Int. J. Econ. Environ. Geol. Vol. 9 (2)01-10, 2018

Journal home page: www.econ-environ-geol.org

Open Access

ISSN: 2223-957X

Spatio-temporal Analysis of Aridity Over Punjab Province, Pakistan using Remote Sensing Techniques

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Received: *9 August, 2018* ***Accepted:*** *8 September, 2018*

Abstract: Aridity is a severe threat to the ecological environment and it leads to desertification. Aridity has become a more serious hazard to agricultural countries like Pakistan, followed by socio-economic problems. Pakistan is an agrarian country and Punjab province of Pakistan is known as the basket of grain for its population due to its fertile lands and lush green fields. Less or no rainfall can convert any land or region from humid to semi-arid and semi-arid to arid land. Deficiency of moisture also defines arid conditions of any region. Hence, in case of Punjab, aridity is a severe threat to halt the use of full potential of its agricultural land resources. There is an irresistible need to comprehensively assess aridity in Punjab at different time scales and to formulate necessary arrangements and action plans to face this issue on sound footing. Remote sensing can be used to accurately measure aridity on local, regional and global scales. Multi-temporal images of Moderate-resolution Imaging Spectroradiometer (MODIS) MOD13Q1 and MOD11A1 of Punjab province are used for aridity assessment. In this study attempt was made to demarcate arid areas of Punjab in the simplest possible form using different vegetation indices and land surface temperature. Maps are developed by using normalized difference vegetation index (NDVI), transformed normalized difference vegetation index (TNDVI), soil adjusted vegetation index (SAVI) and land surface temperature (LST). A weighted overlay analysis of these indices was also done for further comprehensive analysis of aridity. The results indicate that aridity is more in southern Punjab due to increased temperature and reduced precipitation and in northern regions of the province, aridity is developing especially in those areas, which were semi humid or semi-arid in the past.

Keywords: Aridity, MODIS, vegetation indices, land surface temperature, weighted overlay analysis, Punjab.

Introduction

Aridity has been amplified over the global dry lands since 1948 (Feng and Fu, 2013). Aridity has the notable impacts on the environment around the globe. According to Sherwood and Fu (2014) an increase in aridity is due to an increase in temperature. Main cause of aridity is dry, descending warmer air (Dai et al., 2004). Warmer air is followed by insufficient soil moisture, potential evaporation which is also the main indicators of aridity (Tabari et al., 2014; Jensen, 1973; Palmer, 1965; Palmer and Havens, 1958). The life style of present era is another reason of increasing aridity around the globe by increasing carbon dioxide in atmosphere (Cook et al., 2014; Fu and Feng, 2014; Feng and Fu, 2013). Climatic variations and human anti-environmental activities can also cause aridity. While analysis of several other studies concluded that less or no precipitation is the key factor for aridity worldwide.

Pakistan is also suffering from severe aridity in some parts of Sindh and Punjab province. Decreasing precipitation is the key factor that contributes aridity in Pakistan. Losses of agricultural land and climate change have been observed in Pakistan due to which aridity is activated (Haider and Adnan, 2014). Table 1 shows average annual distribution of rainfall and temperature at different climatic stations in Punjab province. About 68% land receives less than 250 mm rainfall per year, 24% area of Pakistan receives 250 to 500 mm rainfall whereas only 8% area of Pakistan receives heavy rainfall which is 500 mm annually. Arid and semi-arid areas of Punjab are more prone to desertification. It is necessary to monitor and analyze the degraded land and drought.

Table 1 Mean annual rainfall and temperature distribution in Punjab province.

	Rainfall in mm			Temperature in °C		
Areas/Year	**2000**	**2010**	**2017**	**2000**	**2010**	**2017**
Northern Punjab						
Faisalabad	17.5	45.4	27.3	49.5	49.1	34.3
Islamabad	78.9	84.8	81.1	43.4	44.7	31.6
khanpur	1.6	26.9	15.0	52.0	52.5	35.5
Lahore	46.5	45.1	47.1	50.3	50.9	33.8
Mangla	94.7	68.8	85.9	46.6	47.6	32.0
Muree	123.7	140.1	111.3	24.3	27.8	18.5
Sialkot	82.4	85.6	79.6	46.7	48.1	31.9
Southern Punjab						
Bahawalnagar	14.2	16.3	15.1	52.9	53.1	35.9
Bahawalpur	6.5	18.6	18.5	52.4	52.3	35.6
Dera Ghazi Khan	11.0	27.6	19.0	51.8	51.5	34.5
Multan	6.7	23.6	19.8	51.9	52.3	36.0
Rahim Yar Khan	0.2	18.1	9.9	52.0	54.0	36.2
Average Annual Data	**40.3**	**50.1**	**44.1**	**47.8**	**48.7**	**33.0**

In remote sensing, processing of multi-temporal images and detection of changing trends has been an active research field (Jianya et al., 2008). Remote sensing can detect change precisely by temporal images. These images are acquired from space borne and air borne sensors to analyze and detect changes over a period of time (Sundaresan et al., 2007). In this paper, we selected the Punjab province of Pakistan as the research region and attempted to utilize a quantitative method for aridity assessment by developing indicators from MODIS data. Data were collected by considering the effect of seasonal variation and environmental heterogeneity. While, aridity is estimated by using the indicator systems (NDVI, TNDVI and SAVI). The classical method is used for retrieving the micrometeorological conditions of land surfaces that is land surface temperature and albedo from satellite image by using thermal infrared band to accurately get micrometeorological parameters of land surfaces. The result of the research can be used as a background document for further study. It can also be a great help in increasing the capacity of local (Punjab) government to implement sound environmental management (Prenzel and Treitz, 2004; Ramachandra and Kumar, 2004).

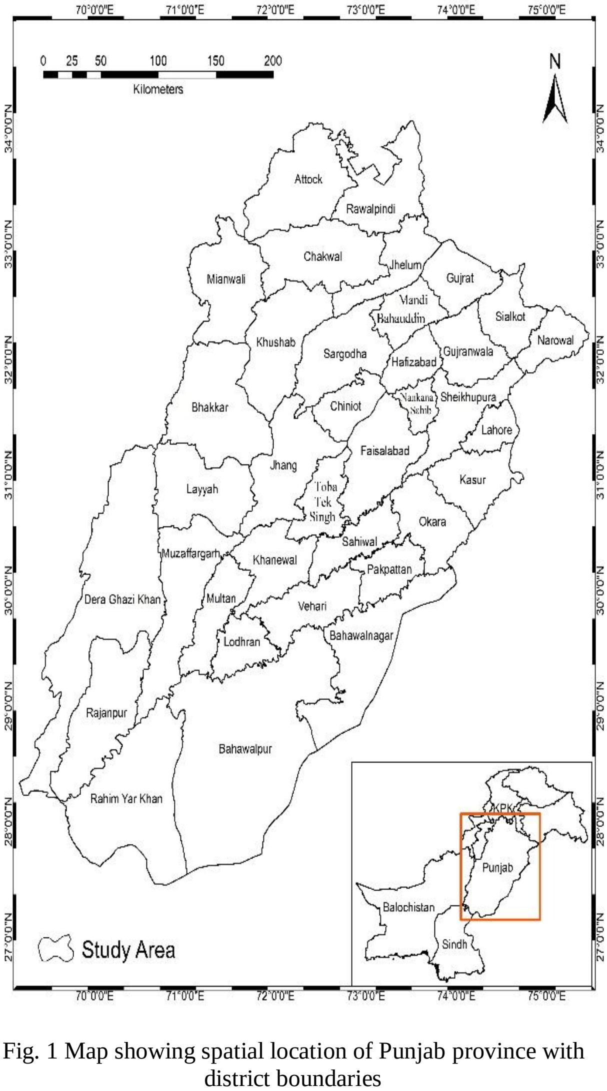


Fig. 1 Map showing spatial location of Punjab province with district boundaries

Materials and Methods

Study Area

The study has been carried out in the Province of Punjab with special emphasis given to estimate trend of aridity in the last 18 years. Punjab is the most active agrarian part of the country and the second largest province of Pakistan with area of (205,344 km^2). Punjab is located in the northeastern part of Pakistan ranging from 31.17° N, 72.71° E and its height is approximately 168.2 meters above sea level (Fig. 1). According to the Pakistan census of 2017, the total population of Punjab is 110 million. The Kashmir border is situated in the northeast of Punjab, while the Indian states of Punjab and Rajasthan are located on the east side. Whereas, Sindh lies in the south and Balochistan to its southwest border. The border of Khyber Pakhtunkhwa is in the north and north-west direction. In spite of well-developed irrigation system, farmers have to depend on rain fed agriculture system too. It has a sub-tropical monsoon climate. The annual average temperature varies from less than 7-12 ºC in the cool zone to above 25º C in the hot lowlands. Monsoon season is the rainy period, from July to September. Average annual rainfall ranges between 96 cm in sub-mountain region and 46 cm in the plains. In the remaining months, the ratio of rainfall varies approximately 50 mm per month, therefore canal and irrigated water is used for crop production during this time.

Remote Sensing Data Analysis

Remote sensing is widely used to monitor and evaluate the desertification in arid and semi-arid regions. Reflection is very important for the satellite sensors to capture the images and features of the earth. Solar energy can be absorbed, transmitted or spread out with interaction processes. Land covers do not absorb and reflect the radiation equally. All land covers behave differently due to their characteristics. For example, vegetation reflects highly in infrared zone and near infrared zone of electromagnetic spectrum. Furthermore, spectral signatures are used to differentiate the earth's surface substances. The chlorophyll content in leaves plays a very important role in absorption, transmission and reflection. Vegetation cover, arable land, soil, water bodies and physical structure of the earth should reflect differently from each other and they vary from place to place and connected with the angle of the sun, angle of the sensor and time of capturing the land surface by satellite sensor. Water has less than 10% reflectance and it is shown only in visible range (0.4-0.7µm). On the other hand water absorbs all energy in the long range than 0.75µm. Vegetation highly absorbs the radiation and reflects the energy in infrared and near infrared range and at 0.65µm vegetation highly reflects due to presence of chlorophyll. Furthermore, 1.45-1.55µm and 1.90-1.95µm are high absorption ranges, due to the presence of water content in leaves. Soil has very less reflection curve with high reflection values as compared to vegetation and water because soil absorbs and reflects the high flux of energy. It goes to more high levels when bands increase. Its curve is formed due to presence of water in the soil. The integration of plant types and their leaves in the infrared region, photosynthesis worked properly and absorbed the radiation from 70 to 90% (Campbell, 1996).

The availability of broad scale spatial data from airborne and satellite imagery has led scientists to frequently use RS applications for the spatiotemporal analysis of aridity. In order to find out extent of aridity in Punjab province Pakistan, three MODIS dataset images of 250 m resolution were acquired for the years 2000, 2010 and 2017. These images were obtained from USGS, an earth observatory website. In arid areas, vegetation index increases from severe deserts to grasslands. Therefore, the vegetation index is effective for delimiting arid areas (Gamo et al., 2013). In present research the aridity classification has been done by computing normalized difference vegetation index (NDVI), transformed normalized difference vegetation index (TNDVI), soil adjustment vegetation index (SAVI) and land surface temperature (LST). A weighted overlay analysis of all techniques was also performed. The layer stacking is a critical operation carried out in the present study. Satellite image is often acquired in separate bands. The total operation of combining these bands for creating a complete image is known as layer stacking, which was carried out in ERDAS Imagine 2014 software. The entire process of creating a mosaic has also been applied to mix all the components of MODIS data of selected study area. Sticking with the operation of layer stacking, sub setting of the mosaic image was performed through clipping process by using digitized boundaries of area of interest (AOI).

Normalized Difference Vegetation Index (NDVI)

NDVI is used to monitor and evaluate the healthy vegetation and green cover areas. It is easily correlated with biophysical characteristics of vegetation e.g. green biomass, leaf area index and chlorophyll moisture in the leaves (Prince et al., 1995; Goward et al., 1985; Justice et al., 1985). Rouse et al. (1973) first used normalized difference vegetation index (NDVI) as a numerical indicator for vegetation monitoring. NDVI has the potential to relate climate changes with vegetation responses (Xu et al., 2011). Areas with least vegetation experience more land surface temperatures (Rahman et al., 2004). NDVI has been widely used in semi-arid and arid regions for vegetation production, soil moisture estimation, crop yield assessment and drought detection (Haroon et al., 2016: Allen et al., 2005; Rahman et al., 2004: Peters et al., 2002; Moulin et al., 1998; Bausch, 1995; Benedetti and Choudhury et al., 1994; Rossini, 1993). According to Gamo et al. (2013), the distribution of NDVI is similar to the trends in the Aridity Index, which increases from dryland to wetland. NDVI is calculated using following equation (Eq. 1).

$$NDVI = (NIR-R) / (NIR+R) \qquad \text{(Eq. 1)}$$

Where NDVI is Normalized Difference Vegetation Index, NIR is Near Infrared band value and red band value denoted with R.

Transformed Normalized Difference Vegetation Index (TNDVI)

The transformed normalized difference vegetation index (TNDVI) is a symbol of vegetation biomass, and it is a ratio between near-IR and red reflection. The TNDVI is computed using the following equation (Eq. 2).

$$TNDVI = \overline{\frac{(Infrared-Red)}{(Infrared+Red)}} + 0.5 \qquad \text{(Eq. 2)}$$

According to Greenland (1994) TNDVI is an integrated function of photosynthesis, leaf area and evapo-transpiration. Total amount of biomass has indirect and direct relation with surface energy balance, surface temperature consistent with interference of sunlight, canopy cover ratio and with evapo-transpiration cooling effect (Yang et al., 2008; Sandham and Zietsman, 1997; Friedl and Davis, 1994).

Soil Adjustment Vegetation Index (SAVI)

The soil adjusted vegetation index (SAVI) is a modified form of normalized difference vegetation index (NDVI) when area of vegetation land cover is very low without the influence of soil brightness (Lyon et al., 1998; Rondeaux et al., 1996; Senseman et al., 1996a; Richardson and Everitt, 1992; Huete, 1988). According to Huete (1988) the soil adjusted vegetation index is a key factor to find out the area of low or no vegetation and exposed soil surface. In arid areas, it is considered preferable to use a soil-adjusted vegetation index and modified soil-adjusted vegetation index (Qi et al., 1994). According to Leprieur et al. (1996) NDVI and MSAVI are proportionally related in arid regions. The results of SAVI vary due to reflectance of soils in different amounts of illumination in the red and near infrared wavelengths (Huete et al., 2002). According to Huete (1988) the SAVI is structurally similar to the NDVI but with the addition of a soil brightness correction factor. SAVI is estimated using the following equation (Eq. 3).

$$SAVI = NIR - \frac{RED}{NIR+RED+L} * \ 1 + L \qquad \text{(Eq. 3)}$$

Where NIR is near infrared band value, RED is reflectance of the red band and L is soil brightness component. The value of L varies, with the amount of green vegetation cover in very high vegetation regions, L=0; and in no green vegetation region, L=1. Generally, L= 0.5 works well in most scenario and used as default value. When L=0 than SAVI results are equal to NDVI results, then SAVI = NDVI (Rondeaux et al., 1996; Huete, 1988). Original SAVI required specific soil brightness factor L which created some uncertainty in the results. Only authorized researchers use L=0.5 as default value, but it also made a circular logic problem of demanding to know what the vegetation amount or cover was before SAVI which concludes the pervious amount of vegetation in a region.

Land Surface Temperature (LST)

Land surface temperature is one of the crucial problems faced globally. LST is highly accelerated by loss of vegetation and soil moisture content, increased temperature and is activated with anthropogenic activities (Kang et al., 2010). LST is one of the global challenges that is directly involved with urban developing activities and hinders sustainable development growth (Adams et al., 2017). LST is estimated using following equation (Eq. 4).

$$DN * 0.02 - (273.15) \qquad \text{(Eq. 4)}$$

In equation (Eq. 4) digital numbers (values of DN) of image are calculated and their average was taken out. Firstly, DN was converted to radiance by multiplying with 0.02. Secondly for the conversion of radiance Kelvin values into degree Celsius, are subtracted with 273.15.

Weighted Overlay Analysis (WOA)

In weighted overlay approach the values of a series of input rasters are reclassified to a specified scale and weights (ArcGIS, 2017). A generalized distribution of aridity over Punjab is shown using this method. Edge examination technique is used to estimate results of aridity over Punjab by reclassifying NDVI, SAVI, TNDVI and LST images through weighted sum.

Results and Discussion

Geographical Distribution of NDVI

NDVI values for the months of June 2000, 2010 and 2017 are shown in Figs. 2a, 2b and 2c. Low NDVI values are related to arid areas and high NDVI values are related to humid areas due to quite green and healthy vegetation. Areas of low NDVI values (high aridity) are mostly present in southern Punjab, including areas of Bahawalpur, Bahawalnagar, Rahimyar Khan, Rajan Pur, Dera Ghazi Khan, Layyah. However, some other areas of low NDVI values are located in NW of Punjab province, including Bhakkar, Khushab and some parts of Mianwali and Attock. Aridity distribution is increasing with the passage of time. The ratio of vegetation decreased in 2017 as compared to past decades particularly in the northern part of Punjab. The temporal comparison of NDVI values clearly indicates that some parts of the Punjab province are turning into arid regions, which were semi-arid in the past.

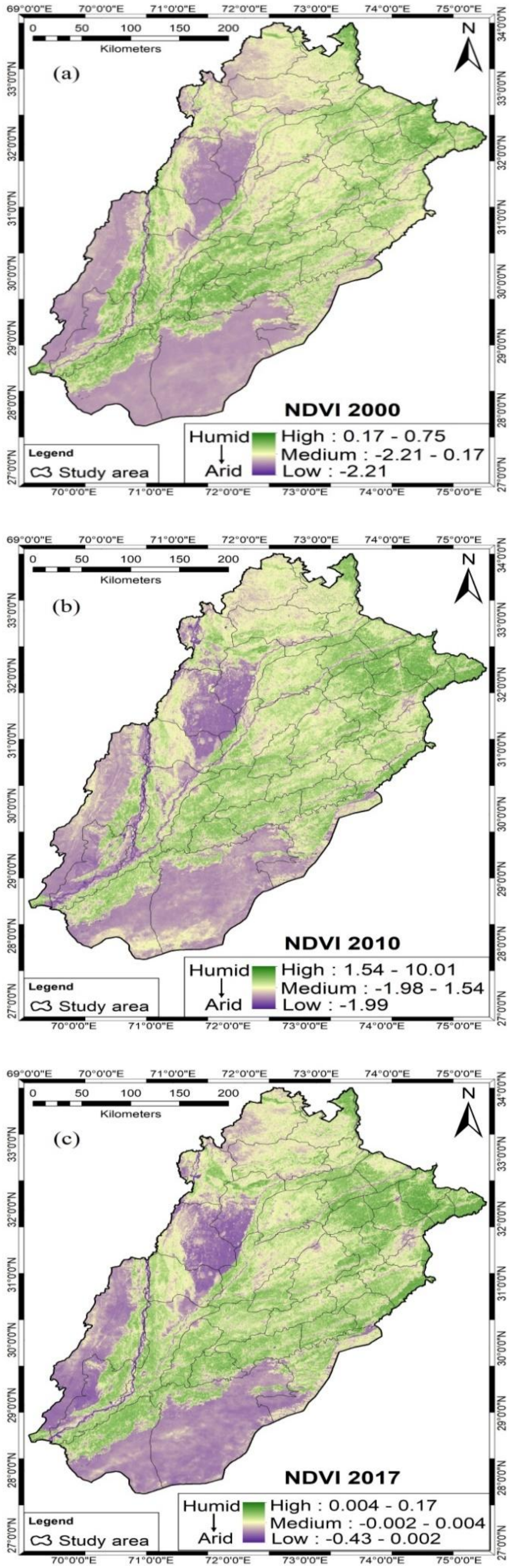
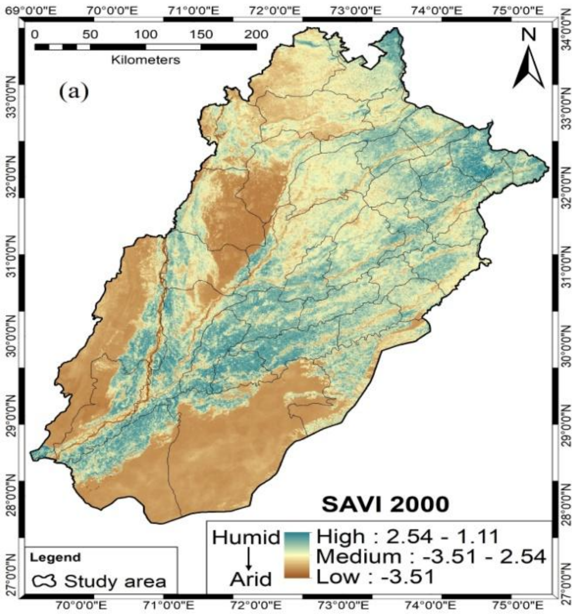
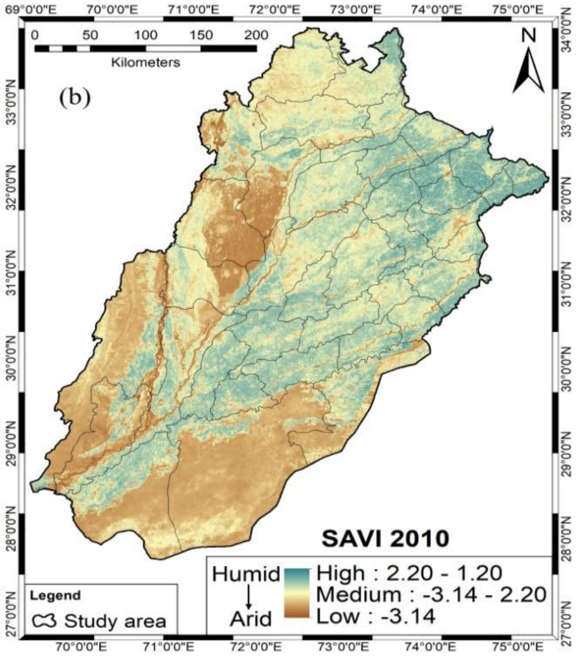


Fig. 2 Map showing classification of NDVI index over Punjab based on pixel data (a) Year 2000 (b) Year 2010 and (c) Year 2017 (Data Source: USGS Earth Explorer).

Geographical Distribution of SAVI

SAVI values for the months of June 2000, 2010 and 2017 are shown in Figs. 3a, 3b and 3c. Low SAVI values are related to arid areas and high SAVI values are related to humid areas. Areas of low SAVI values (high aridity) are mostly present in southern Punjab, including areas of Bahawalpur, Bahawalnagar, Rahimyar Khan, Rajan Pur, Dera Ghazi Khan, Layyah. However, some other areas of high aridity are located in NW of Punjab province, including areas of Bhakkar, Khushab, Mianwali, Attok, Chakwal, Rawalpindi, Jhelum and Lahore. Analysis of SAVI indicates that the vegetation cover has decreased in year 2017 as compared to 2000 and 2010. The temporal comparison of SAVI values clearly indicates that some parts of the Punjab Province are turning into arid regions, which were semi-arid in the past.





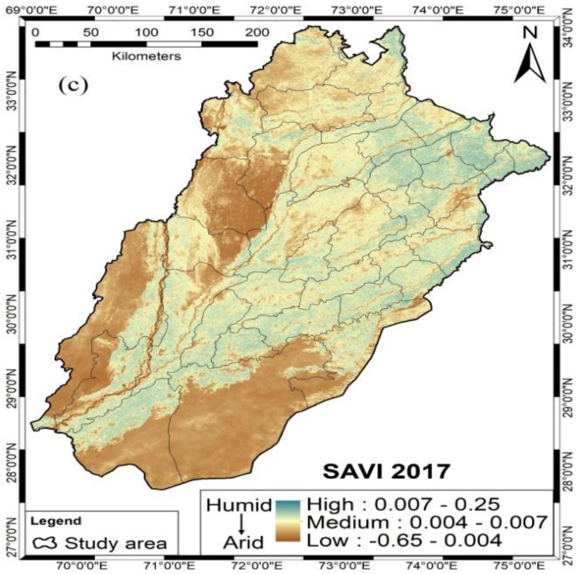
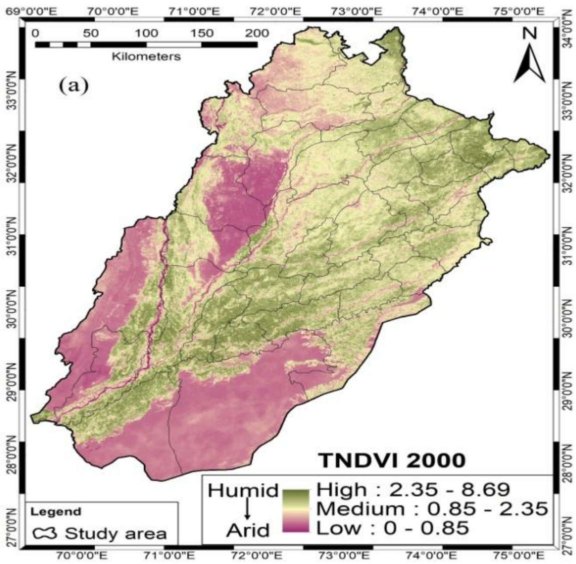


Fig. 3 Map showing classification of SAVI index over Punjab based on pixel data (a) Year 2000 (b) Year 2010 and (c) Year 2017 (Data Source: USGS Earth Explorer).

Geographical Distribution of TNDVI

Temporal analysis of TNDVI values for the months of June 2000, 2010 and 2017 indicate clear variation in vegetation cover over Punjab at different time scales (Figs. 4a, 4b and 4c). Low TNDVI values are related to arid areas and high TNDVI values are related to humid and sub-humid areas. Areas of low TNDVI values (high aridity) are mostly present in southern Punjab, including areas of Bahawalpur, Bahawalnagar, Rahimyar Khan, Rajan Pur, Dera Ghazi Khan, Layyah. However, some other areas of low TNDVI values are located in NW of Punjab province, including areas Bhakkar and Khushab. Aridity is increasing with the passage of time. The ratio of vegetation decreased in 2017 as compared to past decades especially in the northern part of Punjab where Mianwali, Attok, Chakwal, Lahore and Sheikhupura in northern Punjab are getting arid.



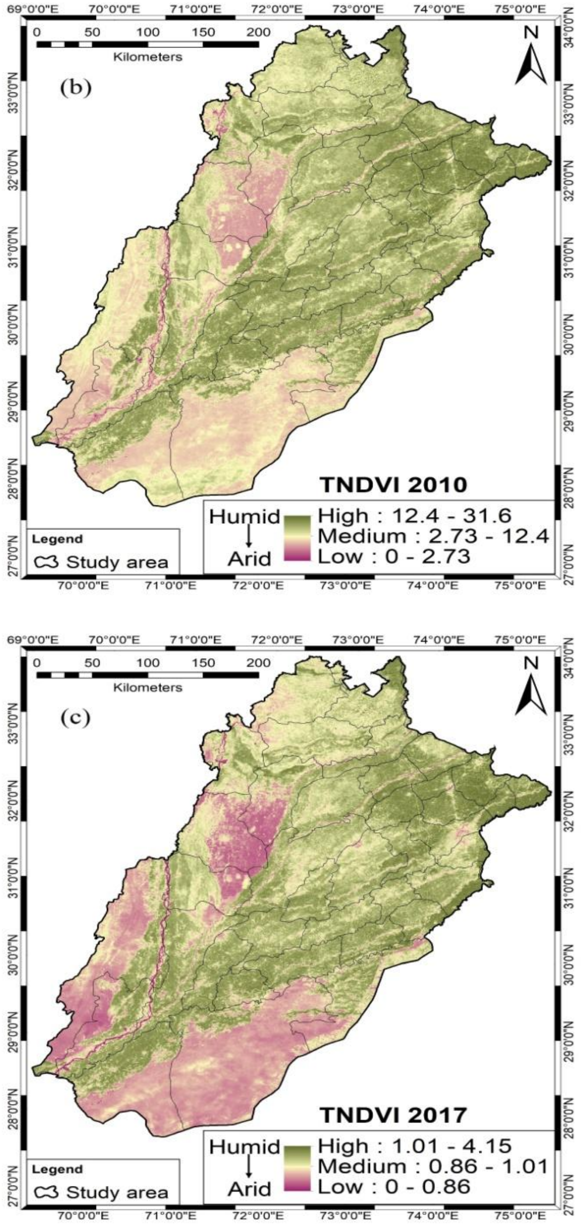


Fig. 4 Map showing classification of TNDVI index over Punjab based on pixel data (a) Year 2000 (b) Year 2010 and (c) Year 2017 (Data Source: USGS Earth Explorer).

Geographical Distribution of LST

LST values for the months of June 2000, 2010 and 2017 are shown in Figs. 5a, 5b and 5c. Land surface temperature is shown in five classes from highest to lowest range in degree Celsius (^{o}C). Areas of high temperature values derived from LST are mostly present in southern Punjab. However with the passage of time, land surface temperature is increasing and northern Punjab is also facing high temperature. Areas of high LST values (high aridity) are mostly present in southern Punjab, including areas of Bahawalpur, Bahawalnagar, Rahimyar Khan, Rajan Pur, Dera Ghazi Khan, Layyah. However, some other areas of high LST values are located in NW of Punjab province, including areas of Bhakkar, Mianwali, Khushab, Jhang, Khanewal and Toba Tek Singh.

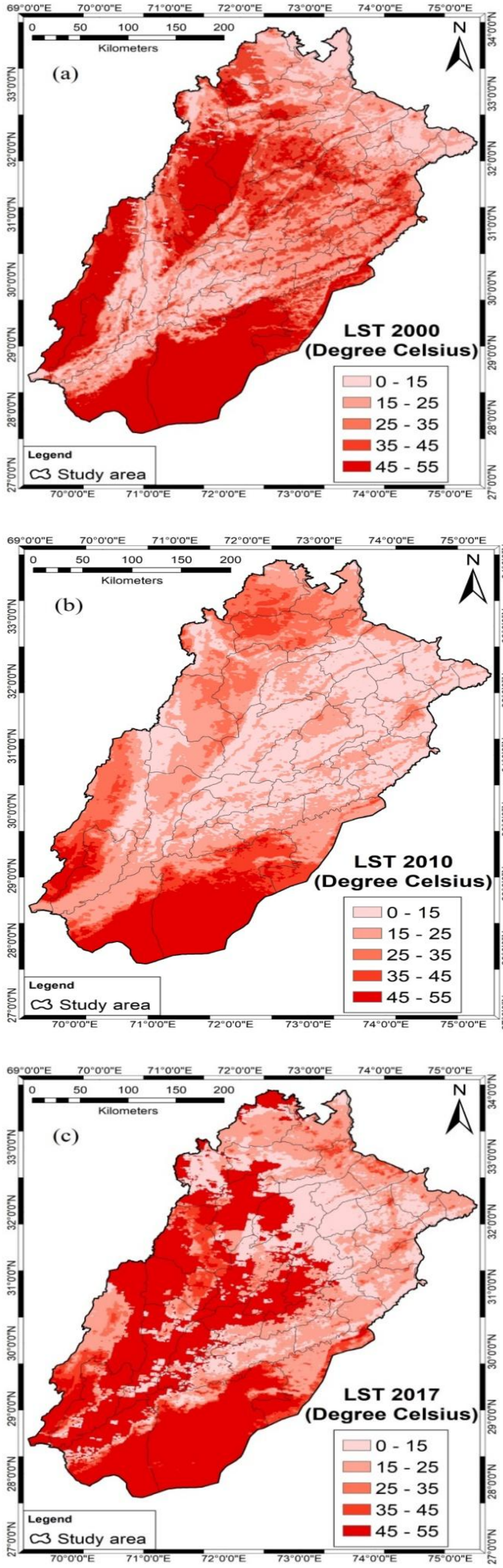
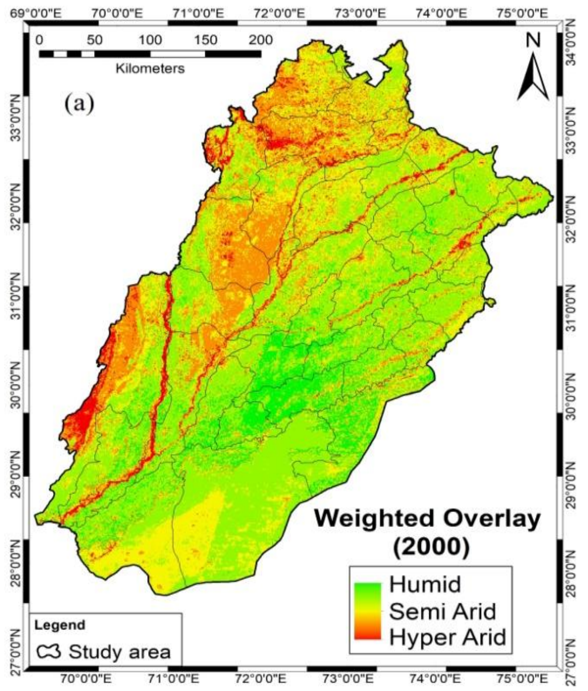


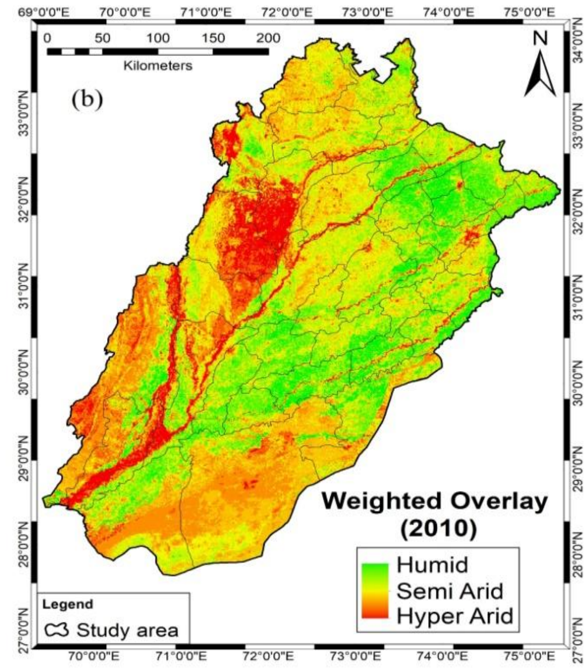
Fig. 5 Map showing classification of LST over Punjab based on pixel data (a) Year 2000 (b) Year 2010 and (c) Year 2017 (Data Source: USGS Earth Explorer).

Characterization of Aridity Using Weighted Overlay Analysis (WOL)

Weighted overlay analysis of NDVI, SAVI, TNDVI and LST over the Punjab province of years 2000, 2010 and 2017 depict a clear picture of aridity distribution. A marked variation in regional aridity distribution can be observed through this analysis. Figs. 6a, 6b and 6c show three classifications which include low, medium and high range values. The areas shown in red colour correspond to hyper arid regions, while the areas in yellow colored tone fall in semi-arid category and the areas shown in green colour are humid regions. It is significant to note that the humid areas are mainly located near and around the main rivers (Indus, Jehlum, Chenab, Ravi and Sutlej) of the Punjab province (Fig. 6c).

In irrigated areas of Punjab the vegetation is relatively abundant despite severe dryness in some parts. WOL analysis shows that the aridity has increased in recent years mainly in southern Punjab. The areas of Bahawalpur, Bahawalnagar and Dera Ghazi Khan show clear temporal transformation. In these areas aridity has increased its extent to a larger scale. Also, areas of Bhakker, Khushab Mianwali, Attok and Lahore are transformed into hyper arid regions. The results are indicative of noticeable climatic change and its worse impact on the geo-environmental conditions of the Punjab province. Considering the changing trend of aridity in study area, it can be predicted that Punjab will face severe arid conditions in coming years. Therefore, timely efforts are required to cope up this situation by making water resource management policies, conserving water, promoting alternate methods of water conservation and by reducing greenhouse gas (GHG) emissions etc.





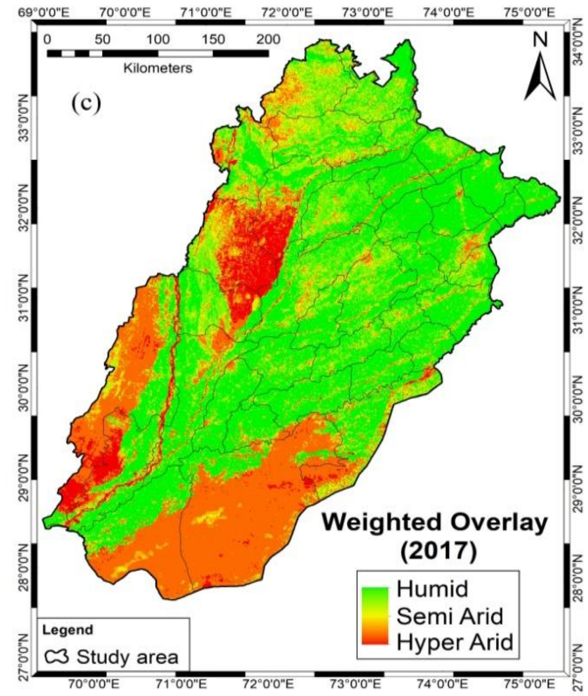


Fig. 6 Map showing classification of aridity over Punjab based on weighted overlay of NDVI, SAVI and TNDVI index by using pixel data (a) Year 2000 (b) Year 2010 and (c) Year 2017 (Data Source: USGS Earth Explorer).

Conclusion

This assessment helped to demarcate various arid zones within the Punjab province. The results of different vegetation indices (NDVI, SAVI, TNDVI) and land surface temperature (LST) reveal self-consistency. The arid and semi-arid areas in Pakistan have experienced dramatic changes on different time scales. These changes can be regarded as resulting from regional and global geographic and climatic changes. Analysis of climatic data indicates that the rate of evapo-transpiration is high in southern Punjab due to increased temperature and less precipitation (Table 1). Across Punjab, there is a consistent southward increase in the mean annual temperature (ranging from 35-55 ^{o}C) and decrease in mean annual precipitation (from 7 to below 21 mm). The WOL analysis indicates that aridity is very high in southern Punjab and in northern region of the province aridity is increasing gradually. The southward increase in aridity is basically controlled by the gradual decrease in the summer monsoon rainfall, since northward advance of the aridity occurs due to reduced precipitation to critical amount. El Niño and La Niña are abnormal climatic conditions that are mostly observed in the tropics. These phenomena have much impact on the climate of temperate and tropical zones. Pakistan is also located in the temperate region just close to tropics, therefore a huge part of Pakistan like Punjab and Sindh are mostly affected with these climatic abnormalities. Due to anthropogenic activities (transportation, urban expansion, industries, constructions, etc.) the climate of Punjab is also affected. The northern part of Punjab that was once considered as humid and cold, has mostly changed into dry semi-arid to the arid region and only a small part remains humid now. The temperature of Punjab has drastically increased with the passage of time and therefore, this area always remains in the threat of droughts. The region is facing a number of critical issues due to dry conditions such as the shortage of water resources, cutoff of river discharge, lowering of ground water levels, and expansion of aridity and loss of biodiversity. Agricultural activities are mostly dependent upon the sufficient amount of rainfall, but Punjab is badly affected with no change in the precipitation pattern. In recent years the aridity trend has been further aggravated due to regional climate change in association with global warming as well as influence of anthropogenic activities, rapid expansion of urbanization and development of social economy. Rainwater harvesting and underground water supply systems are sustainable ways for reduction of water loss in arid areas. The result outcomes will be beneficial for operating and manipulating the irrigation system in identified arid zones. This study can attract the attention of local and regional authorities towards proper land planning and management issues in the identified arid zones.

Acknowledgement

Thanks are due to anonymous reviewers for their valuable comments and suggestions.

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