OnLine Journal of Earth Sciences 1 (4): 163-169, 2007
ISSN: 1991-7708

Analysis of Sudan Vegetation Dynamics-Using NOAA-AVHRR NDVI Data from 1993-2003

Habib Aziz Salim, Xiaoling Chen and Jianya Gong
State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing,
Wuhan University Wuhan, Hubei 430079, China

Abstract: Long term observation of space-borne remote sensing data provides a means to explore temporal variation on the Earth's surface. This improved understanding of variability is required by numerous global change studies to explain annual and inter-annual trends and to separate those from individual events. This study employs daily 8 km NOAA-AVHRR data of the Pathfinder program to study changes in the annual variability of vegetation in Sudan, during the time period from 1993-2003. The daily data were processed to improve 15 day composites using an iterative approach including metadata and robust statistical techniques. Examination of this time series reveals that the period 1994-2003, marked by a trend towards wetter conditions with region-wide above normal NDVI conditions with maximum in 1994 and 1999. This study employs GIS to examine the relationship between rainfall and the Normalized Difference Vegetation Index (NDVI) in the context of the Sudan and the value of NDVI is taken as a tool for drought monitoring. The relationship between rainfall and NDVI during 1993-2003 in Sudan is examined using spatial analysis methods and a strong positive correlation is found. The correlation is strongest during years of heaviest rainfall, indicating that the relationship between rainfall and NDVI is not a simple linear one.

Key words: NOAA-AVHRR, NDVI time series, drought, rainfall, Sudan

INTRODUCTION

The majority of Sudan is characterized as semi-arid region and thus susceptible to degradation or even desertification; semi-arid regions are subject to regular seasonal dryness and large inter-annual variability in precipitation. This results in variable vegetation cover on annual and inter-annual timescales, as both natural ecosystems and non-irrigated crops rely on soil moisture derived from seasonal rains or springtime snow melt (Weiss *et al*., 2004). Figure 1 shows average annual rainfall in Sudan (1993-2003). The Normalized Difference Vegetation Index (NDVI) is established to be highly correlated to green-leaf density and can be viewed as a proxy for above-ground biomass (Tucker and Sellers, 1986). In particular, NOAA-AVHRR (Advanced Very High Resolution Radiometer, onboard National Oceanic and Atmospheric Administration satellites) data can provide useful information on such changes over climatic spatio-temporal scales. The long time series of observations can be very useful for studying vegetation dynamics over inter-annual scales. In this decade, human beings consequently realized the significance of global change monitoring, several international organizations such as IGBP, HDP and WCP, have lunched very important programs, among which land cover and vegetation change monitoring is a key project. The method for studying land use and vegetation change is developed very quickly as the progress of remote sensing technique in the world.

This study's aim to employ GIS to examine the relationship between rainfall and the Normalized Difference Vegetation Index (NDVI) in Sudan, during the time period from 1982 to 1993 and the value of NDVI is taken as a tool for drought monitoring. The objective of this research is to examine whether there is a relationship between rainfall and NDVI in Sudan. Once a positive relationship is established, the research analyses the use of NDVI as a proxy indicator for the occurrence of meteorological drought, that is, when precipitation is significantly below what is normally required by vegetation. This is done by integrating multi-source geo-referenced datasets in a GIS platform in order to facilitate analysis and the generation of cartographic, statistical and modeling products. The final output comprises the spatial analysis products and aims to be useful in the decision making process for drought monitoring and to avert its consequences on lives and livelihoods.

Corresponding Author: Habib Aziz Salim, State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University Wuhan, Hubei 430079, China

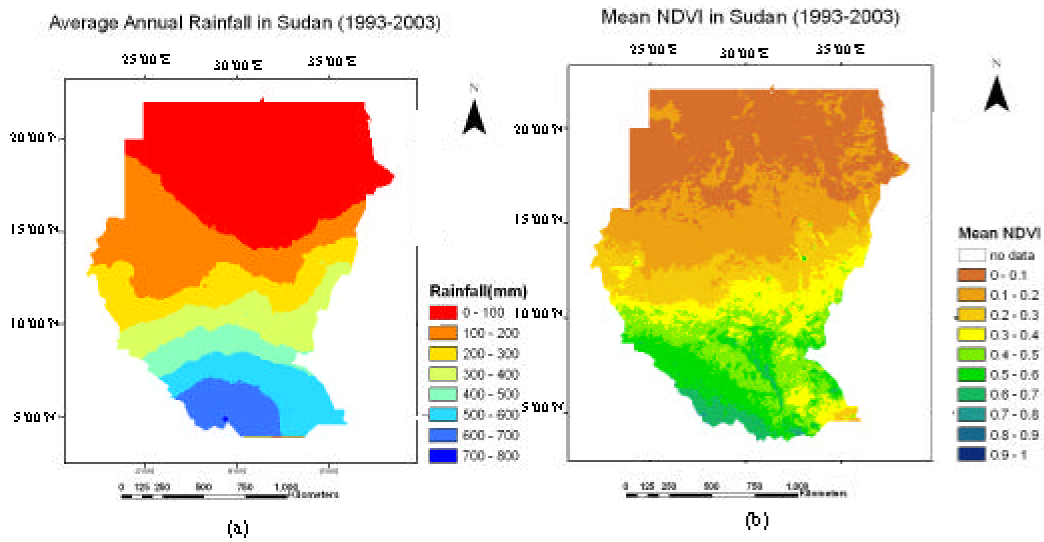


Fig. 1a: Average annual rainfall in Sudan (1993-2003) and (b) mean NDVI in Sudan (1993-2003)

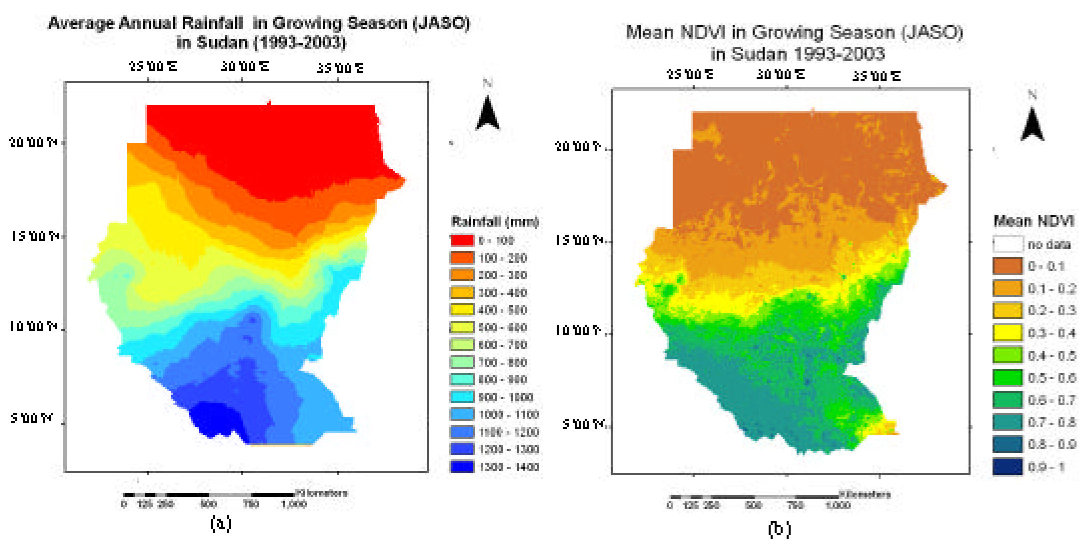


Fig. 2a: Average annual rainfall in growing season (JASO) in Sudan (1993-2003); (b) mean NDVI in growing season (JASO) in Sudan (1993-2003)

MATERIALS AND METHODS

The AVHRR satellite, with its 11 year data record 1993-2003 and reasonably spatial resolution (8 km), provides an excellent tool for the analysis of regional vegetation. AVHRR 15 day composites of surface reflectance and maximum NDVI were downloaded from World Meteorological Organization (WMO) website in this study.

The 15 day NDVI composites were integrated to mean monthly and then to mean growing season values for each of the analysis years. Analysis of seasonal and inter-annual vegetation dynamics and trends of Sudan region is based the Normalized Difference Vegetation Index (NDVI). This index is calculated from AVHRR measurements in the visible and infrared bands as follows:

$$NDVI = (\rho_{nir} - \rho_r)/(\rho_{nir} + \rho_r)$$

Where ρ_{nir} and ρ_r are the surface reflectance's in the 550-700 nm (visible) and 730-1000 nm (infrared) regions of the electromagnetic spectrum, respectively.

The compiled 11 year time series is now exploited to examine the linkages between climate variations and ecosystem dynamics (Lotsch *et al.*, 2003) and more recently to study long-term trends in vegetation (Eklundh and Olsson, 2003; Slayback *et al.*, 2003). For this study, we subset the Sudan region from the continental data set for the period 1993-2003. Figure 1 shows an example of the average of all data for complete years from 1993 to 2003 showing the long-term mean in Sudan. Since the evolution of NDVI in Sudan is closely related to rainfall seasonality. The analysis in this study only focuses on NDVI patterns during the growing season. The growing season was defined by examining the long-term mean patterns of NDVI. The months of July through October, referred to here as JASO, were selected to represent the average start and end of the growing season. The year to year variability in the NDVI patterns was examined by calculating yearly JASO anomalies as follows:

$$NDVI_{\sigma} = \left[\left(\left(NDVI_{\alpha}\right)/\left(NDVI_{\mu}\right)-1\right)100\right]$$

Where:

NDVIσ = The respective JASO percent anomalies,

NDVIα = Individual seasonal JASO means and

NDVIμ = The long-term JASO mean (Fig .2). Figure 2 shows Average Annual Rainfall in Growing Season (JASO) in Sudan in the time period of 1993-2003.

RESULTS AND DISCUSSION

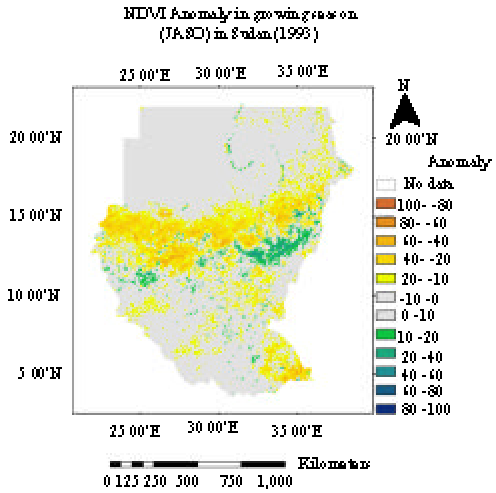
Spatial patterns: The spatial NDVI anomaly patterns in Sudan are shown in Fig. 3. These series of images show the JASO percent NDVI anomaly patterns for selected growing seasons during the 1993-2003 periods. In 1993 and 1996 a patchy pattern of below normal NDVI showed the prevalence of drought conditions across the country, especially in the western and eastern areas and most of the pronounced greenness was concentrated in the central of Sudan. This pattern was enhanced in 2000 and the whole region showed a low NDVI level of below normal conditions and the most extreme negative departures reached 80% lower than the below normal conditions. In 2002, it still showed negative departures in NDVI ranging between 10 and 40%. During the growing season in 1994, central of Sudan showed above normal vegetation conditions and had positive anomalies ranging between 20 and 100%. The above normal greening during this period was associated with positive rainfall anomalies during the months of August, September and October (Nicholson *et al.*, 1996). The patterns in 1994 are similarly observed across the region during the growing season in 1999. In 1993 it showed low NDVI values of below normal NDVI. This is a western extension of the drought that affected eastern Africa in 1991-1993. The period from 1994-2003 is dominated by normal to above normal NDVI with the highest values during the growing seasons in 1994, 1999-2001. The above normal conditions extend across the country suggesting that the causal mechanisms of severe drought in 1984 and greener conditions in 1994 are large scale in nature affecting the continental extent of the Sahel region (Giannini *et al.*, 2003).

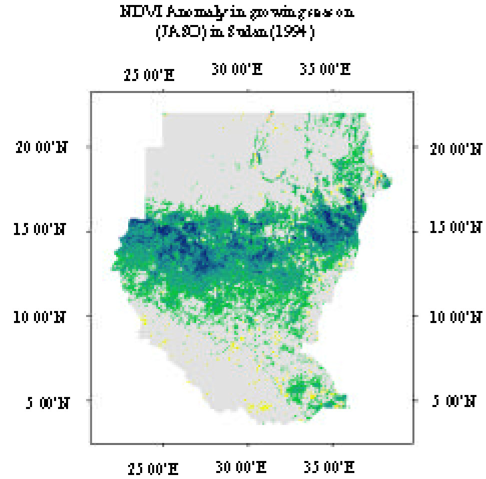
Monthly time series patterns in the time period from 1993 to 2003: The monthly time series of NDVI and rainfall from 1993-2003 in Sudan are shown in Fig. 4 and 5. On average most of the rainfall occurs between July and October, with a maximum in August. Approximately 83% of the annual rainfall falls between the July and October (Lamb, 1980), so averaging NDVI data for these months fairly represents the growing season for the region. From Fig. 6, monthly relationship of rainfall and NDVI for that time series in Sudan showed that the NDVI values had a correlation (0.55) as a linear relation to the rainfall. Both rainfall and NDVI show a maximum in August-September. Mean monthly NDVI ranged from 0.2-0.37 across the country throughout the time series in Fig. 7 and the NDVI values greater than 0.2 corresponded well with the rainy season from July to October. These high NDVI values persisted towards the end of year in November and December indicating the lagged response of vegetation to rainfall in this region. The extent of these values across the region is an indicator of rainfall conditions. The extent and duration of these NDVI values can be used as an indicator of the strength and duration of the rainfall to produce mechanisms associated with the ITCZ (Intertropical Convergence Zone) since vegetation growth in the region is primarily controlled by rainfall, although other factors including potential evaporation influence the fluctuating boundary (Milich and Weiss, 2000).

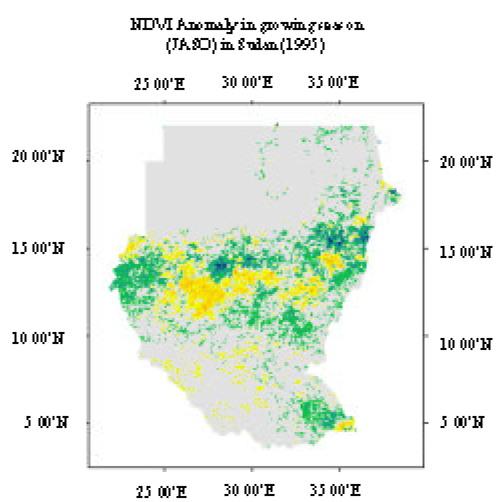
The period from 1994-2003 was dominated by above normal conditions with 70% of the years showing above normal NDVI conditions with severest departures in NDVI in 1994 and 1999 persisting for 7 years between 1994 and 2003, with exception of 1996, 2000 and 2002. The prevalence of above normal conditions during the period from 1994-2003 follows a similar increase in rainfall over the country during the last decade (Nicholson, 2005). These patterns are summarized in Table 1 and Fig. 8.

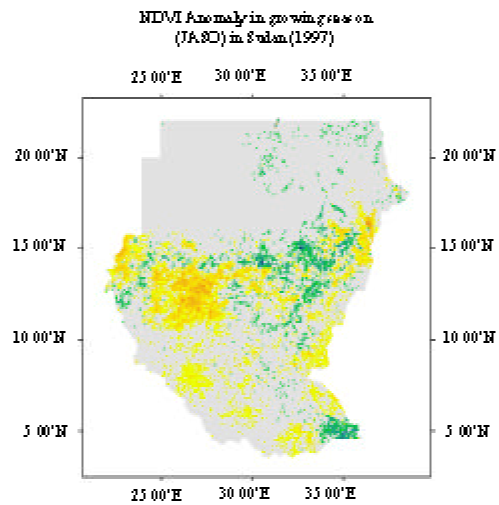
Table 1: NDVI anomaly scores (+/-) showing persistence patterns of above normal or below normal vegetation condition

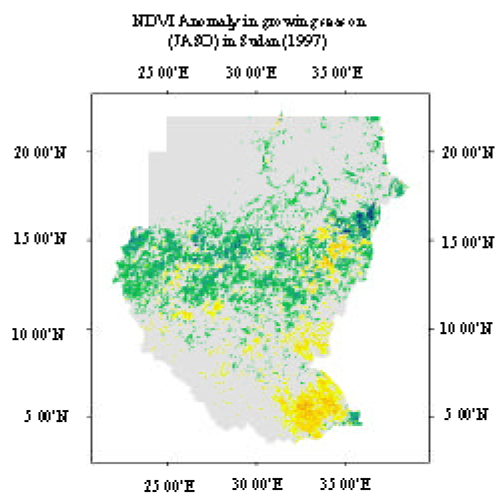
Year	93	94	95	96	97	98	99	00	01	02	03
Anomly (+/-)	-	+	+	-	+	+	+	-	+	-	+

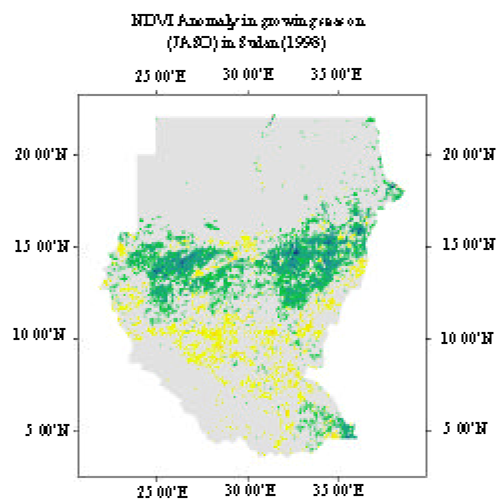

NDVI Anomaly in growing season
(JASO) in Sudan (1993)
25 00'E
30 00'E
35 00'E
20 00'N
15 00'N
10 00'N
5 00'N
N
Anomaly
No data
100- -80
80- -60
60- -40
40- -20
20- -10
-10 -0
0 -10
10 -20
20 -40
40 -60
60 -80
80 -100
Kilometers
0 125 250 500 750 1,000


NDVI Anomaly in growing season
(JASO) in Sudan (1994)
25 00'E
30 00'E
35 00'E
20 00'N
15 00'N
10 00'N
5 00'N


NDVI Anomaly in growing season
(JASO) in Sudan (1995)
25 00'E
30 00'E
35 00'E
20 00'N
15 00'N
10 00'N
5 00'N


NDVI Anomaly in growing season
(JASO) in Sudan (1997)
25 00'E
30 00'E
35 00'E
20 00'N
15 00'N
10 00'N
5 00'N


NDVI Anomaly in growing season
(JASO) in Sudan (1997)
25 00'E
30 00'E
35 00'E
20 00'N
15 00'N
10 00'N
5 00'N


NDVI Anomaly in growing season
(JASO) in Sudan (1998)
25 00'E
30 00'E
35 00'E
20 00'N
15 00'N
10 00'N
5 00'N

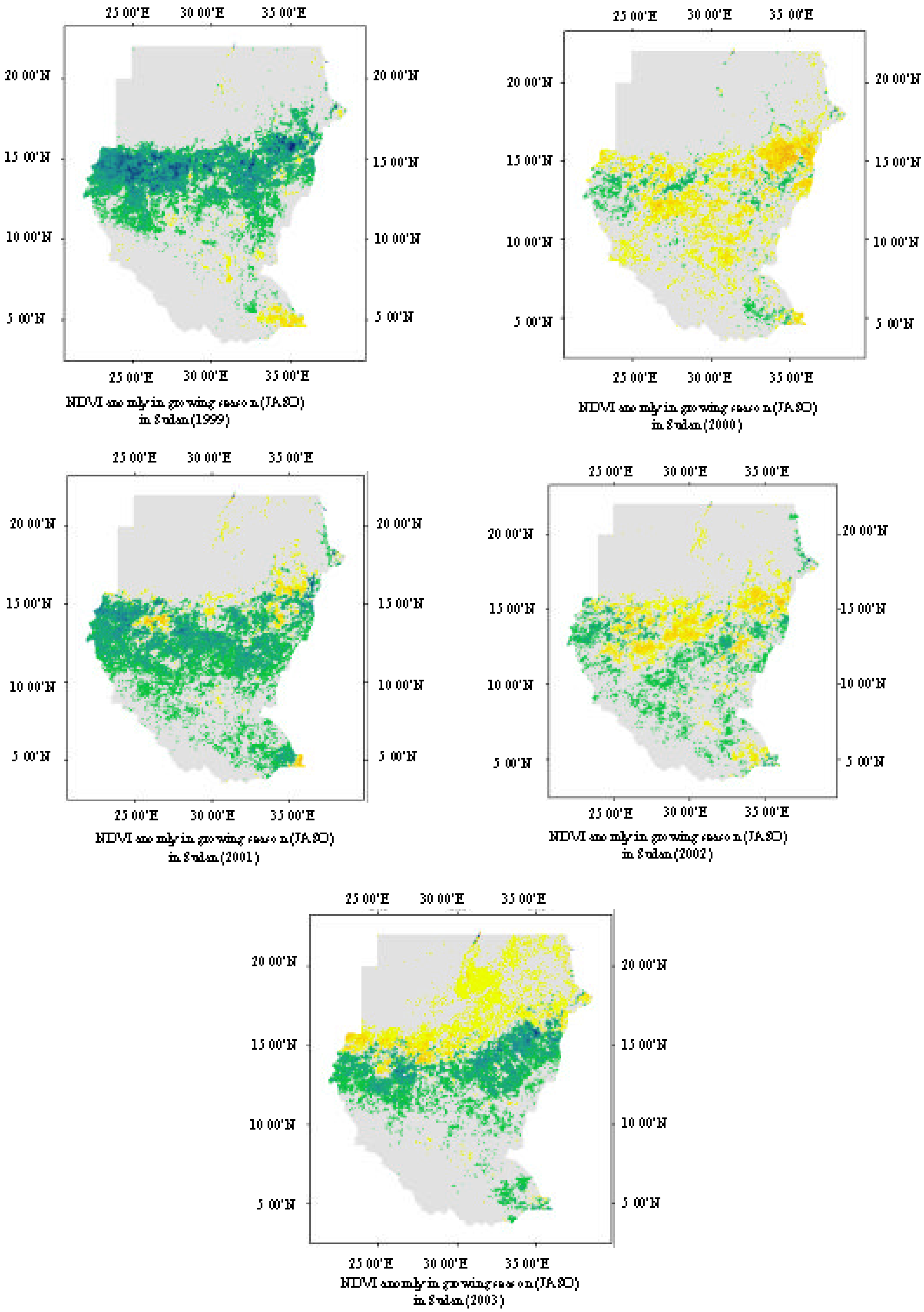


Fig. 3: NDVI anomaly patterns in the growing season (JASO) during the time period of 1993-2003

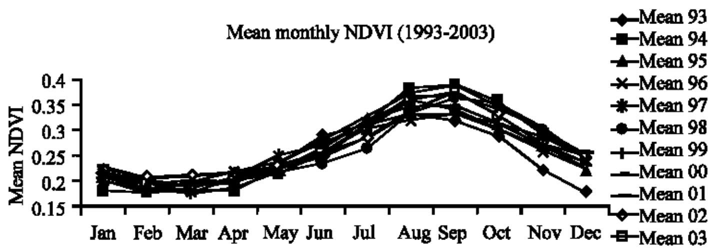


Fig. 4: Mean monthly NDVI in Sudan (1993-2003)

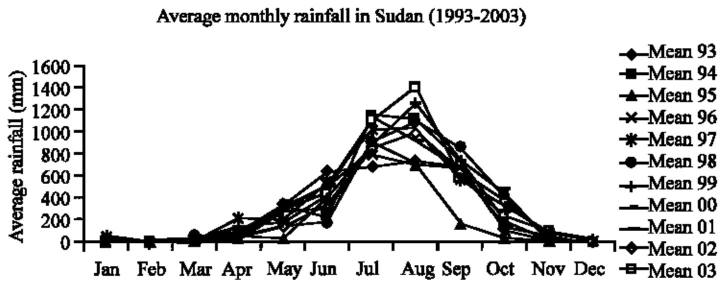


Fig. 5: Mean monthly rainfall in Sudan (1993-2003)

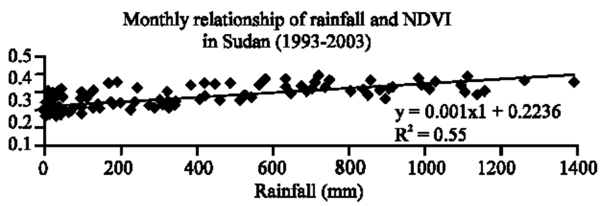


Fig. 6: Scatter plot of the rainfall and NDVI in Sudan (1993-2003)

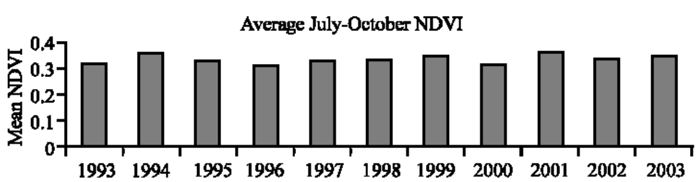


Fig. 7: Average NDVI in the time period of July-October in Sudan (1993-2003)

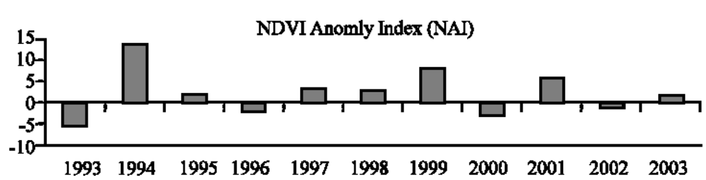


Fig. 8: NDVI Anomaly Index (NAI) in Sudan (1993-2003)

CONCLUSION

The persistent nature of these patterns in NDVI from 1993- 2003 is in agreement with the historical patterns of rainfall anomalies in the region (Nicholson, 2001). In the process it has been demonstrated that in regions such as Sahelian Africa, where there is a dearth of digital data from which useful monitoring and management information can be drawn, GIS using remotely sensed data obtained from satellites is technically feasible. Furthermore, it is a relatively low cost system, as it uses free data for input and can be run on an ordinary desktop computer. The analysis has shown that NDVI is a complex indicator, difficult to interpret, as well as being a delayed outcome indicator. NDVI is a crude indicator of drought risk and needs to be related to other socio-economic and bio-physical data in order to be useful. The precision of NDVI as a vegetation index also needs to be strengthened through establishing its relationship to the growing season, for each specific climatic zone, on the basis of local vegetation and crop types. An effective drought warning system using NDVI should take advantage of remote sensing sources in using real time data, in order to facilitate timely decision making. If this were to be done, NDVI can be a valuable first cut indicator and provide a key input for cost-effective, reliable and timely drought monitoring systems. The vastness of the Sudan, poverty, conflicts and its poorly developed communications infrastructure, pose great difficulty for the collection of data for operational use by a ground based method. Consequently, remote sensing becomes the only feasible source of data that can be used as a decision tool for timely action to avert the negative consequences of drought. There is a need in the Sudan, for a system which can provide timely, reliable and useful information for decision makers on the risk of drought and environmental change. The patchy nature of the increase in NDVI will require the use of higher spatial resolution data from LANDSAT, SPOT and MODIS in order to determine the driving factors of change at the landscape scale. Further studies examining combined climate data including rainfall and sea surface temperature patterns and continued gathering of long-term satellite data sets will help in understanding the long-term changes in the climate and land surface conditions of this sensitive semi-arid environment.

REFERENCES

Eklundh, L. and L. Olsson, 2003. Vegetation index trends for the African Sahel 1982-1999. Geophys. Res. Lett., 30: 1430.

Giannini, A., R. Saravanan and P. Chang, 2003. Oceanic forcing of Sahel rainfall on interannual to interdecadal time scales. Science, 302: 1027-1030.

Lamb, P.J., 1980. Sahelian Drought. New Zealand J. Geography, 68: 12-16.

Lotsch, A., M.A. Friedl and B.T. Anderson, 2003. Coupled vegetation-precipitation variability observedfrom satellite and climate records. Geophys. Res. Lett., 30: 1774.

Le Compte, D., R. Tinker, J. Dione, M. Halpert and W. Thiao, 1994. Wettest rainy season in 30 years across African Sahel. Special Climate Summary 94/2, 5. NOAA, Washington, DC.

Milich, L. and E. Weiss, 2000. GAC NDVI interannual coefficient of variation images: Ground-truth sampling in the Sahel alongno rth-south transects. Int. J. Remote Sensing, 2 1: 235-260.

Nicholson, S.E., 1985. Sub-Saharan Rainfall 1981-84. J. Climate and Applied Meterol., 24: 1388-1391.

Nicholson, S.N., 2001. Climate and environmental change in Africa during the last two centuries. Climate Res., 14: 123-144.

Nicholson, S.E., M.B. Ba and J.Y. Kim, 1996. Rainfall in the Sahel during 1994. J. Climate, 9: 1673-1676.

Nicholson, S.E., 2005. On the question of the recovery of the rains in the West African Sahel. J. Arid Environments, in Press, doi:10.1016/j.jaridenv.2005.03.004.

Slayback, D.A., J.E. Pinzon, S.O. Los and C.J. Tucker, 2003. Northern hemisphere photosynthetic trends 1982-1999. Global Change Biol., 9: 1-15.

Tucker, C.J. and P.J. Sellers, 1986. Satellite remote sensing of primary production. Int. J. Remote Sensing, 7: 1396-1416.

Weiss, J.L., D.S. Gutzler, J.E.A. Coonrod and C.N. Dahm, 2004. Long-term vegetation monitoring with NDVI in a diverse semi-arid setting, central New Mexico, USA. J. Arid Environ., 58: 249-272.