Drought risk assessment using GIS and remote sensing: A case study of District Khushab, Pakistan

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Abstract: Drought is the most complex but least understood of all natural hazards. It is broadly defined as "sever water shortage". In recent years, Geographic Information System (GIS) and Remote Sensing (RS) have played a key role in studying different types if hazards either natural or man-made. This study stresses upon the use of RS and GIS in the field of Drought Risk assessment. In this study an effort has been made to derive spatial-temporal drought risk areas facing agriculture as well as meteorological drought by use of temporal images from Landsat ETM based Normalize Difference Vegetation Index (NDVI) (2003, 2009 and 2015) and meteorological based Standardized Precipitation Index (SPI). Correlation analysis was performed between NDVI, SPI, and rainfall anomaly. SPI values were interpolated to get the spatial pattern of meteorological based drought. NDVI threshold was identified to get the agriculture drought risk. Similarly rainfall and NDVI were correlated and a spatial temporal drought risk maps were generated. Study area District Khushab was divided into three zones including no drought, slight drought and moderate drought. The results revealed that 41.43% are under no drought, 28.36% area under slight drought and 30.21% is the area under moderate drought. It was evident from the study that southern part of District Khushab was a rainfall deficit area with scarce vegetation and hence was the area with the highest drought prevalence. The results obtained can be helpful for drought management plans and will help in revealing true drought situation in the area.

Keywords: Drought, GIS and Remote Sensing, Vegetation Index, Precipitation Index

Introduction

Drought is a hazardous and costly natural phenomena with slow on-set that has dreadful impacts on economy, social life and environment of a country or region. The fact that it is slow on-set and is not quite distinguishable in when is it started or when ended makes the phenomena difficult to study (Hammouri and Naqa, 2007). Drought appears when rainfall in a region is less than statistical multi-year average for that region over an extended time period (Mala *et al*., 2014). It is a normal climatic event but its effect varies from region to region. There are four types of drought namely; meteorological drought, agricultural drought, hydrological drought and socio economic drought (Rathore, 2009). Meteorological drought is deficiency of rainfall which can be observed immediately (Panu and Sharma, 2002). Agricultural drought is measured in terms of deficiency in soil moisture, rainfall, ground water and reduction in crop yield (Wilhite, 2000). Hyrological drought is deficiency in water availability in surface and subsurface water reservoirs. While, socio-economic drought is final phase of drought that is caused by prolong shortage in agricultural production and food thus affecting overall economy (Linsley *et al*., 1975). It is expected that drought will get worse with the overall climate change scenario and the drought affected areas are also expected to increase spatially. But, like all other natural hazards, drought impacts can be mitigated through early detection (Sruthi and Aslam, 2015). Remote sensing and GIS plays an important role in detecting, assessing and managing droughts as they offer up to date information on spatial and temporal scales (Brian *et al*., 2012). To assess drought conditions in an area, different drought indices are used. Major drought indices use parameters like rainfall, vegetation and land surface temperature, soil moisture etc. (Mala *et al*., 2014). The main objective of this study is to assess the drought severity in District Khushab by using Remote Sensing and GIS. While sub objectives are; computation of suitable drought indices in the region, correlations of various drought indices for drought monitoring, spatial and temporal analysis of overall drought patterns in the Khushab District.

Study Area

Khushab District is located in Punjab, a province of Pakistan. Its capital is Jauharabad. It is situated at 32.3054° N latitude and 72.3482° E longitude. Its total area is 6511 sq. km. It is comprised of four tehsils; Noorpur Thal, Khushab, Naushehra and Quaidabad with a population of 1.05 million. Climate in this area ranges from arid to extremely arid.

Datasets used

Meteorological data

The meteorological data was obtained from Pakistan Meteorological Department (PMD) for Chakwal and Sargodha stations because there was no MET center in the Khushab district. The meteorological data relating to monthly rainfall ranges from 2000 to 2015 for Sargodha and 2006 to 2015 for Chakwal. Interpolation method was used to calculate rainfall data, rainfall anomaly and standardized precipitation index. Both of them are indices used to assess drought severity in the study area District Khushab.

Remote sensing data

For the analysis of drought severity, the Landsat (ETM) images (path 150 row 37, path 150 row 38) were obtained from USGS, with spatial resolution 30m and month march for the years 2003, 2009 and 2015.

Fig. 1 Geographical location of study area Khushab

Methodology

To get the required objectives, the following methodology was used for data Processing and analysis as out listed in the flow chart given below. Image processing was necessary to calculate Normalized Difference Vegetation Index (NDVI). The anomalies for rainfall and NDVI were calculated to find out the trend change over years.

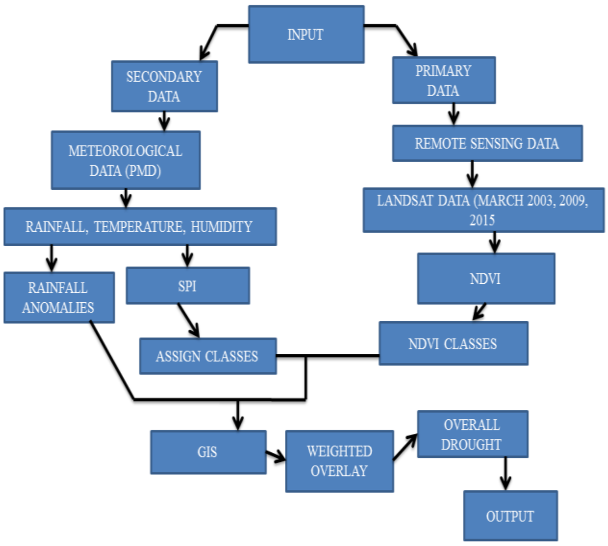

Fig. 2 Flow diagram of research methodology.

Results and Discussions

NDVI and vegetation classes

NDVI for the years 2003, 2009 and 2015 was calculated using ArcMap 10.2. On the basis of this NDVI, vegetation cover classes were derived and the trend in their shift was also identified.

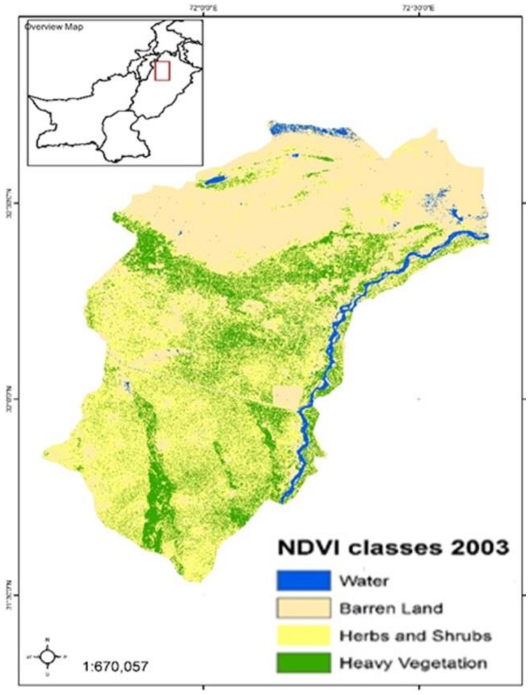

Fig. 3a Vegetation classes on the basis of NDVI for year 2003

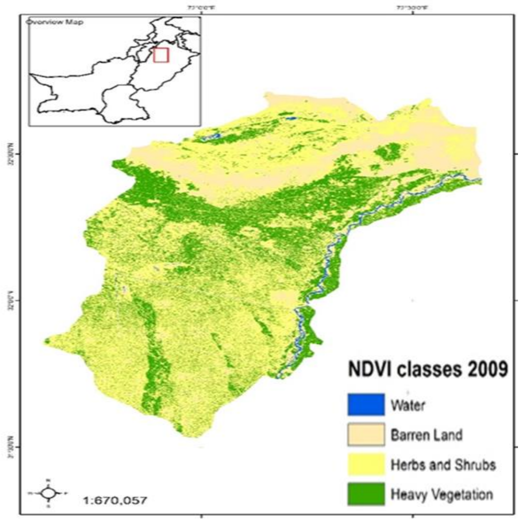

Fig. 3b Vegetation classes on the basis of NDVI for year 2009

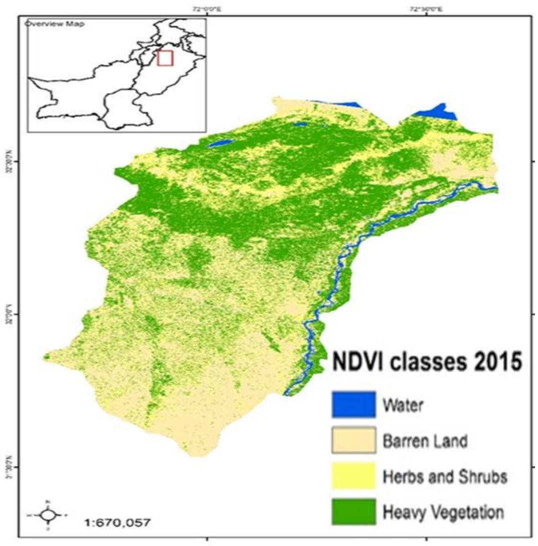

Fig. 3c Vegetation classes on the basis of NDVI for year 2015

A temporal analysis of these images (Fig 3a, 3b, 3c) shows that vegetation has tended to shift in the upper parts of the region over the years leaving the lower region barren. In 2003, maximum vegetation was in the lower i.e. southern part of the Khushab district and northern areas of Khushab were mostly barren. But over the years this trend changed. In 2009, more of the northern part of the study area was covered with vegetation. While in 2015 maximum heavy vegetation was in northern part of the area leaving southern part of Khushab barren. This trend is also verified by the rainfall data we received. Since over the years more rainfall was recorded in northern areas of Khushab than the southern areas thus less vegetation was supported by this area.
The areas for these classes were also calculated (in square kilometer) as shown in table 1 and figure 4.

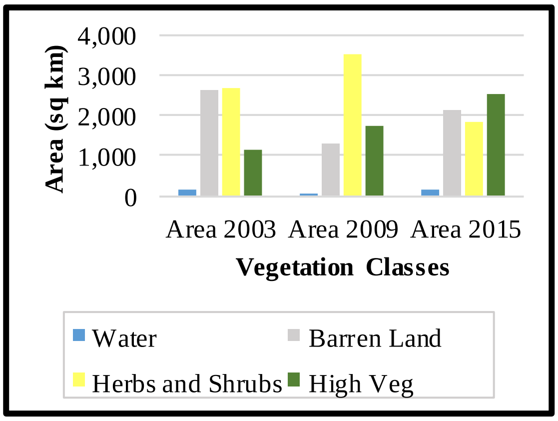

Fig. 4 Change in the areas of vegetation classes over the years

From the figures received, it is evident that area calculated for barren land was largest in 2003. It was due to the fact that whole of the country faced drought from the period of 1998-2003 which is considered to be worst in 50 years in history of this region. In the year 2009, herbs and shrubs covered largest area i.e. 53% of the total area which shows that vegetation had started to grow back. While in 2015, heavy vegetation increased in the area (38.2% of the total area) but only in northern part leaving southern part of the study area bare which support our assessment of drought severity in southern part.

Spatial Patterns of Rainfall Anomalies

The rainfall anomalies were calculated to estimate the change in seasonal precipitation for the years 2003 and 2015. The negative anomalies denote that precipitation was less than the average seasonal rainfall for a particular place (as shown in figure 5).

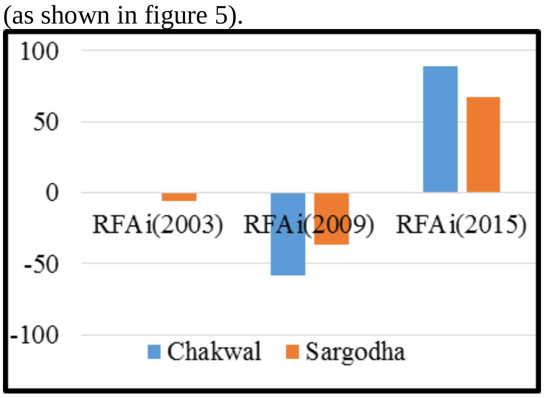

Fig. 5 Graphical representation of rainfall anomalies.

In 2003 and 2009 negative anomalies were observed. In 2003 that there were negative anomalies up to -6.13% while in 2009 the values were as low as -58% and -36.35% for Chakwal and Sargodha station respectively because of low rainfall was received in 2009. While in 2015, rainfall amounts were considerably higher hence positive anomalies were obtained i.e. 89% and 67.35% for stations in Chakwal and Sargodha respectively. Areas having maximum negative anomalies are the areas receiving minimum rainfall and are also the areas that are more prone to drought. Anomalies calculated for the surrounding districts were then interpolated by using the inverse weighted distance algorithm in ArcGIS to calculate the rainfall anomalies spatial distribution in the target district for the 2003, 2009 and 2015. Rainfall pattern for the year 2015 is shown in figure 6.

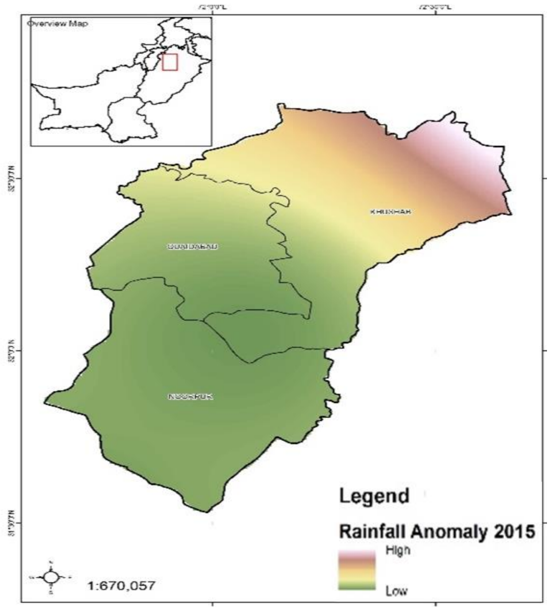

Fig. 6 Seasonal rainfall anomalies for years 2015.

SPI and Drought

Drought risk was identified using SPI values over 15 years. SPI during selected years of 2003, 2009 and 2015 have been presented to show the pattern of SPI during these years as other relevant data was only for these years.

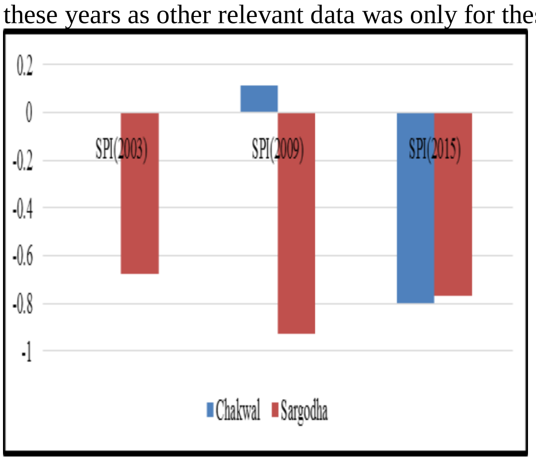

Fig. 7 Graphical representation of SPI values.

Calculated six month SPI values for years 2003 and 2009 were found to be low in southern part of the study area especially in 2009 where values dropped to -0.9 which indicates moderate drought. While in 2015, SPI values were as low as -0.80 for rainfall station in Chakwal. Hence

SPI helped in identifying the medium term trend in precipitation and hence the years in which Khushab was more prone to drought risk.

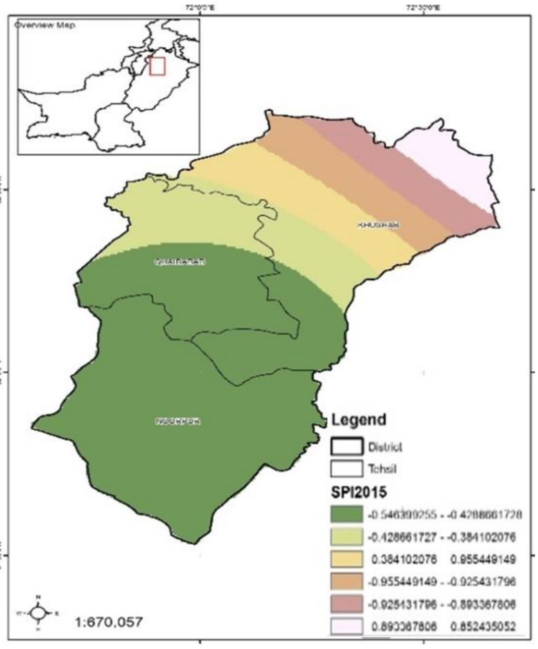

Fig. 8c Six month SPI for years 2015.

Drought characterization

Drought impact was assessed using NDVI and SPI values by linear combination weighted system. Both NDVI and SPI for all three years were separately reclassified and weights were assigned to the classes. The weights were assigned to the each class in the range of 1-6. To the highest negative value of SPI weight of 6 was assigned while for highest vegetation class in NDVI weight of 1 was assigned. Then, drought severity was assessed for the years 2003, 2009 and 2015. It was assessed that in Khushab area, as it is included in Potohar region and thus have sufficient enough rainfall, only 3 drought categories exist i.e. 'no drought', 'slight drought' and 'moderate drought'. Figures 9a,9b,9c show the distribution of these classes for the years 2003, 2009 and 2015.

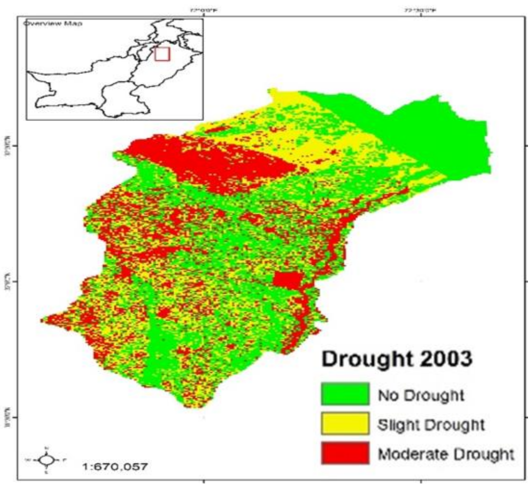

Fig. 9a Drought severity in years 2003.

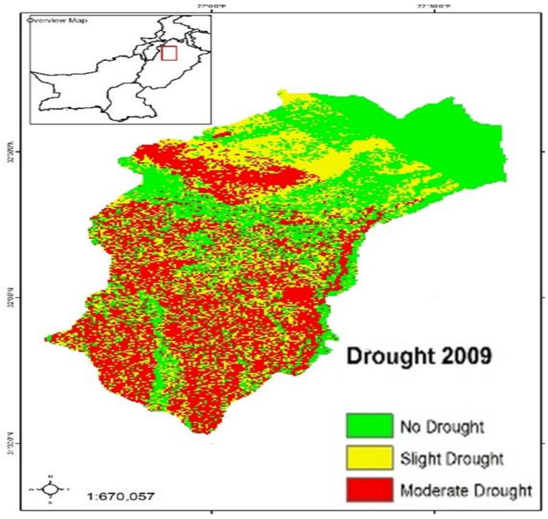

Fig. 9b Drought severity in years 2009.

Table 2 Percent area under different drought conditions

Class	Area (sq km)	Percentage
No Drought	2743.24	41.44
Slight Drought	1877.51	28.36
Moderate Drought	1999.32	30.20

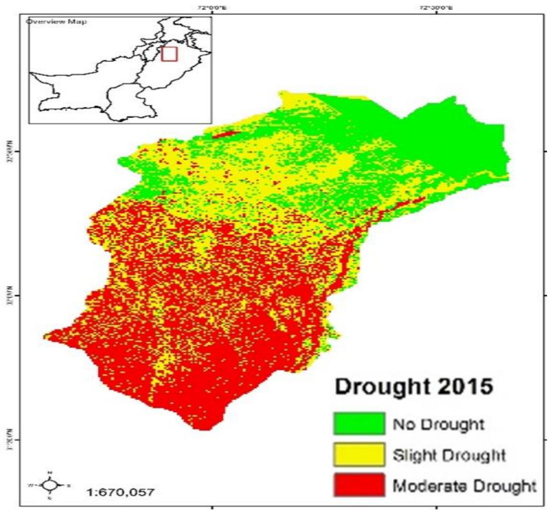

Fig. 9c Drought severity in years 2015.

These images clearly give a scenario of drought prevalence and its trend in the area. In 2003, drought was lesser in extent than in 2009 and 2015. But in 2015, drought severity has increased in the southern part of the study area.

Overall Drought Impact

Final drought impact map was obtained by driving average from drought severity maps for all the three years. According to the map, (figure 10) some areas of the study area are free from drought while others are under different kind of drought. Table 2 and figure 11 show the areas and their percentages affected by different drought severity classes.

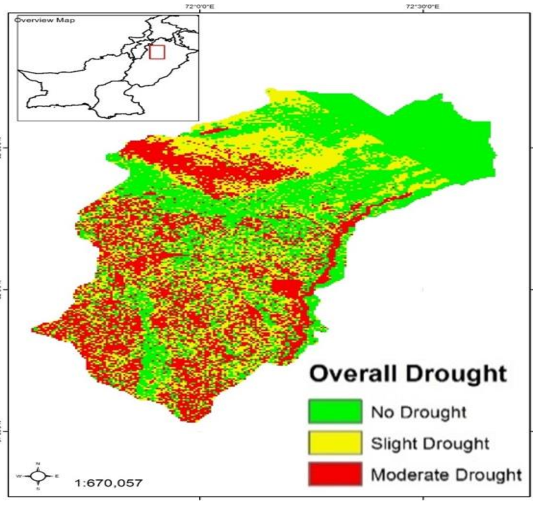

Fig. 10 Overall drought severity in District Khushab.

Almost 42% of the area is not facing any type of drought as Khushab district is located in Potohar region so it does receive sufficient rainfall especially in northern part of Khushab. But the southern part is a rainfall deficit area hence slight drought and moderate drought was seen in these areas especially. Nearly 59% of the area is at risk of drought (slight and moderate drought combined); therefore a stress has to be given on these areas while preparing drought management plans.

Conclusion

Due to climate change the weather patterns are changing on daily basis, drought situation is very common in Pakistan due to less rainfall and water scarcity situation. From this study we can conclude that there is rainfall variability present in the study area. The vegetation of the area is totally dependent on the rainfall. This correlation defines rainfall as a basic and major factor in prone to drought, arid area. Since strong positive correlation exists between NDVI and rainfall in water scarce area, this place is more vulnerable to drought situation. NDVI based vegetation classes showed a shift of vegetation to the northern parts of Khushab District. Calculated values of SPI and rainfall anomalies were negative in the years and in the areas where vegetation was less i.e. southern part of the study area. Thus, these areas were identified to be rainfall deficit areas. Final drought map shows that 30% of the area faces moderate drought, 28% slight drought while nearly 42% faces no drought situation. Drought prevalence and severity is more in southern part of Khushab District than the northern part. Most of the northern part is not under any type of drought. Thus an overall outcome of this study presents that risk areas can be assessed appropriately by integration of various data sources and thereby management plans can be prepared to deal with the hazard.

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