An Approach to analyse Drought occurrences using Geospatial Techniques

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Abstract:

Over the past few centuries India has been adversely affected by drought. Agriculture in India is completely dependent on the climate. Poor monsoon, results in water shortage which results in below average crop yields. During 1871-2012, India has experienced 24 major drought years. Drought can be defined as a continuous period when a region receives a deficiency in its water supply. In arid regions, such as most of the western Rajasthan has maximum drought severity and recurrence. The main reasons for the drought in arid regions are lack of efficient assessment and warning systems leading to delay in reaching affected people or region. To measure meteorological, hydrological and agricultural drought severity various indicators are considered. Also some physical indicators should also be included to analyse drought such as rainfall, effective soil moisture and surface water availability. Therefore, there is an urgent need to develop an approach to perform efficient drought assessment. In the present work, efficient and effective assessment of drought in Jodhpur district is performed with the help of geospatial techniques. Drought assessment indices such as Standardized Precipitation Index, Normalized Difference Vegetation Index and Vegetation Condition Index are used. Standardized Precipitation Index is used to monitor meteorological drought. Normalized Difference Vegetation Index and Vegetation Condition Index are used to assess vegetative drought in the drought-prone areas. Geospatial analysis techniques such as Remote Sensing and Geographic Information system have been used to discover drought conditions in the study area by determining these indices by using meteorological data and other relevant information. To perform data processing and analysis of the collected data ArcGIS software is used. Geographical visualization of the results of analysis helps to identity the unusual patterns of drought occurrences. The present work has been found to be successful in assessment of drought in the Jodhpur District.

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Introduction

Drought is one of the world's most costly natural disaster. Drought appears when the rainfall is deficient in relation to the statistical multi-year average for a particular region over a continuous period. It can be classified into four categories such as agricultural, hydrological, meteorological and socio-economic drought (Rathore, 2004). Agricultural drought is expressed as soil moisture deficit, rainfall deficit, soil water deficit and variation in evapo-transpiration. Meteorological drought can be expressed as the level of dryness measured in terms of rainfall deficiency. Hydrological drought can be expressed as deficiency in water availability in water reservoirs, stream flow and groundwater depth. In tropical regions, such as India, where rain is due to convergence, the migration or weakening of the inter–tropical convergence zone bring droughts. Drought in India is correlated to irregular monsoon rainfall in space and time. The major parameters which are used to analyze drought condition are vegetation health, rainfall, evaporation, stream flow, temperature and soil moisture. Drought indices are commonly used to assess the drought conditions around the world because it is more functional than raw data for decision making. Drought indices are used to trigger drought relief program and quantify deficit water resources to access drought severity in various regions. Drought places enormous demand on water resources of urban and rural areas. Also immense burden on agricultural and energy production. Therefore, timely determination of the level of drought will help in effective decision making process in reducing the impacts of drought.

Aims and Objectives

(i) Collection of meteorological, agricultural and satellite data of the Jodhpur District.
(ii) Digital processing of satellite images for preparation of land use/ land cover maps.
(iii) Estimation of different drought indices such as NDVI (Normalized Difference Vegetation Index) SPI (Standardized Precipitation Index) and VCI (Vegetation Condition Index).
(iv) Comparative study of different drought indices for Jodhpur District.

Software Used

(i) **ArcGIS version 10:** It is used for mapping and geospatial analysis. Also it provides efficient management of spatial data and storage.
(ii) **Microsoft Excel:** Microsoft Excel is used for creating spreadsheets, using a grid of cells arranged in numbered rows and letter-named columns to organize data manipulations like arithmetic operations.

Materials and Methodology

(i) **Data Acquisition**
- **Meteorological Data:** Rainfall data from 1957 -2012 has been collected from Water Resource Department Rajasthan.
- **Satellite Data:** Landsat TM 5 available in UTM projection with resolution 50 m was acquired for this study. MODIS data was acquired from the Land Processes Distributed Active Archive Center (LP DAAC). According to the requirement, product MOD13Q1 was selected, available in UTM projection having resolution of 250 m.

(ii) **Study Area**
- The study area for drought analysis is Jodhpur district in Rajasthan state. The map of study area is shown in Figure: 1. Jodhpur district is one of the largest district of Rajasthan which is situated in Western region of the state with total geographical area of 22850 sq. Kilometers.
- The district stretches between 26.00˚ and 27.037˚ at North Latitude and between 72.55˚ and 73.52˚ at East Longitude. This district is situated at the height between 250-300 meters above sea level. Jodhpur district comes under arid zone of the Rajasthan state.
- The soil type is sandy and loamy. The vegetation of the district includes scrubs and thorny bushes.
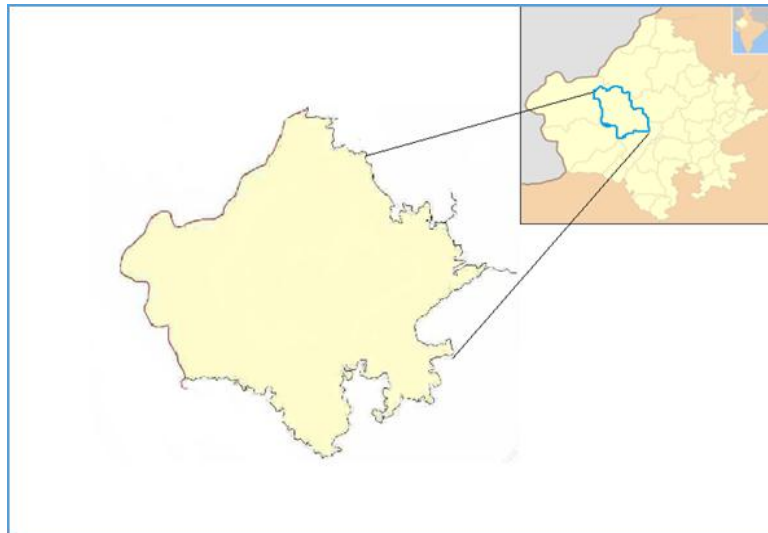- Rainy days are limited to maximum of 15 in a year and average rainfall is 302 mm.

Fig 1: Study Area of Jodhpur in Rajasthan State

(iii) **Methodology**

- **Preprocessing of Satellite Data:** With the help of ArcGIS software, shape file of Jodhpur district was created. UTM projection of raw satellite images was changed to WGS_1984.Using ArcGIS tool, study area was extracted from the raw data using extraction command.

- **Preprocessing of Rainfall Data:** Monthly rainfall records of 5 stations were selected from year 1957-2012.The selected stations are Bilara, Osian, Jodhpur city, Phalodi and Jaswant Sagar. Rainfall data was arranged from October to September.

- Satellite data i.e. Landsat/MODIS and Meteorological data were used for finding NDVI temporal, VCI and NDVI anomaly to observe agriculture drought. Meteorological data including monthly rainfall, which is then processed for finding out the SPI - 3months and SPI - 12 months and rainfall anomaly. It was also used to identify meteorological drought.

- A generalized Landuse/landcover map of Jodhpur was prepared. It was prepared using MODIS-TERRA 8 day composite surface reflectance images. The generalized map is shown in Figure 2. It presents seven major types of land surface namely sparsely vegetation, natural vegetation, grassland, urban and built up and open shrub land.

- To perform data processing and analysis of the collected data ArcGIS version 10 was used. ArcGIS software provides various methods to perform geospatial analysis and display the results in the form of maps. Geographical visualization of the results of analysis helps to identity the unusual patterns of drought occurrences.

- **Normalized Difference Vegetation Index:** The data extracted from MODIS for the years 2001, 2004, 2007, 2010 and 2012 is acquired from June to October in order to find NDVI in these particular months. For this purpose, two bands i.e. band 1 and band 2 were derived for study area. NDVI for MODIS was defined as (band 2-band 1)/ (band2+band1), where band 1 is NIR, reflectance band and band 2 is RED. For LANDSAT TM, TM band 3, that is RED and TM band 4 that is NIR are used to define NDVI as

$$(TM\ 4 - TM\ 3)\Big/(TM\ 4 + TM\ 3) \qquad (1)$$

- **Standardized Precipitation Index:** Monthly Rainfall records for 5 stations of Jodhpur district were selected on the condition of covering the area and availability of data. This data was used in finding out the average rainfall and SPI calculations. SPI index that was developed to quantify precipitation deficit at different timescales. The 3 months provide a seasonal estimation of precipitation, 6 months and 9 months SPI indicates medium term trends in precipitation patterns.

- **Vegetation Condition Index:** The health of the ground vegetation presented by VCI is measured in percent. The VCI values around 50% reflect fair vegetation conditions. Low VCI values over several consecutive time intervals points to drought development. Using equation 2, VCI is calculated to check the vegetation conditions.

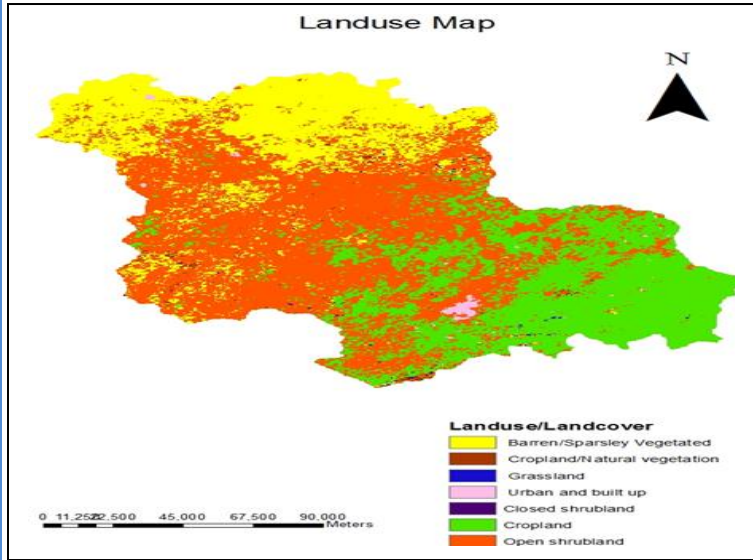$$VCI_j = \frac{NDVI_j - NDVI_{min}}{NDVI_{max} - NDVI_{min}} * 100 \qquad (2)$$
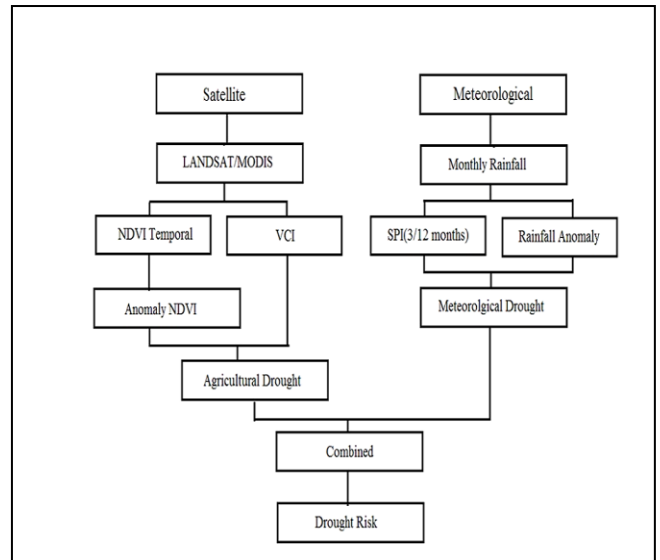

Fig 2: Land Use/Land Cover Map

Fig 3: The schematic representation of methodology

Results and Discussions

- The dominant perception of droughts and drought prone areas in Jodhpur is quite different than what can be supported by the available facts. It is believed that the western arid part has high rainfall variability and is severely affected drought prone region, east and southern parts experience higher rainfall and less variability.
- The analysis of 56 years of seasonal meteorological data shows that the rainfall variability is present in the study area. Maximum variation is shown in the year 2002-2003, where percentage annual deviation is of -53.6 and minimum variation is observed during year 2011-2012, where rainfall is increased by 55.3 percent. Also the coefficients of variation are tending to increase and decrease randomly.
- The rainfall of an area with high Coefficients of Variation tends to be characterized by more extremes that is more very dry and very wet years alternatively.
- In the present scenario from figure 4 it is observed that there is no uniformity in the variations and variations are increasing or decreasing very randomly. That comes to the declaration that there is no assurance when the drought will arise.
- Figure 5 shows the decrement in average annual rainfall that is calculated from the rainfall data of five rainfall stations. It depicts that rainfall has decreased randomly from which it can be concluded that drought conditions are increasing. This falls in meteorological drought category.
- Drought risk has been identified in Jodhpur district by interpolating SPI values over 57 years. For calculating the SPI, 3-month data namely July, August and September are chosen, as they are particularly monsoon months and crop growing seasonal months in Jodhpur.
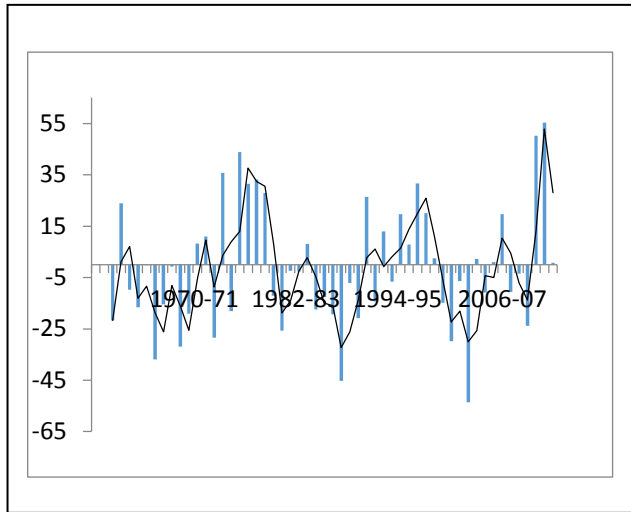
**Fig 4: Graph showing percentage annual Deviation in comparison
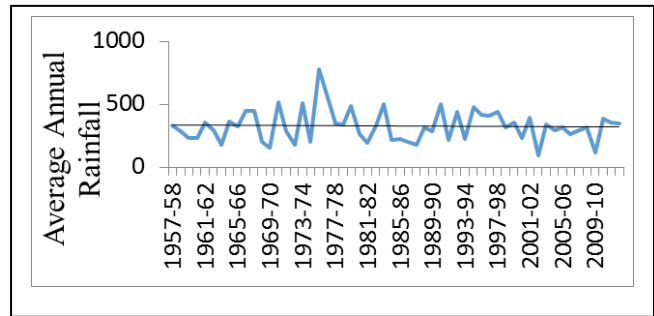With moving average from year 1960-2013**

Fig.5 - Graph showing average annual rainfall

- Figure 6 shows that there were many years that suffered through moderate drought, from past 2 consecutive years. A trend line was drawn on the SPI data, indicating that the value of SPI has decreasing. The results statistically indicates significant exponential correlation between the 3-month SPI for all stations. This correlation is stronger in the southern part due to the higher inter annual variability of monthly precipitation in this area.
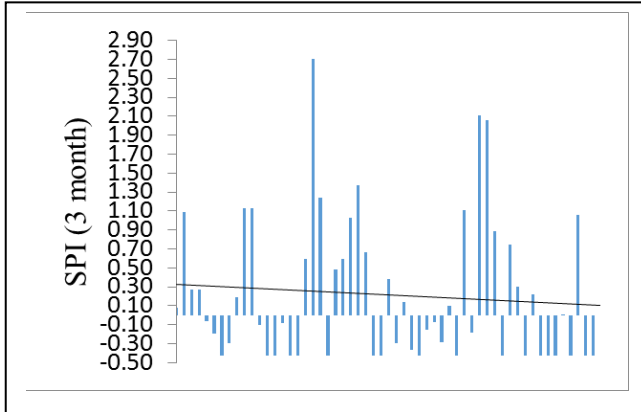

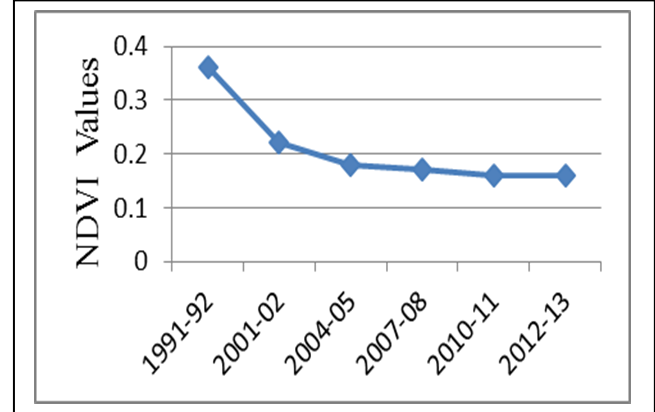**Fig 6: Detailed SPI (3 month) in the District**

Fig 7: Average Seasonal NDVI

- NDVI itself does not reflect drought or non-drought conditions, but the severity of a drought can be defined as NDVI deviation from its long-term mean. Value of the NDVI exists between +1 and -1.Trends in NDVI is identified by means of nonparametric correlation coefficients using annual NDVI values and one series of time in years.
- Also, when the NDVI maps for the year 2001 and 2012 were compared as shown in the Figure 8 and Figure 9 respectively, it was observed that desert is increasing. It was observed that although the NDVI values were not exactly increasing, but medium NDVI values indicated that medium vegetation were still present. It also showed that some proportion of desert area earlier has turned into green now, which may be possible due to the presence of new techniques, or canal irrigation and various new agriculture techniques.
- From Figure 7, average seasonal NDVI, it was observed that the vegetation has decreased by years. There was a difference of 0.06 between the average NDVI of year 1991 and 2012.
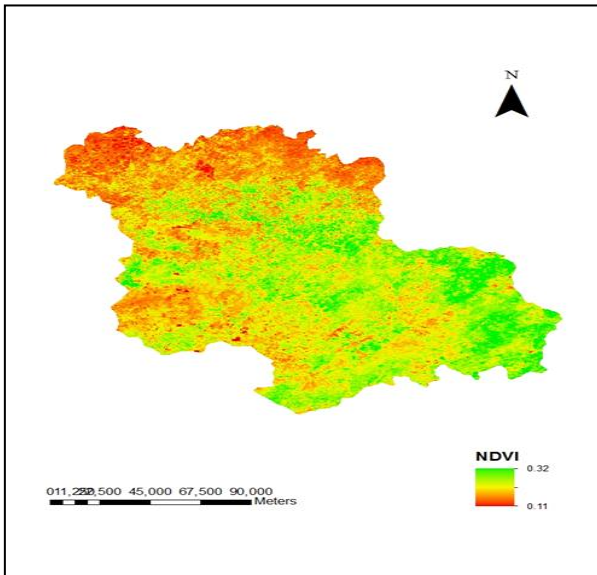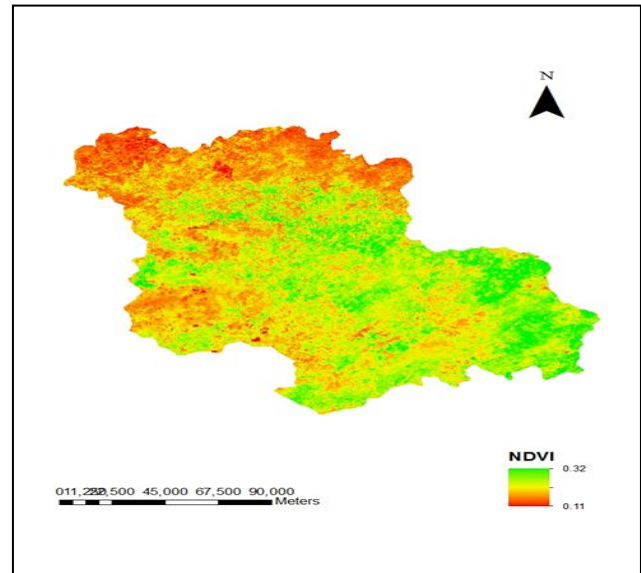
Fig 8: NDVI for year 2001 in the month of August

Fig 9: NDVI for year 2012 in the month of August

- The condition of the ground vegetation presented by VCI was measured in percent, where 50% is fair reflect and 50 to 100% represents normal or optimal conditions. VCI values were calculated by using the NDVI values. By comparing these values it was observed that vegetation condition in year 2001 and 2007 were normal, but in other years it was quite dry.

- A negative trend in the temporal evolution of vegetation was observed while studying NDVI and also during the drought years like 2012, vegetation health was diminishing. These results do not seem to be a consequence of inhomogeneity or artificial trends in the series, which have been calibrated. Abandoned fields present the greatest NDVI increase, followed by shrub cover areas and forests. The smallest increase corresponds to areas with no vegetation or very less vegetation, including the shrub areas and pastures. The relationship between rainfall and NDVI seems to confirm it. NDVI is related not only to recent rainfall events, but also to SPI as shown in table 1.

- Also NDVI might be related only to recent SPI results, which is an important parameter for point-based drought assessment approach. These results indicate that NDVI is a real time drought assessment approach. SPI is usually region-specific and time-dependent, thus better used during plant growing seasons.

- After observing the results, it can be stated that Jodhpur district is basically a water limiting area, which is therefore more prone to drought and is susceptible to drought more often. Also SPI can be used as indicator for regional vegetation status and water prone, which is observed while comparing SPI with annual rainfall. Combination of drought risk from meteorological and agricultural drought risk using rainfall data, SPI and NDVI respectively, proved that the Jodhpur district faces both types of drought risk. Also VCI indicates the diminishing or failing growth of crops by showing the vegetation health. Since results shows that the risk area can be assessed by various data sources and can be managed in the better way by using those resources.

Table 1
Comparison of Drought Indices

Year	SPI	NDVI (Avg.)	VCI (in %)
2012	-0.43	0.16	38
2010	1.05	0.16	47.37
2007	-0.43	0.17	56.84
2004	-0.43	0.18	47.69
2001	0.74	0.22	51.43

1991	-0.07	0.22	40.43

- The results obtained in the present work coincide with the results obtained globally in areas with important climatic and environmental limitations, confirming that high latitudes, like one of Jodhpur are being affected by vegetation increase. These results point out the important role of human management in the process of drought management.

Conclusion

The present work has been found to be successful in assessment of drought in the Jodhpur District. Different drought indices have been estimated using relevant data collected from different sources. Spatial and non-spatial data have been used to assess the drought indices using GIS. Rainfall data from period of 1957-2012 is used to calculate SPI and for NDVI, satellite images were downloaded for further processing for years 1991, 2001, 2004, 2007, 2010 and 2012. In last 20 years both SPI and NDVI displayed the same results, as they have shown drought in particular periods in year 1991, 2004, 2010 and 2012.

Rainfall and SPI are relative to meteorological droughts and tend to indicate a realistic severity and persistence for drought events. But meteorological drought indices are inadequate for the reliable assessment of drought. Also through NDVI the comparative study could be done for various years and for various seasons. Since, the comparative study of the vegetation condition makes the clear picture of vegetation change in various years or season, thus can be helpful in drought assessment. VCI is complementary index to the NDVI as, VCI gives the vegetation health, where vegetation is less or more comparing on the VCI percentage, can be helpful in declaring drought.

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