4th International Conference on Water Resources and Arid Environments (ICWRAE 4): 622-631
5-8 December 2010, Riyadh, Saudi Arabia

Drought Severity Assessment in Arid Area of Thal Doab using Remote Sensing and GIS

Asma Shaheen[1] and Muhammad Anwar Baig[2]

[1]Department of Earth Sciences, University of Sargodha, Sargodha
[2]Institute of Environmental Sciences and Engineering, National University of Sciences and Technology, Islamabad. University of Sargodha, Sargodha Pakistan

Abstract: Thal Doab, which is situated between rivers Indus, Jhelum and Chenab, bears extremely dry weather conditions with very low rainfall. Gram is the most important Rabi crop sown in this region. During drought period, the production of this crop is affected badly. Globally there are four known categories of drought i.e. Meteorological, Agricultural, Hydrological and Socio-economic. In this study meteorological and agricultural parameters were analyzed for the variety of data for the years i.e. 1989, 1995, 2001 and 2007. Initially anomalies were calculated for NDVI, rainfall and crop yield to evaluate percent change in different years. Crop yield and NDVI possess negative anomalies during drought years while in case of non-drought years, static and positive anomalies were found. Then Standardized Precipitation Index was computed on six monthly bases for the time series of nineteen years (1989-2007). The correlation regression analysis was preformed to identify the dependency level among different parameters. Positive correlation was found among SPI, NDVI, crop yield, rainfall anomalies, NDVI anomalies and total seasonal rainfall. Similarly ET_o was also calculated from the data. Negative correlation between crop yield and ET_o was observed. The weighted overlay analysis method was also applied by assigning relative ranks to each factor. The meteorological and agricultural drought were assessed by overlaying SPI, rainfall anomalies, ET_o, crop yield, NDVI anomalies and water table depth data. The well known 2001 drought year was confined by using above method applied in this research. Finally drought severity maps were generated by integrating the meteorological and agricultural drought severity maps, indicating the areas facing combine hazard condition. The maps can be extremely helpful to the planners to reveal the situation in the area.

Key words: Drought • Anomalies • Severity • SPI • Correlation

INTRODUCTION

Drought occurrence is obvious when there are abnormal dry weather conditions and low rainfall prevails more than normal routine. It causes decline in the flow of tributaries and rivers resulting water level begin to decrease in lakes and reservoirs. Groundwater table and wells instigate to turn down. Drought is categorized as the environmental hazard and natural disaster that deteriorates the sustainable development of a society. The drought has greater long lasting impact than any other natural hazard. It has creeping vulnerability and badly increases its span on physical environment, agricultural production, livestock and overall economy [1]. It harmfully distresses the farming, hydropower generation, water supply and industrial sectors of the affected areas. Desertification is the regular phenomena in vulnerable arid, semi-arid and dry sub-humid areas, due to frequent droughts events and adversely human activities [2]. Pakistan is experiencing by and large arid to hyper-arid climatic conditions. It has limited surface and ground water resources and annual water availability per capita has been reduced from 5600 cubic meter (m^2) at the time of independence 1947 to a meager value of 1200 cubic meter during 2001 [3]. The rainfall can't fulfill the agricultural requirements and most of the regions remain dry and uncultivated throughout the season. As an agriculture dependent economy, Pakistan has to face many problems during drought events. The recent drought (1998-2003) was one of the worst droughts of Pakistan due to extremely low rainfall. It affected the Pakistan's socio economic pattern very badly. The study area is exposed

Corresponding Author: Asthma Shaheen, Department of Earth Sciences, University of Sargodha, Sargodha

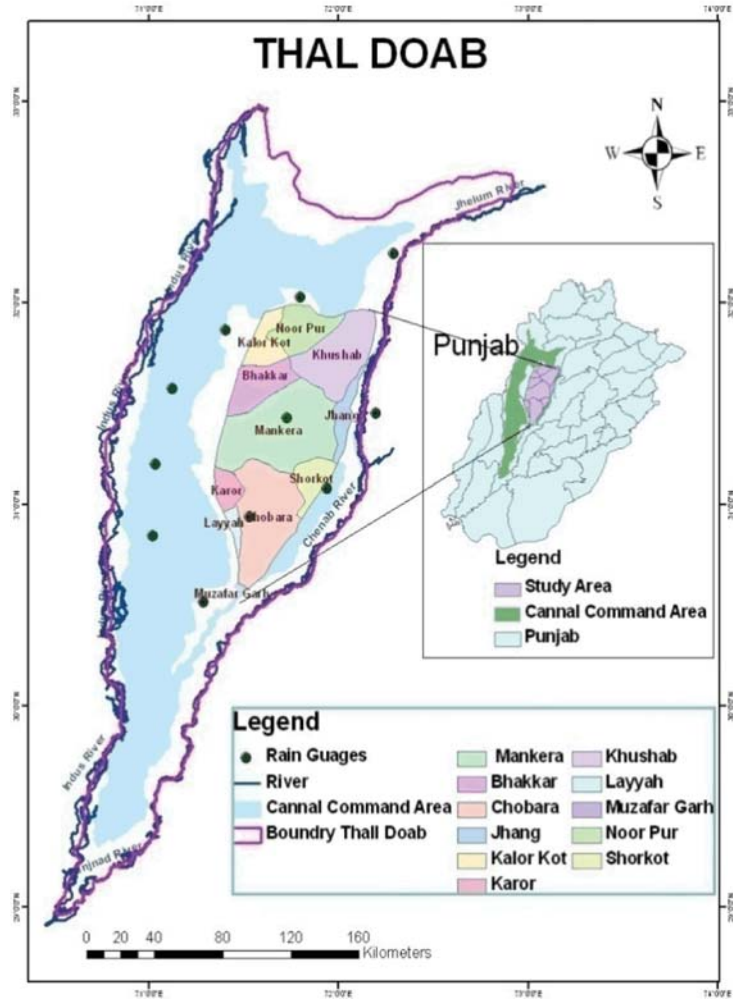

Fig. 1: Location map showing study area of Thal Doab

to harsh arid conditions and it distorted environmental conditions and socio-economic life in the area. Gram is major rainfall reliance crop of the study area. Crop production and other vegetation are affected badly during drought period. In drought years the gram production was reduced 400 to 600 kg/acre due to low rainfall. The sparse vegetation and crop production is highly dependent on the climate of the area. The soil of study area is very prolific and can sustain the cultivation, but due to aridity and low rainfall agricultural practice is very peculiar. Therefore, it was needed to assess the nature of prevailed severity properly. The study area in this research is 'Thal' desert (Figure 1). It is interfluves that lie between Indus, Jhelum and Chenab rivers. Geographically, it looks like the deserts of Cholistan and Thar. Mankera, Chobara, Mari Shah, Sakhira and Noorpur Thal are the main towns of Thal. The rainfed area that was studied covers about 7740 km^2. It lies between latitude 30°59′-32°6′ N and longitude 71°14′-72°16′ E. It is an extensive tropical sandy desert with permanent dry conditions. The dominant landforms of this region are sand dunes of diverse shapes and sizes, with various inter-dune valleys of cultivable land. Arid to extremely arid climate prevails in Thal desert. The summer and winter seasons have bimodal system of rainfall as 60%-70% and 30-40% respectively in this area.

Methodology

Index Calculation: The drought severity analysis was done on temporal basis for the 19 years data with 5 years interval. The Normalized Difference Vegetation Index (NDVI) was calculated form 30 meters Landsat images for 1989, 1995 and 2001 and 20 meters Spot image for 2007. Each image was used to analyze the vegetation condition on sequential basis as given in this equation:

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

Where

λ IR = Reflectance in near infrared band (band 4 of Landsat and 3 of SPOT)

λ IR = Reflectance in Red band (band 3 of Landsat and 2 in SPOT)

Standardized Precipitation Index: Six months Standardized Precipitation Index (SPI) was calculated for 11 rainfall stations using monthly rainfall data during 1989-2007 for crop growing season (October-March). For SPI calculation;

$$Zscore= (X-Pa)/Standard\ Deviation$$

Where, Zscore is SPI value

X is precipitation for particular month

Pa is mean rainfall for six months [4]

Potential Evapotranspiration (ET_o) was calculated from CROPWAT model. This method estimate evaporation from free-water surfaces which combined energy-budget and mass-balance methods [5,6].

Anomalies Calculation: The anomalies were calculated to identify the change in drought severity on temporal scale. NDVI, crop yield and rainfall data was used to discern the anomalies. Negative anomalies support the drought condition.

Crop Yield Anomalies: The crop yield trend was calculated using time series data and then crop yield anomaly was computed. The crop yield anomaly [7] was deviation from the 19 years yield trend. $Y = a + b(X)$

$$*Ya = ((Yi-Yt) / Yt)) * 100$$

Where,

Ya is yield anomaly;

Yi is yield in particular year and

Yt is yield trend in 19 years

NDVI Anomalies: NDVI anomalies were calculated using Zonal Statistics. For each year mean and maximum NDVI was calculated on Tehsil level, then NDVI anomaly has been computed as:

$$NDVI\ i = ((NDVI\ mean\ i-Average\ NDVI\ mean)/ Average\ NDVI\ mean)*100$$

Where,

NDVI i is *NDVI* anomaly for particular year

NDVI mean is mean NDVI of particular year

Average NDVI mean is an average of mean NDVI for the four years.

Rainfall Anomalies: To indicate the meteorological drought for the growing season of Rabi; rainfall anomalies were computed as:

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

Where,

RFA i is rainfall anomaly for given year;

RF i is seasonal rainfall for given year and

RF a is mean seasonal rainfall

Water Table Depth: Water Table depth data was also used to indicate the effect of ground water data on crop production during drought and non-drought years.

Correlation Coefficient Analysis: Correlation Coefficient was calculated between meteorological and agricultural drought related parameters to indicate the dependency level of crops and vegetation on the related precipitation.

$$r = \frac{\sum XY - \frac{\sum X \sum Y}{N}}{\sqrt{(\sum X^2 - \frac{\sum X^2}{N})(\sum Y^2 - \frac{\sum Y^2}{N})}}$$

SPI was correlated with Crop yield and NDVI. NDVI was also correlated with total seasonal rainfall and Evapotranspiration.

Weighted Overly Analysis: The linear combination weighted system and multi criteria assessment to determine drought risk areas. Each was given a weight or multiplier, which represents the factor's importance relative to the other. Then the ratio of weights and ranks was adjusted according to the number of parameters and requirement of the study. Its fact that each of the factors has an influence on the drought condition, they have been analyzed and implemented in the model [8]. At temporal scale 1989, 1995, 2001 and 2007, meteorological and agricultural drought was assessed using weighting linear combination. For the weights following expression was used;

$$Wt = \bullet\ Wi\ Di\ \ldots\ldots Wn\ Dn$$

Where

Wt = Total weight, Wi = Weight value in each parameter i to n,

Di = Score value in each parameter i to n

The aggregate score from a linear combination factor model was computed from and was reclassified into five drought severity classes: 'very severe drought', 'severe drought', 'moderate drought', 'slight drought' and 'no drought'. Then meteorological and agricultural drought maps were overlaid to recognize the in general drought trend and by coalescing all years general drought final drought map was prepared.

RESULTS AND DISCUSSION

Mean Seasonal Rainfall and NDVI: Considering the rainfall and NDVI patterns for Rabi season in 1989, 1995, 2001 and 2007 for the whole study area, it was analyzed that there was positive correlation between NDVI and rainfall. The rainfall values reached up to 120 mm (Figure 2) and consequently NDVI increased up to 0.6 that is the saturation level for NDVI in the study area.

NDVI Anomalies: It was examined that in 1989 and 2001, NDVI had negative anomalies (Table 1) for the whole study area. The drought from 1999 to 2001 was the worst in the last fifty years [9].

The negative NDVI anomalies during drought years (1989, 2001) were extended to the large area and indicated vegetation reduction during these years from the average NDVI of all years.

Table 1: The NDVI Anomalies calculated for different years

Name Tehsil	1989	1995	2001	2007
Bhakkar	-18.14	13.8	-37	38.8
Chobara	-19.7	31.4	-70.8	59.8
Jhang	41.2	10.7	6.8	-58
Kalor Kot	18.6	-9.1	-36.4	27.1
Karor	-2.9	16.5	-65.7	52.1
Khushab	-11.8	-6.7	3.4	15.2
Layyah	-62.2	17.3	-83.6	129.6
Mankera	-6.1	13.5	-28.4	22.3
Kot Adu	-69.7	29.6	-6.8	48.14
Noorpur Thal	0	1.7	-7.1	5.3
Shorkot	-17.8	146.5	-82.2	-42.4

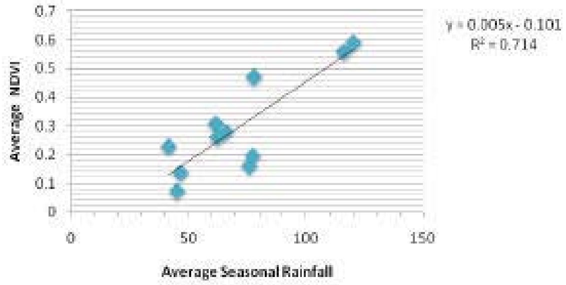

Fig. 2: Correlation Coefficient for mean seasonal rainfall and NDVI

Crop Yield Anomalies: The negative anomalies in crop yield specified the percent reduction in crop production for the particular years. In 1989 and 2001, crop yield anomalies were 6.9--27 and-8.9--40.6 respectively.

Rainfall Anomalies: The negative rainfall anomalies signified that precipitation was less than the average seasonal rainfall for a particular place. It was observed that in 2001, there were ceiling negative anomalies of-98%. According to World Meteorological Organization and reports of climate change, 2001 was declared drought year in Pakistan; while in 2007 there were positive anomalies those show the increasing trend of rainfall in 2007.

The Correlation Analysis: The results in (Table 3) demonstrated the correlation coefficient of total rainfall with NDVI and rainfall anomalies with NDVI anomalies. There was strong positive correlation for rainfall and corresponding NDVI. The correlation analysis between NDVI and SPI (Table 2) represented the strong positive linear correlation which pointed out that vegetation was highly dependent on the available amount of rainfall. The strong positive correlation was shown (Figure 3) in two sample cities Mankera and Chobara.

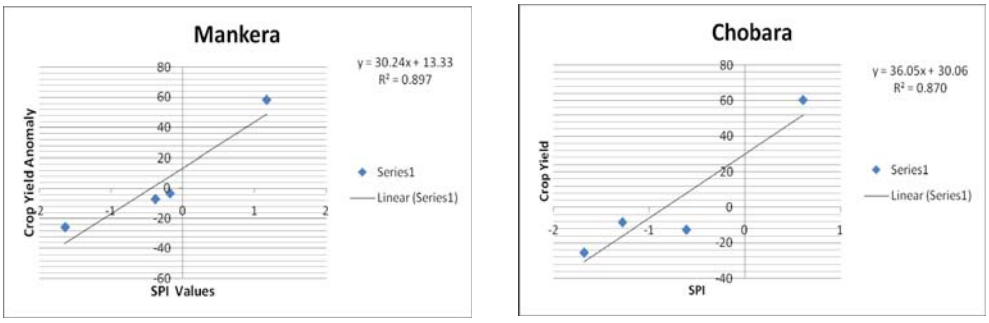

Fig. 3: Correlation Regression Analysis of SPI and Crop Yield Anomalies

Table 2: Correlation of SPI-Crop Yield and SPI-NDVI

Tehsil Name	Correlation (SPI-CropYield)	Correlation (SPI-NDVI)
Bhakkar	0.98	0.91
Chobara	0.93	0.99
Jhang	0.57	0.46
Kalor Kot	0.91	0.87
Karor	0.93	0.91
Khushab	0.94	0.6
Layyah	0.81	0.41
Mankera	0.94	0.96
Kot Adu	0.75	0.45
Noorpur Thal	0.83	0.77
Shorkot	0.77	0.9

Table 3: Correlation Analysis for Total Rainfall, NDVI and Rainfall Anomalies

Name Tehsil	Total Rainfall-NDVI R^2	NDVIAnomaly-RainfallAnomalyR^2
Bhakkar	0.83	0.85
Chobara	0.74	0.71
Jhang	0.62	0.80
Kalor Kot	0.58	0.68
Karor	0.88	0.75
Khushab	0.93	0.64
Layyah	0.76	0.89
Mankera	0.41	0.83
Kot Adu	0.68	0.55
Noorpur Thal	0.94	0.81
Shorkot	0.73	0.65

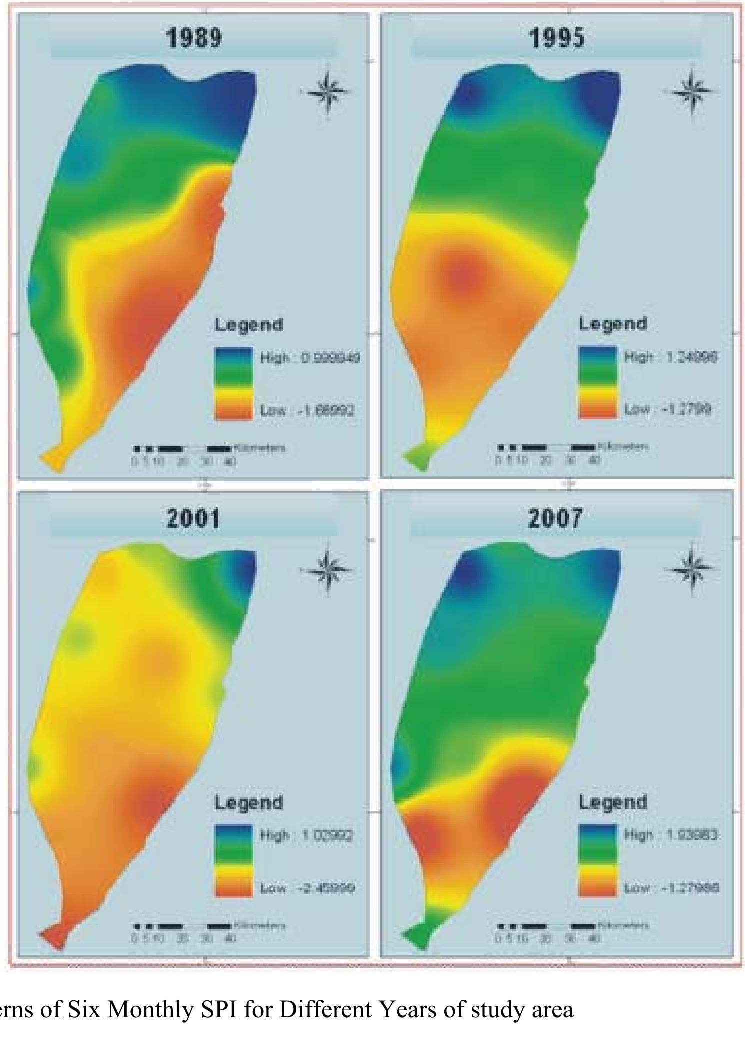

Figure 4: Spatial Patterns of Six Monthly SPI for Different Years of study area

Standardized Precipitation Index and Drought: The SPI was calculated for six months i.e. October through March as rainfall during these months affect the Rabi vegetation.

Using the interpolation techniques, the precipitation deficit areas were identified (Figure 4). It was observed that during drought years of 1989 and 2001, the low SPI values had large spatial extension from southeast to western parts of the study area. During the non-drought years i.e. 1995 and 2007, the low SPI values were observed in the mid-southern part of the study area.

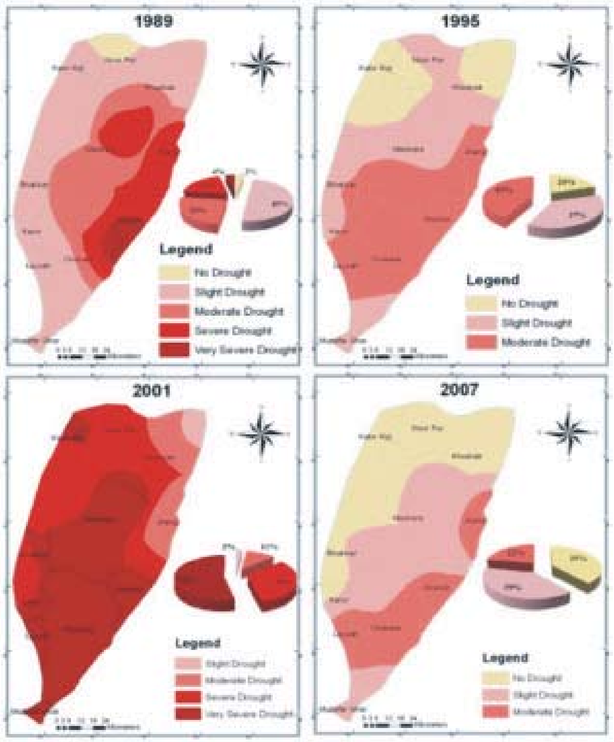

Fig. 5: Meteorological Drought Severities for Different years

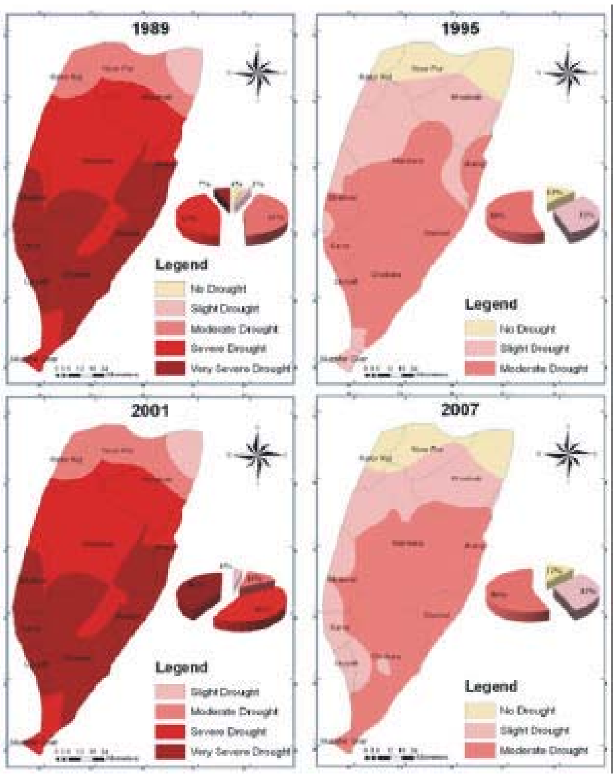

Fig. 6: Agricultural Drought Severities for Different years

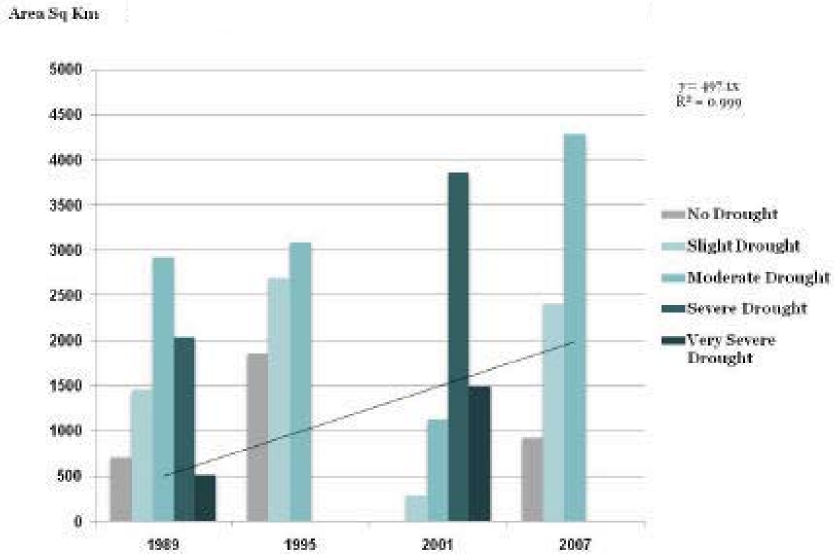

Fig. 7: Drought Severity Trends in Different Years

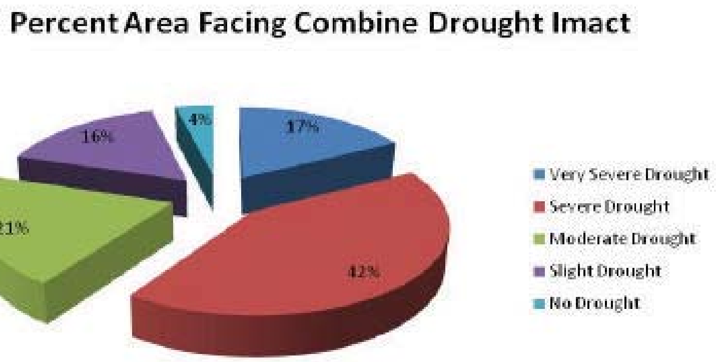

Fig. 8: Percentage of area for the different drought severities

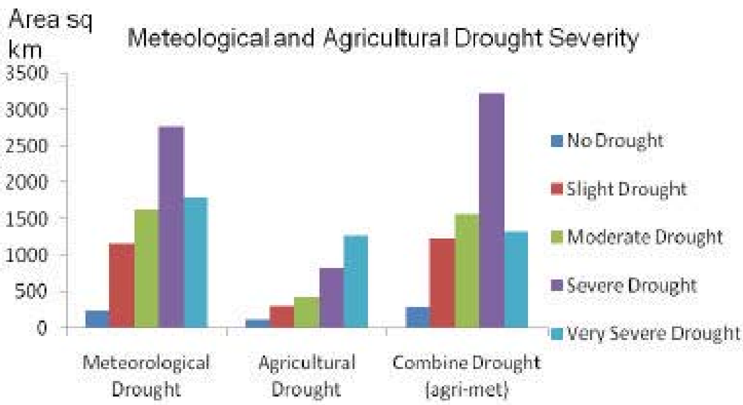

Fig. 9: Area under Metrological and Agricultural Drought Severity

The range between negative values of SPI index was significant during the years 2001 (drought) and 2007 (non-drought). In 1989 and 2001 the SPI values ranged between. 99 to-1.68 and 1.02 to-2.45 respectively. This proved the maximum negative trend of SPI during drought years, which also indicated the rainfall deficiency.

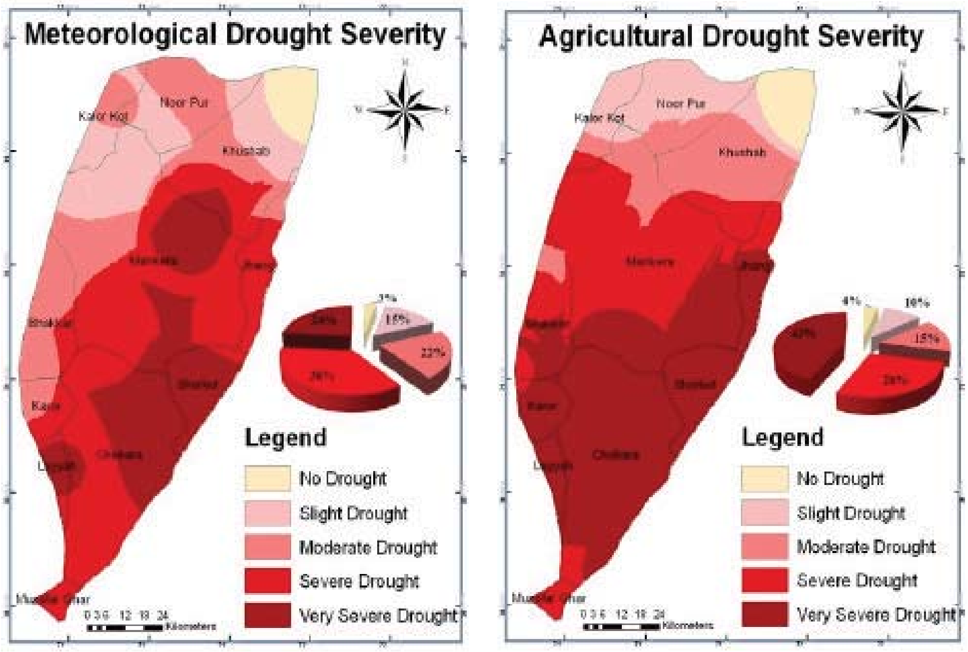

Fig. 10: (a) Meteorological Drought (b) Agricultural Drought

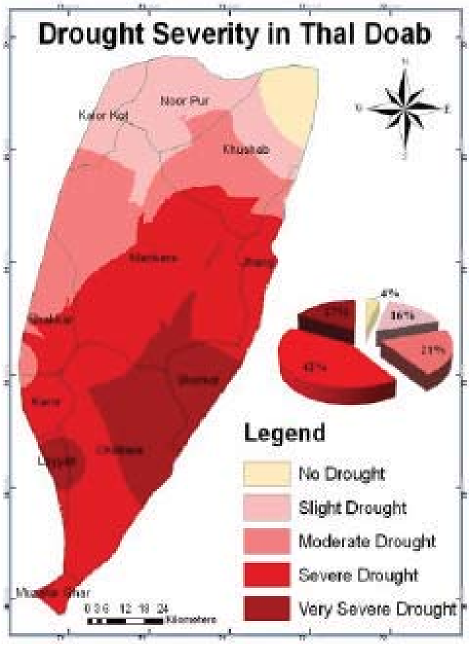

Fig. 11: Over all Droughts in Thal Doab

The Meteorological Drought: The meteorological drought situation in 2001 was very severe. In 1989 all five classes of drought severity existed.

In 1995 and 2007 (Figure 5), severe and very severe categories didn't exist and drought condition prevailed from moderate drought to virtually no drought (Figure 9).

Agricultural Drought Severity: Such as meteorological drought, the agricultural drought also triumphed from southeast to southwestern parts of study area with severe condition. The severe drought prevailed in southeastern to southwestern part and some areas of Bhakkar. In 1995 and 2007 the drought condition was not so severe,

Table 4: percent Area under Different Drought Conditions

Class	Description	Area (sq/km)	Area %
1	No Drought	258.5	3.73
2	Slight Drought	1241.2	16.25
3	Moderate Drought	1563.5	20.47
4	Severe Drought	3230.6	42.3
5	Very Severe Drought	1315.7	17.22

only moderate, slight and 'no' drought categories existed (Figure 9). As 2001 was a drought year, very severe to slight drought categories subsisted in this year (Figure 6).

Drought Trend Analysis: The drought severity was analyzed for 1989, 1995, 2001 and 2007, the two years 1989 and 2001 were considered as drought years and 1995 and 2007 were taken as non-drought years. By analyzing the extent and drought pattern it was observed that extent of drought severity was increased by increasing time scale (Figure 7). In 1989 the area under very severe drought and severe drought was less than as compare to 2001. Similarly for 1995 and 2007 (non-drought years) the extent of no drought class had been decreased while the area under moderate drought had been increased in 2007 as compare with 1995. These trends indicated that with increasing in time scale the drought tend to be more severe.

Combined Drought Impacts: The combined drought severity map (Figure 11) was generated by overlying the agricultural and meteorological drought severity maps as in figure 10-(a) and (b). According to the combine drought map (Figure 11) some areas of Khushab district had exceptional drought events while all other study area experienced different type of drought in scrutinized years. The area under severe to very severe drought conditions was 42.3% and 17.22% respectively (Table 4) of the total study area which indicated that almost 60% area was prone to drought. The moderate and slight drought succeeded to 20.47% and 16.25% respectively of the whole study area, while 3.73% area had no drought (Figure 8). Normally the drought extension was to the eastern and southwestern parts of the study area (Figure 11). The major drought impact and intensity was towards those areas that were chief productive region of gram in arid areas of Thal desert.

CONCLUSIONS

Normalized Difference Vegetation Index and crop yield were dependent on rainfall in the study area. This correlation defined rainfall as a basic and major factor in arid area. Since strong positive correlation existed between NDVI and rainfall in water scarce areas. The negative correlation of ET_o with NDVI demonstrated that during the drought vulnerable time, the amount of evapotranspiration increased and contributes to aggravate the drought risk. The anomalies were calculated for NDVI, Crop yield and rainfall which shown the negative change in vegetation, food grain as well as the received precipitation in drought years. In Thal Doab southern and southeastern areas were more susceptible to droughts. From the 1989, 1995, 2001 and 2007, the 1989 and 2001 were the severe drought years in Thal Doab. In 1989 the northeastern part had "No drought" and all other study area was under drought condition of different severities. In 2001 the entire study area was under drought situation. The 1995 and 2007 years had not severe drought conditions.

ACKNOWLEDGEMENT

I am grateful to Almighty Allah, my loving parents, siblings, HoD (UoS), advisor, committee members and to my University for completion of this research.

REFERENCES

1. Nagarajan, R., 2003. Drought Assessment, Monitoring, Management and Resource Conservation. New Dehli: Capital Publishing Company.
2. Kundzewics, Z.W., 1997. Water Resources for Sustainable Development. Hydrol. Sci. J., 42(4): 467-480.
3. Kahlown, M.A., 2002. Welcome Address. In: Proceedings of the SAARC Workshop on Drought and Water Management Strategies. Pakistan Council of Research in Water Resources, Lahore-Pakistan, pp: 5-7.
4. McKee, T.B., N.J. Doesken and J. Kleist, 1993. The Relationship of Drought Frequency and Duration to Time Scales. Preprints, 8th Conference on Applied Climatology, Anaheim, California, 17-22 January, pp: 179-184.
5. Penman, H.L., 1948. Natural Evaporation from open Water, Bare, Soil and Grass Proc R Soc Lond A., 193: 120-146.
6. Penman, H.L., 1956. Estimating Evaporation, Trans Am Geophysics Union, U.S.

7. Chopra, P., 2006. Drought Risk Assessment using Remote Sensing and GIS: A Case Study in Gujrat. MS Thesis (ITC), Netherlands and (IIRS) India. http://www.wmo.ch/web/catalogue/New%20HTML/frame/engfil/wcn/wcn20.pdf

8. Prathumchai, K., K. Honda and K. Nualchawee, 2001. Drought Risk Evaluation using Remote Sensing and GIS: A case study in Lop BURI Province: Asian conference on Remote Sensing, Singapur, pp: 4-7.