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ISSN:2618-1193

Assessment of Drought in Mithi, Thar Using Satellite based Indices and Geoinformatics Techniques

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Citation | Tahir M M, Asghar, Z, Ali Y.A, Shahid R A, Ali.S, Pervaiz H "*Assessment of Drought in Mithi, Thar Using Satellite based Indices and Geoinformatics Techniques*" International Journal of Agriculture and Sustainable Development, Vol 02 Issue 02: pp 33-49, 2020.
Received | May 20, 2020; **Revised |**June 08, 2020 **Accepted |** June 11, 2020; **Published |** June 12, 2020.

Drought is an incessant process in Thar, Pakistan. The extent of droughts needs to be assessed for better planning of landuse in future. The satellite data from LANDSAT 7, 8, MODIS MOD13Q1 was acquired from United States Geologic Survey (USGS) and precipitation data of TRMM was collected from GIOVANNI for the years from 2010 to 2019. Various indices including NDVI, NDMI, LST, SPI, and DI were calculated and compared with post-drought images of our targeted area and the maps were developed for Spatio-temporal analysis. The results show that vegetation in Mithi improved due to enhanced NDVI from 2010 to 2012 and a declined was observed from 2013 to 2015 with an extreme drought in 2014. The effect of the previous drought on vegetation were calculated to be negative, indicating below- average rainfall. The results showed the TRMM satellite's over-estimation in calculating precipitation or rainfall data. The precipitation and NDVI values were improved throughout 2010 to 2013 due to continuous rainfall which overcome the earlier drought in that region. Due to El -Niño's factor, the temperature was increased most in 2014, which resulted in no precipitation that's why it caused the extreme drought in 2014. Precipitation and NDVI values declined in years 2015 to 2019 in Mithi. A weak, moderate, and extreme droughts were recorded in 2012, 2016

and 2014, respectively. Satellite data provided promising results which were near to actual ground observations.
Keywords: *Drought, SPI, NDVI, LST, NDMI, Decile Index, NDVI Anomaly.*
Introduction

Climate change has become one of major challenges around the world which changes the face of a region completely. Increasing temperature and changed precipitation patterns, leads to the extreme meteorological events like drought, which badly disturbs the agricultural production [1]. Drought is the most harmful natural disaster and slow natural phenomenon which has affected various sectors of life including agriculture, environment, and the regional ecology throughout the world [2,3]. Droughts are caused by various factors such as deficiency of precipitation, high temperature, high evapo-transpiration, reduction of ground water and misuse of water resources etc. [4]. The National Drought Mitigation Centre (NDMC) USA, classified droughts in three types, named as meteorological, agricultural, and hydrological droughts while the US Geological Survey introduced another category of drought as socio-economic category which is occurred due to shortfall of water supply.

Metrological droughts are defined as the deficiency of rainfall observed over a longer period [5]. Since 1950, many regions of Asia, Africa, Australia, Europe, and America have experienced long-term and intense droughts [6]. Drought in China occurred from 1876 to 1878 affected 83 million people. In 1579, drought started in the America and spread around the southwestern region that remained for more than twenty years. The worst drought in the history was African Sahel, started in 1968 and lasted in 1988. Australian drought of 2002–2003 affected 19 million population and led to devastating wildfire. Niger drought affected 3.6 million people during 2004–2006. Severe droughts occurred many times in China, India, Australia, Chile, Bolivia, Ethiopia, and the Philippines [7]. Droughts often hit South Asia, bringing significant water shortages, economic losses, and adverse social consequences. In the last 20 years, the population growth increased the requirements of water and other natural resources. Latest drought in South Asia (2000 to 2003) affected more than 100 million people, in western India, Pakistan, Iran and Afghanistan [8]. In 2012, Pakistan declared emergency in Tharparkar and Mirpur Khas districts therefore, many people had to migrate toward other regions to save their lives [9]. In Pakistan’s climate history, drought of 1998 to 2002 was recorded wickedest one in the past 50 years. As compared to previous years, Pakistan faced shortage of rainfall during this period. This drought affected 88% area of Baluchistan province and 18% area of Sindh Province and Tharparkar was one of the most affected districts. This drought was estimated to affect 3.3 million folks; hundreds of which died of thirst and starvation and thousands were left homeless. It was also reported that about 30 million livestock were affected, that included approximately 2 million deaths. A minor level drought occurred in Sindh KPK, Punjab, GB and AJK and Baluchistan in 2004-2005 [10,11]. In recent past, Tharparkar has been hit three times by droughts, the most recent was of 2014 while the long-term drought occurred in 1992-2002 [10]. Remote sensing and GIS play a vital role in detecting, assessing, and managing droughts as these platforms offer in-depth information on spatial and temporal scale.

To assess drought conditions in an area, a variety of indices are available which incorporate various factors e.g., rainfall, vegetation, land surface temperature and soil moisture [11, 12]. Increasing temperature and altered precipitation patterns are the indications to the utmost weather events like drought which severely affects the agricultural reduction. Several indices have been used by researchers for drought monitoring and assessment of aftermath [10-13]. Traditional Palmer Drought Severity Index (PDSI) incorporates the temperature and precipitation data to monitor the drought conditions for evaluating the relatively dry and wet conditions for quantification of drought up to a long period [14]. Beside PDSI, the Standardized Precipitation Index (SPI) is a probability index which is traditionally used in drought assessment and monitoring on rainfall data on monthly or longer period which are often limited in an area [15,16]. SPI and deciles or percentiles are the most suitable for monitoring meteorological droughts [17].

Relying only on meteorological data is insufficient to monitor drought areas, particularly when this data is collected in an improper way. Incorporation of weather data with satellite images to identify the location and severity of droughts is essential to demarcate drought conditions and for better recovery options [18]. Remote Sensing methods are accurately used in drought monitoring, assessment, and its management [19]. Normalized Difference Vegetation Index (NDVI) is the basic indicator which is widely used to highlight the area under vegetation across the study site. These kinds of assessments are the basic to study the drought conditions in an area under investigation [20-24].

The main objective of this study is to utilize satellite datasets in collaboration with local weather conditions like precipitation, land surface temperature, and moisture to monitor droughts in Mithi and Tharparkar districts. It also aims at computing various indices e.g., NDVI, NDMI, LST, SPI and DI within study site for drought assessment.

Material and Methods.

Investigation Site.

Mithi is a Taluka and the capital of Tharparkar District in the Sindh province of Pakistan. It became the capital of the Tharparkar District in 1990, after separation from Mirpur Khas [25]. This site is located at a spatial location of 24°74'0N, 69°80'0 E with altitude of 42 meters from sea level. It lies 450 kilometers from Karachi and is located in a desert area.

Kertee village is in the south of the study site [26]. Mithi is considered one of the most developed cities of Tharparkar. Its population has exceeded than 500,000. A large number of people have migrated from Tharparkar toward city resulting in high development rates and has become an origin of economic and social activity [27]. The area of Mithi is about 1,535 km^2 and the population density is $142/km^2$ [28]. The study site is mapped in Figure 1,

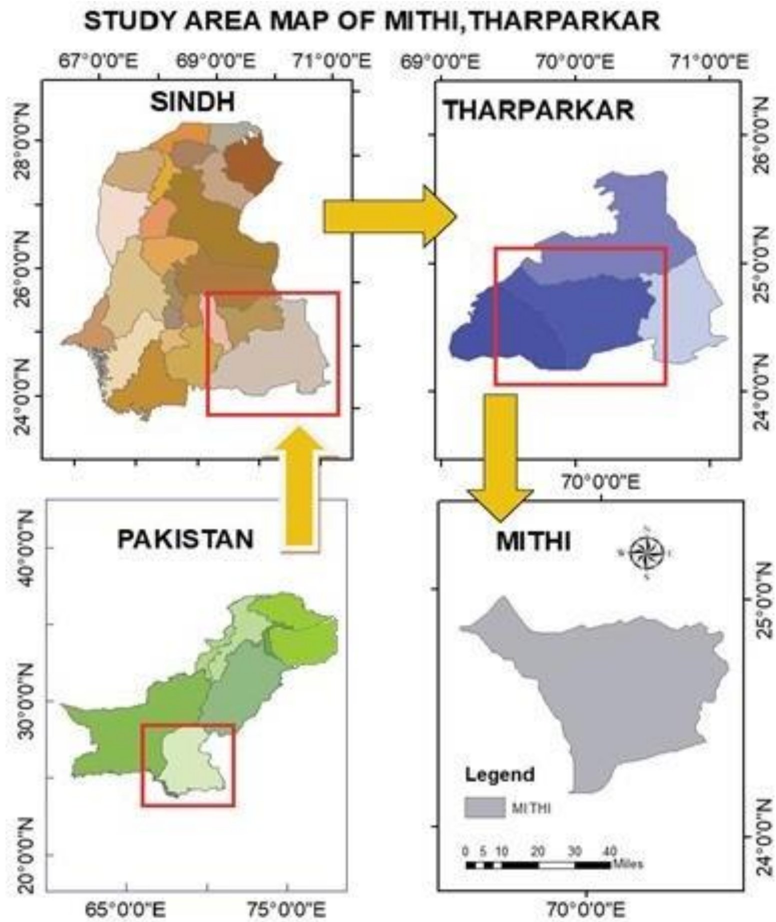


Figure 1. Study Area Map

Material and methods.

This research is based on assessment of drought due to variations in precipitation, land surface temperature, vegetation, and moisture. We acquired satellite derived datasets related to our research for computation of Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), Normalized Difference Moisture (Water) Index (NDMI) and Standardized Precipitation Index (SPI). The datasets used in this research are mentioned in Table 1.

Table 1. List of Primary and Secondary Data Sources Used in Research.

Data Type	Date	Resolution/Accuracy	Source
Landsat7 ETM+	June 2010	30 meters	USGS
Landsat8 OLI	June 2015, June 2019	30 meters	USGS
MOD13Q1	2010 to 2019	250 meters	USGS
TRMM	2010 to 2019	0.25 Degree	Giovanni

MOD13C2	2010 to 2019	0.05 Degree	Giovanni
MOD11C3	2010 to 2019	0.05 Degree	Giovanni

Normalized Difference Vegetation Index (NDVI)

NDVI is used to show drought area by quantification of vegetation by measuring the difference between near-infrared (where vegetation reflects strongly) and red light (which is absorbed by vegetation) [29]. NDVI values ranges between -1 to +1 and a NDVI value closer to zero reveals drought conditions and a value closer to +1 highlights the healthy vegetation [30]. For drought forecasting, we used a time series of 8-day composite clear-sky MODIS product MOD13Q1, tile numbers h24/v06 from June 2010 to 2019 which was downloaded from United States Geological Survey (USGS) website [31] and re-projected the data into UTM 42N.

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

NDVI Anomalies

An NDVI anomaly is the difference between the averaged NDVI for a month of a given year and the average NDVI for the same month over a specified number of years. This approach can be used to characterize the health of vegetation for a month and year relative to what is considered normal, which is a good indicator of drought or declining vegetation health [32]. For this study, we evaluated the NDVI values of June 2019 and compared it to June 2010. We created an NDVI anomaly image and the averaged NDVI for the month of June from 2010 to 2018 and applied the following equation to compute NDVI anomaly,

$$NDVI\ Anomaly = NDVI\_2019 - ((NDVI2010 + NDVI2011 + NDVI2012 + NDVI2013 + NDVI2014 + NDVI2015 + NDVI2016 + NDVI2017 + NDVI2018)/9)$$

Normalized Difference Moisture Index

The Normalized Difference Moisture (Water) Index (NDMI or NDWI) is used to determine moisture or water content which is a satellite-derived index from the Near-Infrared (NIR) and Short-Wave Infrared (SWIR) channels. NDWI is computed using the near-infrared (NIR) and the short-wave infrared (SWIR) reflectance [33]

$$NDMI = (NIR - SWIR) / (NIR + SWIR)$$

Land Surface Temperature (LST)

Land Surface Temperature (LST) is the radiative skin temperature of the land derived from reflected solar flux [34]. From a satellite's point of view, the "surface" is whatever it sees when it looks through the atmosphere to the ground [35]. Landsat surface temperature measures the Earth’s surface temperature in Kelvin and is an important geophysical parameter in global energy balance studies and hydrologic modeling [36]. Landsat 7 ETM+ image data of Mithi with Row 43 and Path 150,151 were downloaded for the month June of 2010 and Landsat 8 OLI images of two years 2015 and 2019 respectively from United States Geological Survey (USGS) [31] with a resolution of 30 meters in clear weather, without atmospheric and geometric errors. The map projection was ‘UTM’, Datum was ‘WGS 84’ and UTM zone was ‘42° N’. We used thermal band-6 of Landsat-7 and Band 10 of Landsat-8 for calculation of

LST. Band 11 of Landsat 8 was not used due to its larger calibration uncertainty [37]. Landsat 7 data had stripping error, therefore we applied focal analysis on band 6 in 'ERDAS' to mitigate stripping.

Computation of Top of Atmosphere (TOA) Reflectance

The pixel-based values in the downloaded raw Landsat 8 images are so called Digital Numbers in the grid. First, these must be converted to TOA reflectance values according to equations given in USGS's Landsat using product handbook, 2013 [38]. We used a statistical computing software "R Studio" to convert these DN values to compute TOA reflectance.

Computation of LST

The LST was computed by conversion of each DN value into irradiance and finally transformation of this irradiance-based value into the pixel-based temperature in centigrade. We calculated LST for the year 2015 and 2019 by given equations in R Studio as follows,

$$\text{Irradiance} = (3.342\text{x}10\text{-}4 \text{ x Thermal band}) + 0.1$$

The value 3.342x10-4 is mentioned in the metadata file (.MTL) saved by a complete Landsat image.

$$T = \left(\frac{K_2}{\ln(\varepsilon K_1 / \text{Irradiance} + 1)}\right) - 273$$

Where K_1 and K_2 are constants and their values are mentioned in the metadata file of each Landsat 8 image as below.

K_1 for B10 = 774.89 K_2 for B10 = 1321.08

Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is used to characterize meteorological drought on a range of timescales. It is used to quantify observed precipitation as a standardized departure from a selected probability distribution function that models the raw precipitation data [39]. The SPI values can be interpreted as the number of standard deviations by which the observed anomaly deviates from the long-term mean [40]. The SPI was created in our case for differing periods of 1-to-3 months, using monthly input data. Precipitation data was downloaded from Giovanni portal [41]. The TRMM data of the year 2010 to 2019 was acquired from the Giovanni and was used to calculate SPI and DI by using metrological Drought Management Tool.

Table 2. SPI Drought Classes

Range	Drought Conditions
Less than -2.00	Extreme drought
-1.50 to -1.99	Severe drought
-1.00 to -1.49	Moderate drought
-0.99 to -0.00	Mild drought
-0.99 to -0.00	Mild drought

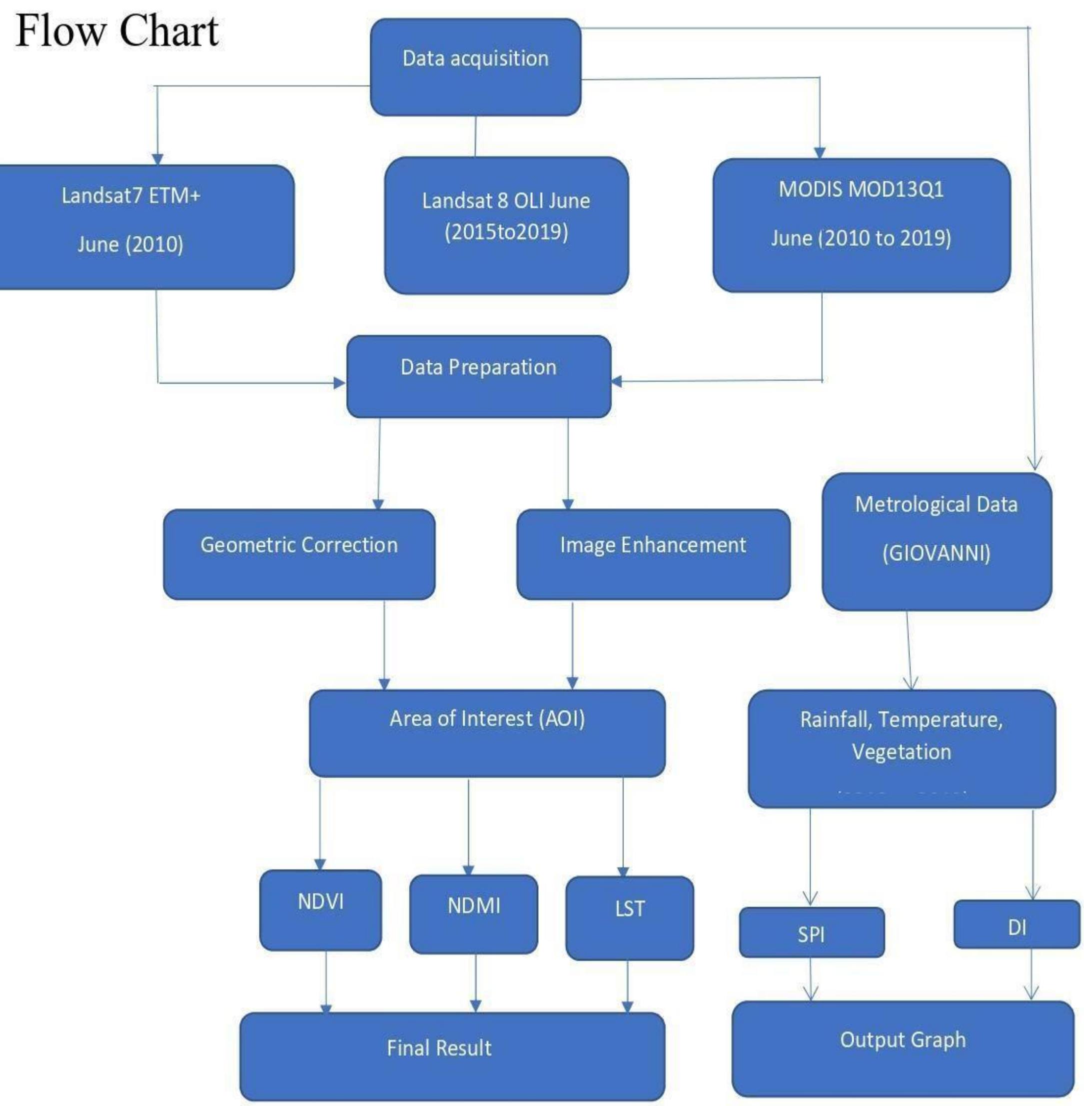


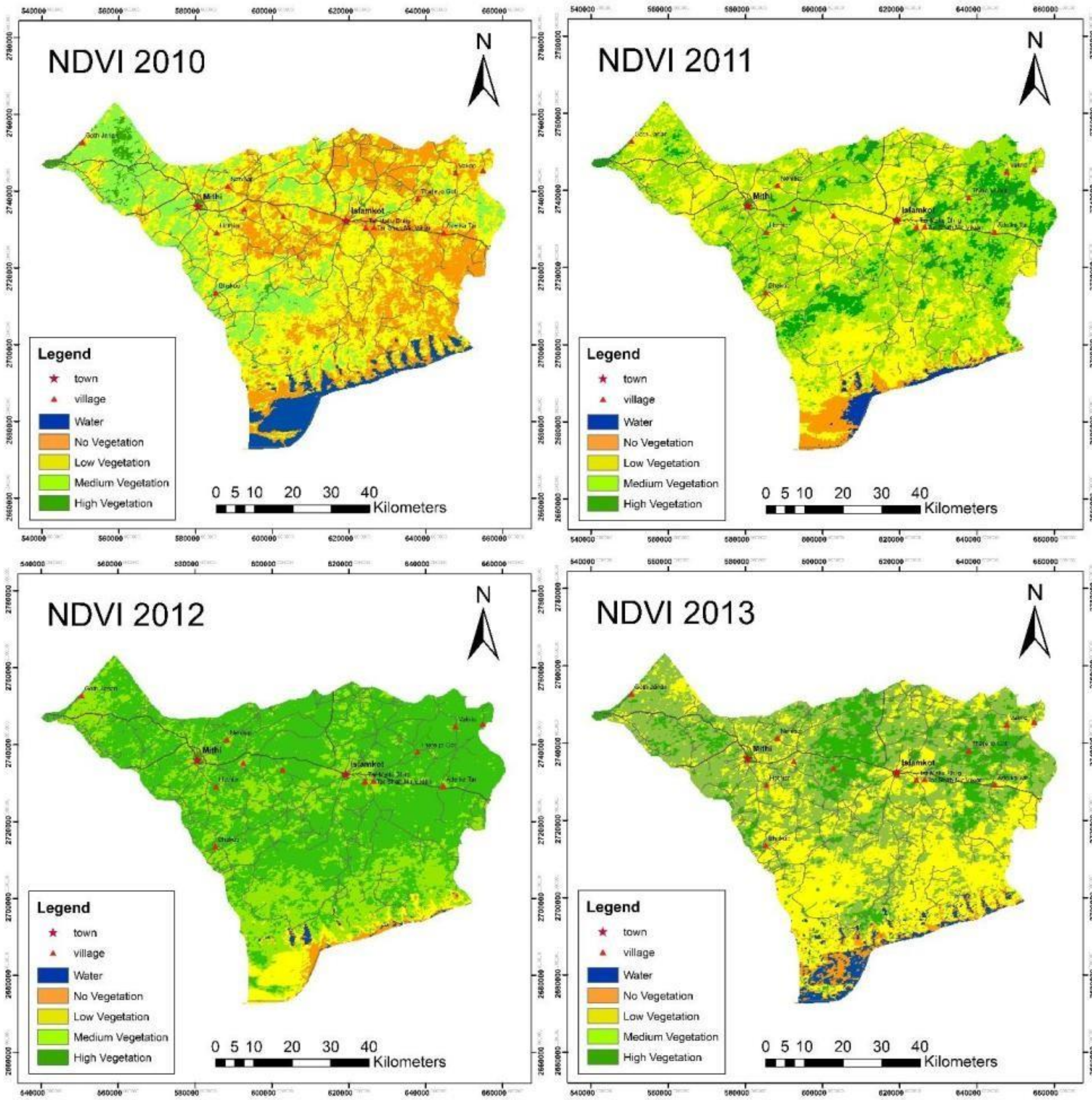
Figure 2. Flow Chart

Result and discussion.

Different indices which helped us in assessment of drought in our study area were calculated as NDVI, NDMI, LST, SPI and DI. We compared these results for assessment of droughts in our study area by using satellite imagery.

NDVI.

NDVI was calculated for the years from 2010 to 2019 and mapped the results in Arc Map 10.4.1. In Figure 3 green color represents healthy vegetation, yellow color represents moderate vegetation, orange color represents low vegetation and blue color represent water bodies in the study site.


NDVI 2010
N
Legend
town
village
Water
No Vegetation
Low Vegetation
Medium Vegetation
High Vegetation
0 5 10 20 30 40 Kilometers
NDVI 2011
N
Legend
town
village
Water
No Vegetation
Low Vegetation
Medium Vegetation
High Vegetation
0 5 10 20 30 40 Kilometers
NDVI 2012
N
Legend
town
village
Water
No Vegetation
Low Vegetation
Medium Vegetation
High Vegetation
0 5 10 20 30 40 Kilometers
NDVI 2013
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Low Vegetation
Medium Vegetation
High Vegetation
0 5 10 20 30 40 Kilometers

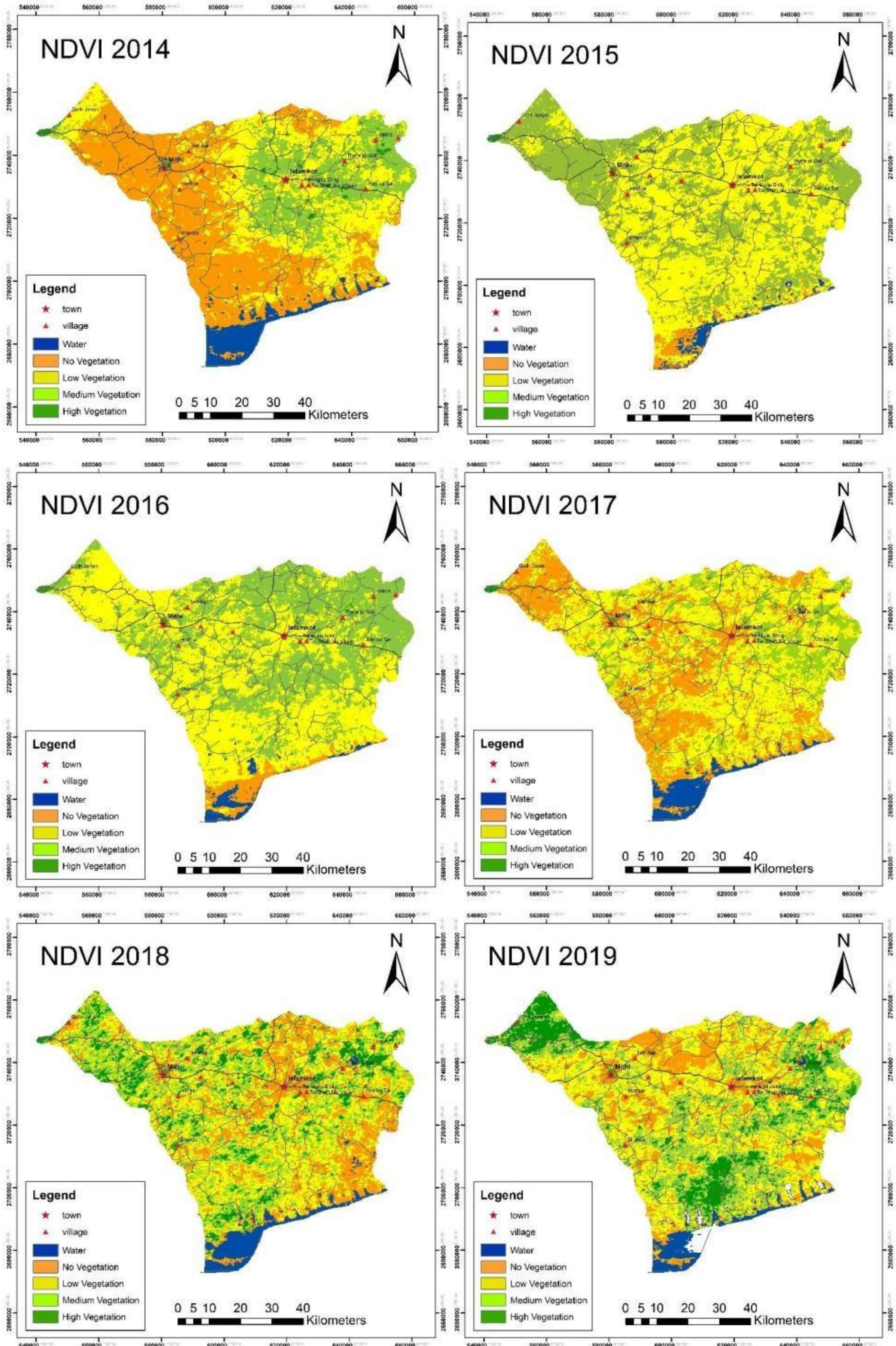

Figure.3 Spatio-temporal distribution of NDVI for the years from 2010 to 2019.

Results show the spatio-temporal variations in NDVI for the years from 2010 to 2019. The NDVI values in 2010 were averaged, areas near Islamkot was observed less vegetated with NDVI value -0.1206 but areas including Mithi and its western parts were in healthy vegetation with NDVI value 0.4127. In 2011 NDVI was observed better than previous year and the areas around Islamkot show better vegetation condition, NDVI high value is 0.4383 and low value is -0.1311. In 2012, NDVI was observed good and the results shows high vegetation in many areas having a value 0.3652.

In 2013, a decline was observed in NDVI values in southern areas of study site. In 2014, there was a major drought observed in Mithi while areas around Islamkot were observed in better condition. In 2015, NDVI values were observed much better than previous year. In 2016, NDVI of eastern areas of Islamkot was in good vegetation condition having NDVI value 0.3886. In 2017, NDVI values were declined and most of area was observed with less vegetation and the NDVI value was observed as 0.5368. In 2018, overall NDVI of study site was observed better than previous year but less vegetation was observed in Islamkot. In 2019, NDVI identified and a medium level drought was observed.

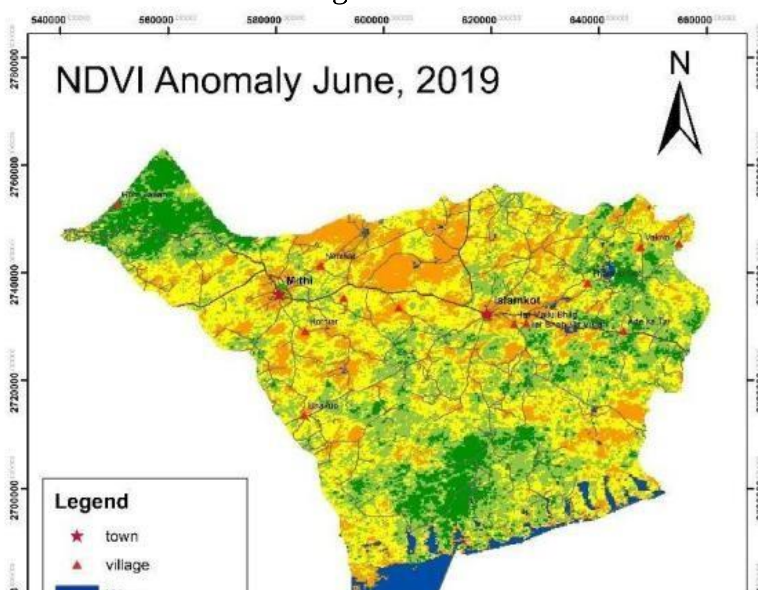

Figure. 4: NDVI Anomaly 2019.

Figure. 4 shows the NDVI anomalies from June of 2010 to 2019, against average conditions over the same period from the past decade. We noticed the below-average vegetation along most of the central area between Mithi and Islamkot. It was generated by subtracting the mean of June of 2010 to 2018 from the current value for June 2019 for each grid cell.

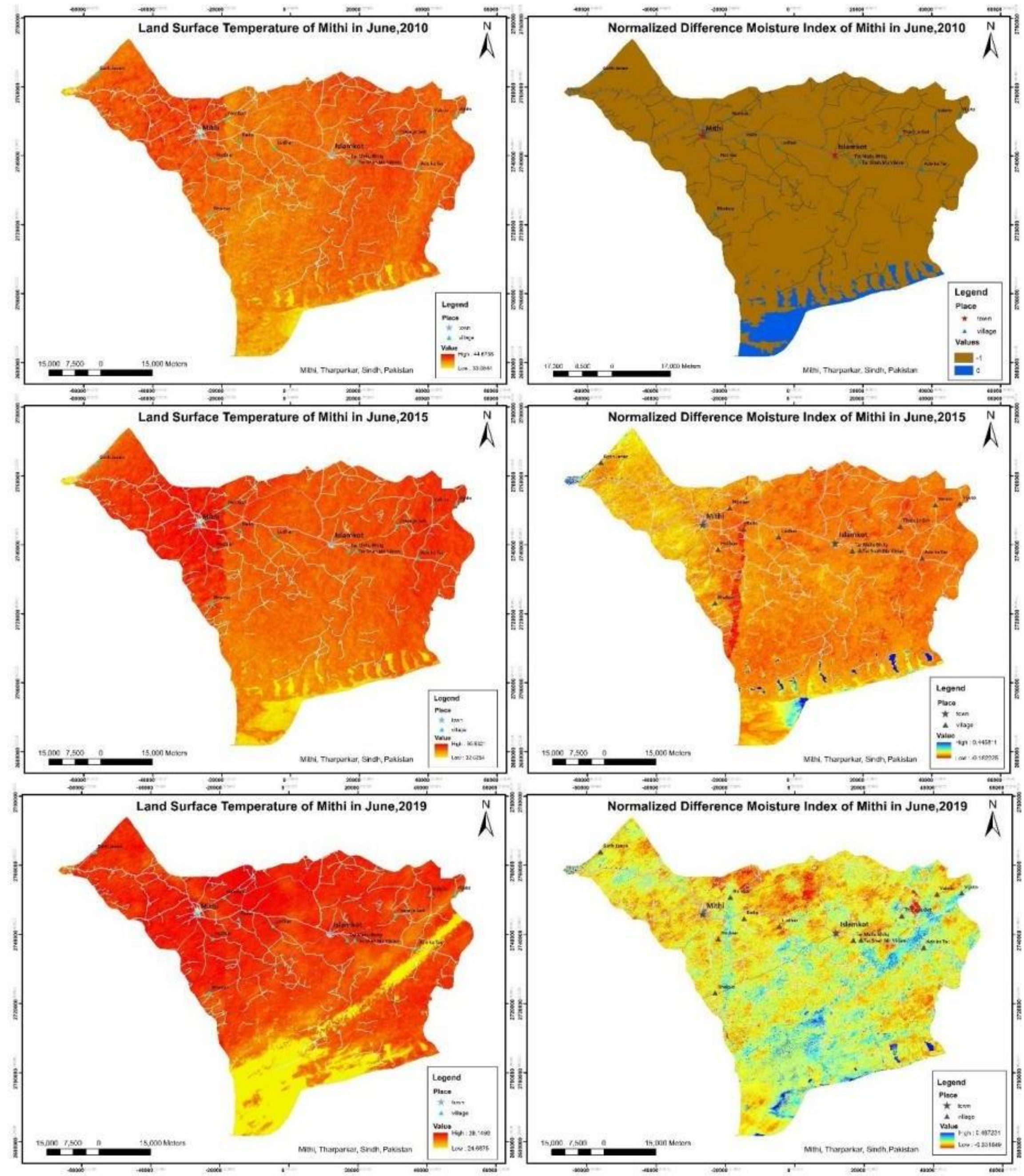

Figure 5. Spatiotemporal variations in LST and NDMI.

Figure. 5 shows variations in LST and NDMI for the years 2010, 2015, and 2019. Results show that in 2010, 2015 and 2019, the highest values of LST were computed as

44, 50 and 39 centigrade and the lowest values were 33, 32 and 24, respectively. The NDMI in 2015 was 0.44 that raised up to 0.48 in 2019.

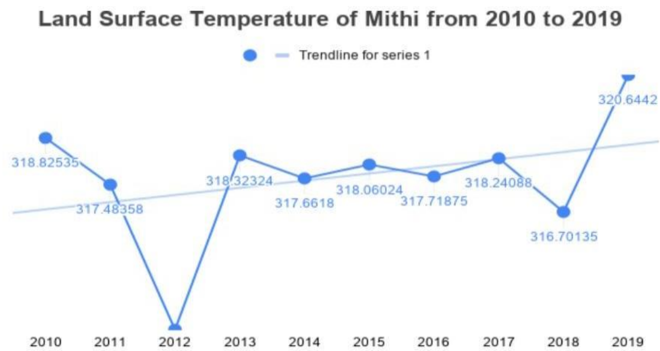

Figure 6. The LST time series of study site for the month of June, (2010-2019)

Figure 6 is showing the variations in LST from (MOD11C3) for the years 2010-2019 in study site. In this figure, the highest value of LST (daytime), was 48 C in 2019, the moderate value was 46 C in 2015, and the lowest value was 41 C in 2012.

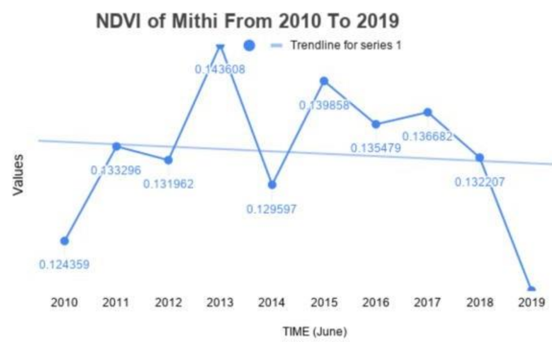

Figure 7. The NDVI of study area (2010-2019)

Figure 7 is showing the variations in NDVI extracted using (MOD13C3) for the years 2010-2019 in Mithi. In this figure, the highest, moderate and lowest values of NDVI were 0.14, 0.12 and 0.11 in 2013, 2014 and 2019, respectively.

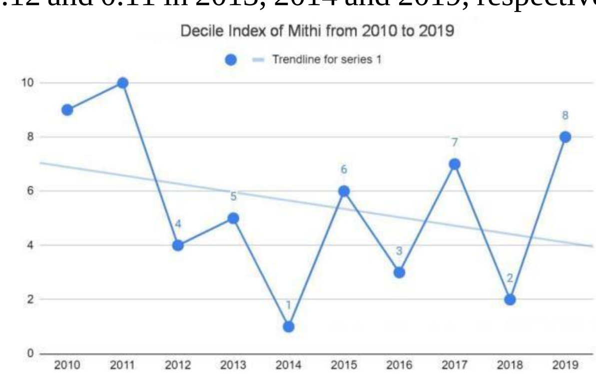

Figure 8. The Decile Index of study area (2010-2019)

Figure 8 shows the variation in DI values which were observed for the years 2010-2019 in Mithi. In this figure, the highest value of DI was observed 1 in 2014, the moderate value of DI was 6 in 2015, and the lowest value was 10 in 2011. The DI value near to 1, 2, 3 and 4 represents extreme, severe, moderate, and weak droughts respectively. The DI values greater or equal to 5 represents no drought.

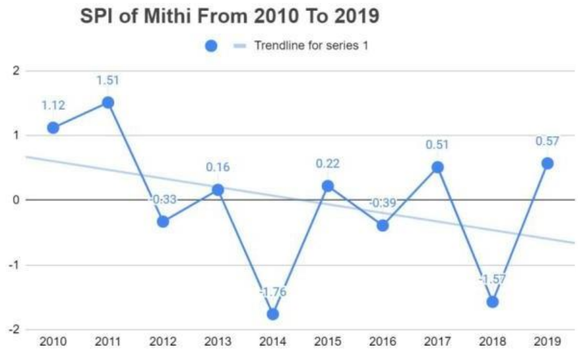

Figure 9. The SPI of study area (2010-2019).

Figure 9 shows the variations in SPI values for the years 2010-2019 in Mithi. In this figure, the highest value of SPI was observed 1.51 in 2011, 0.16 in 2013 and the lowest value in 2014. SPI value ranges between -2 to +2 and the value equal to 0 represents no precipitation. The moderate value of SPI is 0.16 in 2013, and the lowest value is -1.76 in 2014. The SPI value 0 show neutral rainfall condition and as we move below 0, and values above 0 represents no precipitation.

Correlation

The Table 2 shows the correlation among the variables.

Table 2: Correlation among computed variables

	NDVI	LST	Precipitation
NDVI	1		
LST	0.203124	1	
Precipitation	0.381244	-0.00517	1

This table show a positive correlation between LST and NDVI. It also show positive for precipitation and NDVI. It shows that NDVI enhanced as precipitation increases. LST and NDVI were negatively correlated which mean that NDVI declined due to increase in LST.

Conclusion.

The years 2010 and 2011 were observed with high rainfall index in Mithi and Thar. This rainfall overcame the previous drought conditions. LST was increased in 2010 and reached at maximum in 2014 which resulted into a drought. Less precipitation and less rainfall occurred in 2014 which resulted into a drought. A low-level drought was observed in 2015 due to slight rainfall. There was high precipitation in 2017 therefore, LST declined, NDVI enhanced and the drought was finished.

Finally, the frequency and severity of drought have increased in our study area in recent years due to a combination of increasing temperature, increasing events of El Nino and a reduction in rainfall. Significant increase in the frequency of heat waves is an indicator of forthcoming drought which was verified by NDMA Government of Pakistan [42].

We recommend that it is a need to be carried out on drought mapping by incorporating other factors such as soil condition, evapotranspiration, fertility of land and ground water level. High resolution imagery can be used to identify the indices. Soil sample can be collected for checking soil fertility for afforestation in drought affected areas.

To ensure the provision of safe drinking water, additional Reverse Osmosis (RO) plants could be installed. RO plants mostly observed non-functional due to poor maintenance and power supply issues. The feasibility for provision of piped water for drinking purpose from the nearest water source be explored in Cholestane area. Construction of new ponds and small dams must be planned at suitable sites using traditional as well as modern geoinformatics techniques. Government of Sindh may promote 'Rainwater Harvesting' in the drought hit districts. Feasibility studies could be conducted through universities and research institutes to divert flood water to droughty areas to recharge ground water [42].

Acknowledgement.

We would like to thank "Almighty Allah" for giving us strength, awareness, and capability to initiate this study and to proceed and complete it effectively. We would also like to thank our parents, honorable teachers and friends who helped us a lot in finalizing this research. We are thankful to all of you who supported us to do this research.

Author's Contribution. All author contributed equally.

Conflict of interest. Authors declare no conflict of interest for publishing this manuscript in IJASD.

Project details. NIL

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