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Drought Risk Assessment in the Khushab Region of Pakistan Using Satellite Remote Sensing and Geospatial Methods

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Abstract: Drought is a harmful and slow natural phenomenon that has significant effects on the economy, social life, agriculture and environment of the country. Due to its slow process it is difficult to study this phenomenon. Remote Sensing and GIS tools play a key role in studying different hazards like droughts. The main objective of the study was to investigate drought risk by using GIS and Remote Sensing techniques in district Khushab, Pakistan. Landsat ETM images for the year 2003, 2009 and 2015 were utilized for spatial and temporal analysis of agricultural and meteorological drought. Normalized difference vegetation index (NDVI) Standardized Precipitation Index (SPI) and rainfall anomaly indices were calculated to identify the drought prone areas in the study area. To monitor meteorological drought SPI values were used and NDVI was calculated for agricultural drought. These indices were integrated to compute the spatial and temporal drought maps. Three zones; no drought, slight drought and moderate drought were identified. Final drought map shows that 30.21% of the area faces moderate drought, 28.36% faces slight drought while nearly 41.3% faces no drought situation. Drought prevalence and severity is present more in the 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 shows 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.

Keywords: Drought, Pakistan, spatial analysis, NDVI, rainfall.

Introduction

Drought is a hazardous and slow natural phenomenon that has dreadful impacts on economy, social life and the environment of a country or region. Due to the fact that this phenomena is slow in nature, it is difficult to study and distinguish the types of droughts (Hammouri and El-Naqa, 2007). Drought is associated with low rainfall (Rathore, 2005). It is a normal climatic event but its effect varies from region to region. Droughts are differentiated into following classes (1). Meteorological drought, (2). hydrological drought, (3). socio economic drought, and (4). agricultural drought (Panu and Sharma, 2002). Meteorological drought is measured in terms of the deficiency of rainfall which can be observed over a longer period (Wilhite, 2000). Agricultural drought is measured in terms of deficiency in soil moisture, rainfall, ground water and reduction in crop yield (Chopra, 2006). Hydrological drought is measured by the deficiency in water availability in surface and subsurface water reservoirs. Socio-economic drought is final phase of drought that is caused by prolonged shortage in agricultural production and food, thus affecting overall economy (Wardlow et al., 2012; Mala et al., 2014).

It is expected that droughts will get worse with the overall climate change scenario and the areas affected by drought are also expected to increase spatially (Dodamani et al., 2015). But, like all other natural hazards, impacts of drought can be mitigated through early detection (Chandola et al., 2009).

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 (Nasir et al., 2002). To assess drought conditions in an area, different drought indices are used. Major drought indices employ parameters like rainfall, vegetation and land surface temperature and soil moisture (Nasir et al., 2006).

The economy of a country like Pakistan, which is largely based on agriculture, can be affected by droughts especially in the rain-fed areas. Pakistan has inadequate surface and subsurface water resources in the rain-fed areas, where agriculture only relies on rainfall. Due to climatic variation, the rainfall it receives annually is not sufficient for agricultural requirements in the rain-fed regions (Sruthi and Aslam, 2015, Wardlow et al., 2012).

Due to this, rain-fed areas are facing arid and semi-arid conditions. Droughts become severe in zones where rainfall is scarce. Such zones include many parts of Potohar region, Balochistan, southern Sindh, and southeastern Punjab (Prathumchai et al., 2001).

The main objective of this study was to assess the drought severity in district Khushab by using Remote

Sensing and GIS, while sub-objectives were to compute the 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.

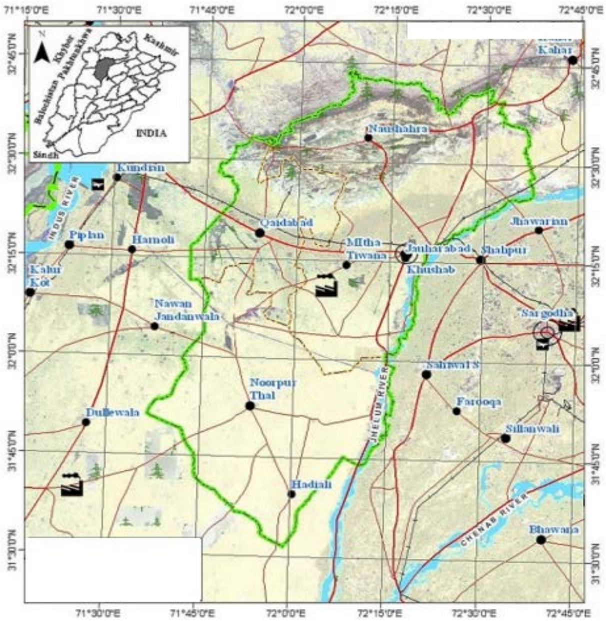

Fig. 1. Geographical location of study area.

Study Area

Khushab district is located in Punjab, a province of Pakistan. It is located at 32.3054° N latitude and 72.3482° E longitude (Fig. 1). Its total area is 6511 sq. km comprising of four tehsils; Noorpur Thal, Khushab, Naushehra and Quaidabad with a population of 1.05 million. The climate in this area ranges from arid to extremely arid. (Fig. 1). Major crops in the Khushab district are rice, wheat, sugarcane, cotton, jowar and bajra. The statistical data of major growing crops in the study area for the period 2000-2009 is shown in Table 1.

Materials and Methods

Meteorological Data

The rainfall historical values were provided by the National Meteor Service (PMD) for Chakwal, Sargodha and Bhakar stations because there was no meteorology station in the Khushab district. Monthly average between 2000-2015 for Sargodha, during 2010-2015 for Bhakar and between 2006-2015 for Chakwal stations were acquired. Data were prepared on annual average basis for all three stations. Interpolation method was used to calculate annual rainfall data, rainfall anomaly (SPI) and standardized precipitation index (RFAi). Rainfall anomaly and standardized precipitation index were used to detect the severity of drought in its spatial and temporal extent in the study area.

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 website, with spatial resolution of 30m for the years 2003, 2009 and 2015 respectively (Table 2).

Meteorological data were used to calculate rainfall anomaly (SPI) and Standardized Precipitation Index (RFAi). Remote sensing data were used to calculate the vegetation index. Interpolation method was used to visualize the spatial variability of SPI, RFAi and vegetation index in the study area. Drought severity areas were calculated. The computed areas are a weighted linear combination for all input factors. The drought condition influences each factor (McKee et al., 1993). Temporally 2003, 2009, 2015 droughts were assessed using weighting linear combinations (Table 3).

Interpolation method was used to visualize the droughts for the year 2003, 2009 and 2015 separately. Final drought risk map was generated to visualize the spatial and temporal variation from the period 2003-2015 in the study area (Fig. 2).

The near infrared band in Landsat dataset is band 4 whereas the red band is at 3. The NDVI was calculated for each satellite based dataset in order to analyze the health of vegetation according to the following formula:

$$\mathbf{NDVI = (\lambda\ IR - \lambda\ R) / (\lambda\ IR + \lambda\ R)}$$

Table 1. Statistical data of major growing crops.

Crops	Production in "000" Hectares								
	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09
Wheat	71.6	65.6	71.2	72.4	86.6	85.4	86.2	85.4	83.3
Rice	14.2	15	15.8	15.4	17	17	16.6	17.8	21.5
Maize	0.7	1.1	1	1	1.1	1.1	0.8	0.9	0.9
Bajra	7.1	8.3	8.6	9.9	7.7	6.8	5.6	7.7	8.3
Jowar	17.2	17.5	18.9	17.5	17	11.3	11.5	12.4	12.1
Barley	1	1.1	1.2	1.2	1	1	1	1.1	1
Sugarcane	8.7	9.3	9.3	8.9	8.9	8.5	9.7	8.5	6.9
Cotton	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

(Source: Government of Pakistan, Statistics Division Federal Bureau of Statistics, Economic Wing, Islamabad)

Table 2. Satellite images and sensors specifications with acquisition dates.

No. of image	Satellite	Sensor	Spectral resolution	Spatial resolution	Date of acquisition
1	LANDSAT 7	ETM+	4 bands	30m	19th March, 2003
2	LANDSAT 5	TM	4 bands	30m	11th March, 2009
3	LANDSAT 8	OLI	4 bands	30m	30thMarch, 2015

Where

λ IR **=** Reflectance in near infrared band

λ R **=** Reflectance in Red band

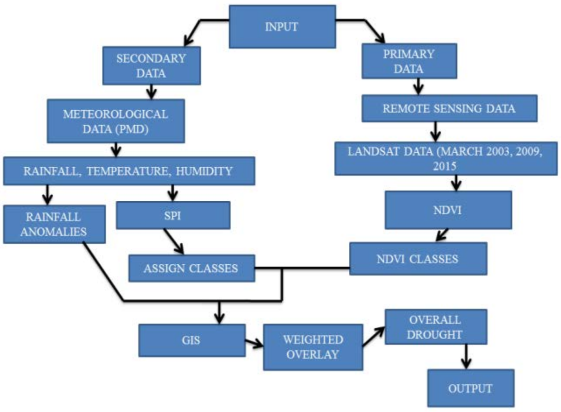

Fig. 2 Flow diagram of Research Methodology.

Rainfall Anomaly

Rainfall anomaly has been computed using the equation proposed from 2003-2015 for the months of January-June to indicate the meteorological drought. Rainfall anomaly was obtained as:

$$\mathbf{RFA\ i = [(RF\ i - RF\ a) / (RF\ a)] * 100}$$

Where,

RFA i is anomaly of rainfall;

RF i is seasonal rainfall for given year

RF a is mean seasonal rainfall

Standardized Precipitation Index

The SPI Index was calculated to quantify the deficiency of rainfall at different time scales.

$$\mathbf{Zscore = (X - Pa) / SD}$$

Where,
Zscore is SPI value;
X is monthly precipitation;
Pa is half yearly mean rainfall

SPI values obtained were given classes according to U.S National Drought Mitigation Center. Category D0 means no drought and its values vary from -0.5 and above, category D1 abnormally dry values vary from -0.5 to –0.7, category D2 moderate drought values from -0.8 to -1.2, and category D3 values vary from -1.3 to -1.5. On the basis of these categories our study area lies only in no drought to moderate drought zones and SPI maps were interpolated using IDW (Inverse Distance Weighted) method in ArcMap 10.2.

Weighted Overlay Linear Combination

Drought severity areas were calculated using weighted overlay linear combination method. At temporal scale 2003, 2009 and 2015 droughts were assessed. Weights were assigned to the values depending upon their importance in Table 2. For the weights, the equation that was used is given below.

$$Wt = WiDi \ldots. WnDn$$

Where

Wt = Total weight,

Wi = Weight value in each parameter,

Di = Score value in each parameter.

The aggregate score from a linear combination factor model was computed from the equation mentioned above and was reclassified into three drought classes i.e. no drought, slight drought and moderate drought.

Results and Discussion

NDVI and Vegetation Classes

Table 3. NDVI and SPI values and their assigned weights in weighted linear combination method.

NDVI Classes	Weights Assigned	SPI Classes	Weights Assigned
-0.2 – 0.007	6	1	1
0.007 – 0.1	5	2	2
0.1 – 0.1	4	3	3
0.1 – 0.2	3	4	4
0.2 – 0.3	2	5	5
0.3 - 0.5	1	6	6

Remote Sensing data for the years 2003, 2009 and 2015 were used to calculate normalized difference vegetation index (NDVI) using ERDAS IMAGINE 2011 and ArcMap 10.2.

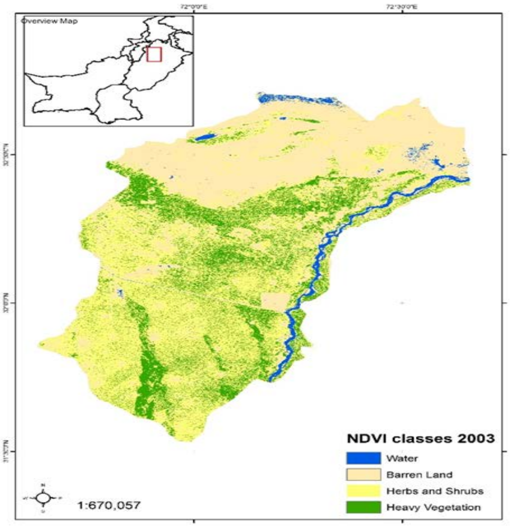

Fig. 3a Vegetation classes on the basis of NDVI for 2003.

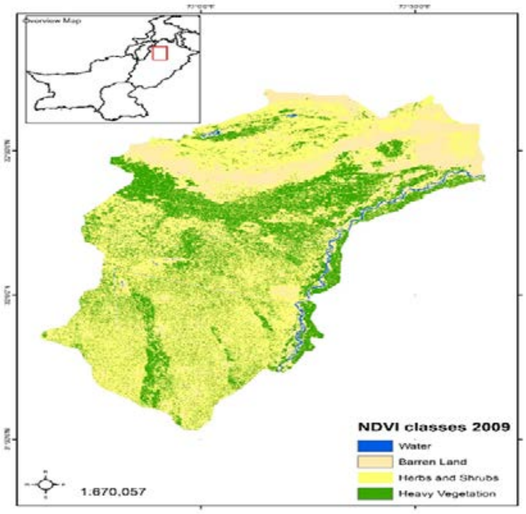

Fig. 3b vegetation classes on the basis of NDVI for 2009.

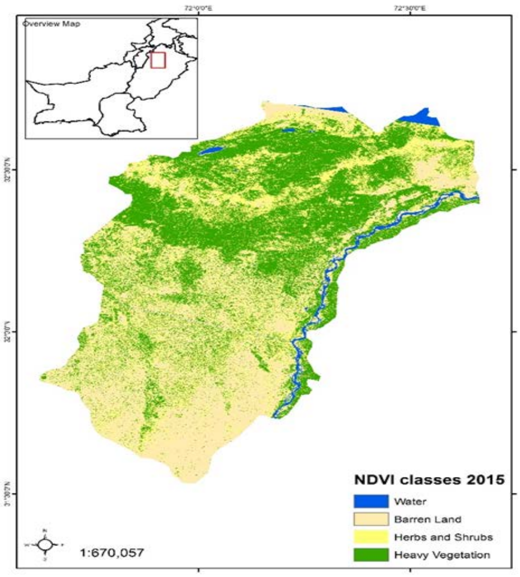

Fig. 3c Vegetation classes on the basis of NDVI for 2015.

On the basis of this NDVI, vegetation cover classes were derived and the spatial and temporal variations were also identified. Temporal analysis of the remote sensing data (Fig 3a, b, c) shows that vegetation has tended to shift in the upper parts of the region over the years, leaving the lower region barren. In the year 2003, maximum vegetation was in the lower (southern) part of the Khushab district while the northern areas of Khushab were mostly barren. But over the years this trend has changed. In 2009, more parts of the northern side of the study area were covered with vegetation. While in 2015, maximum heavy vegetation was seen in the northern part of the area leaving southern part of Khushab barren. This trend is also verified by the rainfall data. 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 sq. km (Fig. 4). From the figures received, it is evident that the area calculated for barren land was largest in 2003. It was because the whole country faced drought from the period 1998-2003 which is considered to be the worst drought in 50 years in the history of this region. In the year 2009, herbs and shrubs covered the largest area (i.e. 53%) of which shows that vegetation had started to grow. While in 2015, heavy vegetation increased in the area (38.2% of the total area) only in northern part, leaving southern part of the study area bare, which supports the assessment of drought severity experienced by the southern part.

Spatial Patterns of Rainfall Anomalies

Annual average rainfall data were used to calculate the SPI and RFAi. Average rainfall recorded at Chakwal station from 2006 to 2015 was 52.14 mm, at Sargodha station, it was 43.19 mm and at Bhakar station it was 32.48 mm. The maximum annual rainfall was recorded at Chakwal station in 2007, which was 83 mm while minimum annual average rainfall was recorded at Sargodha station which was 16.3 mm in 2009 (Fig. 5).

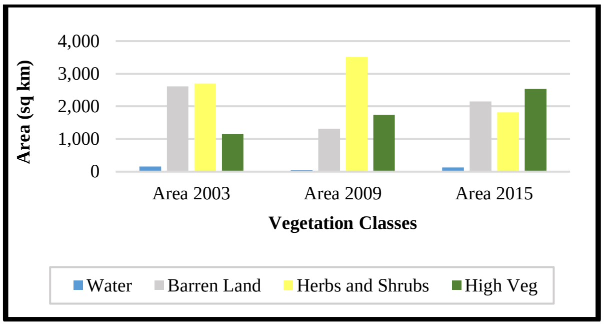

Fig. 4 Change in areas of vegetation classes over the years.

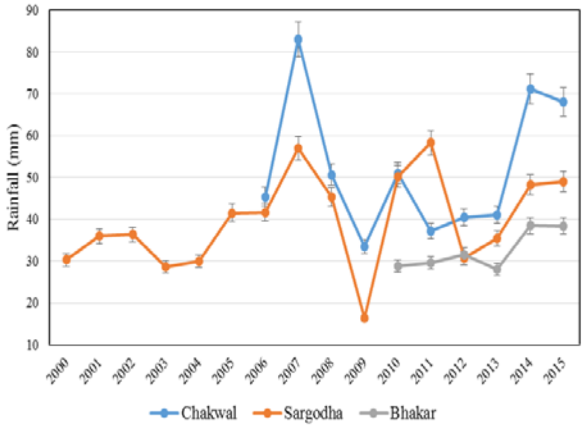

Fig. 5 Annual average rainfall pattern.

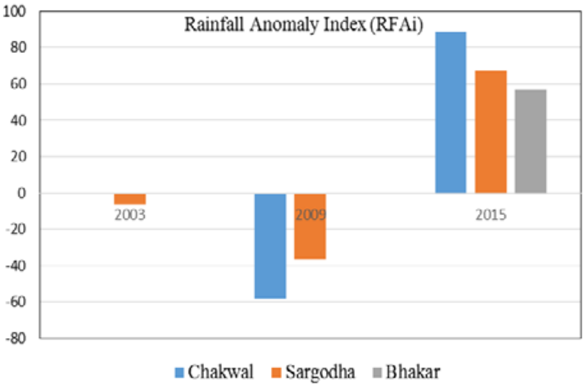

Fig. 6 Graphical representation of rainfall anomalies.

The rainfall anomalies were calculated to estimate the change in seasonal precipitation for the years 2003, 2006 and 2015. The negative anomalies indicate that precipitation was less than the average seasonal rainfall for a particular place (Fig. 6).

In 2003 and 2009 negative anomalies were observed. In 2003 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 stations respectively because of low rainfall in 2009. While in 2015, rainfall amounts were considerably higher resulting in positive anomalies i.e. 89%, 67.35% and 56% for Chakwal, Sargodha and Bhakar stations respectively.

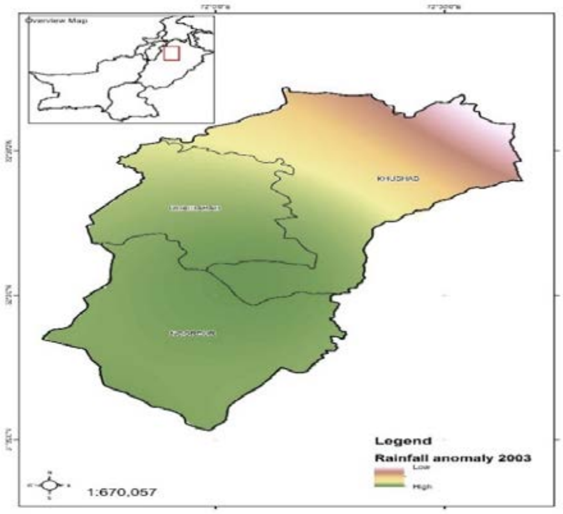

Fig. 7a Seasonal rainfall anomalies for the year 2003.

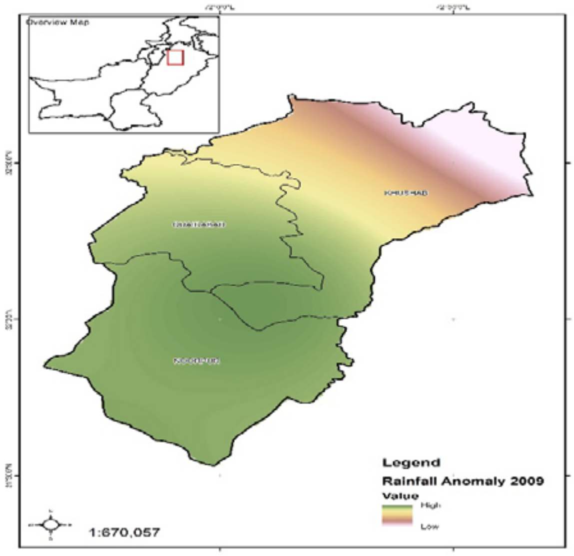

Fig. 7b Seasonal rainfall anomalies for the year 2009.

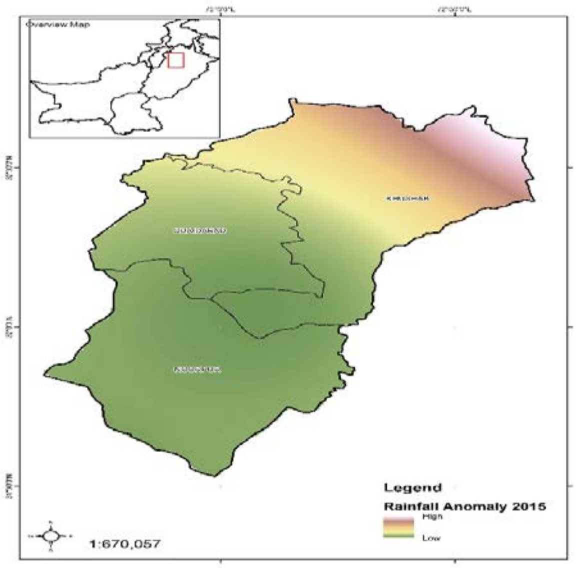

Fig. 7c Seasonal rainfall anomalies for the year 2015.

Areas having maximum negative anomalies are the areas which receive and minimum rainfall and 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 (Fig. 7. a, b, c) for the 3 selected years.

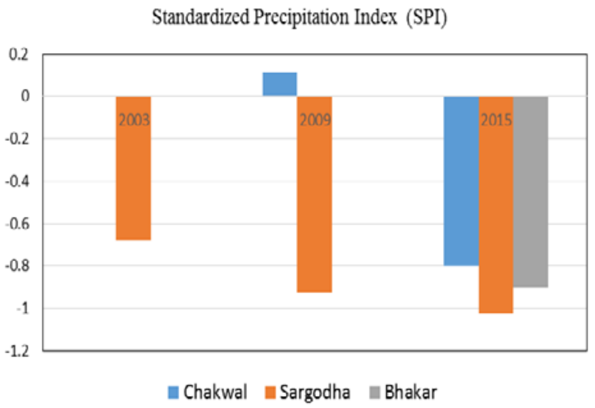

Fig. 8 Graphical representation of SPI values.

SPI and Drought

Drought risk was identified using SPI for 15 years. SPI during 2003, 2009 and 2015 were identified as other relevant data were only for these years. The calculated SPI values for six months for the 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. SPI was calculated for Bhakar station in 2015 and it was -0.9.

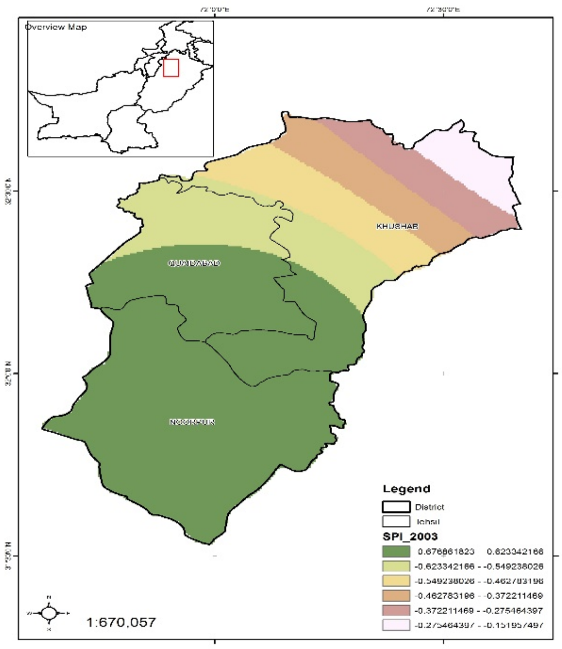

Fig. 9a Six month SPI for year 2003.

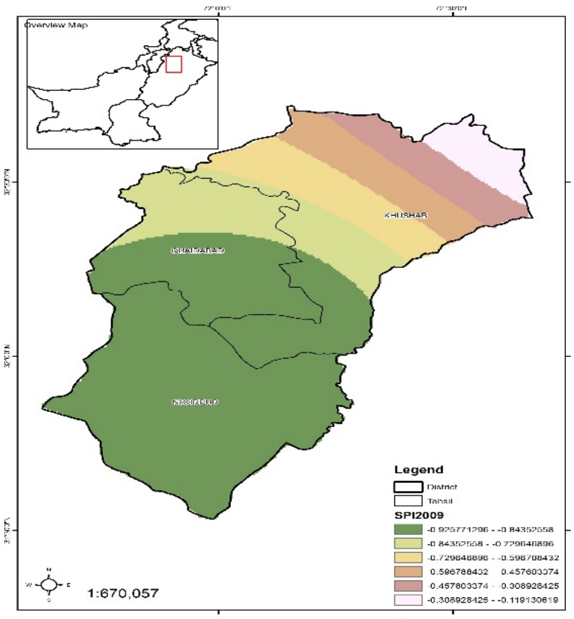

Fig. 9b Six month SPI for years 2009.

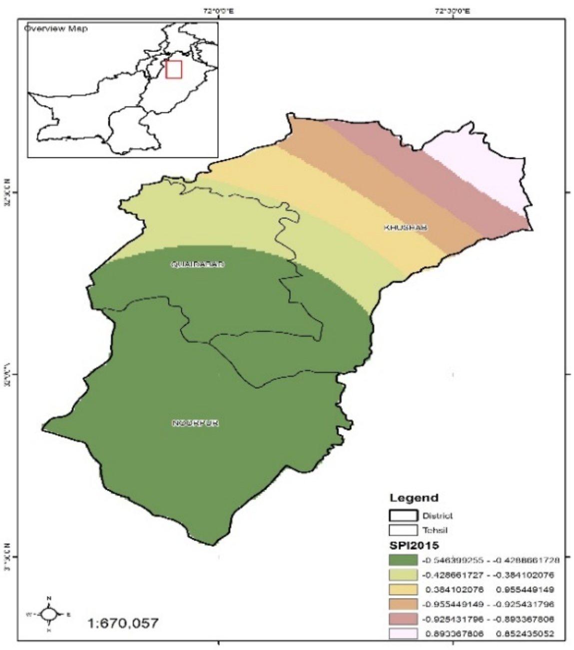

Fig. 9c Six month SPI for years 2015.

Thus, SPI helped in identifying the medium term trend in precipitation and the years in which Khushab was more prone to drought risk (Fig. 8). Interpolation method was used to visualize the spatial and temporal variation of SPI in Khusahb district. Maps generated through interpolation clearly reflect the low SPI values trends towards the southern part of the study area, which confirms the low rainfall availability during the years 2003, 2009 and 2015 (Fig. 9a, b, c.).

Drought Characterization

Drought impact was assessed using NDVI and SPI values by linear combination weighted system. NDVI and SPI of 3 years (2003, 2009, 2015) were separately reclassified and weights were assigned to the classes.

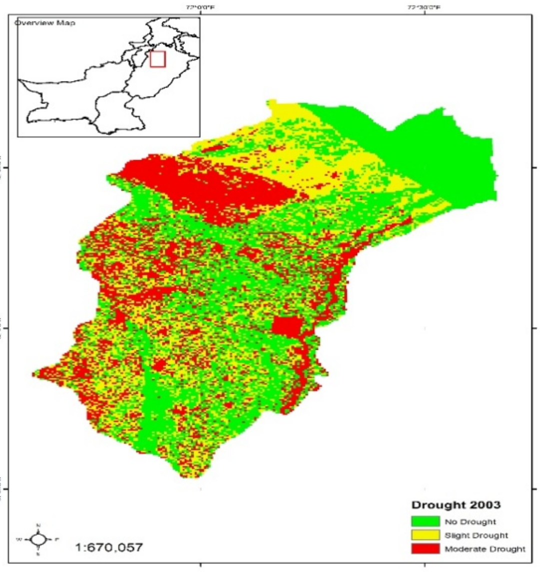

Fig. 10a. Drought severity in 2003.

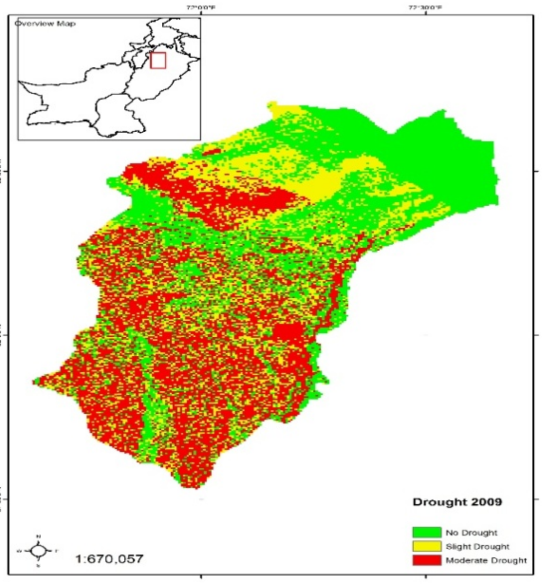

Fig. 10b. Drought severity in 2009.

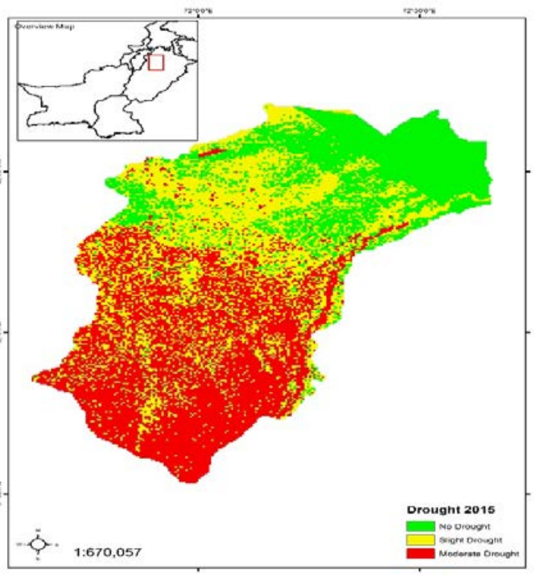

Fig. 10c Drought severity in 2015.

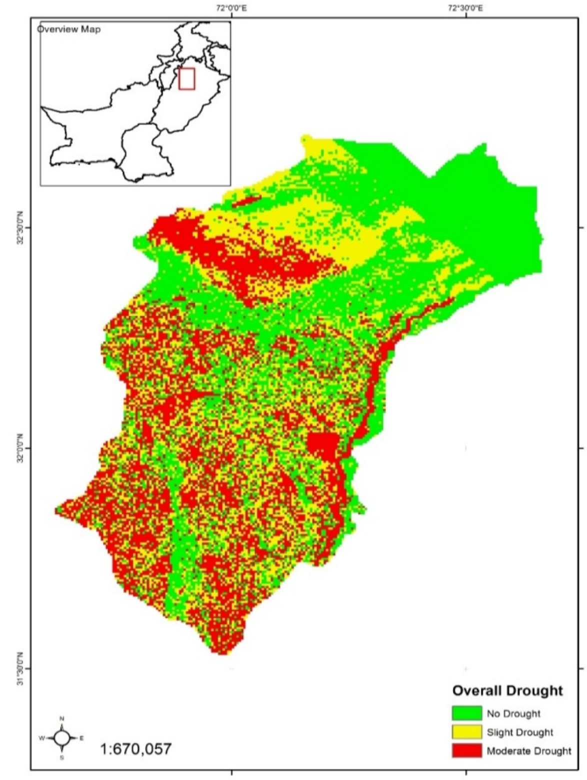

Fig. 11 Overall drought severity in district Khushab.

The weights were assigned to each class in the range of 1-6. To the highest negative value of SPI, weight of 6 was assigned while for the highest vegetation class in NDVI, weight of 1 was assigned. Drought severity was assessed for the years 2003, 2009 and 2015. It was assessed that in Khushab area, which lies in the Pothwar region, has sufficient rainfall and it is concluded that only 3 drought categories exist; no drought, slight drought and moderate drought. Figures 10a, b and c show the distribution of these classes for the years 2003, 2009 and 2015 respectively. Interpolated maps clearly give a scenario of drought prevalence and its trend in the area. Fig.10a clearly shows the drought period in the north and it is showing increasing trend toward south in Fig.10b and Fig.10c for the year 2009 and 2015 respectively because of low rainfall received.

Table 4. 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

Overall Drought Impact

Final drought impact map was obtained by driving average from drought severity maps for all the three years (2003, 2009 and 2015). Composite map generated showed that some areas of the study area are free from drought while others are under drought effects (Fig. 11.). Area coverage under drought categories with percentage is given in Table 4.

Results reveal that almost 42% of the area is not facing any type of drought, as Khushab district is located in Potohar region so it receives sufficient rainfall, especially in its northern part. But the southern part is a rainfall deficit area hence, slight and moderate droughts were seen especially in these areas. Nearly 59% of the area is at risk of drought (slight and moderate drought combined), therefore, 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 and the drought situation is very common in Pakistan due to less rainfall and water scarcity situation. From this study, it is concluded that there is rainfall variability in the study area. Major crops are wheat, rice, sugarcane and jowar, which are totally dependent on rainfall. This study shows that rainfall is a basic and major factor in the drought-prone Potohar area. Average rainfall recorded at Chakwal station from 2006 to 2015 was 52.14 mm, at Sargodha station it was 43.19 and at Bhakar station, it was recorded as 32.48. 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 towards 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, which is 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 shows that risk areas can be assessed appropriately by integration of various data sources and thereby management plans can be prepared to deal with the hazards.

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