Vol. 23, No. 2, pp. 170-179 (2023)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Evaluation of Microwave Integrated Drought Index (MIDI) for Drought Monitoring over India

PRABIR KUMAR DAS[1]*, SANCHARI KUNDU[2] AND SUPARN PATHAK[1]

[1]*Regional Remote Sensing Centre-East, National Remote Sensing Centre, Kolkata-700163, West Bengal*
[2]*Department of Geography, Jamia Millia Islamia, New Delhi-110025*

ABSTRACT

Microwave remote sensors have improved reliability for agricultural drought monitoring due to their all-weather capability. This study aims to evaluate the potential of microwave integrated drought index (MIDI), developed from various microwave sensors, for drought monitoring over the Indian mainland. The microwave-integrated drought index (MIDI) data for 23 years (1998-2020) over the Indian mainland was acquired and transformed into a standardized microwave integrated drought index (SMIDI) at 3- and 6-month timescales using a non-parametric empirical distribution approach. The drought duration and magnitude were computed and were spatially mapped for the monsoon season (June-September) during the study years. Drought duration and magnitude had a positive correlation, indicating that those areas which face longer drought duration, also face a greater drought intensity. Further, the Mann-Kendall trend analysis for drought duration was carried out. At both timescales, increasing trends in drought duration were found in the east-central, north-eastern, and southern parts of the country. Finally, the potential of SMIDI was evaluated based on its ability to detect drought events across the Indian mainland. A good agreement between SMIDI-derived and reported drought events confirmed the capability of SMIDI as a potential microwave derived drought index for operational drought monitoring and assessment.

Key words: Gridded data, Soil moisture drought, Standardized soil moisture index, Trends, Frequency analysis

Introduction

Climate Change increases food security risks, causing degradation of food systems whose magnitude is increasingly felt in the nutrition of most vulnerable countries. According to the Food and Agriculture Organisation (FAO), to meet satisfactory dietary requirements for the growing population, a 60% increase in food is required by 2050 (Shorachi, 2021). Drought, a hydro-climatic extreme event, is one of the major reasons for low food security by reducing agriculture production. Till now, no clear definition of drought has been given, meteorologists usually define drought as persisting dryness caused by to lack of precipitation (Seneviratne *et al*., 2012; AghaKouchak *et al*., 2014). Continued lack of precipitation leads to a deficit in soil moisture and agricultural drought sets in, causing crop stress. Drought frequency has increased by almost 40% and this has not only stagnated but also in some cases, reversed gains from food grain production putting a majority of rural livelihood at risk. In the years 2006-2016, food insecurity caused by drought affected countries in Asia, Africa, and the Pacific and yield losses rose by 7% as compared to earlier drought events of 1960-80s (IPCC Report). Subsequently, due

*Corresponding author,
Email: prabirkumar_d@nrsc.gov.in

to climate change, the area under crop and livestock would decrease globally and also become climatically unsuitable (Seneviratne *et al*., 2012; Dai, 2013; Li and Zhou, 2015).

Drought monitoring faces a challenge because of its spatio-temporal variability and varied severity across regions. Traditionally, climate-based indicators were used for drought monitoring like Palmer Drought Severity Index (Palmer, 1965) and Standardized Precipitation Index (McKee *et al*., 1993), which although useful for large-scale drought monitoring is not suited for monitoring at the local scale. Satellite remote sensing for crop monitoring has become increasingly important, due to its ease of availability and high temporal resolution. Using this technology, one can efficiently carry out temporal analysis of crop yield at synoptic scales, helping in detecting crop stress conditions and also assist in the decision-making process for farmers regarding water usage for irrigation in water-stressed regions. Multi-sensor remote sensing for integrated drought monitoring has advanced modelling capability and prediction reliability (Pai *et al*., 2011). Optical remote sensing has previously been used for monitoring agriculture conditions. Sensors like LANDSAT, MODIS, AwiFS, and Sentinel-2 have been used for crop monitoring along with satellite-based indices like Normalized Vegetation Index (NDVI; Kreigler *et al.*, 1969), Leaf Area Index (LAI; Watson, 1947), and Normalized Difference Water Index (NDWI; Gao, 1996) providing high spatial-resolution outputs. Development of indices integrating temperature, precipitation, soil moisture for robust crop monitoring including Temperature-Vegetation Dryness Index (TVDI), Vegetation Temperature Condition Index (VTCI; Prihodko and Goward, 1997) based on temperature, Soil Moisture Deficit Index (SMDI; Narasimhan and Srinivasan, 2004) based on soil-moisture and Rainfall Anomaly Index (RAI; Rooy, 1965) based on precipitation.

Optical remote sensing operates at short wavelengths of 0.4 to 15 mμ which are unable to penetrate clouds and data is contaminated by cloud cover causing data gaps and reducing temporal reliability of this remote sensing technique for crop monitoring. Microwave remote sensors operate at longer wavelengths of 1cm to 1m, which may be better capable for drought monitoring because of their insensitivity to cloud cover and prevailing weather conditions. Active microwave sensors include RADARSAT-2, Sentinel-1, ALOS-2, TerraSAR-X, providing capability for estimating the dielectric and geometric properties of crops. To avoid the constraints posed by weather conditions on infrared and optical-based indices, microwave drought indices like the Microwave Integrated Drought Index (MIDI; Zhang and Jia, 2020) have been used for short-term drought monitoring integrating certain factors such as precipitation for calculating Precipitation Condition Index (PCI), temperature for calculating Land Surface Temperature (LST) and soil moisture to derive the Soil moisture Condition Index (SMCI). Previously, a study was carried out in East Africa, to monitor drought in a 3-month time series, using passive microwave drought indices like MIDI and VHI where results showed high correlation and clarified drought dynamics (Zhang *et al*., 2019). Evaluation of MIDI data showed its reliability in monitoring drought conditions of arid and semi-arid regions and across various timescales (Alemu *et al*., 2019). Despite extensive literature found on microwave remote sensing for agricultural monitoring, the potentiality of microwave drought indices for crop monitoring is still untapped.

In most of the previous studies related to drought monitoring, remote sensing-based monitoring has been limited to visible and infrared sensors that are highly affected by clouds and varied climatic conditions. For holistic and reliable drought monitoring, it is essential that multiple indicators be combined for developing consistent indices, preferably using microwave remote sensing data. Hence, the present study was undertaken to evaluate the potential of microwave-integrated drought index for detecting and characterizing drought over the Indian mainland.

Study area

India is a country in South Asia having a latitudinal and longitudinal extent of 8°4′ N and 37°6′ N and 68°7′ E and 97°25′ E, respectively. It covers an area of approx. 3.2 million square kilometers and is the 7th largest country in the world. Predominantly, India falls under the sub-tropical climate regime, however, the country experiences a wide range of climates i.e., tropical hot and humid climate in the south to a sub-alpine climate in the Himalayan region. Agriculture in India is still predominantly rain-fed with over 65% of cropped area being dependent on rainfall. Total cropped area has increased from 185 million ha during 2001 to 198 million ha during 2011. Indian soils are majorly classified into alluvial, black (regur), red and laterite, forest, desert and mountain soils. The Indian mainland with state boundary is depicted in Fig. 1.

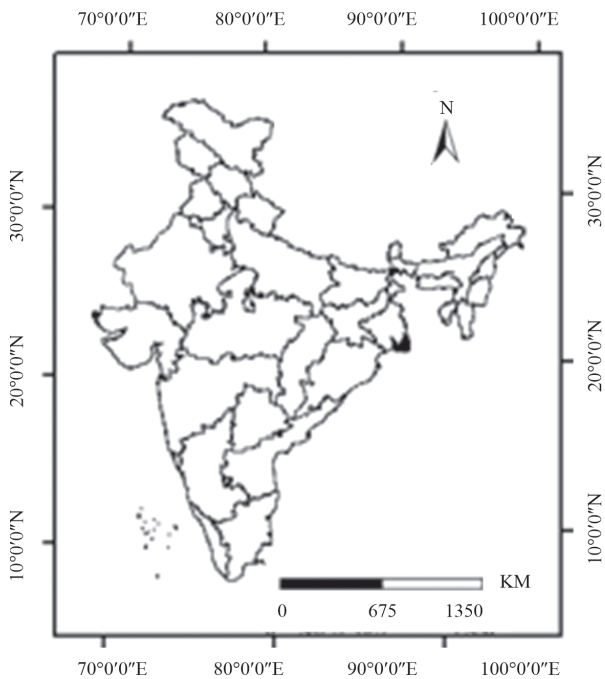

Fig. 1. Study area: Indian mainland with district boundaries

Data and Methodology

Data Processing

The Microwave Integrated Drought Index (MIDI) is a microwave remote sensing-based index developed to minimize the constraints faced by infrared and optical remote sensing indices for drought monitoring. The MIDI data is available online through the Harvard Dataverse Version 3. (*https://doi.org/10.7910/DVN/EVU4PN*) from 1998-2020. MIDI index combines microwave remotely sensed land surface temperature, precipitation, and soil moisture. Using these variables, indices of Temperature Condition Index (TCI), Precipitation Condition Index (PCI), and Soil Moisture Condition Index (SMCI/SSMI) are calculated and linearly scaled (0 to 1) based on maximum and minimum values of the month (Zhang *et al*., 2019). The major satellite data products collected to develop MIDI include TRMM precipitation data, and Land Surface Retrieval Model (LSRM) derived TMI and AMSR 2 soil moisture and land surface temperature data. MIDI data products are available at spatial resolution grids of 0.25° ×0.25° in "TIFF" format.

The monthly Microwave Integrated Drought Index (MIDI) data was transformed into Standardized Microwave Integrated Drought Index (SMIDI) using an empirical distribution approach at different time-scales and the final index values were ranging from -4 to +4. In the present study, 3-monthly and 6-monthly timescales were computed. Similar to standardized precipitation index (SPI), varying time-scales of SMIDI represent different drought types. Short timescales, i.e., 3 months, represent the meteorological droughts, while medium and long timescales, i.e., 6 months, can effectively depict the hydrological conditions. The negative values of SMIDI generally represent drought-like conditions and positive values demote normal or excess soil moisture for the given grid. Further, the SMIDI was converted to drought occurrence with values lower than a threshold of minus one. The drought duration is the total number of months qualifying drought criteria and magnitude is expressed by cumulative SMIDI values under drought month(s).

Trend Analysis

Trend analysis was performed on the seasonal anomaly of SMIDI-derived drought duration using a non-parametric approach, i.e., Mann-Kendall test (Mann, 1945; Kendall, 1975; Gilbert, 1987). The Man-Kendall test is a non-parametric test used for studying the trends of different drought indices (for example, SPI). This is a dimensionless test, and therefore, the trend calculated is not based on scalar units. The Z-statistic ranges from negative to positive, negative values indicating a decreasing trend while a positive value indicates an increasing trend. In the present study, trends of drought duration were calculated at 3-month and 6-month timescales, for the south-west monsoon season (JJAS).

Results and discussion

Analyzing the SMIDI temporal profiles

The 3-month SMIDI (SMIDI3) profiles over three districts of India, namely a) Ratnagiri of Maharashtra, b) Rajnandgaon of Chhattisgarh, c) Bankura of West Bengal have been portrayed in Fig. 2. The values range from –2.76 to 2.11, –2.25 to 2.08, and –2.28 to 2.14 over Ratnagiri, Rajnandgaon and Bankura, respectively. At Ratnagiri district, a total of 130 dry events and 90 wet events were observed. Constituting approximately 58.09% of dry events, this region had the highest number of severe and extreme dry events ranging from –1.5 to > -2. In, the Bankura district of West Bengal, there were approximately 134 wet events and 118 dry events. In Ratnagiri, the drought episodes were decreasing

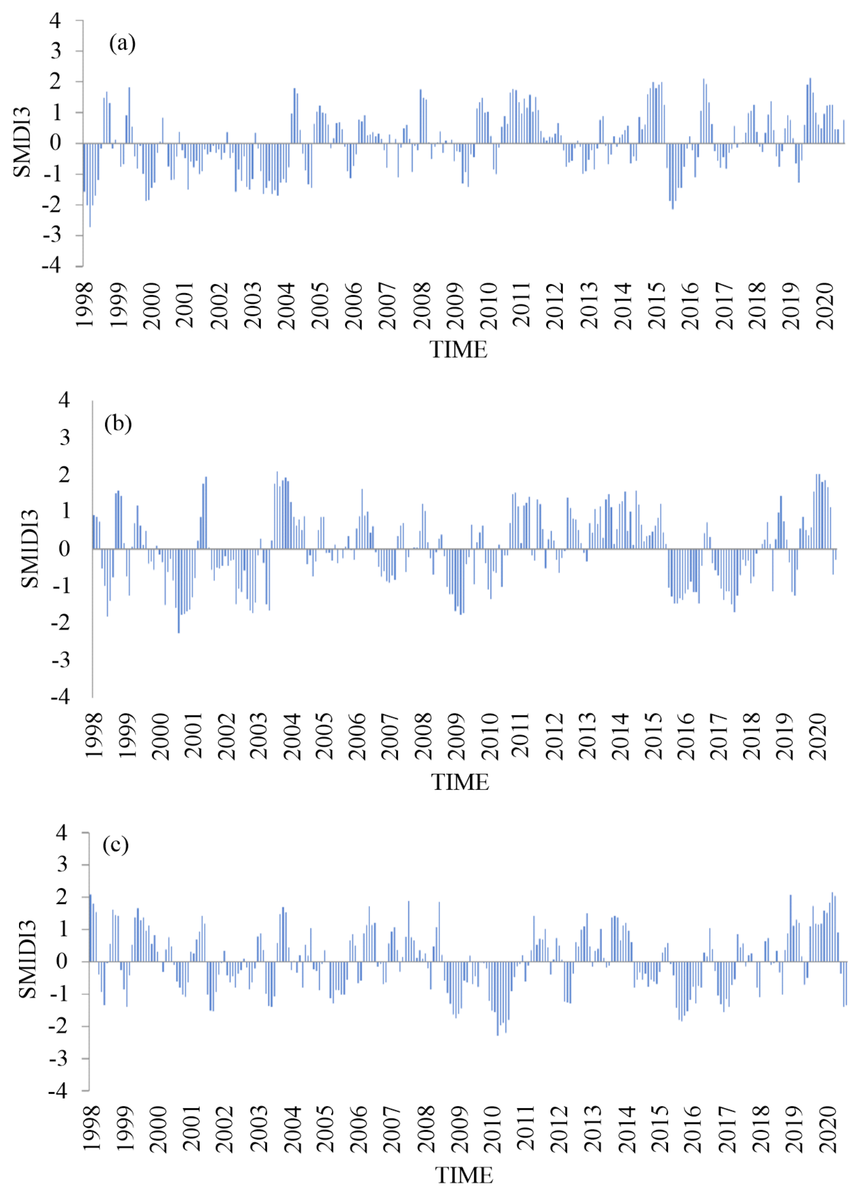

Fig. 2. 3-monthly Standardized Microwave Integrated Index from 1998-2020 over (a) Ratnagiri (b) Rajnandgaon, and (c) Bankura districts

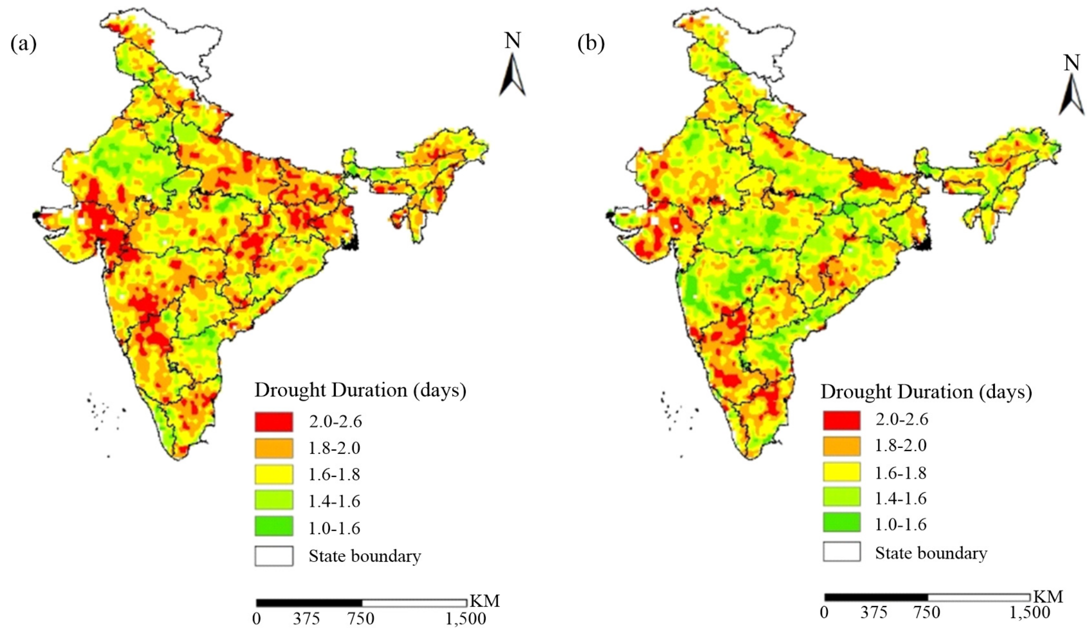

Fig. 3. Drought duration for South-West Monsoon Season (JJAS) at (a) 3-month and (b) 6-month time-scales

over time, whereas it was increasing in the case of Bankura. In Rajnandgaon, the drought episodes were distributed across the study period. Similarly, the drought analysis was carried out over the selected district for a 6-month time scale SMIDI also. The trends were almost the same with a reduced magnitude of SMIDI values.

Drought duration and magnitude

The spatial distribution of drought duration for the south-west monsoon season (JJAS) is shown in Fig. 3, for 3-month and 6-month timescales. During 1998-2020, average seasonal drought duration, both at 3- and 6-month time-scales, varies across states. Based on 3-month SMIDI, the drought duration was highest over parts of Gujarat, Maharashtra, Karnataka, Tamil Nadu, Chhattisgarh, and eastern India. Whereas, lower drought duration was observed over Kerala, Andhra Pradesh, Telangana, Punjab, Haryana, and Rajasthan. Similar observations were also recorded in 6-month SMIDI also. However, the areas with the highest drought duration were restricted to parts of Gujarat, Karnataka, Tamil Nadu, and northern Bihar.

The state-wise drought magnitude values at 3-month and 6-month timescales, for south-west monsoon season (JJAS), is shown in Fig. 4. Drought magnitude as per a 3-monthly timescale was highest (>6.25) in parts of western India, including Gujarat and Maharashtra, parts of southern India including Karnataka and Tamil Nadu, and parts of southern Bihar, West Bengal, and Jharkhand. The districts having the highest drought magnitude include Munger, Bhagalpur, and Khagaria districts of Bihar; Solapur, Osamanabad, Sangli districts of Maharashtra; Shimoga, Bagalkot, Bijapur districts of Karnataka; Barmer, Jalore districts of Rajasthan; Patan and the Kutch region in Gujarat. 6-month timescales showed almost samilar spatial patterns in drought magnitude. However, regional variations existed over certain districts of Maharashtra, and southern Andhra Pradesh. In both timescales, the most widespread drought magnitude was prevalent in the states of Bihar, Gujarat, Karnataka, Maharashtra (Pune and Aurangabad region), and Tamil Nadu.

Drought duration and magnitude usually have a positive correlation, i.e., those areas having higher drought duration, also have higher magnitudes. Regions having a higher drought magnitude (duration) are more vulnerable to climate change impacts. The most vulnerable regions to droughts at both short and medium timescales include, Khera, Patan, Banaskantha districts of Gujarat; Saran, Munger, Begusarai regions of Bihar; Devangere,

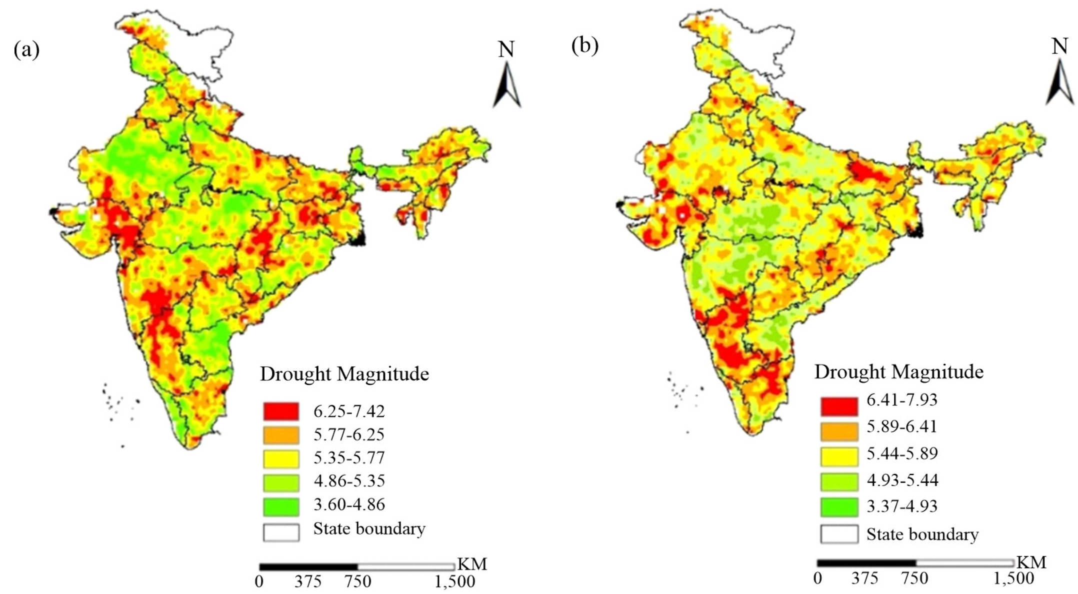

Fig. 4. Drought magnitude for South-West Monsoon Season (JJAS) at (a) 3-month and (b) 6-month time-scales

Bagalkot, and Bijapur districts of Karnataka; Villupuram and Salem districts of Tamil Nadu.

Trend Analysis

A non-parametric test called the Man-Kendall test has been carried out for analysis of state-wise trends of drought duration for both timescales. Being a dimensionless test statistic, the Man-Kendall test, it is not a quantitative scale, and only the direction of trend over the area can be observed. In this, a Z-statistic is calculated whose values range from positive to negative, a positive value denotes an increasing trend, a negative value denotes a decreasing trend, and a value tending toward zero indicates the absence of any trend.

Drought-duration trends calculated for monsoon season, both at 3- and 6-month time-scales, have been shown in Fig. 5. Based on the 3-month MIDI, the positive trends of drought duration were observed over central India covering Madhya Pradesh, Maharashtra, and Chhattisgarh, eastern India covering West Bengal, Jharkhand, Bihar, and parts of Odisha and Uttar Pradesh, Peninsular India including Kerala, Tamil Nadu and southern parts of Karnataka. Whereas, the states showing a negative trend in drought duration for monsoon season, include Rajasthan, Andhra Pradesh, and Telangana, followed by Uttarakhand, Himachal Pradesh, Jammu, Assam, northern parts Karnataka, and southern parts of Chhattisgarh, and Odisha. The 6-month SMIDI-derived drought duration trends across different states were found to be a subset of the former one. The positive trends were mainly found over almost the entire Bihar, considerable parts of Maharashtra, Tamil Nadu, Kartnataka, and Kerala, eastern parts of Madhya Pradesh and Uttar Pradesh, and parts of Gujarat, West Bengal, and Jharkhand.

At both timescales, increasing trends in drought duration were found in the east-central, north-eastern, and southern parts of the country. A significant increasing trend was observed in Bihar state (Das *et al*., 2016 and Goyal *et al*., 2018). Decreasing drought duration trends were found along the eastern coast, western, and north-western India. The decreasing drought duration trends over western India may be attributed to persistent higher drought frequency. States of Punjab, Uttar Pradesh, West Bengal, where agriculture is predominant, decreasing trends were observed in drought duration over the years. For certain areas, a decreasing trend was observed due to better irrigation practices or the success of the Drought Prone Areas Programme (DPAP) in these regions. A significant positive trend has been observed for Bihar, due to a shift in monsoons and extended precipitation deficit during the kharif season (Singh *et al*., 2014).

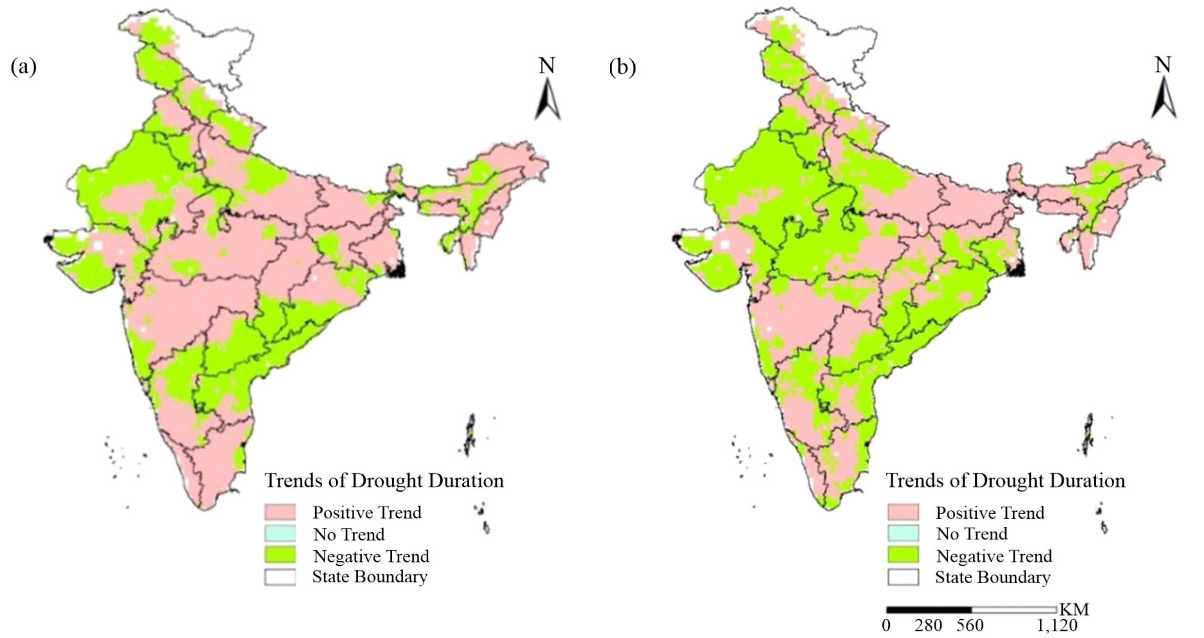

Fig. 5. Spatial distribution of trends of drought duration at Drought Duration Trend for South-east monsoon at a) 3-monthly and (b) 6-monthly time-scale

Spatio-temporal distribution of SMIDI

Over the period of 1998-2020, there have been the most severe and widespread droughts in the years 1998, 1999, 2009, 2012, 2013, 2015, and 2019 to mention a few. In an attempt to find out the efficacy of the Standardized Microwave Integrated Drought Index (SMIDI) in accurately representing drought over the country, the index at 3-monthly and 6-monthly timescales for two droughts years, i.e., 2009 and 2012, were compared with two normal years, i.e., 2007 and 2011. The 6-monthly SMIDI results of drought and normal years are depicted in Fig. 6. It was observed that for both the drought years, i.e., 2009 and 2012, the SMIDI-derived drought was spread over a larger extent. In 2009, except for small patches over Karnataka and Andhra Pradesh, almost the entire country was drought-affected. In some parts of north-eastern India, Uttar Pradesh, Maharashtra, Chhattisgarh, and Maharashtra, the values were even less than -1.50, showing extreme drought conditions. In 2012, the drought was mainly over peninsular India, covering Karnataka, Maharashtra, Telangana, Tamil Nadu, and parts of the Indo-Gangetic Plains. Over parts of Maharashtra and Bihar, even extreme droughts were also observed. While comparing with non-drought years, i.e., 2007 and 2011, it is observed that there were hardly any occurrences of extreme drought events, except Punjab during the former year. A wet to mild dryness was observed as depicted by a higher incidence of positive SMIDI values over major parts of Indian mainland. Hence, it can be inferred that the SMIDI could able to represent the spatio-temporal variations in drought conditions across different drought and normal years.

Conclusions

The potential of microwave-integrated drought index (MIDI), derived from a combination of factors like precipitation and soil moisture, was evaluated in the present study. The temporal profiles of standardized MIDI (SMIDI) over parts of the Indian mainland could able to capture the temporal variations in droughts within the scale of 4 to -4. The drought episodes along with the duration and magnitude information were captured using a SMIDI threshold of minus one. The spatial distribution of average drought duration and magnitude during 1998-2020 can be utilized to identify the hotspots with higher drought occurrence and magnitude. The trends of drought duration information were captured for the entire Indian mainland and it may be an important input towards undertaking preventive

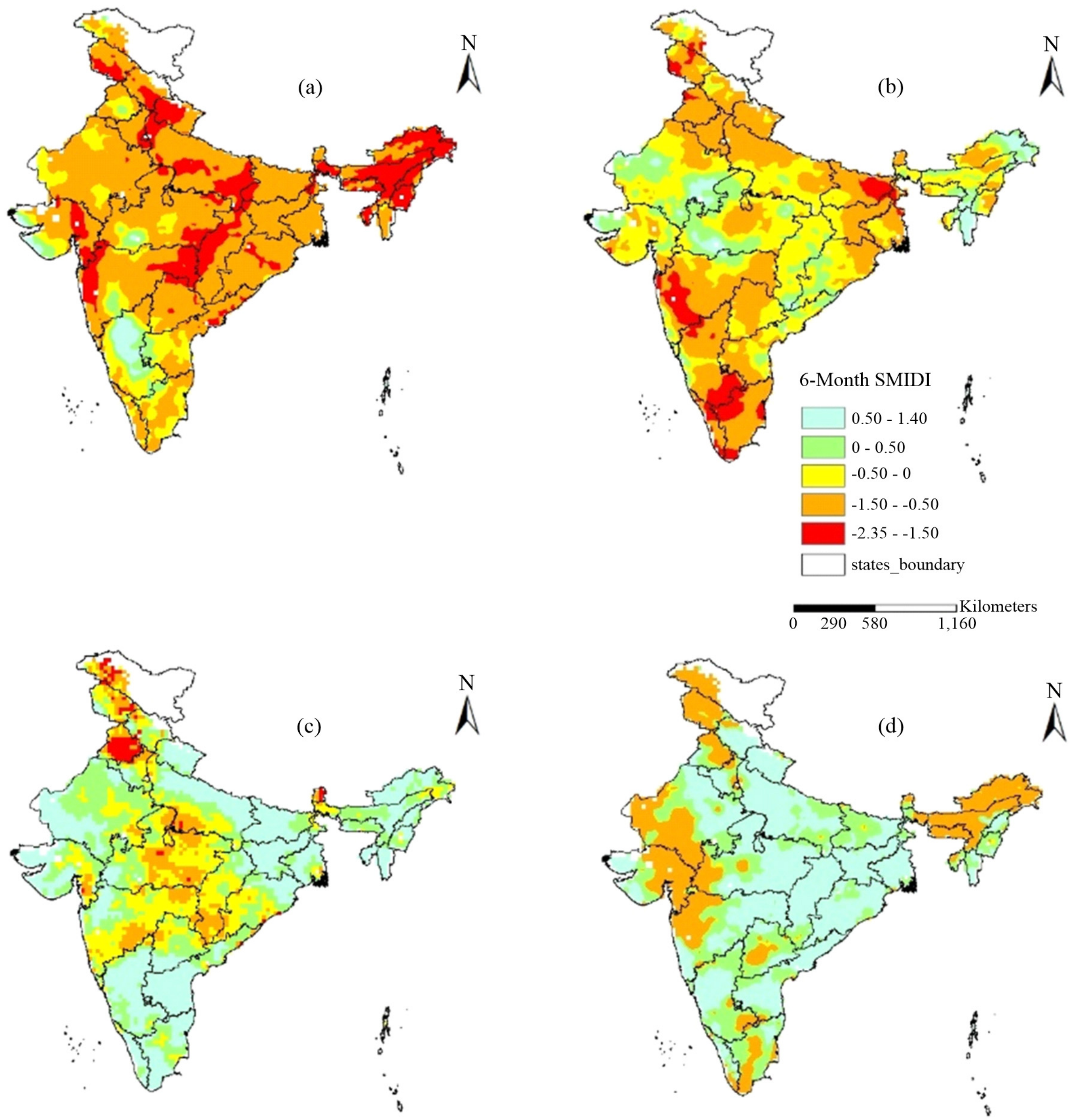

Fig. 6. Spatial distribution of 6-month SMIDI of South-west Monsoon Season (JJAS) for (a) 2009, (b) 2012, (c) 2007 and (d) 2011

measures to address future drought-like situations. In some places where generally drought is prevalent like West Rajasthan, a negative trend was observed. This may be attributable to certain factors like development of the Indira Gandhi Canal which improved the soil-moisture conditions of the area. On the contrary, districts like Nadia in West Bengal, where droughts are not usually heard of, are showing increasing dry conditions. The year-wise performance of SMIDI for both reported normal and drought years was evaluated, and it was inferred that it has high spatio-temporal agreement with the ground situation. Hence, the microwave-integrated drought index, an all-weather drought index, may be a useful tool for efficient monitoring and assessment of the regional drought conditions. The present study could potentially serve as a foundation work for developing a microwave index for drought monitoring. However, further research, supported by ground-based observations, should be performed to get an in-depth knowledge of the index and its potential and limitations. Also, a larger timescale, than that chosen for this study, would have increasing reliability for trend analysis.

Acknowledgements

The authors are thankful to Dr. Prakash Chauhan, Director, NRSC, and Dr. S.K. Srivastav, CGM, RCs for their continuous support and encouragement. We duly acknowledge microwave-integrated drought index data received from Harvard Dataverse websites.

Author statement

The authors declare that the contributions of all team members have been acknowledged and there is no conflict of interest.

References

AghaKouchak, A. 2014. A baseline probabilistic drought forecasting framework using Standardized Soil Moisture Index: Application to the 2012 United States drought. *Hydrology and Earth System Science* **18**(7): 2485–2492.

Alemu, W.G., Melesse, A.M. and Senay, G.B. 2019. Drought monitoring in East Africa using integrated satellite passive microwave drought indices. American Geophysical Union, Fall Meeting 2019.

Das, P.K., Dutta, D., Sharma, J.R. and Dadhwal, V.K. 2016. Trends and behaviour of meteorological drought (1901-2008) over Indian region using standardized precipitation-evapotranspiration index. *International Journal of Climatology* **36**(2): 909-916.

Dai, A. 2013. Increasing drought under global warming in observations and models. *Nature Climate Change* **3**: 52-58.

Gao, B.C. 1996. NDWI - A Normalized Difference Water Index for Remote Sensing of Vegetation Liquid Water from Space. *Remote Sensing of Environment* **58**: 257-266.

Gilbert, R.O. 1987. Statistical Methods for Environmental Pollution Monitoring. John Wiley and Sons, New York.

Goyal, M.K. and Surampalli, R.Y. 2018. Impact of climate change on water resources in India. *Journal of Environmental Engineering* **144**(7): 04018054.

Kendall, M.G. 1975. Rank Correlation Methods. 4th Edition, Charles Griffin, London.

Li, Z., and Zhou, T. 2015. Response of vegetation growth to climate change in China. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XL-7/W3, 36th International Symposium on Remote Sensing of Environment, 11-15 May 2015, Berlin, Germany. doi:10.5194/isprsarchives-XL-7-W3-225-2015.

Mann, H.B. 1945. Non-Parametric Test against Trend. *Econometrica* **13**: 245-259.

McKee, T.B., Doesken, N.J. and Kleist, J. 1993. The relationship of drought frequency and duration to time scales. *In: Proceedings of the 8th Conference on Applied Climatology*, AMS, Boston, MA, pp 179-184.

Narasimhan, B. and Srinivasan, R. 2005. Development and evaluation of soil moisture deficit index (SMDI) and evapotranspiration deficit index (ETDI) for agricultural drought monitoring. *Agriculture Forest Meteorology* **133**: 69-88.

Pai, D.S., Sridhar, L., Guhathakurta, P. and Hatwar, H.R. 2011. District-wide drought climatology of the southwest monsoon season over India based on standardized precipitation index (SPI). *Natural hazards* **59**(3): 1797-1813.

Palmer, W.C. 1965. Meteorological Drought. Office of Climatology Research Paper No. 45, Washington DC: US Weather Bureau.

Prihodko, L. and Goward, S.N. 1997. Estimation of air temperature from remotely sensed observations. *Remote Sensing of Environment* **60**(3): 335-346.

Seneviratne, S.I. 2012. Climate science: Historical drought trends revisited. *Nature* **491**: 338-339.

Shorachi, M. 2021. Investigating the influence of drought on Sentinel-1 C-band SAR data over agricultural crops: A study in the Netherlands. Student Thesis, Delft University of Technology.

Singh, S.K., Singh, K.M., Singh, R., Kumar, A. and Kumar, U. 2014. Impact of rainfall on agricultural production in Bihar: A zone-wise analysis. *Environment & Ecology* **32**(4A): 1571-1576.

Watson, D.J. 1947. Comparative Physiological Studies on the Growth of Field Crops. I. Variation in Net Assimilation Rate and Leaf Area between Species and Varieties and between Years. *Annals of Botany* **11**: 41-76.

Zhang, A., Jia, G. and Wang, H. 2019. Improving meteorological drought monitoring capability over tropical and subtropical water-limited ecosystems: Evaluation and ensemble of the Microwave Integrated Drought Index. *Environmental Research Letters* **14**(4): 044025.

Zhang, A. and Jia, G. 2020. ENSO-driven reverse coupling in interannual variability of pantropical water availability and global atmospheric CO_2 growth rate. *Environmental Research Letters* **15**: 034006.

Received: 15 July 2023; Accepted: 29 September 2023