Research Article

Drought Risk Assessment: A Case Study in Punjab, Pakistan

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Abstract | Drought is a natural hazard spreading gradually and caused serious harm to nature. It is frequently known as a "crawling phenomenon" or "crawling Disaster" as it is a plodding physical process and its effects spatially varies. Misperception on drought and its features is common in defining policies and caused delays in its prevention (Gore, 2002). Pakistan is one the counties which is affected badly by drought. In near Past, Pakistan faced one of the worst drought span drought in 50 years from 1998 to 2003 which harshly affected socially and economically. The present study was conducted on dry land areas of Punjab-Pakistan. The satellite data for NDVI were acquired from MODIS product MOD13A2 for years from 1996 to 2015. For the same period the data of 12-Month SPI values, GPCC precipitation and CPC soil moisture were also used. In formulating Climatological drought year, the droughts of years 2000 and 2002 were categorized as moderate drought years for the area have Precipitation Anomaly of -37% and -31%, respectively whereas Precipitation Anomaly values of -11.5, -15.6, -10.2 and -16.2 were found in years 2003, 2004, 2006 and 2009, respectively and categorized as slight drought years. The coefficient of determination between NDVI and Precipitation is 0.69 whereas between NDVI and Soil Moisture is 0.68. To verify delineated drought years, the data of different NDVI ranges such as Barren land, Dense Vegetation and Sparse Vegetation were analyzed along with Precipitation and soil moisture for monthly, yearly and seasonal basis. In center of study area for year 2000, the spatial analysis of DEVNDVI showed that there were the mild drought conditions during the month of February and intense drought conditions in the months of March and April. During the months of May to July, the eastern and western boundaries of the study area showed the development of drought conditions and these conditions become more intense in June. From August to October, the drought also advances in towards North side. In months of November and December, the drought conditions disappeared in the selected areas. Similarly, the spatial analysis of VCI showed that there were minor drought circumstances in the center and southern sides for the month of February whereas drought conditions found more intense during months of March and April in center part of study area. The southern, eastern and western sides of boundaries showed advances in drought happening from May to July and declining in the month of June. Therefore, the drought intensity decreased relatively in the central part for the months from August to October but it was still active. But for the months of Nov-Dec the drought conditions become intensive again in the area. The results of SPI analysis revealed that Mianwali district experienced moderate dry conditions out of all the districts for year 2000 with SPI value of -1.16 whereas Jhang experienced extreme dry conditions in same year with SPI value of -1.54. It is recommended that the current study should be considered as baseline for delineation and forecasting of drought years in Pakistan.

Links Researchers

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Introduction

Drought is expected when there are extremely dry weather conditions with very low rainfall situations predominated more than normal period (Chopra, 2006). This creates reduction in flow of rivers and streams which caused impairment of water quality in reservoirs, lakes and aquifer due to several reasons. Definitely, drought is threatening to ecology and nature which has extreme critical consequences on sustainable growth of a society. It is one of the major natural threats, has the lifelong impact on ecology as water is always a lifeline of a country or region. The major regional social and economic contributors such as agriculture, surface and groundwater and livestock are most vulnerable to drought by reduction its production and quality (Nagarajan, 2003).

Drought is one of the most widespread climate disaster worldwide which affects agricultural yield (Helmer and Hilhorst, 2006; Dilley et al., 2005; UNDP, 2004) and it is consequently the main perimeter of food security world widely (Tubiello et al., 2007). Since 1970, it was observed that intensity, duration and area affected by drought has been increase world widely, particularly in the tropic and subtopics, where increase in temperature and less precipitation have boosted drought conditions. It has been found that there is a high chance and probability of increasing droughts in coming years due to climate change in drought prone areas (IPCC, 2007) imposing to focus on food security issues more seriously especially the regions already vulnerable to food security (Rosegrant and Cline, 2003; Ericksen, 2008).

Since climatic conditions differ from region to region, therefore various drought indices are being used around the world for monitoring droughts because a single drought index does not provide the detail information about droughts. These indices are used to investigate the spatio-temporal droughts extent as well as to determine drought severity (Hayes, 2000). Drought indices are vey useful to monitor droughts and provide a comprehensive picture of droughts situations (Mendicino et al., 2008). For effective monitoring of drought in any region the choice of drought index is very important. NDVI is the most commonly used vegetation index for monitoring droughts. Its value ranges from +1 to -1. Tucker in 1979 for the first time suggest NDVI as an index of vegetation health and density (Hammouri and Naqa, 2007). NDVI is given by formula.

$$NDVI = NIR - RED/NIR + RED$$

Where;
NIR is near infrared band and *RED* is red band of satellite imaginary. *NDVI* itself does not reflect dry season or non-dry spell condition. Rather the extant of wetness or sensitivity of droughts may be defined as *NDVI* deviation from its long mean i.e. *DEV NDVI*. Lack of rainfall is the main cause of drought. Standard Precipitation Index (SPI) were used to monitor drought due to rainfall. Mckee et al. (1993) developed SPI for quantification of precipitation scarcity for multiple time scale. SPI shows the long-term precipitation record for a selected region.

In present study the effort was made to determine drought years and its intensity using satellite data of MOD13A2 for determining NDVI, SPI indexes were determined for 12-Month from ground station data, precipitation data were acquired from GPCC and soil moisture from CPC websites for years from 1996 to 2015. The main aim of the study is to analyze change in vegetation cover due to change in SPI and NDVI for barren, sparse and dense vegetation areas.

Materials and Methods

Study area

Study area is the dry land area in the province of (Figure 1) Punjab, Pakistan. The area is covers 306 kilometers length and 113 kilometers width, surrounded between Rivers Sindh and Jhelum near Potohar Plateau. The study site is classified as dry lands.

Figure 1: *Dry land area of Punjab, Pakistan (study area).*

This area is sub divided into seven main districts i.e. Chiniot, Jhang, Bhakkar, Mianwali, Khushab, Muzaffargarh and Layyah. Some of the main municipalities of the desert are Mari Shah Sakhira, Mankera, Roda Thal, Mehmood Shaheed, Shahi Shumali, Dullewalla, Koat Aazam, Hyderabad Thal, Jiasel, Jandan Wala, Jandan Wala, Rang pur, Noor pur Thal, Shah Wala and Piplan. Geologically, the dry lands bear a resemblance to the Cholistan and Thar deserts.

The major source of income and activity is the cattle rearing in the area. There are some reformation projects are also working to supply irrigation water in the area.

Data

MODIS product MOD13A2 having spatial resolution 1km by1 km with temporal resolution of 16 days for 16 years 2000-2015 were downloaded from its website (http://reverb.echo.nasa.gov) were used for NDVI analysis. The data of 12-Month SPI values for years 1980-2010 were acquired from Pakistan Meteorological Department. Furthermore, monthly precipitation data set from GPCC up to year 2013 and CPC soil moisture data set upto year 2015 containing 50km × 50km spatial resolution were downloaded from ESRL official website (http://www.esrl.noaa.gov).

The data set of NDVI were downloaded in the file format of Hierarchical Data Format (HDF). Initially, NDVI images are extracted from all the HDF files by applying parameter subset on all the HDF files. Extracted NDVI images were masked in the frame of study area. To generate raster attribute table masked images were altered into integer values. Scale factor of 0.001 was multiplied with all pixels of distinct images. On the raster images, query was applied and pixels of three ranges were extracted: i) Barren Land (0.01 - 0.11), ii) Sparse Vegetation (0.11 - 0.3) and iii) Dense Vegetation (> 0.33). The area was counted in km^2 pixels for all ranges and multiplied with factor of ((1000*1000)/ (1000*1000)). The data set images of soil moisture and precipitation had file format of Netcdf. Initially, these images were used to extract mean monthly values for both parameters and zonal statistics was applied. The relationship between precipitation, soil moisture and NDVI ranges (Barren land, Sparse Vegetation, Dense Vegetation were derived using regression analysis. Furthermore, different graphical techniques are done for monthly analysis, seasonal analysis, and yearly analysis. To define drought years Precipitation Anomaly was calculated. VCI and DEV NDVI were developed for the drought year. For all the districts of the study area, 12-month SPI were plotted and analyzed.

Results and Discussions

Regression analysis

The formulate drought in the dry land regions of the study area, the meteorological parameters such as Precipitation, Soil Moisture were used along with NDVI values.

The relationship of NDVI with Precipitation and Soil moisture data was analyzed with Regression analysis on yearly data and it was found that there is a linear relation among them. Figure 2 and 3 revealed that Precipitation and NDVI have linear correlation (R = 0.69) with relationship equation of y = 4E-05x + 0.2279 while Soil Moisture and NDVI having R of 0.68. Furthermore, regression analysis was also performed on meteorological parameters.

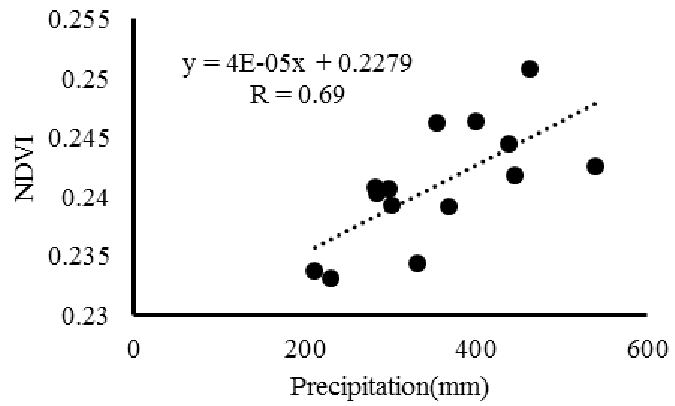

Figure 2: *Regression between Precipitation and Mean NDVI.*

Drought years

Precipitation anomaly and climatological drought years were determined from the following Equation as recommended by Chopra (2006):

$$RFA_i = [(RF_i - RF_a) / (RF_a)] \times 100$$

Where;

RFA_i = anomaly of rainfall for specific year (%); RF_i = rainfall of a seasonal for specific year; RF_a = mean rainfall of a season.

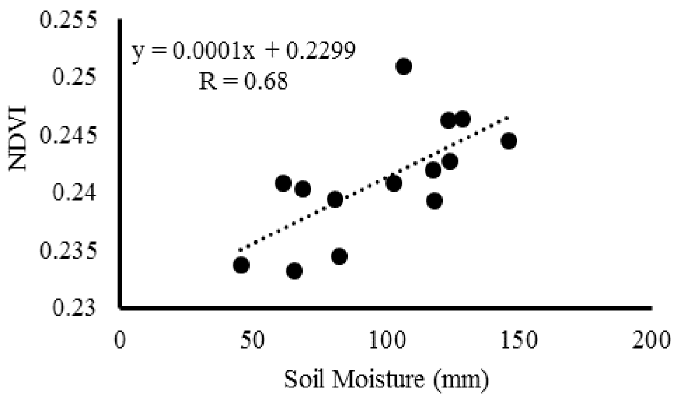

Figure 3: *Regression Between Soil Moisture and Mean NDVI.*

Based on precipitation anomaly (PA), the drought was categorized normally in three levels such as minor drought (PA less than 25% from normal), reasonable drought (PA= 25-50%) and severe drought (PA greater than 75%) (Gore and Ray, 2002). The precipitation anomaly for years 2000 – 2015 are shown in Figure 4, the results showed that the years 2000 and 2002 have -37% and -31% Precipitation Anomaly and therefore showed reasonable drought years for the study area. Whereas, precipitation anomaly for the years 2003, 2004, 2006 and 2009 have values of -11.5%, -15.6%, -10.2% and -16.2%, respectively and showed the trend of minor drought years.

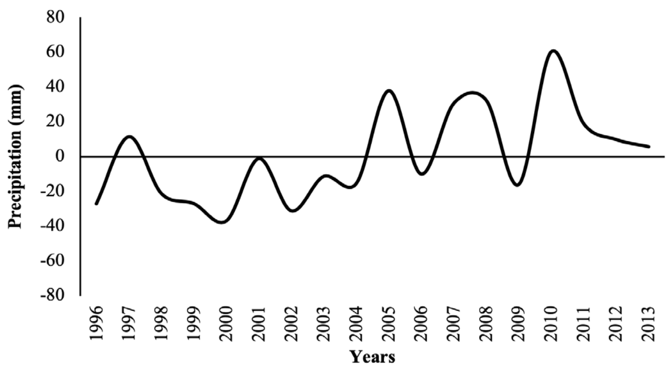

Figure 4: *Precipitation Anomaly for years 1996 – 2013.*

Yearly analysis

The year from 1996 to 2015 is consider as Study period, for that yearly analysis is done on precipitation, soil moisture and different NDVI ranges (Barren land, Sparse Vegetation, Dense Vegetation) to verify delineated drought years. From Figure 5 (a) and Figure 5 (b) it can be seen that with time, precipitation and soil moisture are increasing in the region. All highs

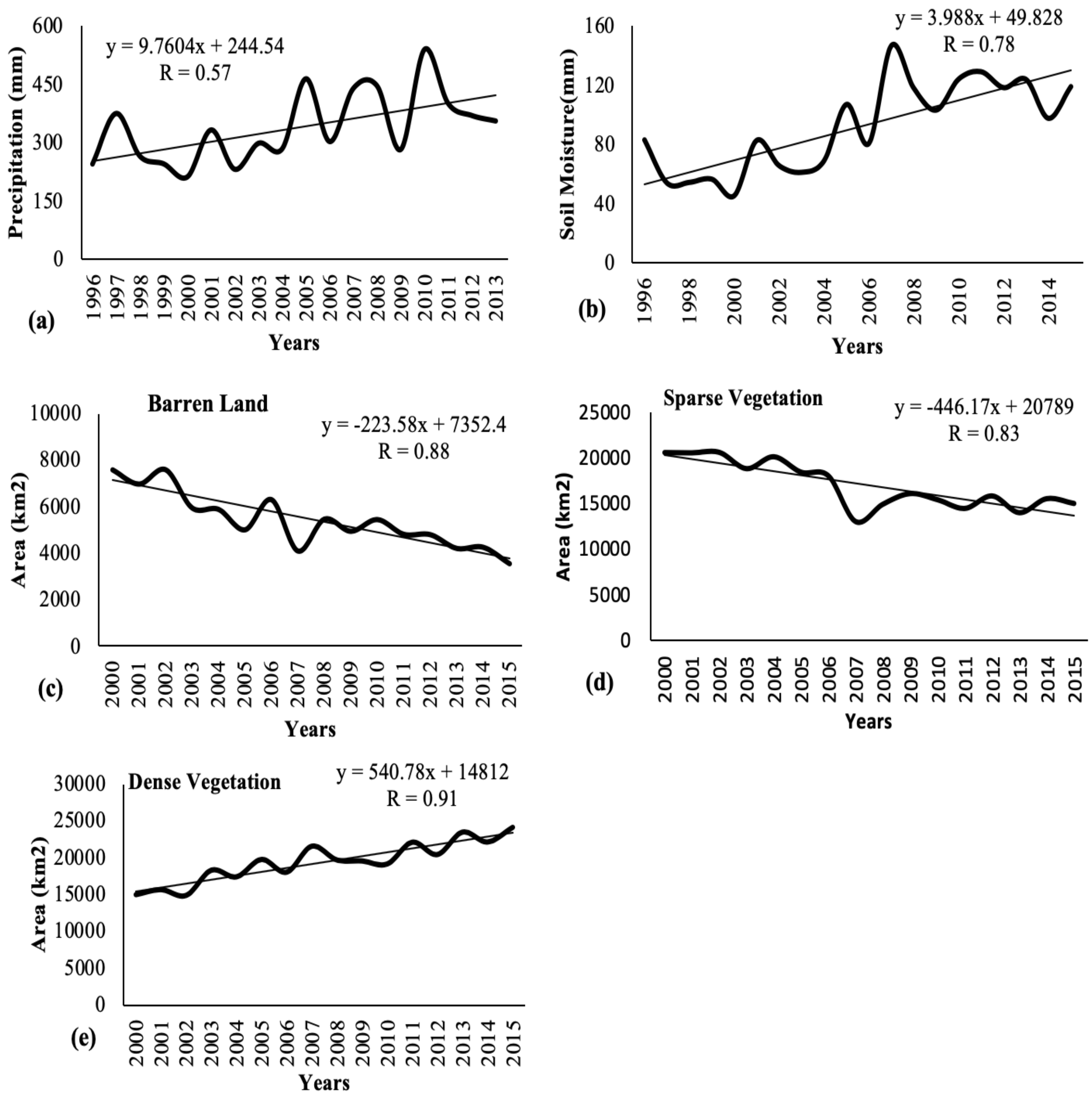

Figure 5: *Yearly analysis of precipitation (a), Soil moisture (b), Barren (c), Sparse (d) and Dens (e) Vegetation.*

and lows of both the parameters are well correlating with each other and delineated drought years. In year 2000, both Precipitation and Soil Moisture have the min. values of 211 mm and 45 mm with R values of 0.57 and 0.78 respectively.

Soil moisture and precipitation relation of barren land, sparse vegetation, dense vegetation

The relationship of soil moisture and precipitation with the land classification are given in Figure 6. Fascinatingly, it was found that the relation between precipitation and barren land and sparse vegetation has opposite relation. In other words, whenever high precipitation occurred in the study periods the area under barren land and sparse vegetation was very low. Ultimately, the area under dense vegetation was increased in in non-drought years. Therefore, it was found that barren land as highly affected by precipitation variations as compared to sparse vegetation. Precipitation and dense vegetation has linear positive relation.

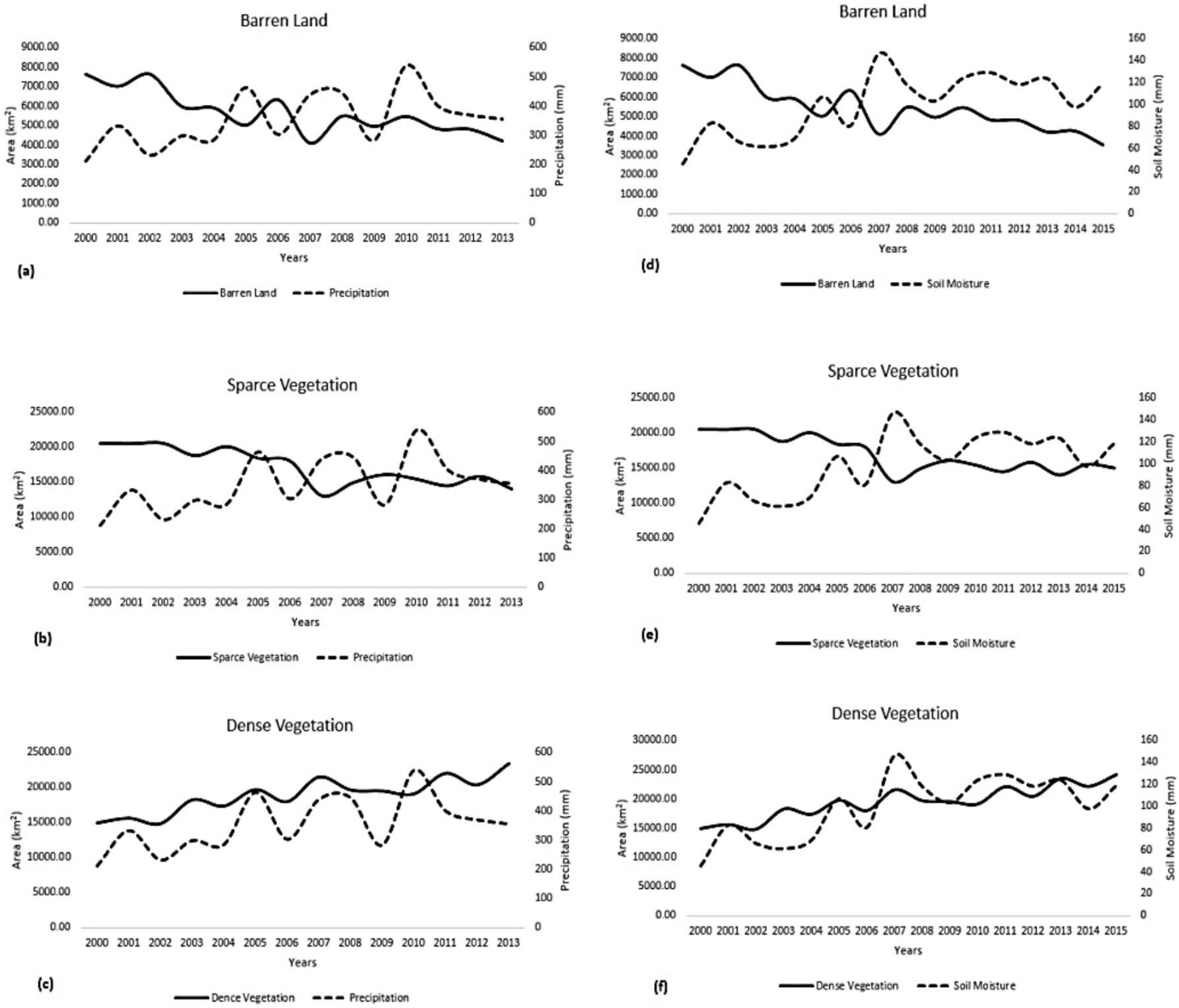

Figure 6: *Soil Moisture and Precipitation Relation with Barren land (a) (d), Sparse Vegetation (b) (e), Dense Vegetation (c) (f).*

Spatial analysis

DEV: The deviation of NDVI from the long-term mean (DEV_{NDVI}) can be a good representative of degree of the drought intensity. It was calculated using Equation given below;

$$DEV_{NDVI} = NDVI_i - NDVI_{mean,\ m}$$

Where;

DEV_{NDVI} = deviation of *NDVI* from the long-term mean, $NDVI_i$ = *NDVI* value of current month and $NDVI_{mean,\ m}$ = *NDVI* mean value for that month for longer period of time.

The results of deviation of NDVI from the long-term mean are presented in Figure 7. For the year 2000, the resulted maps show spatial severity of drought that of the DEVNDVI in the area. In these maps the negative values represent the drought and dark yellow indicated the low drought and dark red represents high drought regions. However light yellow and dark green colored delineate the wet and vegetated surroundings. The maps show that in February 2000, the minor drought was found in the middle of study area. The drought conditions fortify in center in months of March and April (Figures 7b and 7c). The drought happening to progress at east and west boundaries of Thal region from the months of May to July and become more intensive in June

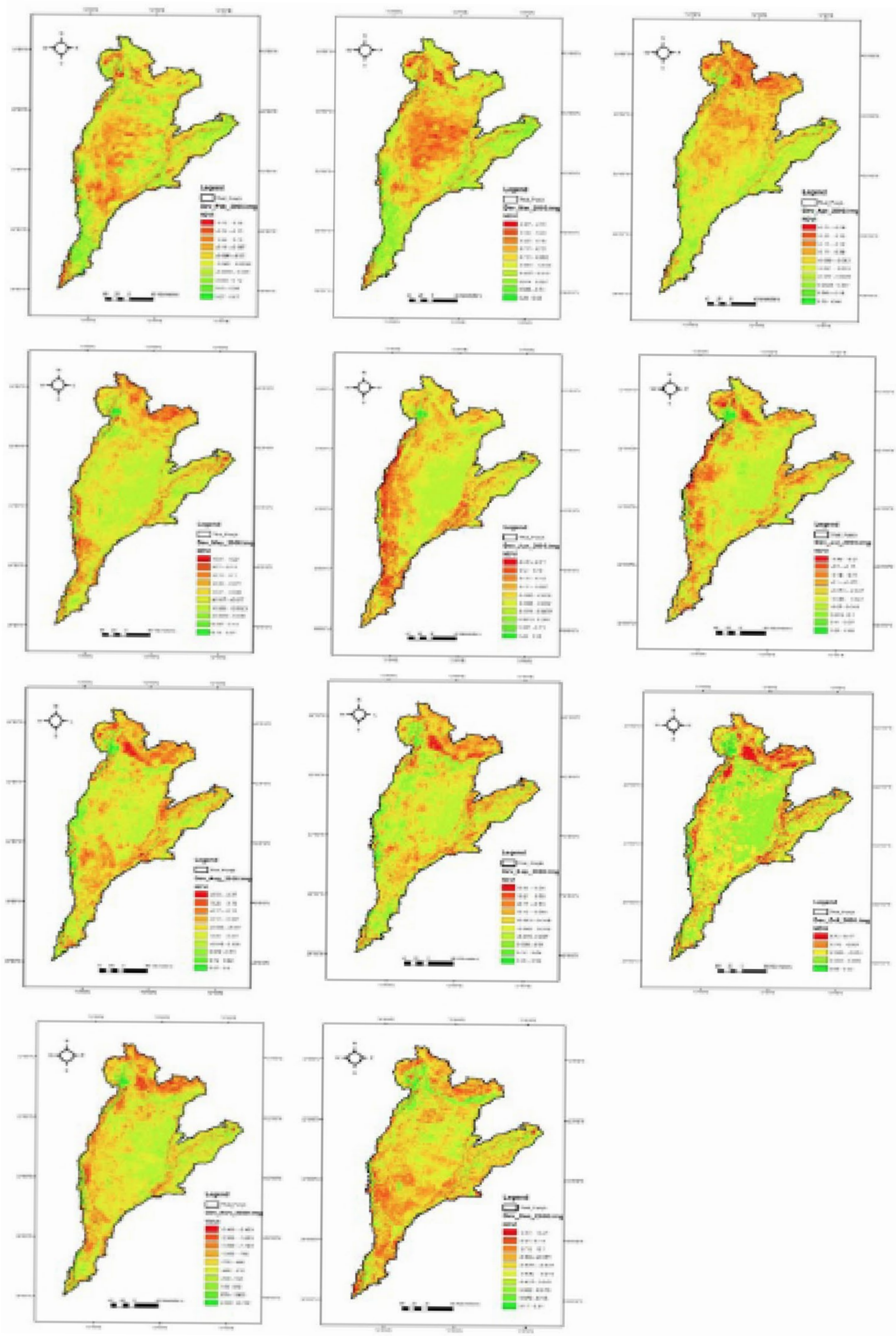

Figure 7: *DEVNDVI of Drought year 2000 calculated from long term means of respective months in a year; (a) Feb, (b) Mar, (c) Apr, (d), May, (e) Jun, (f) Jul, (g) Aug, (h) Sep, (i) Oct, (j) Nov, (k) Dec.*

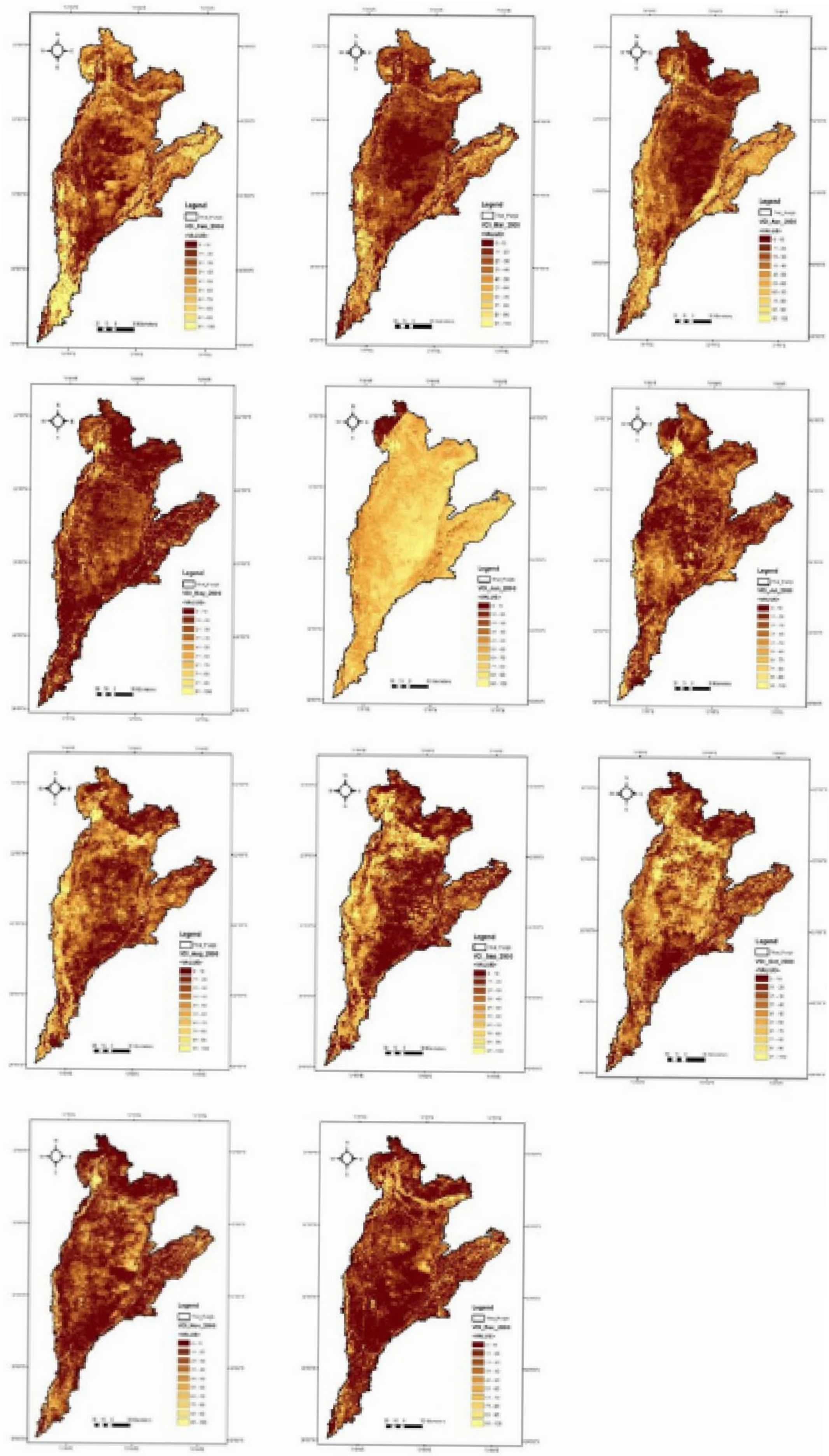

Figure 8: *VCI of Drought year 2000 calculated from long term minimum and maximum of respective months in a year; (a) Feb, (b) Mar, (c) Apr, (d), May, (e) Jun, (f) Jul, (g) Aug, (h) Sep, (i) Oct, (j) Nov, (k) Dec*

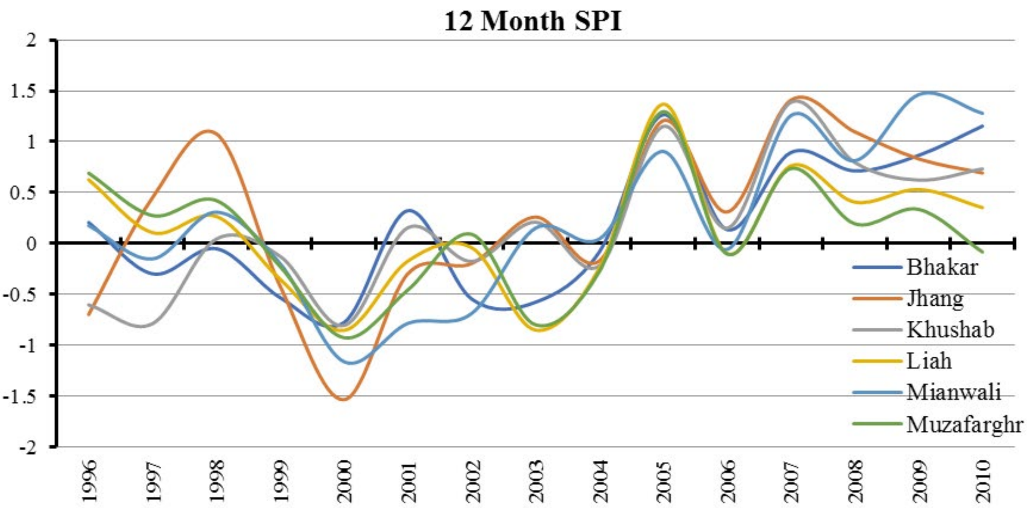

Figure 9: *12-Month SPI of the districts of Thal region.*

(Figures 7d, e, f), from Aug-Oct drought started to develop in extreme North (Figure 7(g), (h), (i)). In Nov-Dec drought started to retreat from the region and dry condition started to scatter Figure 7(j), (k).

VCI: According to (Kogan, 1997) Vegetation Condition Index (VCI) essentially is the calculation of current time step and long term minimum NDVI and shows how close is the current time step is to long term minimum NDVI. VCI is calculated as:

$$VCI= ((NDVI_J-NDVI_{min})/ (NDVI_{max} - NDVI_{min})) *100$$

Figure 8 illustrate VCI of Drought year 2000 calculated from long term minimum and maximum of respective months in a year.

Standardized Precipitation Index (SPI)

Standardized Precipitation Index (SPI) is extensively applied method for observing and calculation of regional drought. In this research SPI was also applied on baseline 1980-2010 data of precipitation from ground stations and temporal assessments were performed. The SPI indices were calculated for 12-month for each year for all the districts as shown in Figure 9. In year 2000, the area surrounded Mianwali district was faced moderate dry conditions with SPI index of -1.16 and Jhang district faced severe dry condition (SPI -1.54). Whereas, the districts of Bhakar, Khushab, Liah and Muzafarghr were saved from dry conditions.

Conclusions and Recommendations

The precipitation data were analyzed on monthly, yearly and seasonal bases. Precipitation, Soil Moisture and different NDVI Ranges (Barren land, Sparse Vegetation, Dense Vegetation) to verify delineated drought years. Interestingly, it was found that the barren land and sparse vegetation has inverse relation with precipitation while dense vegetation has linear relation with Precipitation. In spatial analysis of DEVNDVI during start of 2000 in month of February there were mild drought conditions in the center of study area. In March and April drought conditions harden in center. From May-Jul drought started to mature at east and west boundaries of region and fortify in June. From Aug-Oct drought happening to grow in extreme North. In Nov-Dec drought happening to evacuate from region and dry condition started to scatter. Likewise, in Spatial analysis of VCI from March and April drought situations strengthen in middle of study area. From May-Jul drought was appeared at south, east and west boundaries of region and drought was declined in Jun. From Aug-Oct relatively drought was intensive but it was still active in center. The drought was again increased in Nov-Dec in the region.

Author's Contribution

Muhammad Amin: Satellite Data processing and Analysis.
Abida Perveen: Climate data analysis.
Zareen Rauf: Climate and satellite data comparison for results.
Aftab Ahmad Khan: Discussion, result presentation and referencing
Sher Shah Hassan: Paper structure, writeup, formatting and corresponding with journal.

Muhammad Arif Goheer: General review and proof reading.
Muhammad Ijaz: Literature review, conclusion and review editing.

References

Aslam, M., I.A. Mahmood, T.S. Sultan, Ahmad and M.A. Zahid. 2000. Growth and yield response of chickpea (Cicer arientinum) to various rhizobium strains fertilized with different phosphorus. Int. J. Agric. Biol. 2 (1): 1-2.

Blidaru, T.V., C. Cismaru, I. Bartha, D. Scripcariu, O. Liliana and V. Gabor. 2000. Possibilities of irrigation management in drought conditions through Geographical Information System (GIS) usage, with application in the Prut river basin, ICID. J. Irrig. Dri. 1-5.

Chandresekar, K., S. Sesha, M.V.R. Jeyaseelan, A.T. Dwivedi and P.S. Roy. 2006. Vegetation response to rainfall as monitored by NOAA-AVHRR. Curr. Sci. 91(12): 1626-1633.

Chopra, P. 2006. Drought risk assessment using remote sensing and GIS: A case study in Gujrat. MS Thesis (ITC). Netherlands and (IIRS) India.

Dilley, M., R.S. Chen, U. Deichmann, A.L. Lerner-Lam and M. Arnold. 2005. Natural disaster hotspots: a global risk analysis. Synthesis report. Int. Bank Reconstr. Dev. Washington, DC. https://doi.org/10.1596/0-8213-5930-4

Ericksen, P.J. 2008. Conceptualizing food systems for global environmental change research. Glob. Environ. Change. 18: 234 – 245. https://doi.org/10.1016/j.gloenvcha.2007.09.002

Gore, P.G., K.C.S. Ray. 2002. Drought and aridity over districts of Gujarat. J. Agrometeorol. 4: 75–85.

Hammouri, N. and A.E. Naqa. 2007. Drought assessment using GIS and remote sensing in Amman-Zarqa Basin, Jordan. J. Civ. Eng. 1: (2).

Hayes, M.J. 2000. Revisiting the SPI: clarifying the process. Drought network news. 11314.

Helmer, M., D. Hilhorst. 2006. Natural disasters and climate change. Disasters. 30: 1–4. https://doi.org/10.1111/j.1467-9523.2006.00302.x

IPCC, 2007. Climate change 2007: The physical science basis contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Kogan, F.N., 1997. Global drought watch from space. Bull. Am. Meteorolog. Soc. 78(4): 621-636.

McKee, T.B., N.J.Doesken and J. Kleist. 1993. The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference on Applied Climatology (Vol. 17, No. 22, pp. 179-183). Boston, MA: American Meteorological Society.

Mendicino, G., A. Senatore and P. Versace. 2008. A groundwater resource index (GRI) for drought monitoring and forecasting in a Mediterranean climate. J. Hydrol. 357: 282–302. https://doi.org/10.1016/j.jhydrol.2008.05.005

Nagarajan, R., B.J. Weigel, R.C.Thompson and J.P. Perentesis. 2003. Osteosarcoma in the first decade of life. Med. Pediat. Oncolog. 41(5): 480-483.

Rosegrant, M.W. and S.A. Cline. 2003. Global food security: challenges and policies. Sci. 302: 1917–1919. https://doi.org/10.1126/science.1092958

Tubiello, F.N., J.F. Soussana and S.M. Howden. 2007. Climate change and food security special feature: crop and pasture response to climate change. Proc. Nat. Acad. Sci. USA. 104: 19686–19690. https://doi.org/10.1073/pnas.0701728104

UNDP. 2004. Reducing disaster risk: a challenge for development. A global report. UNDP, New York. Available at www.undp.org/cpr/whats_new/rdr_english.pdf