African Journal of Environmental Science and Technology Vol. 4(12), pp. 845-852, December 2010
Available online at http://www.academicjournals.org/AJEST
DOI: 10.5897/AJEST10.137
ISSN 1991-637X ©2010 Academic Journals

Full Length Research Paper

Drought risk assessment in pasture arid Morocco through remote sensing

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Accepted 18 October 2010

During the last three decades, Morocco has experienced several stern and extended episodes of drought that severely affected pasture production. To cope with this phenomenon, the policy makers have put emphasis on a reactive short term management approach rather than on pro-active risk-based management measures. The purpose of this study is the assessment of drought by remote sensing, which is an important step in the design and implementation of drought management plan. To reach this objective we used bi-weekly TERRA Moderate Resolution Imaging Spectroradiometer (MODIS 250 m) data in arid pasture of Morocco. A preliminary mapping using Landsat TM5 of major land cover types was carried out to extract the pasture area. A comparison of annual and seasonal Normalised Difference Vegetation Indices (NDVI), Vegetation Condition Index (VCI) and rainfall during the time period of 2000 - 2008 were carried out. Results showed that stronger relationship of NDVI with previous seasonal rainfall as compared to VCI indicating that NDVI variation is a good indicator of vegetation changes and consequently can give a better idea on drought conditions in the study area.

Key words: Drought monitoring, pasture area, vegetation indices.

INTRODUCTION

Drought is considered as most complex but least understood of all natural hazards, affecting more people than any other hazard. Drought can be defined as a period when the rainfall is low in regard to long-term average conditions. During the last decades, drought has become globally more frequent. In fact, the Fourth Assessment Report ("AR4") by the International Panel on Climate Change (IPCC 2007) foresees a temperature rise globally in the range of 2 to 6°C by 2100. For North Africa, including Morocco, there will be likely a reduction in rainfall. Moreover, precipitation decline, evaporation increase and vegetation degradation are making Moroccan lands more vulnerable to drought. The assessment of drought magnitude is necessary for effective drought mitigation efforts. Since the consequence of drought varies from a land cover type to another, mapping of this cover is often the primary source for determining the current vegetation status and it is used as a baseline for drought monitoring. Due to repeated and widespread drought impacts, more emphasis on drought risk management is needed. Development of drought monitoring system and management plan or policy will enforce the coping capacity of the country.

The impact of drought depends on its timing and duration, particularly in relation to growth stages of particular crops or plants and the tolerance of individual species or cultivars to drought. The use of remote sensing data presents a number of advantages when determining drought's impact on vegetation. The information covers the whole of a territory and the repetition of images provides multi-temporal monitoring (Kogan, 2002). There are many sensors on board of numerous

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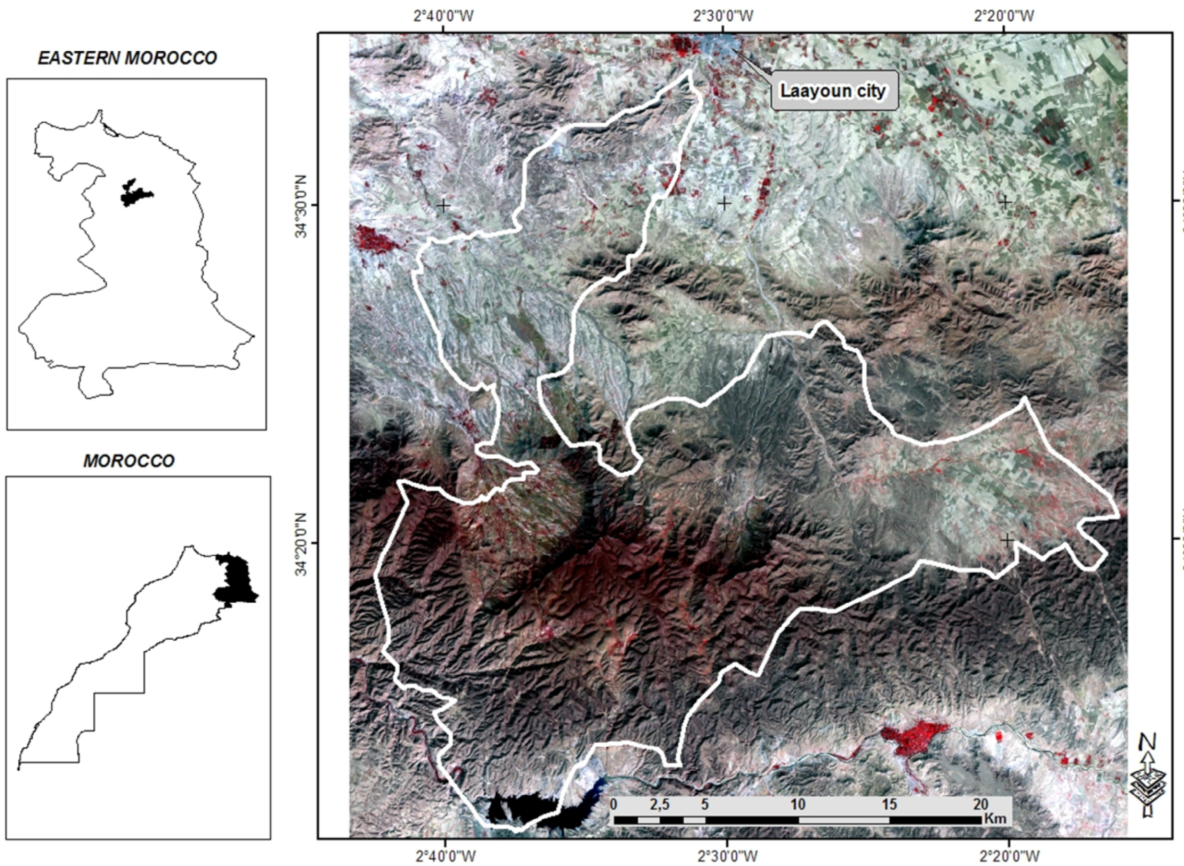

Figure 1. Landsat TM5 subscene of Tancherfi commune.

satellites, which can be used to assist in the prediction of drought. The Moderate Resolution Imaging Spectro-radiometer (MODIS) data are used for climate and environmental changes including drought monitoring and climate impact assessment at regional and global scales (Wan et al. 2004; Gao et al., 2008). In addition, vegetation indices obtained from satellite data allow areas affected by droughts to be identified (Kogan, 1995; Vicente-Serrano, 2007). The Normalized Difference Vegetation Index (NDVI) is the most common indicator that is sufficiently stable to permit meaningful comparisons of seasonal, inter-annual, and long-term variations of vegetation structure, phenology, and biophysical parameters (Tucker and Sellers, 1986). In other words, it has been documented that there is a direct correlation between NDVI and the amount of stress vegetation is experiencing (Schmidt and Karnieli, 2000; Wong, 2003). Also, the comparison between NDVI values and rainfall data shows dependence of the NDVI values on the sum of the amount of rainfall with a time lag (Schmidt et al., 2000; Rahimzadeh et al., 2008). However, several studies suggest that Vegetation Condition Index (VCI) captures rainfall dynamics better than the NDVI particularly in geographically non-homogeneous areas. In fact, VCI has been used for drought monitoring over India (Singh and Kogan, 2002), southern Great Plains, USA (Wan et al., 2004), southeast Spain (Vogt et al., 2000) and Southwest Asia (Thenkabail et al., 2004). It was concluded from the above studies that VCI allows an assessment of spatial characteristics of drought, as well as its duration and severity and it is in good agreement with rainfall patterns (Rahimzadeh et al., 2008).

The Eastern part of Morocco is experiencing the driest periods in its recorded history. As it is not possible to prevent drought occurrence, its impacts can be mitigated through management methods and technologies. The objectives of this study were to use Landsat data for mapping the pasture area in the Eastern part of Morocco, determine the relationships between MODIS Vegetation Indices and rainfall, and to evaluate the time lag between the occurrence of rainfall and vegetation response in this area.

MATERIALS AND METHODS

Study area

The study area is the rural district of Tancherfi in eastern part of Morocco which is located between 2° 15'-2° 42 'W and 34° 10'-34° 40' N. It covers an area of approximately 649 Km^2 (Figure 1). It is characterized by the predominance of mountains in the south and plains in the north. The climate is arid, dry in summer and cold in winter. The long-term annual average rainfall (1970 - 2007) is 242 mm and the annual average temperature is 17°C and ranges between -4°C in winter and 45°C in summer. The main soil types that dominate this area are shallow with low fertility and water retention capacity. They vary from clay sandy loamy to rocky calcareous soils. Livestock grazing is the primary land use activity.

Methodology and data acquisition

In the first step of this study, Landsat imagery is used to develop a Tancherfi land cover map. A sub-scene of Landsat TM5 scene (30 m) used was acquired on 13 March 2007 from path 199, row 36. This scene was acquired in UTM projection (WGS 84, zone 30N). Field data were used as the training area for the Maximum Likelihood classification (Foody, 1992; Maselli et al., 1994). A set of 160 reference pixels were randomly selected and compared to ground truth data to determine the accuracy assessment (Congalton, 1991).

In the second step, the MODIS Normalized Difference Vegetation Index (NDVI) 16-day product (MOD13Q1; 250 m; Version 5) (Huete et al., 2002) was used in this study. NDVI is based on the near infra-red channel (NIR), where the vegetation has an important reflectance, and the red channel (R), where the vegetation has a low reflectance. The formula for determining NDVI is: NDVI = (NIR - R)/ (NIR + R) (Rouse et al., 1973; Tucker, 1979). The time series starts on February 18th, 2000 and ends on April 5th, 2008. The MODIS data were re-projected from the Sinusoidal projection to the UTM projection (WGS 84, zone 30N). The mask of pasture area was produced within a GIS using the created land cover map and re-sampled to 250 m pixel. So, the dataset contained 187 Vegetation index observations per pixel for pasture area.

The VCI was used to estimate the climate impact on vegetation. It is defined as:

VCI = (NDVI - NDVImin)/ (NDVImax - NDVImin) (Kogan, 1995),

Where NDVI, NDVImax, and NDVImin are the smoothed two weekly NDVI, multi-year maximum NDVI and multi-year minimum NDVI, respectively, for each grid cell. VCI varies from 0 to 1, corresponding to changes in vegetation conditions from extremely unfavorable to optimal.

In the third step, rainfall data were collected with 16-day rainfall values over a nine-year period (2000 - 2008) at ground station of Laayoun city located at a distance of 12 km from the study area (Figure 1). Finally, statistical analyses were performed using one-way ANOVA and the mean comparisons were made using the least significant difference (LSD) method with $p<0.05$. In order to study the statistical relationships between rainfall and NDVI or VCI, Pearson correlation analysis and partition method were performed.

RESULTS AND DISCUSSION

Land cover

Figure 2 presents the land cover map of Tancherfi for the year 2007. The Table 1 depicts five land cover types corresponding, respectively, to forest (44%), pasture (30%), cropland (24%), water (1%) and others (1%). The analysis on drought monitoring focuses on the pasture area. Field data shows that the main vegetation species of pasture area are *Stipa tenacissima*, *Artemisia herba-alba*, *Anabasis aphylla* and *Noaea mucronata*. Vegetation cover is less than 15% and it is in an advanced degradation stage. Estimates indicate that the overall accuracy of the classification is 81%.

Trends in vegetation indices and annual rainfall

Figure 3 shows the annual variations of NDVI, VCI and rainfall. Values vary from 0.19 to 0.24, from 0.41 to 0.48 and from 127.60 to 334.40 mm for NDVI, VCI and rainfall, respectively. In general, observed NDVI values were relatively low as compared to other regions (Balaghi, 2007), indicating a weak vegetation cover in this zone. A good agreement was observed between the peak values of NDVI and rainfall values. A significant difference ($p<0.05$) was observed among years for both indices. However, for rainfall, there was no significant year effect and this was due mainly to the high intra-annual variability of rainfall (CV = 76%).

LSD test revealed one group of years with NDVI values varying between 0.17 and 0.34 (Mean = 0.24; CV = 21%) and it was composed of years 2002 - 03. During these years, NDVI response to rainfall showed better vegetation cover as compared with other years. This was confirmed by the important rainfall recorded during the vegetation growth cycle (Figure 3). The NDVI values of the second group ranged from 0.15 to 0.30 (Mean = 0.20; CV = 16%) and included the remaining years. Although, the rainfall recorded during 2001 -2002 was higher than the average (242 mm), the NDVI value of that year was less than or equal to those of the other years, because a significant amount of rainfall was received late in the season, and hence did not have any effect on the vegetative cover. By contrast, 2004 - 2005 is considered as a dry year due to the fact that the rainfall recorded was low. However, NDVI value was equal to that of the normal years because the rainfall distribution was good. This shows the dominant impact of rainfall distribution on vegetation response to drought.

The highest and lowest VCI values were recorded in 2002 - 2003 and 2006 - 2007, respectively. As seen in Figure 3, the lowest rainfalls coincided with the lowest VCI values indicating a relatively good agreement between minimum VCI and minimum rainfall. However, the irregular distribution of the high rainfall of 2006 - 2007 caused a low VCI.

Seasonal rainfall, NDVI and VCI variation

The seasonal NDVI, VCI and rainfall varied from 0.15 to 0.31 (NDVI average = 0.21; CV = 19%), 0.36 to 0.54 (VCI average = 0.44; CV= 8%) and 2 to 171 mm (rainfall average = 64 mm; CV = 76%), respectively. The analysis of variance of these indices showed significant ($P < 0.05$) differences among seasons (Table 2). The LSD test

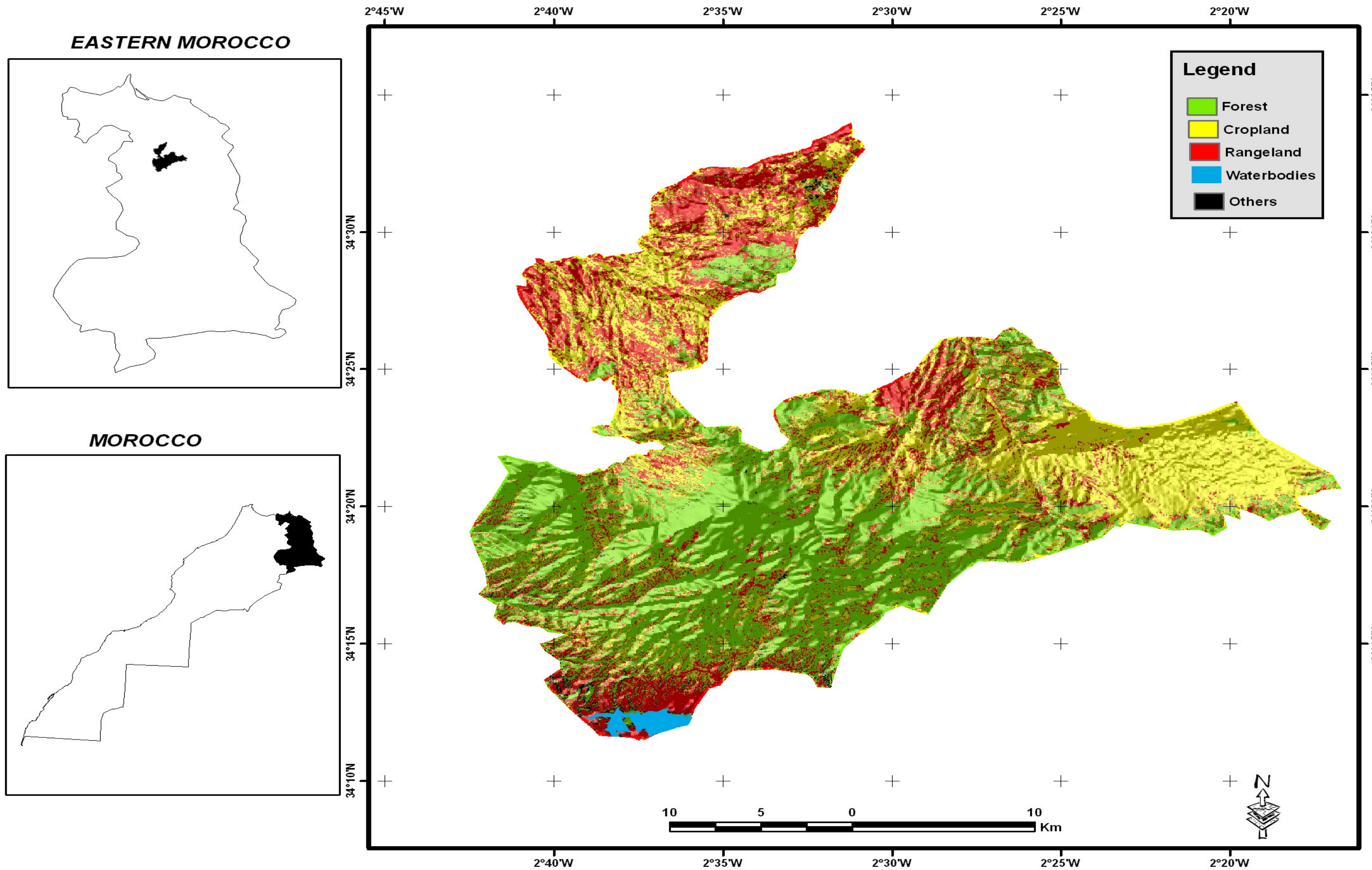

Figure 2. Land cover of Tancherfi Commune.

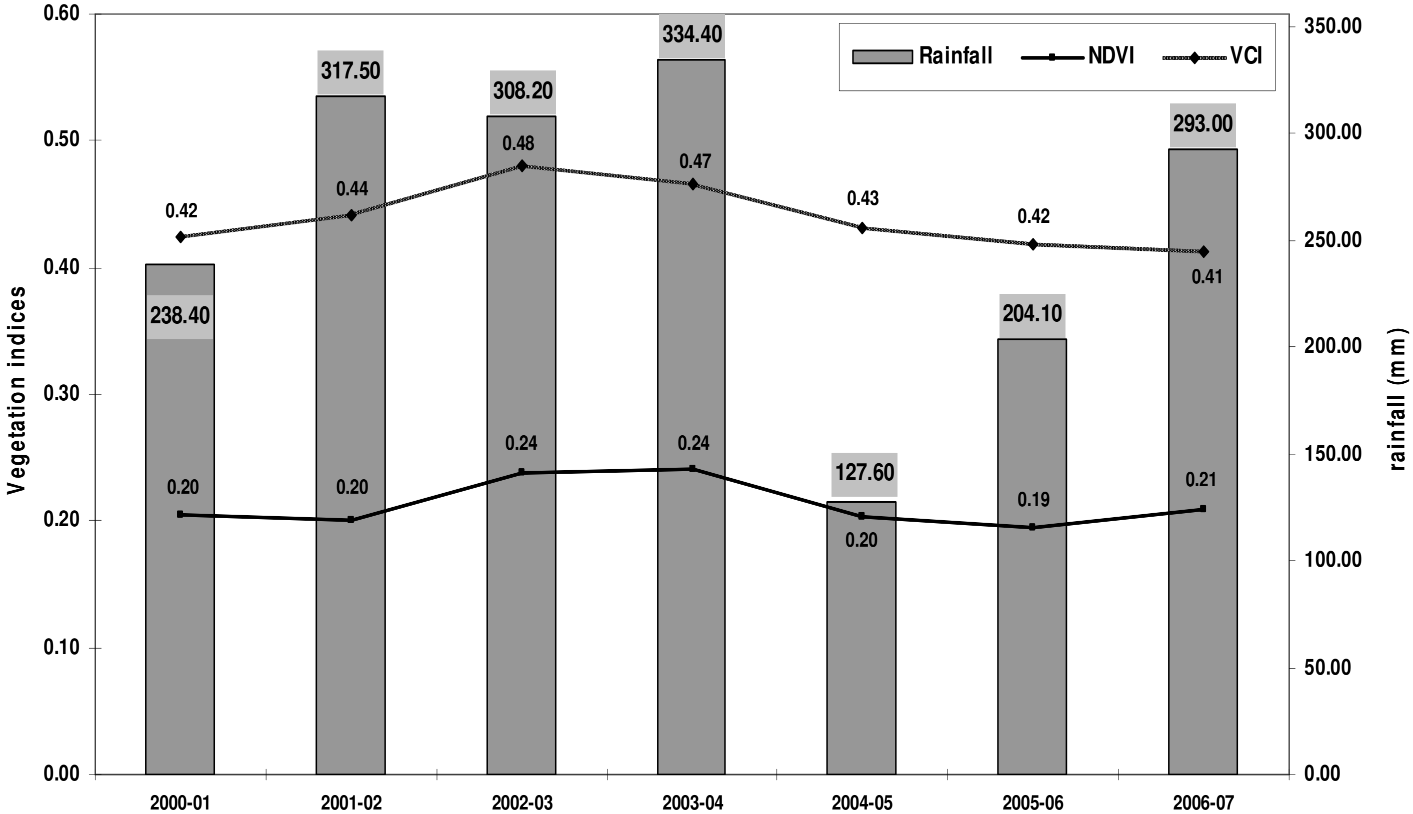

Figure 3. Average NDVI, VCI and annual rainfall profiles at Tancherfi pasture area.

Table 1. Land covers types and their relative spatial importance in Tancherfi.

Land cover	Area (ha)	Area (%)
Forest	30271	44
Cropland	20449	30
Pasture area	16735	24
Water bodies	458	1
Others	684	1
Total	68597	100

showed that NDVI observed in winter (December, January and February) and spring (March, April and May) were higher and significantly different than those observed in autumn (September, October and November) and summer (June, July and August). However, this test on rainfall showed one group with high values composed of autumn, winter and spring and another group with low represented by summer only. Moreover, the analysis showed a significant difference in the temporal rainfall distribution among the seven years. The highest NDVI values were observed when the rainfall was better distributed throughout the year and, in fact, there was no well-defined break between autumn, winter and spring rainy seasons (case of 2002 - 2003, 2003 - 2004). The average NDVI was obtained when significant rainfall was registered during winter and spring (case of 2001 - 2002). Also, a small quantity of well-distributed rains generated a normal NDVI (2004 - 2005). However, the lowest NDVI values were registered when an important rainfall was recorded during autumn, a little rainfall was obtained during winter and spring was dry (2000-2001).

An interesting observation concerning the rainfall distribution was that precipitation of spring or summer did not have any effect on vegetation. In fact, there is a tendency to have lower NDVI values in late spring even though high rainfall was recorded at that time. However, a better agreement was noticed between the rainfall season and NDVI values. It is worth noticing from Table 2 that the highest seasonal variation in rainfall occurs in summer followed by spring. However, the largest CV in vegetation indices corresponds to spring and the lowest to autumn. LSD analysis of VCI indicated high values corresponding to spring and summer and a normal VCI values corresponding to autumn and winter. This result is opposite to the actual situation observed on the ground because during summer there is very little vegetation in comparison to autumn or winter. Despite many authors suggesting that VCI captures rainfall dynamics better than the NDVI in non-homogeneous areas (Singh and Kogan, 2002; Vogt et al., 2000; Kogan et al., 2004), our study showed that VCI appeared to be less sensitive

Table 2. Seasonal NDVI, VCI, rainfall values and their variation coefficients at Tancherfi pasture area.

	NDVI		VCI		Rainfall	
	Value	CV (%)	Value	CV (%)	Value (mm)	CV (%)
Winter	0.24 a	10.27	0.44 ab	6.66	65.13 a	41.22
Spring	0.24 a	18.54	0.46 a	9.65	80.13 a	77.91
Autumn	0.19 b	8.43	0.41 b	5.75	91.38 a	45.57
Summer	0.18 b	10.40	0.45 a	5.88	17.50 b	99.96

Levels not connected by same letter are significantly different.

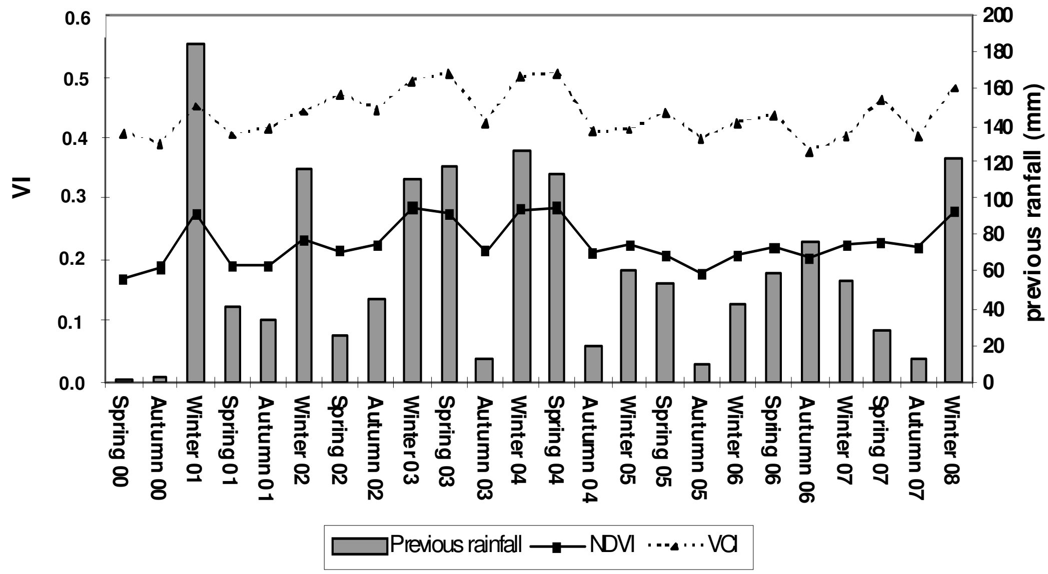

Figure 4. Average NDVI and VCI and previous sum season rainfall (winter, autumn and spring) in Tancherfi rangeland area from 2000 to 2008.

to detect the variation among seasons. In this study area, more vegetation was recorded in autumn than in summer. However, data on VCI showed opposite trends. The peak of VCI was registered after April. The values of this index were more or less in agreement with previous rainfall. For example, during 2002 - 2003 and 2003 - 2004, the lowest VCI values were observed from September to March; but the highest were registered in April.

The general lack of agreement between VCI values and rainfall data clearly showed that the maximum and minimum NDVI values used to determine the VCI at local scale were not influenced by the weather condition but by other factors. While rainfall is the dominant factor that controls plant growth in arid pasture land, its distribution during the plant growing cycle is at least as important as the amount received. In Tancherfi region, plant growth is dependent on both amount and three periods of occurrence, namely October-November, December-January and March-April. A wet year is considered as the one where rainfall occurs in each of these three periods. A normal year is characterized by rainfall occurring in two of these periods, while a dry year has rainfall occurrence in only one period.

NDVI-rainfall and CVI-rainfall relationships as indicators of drought in pasture area.

The relation between the vegetation indices and rainfall was used by several authors to monitor vegetation cover (Evans and Geerken, 2004). Indeed, Davenport and Nicholson (1993) and Wong et al. (2003) showed a high correlation between NDVI and rainfall. Liu and Kogan (1995) found that the NDVI was highly correlated with water deficit and rainfall for Cerrado (Savanna grassland) and Caatinga (woodland and open woodland) which both grow in areas with distinct wet-dry seasons. Also, Wang et al. (2004); Vogt et al. (2000) and Thenkabail et al. (2004) showed high correlation between VCI and rainfall. As presented above, NDVI showed a positive response to previous rainfall, except after April when the vegetation is not responsive to a significant rainfall. In fact, the determining factor of biomass production in Morocco is rainfall that occurs before May. Figure 4 presents average season NDVI, VCI and previous total season rainfall

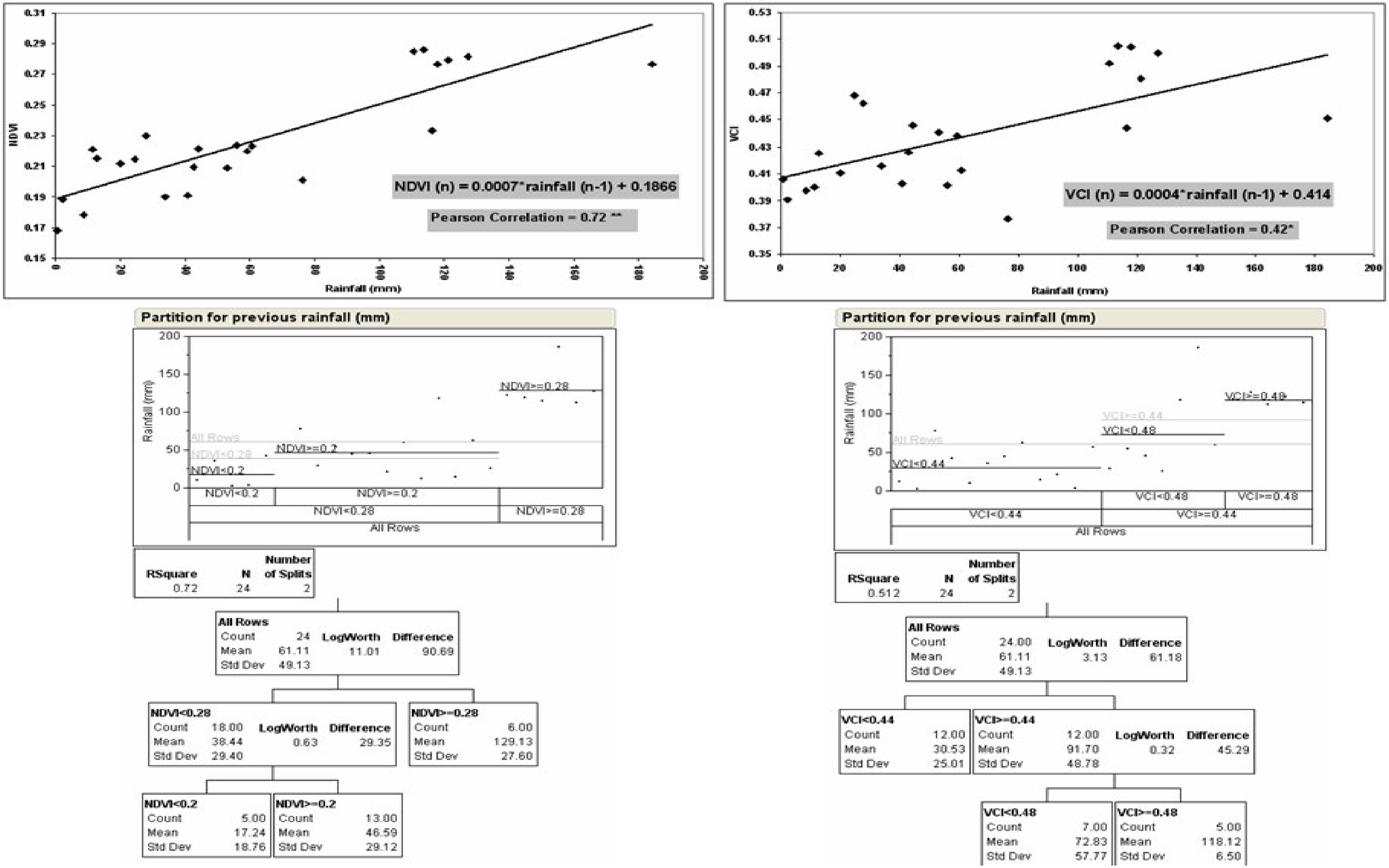

Figure 5. Correlation and partition between NDVI, VCI and previous season rainfall (winter, autumn and spring) in Tancherfi pasture area.

(winter, autumn and spring). This figure clearly shows that vegetation was responsive to previous season rainfall. The highest and lowest average NDVI values corresponded to the highest and lowest previous season rainfall, respectively. However, in our study, average season VCI presents a relatively positive response to previous season rainfall.

Correlations and partition analysis

In order to study the relationships between various time lag periods and NDVI or VCI, Pearson correlation analysis and partition method were performed. The partition (recursive partitioning) is a mining process for extracting information from large amounts of data. The partition divides data using NDVI and VCI to find previous rainfall values that are close to each other. Coefficients of correlation were determined using, on one hand, the average NDVI and VCI, and on the other hand the sum of previous-season rainfall for winter, autumn and spring. The results (Figure 5) show significant correlation of either NDVI ($r = 0.72^{**}$) or VCI ($r = 0.42^{*}$) with past season rainfall. The stronger relationship of NDVI with seasonal rainfall as compared to VCI indicates that NDVI variations can be a good indicator of vegetation changes and consequently of drought conditions in the study area. Furthermore, vegetation status-based indices can be useful tools to assess drought occurrence in a region. The partition for previous season rainfall of NDVI values lower than 0.2 are indicative of drought occurrence in a region. However, previous season rainfall of 47 mm generates a normal NDVI value (between 0.2 and 0.28) and previous season rainfall corresponding to 129 mm produces NDVI value higher than 0.28, indicative of a wet year.

From this study we can conclude that vegetation status-based indices can be useful tools to assess drought occurrence in the study region. NDVI values lower than 0.2 are indicative of drought occurrence. Values between 0.2 and 0.28 indicate average year and higher than 0.28 correspond to a good year. Moreover, significant correlations were found between NDVI and rainfall data at Laayoun station. Therefore, NDVI can be used for monitoring and mapping drought conditions in the study area. However, in order to obtain more reliable results there is a need for wider time span of satellite data. VCI values from the existing data in this area proved to be less reliable.

ACKNOWLEDGMENTS

The authors wish to express their special thanks to ICARDA and IFAD for the funding support of this research.

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