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Detection of Climate Change Signals in the Historical Climate Datasets for Chambal basin in Madhya Pradesh

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Abstract. Water resources management in the arid and semi-arid areas is a quite a challenging task owing to the large number of hydrologic, environmental and management factors. The climate change has opened up a new spectrum of challenges viz., higher occurrences of extreme events like droughts, floods and heat waves alongwith increased variability of rainfall and uncertain water availability scenario in the future. Investigations have been carried out to detect the climate change signals in the historical climate datasets for the Chambal basin in Madhya Pradesh. The average annual rainfall has decreased from 1038.5 mm during 1931-60 to 951.40 mm during 1961-90 and 925.10 mm during 2001-2015. The average annual rainfall varies spatially, with decreasing rainfall from east to west (districts bordering Rajasthan) viz., 800-900 mm in the districts of Neemuch, Mandsaur, Ratlam and parts of Ujjain and Dhar districts, 900 – 1000 mm in the districts of Agar, Indore, major parts of Ujjain and parts of Dhar, Dewas, Shajapur and Rajgarh districts, 1000 – 1100 mm) at Guna, parts of Rajgarh, Shajapur, Dewas, Vidisha and Sehore districts and > 1100 mm in the eastern parts falling partly in the districts of Bhopal, Rajgarh, Shajapur and Sehore. The comparison of the number of rainy days between the baseline period (1961-90) and present period (1991-2015) indicates considerable decrease in the number of rainy days in 47 out of the 53 blocks in the study area. The extreme rainfall (P>200 mm/day) and very heavy rainfall (P>100 mm/day) has also increased in most parts of the study area whereas a mixed trend has been observed for heavy rainfall (P>50 mm/day). The 1-day maximum temperature (1-day MaxT) has shown a significant rising trend at 5% significance level. The very hot days (MaxT>40^{o}C) and hot days (MaxT>35^{o}C) have also increased significantly. The trends detected in these indices suggest towards an increased scenario of water stress in the basin at present as compared to the baseline period and investigations are necessary to understand the impact of climate change on the future drought, desertification and water stress under the challenge of climate change related impacts.

Keywords: rainfall, temperature, semi-arid, drought, heat waves

1. Introduction

The Earth's climate is changing and is a matter of growing concern world-wide, particularly about its impacts on various vital segments including major components of the hydrological cycle and consequently its effects on water resources. The global surface air temperature is projected to keep increasing under all future climate change scenarios. This is expected to decrease the quantum of snow and ice and alter the water availability in streams, dams and aquifers. Understanding the possible changes in the seasonal distribution of runoff is vital for the future management of the water resources. The temperature and precipitation are the two important variables responsible for the generation of runoff in the catchment apart from its physical characteristics and both these climatic variables are expected to undergo substantial changes in future leading to an altered supply-demand scenario in the future. However, the nature and quantum of these changes are expected to vary from region to region.

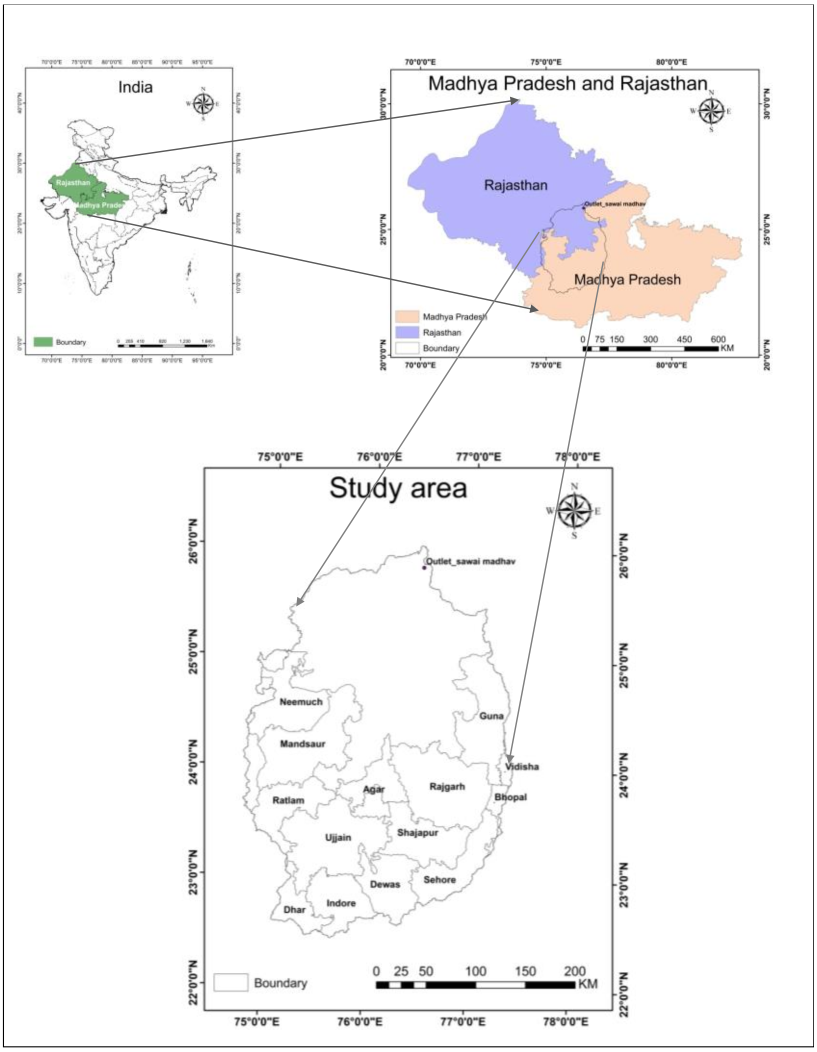
The impact of the global warming, other than changes in the mean precipitation may also lead to changes in the frequency and intensity of extreme precipitation events (Giorgi et al. 2011; Sedlacek & Knutti, 2014; Thackeray et al. 2018). The warming of lands and oceans leads to higher global surface evaporation with increasing Green House Gases (GHG) forcing and this leads to an increase in the global precipitation in the range of 1% to 2% per degree of surface global warming (Trenberth et al. 2007) as indicated by most of the Global Climate Models (GCMs). However diverse patterns are observed regionally, with both areas of increased and decreased precipitation. The changes in the interannual variability and the increase in number and length of dry spells during the crop growing seasons will warrant the necessary provision for life saving supplemental irrigation for crops. Similarly, a number of studies have examined the trends of temperature in different parts of the world, indicating statistically significant warming across the globe (Aesawy & Hasanean, 1998; Çiçek & Doğan, 2006). The rise in global temperatures is attributed partly due to daily minimum temperature increasing at a faster rate than the daily maximum for many parts of the world.

An analysis of the rainfall pattern, its distribution, and trend on a seasonal and an intra-seasonal scale resulting from the implication of a changing climate is important to evaluate uncertainties associated with the availability and management of water resources (Thomas et al., 2015). A number of studies (Ghosh et al. 2009, Ghosh et al. 2012) have analyzed the Indian Summer Monsoon Rainfall (ISMR) variability with most of them reporting ISMR variability in space and time. An increase in the intensity and frequency of extreme rainfall events has been reported over central India, which makes these areas susceptible to flash floods and drought at the same time (Goswami et al. 2006, Rajeevan et al. 2008, Krishnamurthy, 2011). The magnitude and trend of warming of India during the last century over Indian continent is matching with the global condition (Pant & Rupa Kumar, 1997). Kothawale & Kumar, (2005) reported that the annual mean temperature has increased at rate of 0.05°C/10 yr while the minimum temperature showed no trend with an accelerated warming in mean temperature at the rate of 0.22°C/10-yr during recent decades. Kothawale et al. (2010) analyzed seasonal and annual trends in surface air temperature over India and seven homogeneous regions and reported a significant increasing trend in annual values of mean temperatures at the rate of 0.51°C/100 yr, maximum temperatures at the rate of 0.72°C/100 yr, and minimum temperature at the rate of 0.27°C/100 yr. The objectives of this paper include the investigation of the climate change signals in the historical data sets of maximum temperature, minimum temperature and precipitation with special focus on extreme events and their spatial distribution in the Chambal basin.

2.0 Study Area and Data Availability

The Chambal river is the most important tributary of the Yamuna which originates in the southern slopes of the Vindhyan ranges and drain the Malwa region of north-western Madhya Pradesh, while its tributary, the Banas, which rises in the Aravalli range, drains southeastern Rajasthan (Figure 1). The Chambal catchment is a rainfed with a total drained area of 143219 sq. km. up to its confluence with the Yamuna river. The basin lies within the semi-arid zone of north-western India in Madhya Pradesh, Rajasthan and Uttar Pradesh. The study area for this analysis is limited to the southern part of Chambal basin lying in western Madhya

Figure1: Index map of the study area



Pradesh having an area of 48193 sq. km. and covers 14 districts fully or partially. The districts bordering Rajasthan include Neemuch, Mandsaur, Ratlam, Agar, Rajgarh and Guna, whereas the other districts include Ujjain, Dhar, Indore, Dewas, Sehore, Shajapur and one block each of Bhopal and Vidisha districts. The high resolution gridded daily rainfall data at 0.25^o x 0.25^o during 1901 to 2015 (115 years) as well as the gridded maximum and minimum temperature at 1.0^o x 1.0^o during 1951 to 2013 (63 years) provided by the India Meteorological Department (IMD), Govt. of India has been used in the analysis. The daily rainfall and daily maximum and minimum temperature pertaining to 53 grids corresponding to 53 blocks falling inside the basin have been analysed to detect the possible signals of climate change in Chambal basin.

3.0 Methodology

3.1 Correlation analysis

To assess the similarity of the high resolution gridded rainfall data with the station/block rainfall data, the correlation analysis was carried out using the monthly time series. The correlation coefficient has been used to find the strength of the relationship between the station and gridded rainfall data. The correlation coefficient is calculated using Eqn. 1 as given below:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \quad (1)$$

where, n is number of pairs of rainfall data being compared, *x* is the station rainfall data and y is the gridded rainfall data.

3.2 Mean annual rainfall

The daily rainfall data at each of the 53 grids/blocks have been aggregated to compute the annual rainfall for the period spanning 1901 to 2015. Thereafter the average of the rainfall in all the 53 grids during each year has been computed to obtain the average annual rainfall time series for the study area. Similarly, the average of all the 115 years (1901-2015) has been computed for each grid and used for preparing the spatial plots in GIS environment.

3.3 Climate change indices

The expert team on climate change detection indices (ETCCDI) formed by World Meteorological Organization (WMO) finalized 27 core indices for climate change detection based on a set base period. The indices are based on daily precipitation and temperature. As per the suitability of the parameters to the study area, few important indices were selected and studied to detect the changes in the observed daily, monthly, seasonal and annual patterns of the selected indices and is given in Table 1.

Table 1: Indices used for detection of climate change signals in Chambal basin

S. No.	Index	Description
1.	Very hot days	Annual count of days when daily maximum temperature is greater than 40^{o}C
2.	Hot days	Annual count of days when daily maximum temperature is greater than 35^{o}C
3.	Cold days	Annual count of days when daily maximum temperature is less than 15^{o}C
4.	Highest maximum temperature	Highest value of 1-day maximum temperature observed in a year
5.	Very hot nights	Annual count of days when daily minimum temperature is greater than 25^{o}C
6.	Hot nights	Annual count of days when daily minimum temperature is greater than 20^{o}C
7.	Cold nights	Annual count of days when daily minimum temperature is less than 10^{o}C
8.	Highest minimum temperature	Highest 1-day minimum temperature observed in a complete year
9.	Rainy days	Annual count of days when daily rainfall is greater than 2.5mm
10.	Heavy rainfall	Annual count of days when daily rainfall is greater than 50 mm
11.	Very heavy rainfall	Annual count of days when daily rainfall is greater than 100 mm
12.	Extreme rainfall	Annual count of days when daily rainfall is greater than 200 mm

The above indicators have been evaluated and difference in the present time horizon (1991-2015 has been compared with the baseline period (1961-1990).

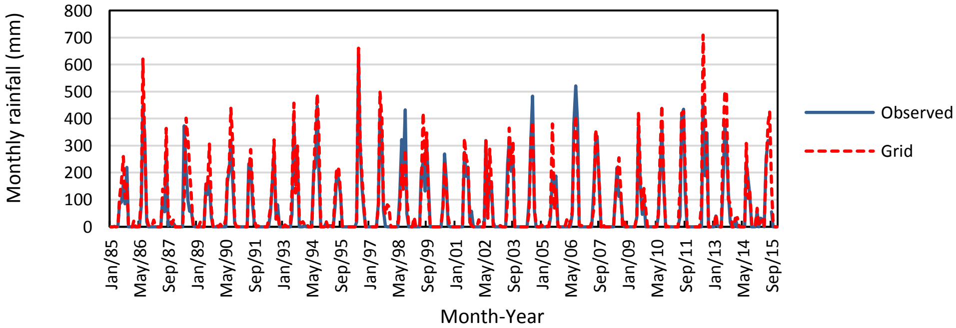
4. Results and Discussions

4.1 Historical rainfall

4.1.1 Correlation analysis

The correlation coefficient between the station monthly rainfall and the gridded monthly rainfall was evaluated and the plots between them were examined critically to find out the similarities and differences. The correlation coefficient varies between 0.85 at Lateri block of Vidisha district to 0.99 at Mahidpur block of Ujjain district except for 0.71 at Berasia block of Bhopal district. As most of the blocks have a correlation coefficient greater than 0.85 with very few exceptions, the gridded rainfall data is considered to be reliable and representative of the station rainfall data and has therefore been used for all further analysis. The plot showing the comparison of the station and gridded rainfall at Bagli block in Dewas district is given in Figure 2.

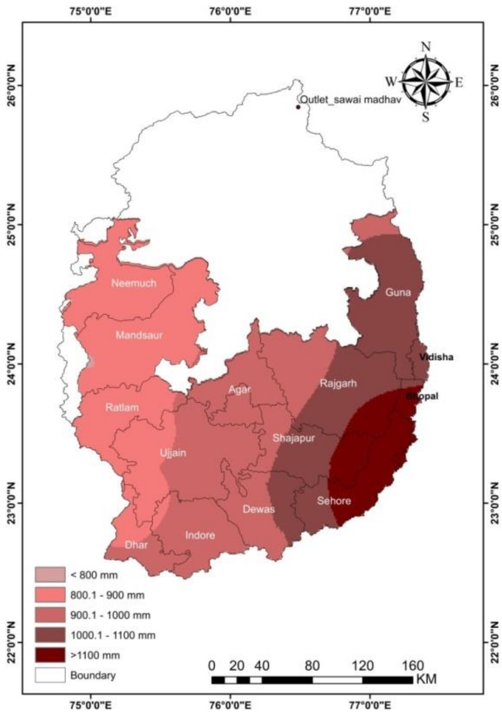
Figure 2: Comparison of station and gridded rainfall for Bagli block in Dewas district



4.1.2 Mean annual rainfall

The average annual rainfall varies between 789.2 mm at Mandsaur and 1193.80 mm at Sehore. The spatial variation of average annual rainfall in the study area is given in Figure 3.

Figure 3: Spatial variation of the average annual rainfall in Chambal basin



The average seasonal rainfall during the monsoon season is 874.8 mm. It has been observed that the average annual rainfall increases from west to east with 800- 900 mm in the districts of Neemuch, Mandsaur, Ratlam and parts of Ujjain and Dhar districts, which thereafter increases to 900–1000 mm in the districts of Agar, Indore, major parts of Ujjain and parts of Dhar, Dewas, Shajapur and Rajgarh districts. Further increases in the average annual rainfall are observed (1000–1100 mm) at Guna, parts of Rajgarh, Shajapur, Dewas, Vidisha and Sehore districts. The maximum average annual rainfall > 1100 mm is observed in the eastern parts falling partly in the districts of Bhopal, Rajgarh, Shajapur and Sehore. The analysis was thereafter extended to shorter time slices of 30 years and the variation of the mean annual rainfall during these time horizons are given in Table 2. It can be observed that the mean annual rainfall in the present time horizon (1991-2015) has reduced considerably to 925.10 mm as compared the baseline period (1961-1990) i.e. 951.4 mm. 35 blocks out of 53 blocks depicted a decreasing rainfall pattern during the current period as compared to the baseline period. The variability of the seasonal rainfall is very high (23.4%) which may be responsible for the regular droughts and water scarcity in the study area.

Table 5.2: Variation in the mean annual rainfall during various 30-yr time horizons

S. No.	Time horizon	Mean annual rainfall (mm)
1.	1931-60	1038.5
2.	1961-90	951.4
3.	1991-15	925.1

4.1.3 Number of rainy days

A day with a rainfall of 2.5 mm or more has been considered as a rainy day. There are 50 rainy days on an average and it varies between 30 and 83 days. The number of rainy days has decreased in almost all the districts falling in the study area. 47 blocks depict decreasing number of rainy days. The plot showing the spatial variation in the changes in the number of rainy days is given in Figure 4.

4.1.4 Extreme / Very Heavy Rainfall / Heavy rainfall

To understand the historical pattern of the extreme rainfall events, the rainfall is categorized into three categories viz., heavy rainfall (>50 mm/day), very heavy rainfall (>100 mm/day) and extreme rainfall (> 200 mm/day). A mixed trend has been observed in the quantum of heavy rainfall (>50 mm/day) with increase in heavy rainfall observed in the districts of Neemuch, Mandsaur, Ratlam and Ujjain, whereas the remaining ten districts experienced a decrease in the heavy rainfall. However, some parts of Indore and Dewas districts have seen a decrease of more than 25% in the heavy rainfall contribution to the seasonal rainfall. The number of rainy days with heavy rainfall showed an increase in 25 blocks and decrease in 28 blocks during the current period as compared to baseline period. Similarly, the number of heavy rainfall days showed an increase in 25 blocks and a decrease in 28 blocks the current period as compared to the baseline period. The increase in heavy rainfall events has been observed at of Neemuch, Mandsaur, Ujjain, Dhar, Agar, Indore and Rajgarh whereas a reduction has been observed at Guna, Vidisha, Bhopal, Sehore, Agar, Shajapur and Dewas districts.

The very heavy rainfall (>100 mm/day) has increased in Neemuch, Mandsaur, Ujjain, Indore and Dhar whereas it has decreased in the other districts. Out of the 53 grids, 32 grids show an increase in the very heavy rainfall events varying between 1 to 16 days during the current period. This indicates that the occurrences of the very heavy rainfall events have increased in substantial parts of the study area as compared to the baseline period. The extreme rainfall (>200 mm/day) has increased almost for the entire study area. More than 25% increase has been observed in the districts of Agar, Ujjain, Dhar, parts of Mandsaur, Ratlam, Shajapur, Indore, Damoh and Sehore during the current period. The number of extreme rainfall events has increased in 35 blocks and the increase varies between 1 to 5 days as compared to the baseline period. The temporal variation in the extreme rainfall events is given in Figure 5.

Figure 4: Changes in the number of rainy days during present time horizon and the baseline period

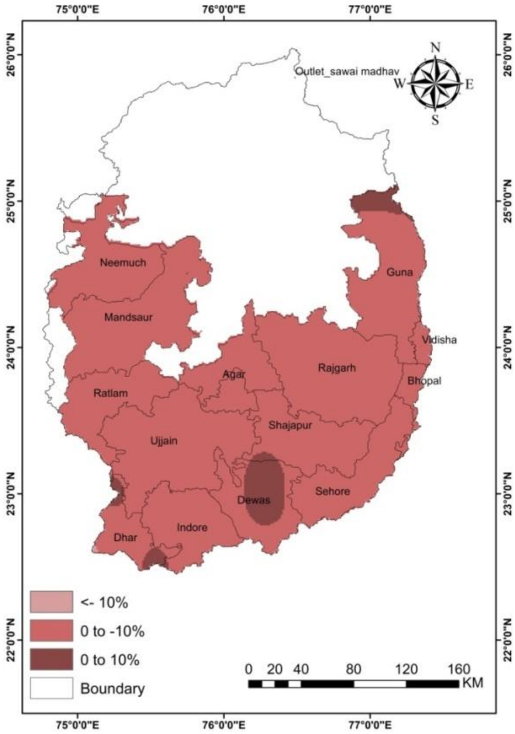
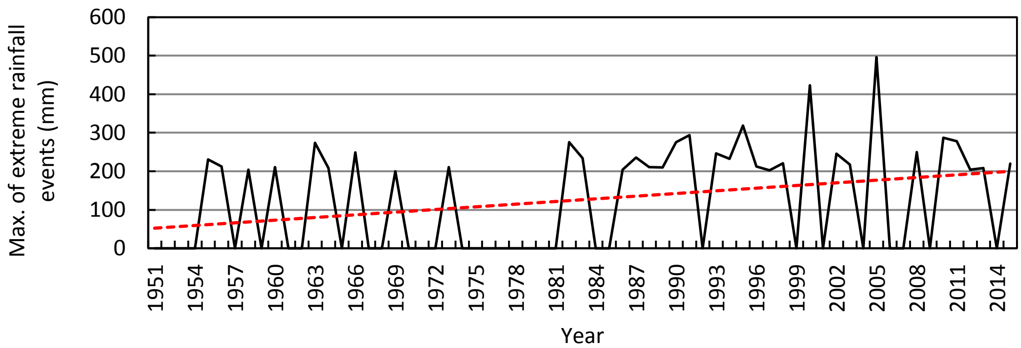


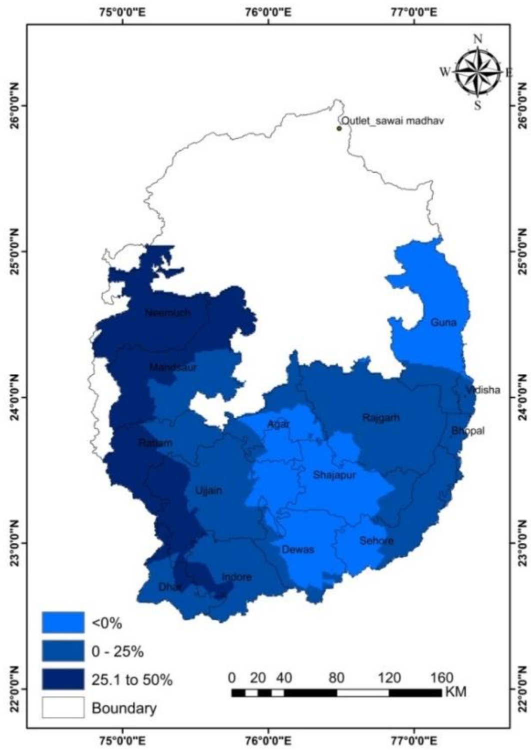
Figure 5: Extreme rainfall changes during current period as compared to baseline period



4.1.5 1-day maximum rainfall

The 1-day maximum rainfall varies between 104.0 mm and 520.0 mm in the study area. The 1-day maximum rainfall has also increased in 29 out of the 53 grids, but there is no significant trend at 5% significance level based on the trend analysis performed using Mann-Kendall test. The 1-day maximum rainfall has increased in the districts of Neemuch, Mandsaur, Ratlam, Ujjain, Dhar, Indore, Rajgarh, and parts of Sehore, Bhopal and Vidisha. The comparison of the changes in the 1-day maximum rainfall during current period and baseline period is given in Figure. 6.

Figure 6: Changes in 1-day maximum rainfall during the current period as compared to baseline period



4.2 Historical rainfall

4.2.1 Maximum temperature (MaxT)

The analysis of the maximum temperature comprises of four indices viz., 1-day maximum temperature, very hot days (MaxT>40 ^{o}C) and hot days (MaxT>35 ^{o}C). The temporal variation of the 1-day maximum of the MaxT during the period 1951-2013 (63 years) is given in Figure 7. A clear increasing trend in the 1-day maximum temperature is observed and the entire study area has witnessed an increase in MaxT. The average maximum temperature during the baseline period is 43.4^{o}C which increased to 44.06^{o}C during 1991-2013, which is an increase of 1.05^{o}C/100 years, and is quite significant and in line with the IPCC global warming predictions. The maximum temperature is increasing steadily during the very hot days (MaxT>40^{o}C) and all the 12 grids have depicted an increasing trend in the maximum temperature during the very hot days. The number of very hot days has also increased in line with the very hot day temperature increases. On an average there are 37 very hot days. It has been observed that the number of very hot days are higher in all the districts bordering Rajasthan viz., Neemuch, Mandaur, Ratlam, Agar, Rajgah and Guna. However, the middle portions of the study area comprising of Ujjain, Shajapur, Rajgarh, Bhopal, Vidisha and Guna also experience considerable number of very hot days (Figure 8). Similar trends have been observed for the hot days (MaxT>35^{o}C) also.

4.2.2 Minimum Temperature (MinT)

The analysis of the minimum temperature comprises four indices viz., 1-day maximum of minimum temperature, very hot nights (MinT>25^{o}C) and hot nights (MinT>20^{o}C) and cold nights (MinT<10^{o}C). Major portions of the study area, particularly all districts bordering Rajasthan have witnessed increase in the minimum temperature. Moreover 11 grids have

Figure 7: Temporal variation of the 1-day maximum of MaxT

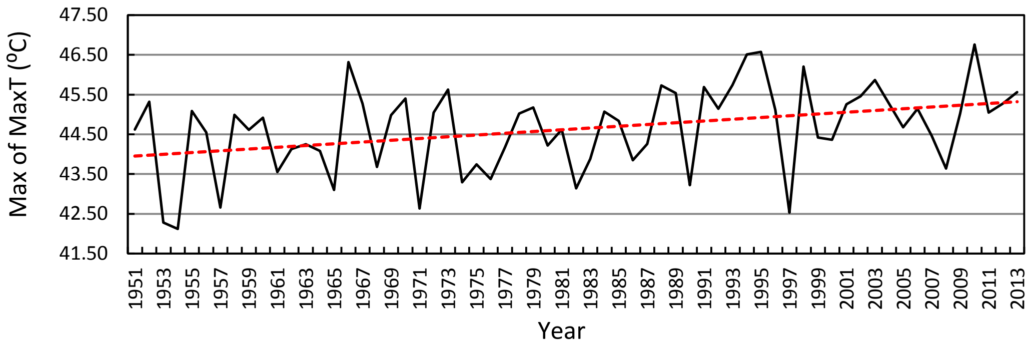
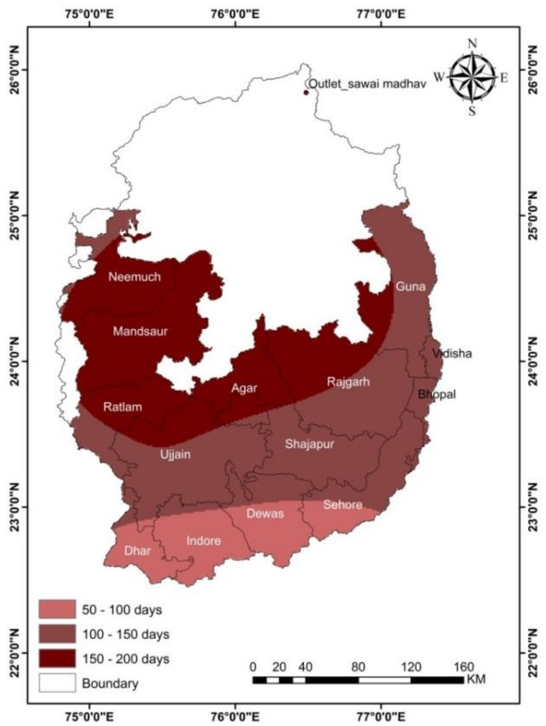


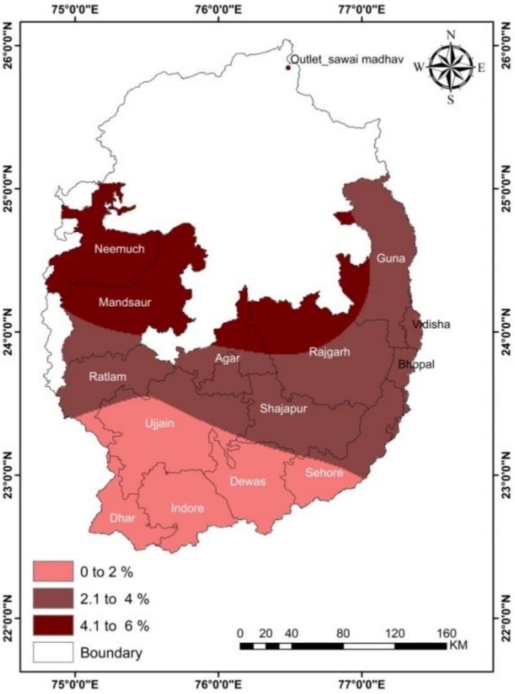
Figure 8: Changes in the number of very hot days during current period as compared to baseline period



depicted an increase in the 1-day maximum of the minimum temperature (Figure 9). The bordering districts of Neemuch, Mandsaur, parts of Agar, Rajgarh and Guna have recorded the highest increase in the minimum temperature in the range of 4 to 6% as compared to the baseline period whereas districts located in the central portion of the study area viz., Ratlam, Shajapur, major portions of Rajgarh and Guna have seen an increase in the minimum temperature in the range of 2 to 4% as compared to the baseline period. The comparison of the changes in 1-day maximum of MinT during the present time horizon and baseline period is given in Figure 10. The average MinT has increased from 28.67^{o}C during the baseline period to 28.91^{o}C during 1991-2013. The average increase in the minimum temperature during the period of analysis is 0.38^{o}C/100 yr.

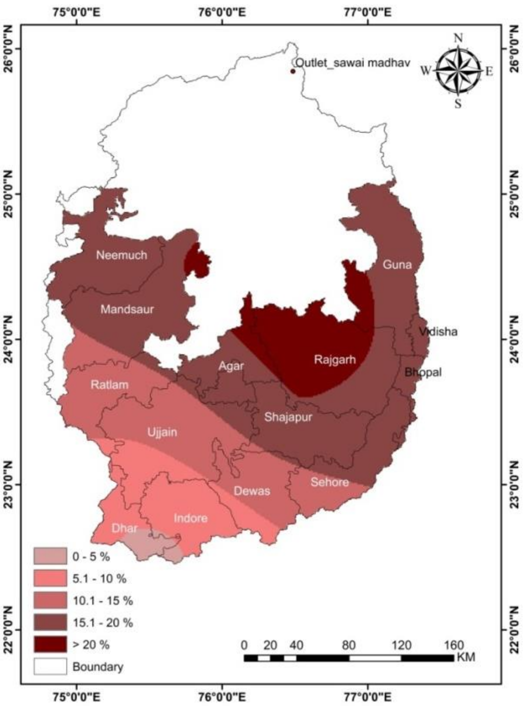
The average minimum temprature during the very hot nights (MinT>25^{o}C) has increased in all the 12 grids during the current period as compared to the baseline period. On an average there are 48 very hot nights in the study area. The number of very hot nights has increased in all the 12 grids. Similar trends have been observed for hot nights as well.

Figure 9: Changes in 1-day maximum of MinT during current period as compared to baseline period



All the bordering districts near Rajasthan have seen an increase in the number of very hot nights (Figure 10). The highest increase is in Rajgarh district (>20%) followed by Neemuch, Mandsaur, Agar, Shajapur, Bhopal, Vidisha and Guna (15-20%). Ratlam, Ujjain, Dewas and Sehore districts have also recorded increase in the number of very hot nights in the range of 10-15%. Similar trends have been observed for the hot nights (MinT>20^{o}C). On an average there are 41 hot nights in the basin. The number of cold nights (MinT<10^{o}C) have decreased

Figure 10: Changes in number of very hot nights during current period compared to baseline period



and is prominent in all the bordering districts of Rajasthan, particularly Neemuch, Mandsaur, Ratlam, Agar, Ujjain, Dhar, Rajgarh, Guna, Bhopal and Vidisha.

5. Conclusion

The present study has been an attempt to identify the climate change signals in the historical data sets of temperature and precipitation so that further analysis can be carried out on how the impacts the change in these variables would have on the evapotranspiration and runoff. The study has been carried out for the Chambal basin in central India which faces regular droughts, water scarcity and land degradation. Some of the conclusions that can be drawn based on the results obtained from the comprehensive analysis can be used as inputs for further modeling exercises. The annual average rainfall has decreased substantially during the current period as compared to the baseline scenario as well as the earlier 30-yr time slices. The variability of the rainfall is which is very high coupled with the reduction in the annual average rainfall will have implications on the water supply scenario. The increase in the extreme, very heavy and heavy rainfall events and the considerable increases in the occurrences of these extreme events coupled with the decrease in the number of rainy days indicate the evident climate change signals in the study area which is responsible for the droughts and land degradation in the study area. The climate change signals are clearly evident from the increase in the maximum and minimum temperature and their occurrences, which has implications for the demand scenario as well. The increase in the very hot nights and hot nights coupled with the decrease in the cold nights suggest that the study area has been subjected a pronounced warming during the recent years. These extreme events are more predominant in the districts bordering the state of Rajasthan. Therefore it can be concluded that climate change signals are clearly evident and appropriate water supply side and demand side management strategies are needed after studying the impacts of these changes on the evapotranspiration and water availability in the basin.

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