four equal intervals (1982-1986, 1987-1991, 1992-1996, and 1997-2001). From Figure 6, it could be noted that the residual effect of the human activities is severe for zones 1 and 2 during 1982-1986, during severe drought. During 1987-1991 the area experienced 2 consecutive drought years (1990-1991) that covered the whole area of Butana. The effect of human activities became more severe in all of the 4 zones, especially the area adjacent to the Rahad irrigation scheme and the rain-fed agricultural area. This is due to the fact that the nomads concentrate in the areas where there water and fodder is available for the livestock. After 1992-1996, the effect decreased as 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). During the period of 1997-2001, the area experienced a drought in 2000 and the human influence increased 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 4 zones during 1992-1996. This indicated 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

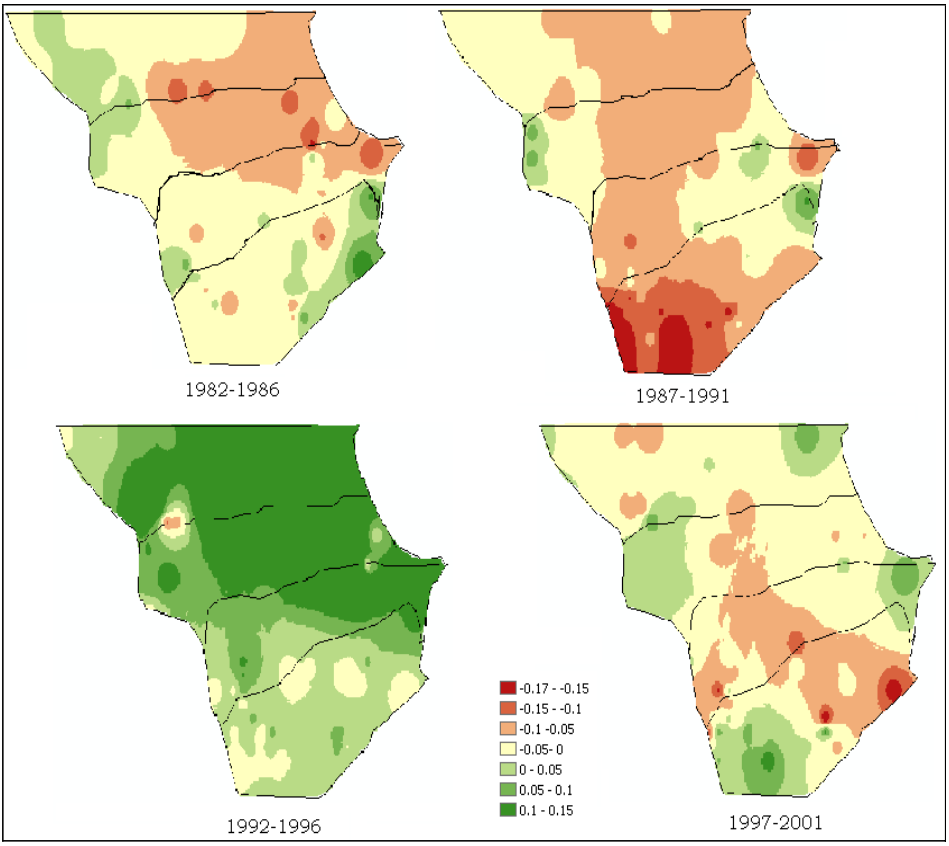

Figure 6: Residual effects of the human activities in the Butana area from 1982-2001 in 5 years step

5. CONCLUSIONS

The trend of the rainfall at Wad Medani and Shambat showed a significant decline, while that of Halfa and El Gadaref did not show a significant change. The results showed 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 indicated an increase in the green vegetation after 1992. This revealed the fact of the recovery from the Sahelian drought at the northern part of the Butana area.

The residual effects indicated that the predicted peak NDVI was higher than the observed peak NDVI from 1984 to 1989. This supported 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. In general, this impact was severe for zone 1 and 2 during the 1984 drought. There is significant impact of human activities on the whole area during 1987-1991 during severe droughts and the nomads started to congregate in the area near the irrigation schemes and rain-fed 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.

It was thus recommended to advise the planners and decision makers 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 the establishment of evidence to rainfall changes that have a significant impact on vegetative cover in the area and hence sustainability of the nomad life style.

6. REFERENCES

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