European Journal of Geography Volume 10, Number 4:115-131, December 2019

GEOSPATIAL ASSESSMENT OF DROUGHT IN MARATHWADA REGION, INDIA

Sagar KHETWANI
Department of Geography, Delhi School of Economics, University of Delhi, India
sagardse96@gmail.com

Ram Babu SINGH
Department of Geography, Delhi School of Economics, University of Delhi, India
rbsgeo@hotmail.com

Abstract

The increased frequency and intensity of droughts is a challenging phenomenon for humankind, its impact on developing nations has increased significantly. Marathwada region is chronically prone to drought and has been impacted severely between the years 2012 to 2016. The paper attempts to make a spatio-temporal analysis of drought events in the Marathwada region. Three drought indices, namely Rainfall Anomaly Index (RAI), Standardized Water level Index (SWI) and NDVI Anomaly Index (NAI) were used for meteorological, hydrological and agricultural drought analysis. This study is mainly based on the secondary data sources along with field-based observation. The analysis revealed that meteorological drought events are not new for the Marathwada region. The Marathwada region has witnessed the worst hydrological drought in the year 2015. The correlation analysis shows that meteorological drought is directly followed by hydrological drought without any lag. The NDVI Anomaly Index of the year 2015 revealed a prevalence of agricultural drought while the results of crop Yield Anomaly Index of principal crops of region validates the outcomes of NDVI Anomaly Index.

Keywords: *Drought, Rainfall Anomaly Index (RAI), Standardized Water level Index (SWI), NDVI Anomaly Index (NAI), Yield Anomaly Index (YAI)*

1. INTRODUCTION

Droughts are a common feature of the arid and semi-arid tropical landscapes, widely impacting the densely occupied developing nations. The increased frequency and intensity of droughts in the 21st century are posing a serious threat to the human health and well-being (Dagel, 1997; Ashraf and Routray; 2013; Singh and Kumar, 2014; Singh and Kumar, 2015; Arraf, 2016; Mage and Tyubee, 2017). Between the years 1995 to 2015, drought has affected the lives of more than one billion people globally (Centre for Research on the Epidemiology of Disasters [CRED], 2015). Particularly, the 2015-2016 drought has impacted more than 330 million people in 11 states of India (Action Aid, 2016).

The severity of droughts is more acute in countries like India where 54.6 percent of the population is occupied in agriculture and allied activities (Department of Agriculture, Cooperation & Farmers Welfare [DAC&FW], 2018). There is not any universally accepted definition of drought because of its complex nature (Wilhite and Glantz, 1985; Gupta et al., 2014; Singh and Kumar, 2014; National Disaster Management Authority [NDMA], 2016; Mohammed et al., 2018). It is a difficult task to demarcate the onset and ending phase of drought due to its complex nature (Morid et al., 2006; National Institute of Disaster Management [NIDM], 2009). The frequency, intensity, duration and spatial extent of drought are the governing factors which determine its impacts over society (Zargar et al., 2011; Singh and Kumar, 2015; Mohammed et al., 2018).

However, its impacts could remain even after the cessation of the drought event (NIDM, 2009; Udmale et al., 2014; Singh and Kumar, 2015). The frequency of drought refers to its return period, i.e., the average time between drought events (Nair et al., 2013; Singh and Kumar, 2015). The duration refers to the longevity of drought and the spatial extent refers to its area of extent affected by a drought event (NIDM, 2009; NDMA, 2016; Mohammed et al., 2018). Wilhite and Glantz (1985) classified drought into meteorological, hydrologic, agricultural and socio-economic. The magnitude of drought events can be quantified using different drought indices with the help of parameters like rainfall, streamflow, groundwater level, vegetation health, etc., depending on the nature of the investigation (NIDM, 2009; NDMA, 2016). Geospatial technologies like Geographic Information System (GIS) and Remote Sensing (RS) could play a key role in the assessment of spatio-temporal patterns of drought (NIDM, 2009; Nair et al., 2013; Singh and Kumar, 2014; Singh and Kumar, 2015; NDMA, 2016).

Between the years 2012 and 2016, Marathwada region of Maharashtra state had emerged as one of the most badly drought-affected Indian regions (Dandekar, 2015; Dandekar, 2016; Action Aid, 2016). The Marathwada region had witnessed failure of monsoon and its after affects like water scarcity, acute groundwater level depletion, decline in crop productivity and water conflicts in society (Purandare, 2013; Dandekar and Naravade 2013; Dandekar and Thakkar, 2013; Dandekar 2015; Dandekar, 2016; Khetwani and Singh, 2018a; Khetwani and Singh, 2018b). By taking into consideration all these factors, the main objectives of this study are to make a spatio-temporal analysis of droughts (Meteorological, Hydrological and Agricultural) in the Marathwada region, and explore the relationship between meteorological and hydrological drought.

In this study, Rainfall Anomaly Index (RAI) has been used for the assessment of meteorological drought. Further, for the assessment of hydrological and agricultural drought, this study uses the Standardized Water level Index (SWI) and NDVI Anomaly Index (NAI). The crop Yield Anomaly Index (YAI) were computed to validate the findings of remote sensing based drought index NAI. The rationale behind the usage of these indices was to assess the complex nature of drought in Marathwada region. Correlation test was performed to assess the relation between meteorological and hydrological drought. Further, this study employed a field-based investigation in the study area for developing an enhanced understanding of drought. The scarcity of significant research works that deal with the drought in a comprehnsive manner, make this study more meaningful in understanding the factors that make the drought in the semi-arid Marathwada region more complicated in nature.

2. LITERATURE REVIEW

2.1 Drought and Indices for Assessment

The scientific literature confirms the sequential expansion of drought from meteorological to hydrological, hydrological to agricultural and agricultural to socio-economic (NIDM, 2009; NDMA, 2016; Wang et al., 2016). The lack of understanding among society related to nature of drought could trigger even a mild to moderate drought event into a threatening episode for the human society (NIDM, 2009; Purandare, 2013; NDMA, 2016; Fadina and Barjolle, 2018). Van Rooy (1965) first devised the Rainfall Anomaly Index. The general concept of

Rainfall Anomaly Index is used differently by various authors by different names with varied scale for assessing the intensity of drought (Pandey et al., 2014; Rupanarayan and Patel, 2018; Costa and Rodrigues, 2017; Fluixa-Sanmartin, 2018; Tadic et al., 2015). It considers percent deviation of rainfall from long-term average (Pandey et al., 2014; Rupanarayan and Patel, 2018; Fluixa-Sanmartin, 2018).

Nanzada et al. (2019) in their study attempted to map the drought intensity in Mongolia for 2000 to 2016 with the help of NDVI anomaly index. They found that 41 to 57 per cent of the country went through mild to severe drought. The droughts of various intensity were experienced in the years like 2001, 2007, 2002, 2005, 2004, 2009 and 2006. Patel and Yadav (2015) assess spatial drought variability and crop related losses in Bundelkhand region. They employed linear weighted index called spatial vegetation drought index (SVDI) developed from vegetation condition index and rainfall anomaly index for drought assessment in Bundelkhand region.

Sahoo et al. (2015) examined drought in two districts of India, i.e., Mewat of Haryana and Dhar of Madhya Pradesh state, with the help of meteorological, hydrological and vegetation based drought index, i.e., Standardized Precipitation Index (SPI), Standardized Water Level Index (SWI) and Vegetation Condition Index (VCI). They observed that drought resulted into remarkable shift and shortening of crop-growing season, specifying a delay in crop sowing. A comprehensive spatio-temporal drought analysis through VCI, depicted the events of severe drought during the year 2002 and 2008. Bhuiyan (2004) in his study used multi-sensors data to assess drought using SPI, SWI and VCI of Aravalli region for the years 1984 to 2000. They had used SPI to quantify the rainfall deficits while SWI was used to quantify hydrological drought. VCI was used to assess the vegetation stress. It was found that meteorological, hydrological and agricultural droughts are not linearly inter related.

Jain et al. (2015) in their study of chronically drought affected Ken River Basin of India made a comparative analysis of the performance of meteorological drought indices, i.e., Rainfall Departure (RD), Standardized Precipitation Index (SPI), China Z-Index (CZI), Effective Drought Index (EDI), statistical Z-Score, Rainfall Decile based Drought Index (RDDI). They found that one month time step in all drought indices may provide erroneous estimations of drought duration. The drought indices calculated for nine month time step are best correlated with each other. However, the duration of drought and the frequencies of drought calculated through RDDI and RD are in dissimilarity with other drought indices and are not appropriate for areas where the precipitation concentration in summer season is very high. They also found that drought indices are highly correlated at same time steps and could be employed alternatively.

2.2 Studies on Drought in Marathwada region

Purandare (2013) found that the absence of efficient water governance policies and faulty operation of watershed development and irrigation projects are the major factors responsible for the drought. Khairnar et al., 2015, widely covered the issue of farmer suicides in the region and linked the responsible social factors that are further aggravating the impacts of drought. Pandey and Sharma (2016) emphasized on the issue of water scarcity as a worsening situation in the Marathwada region, they stressed on the urgent need of adoption of water harvesting measures on a priority basis in every municipal council and to make the society aware of the water harvesting measures with the help of people's participation.

Kulkarni et al. (2016) quantified the events of the deficiency of monsoon rainfall (rainfall during the months of June, July, August and September) from normal in the Marathwada region between 1871 and 2015. The study has effectively proved that the rainfall deficits are not new in the history of Marathwada but it opens the scope for an inter-disciplinary investigative framework.

The Marathwada region has been at the center of global community due to the negative impacts of drought which were clearly visible in the form of dry wells, crop failure and water conflicts in the society (Biswas, 2015; Deulgaonkar, 2015; Khairnar et al., 2015; Deshpande, 2016; Kale and Gond, 2016). Majority of the farmers in the Marathwada are poor, lack irrigation and are dependent on monsoons (PDGOM, 2013; Dandekar, 2015; Khairnar et al., 2015; Kale and Gond, 2016; Dandekar, 2016).

Therefore, the appraisal of drought events in such areas is very vital in order to provide an enhanced understanding of the complex nature of drought. The existing research work related to the drought in Marathwada provides the opportunity for further scientific investigation by encompassing the meteorological, hydrological and agricultural drought indices for assessment along with field-based investigation.

3. STUDY AREA

The Marathwada region is stretched between 17°37’ to 20°39’ North latitudes and 74°33’ to 78°22’ East longitudes in the Maharashtra state of India (Groundwater Survey & Development Agency [GSDA], 2017). The region consists of 8 districts and 76 sub-districts (*talukas/tahsils*) within 8 districts (Figure 1).

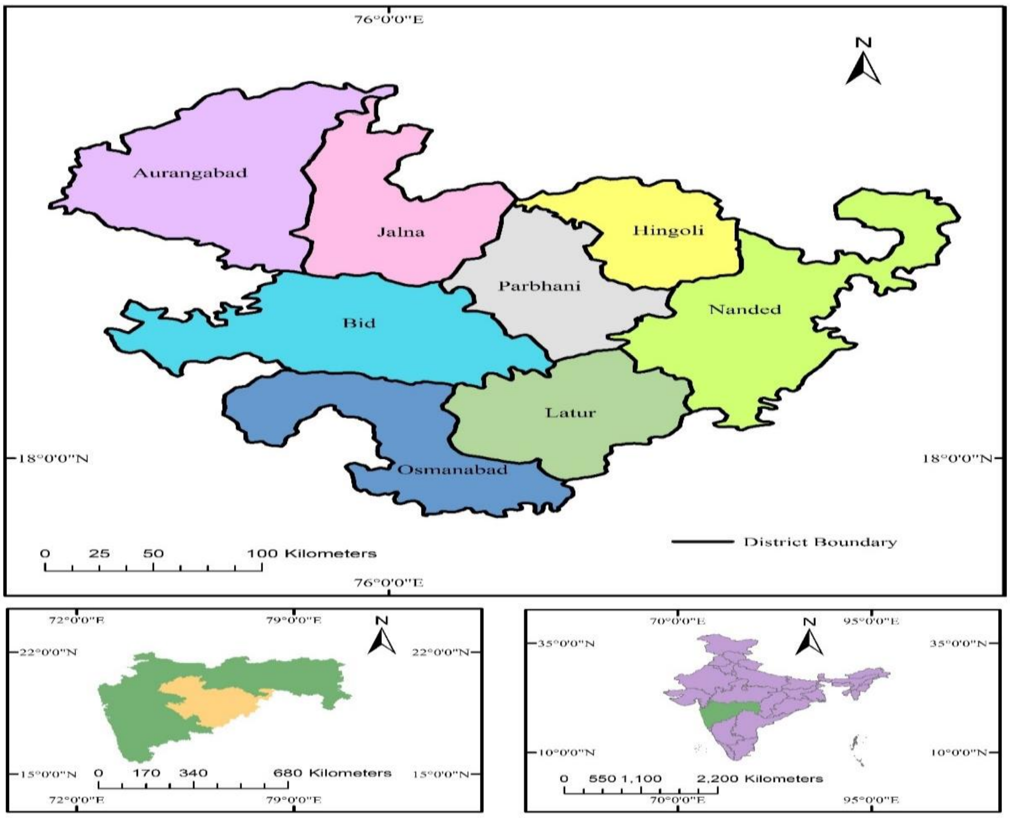

Figure 1. The Marathwada Region

It is a part of the rain shadow region of Sahyadri mountain range of Maharashtra state. The topography of the Marathwada is characterized by the Deccan Traps which are of upper Cretaceous to lower Eocene. The thickness of lava flows in the region varies from a few meters to 40 to 45 meters (GSDA, 2017; Maharashtra Status of Environment & Related

Issues [MAHAENVIS], 2005). Marathwada region has a total geographical area of 64813 square kilometers (Planning Department Government of Maharashtra [PDGOM], 2013). The climate of region is generally hot and dry climate while rainfall in the region is erratic with the normal average rainfall of about 825mm (PDGOM, 2013). The river Godavari is one of the most important rivers of the region and because of numerous large and small projects, it is known as the lifeline of the region (MAHAENVIS, 2005). The region has a total population of 1,87,31,872 (18.7% of Maharashtra state), a majority of the population of the region i.e. 72.9% lives in rural areas and 27.1% in urban areas. A majority of the population of Marathwada is highly dependent on agriculture and allied activities (PDGOM, 2013; MAHAENVIS, 2005).

4. METHODOLOGY

4.1 Research Design

The assessment of drought is highly dependent on the effective utilization of various drought indices. For this reason, this study uses the Rainfall Anomaly Index (RAI), Standardized Water level Index (SWI) and NDVI Anomaly Index (NAI) for the spatio-temporal assessment of drought and to develop a better understanding towards factors that make drought more complex. Correlation analysis was done for the assessment of the relationship between meteorological and hydrological drought. Further, for validating the findings of NAI the crop Yield Anomaly Index (YAI) were computed. The field survey was done during the month of June in the year 2017 for identifying the factors affecting the complex nature of relationship of meteorological and hydrological drought. Arc GIS 10.2.2 mapping software has been used for showing the spatio-temporal patterns of meteorological and hydrological drought in the Marathwada region. While Q-GIS has been used for the computation of NAI in this study.

4.2 Data Sources

The district wise long-term monthly rainfall data (1968–2016) were obtained from India Meteorological Department (IMD), Pune. The post-monsoon groundwater level data for the month of October of the years 2000 to 2016 for 8 districts was obtained from Groundwater Surveys and Development Agency, Maharashtra. The 250-m MODIS Terra NDVI (MOD13Q1) dataset for the second fortnight of the month of September from the year 2000 to 2015 was obtained from NASA Earth Data (https://earthdata.nasa.gov/). The district wise data of principal crops of the region for the period 2000 to 2015 were procured from the website of Department of Agriculture, Government of Maharashtra. The crop yield statistics of major rainfed crops of region i.e., Jowar (Sorghum) and Tur (Pigeon Pea) for a period of 16 years (2000–2015) were procured from the Department of Agriculture, Government of Maharashtra.

4.3 Drought Indices

The Rainfall Anomaly Index (RAI) has been used for the quantification of meteorological drought. In this paper RAI has been calculated for the Monsoon months, i.e., June, July, August and September (JJAS) from the year 1968 to 2016. The formula for the computation of RAI is explained in equation one.

$$\text{RAIi} = \frac{(\text{RFi} - \text{RF}\mu)}{(\text{RF}\mu)} \times 100 \quad (1)$$

where,
RAIi = Rainfall Anomaly Index for ith year
RFi = Seasonal Rainfall for ith year,
RFµ = Average Seasonal Rainfall
This study adopts the same criteria as defined by India Meteorological Department to quantify the drought events (Table 1).

Table 1. Categorization of meteorological drought intensity

RAI range	Intensity
> 0.0	No drought
0.0 to -25.0	Mild
-25.0 to -50.0	Moderate
-50.0 to -75.0	Severe
-75.0 >	Extreme

Source: India Meteorological Department, 1971

Standardized Water level Index (SWI) has been used for the quantification of hydrological drought events. The post-monsoon groundwater levels of 8 districts have been examined. Bhuiyan (2004) postulated the SWI for hydrological drought assessment, explicated in the second equation and Table 2.

$$\text{SWI} = \frac{(\text{Wij} - \text{Wim})}{\sigma} \times 100 \quad (2)$$

where,
Wij = Seasonal water level of the ith well and jth observation
Wim = Seasonal mean of the ith well and jth observation
σ = Standard deviation of the ith well and jth observation

Table 2. Categorization of hydrological drought intensity

SWI	Intensity
< 0.0	No drought
> 0.0	Mild
> 1.0	Moderate
> 1.5	Severe
> 2.0	Extreme

Source: Bhuiyan, 2004

The groundwater level data of 8 districts were taken for attaining the objectives of this study. The equation of SWI for hydrological drought assessment has been explained below in the third equation.

$$\text{SWI for i district} = \frac{(\text{Dij} - \text{Dim})}{\sigma} \times 100 \quad (3)$$

where,
Dij = Seasonal water level of the ith district and jth observation
Dim = Seasonal mean of the ith district and jth observation
σ = Standard deviation of the ith district and jth observation

NDVI Anomaly Index (NAI) has been used to assess vegetation condition through analysis of NDVI for the second fortnight of the month of September of the year 2015. It highlights the intensity of agricultural drought with the help of negative deviation of NDVI values from long-term mean of NDVI values. The formula used for computation of NAI is shown in equation 4.

$$\mathrm{NAI} = \mathrm{NDVIi} - \mathrm{NDVImean, m} \quad (4)$$

In this study, NDVIi is the NDVI value for the second fortnight of September of the year 2015 and NDVImean, m is the long-term mean NDVI for the second fortnight of September of 12 years from 2000 to 2011. The negative NDVI Anomaly shows below-normal vegetation health of a region and, hence, indicates the existence of agricultural drought. The higher negative departure denotes the poor status of vegetation health or greater the intensity of agricultural drought. The long-term NDVI value reflects the normal circumstances of vegetative health, the negative deviation from the long-term mean NDVI is effectively more than just a drought indicator. Some of the limitations of NAI includes, it does not take into account the standard deviation, and it could be misunderstood when the vegetation condition variability in any region is very high, in any one given year (Bandyopadhyay and Saha, 2014; Bandyopadhyay and Saha, 2016).

Crop Yield Anomaly Index (YAI) is one of the most useful techniques for the identification of crop yield deviation for a particular year from its long-term record (Dutta et al., 2011; Dutta et al., 2015). Yield anomalies of Jowar and Tur were computed using equation 5.

$$\mathrm{YAI} = \frac{(\mathrm{Y} - \mu)}{\sigma} \quad (5)$$

where, YAI = Yield Anomaly Index, Y= Crop Yield, μ = Long term average yield, σ = Standard Deviation.

5. ANALYSIS

5.1 Temporal Patterns of Meteorological Drought Events

The temporal analysis of drought events clearly depicts that the exceptional nature of rainfall deficit from normal is not new for the Marathwada. The results of RAI clearly reveals that the number of affected districts due to severe drought was much greater in the year 1972 as compared to the 2015 drought. In the last decade, the region has witnessed a shift in the increase in the number of mild droughts to moderate drought. However, the overall analysis of mild, moderate and severe droughts clearly reveals that it is not new for the Marathwada region to experience the droughts of varying intensity (Figure 2a to 2c).

5.2 Spatio-temporal Patterns of Meteorological Drought

The analysis of monsoon rainfall data during the JJAS reveals that all of the districts of Marathwada had witnessed the droughts of varying intensity in the years 2012, 2014 and 2015. The district Jalna has witnessed the severe meteorological drought in the year 2012 with the 53.63 percent deficiency of rainfall from normal while the districts like Parbhani and Bid have witnessed the severe drought with the rainfall deficiency of 51.44 and 50.16 percent in the year 2015. In the year 2012, the deficiency of rainfall from normal was highest in the

Jalna, followed by the districts like Aurangabad, Bid and Osmanabad with the 41.82, 38.21 and 37.58 percent deficiency of rainfall from normal which are further followed by the districts like Nanded, Parbhani, Hingoli and Latur with rainfall deficiency of 21.11, 18.41, 14.84 and 5.96 percent from the normal rainfall. In the year 2013, none of the districts had witnessed meteorological drought of any intensity. The year 2014 and 2015 were two consecutive drought years for the Marathwada region. In the year 2014, rainfall deficiency from normal rainfall was highest in the Parbhani district (49.49%), followed by the districts like Nanded (48.49%), Hingoli (44.36%), Bid (37.43%), Jalna (36.40%), Latur (35.48%), Aurangabad (27.95%) and Osmanabad (22.17%). Parbhani district has witnessed the highest deficiency of rainfall from the normal, i.e., 51.44 percent in the year 2015, followed by the districts, i.e., Bid (50.16%), Latur (44.12%), Osmanabad (40.97%), Nanded (37.08%), Hingoli (25.68%), Jalna (25.19%) and Aurangabad (12.88%). Parbhani and Bid districts have witnessed the worst expansion of drought from the moderate to severe drought between the years 2014 and 2015 (Figure 3).

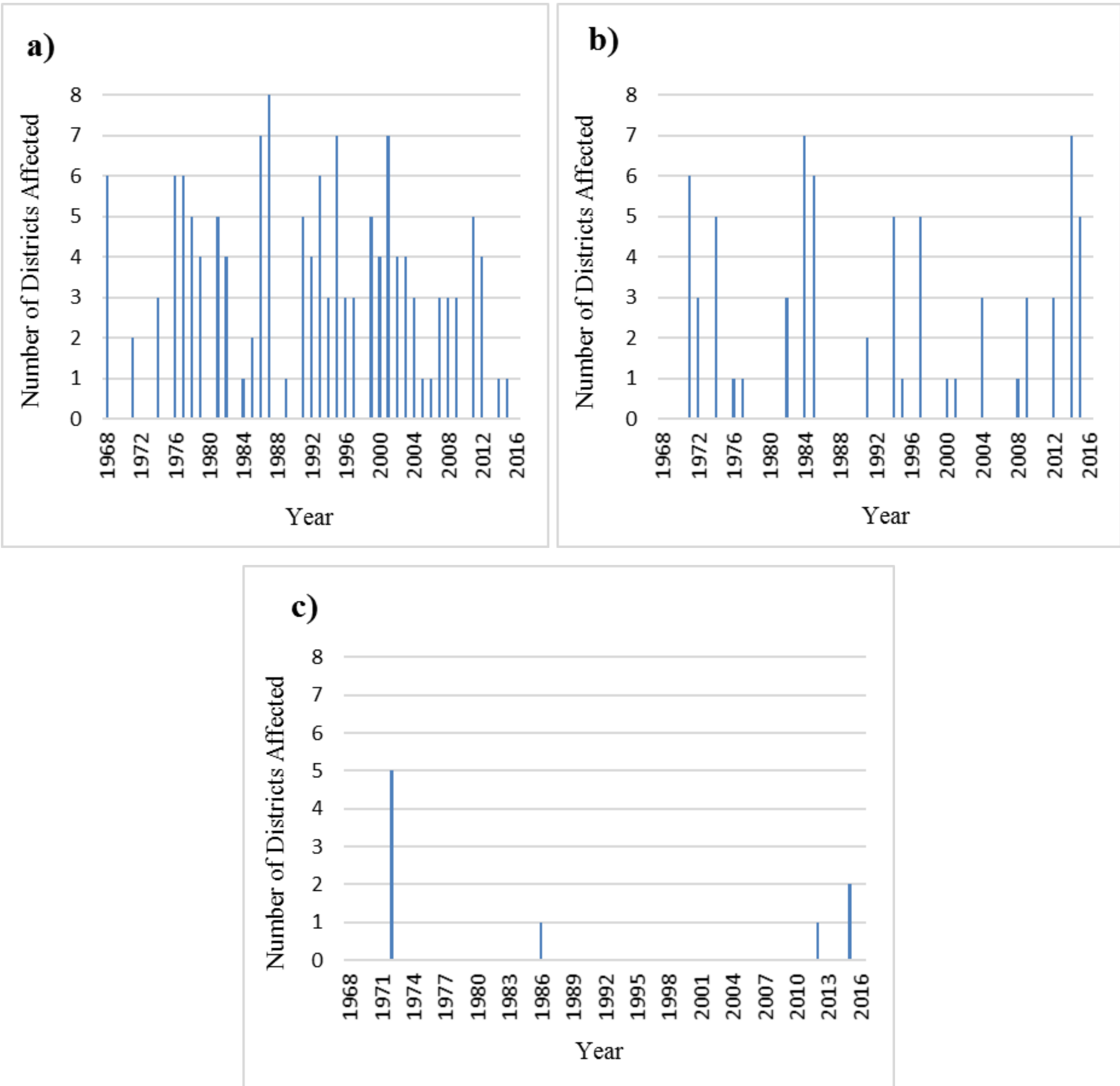

Figure 2. Temporal Patterns of Mild Drought (a), Moderate Drought (b) and Extreme Drought (c)

Source: Based on data obtained from India Meteorological Department, Pune

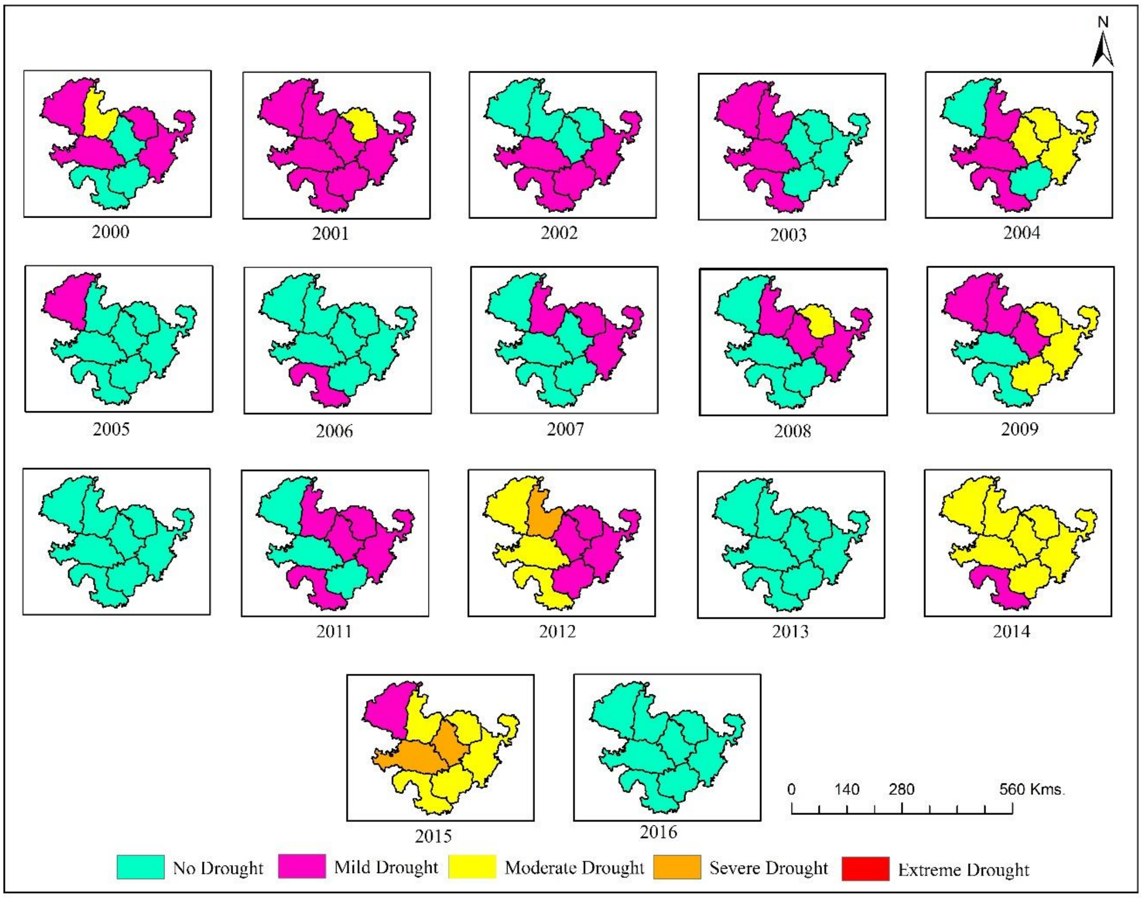

Figure 3. Marathwada Region: Spatio-temporal Patterns of Meteorological Drought

Source: Based on data obtained from India Meteorological Department, Pune

5.3 Spatio-temporal Patterns of Hydrological Drought

The analysis of groundwater level data revealed that between the years 2000 to 2016, the region has remained worst affected due to the hydrological droughts of varying intensity in the years 2012, 2014 and 2015 which were also the rainfall deficient years, as observed in the analysis of RAI. In the year 2012, the districts like Aurangabad and Jalna experienced the extreme hydrological drought, followed by the Osmanabad and Bid districts which had witnessed the severe and moderate drought, further followed by the districts like Parbhani, and Nanded, that experienced the mild drought while the Latur and Hingoli district were left untouched of hydrological drought. The Parbhani district had experienced the severe hydrological drought in the year 2014, followed by the Latur and Nanded districts which experienced the moderate drought while the Aurangabad, Bid and Hingoli went through the mild drought. In the year 2015, the districts like Latur, Bid, Parbhani and Nanded had experienced the extreme drought, followed by the Hingoli that faced the moderate hydrological drought, further followed by the Aurangabad, Jalna and Osmanabad districts which went through the mild hydrological drought (Figure 4).

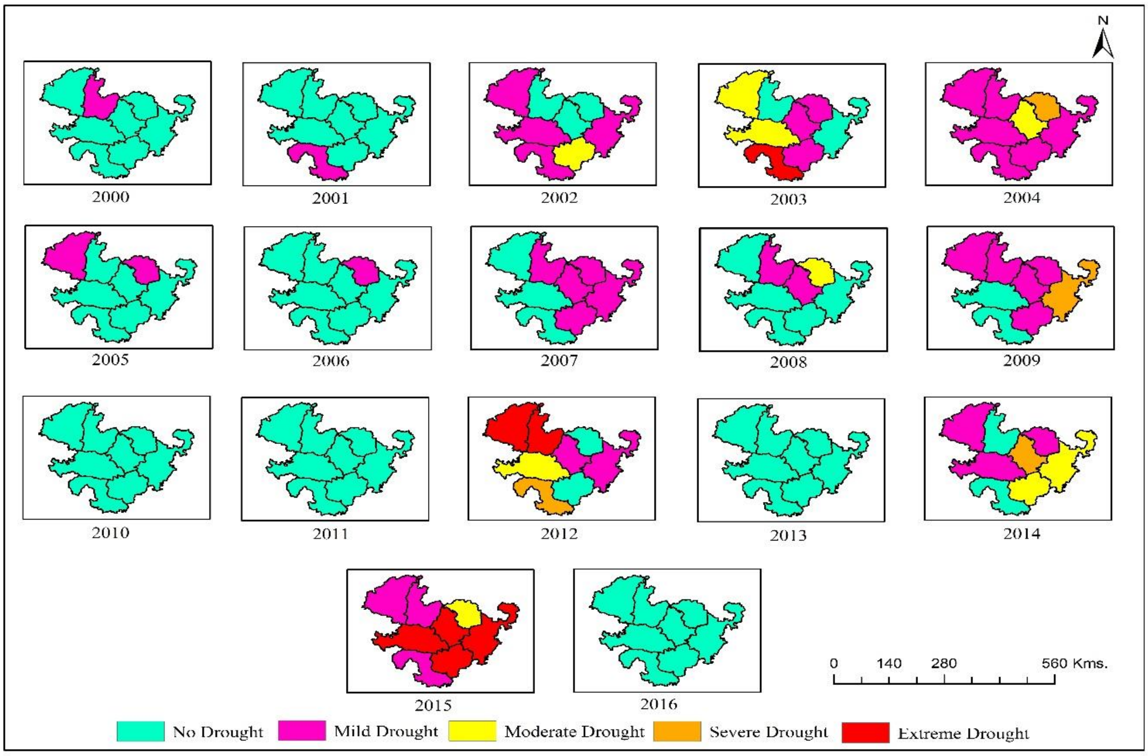

Figure 4. Marathwada Region: Spatio-temporal Patterns of Hydrological Drought

Source: Based on data obtained from Groundwater Surveys and Development Agency

5.4 Agricultural Drought and its Impacts

The NAI of Marathwada region for the second fortnight of September 2015 showed the higher negative deviation of vegetation health of Marathwada region from normal conditions, particularly more in the western, southern and central Marathwada region (Figure 5). For comparing the NAI with crop yield based drought index, Yield Anomaly Index was computed with the help of yield data of Jowar and Tur (2000–2015) for the year 2015. YAI of Jowar and Tur of the year 2015 shows that all the districts of Marathwada were having negative YAI in 2015 (Figure 6a and 6b). As a RS based drought index NAI indicated the existence of agricultural drought during the year 2015 while the results obtained after the analysis of YAI also validates the findings of NAI.

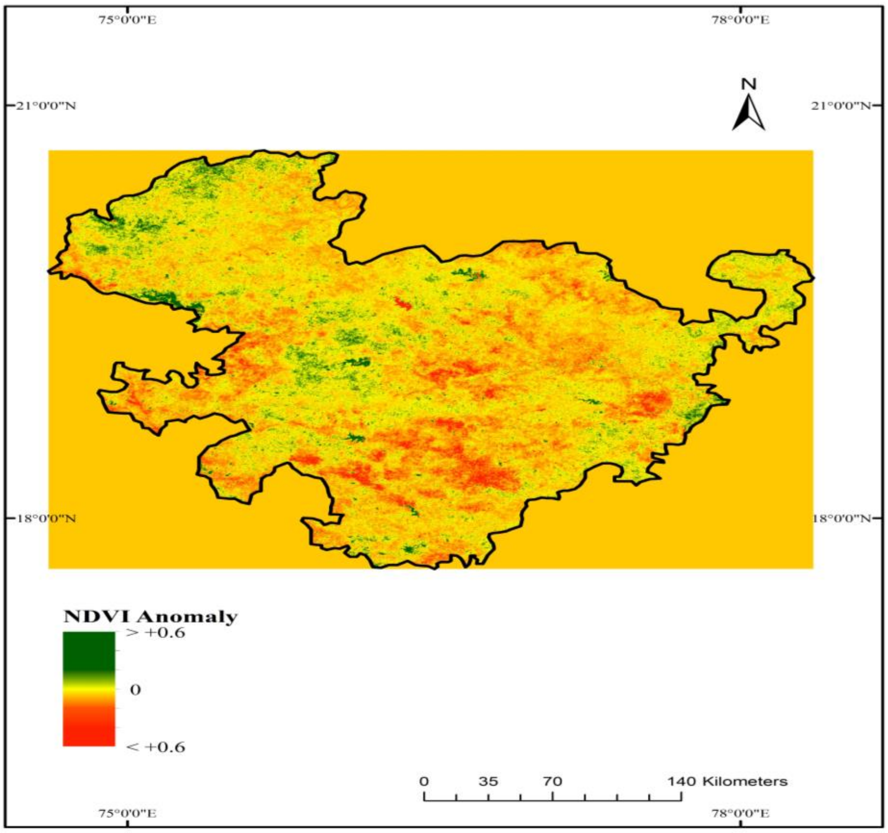

Figure 5. NAI of Marathwada Region for the second fortnight of September, 2015

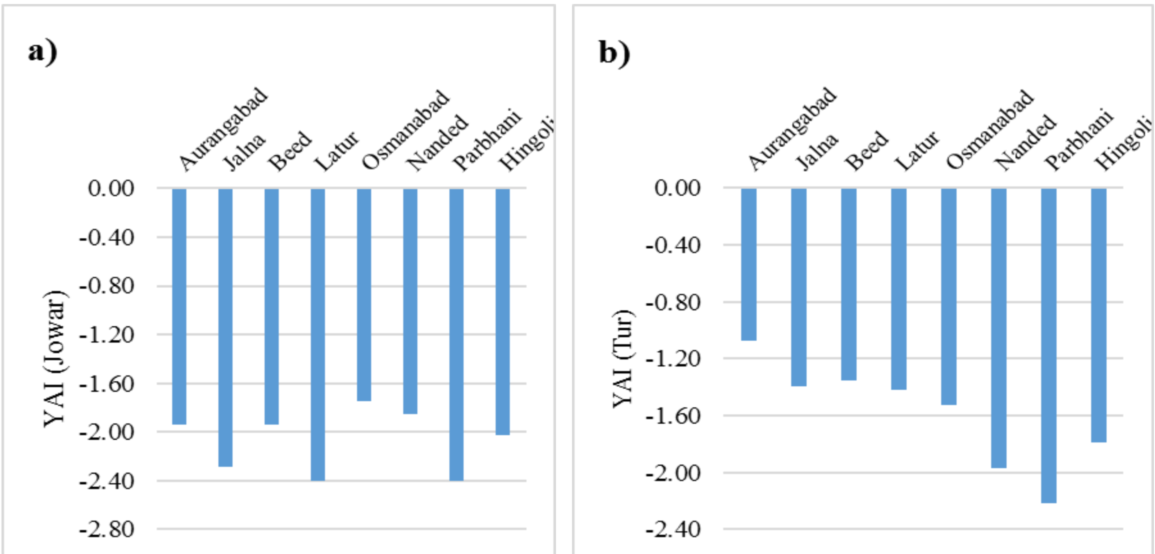

Figure 6. District wise yield anomaly of Jowar (a) and Tur (b)

Source: Based on data obtained from Department of Agriculture, Government of Maharashtra

5.5 Analysis of Correlation between Meteorological and Hydrological Drought

The results of correlation analysis between the meteorological and hydrological drought for Marathwada region from the year 2000 to 2016 reveals that the meteorological drought triggers hydrological drought due to which hydrological drought followed meteorological drought without a time lag. It is well to be noted that the magnitude of meteorological drought index (RAI) is denoted in decreasing values while the magnitude of hydrological drought (SWI) is denoted with increasing values. Thus, negative values of correlation coefficient signify a higher correlation between RAI and SWI (Table 3).

Table 3. Correlation between meteorological and hydrological drought

District	With zero year lag	With 1 year lag
Aurangabad	-0.685364715	0.157672837
Bid	-0.783289581	-0.191172665
Nanded	-0.766640796	0.055995546
Osmanabad	-0.718957003	-0.285100931
Parbhani	-0.890956925	-0.052943489
Latur	-0.756516873	-0.159716563
Jalna	-0.803519418	0.067173461
Hingoli	-0.485118072	0.084886065

Source: Computed by Authors

The discussion with key informants during the field survey revealed that during the dry spells of monsoon, the dependency on groundwater increases manifold in order to meet the water requirements for irrigating the standing crops (Figure 7a). Further, the erratic nature of rainfall or failure of monsoon is responsible for meager groundwater recharge and increased groundwater consumption which further intensifies the hydrological drought (Figure 7b). The region lacks perennial surface water bodies that make the groundwater most vulnerable to increased water requirements during the delay or failure of monsoon. Particularly, during the non-monsoon months (other months apart from JJAS) groundwater acts as the most reliable sources to meet the water requirements of the region. The high irrigation requirements of water-intensive crops like sugarcane during the deficit rainfall season generates the critical groundwater scarcity (Figure 7c and 7d). Consecutive drought years further leads to inadequate surface and groundwater recharge that aggravates the impacts of drought in the form of crop failure and water conflicts in the society.

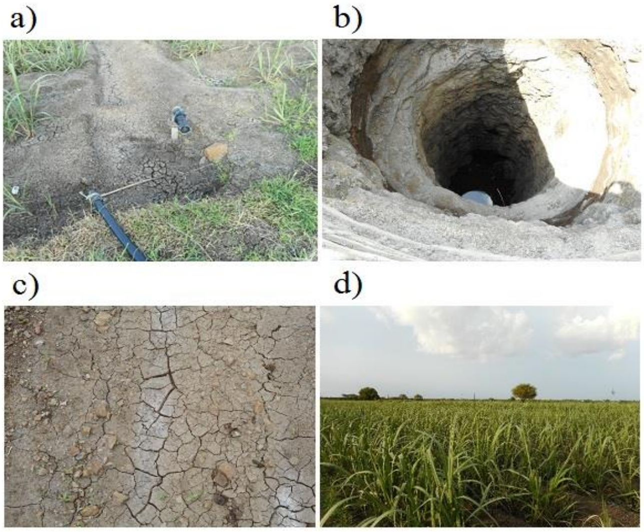

Figure 7: (a) Borewell irrigating sugarcane farm (b) Fallen water level of village well (c) An unirrigated patch of farmland (d) Water intensive sugarcane cultivation. *Source: Field survey*

6. CONCLUSION

Consecutive drought years in the Marathwada region caused critical drought impacts like drinking water scarcity, groundwater depletion, fodder scarcity, and also the decline in crop productivity. All the districts had suffered from acute groundwater scarcity due to deficiency of rainfall and an increase in the dependency on groundwater resource. The results obtained after the analysis of RAI revealed that the number of affected districts due to severe drought was much greater in the year 1972 as compared to the 2015 drought that also means droughts are not new in the Marathwada region.

The year 2014 and 2015 were two consecutive drought years for the Marathwada region. The districts like Parbhani and Bid districts have witnessed the worst expansion of drought from the moderate to severe meteorological drought between the years 2014 and 2015. The Marathwada has remained affected due to the hydrological droughts of varying intensity in the years 2012, 2014 and 2015, in which the year 2015 was worst affected. In the year 2014, rainfall deficit from normal was highest in the Parbhani district (49.49%), followed by the districts like Nanded (48.49%), Hingoli (44.36%) while in the year 2015 Parbhani district has experienced the highest deficit of rainfall from the normal, i.e., 51.44%, followed by the districts, i.e., Bid (50.16%), Latur (44.12%). The Aurangabad and Jalna districts went through extreme hydrological drought in the year 2012. During the year 2015, the districts like Latur, Bid, Parbhani and Nanded had experienced the extreme hydrological drought. The remote sensing based drought index NAI also indicated the existence of agricultural drought during the year 2015, the results of NAI was supported through the findings of YAI which also indicated the acute decline in crop productivity of major crops of the region. During the failure of monsoon, the dependency on groundwater increases manifolds for meeting the immediate water requirements for irrigating the standing crops which also triggers acute hydrological drought. The chronically drought-prone region like Marathwada requires the extensive development and constant monitoring of water conservation structures and practices like soak pits, farm ponds, contour trenches, water budgeting, and area-specific crop farming according to water availability during a particular year.

ACKNOWLEDGMENTS

The authors acknowledge the financial support for this study from University Grant Commission (UGC), Government of India through Junior Research Fellowship to Sagar Khetwani. The authors gratefully acknowledge the agencies like India Meteorological Department, Groundwater Surveys and Development Agency (Government of Maharashtra) and Department of Agriculture (Government of Maharashtra) for providing the data support.

REFERENCES

Action Aid. (2016). *Drought 2015-16 Lessons from Desolation: A Citizen's Report on Impact of Drought and Learnings for Future*. New Delhi, India.

Arraf, F. (2016). The agriculture sector and its impact on Syria's water basins between 1980 - 2010. *European Journal of Geography*. 7(3): 25-40.

Ashraf, M. and Routray, J.K. (2013). Perception and understanding of drought and coping strategies of farming households in north-west Balochistan. *International Journal of Disaster Risk Reduction*. 5: 49–60.

Bandyopadhyay, N. and Saha A.K. (2014). Analysing Meteorological and Vegetative Drought in Gujarat. In: Singh M., Singh R., Hassan M. (eds) *Climate Change and Biodiversity. Advances in Geographical and Environmental Sciences*. Springer, 61-71.

Bandyopadhyay, N. and Saha A.K. (2016). A comparative analysis of four drought indices using geospatial data in Gujarat, India. *Arabian Journal of Geosciences*. 9:341.

Bhuiyan, C. (2004). *Various drought indices for monitoring drought condition in Aravalli terrain of India*. In: Proceedings of the XXth ISPRS Conference. International Society Photogrammetry Remote Sensing, Istanbul. Available at http://www.cartesia.es/geodoc/isprs2004/comm7/papers/243.pdf (accessed 18 May 2017).

Biswas, P. S. (2015). Maharashtra turning into drought capital of country. *The Indian Express*, 23 August. Retrieved on 25 October 2017, from https://indianexpress.com/article/cities/pune/maharashtra-turning-into-drought-capital-of-country/

Centre for Research on the Epidemiology of Disasters (CRED). (2015). *The Human Cost of Natural Disasters: A Global Perspective*. Brussels, Belgium.

Costa, J.A. and Rodrigues, G.P. (2017). Space-time distribution of rainfall anomaly index (RAI) for the Salgado Basin, Ceara State-Brazil. *Ciencia e Natura*. 39(3): 627-634.

Dagel, K.C. (1997). Defining Drought in Marginal Areas: The Role of Perception. *The Professional Geographer*. *49*(2): 192-202.

Dandekar, A. and Naravade, S. (2013). The Case of Maharashtra's Disappearing Water. *Economic & Political Weekly*. *48*(18): 19-21.

Dandekar, P. (2015). August 18. Drought and Marathwada: An Oft repeated Tragedy [Blog Post]. Retrieved on 02 June 2016, from https://sandrp.in/2015/08/18/drought-and-marathwada-an-oft-repeated-tragedy/

Dandekar, P. (2016). January 18. Beautiful but Dry: Dug-Wells of Marathwada in the times of drought [Blog Post]. Retrieved on 01 June 2017, from https://sandrp.in/2016/01/18/beautiful-but-dry-wells-of-marathwada/

Dandekar, P. and Thakkar, H. (2013). March 30. How is 2012-13 Maharashtra Drought worse than the one in 1972? [Blog Post]. Retrieved on 14 August 2017, from https://sandrp.in/2013/03/30/how-is-2012-13-maharashtra-drought-worse-than-the-one-in-1972/

Department of Agriculture, Cooperation & Farmers Welfare (DAC&FW). (2018). *Annual Report 2017-18*. New Delhi, India.

Deshpande, A. (2016). January 14. Maharashtra saw 3,228 farmer suicides in 2015. *The Hindu*. Retrieved on 05 October 2017, from https://www.thehindu.com/news/national/other-states/Maharashtra-saw-3228-farmer-suicides-in-2015/article13997850.ece

Deulgaonkar, A. (2015). October 1. This is the worst drought in the history of Marathwada. *DNA*. Retrieved on 18 March 2017, from https://www.dnaindia.com/analysis/interview-this-is-the-worst-drought-in-the-history-of-marathwada-atul-deulgaonkar-2130577

Dutta, D., Kundu, A., Patel, N.R., Saha, S.K. and 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 Sciences*. 18: 53–63

Dutta, D., Patel, N.R. and Kundu, A. (2011). Analyzing the performance of auto regressive integrated moving average (ARIMA) model for predicting agricultural productivity in eastern Rajasthan. *Research Journal of Agricultural Science*. 2: 555–559.

Fadina, A. M. R. and Barjolle, D. (2018). Farmers' Adaptation Strategies to Climate Change and Their Implications in the Zou Department of South Benin. *Environments*. 5(1): 1-17.

Fluixa-Sanmartín, J., Pan, D., Fischer, L., Orlowsky, B., Garcia-Hernandez, J., Jordan, F., Haemmig, C., Zhang, F. and Xu, J. (2018). Searching for the optimal drought index and timescale combination to detect drought: a case study from the lower Jinsha River basin, China. *Hydrol. Earth Syst. Sci*.. 22: 889–910.

Groundwater Surveys and Development Agency (GSDA). (2017). *Aurangabad Region*. Retrieved on 07 March 2017, from https://gsda.maharashtra.gov.in/english/index.php/Regions_Information_InDetailed/index/6

Gupta, A. K., Nair, S.S., Ghosh, O., Singh, A. and Dey, S. (2014). *Bundelkhand Drought: Retrospective Analysis and Way Ahead.* National Institute of Disaster Management, New Delhi, India.

India Meteorological Department (IMD). (1971). *Climate Diagnostic Bulletin of India - June, July, August, Report No 88, 89 and 90*. National Climate Center, India Meteorological Division, Pune.

Jain, V.K., Pandey, R.P., Jain, M.K. and Byun, H.R. (2015). Comparison of drought indices for appraisal of drought characteristics in the Ken River Basin. *Weather and Climate Extremes*. 8: 1-11.

Kale, S. and Gond, J.K. (2016). Drought in Marathwada: Water Scarcity Worsening Situation in Marathwada. *International Journal of Innovative Research in Science, Engineering and Technology*. 5(5): 8376-8384.

Khairnar, D.R., Bhosale, M.J. and Jadhav, M.A. (2015). Lack of Irrigation Facilities, Draught Conditions and Farmers Suicides in Marathwada Region, India. *American Journal of Rural Development*. 3(3): 74-78.

Khetwani, S. and Singh R.B. (2018b). Assessment of hydrological drought in Marathwada Region: A spatiotemporal analysis. *Journal of Geography, Environment and Earth Science International*. 17(1):110. DOI: 10.9734/JGEESI/2018/43612

Khetwani, S. and Singh, R.B. (2018a). Groundwater dynamics in Marathwada Region: A Spatiotemporal Analysis for Sustainable Groundwater Resource Management. *International Journal of Conservation Science*. 9(3):537-548.

Kulkarni, A., Gadgil, S. and Patwardhan, S. (2016). Monsoon variability, the 2015 Marathwada drought and rainfed agriculture. *Current Science*. 111(7): 1182-1193.

Mage, J.O. and Tyubee, B.T. (2017). Temporal trend in daily rainfall intensity in a changing climate in the middle belt region of Nigeria. *European Journal of Geography*. 8(4): 103-117.

Maharashtra Status of Environment and Related Issues (MAHAENVIS). (2005). *Environmental Status Report of Aurangabad Region*.

Mohammed, Y., Yimer, F., Tadesse, M. and Tesfaye, K. (2018). Meteorological drought assessment in north east highlands of Ethiopia. *International Journal of Climate Change Strategies and Management*. 10(1): 142-160.

Morid, S., Smakhtin, V. and Moghaddasi, M. (2006). Comparison of Seven Meteorological Indices for Drought Monitoring in Iran. *International Journal of Climatology*. 26: 971-985.

Nair, S.S., Singh, A. and Gupta, A.K. (2013). Drought Risk and Vulnerability Analysis for Bundelkhand Region of India. *International Geoinformatics Research and Development Journal*. 4(3): 1-19.

Nanzada, L., Zhanga, J., Tuvdendorja, B., Nabila, M., Zhanga, S. and Baia, Y. (2019). NDVI anomaly for drought monitoring and its correlation with climate factors over Mongolia from 2000 to 2016. *Journal of Arid Environments*. 164: 69-77.

National Disaster Management Authority (NDMA). (2016). *National Disaster Management Plan*. Government of India, New Delhi, India.

National Institute of Disaster Management (NIDM). (2009). *Manual for Drought Management*. Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India.

Pandey, N. and Sharma, D. (2016). Participatory Approach of Water Resource Management: A Case Study of Marathwada. *IOSR Journal of Business and Management (IOSR-JBM)*. 32-38.

Pandey, S., Kumar, M. and Mahanti, N.C. (2014). Assessment of Drought Severity in Various Regions of Jharkhand State of India. *International Research Journal of Environment Sciences*. 3(2): 8-14.

Patel, N.R. and Yadav, K. (2015). Monitoring spatio-temporal pattern of drought stress using integrated drought index over Bundelkhand region, India. Natural Hazards. 77: 663–677

Planning Department Government of Maharashtra (PDGOM). (2013). *Report of the High Level Committee on Balanced Regional Development Issues in Maharashtra*, Government of Maharashtra.

Purandare, P. (2013). Water Governance and Droughts in Marathwada. *Economic & Political Weekly*. 48(25): 18-21.

Rupanarayan and Patel, N.R. (2018). Drought assessment using satellite based vegetation condition index and rainfall anomaly index over Bundelkhand region, India. *IJARIIE*. 4(4): 257-264.

Sahoo, R.N., Dutta, D., Khanna, M., Kumar, N. and Bandyopadhyay, S.K. (2015). Drought assessment in the Dhar and Mewat Districts of India using meteorological, hydrological and remote-sensing derived indices. *Natural Hazards*. 77: 733-751.

Singh, R.B. and Kumar, A. (2015). Climate variability and water resource scarcity in drylands of Rajasthan, India. *Geoenvironmental Disasters*. 2(7): 1-10.

Singh, R.B. and Kumar, D. (2014). Water Scarcity. In S. Eslamian (Ed.), *Handbook of Engineering Hydrology: Environment Hydrology*: 519-543. Boca Raton, Florida: Taylor & Francis Group.

Tadic, L., Dadic, T. and Bosak, M. (2015). Comparison of different drought assessment methods in continental Croatia. *GRADEVINAR*. 67(1): 11-22.

Udmale, P., Ichikawa, Y., Manandhar, S., Ishidaira, H. and Kiem, A.S. (2014). Farmers' perception of drought impacts, local adaptation and administrative mitigation measures in Maharashtra State, India. *International Journal of Disaster Risk Reduction*. 10: 250-269.

Van-Rooy, M.P. (1965). A rainfall anomaly index (RAI) independent of time and space. *Notos*. 14: 43–48.

Wang, W., Ertsen, M. W., Svoboda, M. D., and Hafeez, M. (2016). Propagation of Drought: From Meteorological Drought to Agricultural and Hydrological Drought. *Advances in Meteorology*. (1-2): 1-5.

Wilhite, D. A. and Glantz, M. H. (1985). Understanding: the drought phenomenon: the role of definitions. *Water International*. 10(3): 111–120.

Zargar A., Sadiq, R., Naser, B. and Khan, F. I. (2011). A review of drought indices. *Environmental Reviews*. 19: 333 -349.