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Identification of Desertification Hot Spot Using Aridity Index

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Abstract: Aridity index (AI) is a useful parameter to study desertification condition and its pattern. The AI formulation adopted by United Nations Environment Program (UNEP), Food and Agriculture Organization (FAO), and United Nations Convention to Combat Desertification (UNCCD), represents a simple but effective scientific investigation tool. AI is calculated by dividing the total annual precipitation by the annual potential evapotranspiration (PET). The objective of this paper is to study and identify the desertification hotspot using the AI over the Gujarat state. Desertification hot spots are the vulnerable areas within defined aridity zones. The weather data e.g. minimum temperature, maximum temperature, solar radiation, wind speed, humidity and rainfall for more than 18 locations all over Gujarat for the past 20 years has been used in this study. FAO Penman-Monteith method was used to calculate PET. Which along with rainfall were used to calculate AI for different locations. Annual AI map for the whole Gujarat has been generated using these values and compared with CGIAR based aridity map. MODIS-Terra NDVI product for the past 20 year period of rabi season has been used to get a correlation of AI with NDVI. In addition to comparing annual AI and NDVI data, thirty years average AI map has been generated for the State.

Key words: Desertification, aridity index, NDVI, potential evapotranspiration.

Desertification and land degradation are two main processes affecting two third countries of the world on which one billion people live. Climatic variations and anthropogenic activities are the main causes of desertification. As the days become warmer and precipitations become infrequent, periods of drought become more frequent, desertification is imminent.

"Land degradation" means reduction and loss of the biological and economic productivity of land due to natural processes, like climate change and human activities, such as soil erosion caused by wind and/or water, deterioration of the physical, chemical, and biological properties of soil with long-term loss of natural vegetation. The UNCCD (UN Convention to Combat Desertification) reported that land degradation has happened over the globe and it has become a serious environmental issue (UNCCD, 1994). Desertification is the most severe form of land degradation which occurs due to natural calamities like drought and flood as well as human activities.

Desertification is an extreme case of land degradation. This happens under the influence of climate change due to global warming, overexploitation of soil by human activities, overgrazing, deforestation, urbanization and other types of land development. In 1992, UNEP refined the definition of desertification as "Land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" and this adopted by United Nations Convention to Combat Desertification (UNCCD, 1994). Land degradation does not include the hyper arid regions like the Sahara desert. In hyper arid regions there is very less rainfall and very high evapotranspiration which restrict the plant growth in those conditions. Land degradation occurs everywhere but is defined as desertification when it occurs in the dry lands. Hotspots are small discontinuous pockets with very high aridity index within the area of low aridity index due to change in local weather condition.

Aridity index is the numerical representation of dryness of the climate for a particular location. Aridity index (AI) is a useful parameter to study desertification condition and its pattern. The AI formulation has been adopted by UNEP, FAO, and UNCCD for explaining different situations. The ratio of precipitation (P) to potential evapotranspiration (PET) is defined as Aridity Index (Barrow, 1992). The idealized quantity of water evaporated per-unit area, per unit time

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Table 1. Classification of arid zones by aridity index

Arid zone	Aridity index (AI)
Hyper-arid	< 0.05 (Desert)
Arid	0.05 - 0.20
Semi-arid	0.20 - 0.50
Dry sub-humid	0.50 - 0.65
Sub-humid	0.65 - 1.00
Humid	> 1.00

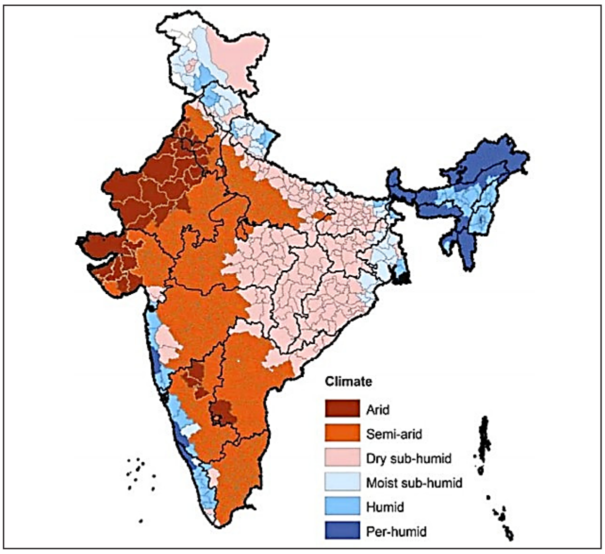

Fig. 1. District level climate classification of aridity zones of India.

from an idealized, extensive free water surface under existing atmospheric conditions is known as potential evapotranspiration. Precipitation defines the water vapor from the atmosphere which falls on the earth due to gravity.

As per this index, different aridity zones are classified as given in Table 1. Areas, other than polar and sub-polar regions, in which the ratio of annual precipitation to potential evapotranspiration falls within the range from 0.05 to 0.65 is called "arid, semi-arid and dry sub-humid areas". Figure 1 depicts the climatic zones delineated by Raju *et al.* (2013) with the district area as a unit of study.

Data Used

Weather data of Gujarat from agro-meteorology observations for more than 18 locations and for past years from 1995-2015 has been used in this study. Figure 2 shows the locations of the agro meteorology stations in Gujarat. Meteorological parameters like minimum temperature, maximum temperature, rainfall, relative humidity, wind speed and wind direction and bright sunshine hour parameters were collected along with the geographic location of each station. In addition, the satellite-derived product like MODIS-

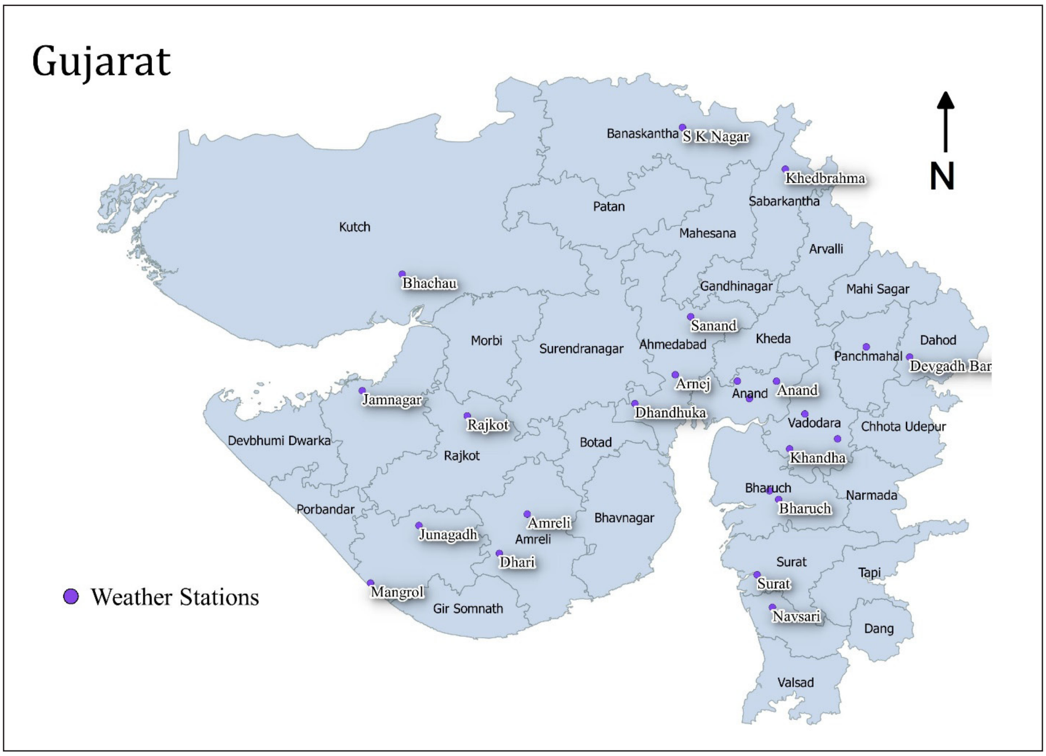

Fig. 2. Location of Agro-meteorological observatories in Gujarat.

Terra Normalized Difference Vegetation Index (NDVI) product for the past 20 year period of rabi season is used for the analysis.

Methodology

Climate data are the daily data for different weather parameters as given above. Some ambiguity and randomness were corrected and from daily data weekly, monthly and yearly data are generated to calculate the AI. Potential-Evapotranspiration were calculated for all stations of Gujarat using FAO Penman-Monteith equation (Allen *et al.*, 1998). PET and rainfall were used to calculate AI for different locations. Spatial interpolation using kriging was performed to get continues map from point data and annual AI map for the whole Gujarat was generated using these values. Surfer mapping, modeling and analysis software were used for interpolation. Kriging weights the surrounding measured values to derive a prediction for an unmeasured location. The general formula for kriging interpolator is formed as a weighted sum of the data:

$$Z(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i)$$

where,

$Z(s_i)$= the measured value at the i^{th} location

λi = an unknown weight for the measured value at the i^{th} location

s_0= the prediction location

N = the number of measured values

To develop aridity index map for the Gujarat state from our collected weather data, first evapotranspiration was calculated on yearly mean data for the stations in which required meteorological parameters were available. ET_0 was using the FAO Penman-Monteith method as explained below. The FAO Penman-Monteith method was developed by adopting the Penman-Monteith combination method for reference evapotranspiration. The method gives more significant values with actual crop water use data worldwide. The FAO Penman-Monteith (Allen *et al.*, 1998) method to estimate ET_0 is expressed as:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Utilizing rainfall data collected from observatories, AI was calculated for different stations of Gujarat for available stations. From point data, interpolation was performed to get the Aridity index map of whole Gujarat. Kriging interpolation was used to get continues map from point data. Using this method the AI maps for the Gujarat region over the 20 years are developed. Our AI result was also compared with the satellite derived product NDVI. The Modis-Terra NDVI product for the same year's data of AI was taken and compared. The NDVI for the Gujarat region is processed and formatted to match at the same resolution as that of AI map. The AI results are checked and correlated with the comparison for different years under drought and normal year according to meteorology throughout Gujarat State.

Results and Discussions

Gujarat state region were classified into three aridity zones e.g. arid, semi-arid and sub-humid zones. Figure 3(a-c) shows average potential evapotranspiration, rainfall and aridity index map of Gujarat. The AI map represents the climatic zones of Gujarat. Aridity zones were classified as explained in Table 1. Figure 3(d) shows the aridity index map of Gujarat using CGIAR-CSI Global Aridity Index database. The Global-Aridity is modeled using the data available from the WorldClim Global Climate Data as input parameters, for 1950-2000 (Dave *et al.*, 2018). Visual comparison of the developed Aridity Index (AI) map with the globally available CGIAR-CSI AI map revealed small discontinuous patches of arid zones in Bharuch, Amreli and Ahmedabad districts although these districts are located in a semi-arid zone. These areas can be considered as desertification prone zones. Similar pockets were noted in north Gujarat and some parts of Saurashtra despite of them being located in semi-arid zone. Both the aridity index maps as shown in the Fig. 3c and 3d are estimated by the Penman-Monteith method but the developed map has used real observatory data over eighteen meteorological observatories of Gujarat as given in Fig. 2. Figure 3c-d clearly shows that use of observatory based data found a detailed identification of hotspot which could not be found CGIAR aridity map as the modelled data has been used in it. So, this AI maps can be used to classify Gujarat state based on aridity indices. As there is a very

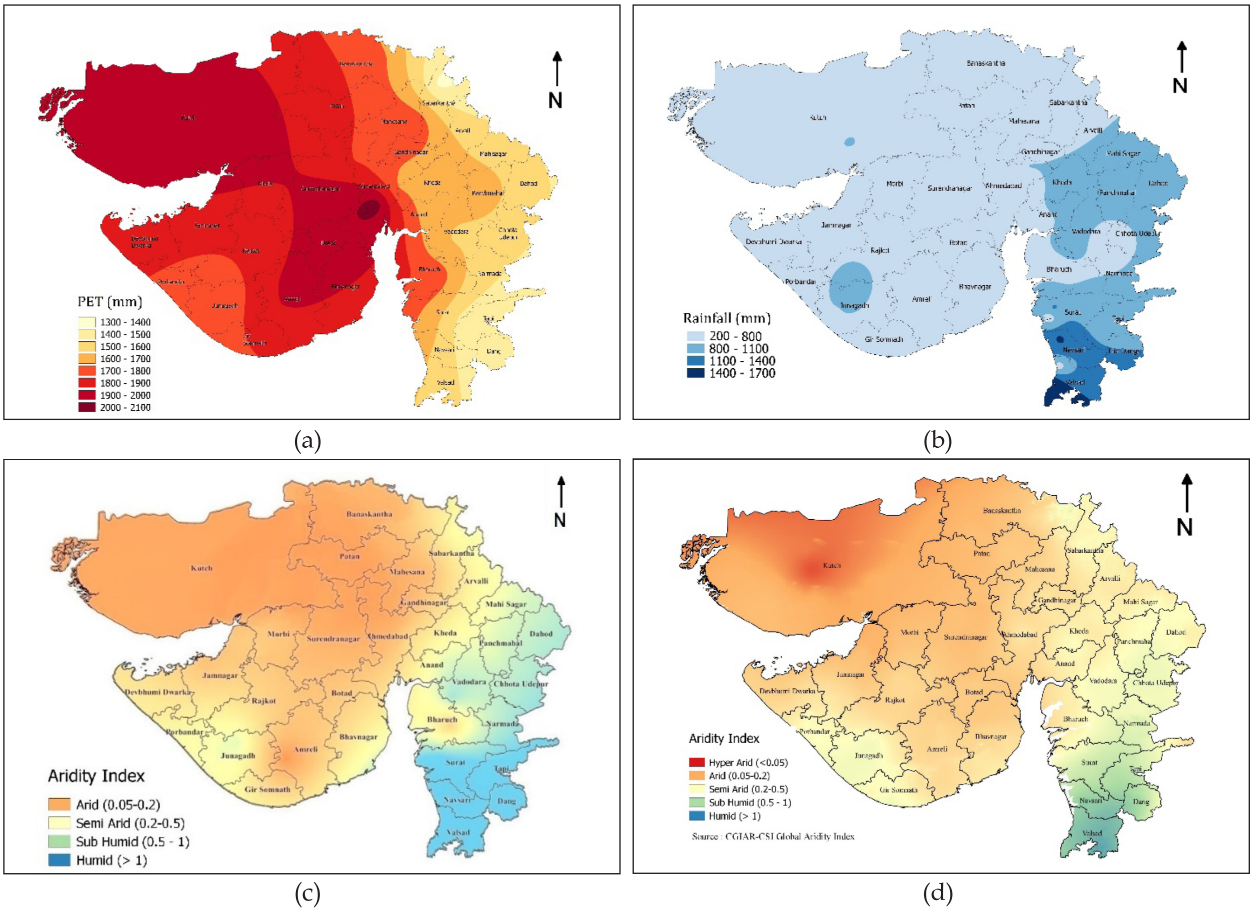

Fig. 3. Average (a) PET, (b) rainfall and (c) developed aridity index map of Gujarat (d) CGIAR-CSI global aridity index.

strong relationship between NDVI and rainfall (Dubey *et al.*, 2012) so Annual AI and NDVI maps were used for comparing the trend under normal (2008) and drought (2012) situation as depicted in Fig. 4 and 5, respectively. In Fig. 4 NDVI results are compared with rabi data of normal rainfall year (2008). Comparing the AI map with NDVI map using pixel-based correlation gives a correlation coefficient value from 0.48 to 0.7. The results of the NDVI are compared with AI map for different years based on histogram method as shown in Fig. 6. The mean AI in the year 2008 is 0.73 and NDVI is 0.33 and in the year 2012 mean AI is 0.49 and NDVI is 0.31. The NDVI value decreases as the AI value decreases. To get 1:1 relation between NDVI and AI value of random points (sixty) were selected from the 2008 and 2012

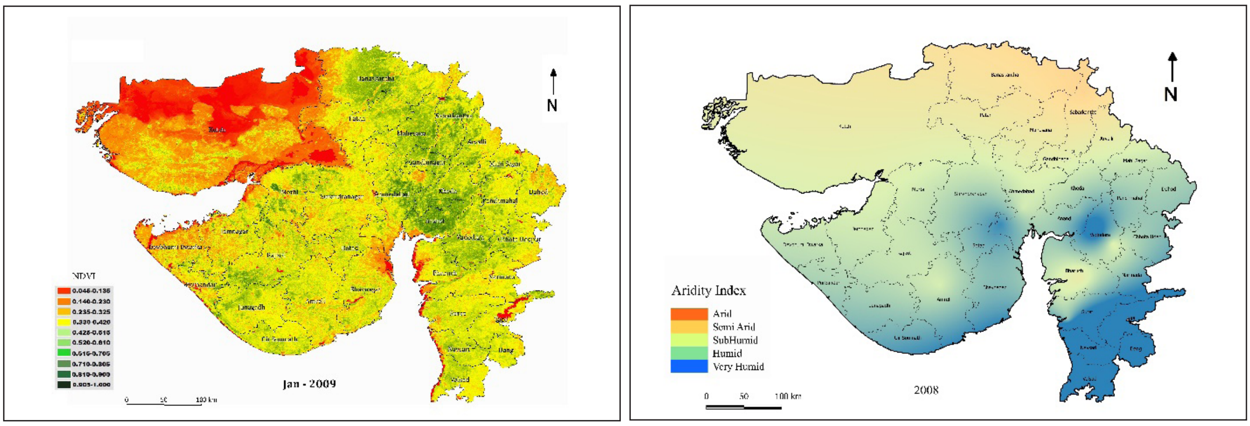

Fig. 4. Comparison of normalized difference vegetation index (NDVI) during rabi season of 2008 and aridity index map of 2008.

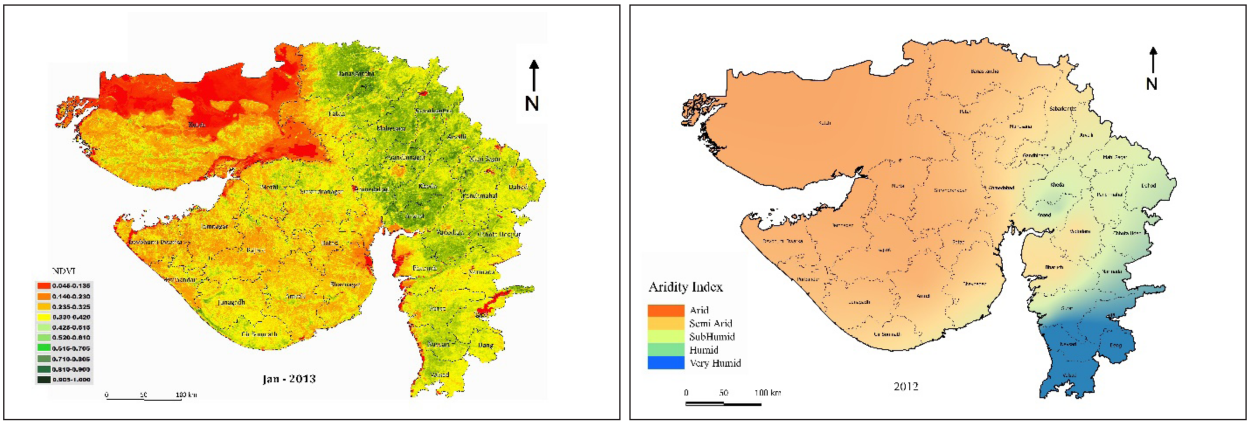

Fig. 5. Comparison of normalized difference vegetation index (NDVI) during rabi season of 2012 and aridity index map of 2012.

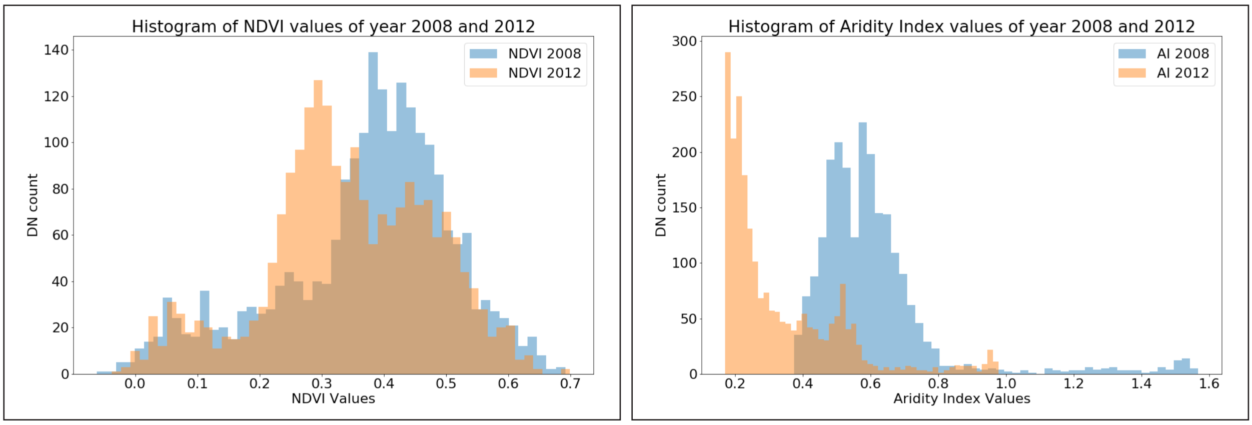

Fig. 6. Histogram of rabi NDVI and AI map for year 2008 and 2012.

year data (Fig. 7). Positive correlation of NDVI with AI, was observed because as the AI values increased the NDVI is also increases.

Conclusion

This study was performed using very limited meteorological observatory station points to calculate aridity index for Gujarat. Aridity index is found to be a useful tool for identification as well as monitoring of the desertification hotspots regions. It can be helpful to identify desertification trend and process. Village level climate data will be very important for locating more desertification prone zones with good

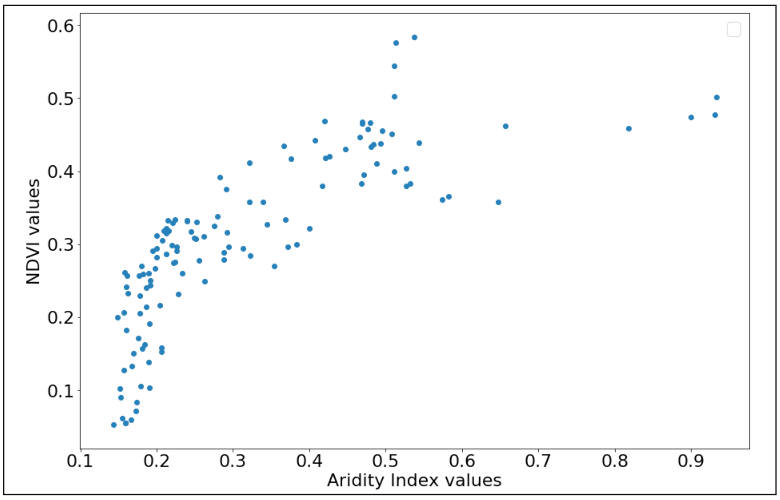

Fig. 7. Relation between NDVI and AI value of random points for the year 2008 and 2012.

accuracy. The mean NDVI value decreases with decrease in mean AI value for the entire Gujarat. These positive trend between AI and NDVI shows that vegetation indices is also a useful tool for monitoring desertification over time.

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