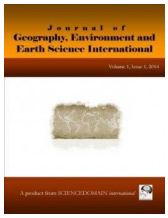

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Assessment of Hydrological Drought in Marathwada Region: A Spatio-temporal Analysis

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Authors' contributions

This work was carried out in collaboration between both authors. Author SK procured the data and contributed to data analysis, interpretation and drafted the manuscript. Author RBS provided supervision of study at all stages and commented on the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

The erratic nature of rainfall has increased the human dependency on surface and groundwater resources manifold. The increased pressure on surface water and groundwater resources makes hydrological drought a very important subject. The streamflow and run-off analysis are widely used methods for the quantification of hydrological drought. However, in the regions which lack perennial streams, the groundwater analysis may prove more effective for the assessment of hydrological drought rather than streamflow and run-off analysis. This study attempts to investigate the spatio-temporal patterns, frequency and intensity analysis of hydrological drought in the Marathwada region of Maharashtra state in India. The standardized water level index has been used to quantify hydrological drought. Maps have been generated to represent spatio-temporal patterns of hydrological drought. The frequency and intensity analysis of hydrological drought across seventy-six sub-districts were assessed by multiplying the frequency of each class of drought severity with its assigned weightage. The spatio-temporal assessment of hydrological drought depicts significant spatial expansion of hydrological drought during the period of 2011 to 2015. The analysis revealed

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that hydrological droughts of mild to the moderate category are more frequent than the severe and extreme droughts. However, there are also pieces of evidence of the severe and extreme drought occurrences in the Marathwada region, particularly more between the years 2011 and 2015.

Keywords: Hydrological drought; groundwater; standardized water level index; spatio-temporal patterns; Marathwada region.

1. INTRODUCTION

The world is experiencing increased frequency and intensity of droughts which is a big challenge for the wellbeing of the human society. Between the years 1994 to 2013, drought affected 25% of global population or more than one billion people [1]. Droughts put up multiple detrimental ecological and socio-economic impacts [1,2,3]. The impacts of drought are more critical in the developing world, where a majority of the population is dependent on agriculture [4,5,6,7]. The impacts of climate change and rainfall variability is much in developing countries, impacts such as droughts, flash floods, sea-level rise, heat waves, etc. By the year 2080, the impacts of climate change may push about 600 million people into food shortages and the number of people affected by water scarcities would reach 1.8 billion [8]. Several research works related to the increased variability of rainfall and its impacts over developing nations raised the need to sensitize the global society to develop adaptation measures for reducing the impacts of climate change [8,9]. In developing countries like India where the expanding industrial sector, mushrooming cities, and traditional predominant agriculture sector co-exists, droughts trigger the haphazard consumption of groundwater level in order to meet water requirements by all the sectors [10]. The situation is more critical in regions which lack surface irrigation facilities and where the society is highly dependent on groundwater resources in order to meet water requirements [11].

Drought could be categorized into four categories, i.e., meteorological, hydrological, agricultural and socio-economic [12]. Hydrological drought refers to an abnormal decrease in the availability of water in all its forms [13]. Hydrological drought could be manifested in the form of the significant reduction in natural stream flows or abnormal reduction in the availability of water in lakes, reservoirs or groundwater [13,14]. The increased dependency on surface water resources or groundwater resources in order to meet day to day water requirements makes hydrological drought a very complicated issue to study [15]. In the management of water resource, hydrological drought assessment plays a crucial role [13]. For the quantification of hydrological drought, there are several hydrological drought indices. Shafer and Dezman [16] developed the Surface Water Supply Index (SWSI) while Shukla and Wood [17] developed the Standardized Runoff Index (SRI) to quantify hydrological drought. Nalbantis and Tsakiris [18] developed Streamflow Drought Index (SDI) to characterize hydrological drought. Generally, there are hydrological drought indices that take into consideration the deficit of streamflow from normal conditions for quantifying the intensity of hydrological drought. But for hydrological drought analysis in regions where streams and channels remain dry during most part of the year or where groundwater plays an important role in meeting the water requirements, groundwater level monitoring, analysis, and groundwater level fluctuation can be considered for assessment of hydrological drought [19]. This study analyzes the dimension of hydrological drought.

The Marathwada region in the Maharashtra state of India is one of the worst drought-affected regions of India which has experienced the three droughts between the years 2012 and 2016, i.e., 2012, 2014 and 2015 [20]. The parched agricultural fields, depleted groundwater level, the endless queue of people for filling water from tankers, wells, and taps, and economic shutdown in the region shook the entire nation [21,22,23,24,25]. Groundwater is one of the most important sources in meeting the water requirement of Marathwada region, erratic rainfall further increases the dependence on groundwater which further leads to a deep fall in groundwater level [26,27]. A lot of research work had been done during the period of consecutive droughts in the region by the researchers, organizations and government agencies for the identification of reasons of drought, analysis of rainfall and changes in crop concentration [25,26,27,28,29]. The spatial delineation of water stress on the basis of the frequency and intensity of stress associated with it brings out the clear

picture of critical areas [30]. Several others have also raised the need for stress zonation for providing the assistance during decision-making process [31,32]. The current study, therefore, aims to assess spatio-temporal patterns of hydrological drought in the region which can assist in the identification of chronically affected sub-districts of the region. The usage of the standardized water level index (SWI) for hydrological drought assessment can be fruitful as the region lacks perennial streams. Hence in the present study, SWI has been used that considers groundwater level fluctuations from normal for the assessment of hydrological drought in the region. The specific objectives of this study are to present the spatio-temporal patterns of hydrological drought in the region and assess the intensity of hydrological drought across sub-districts.

2. MATERIALS AND METHODS

2.1 Study Area

The Marathwada region lies between 17° 37' North and 20° 39' North latitudes and 74° 33' East and 78°22' East longitudes in the Maharashtra state of India [33]. The Marathwada region includes eight districts, i.e., Aurangabad, Jalna, Bid, Osmanabad, Nanded, Latur, Hingoli and Parbhani, and seventy-six sub- districts (*Tahsils or Talukas*) within eight districts (Fig. 1).

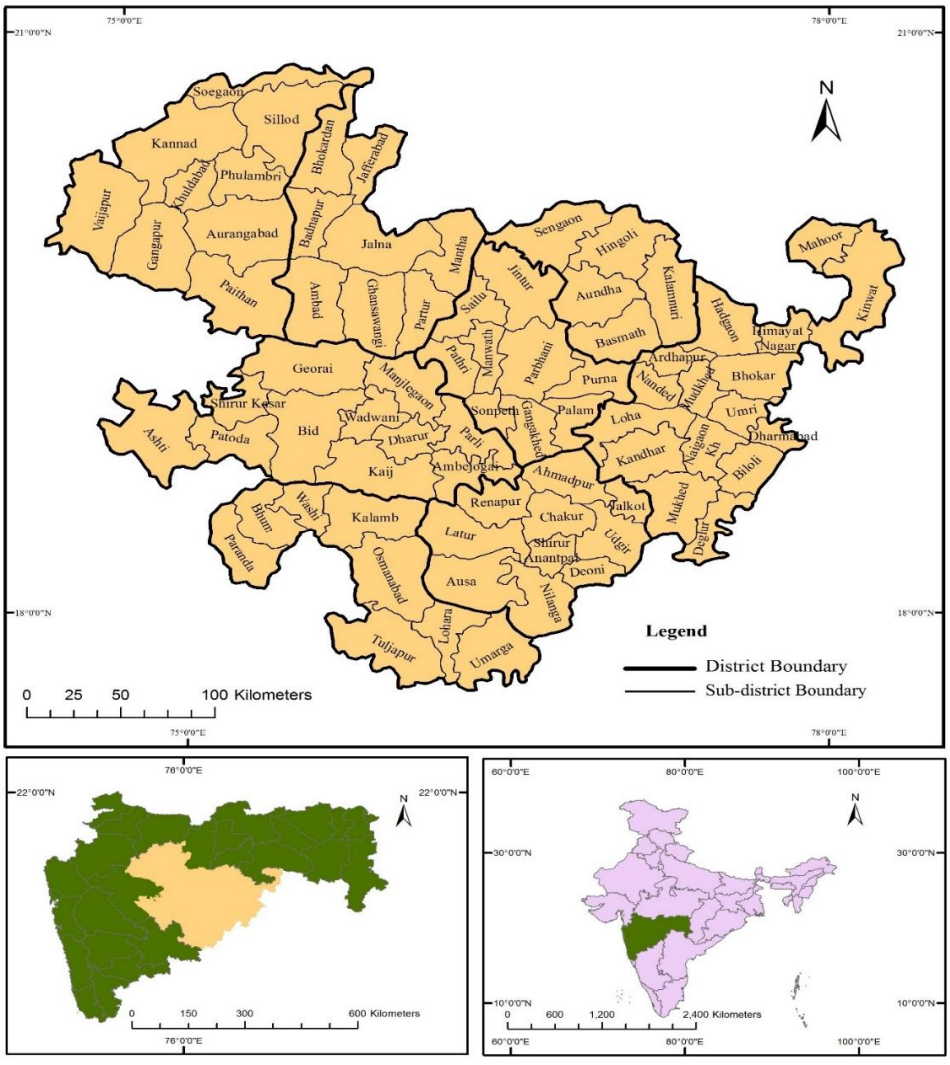

Fig. 1. Location map of the study area, Marathwada region
Source: Census of India, 2011

Each district of Marathwada region is further divided into sub-districts (sub-districts are known differently in different states of India, e.g., *Tahsil, Taluka*, etc.). The total geographical area of Marathwada region is 64,813 sq. km which constitute around 21% area of the Maharashtra state. The region lies in the rain shadow zone of the Western Ghats in Maharashtra state. The average rainfall of Marathwada is about 825 mm but is highly erratic. Due to its location in rain shadow zone, erratic rainfall and longer dry spells make droughts frequent in the Marathwada region. The climate of Marathwada is generally hot and dry. The average temperature of day ranges from 27.7°C to 38.0°C while the average temperature of night ranges from 20.0°C to 26.9°C. The Godavari is a most important river of the Marathwada region, comprises many large and small projects in the region [33,34,35]. Due to lack of surface irrigation facilities and erratic rainfall, groundwater is one of the most reliable and dependent sources to meet the water requirements of the region [36,22]. The haphazard exploitation and mismanagement of groundwater resource particularly during the failure of monsoon make groundwater resource more critical [6,7,22]. The total population of Marathwada region is 1,87,31,872 represents 18.7% of Maharashtra state out of which 72.9% of the population is rural while 27.1% is living in urban areas. In Marathwada, a majority of the population are dependent on agriculture sector [34,28,29].

2.2 Materials

The secondary data sources used in this study include pre-monsoon (May) and post-monsoon (October) groundwater level data for 15 years from 2001 to 2015 of 76 sub-districts in the region. The groundwater level data of 76 sub-districts were obtained from the Groundwater Surveys and Development Agency (GSDA) Maharashtra.

2.3 Methods

The identification and assessment of hydrological drought intensity have been done with the help of standardized water level index (SWI), the pre-monsoon and post-monsoon groundwater levels of 76 sub-districts in the region have been analyzed. The SWI was postulated by Bhuiyan (2004) for hydrological drought analysis and explained in the equation (1) and Table 1.

$$SWI = \frac{(Wij - Wim)}{\sigma} \quad (1)$$

Wij is the seasonal water level of the ith well and jth observation, Wim is its seasonal mean, and σ is its standard deviation.

Table 1. Standardized water level index

Drought intensity	SWI values
Extreme drought	> 2
Severe drought	> 1.5
Moderate drought	> 1
Mild drought	> 0
No-drought	< 0

Source: Bhuiyan, 2004

In order to attain the specific objectives of the study, groundwater level fluctuations of 76 sub-districts rather than individual wells were considered. The equation of SWI for assessing the hydrological drought across 76 sub-districts from 2001 to 2015, used in this study is explained below in Equation (2).

$$\text{SWI for ith sub-district} = \frac{(SDij - SDim)}{\sigma} \quad (2)$$

SDij stands for seasonal water level of the ith sub-district and jth observation, SDim stands for its seasonal mean while σ is its standard deviation.

SWI value represents the intensity of hydrological drought. As the groundwater level is measured down from the surface, negative SWI values depict 'no-drought' or normal condition while positive SWI values depict drought [19]. SWI values of the sub-districts showing the intensity of hydrological drought across talukas have been represented through generated maps. The hydrological drought frequency and intensity were assessed for each sub-district from the year 2001 to 2015. The weightage of 0, 1, 2, 6 and 10 were assigned to hydrological drought intensity classes of no-drought, mild drought, moderate drought, severe drought and extreme drought. The hydrological drought frequency and intensity of each sub-district were assessed by multiplying the frequency of each class of drought severity with the corresponding assigned weightage. The hydrological drought frequency and intensity were divided into categories like low, moderate, high and very high. The spatio-temporal patterns of hydrological drought are represented by maps. Arc GIS 10.2.2 software was used for generating

the maps, representing the spatio-temporal patterns of hydrological drought.

3. RESULTS AND DISCUSSION

3.1 Hydrological Drought between the Years 2001 and 2005

Between the years 2001 and 2005, the number of sub-districts that experienced severe and extreme droughts are comparatively more in the years 2003 and 2004. In the year 2003 during post-monsoon out of seventy-six (76) sub-districts of Marathwada region, twenty-six (26) sub-districts experienced mild drought, four (4) sub-districts experienced moderate drought while seven and six sub-districts were affected by severe and extreme drought. It could clearly be seen that the increased number of sub-districts were affected by severe and extreme drought between the pre-monsoon and post-monsoon season in the year 2003. In the year 2004 between pre-monsoon and post-monsoon season, sub-districts affected with mild drought increased from thirty-one (31) to thirty-five (35) while sub-districts experiencing severe drought increased from four (4) to eleven (11). On the other hand, sub-districts experiencing moderate drought increased from fourteen (14) to sixteen (16) between pre-monsoon and post-monsoon season in the year 2004. In the year 2004, between the pre-monsoon and post-monsoon, the region has witnessed the increase in the number of sub-districts affected with mild and severe drought (Fig. 2).

3.2 Hydrological Drought between the Years 2006 and 2010

During the period of 2006-10, the year 2009 was marked by the comparatively higher number of sub-districts affected by the moderate to extreme drought. In the year 2009 during pre-monsoon, forty-four (44) sub-districts experienced mild drought and four (4) sub-districts experienced moderate drought. On the other hand, during the post-monsoon season of the same year, thirty-three (33) sub-districts were affected by mild drought and six (6) sub-districts were affected by moderate drought, nine (9) sub-districts witnessed the severe drought while two (2) were affected by extreme drought. Parbhani district witnessed an increase in the number of sub-districts affected by moderate drought between the post-monsoon season of the year 2009 and pre-monsoon season of the year 2010 (Fig. 3).

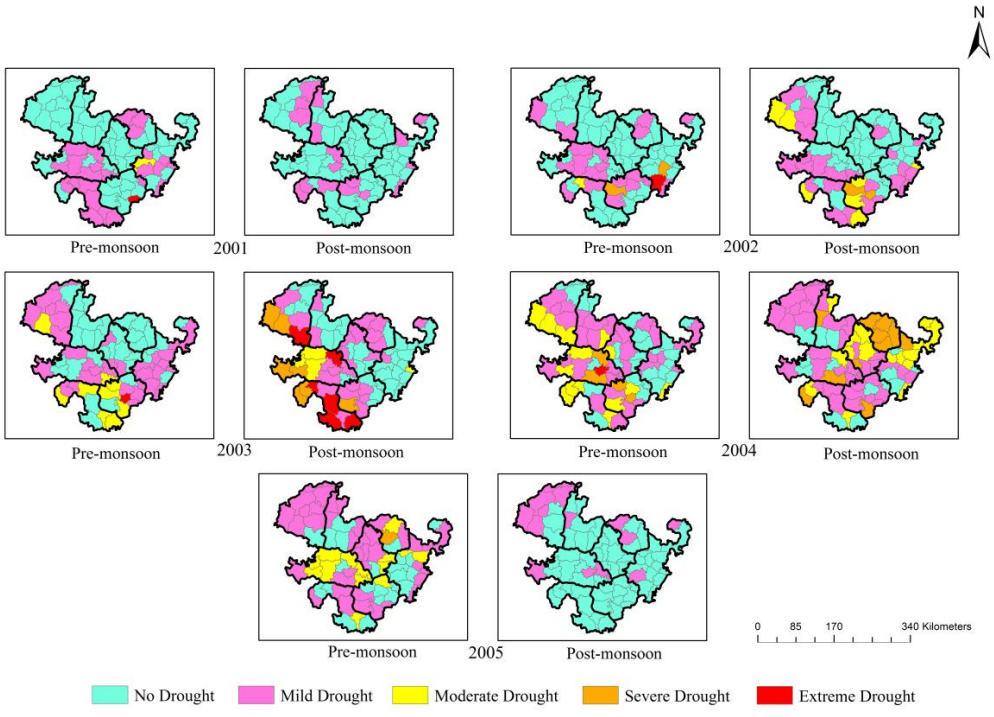

Fig. 2. Hydrological drought in Marathwada region from the year 2001 to 2005
Source: Based on data obtained from Groundwater Surveys and Development Agency, Maharashtra

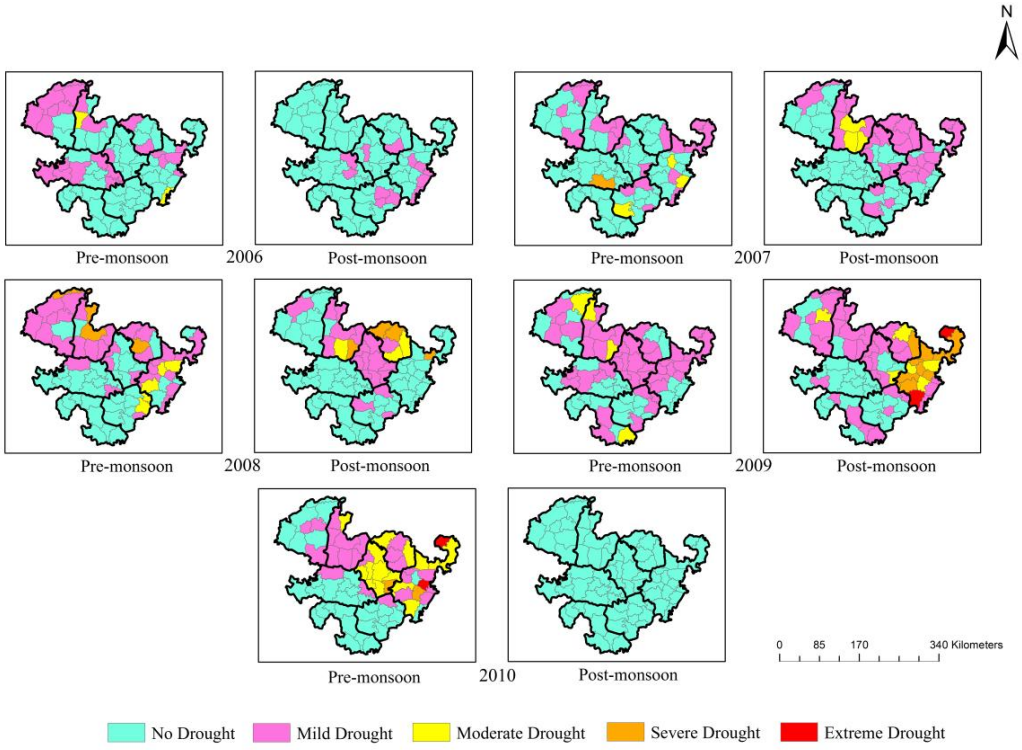

Fig. 3. Hydrological drought in Marathwada region from the year 2006 to 2010
Source: Based on data obtained from Groundwater Surveys and Development Agency, Maharashtra

3.3 Hydrological Drought between the Years 2011 and 2015

The period of 2011-15 experienced the worst hydrological drought. The years 2012 and 2015 registered a phenomenal increase in the number of sub-districts affected by the severe and extreme hydrological drought amongst all years. During pre-monsoon season of the year 2012, none of the sub-districts were affected by the extreme drought but by the post-monsoon season of the same year it increased and registered the all-time high seventeen (17) sub-districts. The districts like Aurangabad and Jalna were marked by the higher proportion of sub-districts affected by the severe and extreme drought followed by the districts like Osmananbad and Bid. Between post-monsoon season of 2012 and pre-monsoon season of the year 2013, a substantial expansion of hydrological drought was observed by the sub-districts of districts like Parbhani, Hingoli, and Latur. While during the post-monsoon season of the year 2013, none of the sub-districts were affected from hydrological drought except three (3) sub-districts that experienced mild drought. The Marathwada region has witnessed the continuous spatial expansion of hydrological drought between the pre-monsoon season of the year 2014 and post-monsoon season of the year 2015. During pre-monsoon season of the year 2014, none of the sub-districts were suffering from moderate, severe and extreme drought but by the post-monsoon season of the same year fourteen sub-districts were affected by moderate drought, seven by severe drought and one was affected by extreme drought. Between the post-monsoon season of the year 2014 and pre-monsoon season of the year 2015, increase in the number of sub-districts suffering from severe to extreme hydrological drought was observed particularly more in the districts like Parbhani and Latur. During the post-monsoon season of the year 2015, Marathwada region had witnessed one of the worst hydrological droughts, except only four (4) sub-districts of the region all sub-districts were affected by the hydrological drought of varied intensity. A significant increase was observed in the number of sub-districts suffering severe drought from seven (7) to twenty-seven (27) while sub-districts suffering from extreme drought increased from five (5) to thirteen (13) between pre-monsoon season and post-monsoon season of the year 2015 (Fig. 4).

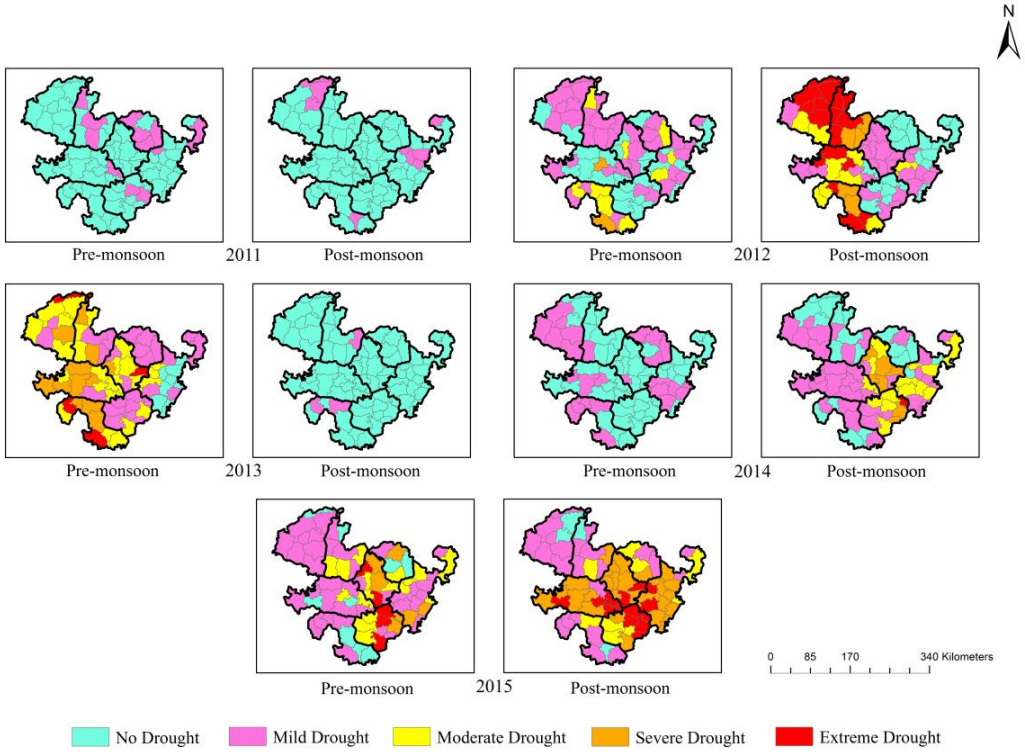

Fig. 4. Hydrological drought in Marathwada region from the year 2011 to 2015
Source: Based on data obtained from Groundwater Surveys and Development Agency, Maharashtra

Table 2. Drought frequency and intensity analysis of Marathwada region

Drought frequency and intensity	Sub-district/s
Very high	Tuljapur, Mukhed, Washi, Gangakhed, Soegaon, Deoni, Purna, Sailu and Georai
High	Kaij, Wadwani, Mahoor, Patoda, Dharur, Nilanga, Jalkot, Umri, Hingoli, Manjlegaon, Udgir, Shirur-Anantpal, Bhum, Sonpeth, Aundha, Bhokardan, Ahmadpur, Chakur, Osmanabad, Kandhar, Naigaon (Khairgaon), Jalna, Badnapur and Hadgaon
Medium	Aurangabad, Shirur Kasar, Loha, Parbhani, Jafferabad, Ashti, Paranda, Kalamb, Mudkhed, Pathri, Jintur, Sengaon, Kannad, Partur, Ghansawangi, Mantha, Bid, Nanded, Basmath, Paithan, Khuldabad, Parli, Latur, Renapur, Umarga, Biloli, Himayat Nagar, Ardhapur, Palam, Gangapur, Phulambri, Lohara and Kalamnuri
Low	Vaijapur, Sillod, Ambad, Ambejogai, Kinwat, Bhokar, Deglur, Manwath, Ausa and Dharmabad

Source: Computed by authors

3.4 Hydrological Drought: Frequency and Intensity Analysis

On the basis of assessment of hydrological drought in Marathwada region from the year, 2001 to 2015, frequency and intensity analysis has been made. The seventy-six sub-districts of Marathwada region have been classified into categories like, Very High, High, Medium and Low, on the basis of hydrological drought frequency and intensity analysis. The analysis revealed that sub-districts like Tuljapur, Mukhed, Washi, Gangakhed, Soegaon, Deoni, Purna, Sailu, and Georai emerged as the most

frequently affected due to intense hydrological droughts. While the sub-districts like Vaijapur, Sillod, Ambad, Ambejogai, Kinwat, Bhokar, Deglur, Manwath, Ausa, and Dharmabad lies at the bottom of the category (Table 2). The hydrological drought analysis reveals that hydrological drought in Marathwada region has expanded and intensified, particularly more between the years 2011 to 2015. The increase in the number of sub-districts affected with mild to severe drought indicates the increased pressure on groundwater resource for meeting irrigation needs and other water requirements.

4. CONCLUSION

The spatio-temporal analysis of hydrological drought during the period of 2001 to 2015 in Marathwada region reveals that the region has experienced spatial shifts and intense expansion of hydrological drought, particularly more between the years 2011 to 2015. The location-specific remedial measures need to be taken for the amelioration of groundwater resources in the sub-districts like Tuljapur, Mukhed, Washi, Gangakhed, Soegaon, Deoni, Purna, Sailu and Georai, sub-districts which emerged as most affected in frequency and intensity analysis. The groundwater resource of the Marathwada region needs constant monitoring due to its dynamic nature. The pre-monsoon and post-monsoon groundwater level analysis clearly reveals that intensification and expansion of hydrological drought in the post-monsoon season of years like 2012, 2014 and 2015, possibly due to chain effects of erratic rainfall that increases the dependency on groundwater resources which further led to haphazard consumption of groundwater in the region. The area-specific mitigation measures like water budgeting, cultivation of best-suited crops according to water needs and integration of local knowledge with scientific technology may result not only groundwater development but will also in mitigating the water stress during drought.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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