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SHORT-TERM DROUGHT ASSESSMENT IN PAKISTAN AND ADJOINING AREAS BY REMOTE SENSING MODIS-NDVI DATA: A POTENTIAL CONSEQUENCE OF CLIMATE CHANGE

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Abstract

Currently normalized difference vegetation index (NDVI) is extensively used for appraise vegetation composition, structure, stratification and distribution. Spatial and temporal rainfall distribution and its effect on NDVI can be helpful for drought examining. This study has been done to improved comprehend this association. The response of vegetation growth to current climate change in Pakistan and adjoining south Asian countries (22–42°N, 60–80°E) were investigated by analyzing the time series of the NDVI maps. We also obtained and analyzed time series of different variable *i.e.* rainfall, soil moisture, evapotranspiration and soil temperature model data, through NASA Geospatial Interactive Online Visualization and analysis Infrastructure (Giovanni) system, during Jan- Dec, 2014 for every three month interval. The NOAA Climate Prediction Center from International Research institute (IRI) for climate and society's platform was also used for rainfall anomaly data. We found that NDVI values varies and depend on land cover types and its spatial location and dependant on rainfall. We found a strong positive relationship among NDVI, rainfall and soil moisture. Seasonal variations of rainfall are having also affects on evapotranspiration, soil temperature, and soil moisture conditions.

Key words: Vegetation assessment, Normalized difference Vegetation index (NDVI), Remote sensing, Drought assessment, Drought monitoring, Climate, Pakistan.

Introduction

Vegetation indices are important remotely sensed metrics for ecosystem monitoring and land surface process assessment, among which Normalized Difference Vegetation Index (NDVI) has been most widely used (Nicholson *et al.,* 1994; Ichii *et al.,* 2002; Wang *et al.,* 2003; Gu *et al.,* 2008; Khan *et al.,* 2010). Rising temperature and altered precipitation patterns, leads to the extreme weather events like drought, which drastically affects the agricultural production and natural vegetation (Nicholson *et al.,* 1994; Farrar *et al.,* 1994). Drought is nothing but the turn down in the productivity of crops due to irregularities in the rainfall as well as a decrease in the soil moisture, which in turn affects the economy of the nation (Bolton & Friedl, 2013). As the South Asian vegetation and cropping is largely dependent on the Monsoon, a slight change in it affects the production as well as the crop yield drastically.

In an effort to achieve a better understanding of drought processes, the characteristics of their occurrence need to be systematically formulated with continuing data analysis. Several research organizations like NASA, Global Water Partnership (GWP), World Meteorological Organization (WMO), The National Drought Mitigation Center (NDMC) and so many others are doing research on water management and drought conditions from local to global level. Water management scientists developed Drought Indicators System (DIS) that has 7 indicators as following (Sepulcre *et al.,* 2012; Stahl *et al.,* 2012; Wardlow *et al.,* 2012; GWP, 2015):

1. Standardized Precipitation Index (SPI)
2. Fraction of Absorbed Photossynthetically Active Radiation (fAPAR)
3. WEI +: Water Exploitation Index Plus
4. Snowpack indicator
5. Standardized Run off Index (SRI)
6. Groundwater indicator
7. Soil Moisture indicator

Most countries in the South Asian region mainly use traditional methods in applying climate indices like (Standardized Precipitation Index) SPI in drought assessment and monitoring on rainfall data. Drought monitoring, estimation and its management can be done more accurately with the help of geospatial techniques like NDVI assessment that is useful method in Remote Sensing (Horionet *et al.,* 2012; Eckert *et al.,* 2015). Interpretation of satellite data potentially confers much greater spatial and temporal coverage of drought conditions than from site measurements of soil moisture and precipitation, and any relationships identified between these indicators might greatly improve future drought monitoring efforts globally (Gu *et al.,* 2008; Caccamo *et al.,* 2011; Köksal *et al.,* 2012; Poggio *et al.,* 2013).

Remote sensing technology grants alternate information with advanced sequential and spatial characteristics of the regions (Khan *et al.,* 2015). However, other inputs like soil water content that is usually adjusted with rainfall distribution, soil capillarity and drainage, surface run-off, rate of evapotranspiration, and irrigation still need to be incorporated in order to systematically explain the anomaly in vegetation caused by drought for a long term study. In this study we appraise short term assessment with remote sensing tools. This study addresses three key questions. (1) What climatic variables (e.g. rainfall, soil moisture soil temperature and evapotranspiration) best explain variation in NDVI? (2) How rapidly and over what time period does NDVI respond to different patterns of rainfall, temperature and evapotranspiration? (3) How does NDVI respond to variation of climatic factors for different land cover categories, in particular grassland, cropland, forest and desert areas? In this study, we examined influences of rainfall, soil moisture and temperature on the patterns of NDVI in the Pakistan and neighboring areas in month wise assessment in 2014.

The main objective of this study is provide an analysis of NDVI and climatic variables of Pakistan and some adjoining areas to assess drought conditions within no time and without any other assistance. In this drought monitoring study by using remote sensing is based on following methods:

1. Assessment of vegetation (Monitoring NDVI)
2. Assessment of rainfall
3. Evaluation of soil moisture
4. Strength of relationship among variables *i.e.* NDVI, rainfall and soil moisture
5. Estimation of evapotranspiration and rainfall association
6. Temporal measurement of rainfall, soil moisture, evapotranspiration and soil temperature data.

Materials and Methods

The response of vegetation growth to current climate change in Pakistan and adjoining south Asian countries (22–42°N, 60–80°E) were investigated by analyzing the time series of the NDVI maps and data. We also obtained and analyzed month wise time series of different variable *i.e.*, rainfall, soil moisture, evapotranspiration and soil temperature data with the Moderate Resolution Imaging Spectroradiometer (MODIS), and the Goddard Earth Sciences Data and Information Services Center (GES DISC) online data analysis system Giovanni to assess NDVI and other climatic variables from Jan- Dec, during the year 2014. NDVI time series maps and data are based on the maximum value compositing monthly product Data Enhanced Investigations for Climate Change Education (DICCE) Basic Monthly Data Portal, and Global Land Data Assimilation System (GLDAS) by NASA GES DISC (http://disc.sci.gsfc.nasa.gov/giovanni). Rainfall anomaly data is also obtained from the NOAA Climate Prediction Center from International Research Institute (IRI) for climate and society's platform (http://iridl.ldeo.columbia.edu). The IRI was established as a cooperative agreement between NOAA's Climate Program Office and Columbia University.

Results and Discussion

We found that NDVI magnitude varies and depend on land cover types and its spatial location. Forest, crop land, grassland and desert are having NDVI quantity from very high, high, low and very low respectively (Fig. 1). Forest areas are having highest NDVI values as it receives both monsoon and winter rainfall while Crop land NDVI shows two peaks, as two growing seasons of agriculture (Fig. 1). We also found a strong positive relationship among NDVI, rainfall and soil moisture (Fig. 2). It means that remote sensing data is useful for monitor these variables to assess drought conditions. Reduction in precipitation is causing low soil moisture that leading to decline NDVI values.

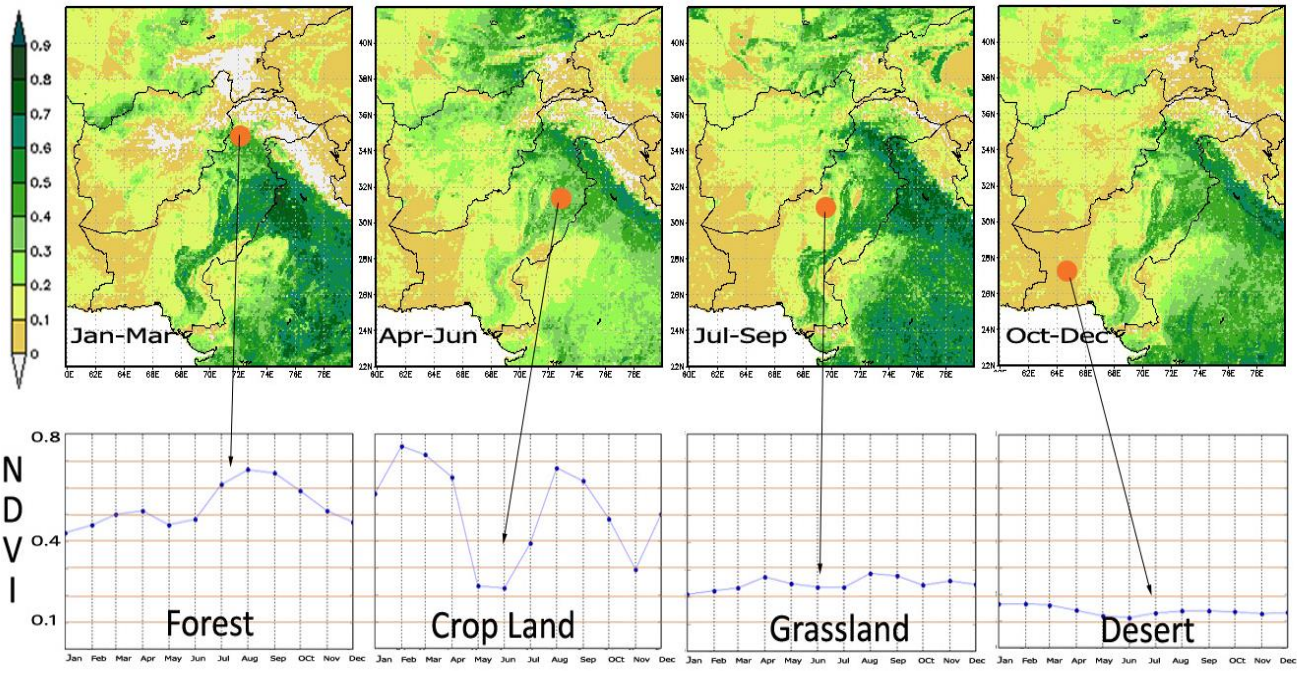

Fig. 1. Above: Images are derived from three monthly climatology of NDVI year 2014 from Jan-March, Apr-Jun, Jul-Sep and Oct-Dec at 5.6 km from MODIS-Terra. Below: Time series shows, seasonal variation of NDVI over different land cover types.

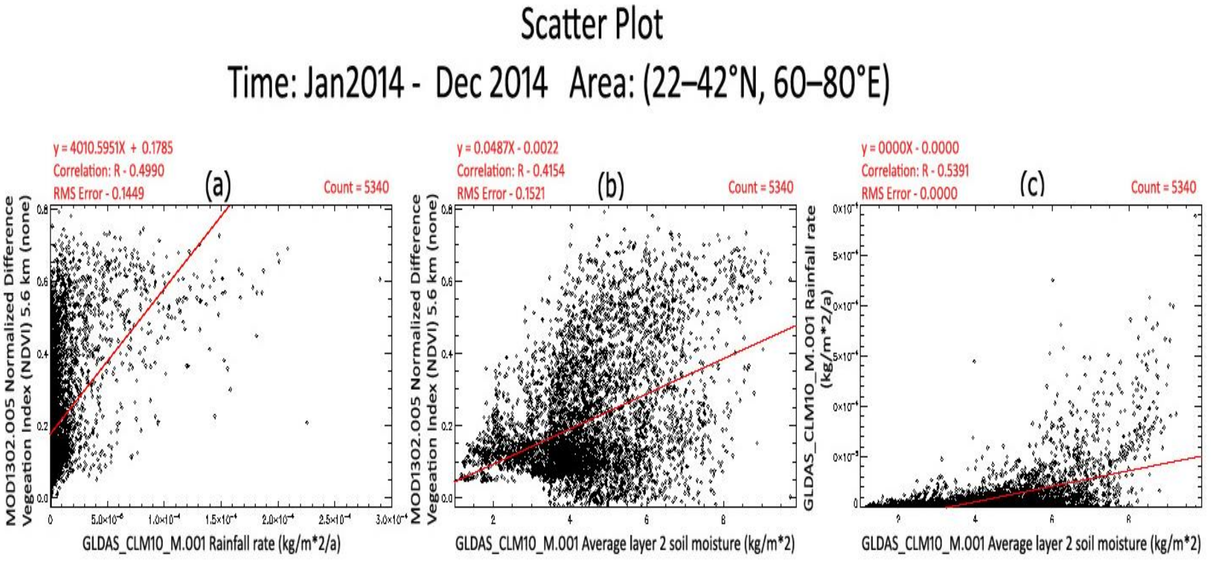

Fig. 2. Correlation among variables (a) NDVI with rainfall (b) NDVI with soil moisture (c) Soil moisture with rainfall.

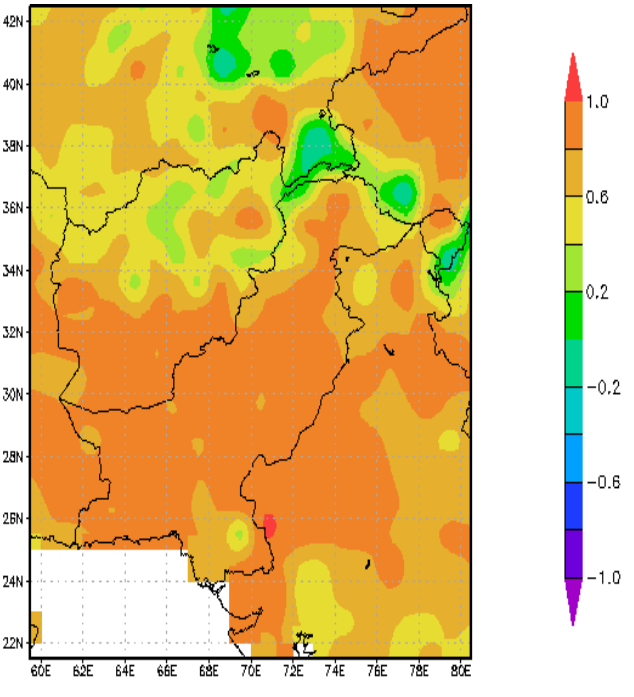

Fig. 3. Correlation map of evapotranspiration and rainfall.

Correlation map of evapotranspiration and rainfall of the study area showed in Fig. 3. Almost all types of land cover, including high and plain areas are affected by high temperature. The study area lies in BWh region (mild desert category) of Koppen's classification that is arid and semi arid. High temperature with low rainfall can affect soil moisture conditions so this area is having a high risk zone for a drought occurrence while small amount of variation can concern with millions of people (Zhang & Jia, 2013).

Seasonal variation of rainfall affects on evapotranspiration, soil temperature, and soil moisture (Fig. 4). When rainfall decline while temperature and the evapotranspiration rate remain the same, it will cause a reduction in soil moisture and ultimately low NDVI values. Almost every type of land cover has low NDVI values along with low rainfall and low soil moisture during October to December (Fig. 4 red circle). Seasonal anomaly of rainfall data from June to August 2014 is described in Fig. 5 which showed the distribution of 25, 50 and 100 mm lesser rainfall as compared to normal rainfall in these days. Even this 100mm lesser rain has immense significance because in most areas of this region rainfall occurrence is less than 250mm annually. The area is plain and used for crop cultivation while it also receives some amount of water through winter rainfall by western depression while summer monsoon rainfall is the major component.

Decline in the rainfall may develop drought conditions. This analysis has many limitations; larger duration (at least 3 years) with the modeling approach could provide much better information and results. However, this study provides some vital understanding to use of remote sensing data to monitor, assess and analyzed many environmental variables that could collectively describe drought conditions and climatic variations.

Variation of rainfall: The distribution of monsoon rainfall varies intra-seasonally, intra-annually, and inter-regionally. Such variation of rainfall causes meteorological risks like aridity and drought. As this short term assessment or earlier describe results verifies that the amount of rainfall is declining. This unusual continuous dry weather of long duration is producing a serious agricultural, ecological, or hydrological difference. Millions of people of South Asia are reliant on agriculture related livelihoods, they are mostly poor and exposed to high levels of vulnerability to drought (Kates *et al.*, 1987; Vicente- Serrano *et al.*, 2012; Khakwani *et al.*, 2012; Marengo *et al.*, 2013; Zhang & Jia, 2013; Birthal *et al.*, 2015). It is also creating significant socio-economic problems. The lack of rain is effecting in crop loss, a decrease in land prices, and joblessness due to declines in agro-production (Melton *et al.*, 2014).

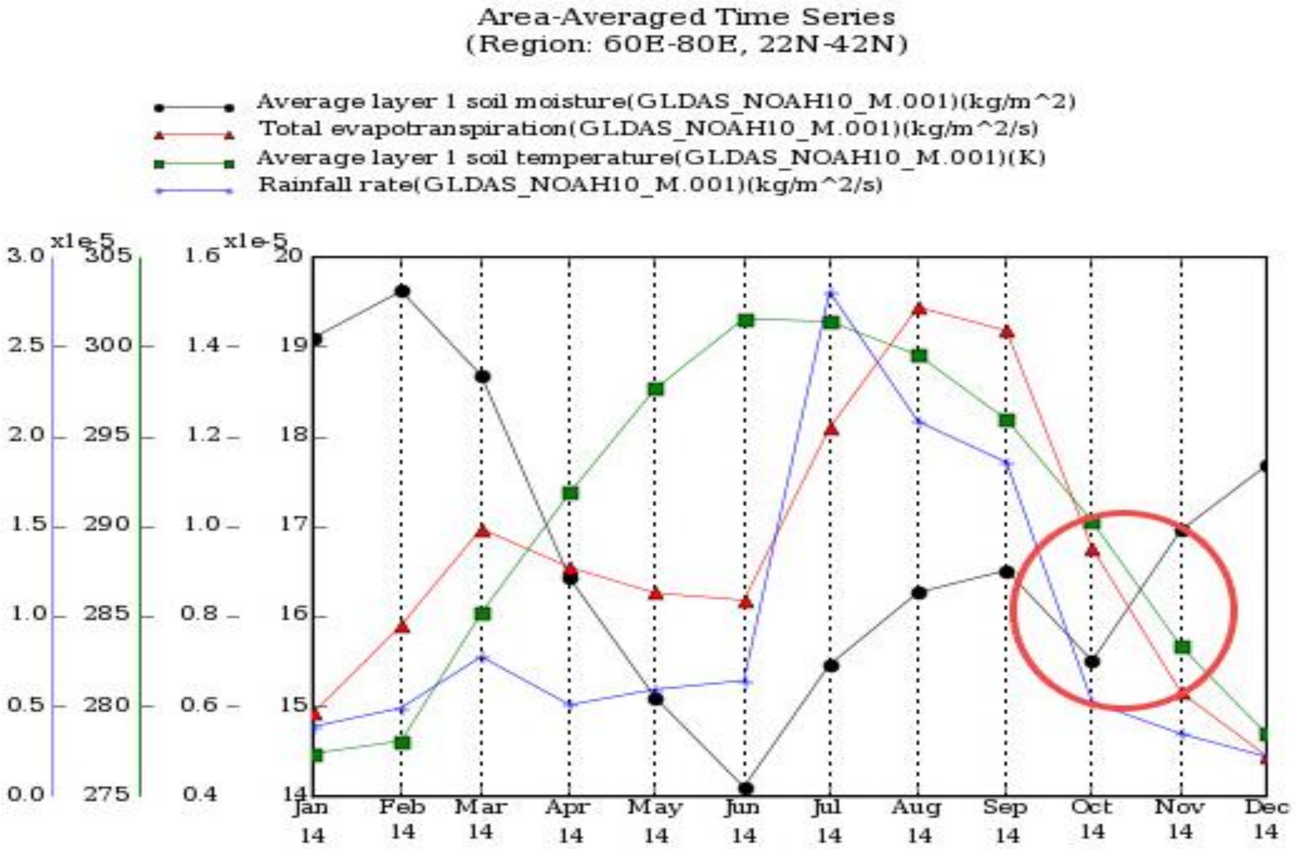

Fig. 4. Monthly (Time series) data of rainfall data, soil moisture, evapotranspiration and soil temperature.

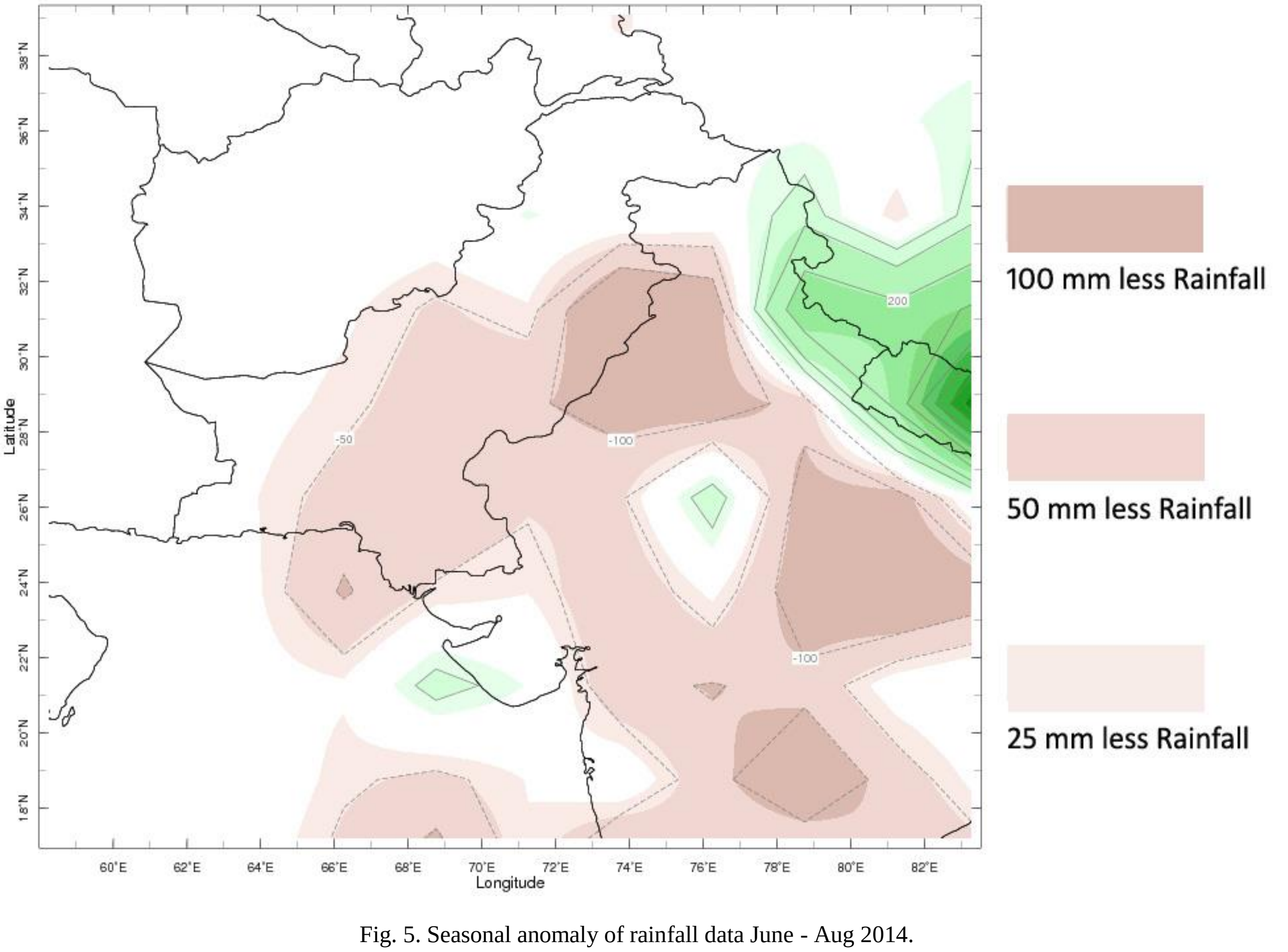

Fig. 5. Seasonal anomaly of rainfall data June - Aug 2014.

Impact on highly populated poor areas: Insufficient precipitation, high evapotranspiration and over exploitation of water resources are consequences of severe water scarcity during drought (Bhuiyan *et al*., 2006). From early 2000 onwards severe droughts affected vast areas of South Asia, including Western India, Southern and Central Pakistan. The South Asian regions have been surrounded by the perennially drought-prone regions of the world including Afghanistan, India, Pakistan and Sri Lanka (Joshi *et al.*, 2004). These countries have reported that drought occur at least once in every three year period in the past five decades, while Bangladesh and Nepal also suffer from drought frequently. In Pakistan and adjoining countries like India, Iran and Afghanistan the majority population still engage with agriculture and agro based industries. In 2012, Pakistan declared emergency in Tharparkar and Mirpur Khas districts due to severe drought and many people had to be re-settled (Miyan, 2015). A study reveals that the monsoon has been delayed by 20 to 30 days affecting crops and livelihoods (Krishnamurthy & James, 2003). The terrible affects of drought highly significant worldwide, global drought mapped by the University College of London shows 258 million people affected internationally by exceptional drought in last 3 years (Miyan, 2015).

Harmful effects on ecology: Environment and ecology is also in danger by drought severity. Harmful impacts include habitats loss, destroy of biodiversity, soil erosion, and a superior risk from wildfires (Eisenhauer *et al.,* 2012, Anderegg *et al.,* 2013; Grossiord *et al.,* 2014). Water supply problems are developing water levels in rivers and lakes go down. These are causing other social and health related problems for example lack of water, poor nutrition, and food crisis (Ashraf *et al.,* 2007; Ding *et al.,* 2011). Additionally other troubles may include clashes over water use and foodstuff, and forced migration away from drought suffering areas to protected place (Saatchi *et al.,* 2013; Bokal *et al.,* 2014).

Strength and limitations: This present study has several limitations because of lesser time period mainly; however it provides some very important information to review drought condition at somehow preliminary stage to make useful decisions. As the integration of traditional meteorological data along with long-term remotely sensed drought statistics could be great support for drought assessment. Additionally collectively information on vegetation type, elevation, and artificial irrigation with this study design, can also provide a hopeful approach to better understanding of drought intensity and its spatial extent. Remote sensing has now become a wonderful tool to assess several climatic and environmental phenomena's like we practically use NDVI and allied data for drought assessment. GES DISC NASA portal and NOAA Climate Prediction Center together with International Research Institute (IRI) are very useful institutes that provides several research tools for environmental monitoring and this type of observable fact (Khan *et al.,* 2015).

Conclusion

This study demonstrates a strong association between factors like rainfall, soil moisture and NDVI. Decline in the rainfall is developing drought conditions in many areas of the study area. This study tells us that unanticipated changes in rainfall declining may consequential to disappearing in NDVI values means vanishing in vegetation or occurring of drought conditions. Assessing the regional scale drought condition with remote sensing data is very important for this very high deprived populated region.

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