International Journal of Future Generation Communication and Networking
Vol. 13, No. 4, (2020), pp. 2903–2911

Assessment of Future Meteorological Drought in Bhima basin based on CMIP5 Multi-model Projections

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Abstract

Agriculture in India is an important activity to aid economy and more than 70% of Indians livelihood is dependent on this. South Western monsoon contributing major part of rainfall and 75-90% of this rain occurs in only four months (June to September) thus, causing abnormalities in monsoon precipitation to trigger drought frequency in most part of the country. Rapid urbanization has put forth the everlasting demand for water for drinking as well as for industry. The pattern of rainfall, shifts in the season and non-sustainable development owing to urbanization has disturbed the demand and supply mechanism of water resources in the Bhima river basin. After examination using 12-months SPI, 'Mild to Moderate' drought events occur extensively under RCP 2.6 and 6.0 scenarios. 'Severe' drought events under RCP 6.0 scenario dominates other RCPs scenarios. Lastly, the 'Extreme' droughts events occur extensively for RCP 2.6 and 6.0 scenarios. RCP 8.5 scenario has unclear drought characteristics owing its highest emission of GHG as per IPCC thus, making this more ambiguity in possible predictions of drought events.

Keywords: *Climate change, Meteorological drought, Multi-model Projections, Rapid urbanization and Standardized Precipitation Index.*

Introduction

Climate change and global warming have severe impact on the periodic and chronic shortfalls of water, particularly in arid and semi-arid areas of the world and may have an adverse effect on hydrological cycle

(IPCC, 2001) [1]. Thus, impact of climate change can affect the water resources sector severely causing frequent natural disasters to hamper the socio-economic life and has the potential to affect hydrological cycle and its entities resulting floods and droughts besides impact on water quality, soil moisture etc.(IPCC, 2001; Cunderlik and Simonovic, 2005, Kundzewicz et.al, 2010) [1,2,3]. Drought is one of the exorbitant natural disaster having widespread and significant impacts on the world's economy, environment, industries and the community (Keyantash and Dracup, 2002) [4]. It certainly has a negative impact on society resulting increase demand for water (Mishra & Singh, 2010) [5]. Detection of drought at its early stage is vital to adopt the drought mitigation strategies and avoid its recurrence. Thus, forecasting drought is an important strategy for planning and effective management of water resource. However, assessment and forecasting of drought are not easy as always.

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rain occurs in only four months (June to September) thus causing abnormalities in monsoon precipitation to trigger drought frequency in most part of the country(Mahajan et al., 2016) [6]. Amongst the 140Mha. of area falling under net sown area, approximately 70% of the area are vulnerable to drought and 50% of this are more likely be considered as severely drought prone areas(Kamble et al., 2010) [7]. Thus, this frequent drought in Bhima upper region falling under Maharashtra state are by and large depend on rain fed agriculture activity and is a major source of livelihood [8].

Study area

Bhima river basin is one among the twelve sub-basins of Krishna basin, the eastward draining river of India (Biggs et al., 2007) [9]. The watershed designated as Upper Bhima (K5) and Lower Bhima (K6) is situated between 150N to 200N latitudes and 730E to 780E longitude with an approximate catchment area of 70,263 km2 (Figure 1). The pattern of rainfall, shifts in the season and non-sustainable development owing to urbanization has disturbed the demand and supply mechanism of water resources in the Bhima river basin (Garg et al. 2012) [10]. This has also hampered on the availability of surface source and resulted the stakeholders to depend on ground water. Report released by Ministry of Environment and Forests (2010) [11] has also cautioned the river basin to suffer from chronic shortage of water in future. Most of the upper region of Bhima basin (K5), owing to its proximity to Western Ghats receives abundant rainfall but, the stringent policy and inter-state tribunal obstruct the complete usage and claims to share amongst the neighboring states to cater the need due to low rainfall situations. In addition to this, the study region has lingering issues of water quality and over draft of ground water to hamper the basaltic aquifer (Surinaidu et al. 2013 and Udmale et al., 2014) [12,13] and lacks the effective monitoring of watershed management programs since decades (Biswas et al. 1987) [14].

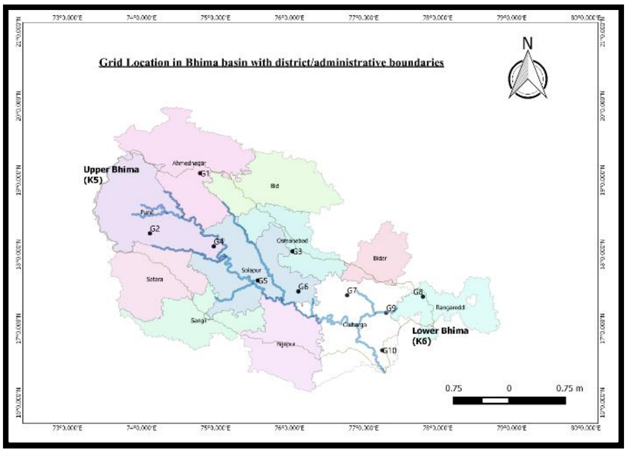

Figure 1: Bhima basin (Sub basin of Krishna) district/administrative boundaries details

Drought Assessment

Information based decision making for water resource management requires to know the information about probability of occurrence drought in addition the intensity, duration, and spatial distribution. Thus, bringing an excellent best practices to benefit the society. Historical drought can be compared and contrast with the current ones to know the trends. Therefore, the drought indices are effective tools to evaluate the drought events and also to assess their impacts. A drought indicator recognizes the drought and classify it according to the condition (Steinemann, 2003) [15]. Most of the indictors are bases on hydrological and meteorological variables and the later one uses rainfall as an input. The response action for a drought to indicate it's begin or end time is depended on its threshold value. Further, this will categories the drought to indicate different stages of drought conditions namely, extreme, severe, moderate and mild drought. Most popular drought indicators: Standardized Precipitation Index (SPI), Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Surface Water Supply Index (SWSI) and Reclamation Drought Index (RDI) [16].

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Standardized Precipitation Index (SPI) is robust and easily adopted by researchers owing to its single input data (rainfall) was developed by McKee et al., (1993) [17].

The assessment is based on the rainfall probability distribution and the procedure to compute SPI as given by McKee et al., (1993) is as:

i. Long term rainfall data is examined using probability density function (PDF).
ii. Calculate the cumulative probability of an observed rainfall data.
iii. Gaussian function having inverse normal with mean 0 and variance 1 is considered for cumulative probability function to find SPI.

Based on the SPI value, the severity of drought can be assessed and categorized into different classes as shown in Table 1. A positive (+) value of SPI indicates no drought condition and in other way is referred as wet conditions (SPI value greater than 0)

Table 1: Drought categories and SPI values (McKee et al., 1993; Steinemann, 2003) [17,15] .

Drought Category	SPI values
Near Normal Conditions	0 to -0.99
Mild to Moderate Drought	-1.00 to -1.49
Severe Drought	-1.50 to -1.99
Extreme Drought	-2.00 or less
Wet conditions	Value greater than 0

The Global Climate Model: Coupled Model Intercomparison Project Phase-5 (CMIP5) through statistical downscaling provides the multi-model ensemble average downscaled rainfall data as an input for drought assessment (Zhang, Q et al., 2019)[18]. IPCC in its fourth annual report has identified four Representative Concentration Pathways (RCPs) based on the emission scenarios in the probable range of radiative forcing values of 2.6, 4.5, 6.0 and 8.5 W/m^2 until 2100 and named as RCP-2.6, RCP-4.5, RCP-6 and RCP-8.5 respectively.

Results and discussion

Rainfall anomalies

Monthly rainfall anomalies of projected climate data for Bhima basin under basin average conditions for the period 2021-2100 as temporal variations are shown in the figure 2 to 5 for the four RCP scenarios. The 12 months SPI presented here uses the algorithm presented in K. F. Gimbel et al.,(2015) [19] with modification using 'precintcon' package to analyses the rainfall anomalies. These temporal variation for 12-month SPI portray significant changes over RCP scenarios. Amongst all the RCPs, RCP 8.5 has a greater fluctuations indicating inconsistent occur ace of droughts with the greater magnitude in the time series 2041-2060.

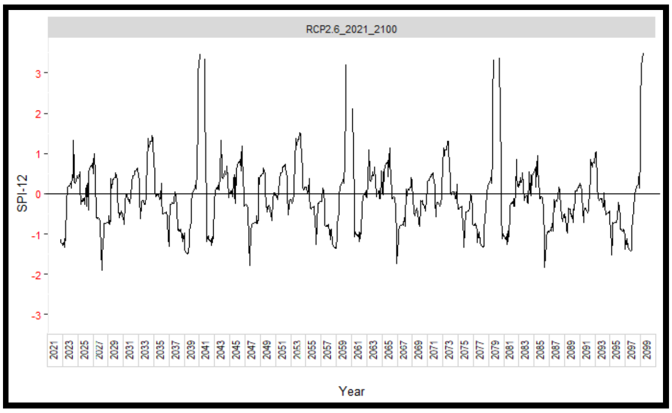

Figure 2: 12-month SPI variation for of rainfall anomalies under RCP 2.6 scenario.

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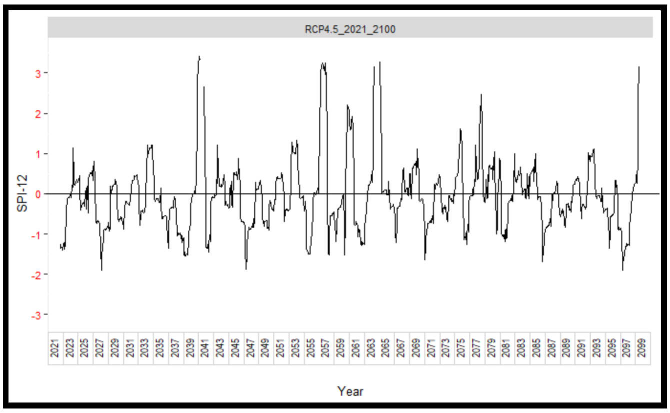

Figure 3: 12-month SPI variation for of rainfall anomalies under RCP 4.5 scenario.

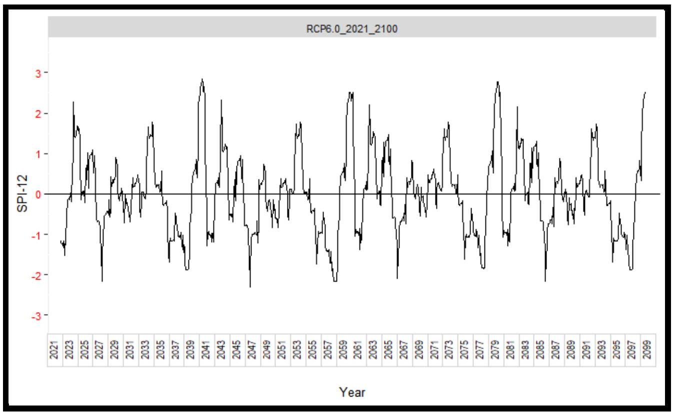

Figure 4: 12-month SPI variation for of rainfall anomalies under RCP 6.0 scenario.

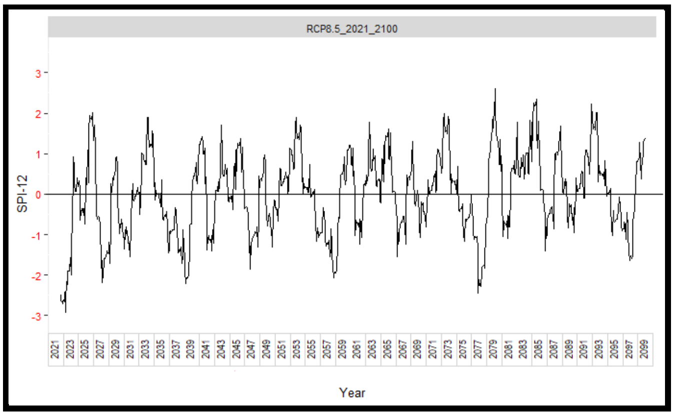

Figure 5: 12-month SPI variation for of rainfall anomalies under RCP 8.5 scenario.

Spatial Plots of 12 months SPI

Spatial distribution of the percentage (%) occurrence of drought under four RCPs are outlined in

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figure 6 to 9. RCP 2.6 scenarios during 2021-2040 portray predominant occurrence of mild to moderate and severe drought events covering 35.5 % and 32.5% of occurrence respectively over Bhima basin. It can be inferred from the figure 6 that, extreme drought with 17.5% occurrence during this time period has more impact on the mid region of basin with G5, G6 and G7 grid point location. The Upper Bhima (K5) has a low impact of drought while, the Lower Bhima (K6) is more likely to witness moderate drought conditions. There is a marginal changes for the time period 2041-2060 comparing with the events of drought. However, during 2061-2080 and 2081-2100 the extreme event of drought has enhanced to an extent of 21.5 % and 28 % of occurrence over the entire basin respectively and resulted the K5 region to fall under severe drought conditions. The detailed summery of occurrence of drought under RCPs scenarios is presented as table no.2.

Table 2: Summery of percentage (%) of occurrence of 12-months SPI drought events under RCPs Scenarios

	SPI Range	**RCP 2.6**	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**
2021-2040	Near Normal Conditions	7.5	30.5	12.5	8.5
	Mild to Moderate Drought	35.5	16.5	26.5	12
	Severe Drought	32.5	21.5	24.5	9.5
	Extreme Drought	17.5	7.5	20.5	14
	Wet Conditions	7	24	16	56
2041-2060	Near Normal Conditions	9.5	26	10.5	10.5
	Mild to Moderate Drought	37.5	16.5	28.5	10
	Severe Drought	21.5	15	29.5	7.5
	Extreme Drought	15.5	3.5	12.5	18
	Wet Conditions	16	39	19	54
2061-2080	Near Normal Conditions	21.5	35	13.5	9.5
	Mild to Moderate Drought	29.5	12.5	33	14.5
	Severe Drought	17.5	8.5	26.5	8
	Extreme Drought	21.5	0	8.5	12
	Wet Conditions	10	44	18.5	56
2081-2100	Near Normal Conditions	17.5	29.5	20.5	11.5
	Mild to Moderate Drought	29.5	12.5	24.5	20
	Severe Drought	17.5	26.5	22.5	10.5
	Extreme Drought	28	2.5	14.5	8.5
	Wet Conditions	7.5	29	18	49.5

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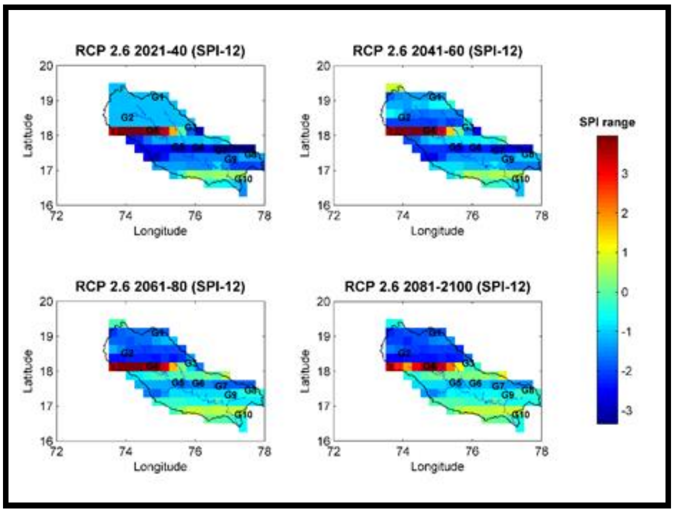

Figure 6: Spatial distribution of the percentage (%) occurrence of drought under RCP 2.6

In most the region under RCP 4.5 scenarios witness near normal conditions with the magnitude of 26 % to 35 % during 2021-2100 (Figure 7). Extreme events of drought decline from the beginning of 2021 and during 2061-2080 the basin has nil extreme events with only 8.5% of region under sever conditions of droughts.

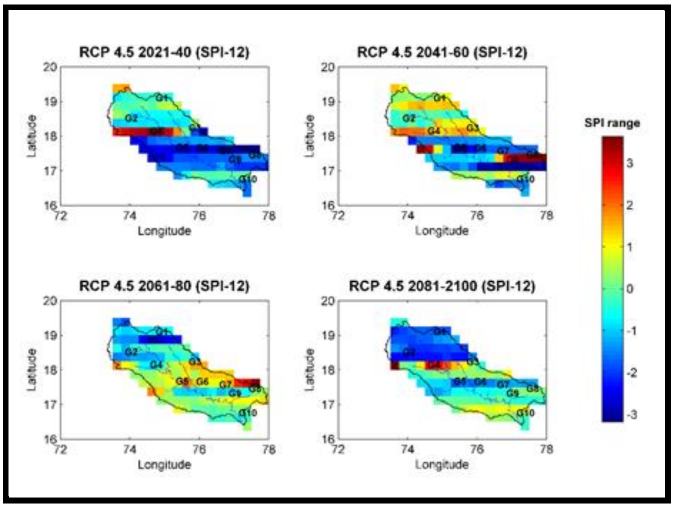

Figure 7: Spatial distribution of the percentage (%) occurrence of drought under RCP 4.5

Moderate and severe droughts prevail in the lower region during 2021-2040 at grid G8, G9 and G10 and upper region at G1 and G2 grids during 2081-2100 for RCP 6.0 scenarios. Most part of upper Bhima is affected with this severity until 2080 (Figure 8). Extreme droughts with 20.5% of occurrence during 2021-2040 and tend to fluctuates with 12.5%, 8.5% and 14.5% occurrence later part. Figure 9 shows the RCP 8.5 scenario emission of Green House Gas (GHG) considered during may likely to resemble wet periods over dry periods (drought conditions). Uncertainties are more likely to shift from one time period to another making this more ambiguity in possible predictions of drought events.

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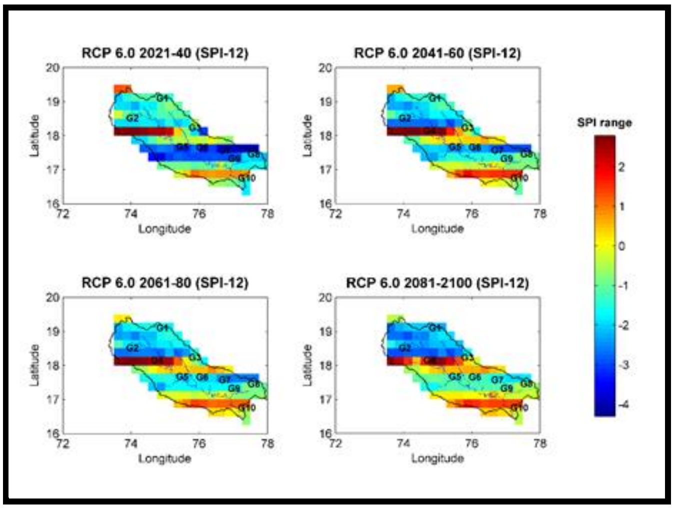

Figure 8: Spatial distribution of the percentage (%) occurrence of drought under RCP 6.0

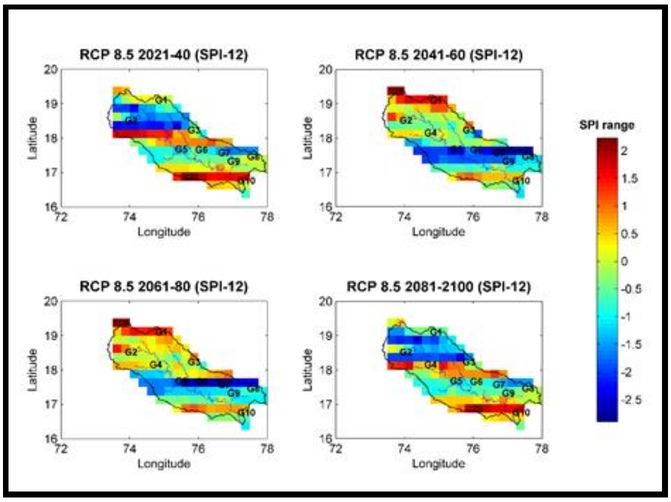

Figure 9: Spatial distribution of the percentage (%) occurrence of drought under RCP 8.5

Conclusion

The future changes of drought characteristics through percentage of occurrence over Bhima basin were examined through ensemble GCM projections for the period of 2021-2100. The frequency of different categories namely, moderate, severe or extreme drought based on 12-months SPI was analyzed through temporal variation and spatial plots. Even though all the four RCP scenarios had differences in occurrence of drought conditions but certainly were not obvious from the results as the study did not include the trend analysis. Rather, this study focused on the occurrence of drought characteristics over Bhima basin region with a downscaled precipitation values through the multi-model ensemble average. However, with the visual interpretation no obvious difference was observed between scenarios. It is also inferred from the study that, for 12-months SPI, 'Mild to Moderate' drought events occur extensively under RCP 2.6 and 6.0 scenarios. 'Severe' drought events under RCP 6.0 scenario dominates other RCPs scenarios. Lastly, the 'Extreme' droughts events occur extensively for RCP 2.6 and 6.0 scenarios. RCP 8.5 scenario has unclear drought characteristics owing its highest emission of GHG as per IPCC thus, making this more ambiguity in possible predictions of drought events.

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