Moving from Crisis Management to Risk Assessment for Drought Planning Using Standardized Precipitation Index (SPI) and Standardized

Groundwater Level Index (SWI): Case Study of Marathwada, India

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Abstract

The growing demand for water resources is aggravating its scarcity across the world. It is used in a large spectrum of sectors ranging from domestic to industrial, agricultural and environmental activities. Additionally, water resources form a prime indicator of social and economic development for nations. Population explosion, industrialization, rapid urbanization, and mismanagement of resources has led to depletion of water resources often causing water stress leading to scarcity. Water scarcity compounded by droughts, affect both surface water and groundwater resources. This affects water quantity and quality of freshwater thereby, adversely impacting the economy, ecology, socio-cultural and political aspects. However, the vulnerability can be reduced considerably by effective development and implementation of mitigation strategies.

This study focuses on the drought conditions in India, since water problems are worsening in most parts of India especially in the Marathwada region of Maharashtra. Particularly Latur, a district in Marathwada region has been confronting severe water shortage due to drying up of a major source of water i.e., Dhanegaon dam. For droughtprone regions, it is critical to understand its climatology and establish an integrated drought management system that incorporates climate, water supply and factors such as precipitation, temperature, soil moisture, groundwater levels, reservoir and lake levels. In the wake of the water crisis in this region, it has emerged that proper water management is necessary. Drought is categorised as meteorological drought, hydrological drought and agricultural drought. The occurrence of meteorological and hydrological drought is influenced by temperatures and rainfall characteristics. Agricultural drought is affected due to intensity, duration and distribution of rainy days during crop growing seasons. The primary objective of the study is to develop an approach for early warning based on historical monthly precipitation data and groundwater level data. It is achieved using two indices, i.e., Standardized Precipitation Index (SPI) and Standardized water level Index (SWI). Further, trend analysis using Mann-Kendall's test is applied to understand significant increase and decrease in the precipitation. It is evident from the study that a major part of the Marathwada region is prone to drought, either meteorological or hydrological. Lastly, the paper discusses policy and management strategies to mitigate the effects of meteorological and hydrological drought in the region.

1. Introduction

Drought is a multifaceted phenomenon which can be defined from several perspectives, i.e., conceptual and operational (Hisdal & Tallaksen, 2003). In recent decades, intense drought events have been observed all around the world with high economic and social costs (Gupta, Tyagi, & Sehgal, 2011). It differs from other natural hazards due to its slow occurrence and its indefinite start and end. It often fails to draw attention of the world community and its impact persists even after the event is over (Bhuiyan, 2004a).

As a natural hazard, drought is characterized by several climatological and hydrological parameters (Belal et al., 2014). The relationship between these parameters will define the impacts of drought, which will help in developing mitigation measures. Drought planning activities are usually activated after conditions are worsened beyond a defined threshold. Planned activities typically involve, enhancing the understanding of drought information, assessing losses or deficits related to pre-drought conditions (i.e., impacts) (Tadesse et al., 2005) and organizing resources to adequately anticipate and respond to these impacts (Nilson & Nilson, 2014). Hazard management and policy must begin incorporating more pre-hazard planning and mitigation programs aimed at reducing vulnerability (Wilhite, Sivakumar, & Pulwarty, 2014).

1.1 Need to shift from crisis management to risk assessment

Drought risk depends on a combination of the physical nature of drought and the degree to which a population or activity is vulnerable to the effects of drought. Belal et al., (2014) defined drought risk as: "the probability of harmful consequences, or expected losses resulting from interactions between hazards and vulnerable conditions." UNISDR (2009) defines the risk assessment as: "A methodology to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend." A necessary step for drought management is a risk assessment-based approach, which provides a dynamic framework for actions which are ongoing, to prepare for and respond to drought (Sayers et al., 2016). Drought risk assessment in a particular region plays a vital role in water resource management. It is essential to understand relevant components and analyze alternative strategies for efficient water management. Crisis management efforts for droughts in the past have been reactive, ineffective as well as poorly coordinated (Wilhite & Knutson, 2008). It is time to change the paradigm from crisis management to risk assessment through integrated drought management and early warning.

This study aims to analyze the need to adapt for risk assessment by analysing the spatial and temporal effects of annual precipitation on the region. Rainfall has a direct impact on water resources particularly in arid regions where groundwater recharge is dependent on monsoon-rainfall (Bhuiyan, 2004a). Spatiotemporal patterns and variations of seasonal drought pattern and drought vulnerability in the study area is addressed through drought indices. Meteorological drought is monitored using the Standardized Precipitation Index (SPI) due to its ease of use since precipitation is the only input factor. Standardized water level Index (SWI) is used to analyze the hydrological drought conditions of study area. The spatial results generated through different indices are studied, analyzed and correlated. The drought severity and vulnerability of the region are analysed in order to provide a framework for assessing the impact due to climate change and postulate mitigative measures.

2. Study Area- Latur district, Marathwada

The Marathwada region of Maharashtra has been confronting drought since decades consisting of eight districts, i.e., Aurangabad, Beed, Osmanabad, Latur, Jalna, Parbhani, Hingoli, and Nanded. The Marathwada region is first analysed to understand drought severity using Standardized Precipitation Index (SPI). Based on the trend observed through early warning system of Marathwada, the study is further conducted for Latur district. Latur lies to the South-East of Maharashtra on the border of Maharashtra and Karnataka. As per 2011 census, Latur district has an area of 7,157 square kilometers with a population of 2,455,543. The population density of the district is 343 inhabitants per square kilometer (Census, 2011). Population growth rate over the decade 2001-2011 is 18.04

percent. Figure 2 illustrates the water demand of Latur district where the highest percentage share is of sugarcane irrigation. The total water demand for Latur district is 75MLD but water supplied is 60MLD (LMC, 2006).

The geographical location of Latur district is illustrated in Figure 1. The district is situated on the Balaghat plateau

Sugarcane Irrigation



Figure 2: Percent share of water Demand, Latur district



Figure 1: Geographical location of Latur district

at an average elevation of 631 meters (2,070 feet) above mean sea level. The region receives rain from the southwest monsoons with an annual average rainfall of 600 mm (Balpande, 2013). The temperature varies from 24°C to 39.6°C. The temporal rainfall distribution of this region is quite erratic and occurrence of drought is common. The temporal rainfall distribution is erratic and causing drought can be observed in Figure 5 where monthly distribution of precipitation is shown. The soil is chemically rich in calcium and magnesium carbonates but is deficient in nitrogen and phosphorus which leads to cracking of soil during summer.

Water stress in Latur has been intensifying over the years (LMC, 2006). The present water supply conditions are not adequate to meet the daily demand of the region (LMC¹, 2006). The daily demand of water in Latur is 60 litre per capita per day (lpcd), whereas the supply is only 30 lpcd. The only major source of water supply, i.e., Dhanegaon dam is drying up over the years as shown in Figure 3². In 2015, this dam dried completely due to drought. Water tankers were the only source of drinking water after drying up of reservoir and borewells.



¹LMC stands for Latur Municipal Corporation

²Google earth pro time series satellite data.

2.1.1 Status of surface water: There are three surface water sources to Latur, i.e., Sai weir, Sai Barrage, Dhanegaon Dam as shown in Figure 4. Dhanegaon dam receives sufficient water after small reservoirs/tanks dams on the river upstream (divert/store water) are filled. The other available water sources to Latur are Limboti Dam in Nanded district at 100 km and Bhandarwadi Dam at 30-50 km distance. The precipitation data for the census years



Figure 5: Network of rivers and dams to Latur district

1981, 1991, 2001, 2011, 2015, and 2016 is presented in Figure 5. It illustrates that the rainfall received for the region is almost negligible from November till March, which shows that the amount of rainfall received during winter (ranges from 0 mm to 10 mm; December, January, February) is less compared to summers (ranges from 10 mm to 60 mm; March April, May).



2.1.2 Status of Groundwater: The borewells in this region meet part of the unmet water demand of the

households (GSDA3, 2015). The groundwater levels have dropped 10 meters below ground surface for January, March, and May as seen in Figure 5. High water demand for irrigation (Figure 1) for the region



groundwater. As per government regulations, the Latur district having an area of 7,157 sq.km holding ten taluks4 should have only 3,575 bores of up to 60m depth. However, the unofficial number is 90,000 and borewells have been drilled up to 100m depth due to negligible success at hitting water at 60m depth.

3. Methodology

There have been several studies by Belal (2014), Kipketer & Mundia (2013), Sayers et al. (2016), Venton (2012) which deal with drought risk assessment. Different researchers provide various parameters to reduce the vulnerability. However, the need is to have a region-specific framework which incorporates a broad level policy guideline and strategies based on the early warning.

The present study discusses, spatiotemporal patterns of seasonal drought indicated through meteorological and hydrological indices. The study first focusses on the analysis of the Marathwada region using SPI. Further, the SPI and SWI are calculated for the most drought-prone district of Marathwada based on time series trend analysis. Lastly, the study incorporates the policy measures based on the analysis. The secondary data i.e., soil type, groundwater level, drainage, groundwater recharge, types of crop grown, temperature and monthly precipitation level data was acquired from various departments like Ground Survey and Development Agency (GSDA), Latur Municipal Corporation (LMC), Agriculture Department.

³ GSDA stands for Ground Survey and Development Agency.

⁴ Taluk is a terminology that defines an administrative unit which is a subdivision of a district or a group of several villages in India

3.1 Meteorological drought: Standardized Precipitation Index (SPI):

Standardized Precipitation Index (SPI) designed by (Mckee, Doesken, & Kleist, 1993) is selected to analyze the monthly rainfall data since the input factor for the index is only precipitation data. Also, WMO⁵ selected SPI as a key Meteorological indicator (Hayes, 2011). The SPI is a probability index that was developed to represent abnormal wetness and dryness (Wilhite & Glantz, 1985). The index is designed to quantify the precipitation deficit for multiple timescales or moving averaging windows. The impacts of drought on different water resources are indicated through these timescales (Bijaber et al., 2018). Since it standardizes the data, all users of the index will have a common basis for both temporal and spatial comparison of index values. SPI is used to study various characteristics of droughts, for example, forecasting, frequency analysis , spatiotemporal analysis and climate impact studies (Mishra & Desai, 2005a; Mishra & Desai, 2005b; Mishra & Singh, 2011; Mishra et al., 2009). It is spatially consistent as it allows comparison between different locations in different climates. The probabilistic nature of SPI index gives it a historical context which is well suited for decision-making. The equation for SPI is given by

$$SPI = \left(\frac{X_{ij} - X_{im}}{\sigma}\right) \tag{1}$$

Where, X_{ij} = Seasonal precipitation in ith rain-gauge station and jth observation

X_{im} = long term Seasonal mean;

 σ = Standard deviation

For the desired period, the SPI calculation for any location based on the long-term precipitation is recorded. In probability function, this long-term record is fitted to transform into normal distribution achieving the mean SPI for the location and desired period as zero (Edwards & McKee, 1997). Positive SPI values indicate greater than average precipitation, and negative values indicate less than average precipitation. The above-mentioned process is unattainable to compute manually. Thus, a SPI program developed by National Drought Mitigation Center is used to calculate the index. For this software, monthly precipitation data for 45 years from (1972-2016) has been used as an input file. Meteorological and soil moisture condition (agriculture) respond to precipitation anomalies for

⁵World Meteorological Organization; reference "user guide for Standardized Precipitation Index"

relatively shorter timescales (like 1-6 months). Whereas Table 1: SPI values and its classification streamflow, reservoirs and groundwater respond to long-term precipitation anomalies of the order of 6 months-up to 24 months or longer.

For example, 1- or 2-month SPI are checked for meteorological drought. SPI anomaly anywhere from 1-month to 6-month identifies agricultural drought and SPI 6-month up to SPI 24-month SPI or more classifies hydrological drought.

SPI Values	Class	Color	
SPI ≥ 2.00	Extreme Wet	Blue	
1.5 < SPI ≤ 2.00	Severe Wet	Purple	
1.0 < SPI ≤ 1.5	Moderate Wet	Lilac	
-1.0 < SPI ≤ 1.0	Near Normal	White	
-1.5 < SPI ≤ 1.0	Moderate Dry	Yellow	
-2.0 < SPI ≤ -1.5	Severe Dry	Orange	
SPI ≥ -2.00	Extreme Dry	Red	

3.2 Hydrological Drought: Standardized Ground Water Level Index (SWI):

Examination of the stream-flow statistics is widely used to analyze the hydrological drought. The region receives less annual rainfall of 600mm due to which streams and dams remain dry throughout the year. Therefore, domestic and agricultural water supply has to depend on groundwater resources. Hence, analyzing and monitoring hydrological drought is necessary. The year is divided into two periods i.e., the post-monsoon and the pre-monsoon groundwater levels. The wells are observed twice a year since groundwater levels are measured once before the start of monsoon and again after the end of monsoon. Standardized Water Level Index has been developed to scale groundwater recharge deficit (Bhuiyan, 2004a). The SWI expression is given by

$$SWI = \left(\frac{W_{ij} - W_{im}}{\sigma}\right) \tag{2}$$

Where W_{ij} = Seasonal groundwater depth in ith well and jth observation

W_{im} = long term Seasonal mean;

 σ = Standard deviation

Hydrological drought intensity has been measured after classifying SWI values for post and pre-monsoon

anomalies correspond to normal conditions, since groundwater levels are measured down from the surface. The SWI point values are being interpolated using IDW method to generate a spatial depiction of the groundwater conditions. The classification of drought based on the SWI values (Bhuiyan, 2004b) are as shown in table 2. The same categorization is used while spatially representing the SWI values.

Classification	SWI Values
Extreme Drought	SWI ≥ 2.0
Severe Drought	2.0 > SWI≥1.5
Moderate Drought	1.5> SWI≥1.0
Mild Drought	1.0> SWI≥0
Non-Drought	SWI ≤ 0

periods. Positive anomalies correspond to drought, and negative Table 2: SWI values and its classification

3.3 Normalised Deficit Cumulated (NDC)

Normalised deficit cumulated (NDC) is referred to maximum cumulative deficit of water. NDC calculation is preferred over Normalised Deficit Index (NDI) since NDC simulates across all the years to account for multiyear droughts, whereas NDI calculates the water deficit for each year, considering only within year rainfall (Devineni et.al., 2013). It can be understood as the amount of water that needs to be drawn from external storage to meet the current demand or as a measure of impact of a multi-year drought. The NDC value more than 5 indicates serious overdraft of water from a region.

Cumulated Water Deficit	NDC Values
(Ratio)	
Low	NDC < 0.6
Medium	0.6 < NDC ≤ 1.0
High	1 < NDC ≤ 2.0
Very high	2.0 < NDC ≤ 5.0
Extreme	5.0 < NDC

Table 3: Classification of NDC values

The equation 3 calculate NDC as follows:

$$NDC_{j} = (SIC_{j})/(AP_{j})$$
(3)

Where, AP= Average annual rainfall

 $SIC_i = max_t$ (deficit_{j,t}; t= 1:n*365)

Deficit_{j,t}= max (deficit_{j,t-1}+ D_j,t-S_{j,t},0)

Deficit= accumulated deficit

D= total water demand

S=total water supply volume

N=number of years in the record for location "j" on day "t"

3.4 Mann-Kendall's time series trend analysis

The Mann-Kendall's (MK) test given by Mann (1945) and Kendall (1975) is widely used to assess the significant trends in hydro-meteorological time series such as precipitation, temperature and stream flow (Gan, 1998; Yang et al., 2004; Zhang et al., 2001). This test is preferred over other trend analysis test since it is flexible and can handle the peculiarity of data like the presence of missing values, seasonality and highly skewed data (Vousoughi et al., 2013). The present study uses Kendall package in R to calculate the time series trend of the region. The autocorrelation (ACF) property defines a distinct pattern for the autocorrelations in time series. Theoretically, ACF is defined as given in equation 4:

$$\frac{Covariance(x_{t,}x_{t-h})}{Std. Dev.(x_{t})Std. Dev.(x_{t-h})} = \frac{Covariance(x_{t,}x_{t-h})}{Variance(x_{t})}$$
(4)

Where, x_t = Value of a time series at time t.

The ACF of the series gives correlations between x_t and x_{t-h} for h = 1, 2, 3, etc.

The partial correlation is a conditional correlation of two variables and can be found by correlating the residual from two different regressions. The pacf is theoretically defined as given in equation 5:

$$pacf = \frac{Covariance(y, x_3 | x_1, x_2)}{\sqrt{Variance(y | x_1, x_2)Variance(x_3 | x_1, x_2)}}$$
(5)

For a time series, the partial autocorrelation between x_t and x_{t-h} is defined as the conditional correlation between x_t and x_{t-h} , conditional on x_{t-h+1} , ..., x_{t-1} for the set of observations that come between the time points t and t-h.

4. Results and Discussion

Two types of droughts have been assessed, i.e., meteorological and hydrological using respective indices. The drought risk map has been prepared from the monthly precipitation data of past 45 years using SPI program. The spatial variations were studied first for Marathwada region consisting of eight districts. The time series trend of increasing or decreasing drought condition was analyzed using Mann-Kendall's test for Marathwada region. Further, the district with major drought events is selected for detailed study as observed from the trend analysis. The groundwater conditions are assessed for 20 years (1996-2016; pre-monsoon and post monsoon levels) and the status of groundwater is spatially presented for three years for the data obtained from 39 observation wells.



Figure 7: Met station location reference for Figure 9

4.1 Spatial variation of SPI-12 for Marathwada:

First, the SPI has been calculated for each of the eight-meteorological stations of Marathwada to study the trend in drought based on precipitation levels. SPI-12 for December is calculated for Marathwada from 1972 to 2016 as depicted spatially in Figure 9. The met stations location recording the precipitation level are marked in Figure 7. The SPI-12 at these time scales reflects long-term precipitation patterns. Critical conditions for Marathwada were observed during the year 2012, 2014 and 2015. Further, Normalized Deficit Cumulated (NDC; Figure 8)⁶ map is generated to assess multiple year dry periods. An NDC of greater than one represents an area where average rainfall is less than the average water use. The NDC maps shows very high values for Latur district, meaning, the demand for water resources is more compared to average supply.



Figure 8: Normalised Deficit Cumulated Map, Marathwada









Figure 9: Spatial Variation of SPI-12, Marathwada for year 2001 to 2016 (Legends as per Table 1)

4.2 Trend analysis of drought occurrence for Marathwada region

The precipitation data is analysed using MK test of trend to understand the drought pattern in Marathwada region for eight Meteorological stations (eight districts). SPI-12 is used for analysis of increasing or decreasing trend of precipitation. Table 3 shows the p-value, Sen's slope, and z-score with a 95% confidence

interval calculated to comprehend the significant trend pattern. As ACF observed, it follows a significantly increasing trend for Latur district, which denotes that the area is PACF drying since the precipitation levels are decreasing over the years. In Figure 10, examining the ACF and partial autocorrelation (PACF) plots for the time series of monthly precipitation levels suggests that the ACF and PACF present in this series appear significant (indeed, most of the vertical spikes in the ACF and Partial ACF plots fall outside the blue dotted horizontal lines). The blue dotted lines represent the confidence interval in Figure 10. Decomposition of time series from 1971 to 2017, i.e., observed and trend values are represented in Figure 11.



Figure 10: ACF and PACF for Latur district

District	Z-score	p- Value	Tau (T)	Sen's Slope
		•		
Aurangabad	-1.58	0.113	-0.0452	-0.000239
Beed	-1.58	0.113	-0.045	-0.000239
Hingoli	-0.43	0.661	-0.012	-0.0012
Jalna	-3.68	0.00022	-0.1052	-0.0010
Latur	1.76	0.0773	0.009	0.0005656
Nanded	-4.62	0.0000037	-0.1319	-0.00129
Osmanabad	-2.74	0.0060	-0.0783	-0.0008
Parbhani	-2.50	0.0122	-0.0714	-0.000719



Figure 11: Decomposition of additive time series from 1971 to 2017 (from top: observed, trend, seasonal, random) for Latur district.

The time series plot reveals the presence of a downward trend in the monthly precipitation levels of Latur region from the period 1971 to 2017. Figure 12 denotes a fitted model for non-parametric data, where blue line indicates that after 2001 there is a decrease in the trend which means the precipitation levels are decreasing leading to drought condition. Latur is facing severe drought condition as observed through trend analysis. Spatial maps are generated to analyze and prepare the detailed drought risk scenario. The values calculated using the SPI program are further interpolated using IDW (GIS tool for interpolation) method.



Figure 12: Trend and Fitted Model from 1971 to 2017, Latur District

SPI 6, SPI-9, SPI-winter, SPI monsoon is calculated to understand the severity of meteorological,

hydrological and agricultural drought on the region. SPI 6 at the end of March has been calculated to understand the anomalous stream flows and reservoir levels (Figure 14). The abrupt changes of precipitation for SPI-6 at the end of November (Figure 14) illustrates that the region faced extreme water scarcity in 1972 and the region was hit by drought in the year 2001, 2002, 2014 and 2015 where it has undergone tremendous degradation in reservoir levels. Similarly, SPI-9 has been calculated at the end of May



Figure 13: Met station locations of Latur district for reference to Figure 14



SPI-Winter (3 month) at the end of January



SPI-Monsoon (4 month) at the end of September



Figure 14: Spatial variation of SPI_6, SPI-9, SPI-Winter, SPI-monsoon, and Latur District

(figure 14) which gives the hydrological drought condition of an area. The spatial variation for SPI-9 at the end of May shows moderately dry condition for the region during 2001 and 2015. Latur was hit by extreme drought at the end of 2015. As observed in Figure 15, the SPI-24 value at the end of 2015 is -2.33 which shows extreme drought condition. The spatial map for SPI-Winter (3 months) at the end of January shows dry condition in some parts of the Latur and normal condition otherwise. SPI- Monsoon (4 months) at the end of September shows dry conditions in some regions during 1981 and spatial variation of pre and post-monsoon Groundwater Level for Latur district.



Figure 15: Graph showing SPI-3, SPI-6, SPI-12, SPI-24 values at the end of November, Latur district

4.3 Spatial Variation of pre and post-monsoon groundwater level for Latur district

There are 39 groundwater monitoring wells (28- Dug wells; 11- Piezometers) in Latur district. As per ministry of water resource Central Ground Water Board (CGWB), Latur district is categorized under semi-critical groundwater conditions. Also, the stage of groundwater development for the region has already reached about 78% which coincide with the deeper water level (Balpande, 2013). The values recorded by Groundwater Survey and Development Agency (GSDA) for the pre-monsoon and post-monsoon water levels were spatially interpolated using the IDW method to understand the groundwater conditions. The maps were generated for the year 2015, 2014, and 2011. The water levels depth is between 5-10m for most part of Latur district during the post-monsoon period of May 2015 (figure 17). Deeper water levels between 10-20m were observed for pre-monsoon in 2015. Through observation wells, pre-monsoon and post-monsoon groundwater levels are recorded. Hence, SWI values were calculated to analyze the groundwater conditions of Latur district for pre-monsoon and post-monsoon. Figure 18 represents spatially interpolated SWI values to analyze the effects of drought on groundwater levels. It is observed that even post-monsoon, the region suffers through severe or moderate drought conditions.



Figure 16: Location of observation wells for reference to Figure 17,18

During 2014 and 2015 the region was severely hit by drought as observed from figure 18 where the postmonsoon SWI for both the years show severe drought condition.



Figure 17: Spatial representation of Pre-monsoon and post-monsoon ground water level for the year 2015, 2014, 2011, 2001 showing water level depletion zone

The groundwater levels are getting affected over the years because of drought coupled with over exploitation due to indiscriminate digging of wells. These groundwater levels are not recovered even post monsoon thus affecting the agricultural sector. The region cannot rely on the monsoon water to reduce the demand and supply gap. Adoption of other measures is required to overcome drought for this region.



4.4 Future Drought events for Latur district

Future rainfall series is generated for Latur district by downscaling Precipitation data using HadCM3_A2⁷ scenario for the period of 100 years from 2001 to 2099. This scenario contains 139 years of daily Global climate Model (GCM) predictor data, derived from the HadCM3 A2 scenario, normalised over 1961-1990 period (Nakicenovic et al., 2000). The SPI values are calculated for this period for a time scale of 12 months using the SPI program. The data used in this analysis was acquired from an organization named climate-wizard, the nature conservancy⁸. Future drought events and their characteristics are identified using SPI-12 values at the end of December. Figure 19 plots the SPI 12 for the projected 100 years. The graph depicts the trend of semi-critical to critical drought condition for the region in approaching years predicting the region to be dry.





4.5 Policy and planning strategies for mitigation

Various organizations like WMO, GWP and UNISDR has recommended integrated drought management strategies to overcome drought situation. These principles can be altered to formulate a regionspecific water management strategy. Through analysis, it is observed that the drought needs to be monitored based on the early warning to prevent crisis management. Based on the analysis, it is noted that the region undergoes severe meteorological as well as hydrological drought condition also affecting agricultural sector. The initial

⁷Visit IPCC-DDC GCM Data Archive (<u>http://apps.ipcc-data.org/maps/</u>)

⁸Support of this dataset is provided by the Office of Science, U.S. Department of Energy

government policies implemented during drought condition were not adequate to monitor the situation. Therefore, there is a need to have local policy-based solutions to manage these drought condition strategically.

UNISDR (2009) has mentioned the guiding principle for developing national and local strategies, impact assessment and early warning activities, drought awareness and knowledge management activities to reduce the impact of drought. Another framework was given by UNISDR (2015) to review the implementations of guiding principles. The policy and governance should be based on community participation, local governance, availability of resources, the local requirement of the region (UNISDR, 2009b). A drought manual provided by Government of India states the role of national to local authorities and various departments. The manual is divided into four parts: understanding drought, monitoring drought, declaring a drought, providing relief, mitigating drought (NIDM, 2009).

Assessing the impacts of drought and identification of the most vulnerable sectors can be done using early warning which may help reduce potential damage (UNISDR, 2009b).

For preparedness of meteorological drought condition, risk assessment for early warning and policy formation using local governance may be adopted as it will help in conservation of surface water. The hydrological drought condition, i.e., groundwater levels can be improved by adapting, artificial recharge techniques, limiting the number of wells dug per area. This may reduce the stress on groundwater condition. To improvise the effects of drought on the agricultural sector, strict action for change in cropping pattern, adoption of drip irrigation and crop rotation techniques can be applied to manage the water demand appropriately for other sectors. A proper drought risk assessment framework is required which incorporates integrated management of natural resources, socioeconomic development, carrying capacity of land based on water availability. This will lead to a systematic assessment of drought and reduce the overall potential damage.

5. Conclusion

Latur has prolonged drought condition due to which domestic, industrial and agricultural sectors are affected, thereby influencing the economic and social costs. The region receives less annual rainfall affecting the primary source of water supply which has been drying over the years. Another factor leading to the imbalance of water is due to the production of sugarcane which uses about 71% of available water resources leading to depletion of groundwater levels and water shortage for other sectors mainly domestic sector. Thus, the gap between the water supply and demand is increasing with the increase in population growth and urbanization. Hence, this study assesses the risk by analyzing the issues to reduce the potential damage and arrive at a framework for the drought-prone area. The present framework is useful for temporal and spatial dispersion analysis of drought using SPI and SWI algorithm which performs well in monitoring meteorological and hydrological drought respectively for Latur district. Based on the drought analysis using SPI and SWI, the study could set a framework assessing the impact due to climate change for Latur region. This helped in forming the mitigating strategies and policy-based solution which can be implemented to reduce the impact of drought affecting various sectors. Since the region depends on groundwater to meet the demand, it is essential to regulate groundwater through strict actions like a change in cropping pattern, change in the type of irrigation system, adoption of artificial groundwater recharge techniques, Phad⁹ irrigation to avoid risk of crop failure may be considered. Since drought is a multifaceted phenomenon therefore coupling these drought indices with agriculture drought index may generate enhanced results for analysts and policymakers.

There is a need for a holistic approach by government to form and implement broad level policy guideline and strategies. These strategies shall be strengthened by boosting awareness amongst people and linking public participation to overcome drought conditions. As vulnerability is dynamic in nature, it would be beneficial to assess the drought risk to evaluate, how vulnerability is changing temporally to maintain an appropriate level of preparedness.

⁹Phad irrigation- It is a low cost small irrigation system developed on the check dam or cement plug in which the flowing river water is diverted to nearby field by gravity through diversion weir, contour canal.

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ACRONYMS

ACF	-Autocorrelation
CGWB	- Central Ground Water Board
EWS	-Early Warning System
GSDA	- Groundwater Surveys and Development Agency
GWP	- Global Warming Potential
IDW	- Inverse Distance Weighting
LPCD	- Litre per Capita per day
LMC	-Latur Municipal Corporation
MK test	-Mann-Kendall's test
MBGL	-Meters below ground level
MLD	-Millions of Litres Per Day
NDMC	-National Drought Mitigation Centre
NDC	-Normalised Deficit Cumulated
PACF	-Partial Autocorrelation
SPI	-Standardized Precipitation Index
SWI	-Standardized Ground Water Level Index
WMO	-World Meteorological Organisation
UNDP	-United Nations Development Programme
UNISDR	-United nations International Strategy for Disaster Reduction