Assessment of Drought Risk by Using Vegetation Indices from Remotely Sensed Data: A Perspective from Hot and Arid District of Pakistan

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Abstract-The Shaheed Benazir Abad District is situated at the center of Sindh Province, which is one of the hottest and driest part of Pakistan. In the past few decades, the extreme and moderate droughts had been reported in the district with peak value -2.4 recorded using the Standardized Precipitation Index (SPI). In this study, satellite remote sensing and digital image processing techniques were used to monitor the drought conditions in the district. Multiple drought indices were calculated by using Thematic Mapper (TM) data of the Landsat satellite program, jointly managed by the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA), including Land Surface Temperature (LST), Normalized Vegetation Index (NDVI), Vegetation Condition Index (VCI) and Temperature Vegetation Index (TVX). These indices provided the agricultural drought conditions for the duration of 1992-2011. The VCI maps indicated the high drought conditions in the plain land, away from the built-up areas, while the proximity of the built-up land is under a moderate drought. However, in cultivated lands, the agriculture drought condition is not obvious due to canal irrigated cultivation. A drought in year 2011, was more severe than in the year 2000. It is an indication of climate change impacts in the region.

Keywords-Drought, Remote Sensing, GIS, Vegetation Indices, NDVI, VCI, LST

I. Introduction

A universally accepted definition of drought does not exist because this natural disaster is a complex but least understood phenomenon [i]. The major reason of this disaster is a deficiency of precipitation or shortage of water [ii]. Depending on the specific interest of different people, drought has different meanings. For a former, it is a shortage of moisture in the root zone of crops; whereas hydrologists suggest that it is below the average water level in stream, reservoir and lake, and economists define it as a shortage, which affects the established economy. The drought is considered as a unique event in its spatial expansion, climate characteristics and impact [iii].

Pakistan is facing by and large arid to hyper-arid climate condition in which its limited surface and ground water availability have been reduced from 5600 cubic meters per capita to 1200 cubic meters per capitafor the duration of 1947-2001[iv]. In the last few decades, extreme and moderate droughts have been observed in many parts of the country including Shaheed Benazir Abad, wherea peak value of Standardized Precipitation Index (SPI) was assessed -2.4 during 1975-2003 [v]. The SPI is an empirical drought monitoring index that is calculated as the difference of precipitation from the mean divided by the standard deviation. It is a theoretical probability distribution, which is calculated based on a long-term precipitation record of data for a desired period. Drought occurs when the SPI value reaches -1 or less [vi]. Using SPI for drought monitoring have some

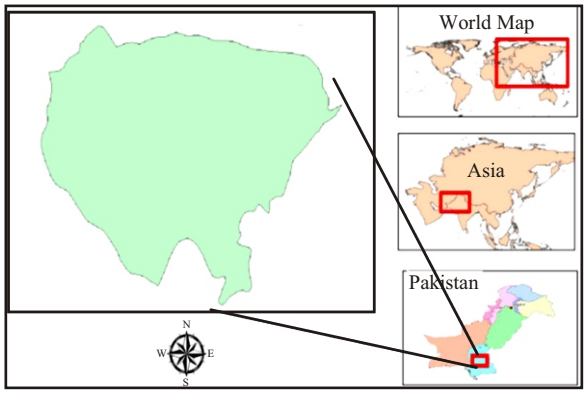


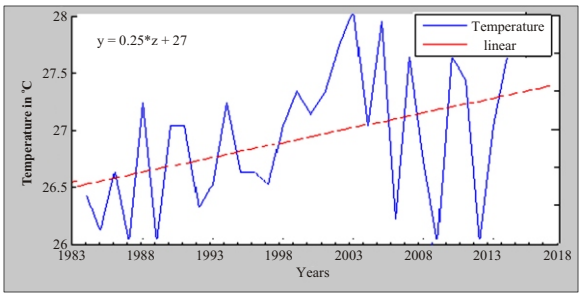
Fig. 1. Study Area "Shaheed Benazir Abad"

disadvantages, the first being the assumption that a suitable theoretical probability distribution can be found to model the raw precipitation data prior to standardization. The second disadvantage is that the extreme drought condition occurs over longer period with the same frequency in all locations; therefore, identification of the drought prone region is difficult [vii, viii]. Moreover, area with small seasonal precipitation causes misleading the large positive and negative values of SPI [vii , viii].

Integrated remote sensing and GIS technologies have become the most efficient way to systematically retrieve information from the atmosphere, land surface, and water resources. The long time period and large region data collection represent a great advantage for the natural resource monitoring, disaster risk assessment and dynamics processes studies. These are cost effective and give the up-to-date information over a large geographical area [ix, x]. The vegetation index NDVI is most frequently used to classify the land cover of a region [xi]. It has been successfully and effectively employed by geographers in different studies to appraise vegetation vigor all over the world [xi]. The statistical relationship between drought indices and NDVI at regional scale has been presented in many studies, for instance Boushaki [xii]. Many researchers, including Ramesh [xiii] and Kogan [xiv] have used the Advanced Very High Resolution Radiometer (AVHRR) onboard the National Oceanic and Atmospheric Administration (NOAA) series of satellites to show the application of vegetation and temperature condition indices for drought monitoring. A comparison of vegetation Indices over a Global set of TM Images with EOS-MODIS has been done by Huete [xv]. Liu [xvi] highlighted the VCI as a useful tool to analyze temporal and spatial evolution of the regional drought as well as to estimate regional agriculture production qualitatively. The VCI can give a comprehensive picture for drought analysis and decision- making [xvii].

Shaheed Benazir Abad is known as a lush agricultural area irrigated by canal network, which is situated in the geographical center of the Sindh province of Pakistan (see Fig. 1). It is one of the hottest and driest part of the country and it has arid environment due to the less precipitation.

The average temperature of Shaheed Benazir Abad is 26.6°C and precipitation averages is 143 mm. Using



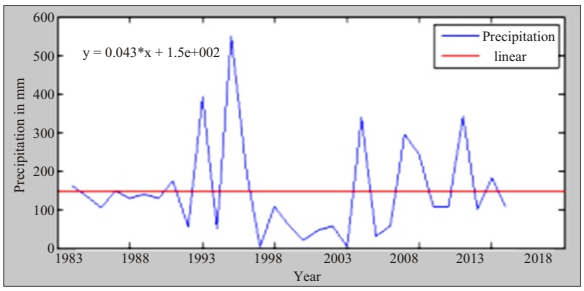


Fig. 2. Precipitation and Temperature Pattern in Shaheed Benazir Abad during 1983 to 2013

the Matlab software, temperature and precipitation trends are observed in Shaheed Benazir Abad for duration of 1980 to 2013 as shown in Fig. 2, which indicate a rising trend in temperature and no change in precipitation trend over the time.

The focus of this paper is to monitor the drought risk in Shaheed Benazir Abad, using remote sensing and GIS techniques by calculating NDVI, LST, TVX and VCI for the duration 1992-2011. These vegetation indices have identified drought prone regions.

II. Materials and Methods

NDVI and VCI can provide a comprehensive picture for drought monitoring, analyzing, and decision-making. Lower value of VCI in percentage, indicates higher degree of drought, whereas higher percentage value reflects lower drought Table I. It provides a quantitative estimate of weather impact on vegetation and also measures the vegetation condition. It gives a synoptic view of the land surface and a spatial context for measuring drought impacts in a convenient spatio-temporal approximation. VCI can be represented by the following equation:

$$VCI = \frac{NDVI - NDVImin}{NDVI\ max - NDVImin} \quad (1)$$

Where, NDVI, NDVImax, and NDVImin are given year NDVI, multiyear maximum NDVI and multiyear minimum NDVI, respectively, for each grid cell [xviii].

TABLE I
VCI-Criteria of Drought Conditions

Drought Condition	VCI (%)
Extreme	1 - 10
High	10 - 20
Moderate	20 - 30
Low	30 - 40
No Drought	40 >

The ratio of LST and NDVI, known as TVX, gives more spectral information for drought detection because it integrates both reflective and thermal bands

of remotely sensed data [vii]. It is also used to examine the local moist conditions [xix]. It can be defined as follows:

$$TVX = \frac{LST}{NDVI} \quad (2)$$

ArcGIS, a geographical information system software, works on both raster and vector maps, has been used for calculating the LST and vegetation indices. Landsat-5 TM images for the month of June (1992, 2000, 2009, 2010, and 2011) were used for generating the maps. First, all historical images were radiometrically corrected by converting digital number DN into Spectral radiance with the help of the given equation:

$$L\lambda = Lmin + (Lmax - Lmin) * \frac{DN}{255} \quad (3)$$

Where,
Lλ = Spectral radiance,
Lmin = Spectral radiance of DN value 1
Lmax = Spectral radiance of DN value 255,
DN = Digital Number.

In the next step for calculation of LST, the brightness temperature was computed from the spectral radiance at the thermal band (band 6) by the equations [xx]:

$$Tb = \frac{K2}{\ln\left(\frac{K1}{L\lambda}\right)} + 1 \quad (4)$$

Where, K1 and K2 are constants (for Landsat 5 TM: K2 = 1260.56 and K1 = 607.76)
Lλ is the spectral radiance at band 6.
Then, the surface temperature has been computed from the brightness temperature as:

$$LST = \frac{T_b}{\varepsilon_0^{0.25}} \quad (5)$$

where, emissivity is:

$$\varepsilon_0 = 1.009 + 0.047 * ln(NDVI) \quad (6)$$

Source: Ahmad [xxi]

The relation is only valid for NDVI values greater than 0.16. Therefore, an adjustment has been made for NDVI less than 0.16, emissivity has been set to 0.92 and for NDVI less than 0 (normally water surface), the emissivity has been set to 1.

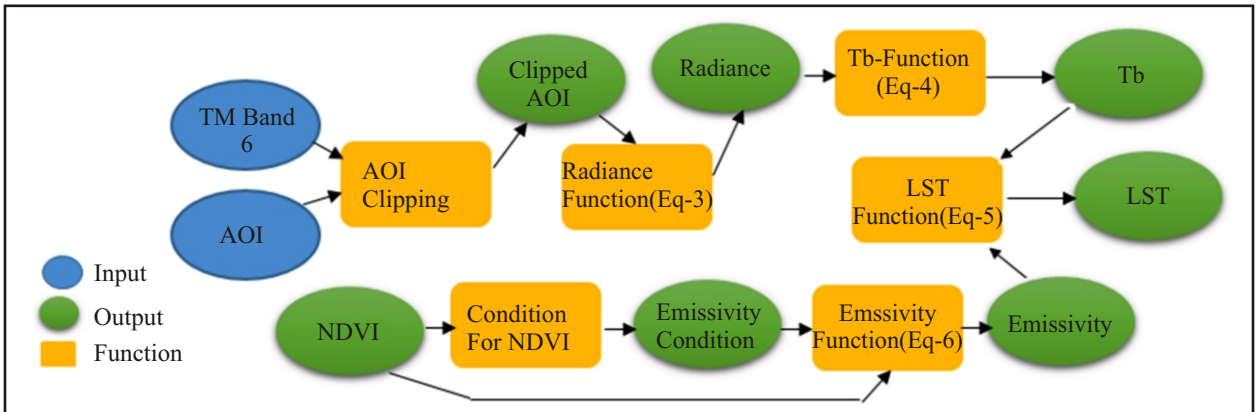


Fig. 3. GIS Process Model for Land SurfaceTemperature Assessment

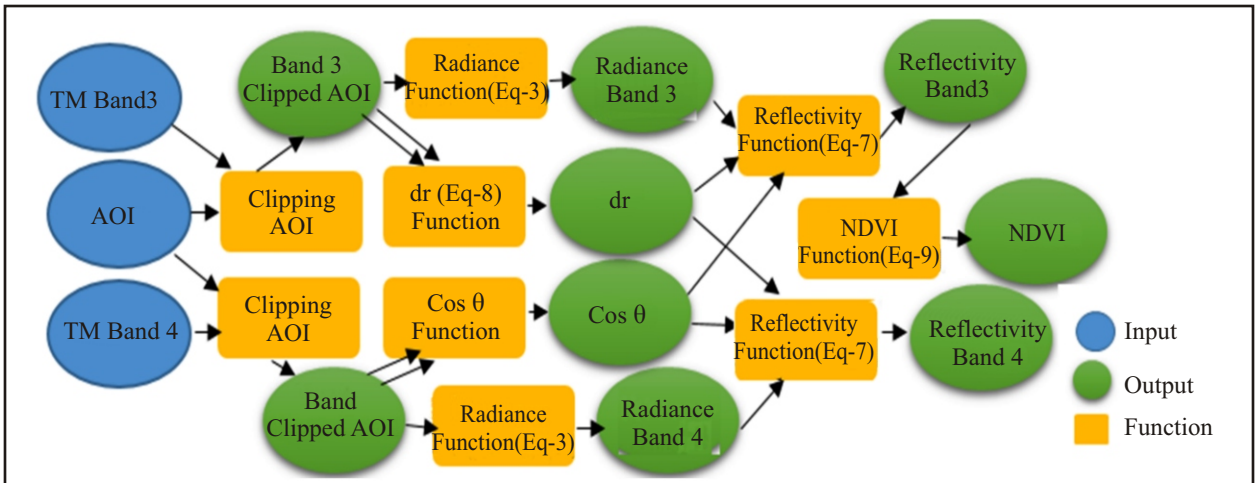


Fig. 4. GIS Process Model for NDVI Assessment

Spectral Reflectance can be calculated by equation:

$$\rho_\lambda = \frac{\pi \cdot L_\lambda}{ESUN_\lambda \cdot \cos\theta \cdot d_r} \quad (7)$$

Where, ESUN is mean solar exo-atmospheric irradiance for each band, θ = 90 - sun elevation, d_r is the relative distance between the sun and Earth.

$$d_r = 1 + 0.033 \cos\left(DOY \frac{2\pi}{365}\right) \quad (8)$$

Where DOY is the sequential day of the year

The NDVI is a measure of the amount and vigor of the surface vegetation and has been calculated by reflectance in near infrared and red band of the visible spectrum as follows:

$$NDVI = \frac{\rho_4 - \rho_3}{\rho_4 + \rho_3} \quad (9)$$

With the help of LST and NDVI model as shown in Fig. 3 and Fig. 4, VCI and TVX have been calculated.

III. Results and Discussion

The outcome of NDVI shows that during the study time period from 1992 to 2011, the highest calculated value was in 1992 i.e. 0.657. Whereas, the maximum value of NDVI in 2011 was only 0.35; therefore, this year has less vegetation as shown in Fig. 7.

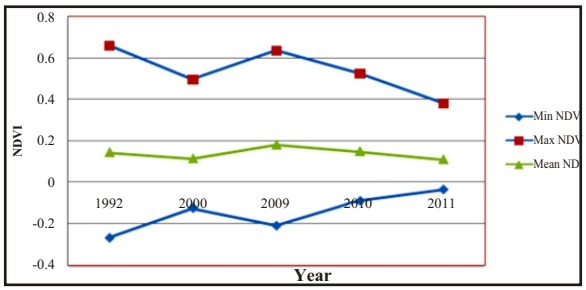


Fig. 5.NDVI for the duration for 1992 to 2011

With the graphical representation shown in Fig. 5, decreasing trend has been noticed for the given duration that indicates the presence of drought condition in the study area.

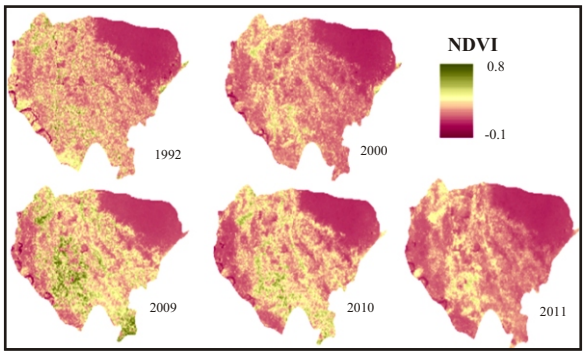


Fig. 7. NDVI for the duration of 1992 to 2011 (Shaheed Benazir Abad District)

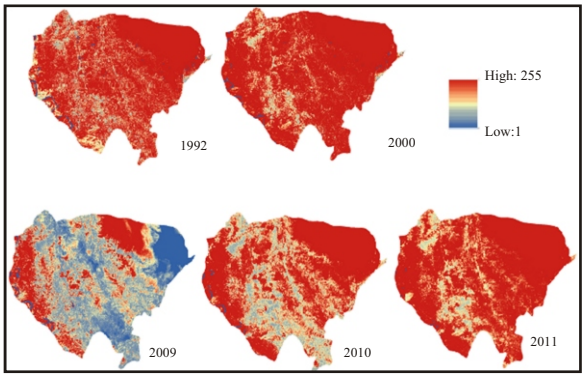


Fig. 8. TVX for the duration of 1992 to 2011

The TVX higher value indicates a drought condition (low soil moisture) whereas the lower value shows no drought condition (see Fig. 8)

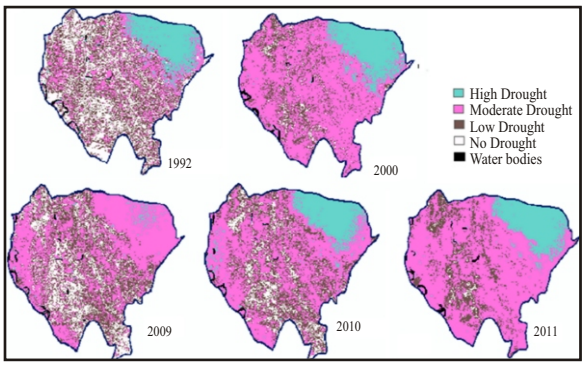


Fig. 6. VCI for the duration of 1992 to 2011

The VCI maps shown in Fig. 6 indicate that the high drought conditions have been observed in deserted region that is outside the irrigated land. However, the agricultural areas with open land are indicated with the moderate drought conditions. As most of the regions of Shaheed Benazir Abad are canal irrigated agricultural lands, therefore severe agriculture drought conditions is not present in such areas; but in particular years, these areas contain low or moderate drought conditions. It

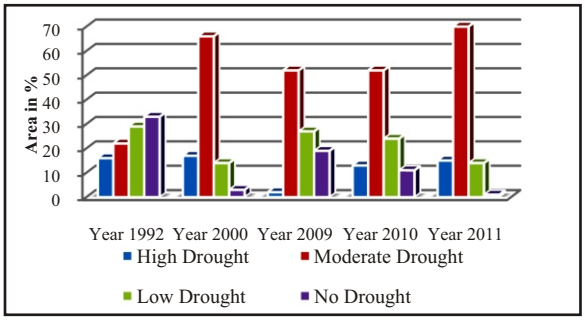


Fig. 9. Distribution of Drought Area (%)

has also been noticed that moderate drought is present near the water bodies areas which are suitable for the agriculture. The dryness of these areas is an alarming situation because these water bodies can provide water

for the land in the absence of precipitation. NDVI and TVX maps also verified this condition as in 1992 agriculture land was spread over a large area near the water bodies but later the situation has been changed. In 2009 vegetation condition was slightly better as compared to 2010 and 2000 because drought is a stochastic phenomenon that repeats after a certain time period. Therefore, it is possible to observe this pattern and make predictions for the future.

The VCI graphical representation with respect to the percentage of area covered, as shown in Fig. 9, indicates that moderate drought conditions have been observed in Shaheed Benazir Abad during 1992 to 2011 that covered 50% to 60% of the area. But in 1992, the moderate drought condition was observed only in 20% of the area, which is the lowest percentage as compared to others. In this graph, on an average, high drought conditions are present only in 10 percent of the area.

IV. Conclusion

The vegetation indices are helpful for estimation of vegetation health and drought. VCI has excellent capability to detect drought and measure the time of its onset, strength, duration, and impact on vegetation. The VCI presents accurate information about drought not only for well-defined, widespread and severe droughts, but also for non well-defined, short-term, and very localized droughts. In this study, the vegetation indices; NDVI, VCI, and TVX provided continuous spatial surface data for monitoring the drought condition over a region, which is impossible to get from the discrete and distant meteorological stations.

From the VCI map analysis, we concluded that most parts of the Shaheed Benazir Abad are perpetually affected by a moderate drought condition. The TVX map also validated the drought conditions. During last decade, it has become more prominent and indicating some possible impacts of climate change in the region.

Acknowledgments

The authors acknowledge the Meteorological Department of Karachi for providing the weather data for this study.

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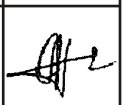
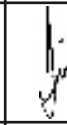
List of Abbreviations:
SPI - Standardized Precipitation Index
NDVI - Normalized Vegetation Index
VCI - Vegetation Condition Index
TVX -Temperature Vegetation Index
GIS - Geographical information System
Landsat-5 (TM) - Landset-5 (Thematic Mapping)
USGS - U. S. Geological Survey
NASA - National Aeronautics and Space Administration
AVHRR - Advanced Very High Resolution Radiometer
NOAA - National Oceanic and Atmospheric Administration
EOS-MODIS - Earth Orbiting system - Moderate Resolution Imaging Spectroradiometer

List of Mathematical Symbols:
$L\lambda$ - Spectral radiance
Lmin - Spectral radiance of DN value 1
Lmax - Spectral radiance of DN value 255,
DN - Digital Number.
Tb - Brightness Temperature
K1 = 607.76 (for Landsat 5 TM)
K2 =1260.56 (for Landsat 5 TM)
ε_0 - Emissivity
ρ_λ - Spectral Reflectance
ρ_4 - Spectral Reflectance of band 4
ρ_3 - Spectral Reflectance of band 3
ESUN - Solar exo-atmospheric irradiance
$\theta = 90$ - Sun elevation
d_r - Relative distance between sun and Earth
DOY - The sequential day of year

Authorship and Contribution Declaration			
	Author-s Full Name	**Contribution to Paper**	
1	Ms. Rabia Tabassum (Main /Principal Author)	Proposed topic, statistical analysis and manuscript writing	
2	Dr. Mudassar Hassan Arsalan (2nd Author)	Basic study design, methodology and interpretation of results	
3	Ms. Anam Khalid (3rd Author)	Literature review & referencing, data collection and statistical analysis	
4	Prof. Dr. Ijaz Ahmad (4th Author)	interpretation and discussion writer and quality insurer	
5	Dr. Ali Iqtidar Mirza (5th Author)	Cartographic interpretation and illustration preparation