Assessment of Drought using Meteorological and Remote sensing data

D. Pavan Kumar[1], Sanat Nalini Sahoo[2]

[1]*M.tech Scholar, Department of Civil Engineering, National Institute of Technology Rourkela, India – 769008;* Email: pavankumardasari0705@gmail.com

[2]*Assistant Professor, Department of Civil Engineering, National Institute of Technology Rourkela, India – 769008;* Email: sahoosanat@nitrkl.ac.in

Abstract

The frequency of droughts has increased in recent years due to global warming, and it is a complicated natural hazard that is poorly understood. There are four types of droughts: meteorological, hydrological, agricultural, and socioeconomic. Precipitation deficits leads to meteorological drought. Agricultural drought is a result of several consequences like water deficits in soil, reduction of evapotranspiration and decreased crop yield. Drought occurrence cannot be eliminated; however, their consequences can be diminished if decision makers have access accurate spatio-temporal information about crop status. The objective of the study is to identify the meteorological and agricultural droughts across Anantapur district of Andhra Pradesh by using meteorological and remote sensing data. The SPI (Standardized Precipitation Index) and the SPEI (Standardized Precipitation Evapotranspiration Index) are two multiscalar drought indices that are used to identify Meteorological drought. Agricultural drought is identified by using IDCI (integrated drought condition index). IDCI was used by integrating vegetation conditions, temperature, precipitation, soil moisture and potential evapotranspiration. SPEI, SMCI (Soil Moisture Condition Index) and VCI (Vegetation Condition Index) are three drought indices that make up IDCI. The IDCI is computed in this study using Principal component analysis (PCA). The results shows that 2016 and 2018 are meteorological drought years and 2016,2017 and 2018 are agricultural drought years during 2012-2021in Anantapur district, Andhra Pradesh. The results of the study indicate that drought can be accurately evaluated by merging various data sources and drought indices, allowing for the estimation of risk management plans and the signing of new treaties.

Keywords: meteorological drought, SPI, SPEI, agricultural drought, IDCI, PCA.

1. Introduction

Global climate change, which is the most serious threat and the most difficult challenge confronting humanity, has captured the attention of the governments and public worldwide (Zhongwei, 1992). Since 1970s, extreme climatic occurrences like drought have become more frequent and intense. The intensity, duration and frequency of droughts are increasing in a variety of climatic regions in India. Droughts are a complicated natural hazard. Almost 100 crores of people lack access to drinking water, and around one third of the population in the world lives in an area with water shortages. Drought (7.5%) is regarded as the geographically broad hazard with the second-highest global prevalence on earth's terrestrial area after floods (11%). From the 1970s to the early 2000s, the percentage of the world affected by severe drought doubled (Nagarajan 2009). Nearly one-sixth of India's total land area, home to 12% of the population in the country, is prone to drought. Millions of people have died as a result of drought in India throughout the 18th, 19th, and 20th centuries.

The primary cause of India's drought is monsoon failure, which lowers crop yields and has a negative impact on the country's social and economic conditions. Approximately 68% of India is at risk of drought to varying degrees. A total of 35% of the region is thought to be drought-prone (receiving 750 to 1,125 mm of precipitation), while another 33% is thought to be chronically drought-prone (receiving precipitation below 750 mm). Major drought-prone areas including northern Karnataka, Rajasthan, southern and eastern Maharashtra, Odisha, Andhra Pradesh, Gujarat and Telangana are particularly affected.

Drought is a recurring occurrence in India. Drought affects about 107 million hectares of the nation, or more than 68 percent of India, which is dispersed throughout numerous administrative districts in various states. One district in Andhra Pradesh (AP) State where drought conditions have persisted for years is Anantapur. This has put a great deal of strain on the local economy, particularly the agricultural sector. Drought is complicated, poorly understood, and has significant effects on both people and the natural world. Droughts have typically been divided into four categories: meteorological, agricultural, hydrologic, and social-economic (Mishra and Singh, 2010).

The shortage in precipitation results in Meteorological drought. The result of insufficient soil moisture throughout the growth period of crops due to a lack of precipitation, high temperatures, high evapotranspiration, and lack of soil moisture is agricultural drought (Zhao et al., 2017). Agricultural drought is associated with meteorological and hydrologic circumstances, as well as vegetation's resistance to water shortage, which have an adverse effect on agricultural production (Zexi Shen,2019). The major application of drought indices and indicators is to monitor the conditions of drought, which vary depending on the climate and region. The standard precipitation index (SPI) was proposed by McKee et al. (1993). Vicente-Serrano et al. (2010) presented the standard precipitation-evapotranspiration index (SPEI), which they claimed that the value of SPI has improved by taking interactions between potential evapotranspiration and precipitation into account.

Drought indices based on remote sensing, such as VCI and NDVI, have the advantage of describing the spatial pattern. Remote sensing has been shown to be effective for monitoring agricultural drought and analysing it's occurrence spatially when combined with a complete view of the Earth's surface (Gu et al. 2007). Vegetation condition index (VCI), normalised difference vegetation index (NDVI), vegetation health index (VHI) and temperature condition index (TCI) are the remotely sensed drought measures that have been created and implemented (AghaKouchak et al. 2015; Shefeld and Wood 2012; Kogan 1995). The vegetation condition index has proven to be the most effective among these indices for tracking drought occurrences (Ji and Peters 2003; Rhee et al. 2010). Without taking into account meteorological aspects like precipitation, SMCI is able to define the conditions of drought from the perspective of soil moisture. However, the delayed effect of soil moisture and agricultural drought on precipitation changes is large in both space and time. With these ideas in mind, additional elements were considered in this study, including precipitation, potential evapotranspiration, soil moisture, and vegetation conditions.

Therefore, by evaluating several drought indices, the current study makes an effort to identify drought for the Anantapur area. The study area experiences drought frequently due to a lack of rainfall; the goal was to quickly identify the dry year using meteorological and remote sensing data. Because of rising population and increased usage of ground water, the levels of ground water are steadily decreasing. The region's agriculture is entirely dependent on precipitation because there is no other source of water.

This study combined meteorological, soil moisture, and vegetation conditions to calculate an integrated drought condition index (IDCI). IDCI is used to monitor the agricultural drought. The weighted indices for SPEI (Standardized Precipitation Evapotranspiration Index), SMCI (Soil Moisture Condition Index) and VCI (Vegetation Condition Index) are calculated by using PCA (principal component analysis) in STATA Software.

2. Materials and Methods

2.1 Drought Indices

2.1.1 Standardized Precipitation Index (SPI)

McKee et al. proposed the Standardized Precipitation Index (SPI) in 1993. The World Meteorological Organization (WMO) uses this index among others to show how much precipitation fell over a given time frame. The R-package in R-studio computes SPI. The spatiotemporal extent and intensity of the meteorological drought event were estimated to be observed by SPI. The gamma distribution is given as:

$$g(x) = \frac{1}{\beta^{\alpha}\,\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}}, \mathrm{x} > 0$$

where α and β are the parameters of shape and scale, $\alpha > 0$, $\beta > 0$.

2.1.2 Standardized precipitation-evapotranspiration index (SPEI)

The R-package created by (Beguera et al. 2014) was used to generate the standardized precipitation-evapotranspiration index (SPEI).

2.1.3 Vegetation Condition Index (VCI)

On the final NDVI database, the following VCI equation was used:

$$\mathrm{VCI} = \frac{NDVI_i - NDVI_{min}}{NDVI_{max} - NDVI_{min}}$$

where $NDVI_i$ refers to monthly NDVI at location i while $NDVI_{min}$ and $NDVI_{max}$ are the absolute 10-year (2012–2021) minimum and maximum values of NDVI at location i.

2.1.4 Soil moisture condition index (SMCI)

Scaled soil moisture is represented by the soil moisture condition index (SMCI) (Sanchez et al., 2016):

$$\mathrm{SMCI}_{i,j,y} = \frac{SM_{max} - SM_{i,j,y}}{SM_{max} - SM_{min}}$$

where $\mathrm{SMCI}_{i,j,y}$ is the reanalysis soil moisture (SM) at pixel i in the jth month of the yth year, while SM_{max} and SM_{min} are 10- year (2012–2021) absolute maximum and minimum values of SMCI at pixel i.

2.1.5 Integrated drought index (IDCI)

In this study, PCA (Liu et al., 2016) was utilized to construct IDCI by merging VCI for vegetation condition, SPEI for assessment of relationships between precipitation and potential evapotranspiration, and SMCI for soil moisture conditions.

IDCI= x_i *SMCI +y_i *VCI + z_i* SPEI

Where x, y and z are the coefficients for SMCI, VCI and SPEI, respectively, at station i.

2.2 Study Area and Data Source

2.2.1 Anantapur District

The research area is the Rayalaseema Region range's Anantapur District, which is located at latitudes 14°42′N and 77°36′E in Andhra Pradesh, India. It has a total size of 19,197 km2. Anantapur district is the seventh most populous district in Andhra Pradesh out of its 13 districts (Figure 1). This region is underdeveloped economically. The district's average yearly rainfall is found to be 381 mm. The state administration has classified it as a drought-affected area as a result of its low and high interannual variability. According to the 2011 census, the population density increased from 54 people per square kilometer in 1901 to 213 people per square kilometer. The district's main agricultural products include paddy, jowar, ragi, chili, sugarcane, onion, and peanut. The two main crops, paddy and groundnut, account for 65,550 and 36,500 gross hectares, respectively.

2.2.2 Data collection

The average monthly precipitation and temperature are gathered from the IMD, Pune, for the years 2012 to 2021. The monthly NDVI data for the period of 2012 to 2021 and the monthly Terra MODIS data with a spatial resolution of 500 m by 500 m were obtained from NASA LPDAAC COLLECTIONS of USGS Earth Explorer (https://earthexplorer.usgs.gov/). Soil moisture data from NOAA/OAR/ESRL PSD, Boulder, Colorado, USA (https://www.esrl.noaa.gov/psd/), with a spatial resolution of 0.5°× 0.5°, was gathered for the CPC (Climate Prediction Centre).

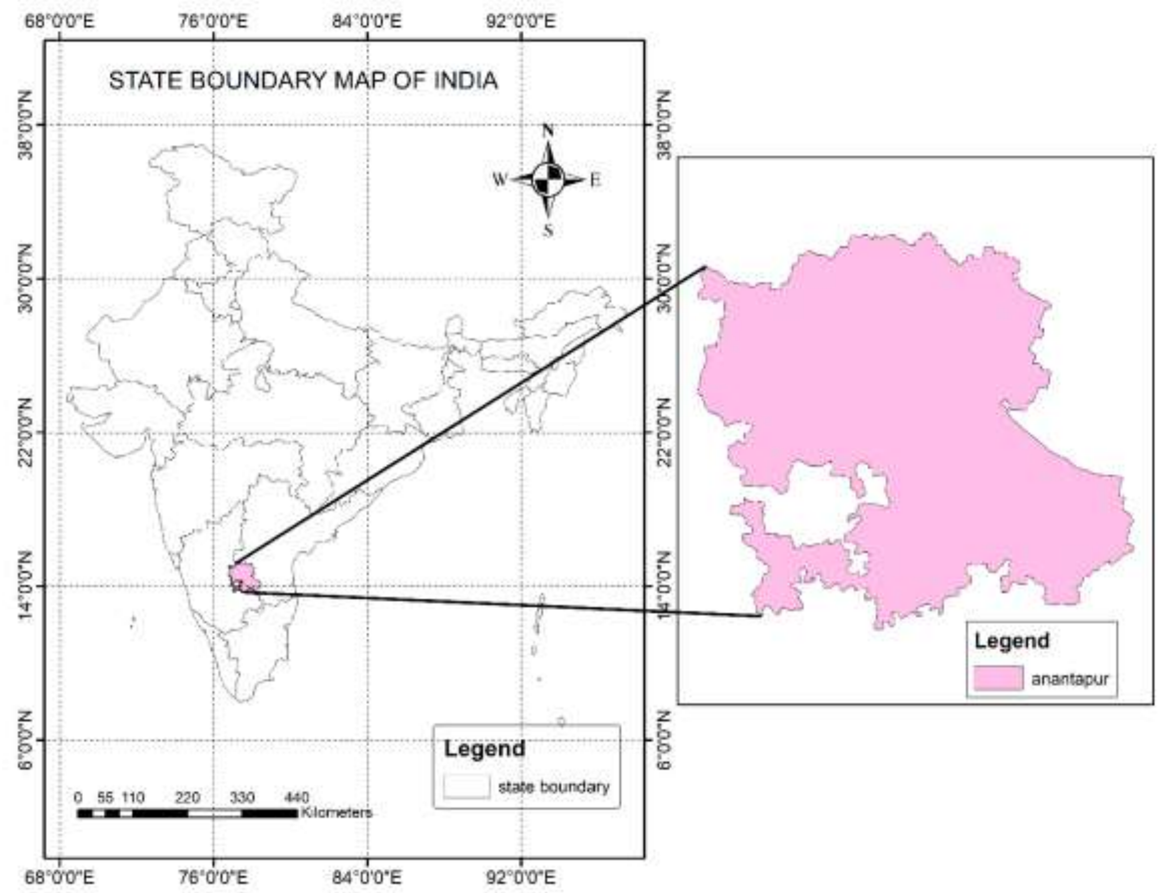

Figure 1 Study Area Map.

2.3 Data processing

SPI index is calculated by using monthly precipitation. SPEI is computed by using the precipitation and temperature data. Both indices are calculated by using SPEI package in the R-studio software. VCI and SMCI are calculated in ARCMAP software by using remote sensing data (from Modis and NOAA). For IDCI weighted index are calculated by using PCA (Principal component analysis) in STATA software.

3. Results and Discussions

Standardized Precipitation Index (SPI*)*:

To assess the drought stress condition, 1-month SPI values were calculated from 2012 to 2021. As indicated in figures 2 and 3, SPI is taken into account in all months of all years for clear analysis. SPI can easily identify meteorological drought years and diagnose drought stress because it is an indicator of both dryness and wetness. Figures 2 and 3 show that the drought event in the Anantapur district begins with a -3 (negative) and finishes with a +3. (Positive).

Due to the fact that we only take into account precipitation values when calculating the SPI values, we can see that years with more negative value months are classified as meteorological drought years. Figures 2 and 3 make it clear that the years 2016 and 2018 are years of meteorological dryness.

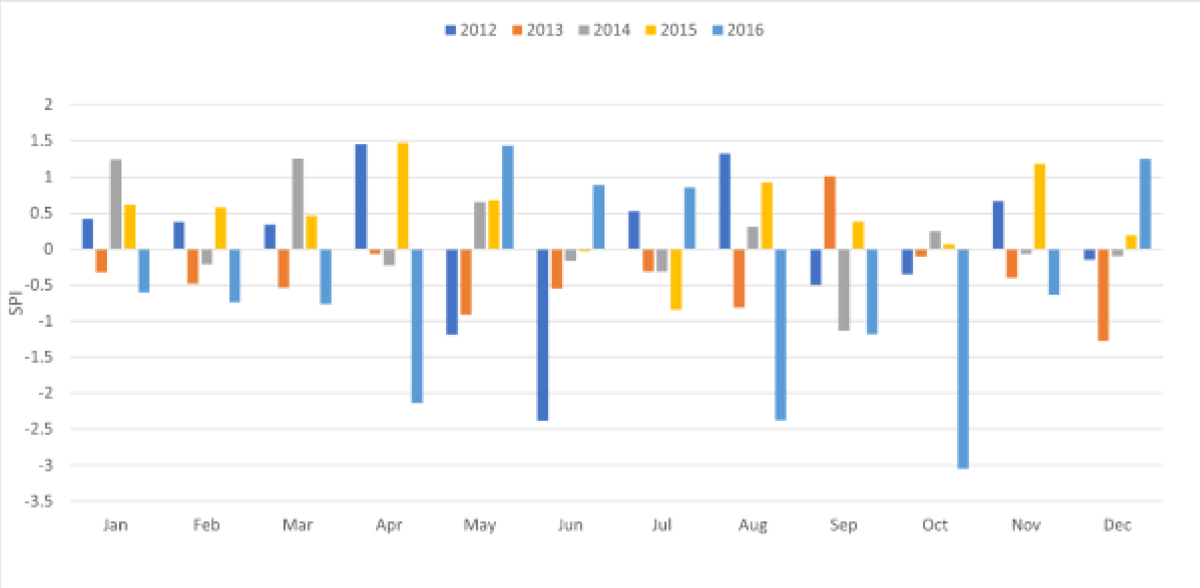

Figure2 SPI values from 2012 to 2016

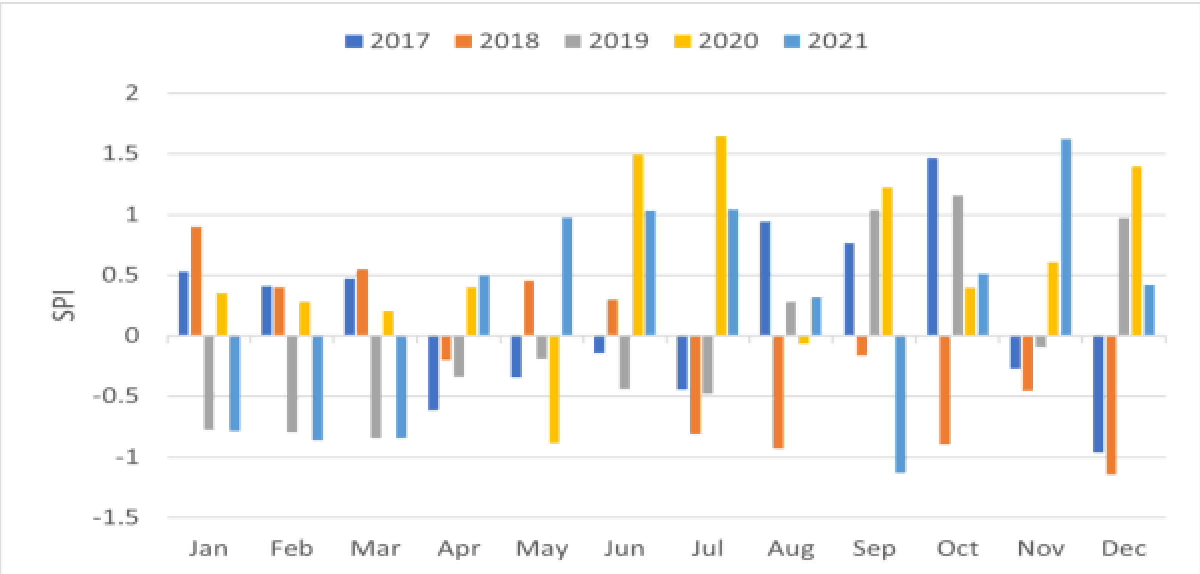

Figure 3 SPI values from 2017 to 2021

Standardized precipitation-evapotranspiration index (SPEI):

To monitor the vegetation's drought stress condition, 1-month SPEI values were calculated from the years 2012 to 2021. Temperature and precipitation data are used to calculate SPEI.

SPEI is taken into account in all months of all years as indicated in figures 4 and 5 for clear analysis. SPEI can quickly identify drought years and drought stress because it is a dryness and wetness indicator. Figures 4 and 5 show that the drought event in the Anantapur district begins with a -2 (negative) and finishes with a +2. (Positive). The SPEI values show that years with more negative value months are considered to be drought years. Figures 4 and 5 make it clear that the years 2016–2018 are drought years.

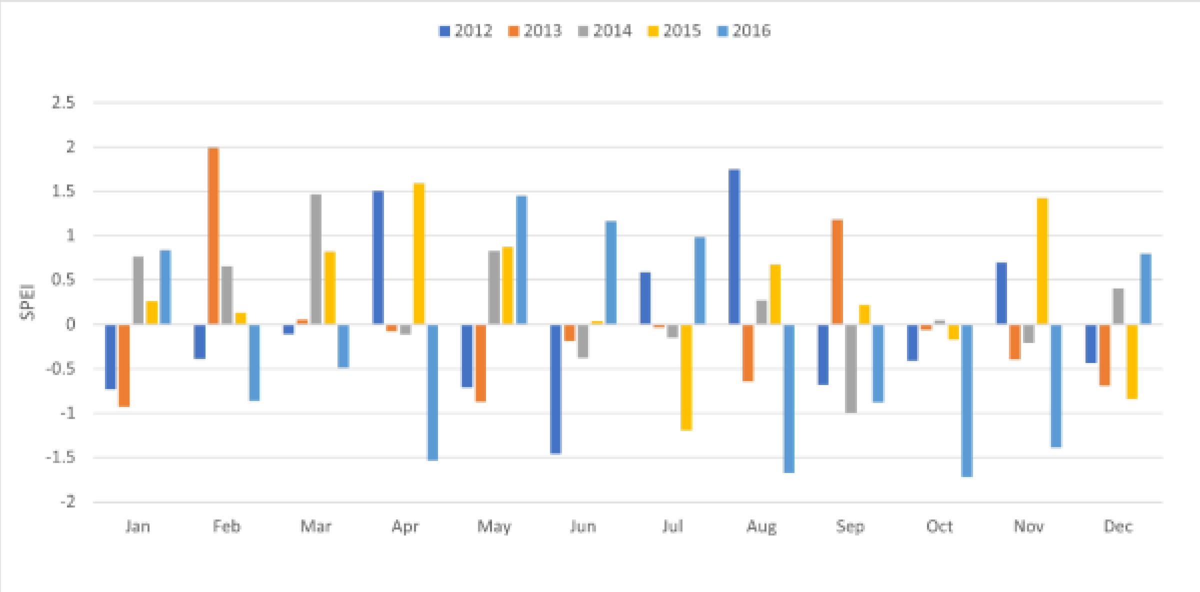

Figure 4 SPEI values from 2012 to 2016.

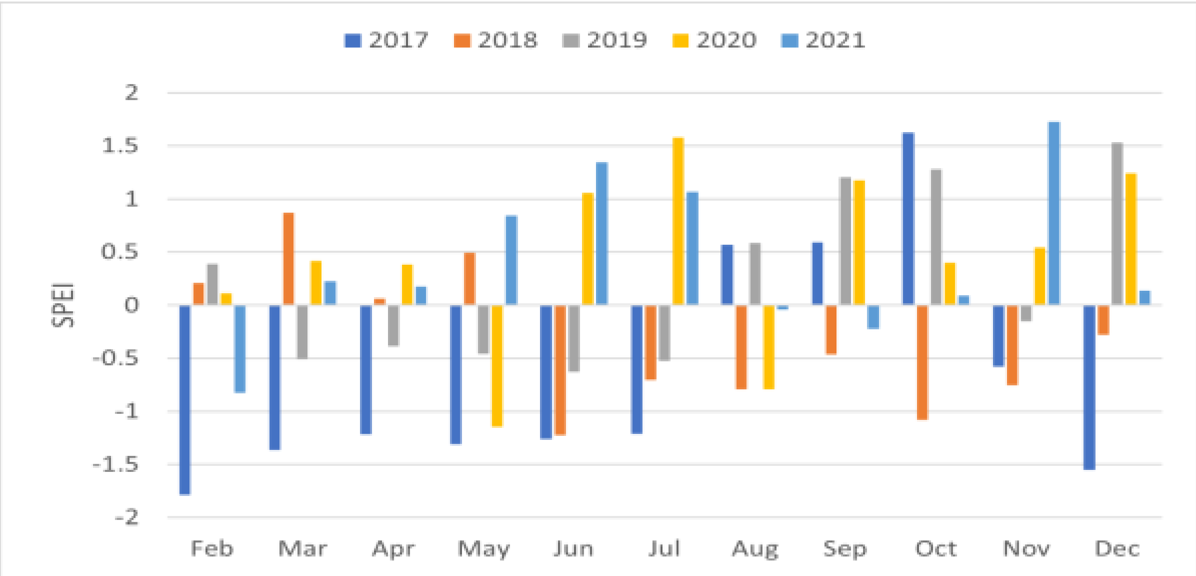

Figure 5 SPEI values from 2017 to 2021.

Vegetation Condition Index (VCI):

VCI values are calculated by using the Modis satellite data. Fig 6&7 shows the monthly VCI values from 2102 to 2021.

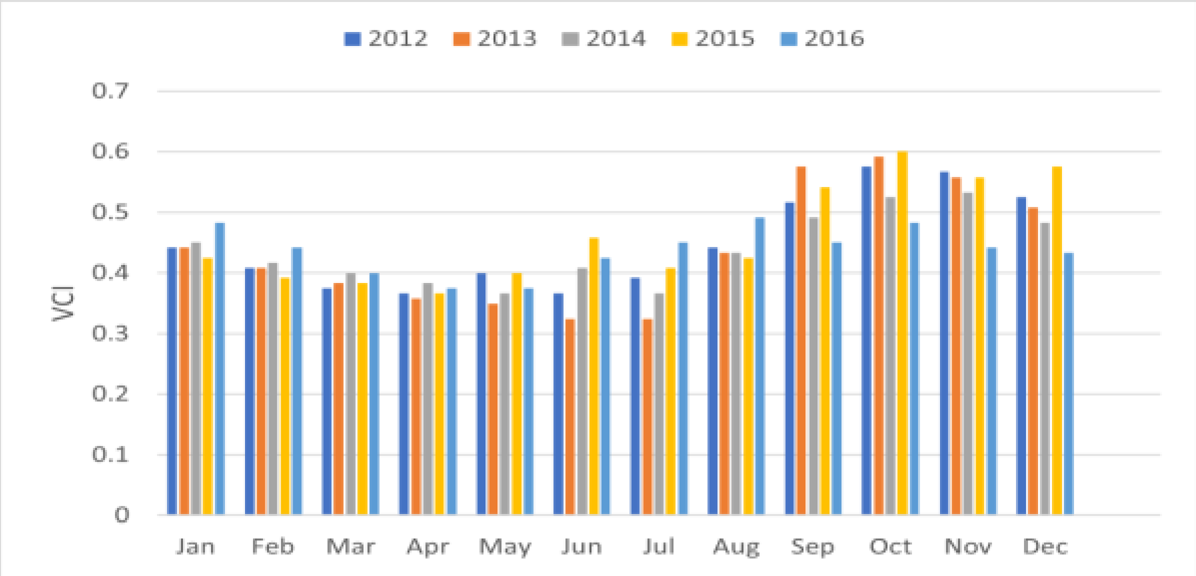

Figure 6 VCI values from 2012 to 2016.

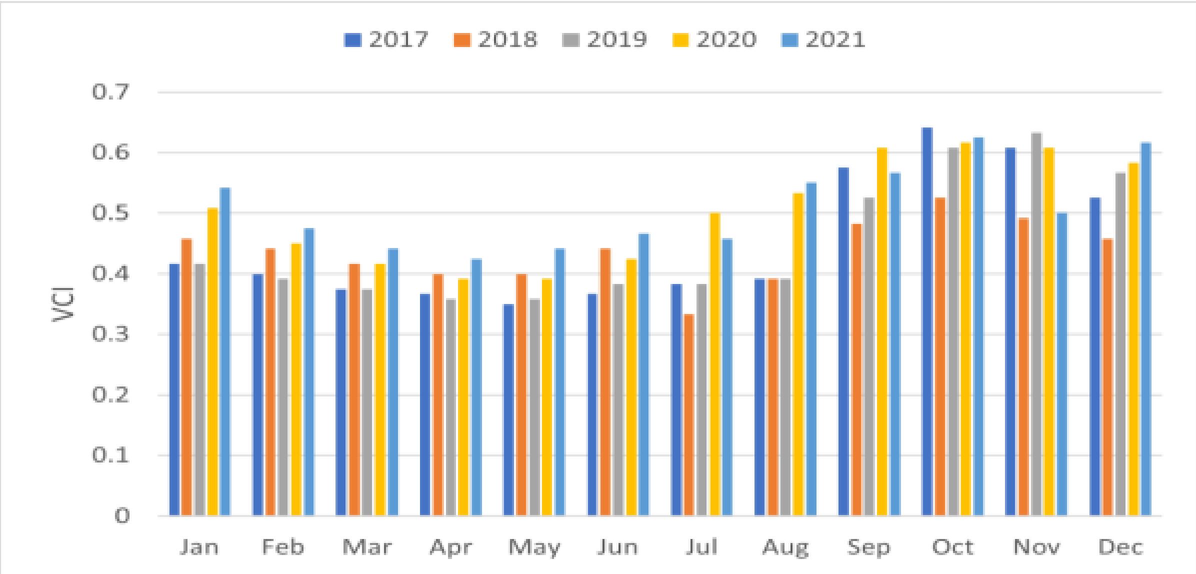

Figure 7 VCI values from 2017 to 2021.

Integrated drought index (IDCI):

IDCI is a combined drought index especially used to find the agricultural drought. It is combination of VCI, SPEI and SMCI. Monthly IDCI values are calculated from 2012 to 2021. Fig 8&9 shows the IDCI values from 2012 to 2021 From Fig.8&9 it was observed that in

Anantapur district drought event starts from -2 and ends with a +2. According to the IDCI values we observe that the years which have more negative value months treated as agricultural drought years. From figure 8&9 we can easily observe that 2016 ,2017 and 2018 are agricultural drought years.

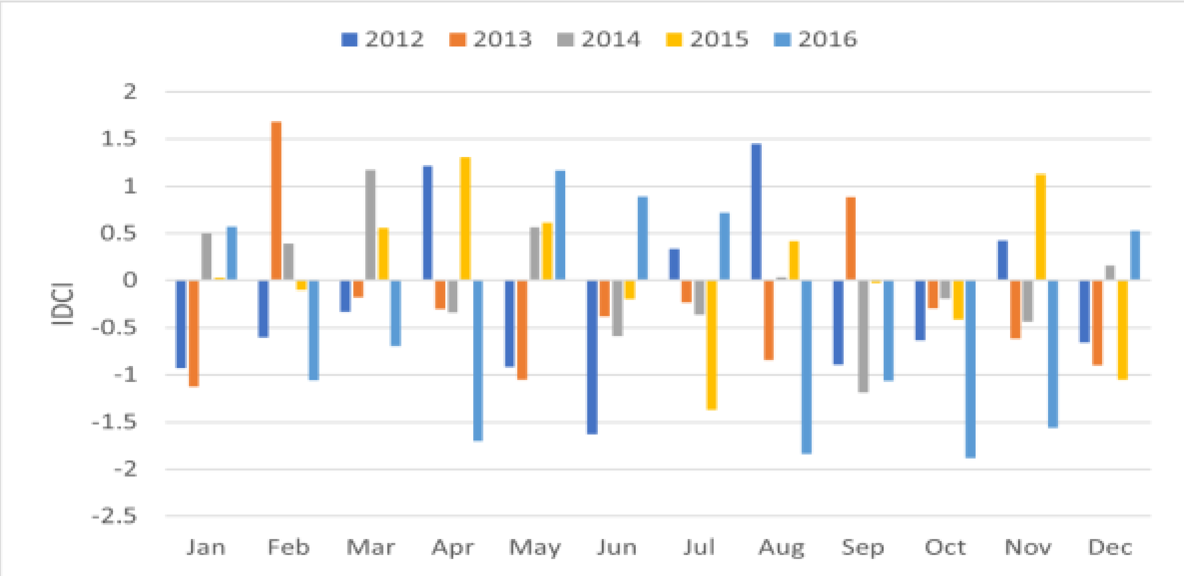

Figure 8 IDCI values from 2012 to 2016.

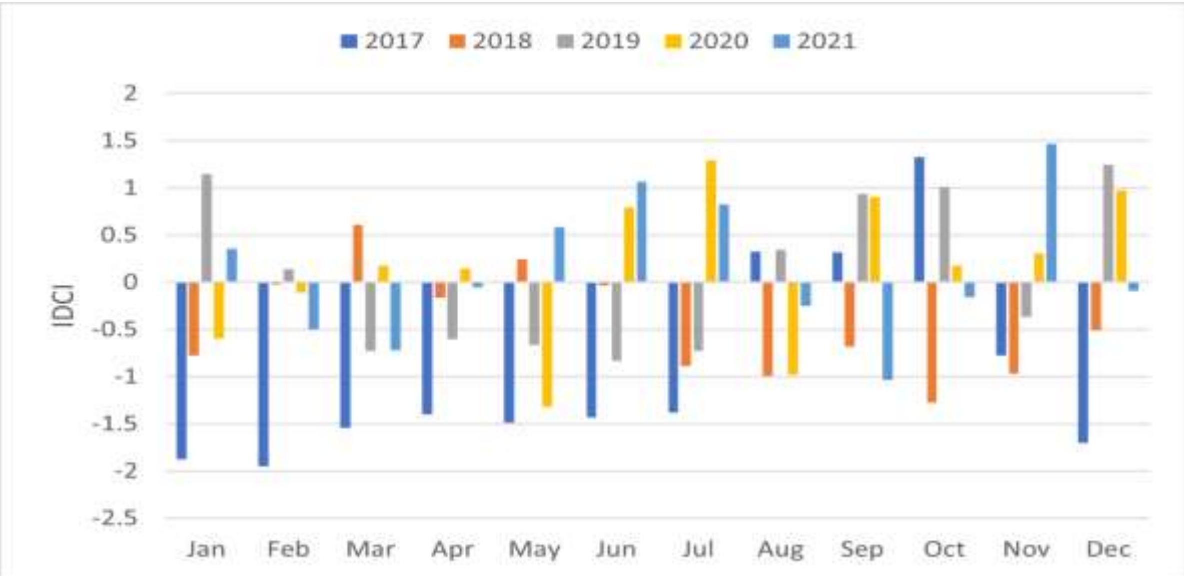

Figure 9 IDCI values from 2017 to 2021.

4. Conclusions

The following conclusions are derived from the foregoing study:

(i) We can conclude that 2016 and 2018 are meteorological drought years in Anantapur district, Andhra Pradesh as per SPI and SPEI indices.

(ii) We can conclude that 2016,2017 and 2018 are agricultural drought years in Anantapur district, Andhra Pradesh as per SPI, SPEI and IDCI indices.

(iii) Even though 2017 is not a meteorological drought year we get it as agricultural drought year because in 2017 evapotranspiration is too high which leads to lower SPEI values that leads to lower IDCI values which leads to agricultural drought.

(iv) In further My study is used to estimate the crop yield by using IDCI values.

References

Agutu, N. O., Awange, J. L., Zerihun, A., Ndehedehe, C. E., Kuhn, M., & Fukuda, Y. (2017). Assessing multi-satellite remote sensing, reanalysis, and land surface models' products in characterizing agricultural drought in East Africa. *Remote sensing of environment*, *194*, 287-302.

Alwan, I. A., Ziboon, A. T., Khalaf, A. G., Pham, Q. B., Anh, D. T., & Khedher, K. M. (2022). Monitoring agricultural and meteorological drought using remote sensing. *Arabian Journal of Geosciences*, *15*(2), 1-15.

Arun Kumar, K. C., Reddy, G. P. O., Masilamani, P., & Sandeep, P. (2022). Indices-based assessment of vulnerability to agricultural drought in the tropical semi-arid ecosystem using time-series satellite and meteorological datasets. *Arabian Journal of Geosciences*, *15*(11), 1-18.

Baig, M. H. A., Abid, M., Khan, M. R., Jiao, W., Amin, M., & Adnan, S. (2020). Assessing meteorological and agricultural drought in Chitral Kabul river basin using multiple drought indices. *Remote Sensing*, *12*(9), 1417.

Dutta, D., Kundu, A., & Patel, N. R. (2013). Predicting agricultural drought in eastern Rajasthan of India using NDVI and standardized precipitation index. *Geocarto International*, *28*(3), 192-209.

Dutta, D., Kundu, A., Patel, N. R., Saha, S. K., & Siddiqui, A. R. (2015). Assessment of agricultural drought in Rajasthan (India) using remote sensing derived Vegetation Condition Index (VCI) and Standardized Precipitation Index (SPI). *The Egyptian Journal of Remote Sensing and Space Science*, *18*(1), 53-63.

Homdee, T., Pongput, K., & Kanae, S. (2016). A comparative performance analysis of three standardized climatic drought indices in the Chi River basin, Thailand. *Agriculture and Natural Resources*, *50*(3), 211-219.

Khosravi, H., Haydari, E., Shekoohizadegan, S., & Zareie, S. (2017). Assessment the effect of drought on vegetation in desert area using landsat data. *The Egyptian Journal of Remote Sensing and Space Science*, *20*, S3-S12.

Liu, Z., Wang, Y., Shao, M., Jia, X., & Li, X. (2016). Spatiotemporal analysis of multiscalar drought characteristics across the Loess Plateau of China. *Journal of Hydrology*, *534*, 281-299.

Mishra, A. K., & Singh, V. P. (2010). A review of drought concepts. *Journal of hydrology*, *391*(1-2), 202-216.

McKee, T. B., Doesken, N. J., & Kleist, J. (1993, January). The relationship of drought frequency and duration to time scales. In *Proceedings of the 8th Conference on Applied Climatology* (Vol. 17, No. 22, pp. 179-183).

Nagarajan, R. (2009). Drought indices. In *Drought assessment* (pp. 160-204). Springer, Dordrecht.

Narasimhan, B., & Srinivasan, R. (2005). Development and evaluation of Soil Moisture Deficit Index

(SMDI) and Evapotranspiration Deficit Index (ETDI) for agricultural drought monitoring. *Agricultural and forest meteorology*, *133*(1-4), 69-88.

Ojha, S. S., Singh, V., & Roshni, T. (2021). Comparison of meteorological drought using SPI and SPEI. *Civil Engineering Journal*, *7*(12), 2130-2149.

Rhee, J., Im, J., & Carbone, G. J. (2010). Monitoring agricultural drought for arid and humid regions using multi-sensor remote sensing data. *Remote Sensing of environment*, *114*(12), 2875-2887.

Sharma, A. P. M., Jhajharia, D., Gupta, S., & Yurembam, G. S. (2022). Multiple indices based agricultural drought assessment in Tripura, northeast India. *Arabian Journal of Geosciences*, *15*(7), 1-13.

Shen, Z., Zhang, Q., Singh, V. P., Sun, P., Song, C., & Yu, H. (2019). Agricultural drought monitoring across Inner Mongolia, China: Model development, spatiotemporal patterns and impacts. *Journal of Hydrology*, *571*, 793-804.

Wolteji, B. N., Bedhadha, S. T., Gebre, S. L., Alemayehu, E., & Gemeda, D. O. (2022). Multiple indices based agricultural drought assessment in the Rift Valley region of Ethiopia. *Environmental Challenges*, *7*, 100488.

Zhang, Y., Liu, X., Jiao, W., Zeng, X., Xing, X., Zhang, L., ... & Hong, Y. (2021). Drought monitoring based on a new combined remote sensing index across the transitional area between humid and arid regions in China. *Atmospheric Research*, *264*, 105850.

Zhao, H., Gao, G., An, W., Zou, X., Li, H., & Hou, M. (2017). Timescale differences between SC-PDSI and SPEI for drought monitoring in China. *Physics and Chemistry of the Earth, Parts a/b/c*, *102*, 48-58.

Zhongwei, Y., Duzheng, Y., & Cun, W. (1992). Climatic jumps in the flood/drought historical chronology of central China. *Climate Dynamics*, *6*(3), 153-160.