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RESEARCH

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Assessment of long-term climate variability and its impact on the decadal growth of horticultural crops in central India

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Abstract

Background: The impact of climate change on horticultural production is of utmost concern worldwide. One such vulnerable region of horticultural importance is the Madhya Pradesh state in the central part of India. It is crucial to analyse the long-term trend in climatic variations and its effect on horticultural crop production. Therefore, this study focuses on detecting trends in mean annual precipitation and temperature of 115 years for the 15 districts covering all the regions of the state as well as projections of all the Representative Concentration Pathway (RCP) climatic scenarios for 2050 and 2080 of Madhya Pradesh state. The decadal (2010–2020) insight into the area and production of horticultural crops is undertaken which will help forecasting the future growth trend. For a better insight, case study on four horticultural crops is undertaken to assess their decadal growth trend vis-à-vis climate parameters in these 15 districts.

Results: The Mann–Kendall test for 1901–2016 and Sen's slope indicated a non-significant change in long-term trend for precipitation except for increasing change in Khargone and decreasing change in Rewa districts. Significant increasing trend of average temperature is obtained for Hoshangabad, Jabalpur, Sagar and Rewa districts. The Sen's slope indicated an increase of 0.005 to 0.009 °C for maximum temperature and 0.005 to 0.012 °C for minimum temperature annually. The projections of all the RCP climate scenarios for the years 2050 and 2080 indicated non-significant variation in precipitation but an increase in maximum (1.4 to 4.1 °C) and minimum (1.45 to 4.65 °C) annual temperatures. An increasing trend in area and production for horticultural crops is also observed in central India for the study period. There is yield increase in all the crops selected in case study except for potato, which recorded a decreased yield between the years 2010–2015.

Conclusion: The Mann–Kendall test and projections indicate towards climate change with a temperature rise. Though the decadal study indicates an increasing trend in horticultural crops, the districts identified to be affected by climate change need to have a plan to lessen the horticultural loss in the state. This study contributes to understanding the future climate change trends and its impact on horticultural crop production to formulate various adaptation strategies.

Keywords: Climate change, Horticulture, Madhya Pradesh, Precipitation, Temperature, Trend analysis

Background

The long-term climate pattern is a natural phenomenon that directly affects biodiversity, ecosystem, and natural resources on the Earth. Temperature and precipitation are fundamental components of climate, and changes in their pattern can affect ecosystems, plants, and animals

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(Onoz and Bayazit 2012). Climate change is one of the most complex and challenging global environmental threats faced by the world today, affecting our ecosystem. The Intergovernmental Panel on Climate Change (IPCC 2021) has observed considerable changes in global temperature, precipitation patterns, and extreme weather events in all regions in near to mid-time slices. In the following decades, the global temperature may rise by 1.5–2.0 °C resulting in increasing heat waves, longer warm seasons, and shorter cold seasons. Climatic factors such as temperature, rainfall, solar radiation, relative humidity, and carbon dioxide concentration directly affect commercial agriculture by affecting plants' photosynthesis and dry matter allocation (Mohanty et al. 2015). As climatic variability affects almost 60% of yield variability, it is one of the most important factors influencing crop production (Osborne and Wheeler 2013; Matiu et al. 2017). Previous studies worldwide have documented the relation between climate change and its effect on crop productivity in general and in South Asia in particular (Lasco et al. 2011; Aryal et al. 2020). However, the actual effect of climate change on crop production depends on the crop type, location, and adaptive capacities to climatic vagaries (Vermeulen et al. 2012).

The diverse climatic zones, ecosystems, and topography of a diverse country like India are more vulnerable to climate risks. One such state of this country is Madhya Pradesh (Fig. 1), located in the central part of India, wherein natural calamities like drought, excessive rains, floods, and hails storms are being observed more frequently. Many districts of Madhya Pradesh state have faced challenges related to climate change like late arrival of rains, early withdrawal, long break in rainfall spell, and lack of sufficient water in reservoirs, which adversely affected crop production. It is the second-largest state of India with 9% (30.8 million ha) of the country's total geographic area, with a cultivated area of 14.9 million ha, constituting almost half of the state's total geographical area. However, a greater part of the area (62%) is under the rainfed condition with substantial precipitation during monsoon, making this area even more prone to climatic variability (Anonymous 2022). It ranks sixth in the country in terms of total population (72 million), and a significant part of the rural population is dependent on agriculture and allied sector for its livelihood. The state is rapidly diversifying into the horticulture sector. Presently, 6% of the gross cropped area of the state is under horticulture cultivation, ranking fourth in the country in terms of horticulture production (MP Economic Survey 2016). Some of the major horticultural crops grown are fruit crops (mango, guava, banana, oranges, papaya), vegetable crops (potato, onion, peas, tomato, cucurbits, brinjal, cabbage), spices (chillies, garlic, coriander, ginger) and flower crops (marigold, gaillardia, rose, gladiolus) (Table 1). The vegetable crops dominate with about 45% share in the area, followed by spices at 35%, fruits at 18%, and flowers contributing 2% (Fig. 2).

The extreme climatic factors influence production of horticultural crops due to their adverse effect on flowering, fruit development, fruit quality, and pest-diseases infestation. Though these crops are affected by climatic vagaries, studies on the long-term impact of climate change on the area expansion and production of horticultural crops in this important region are not available. Therefore, this study focuses on long-term trends analysis in annual precipitation, temperature, and its effect on horticultural crop production in Madhya Pradesh.

Materials and methods

This study was undertaken with the objective to understand the trend in annual precipitation and maximum–minimum temperature of 115 years (1901–2016) in the 15 districts of Madhya Pradesh state of central India. The assessment of precipitation and temperature under different RCP scenarios for the whole state are also computed with projections for years 2050 and 2080 which would be helpful in planning the future strategies for horticultural crop production. With these data in background, the decadal growth trend of the horticultural production in the preceding decade of the state is analysed and future trend assessed. Case study on four horticulture crops has also been undertaken to assess their decadal growth trend vis-à-vis climate parameters in the 15 districts to support the climatic projections.

Description of the study area

Madhya Pradesh state geographically lies between 21.6°–26.30° North latitude and 74° 9′–82° 48′ East longitude (Shukla et al. 2017). The climate is subtropical with hot, dry summer (April–June) followed by monsoon rains (July–September), and the winter months (November to February) are cool and relatively dry. The annual average rainfall is 1160 mm with maximum rain in the southern–eastern parts and decreasing towards the north–west direction. This study focuses on trend detection in annual precipitation and temperature for the 15 districts viz., Bhind, Gwalior, Guna, Tikamgarh, Chhattarpur, Sagar, Jabalpur, Balaghat, Chhindwara, Rewa, Bhopal, Hoshangabad, Indore, Khargone and Neemuch of Madhya Pradesh state, India, covering the whole geographic region of the state. For RCP projections, the whole state was considered. Similarly, for assessing the horticulture growth trend of the preceding decade (2010–2020), all the districts of the state were considered, whereas for case study, the yield data of four horticultural crops (potato, onion, chillies and garlic) for the decade (2005 to

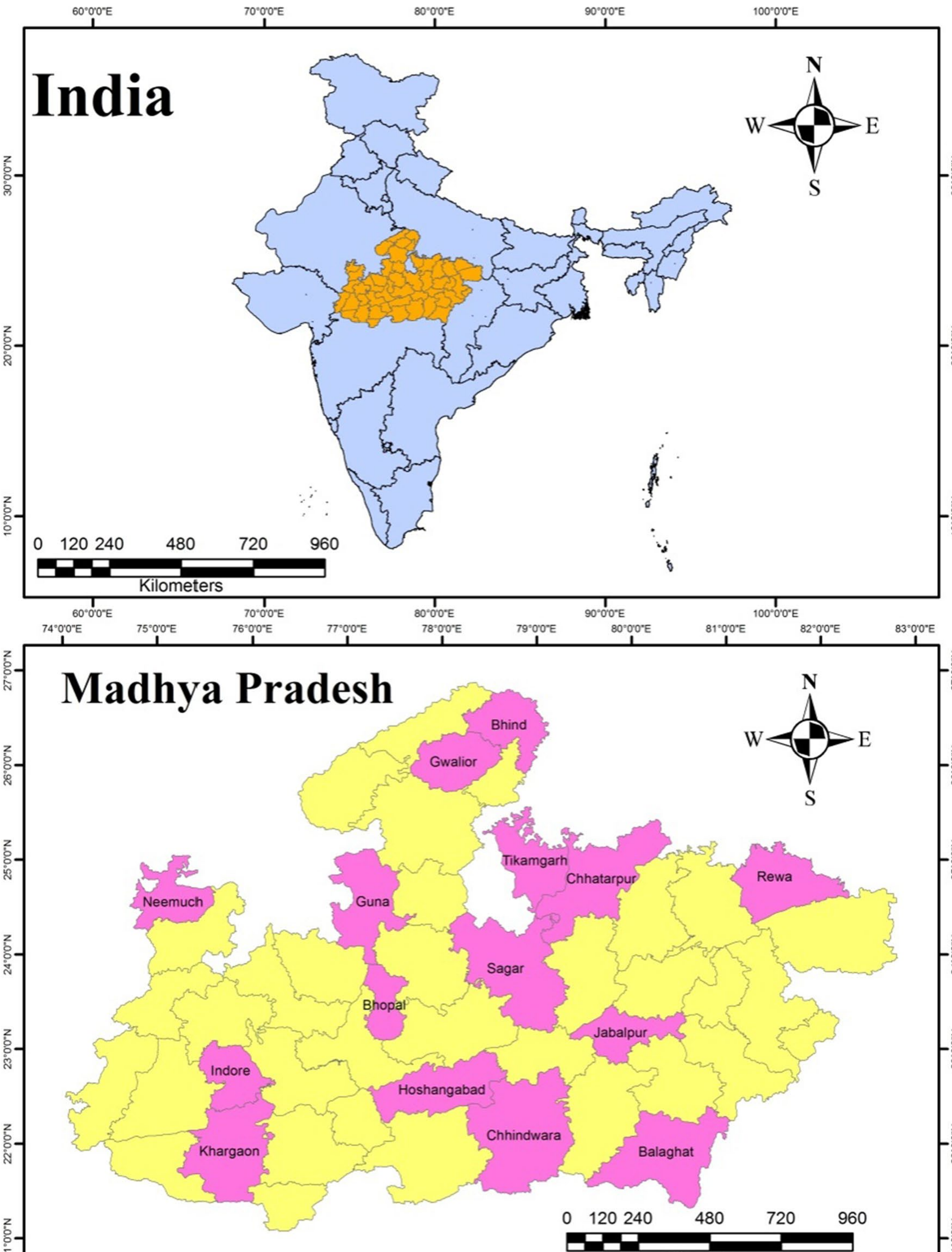

Fig. 1 Geographical location of Madhya Pradesh State in the central part of India and the selected 15 districts of interest undertaken in the study covering all the regions of state

Table 1 The major horticultural crops viz., fruits, vegetables, spices and flowers grown commercially by farmers in Madhya Pradesh state of central India

Sector	Major crops
Vegetables	Potato (*Solanum tuberosum*), onion (*Allium cepa*), tomato (*Solanum lycopersicum*), cauliflower (*Brassica oleracea* var. *botrytis*), okra (*Abelmoschus esculentus*), brinjal (*Solanum melongena*), bottle gourd (*Lagenaria siceraria*), cabbage (*Brassica oleracea* var. *capitata*), peas (*Pisum sativum*)
Spices	Chillies (*Capsicum annuum*), garlic (*Allium sativum*), ginger (*Zingiber officinale*), coriander (*Coriandrum sativum*)
Fruits	Guava (*Psidium guajava*), citrus (*Citrus* spp.), aonla (*Phyllanthus emblica*), papaya (*Carica papaya*), banana (*Musa paradisiaca*), mango (*Mangifera indica*)
Flower	Marigold (*Tagetes erecta*), gaillardia (*Gaillardia pulchella*), rose (*Rosa* spp.), tuberose (*Polianthes tuberosa*), gladiolus (*Gladiolus* spp.), gerbera (*Gerbera jamesonii*)

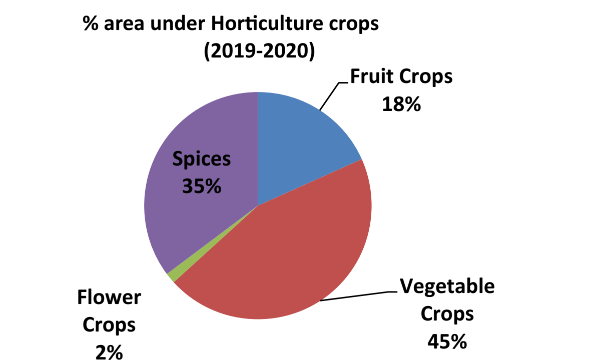

Fig. 2 Per cent area under different horticultural crops cultivated in Madhya Pradesh. The maximum cultivated area is of vegetable crops followed by spices, fruit and flower crops

2015) were considered which was compared with 15-year average yield (2000–2015).

Data sources

The time period under investigation for climatic parameters is 1901 to 2016 (115 years), whereas horticultural crop production and area statistics are 2010–2020. The precipitation and temperature data were obtained from the Indian water portal (https://www.indiawaterportal.org/). For the decadal growth study of the horticultural crops, the year-wise area and production information of horticultural crops of the preceding decade (2010–2020) of the whole state were obtained from the National Horticulture Board, New Delhi, and Horticulture Directorate, Government of Madhya Pradesh, Bhopal. Further, to have a better and realistic understanding of the current yield trend as affected by the climate variables, case study of four horticultural crops (vegetables and spices) of commercial importance but susceptible to climate change viz., potato, onion, chillies and garlic were undertaken in the 15 districts under study. The long-term average yield data from 2000 to 2015 of the selected four crops of all the 15 districts were collected from the Madhya Pradesh land records department (http://www.landrecords.mp.gov.in) which has updated records available up to the year 2015. The average yield data were worked out as a base for comparison with the decadal yield trend (2005–2015). For getting still better view of the trend, the decadal yield data (2005 to 2015) were divided into two phases, phase I comprised 5-year average yield of the years 2005–2006 to 2009–2010 and phase II comprising the 5-year average yield of the years 2010–2011 to 2014–2015. The yield trend of phases I and II was compared and also with the long-term average yield of 15 years as affected by the climate variables, i.e. temperature and precipitation. To determine the relationship between climatic change and major crop yield, a correlation analysis was performed. To test whether there is a direct relationship between climatic variables and crop yield, linear regression analysis between the crop yield and temperature and precipitation was performed.

Data analysis

Mann–Kendall trend test and Sen's estimator were applied to investigate the long-term change for precipitation and temperature. The Mann–Kendall test is a non-parametric procedure, widely used to analyse the trend in climatologic and hydrologic time series (Mavromatis and Stathis 2011; Yue and Wang 2004). Non-parametric tests are preferred in environmental and climate data analysis because they do not require data to be normally distributed (Hamed 2008). This test has low sensitivity to abrupt breaks due to inhomogeneous time series and accommodates trace values or non-detects. Statistical trend analysis is a hypothesis testing process; the null hypothesis H_0 is that there is no trend tested against the alternative hypothesis H_1, which assumes that there is a trend (Onoz and Bayazit 2012).

The Mann–Kendall test considers the time series of n data points and T_i and T_j are two subsets of data, where $i = 1, 2, 3, \ldots, n - 1$ and $j = i + 1, i + 2, i + 3, \ldots, n$. The computational procedure for the test considers computing the difference between the later-measured value and all earlier-measured values, $(T_j - T_i)$, where T_j and T_i are the annual values in years j and i and $j > I$, whereas n = time series of data points (Motiee and Mcbean 2009). If a data value from a later time period is higher than from an earlier time period, the Mann–Kendall test statistic S is incremented by 1. If the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S and assigns the integer value of 1, 0, or −1 to positive differences, no differences, and negative differences, respectively. A positive value of Mann–Kendall test statistic S indicates an upward trend and a negative value a downward trend. If the standard test statistic Zs follows a normal distribution, its positive or negative value refers to an upward or downward trend for the studied period.

Kendall's tau is carried out on the ranks of the data. It measures the strength of the relationship between the two variables in the range of ±1. A positive correlation indicates that the ranks of both variables increase together, whereas a negative correlation indicates that with the increase in the rank of one variable, the other one decreases.

However, prior to testing for trends, analysis of autocorrelation is also carried out for correlation of a variable with itself over successive time intervals. The autocorrelation can be calculated between the ranks of the data after removing the apparent trend as per modified Mann–Kendall test suggested by Hamed and Rao (1998). The adjusted variance is given by:

$$\mathrm{Var}[S] = \frac{1}{18}[N(N-1)(2N+5)]\frac{N}{\mathrm{NS}*},$$

where $\frac{N}{\mathrm{NS}*} = 1 + \frac{2}{N(N-1)(N-2)}\sum_{i=1}^{P}(N-i)(N-i-1)(N-i-2)\mathrm{ps}(i)$.

N is the number of observations in the sample, NS* is the effective number of observations to account for autocorrelation in the data, ps (i) is the autocorrelation between ranks of the observations for lag i, and p is the maximum time lag under consideration.

Sen's slope estimator is a non-parametric method for trend analysis of the hydroclimatic data set. It is used to detect the magnitude of the trend. The trend magnitude could be calculated by slope estimator methods (Sen 1968). Here, the slope T_i of all data pairs is calculated according to Sen (1968). In general, T_i for any time series x could be predicted from the following:

$$T_i = (x_j - x_k)/(j-k),$$

where x_j and x_k are considered as data values at time j and k (j > i) correspondingly. The median of these N values of T_i is represented as Sen's estimator of the slope which is calculated as Qmed = $T(N+1)/2$, if N is an odd number, and it is computed as Qmed = $[T_{(N/2)} + T_{((N+1)/2)}/2]$ if N is an even number. A positive value of T_i indicates an upward or increasing trend and a negative value of T_i gives a downward or decreasing trend in the time series (Mohamed and El-Mahdy 2021).

The Mann–Kendall test and Sen's estimator were performed using the R-statistical platform's "trend" package. For the Mann–Kendall test, the significance level was 0.05. Further, for assessment of climatic variability parameters, i.e. maximum and minimum temperature and rainfall for the coming 60-year period (2080) were computed for Madhya Pradesh state. Weather data were analysed and projected for years 2050 and 2080 under different climate scenarios (RCP 2.6, 4.5, 6.0, and 8.5) and were compared with that simulated for baseline.

Results

Mean precipitation and temperature

The annual means of precipitation and temperature of the 15 districts of Madhya Pradesh for 115 years (1901–2016) are given in Fig. 3 and the monthly means in Fig. 4. It is evident from these figures that Balaghat district recorded the highest annual mean precipitation (1532.3 mm), followed by Hoshangabad district (1249.6 mm). The lowest annual precipitation was recorded in Bhind district (563.5 mm), followed by Khargone, Gwalior, and Neemuch districts. The highest annual mean temperature was observed in the district Khargone (26.5 °C), followed by Balaghat (26.3 °C), Bhind (25.8 °C), and Gwalior (25.7 °C). Moreover, Bhind, Khargone, Gwalior, and Neemuch are districts with low precipitation and high temperature. These districts with history of low precipitation and high mean temperature, are more sensitive to climate change. The monthly mean temperature trend was similar in all the districts, with May and June being the hottest month. The highest mean maximum temperature was recorded in Bhind (34.6 °C), followed by Gwalior (34.4 °C) in June and Balaghat (34.4 °C) in May. Also, Bhind, Gwalior, and Guna are the only districts that received mean rainfall of less than 100 mm in June. It can be noticed that there is a lower rainfall in northern and western districts and higher rainfall in the eastern region of the state. In general, more rainfall towards the south-eastern parts of Madhya Pradesh (some now in Chhattisgarh state) has also been reported by Kulkarni and Patwardhan (2016).

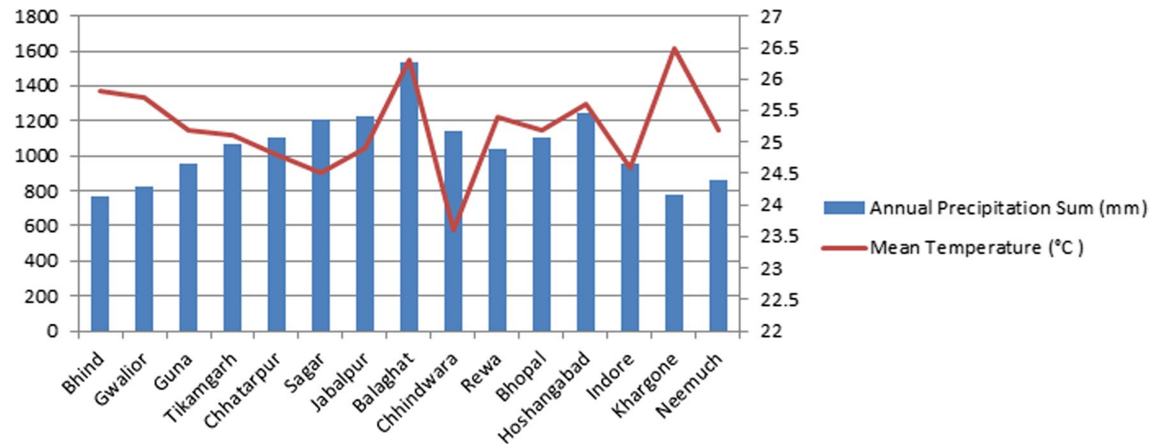

Fig. 3 District-wise annual mean precipitation and temperature of Madhya Pradesh state in central India during 1901–2016 (115 years). The blue bars depict the mean annual rainfall (mm) of the district, whereas the red line shows the mean annual temperature (°C) of the district. The maximum mean annual rainfall is recorded in Balaghat district, whereas the maximum mean temperature is recorded in Khargone district

Mann–Kendall test for precipitation trends

The annual precipitation trend analysed by the Mann–Kendall test (Table 2) indicated a non-significant change in long-term trend at all the studied districts of Madhya Pradesh except for the Khargone and Rewa districts, where the trend was highly significant. The test indicated a significant increasing change in long-term trend in precipitation for the Khargone district, with a Tau value of 0.195 and *P*-value of 0.001 but a significant decreasing change for Rewa with a *P*-value of 0.035 and Tau value of − 0.132. Besides, the Sen's slope also exhibited a 1.436 mm increase in annual precipitation in Khargone and a 1.44 mm decrease in the annual rainfall for Rewa. A non-significant decrease is prominent except for some districts of north-west and south-west region which showed positive slopes viz., Khargone, Indore, Guna, and Hoshangabad, which recorded increasing trend values (1.436, 1.018, 0.413, and 0.213 mm, respectively).

These findings align with Kumar et al. (2010), who reported non-significant trends over east and west Madhya Pradesh from 1871 to 2005. Duhan and Pandey (2013) also observed non-significant trend for the entire Madhya Pradesh in annual precipitation during the year 1901–2002. In contrast, Kundu et al. (2015) reported a decrease in precipitation trend in 111 years (1901 to 2011) studies of this state. It is also evident from Table 2 that a significant abrupt change in precipitation occurred in the districts of Hoshangabad and Indore in the year 1921, Jabalpur, Chhatarpur, Sagar, and Tikamgarh in 1983, and at Gwalior and Bhind in 1985. It can be inferred from the precipitation trend analysis that a non-significant but declining trend was observed from 1901 to 2016, barring a few regions of western Madhya Pradesh.

Mann–Kendall test for temperature trends

The Mann–Kendall test with Tau parameter and *P*-value showed a significant increasing trend for maximum temperature (Table 3) for all the selected districts of Madhya Pradesh except Chhatarpur and Chhindwara districts which were found to be non-significant. The trend was highly significant in Hoshangabad, Jabalpur, Sagar, and Rewa districts, whereas the trend showed a low relationship in Chhindawara and Indore districts. The Mann–Kendall test showed a significant increasing trend for minimum temperature in all the selected 15 districts of Madhya Pradesh except Chhatarpur (Table 4).

The Sen's slope indicates an increase of 0.005 to 0.009 °C in annual maximum temperature and 0.005 to 0.012 °C rise in minimum temperature annually. It has also been previously reported that the annual, maximum and minimum temperatures increased by 0.6, 0.6, and 0.62 °C, respectively, over the past 102 years (1901 to 2002) in Madhya Pradesh (Duhan et al. 2013). Likewise, trend analysis with the hike in temperature for the period 1901 to 2005 (105 years) was noted by for Madhya Pradesh and in the Prakasam district of Andhra Pradesh (Shukla et al. 2017; Rani et al. 2020).

The abrupt change in annual maximum and minimum temperature was noted in Chhindwara (1946 and 1950), Bhind (1997 and 1984), Tikamgarh (1983 and 1984), and Neemuch (1984 and 1978). The abrupt change in both the annual maximum and minimum temperature in 1963 was observed at five districts viz., Indore, Jabalpur, Sagar, Hoshangabad, and Khargone.

Mapping variability of precipitation and temperature

The assessment of climatic change parameters, i.e. maximum and minimum temperature and precipitation for

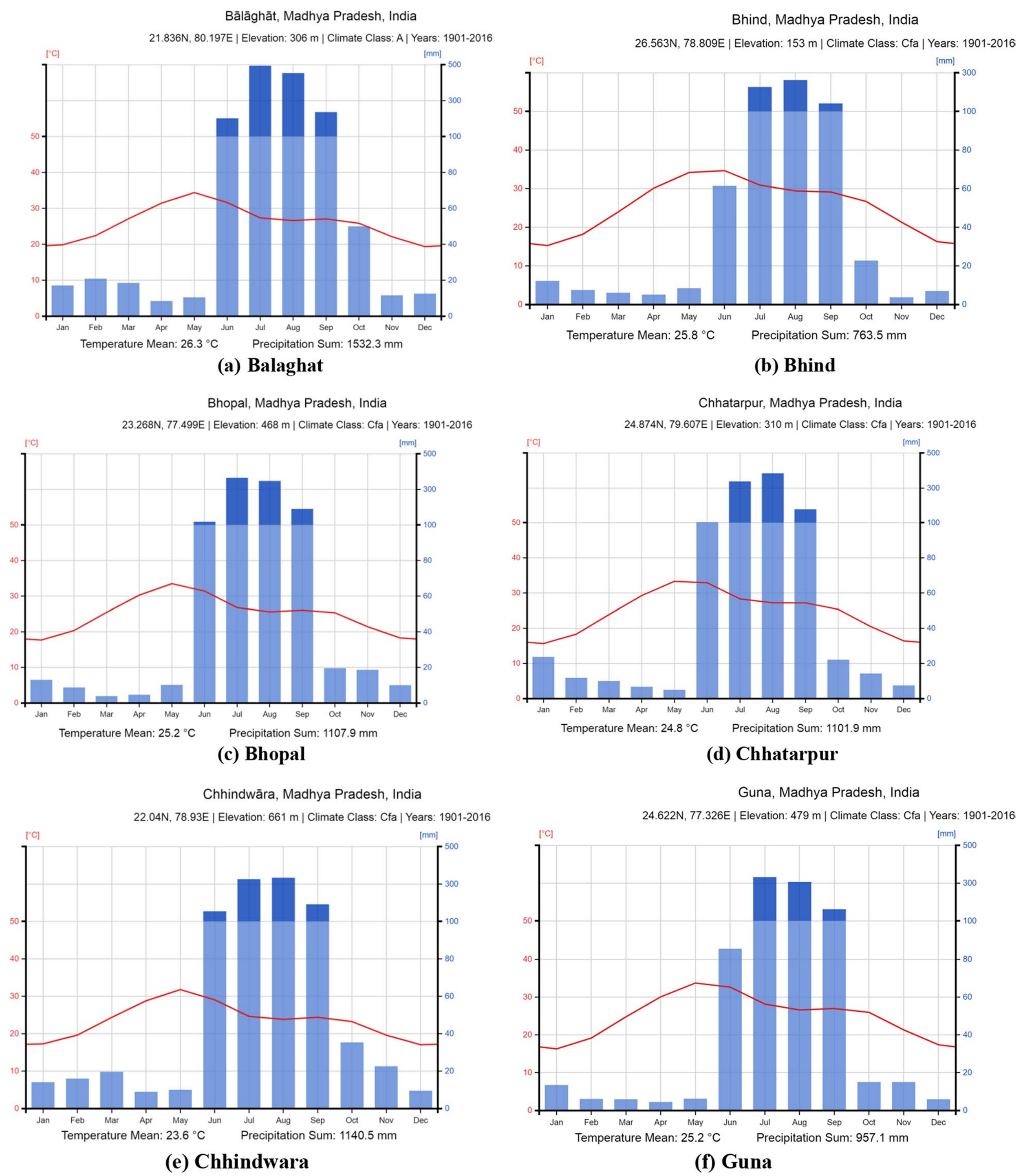

Fig. 4 Mean monthly temperature and precipitation (1901–2016) of the selected districts (Zepner et al. 2021). Mean monthly temperature and precipitation of each district for the 115 years duration are shown in figure **a** to **m**. The red line depicts the average temperature (°C) per month and the blue bars indicate the mean monthly rainfall in mm of each district

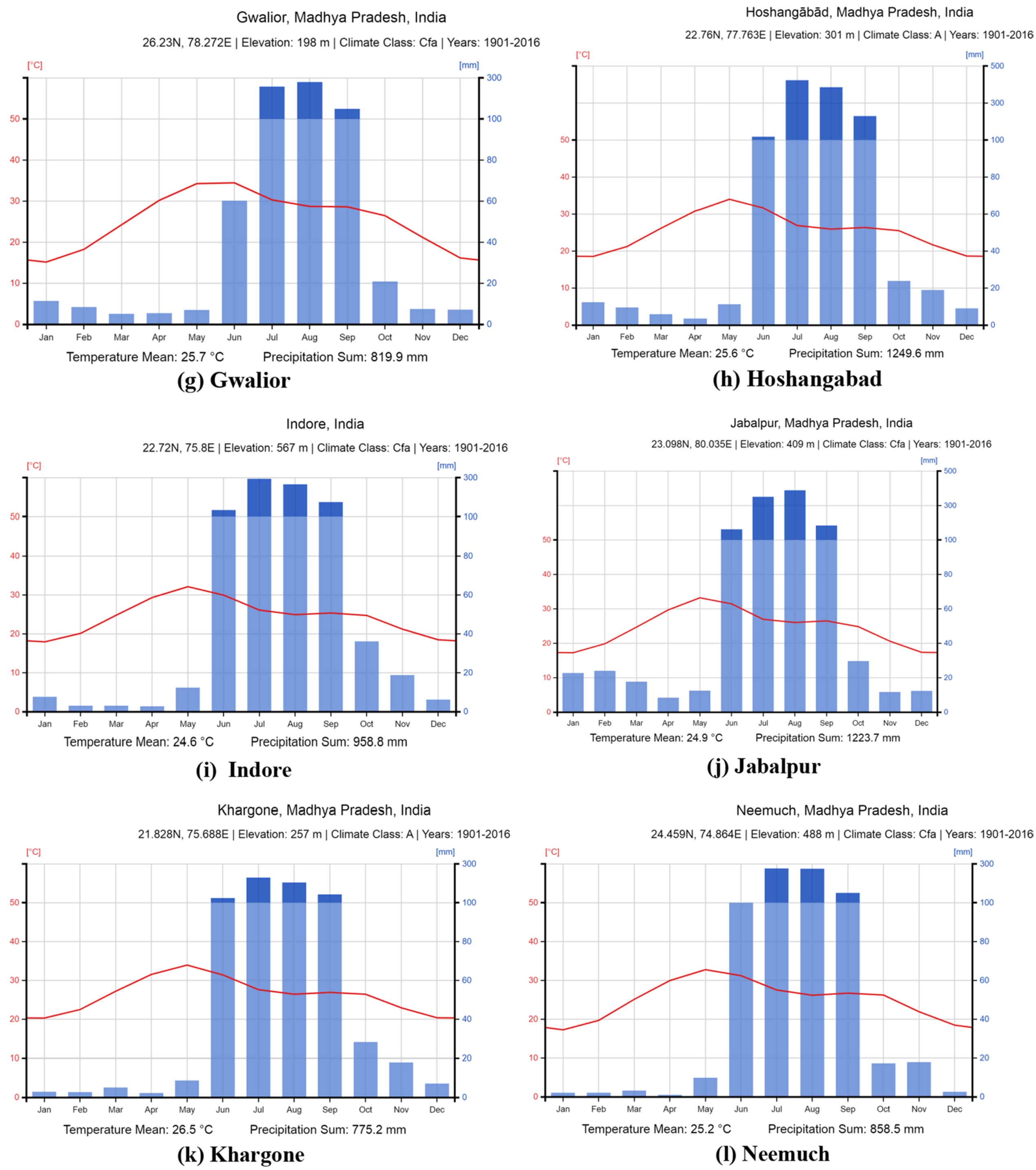

Fig. 4 continued

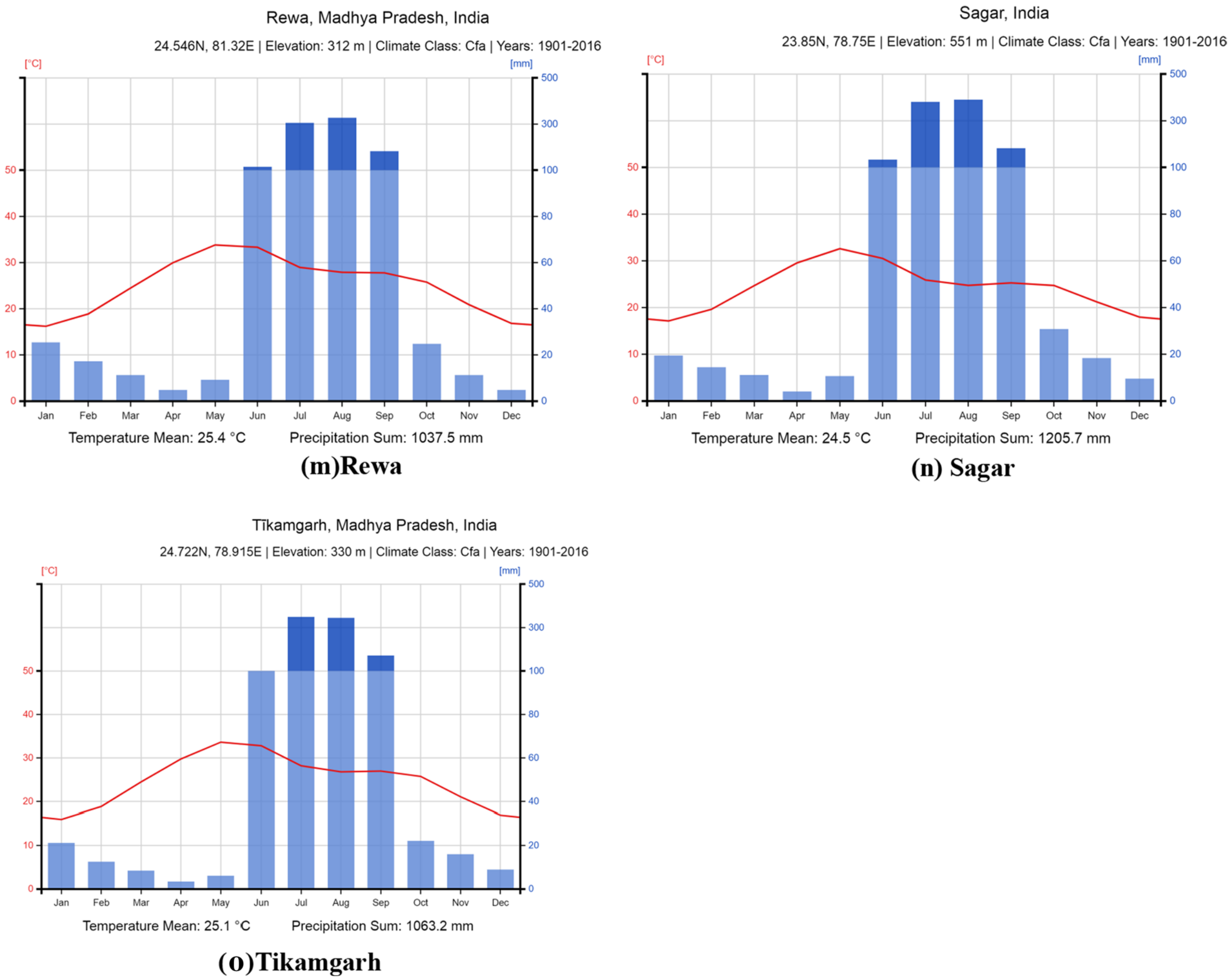

Fig. 4 continued

60 years (2020–2080), were computed, and weather data mapped and projected for years 2050 and 2080 under different climate scenarios (RCP 2.6, 4.5, 6.0, and 8.5) and were compared with that simulated for baseline of the Madhya Pradesh state.

Precipitation projections

The assessment of precipitation under different climate scenarios (RCP 2.6, 4.5, 6.0, and 8.5) were computed, weather data mapped with projections for years 2050 and 2080, and compared with that simulated for baseline (Figs. 5 and 6). Projections of rainfall in the state for the period 2050–2080 (RCP 2.6, 4.5, 6.0, and 8.5) lie between <700 and >1000 mm, indicating no major abnormal variation in the rainfall in all the RCP 2050 and 2080 scenarios. This is in line with the anticipation made earlier that during the 2020s, there would not be much change in the rainfall pattern (Kulkarni and Patwardhan 2016). However, towards the middle of the century, the mean seasonal rainfall may rise by 5–20%, while towards the end of the century, it may increase by around 20–40%, with more wet over western parts of Madhya Pradesh. Gosain and Rao (2016) mentioned that the mean annual rainfall is projected to increase by 11.6% by mid-century and about 30% by the end of the century. Most of the increases occur in the monsoon period. Further, a slight increase (1.25 times) in rainfall during the monsoon compared with the current climate across Madhya Pradesh is expected (MPSAPCC 2014). However, for post-monsoon, western parts of Madhya Pradesh are likely to face a decrease in rainfall. In contrast, a slight increase in rainfall is projected in most other parts of the state, while more pre-monsoon rain is expected in the south of Madhya Pradesh for 2021–2050.

Table 2 The trend in annual precipitation of 115 years (1901–2016) in the 15 districts of Madhya Pradesh state of central India selected for study as per Mann–Kendall test and Sen's estimator indicating a non-significant change in long-term trend at all the studied districts of Madhya Pradesh except for the Khargone and Rewa districts

Districts	Mann–Kendall statistics	Tau	*P*-value	Sen's slope	Probable change
Balaghat	− 384	− 0.057	0.360	− 0.574	49 (1949)
Bhind	− 276	− 0.041	0.511	− 0.409	85 (1985)
Bhopal	362	− 0.054	0.389	-0.521	78 (1978)
Chhatarpur	− 822	− 0.123	0.317	− 1.440	83 (1983)
Chhindwara	− 128	− 0.019	0.761	− 0.189	62 (1962)
Guna	338	0.050	0.421	0.413	30 (1930)
Gwalior	− 202	− 0.030	0.631	− 0.298	85 (1985)
Hoshangabad	114	0.017	0.787	0.213	21 (1921)
Indore	758	0.113	0.070	1.018	29 (1929)
Jabalpur	− 14	− 0.002	0.975	− 0.010	83 (1983)
Khargone	1306	0.195	0.001	1.436	29 (1929)
Neemuch	− 282	− 0.042	0.502	− 0.410	79 (1979)
Rewa	− 882	− 0.132	0.035	− 1.448	82 (1982)
Sagar	− 56	− 0.008	0.895	− 0.152	83 (1983)
Tikamgarh	− 226	− 0.033	0.591	− 0.428	83 (1983)

Table 3 The trend in annual maximum temperature of 115 years (1901–2016) in the 15 districts of Madhya Pradesh state of central India selected for study as per Mann–Kendall test and Sen's estimator showing a significant increasing trend for maximum temperature for all the selected districts of Madhya Pradesh except Chhatarpur and Chhindwara districts which were found to be non-significant

Districts	Mann–Kendall statistics	Tau	*P*-value	Sen's slope	Probable change
Balaghat	1784	0.267	0.000	0.005	50 (1950)
Bhind	1888	0.283	0.000	0.006	97 (1997)
Bhopal	1381	0.207	0.000	0.005	63 (1963)
Chhatarpur	2022	− 0.010	0.865	0.005	102 (2002)
Chhindwara	700	0.104	0.095	0.002	46 (1946)
Guna	2122	0.318	0.000	0.006	83 (1983)
Gwalior	2402	0.325	0.000	0.007	84 (1984)
Hoshangabad	2935	0.440	0.000	0.009	63 (1963)
Indore	943	0.141	0.024	0.003	63 (1963)
Jabalpur	2864	0.429	0.000	0.008	63 (1963)
Khargone	1827	0.273	0.000	0.005	63 (1963)
Neemuch	1990	0.298	0.000	0.006	84 (1984)
Rewa	2408	0.361	0.000	0.007	45 (1945)
Sagar	2454	0.367	0.000	0.008	63 (1963)
Tikamgarh	2226	0.333	0.000	0.007	83 (1983)

Maximum and minimum temperature projections

The average annual temperatures projected for 2050 and 2080 under RCP 2.6, 4.5, 6.0, and 8.5 scenarios were compared with the simulated baseline (Figs. 7, 8, 9 and 10). For 2050 projection, the maximum average annual temperature (higher side) is expected to increase in all cases, i.e. > 33.40 °C (RCP 2.6), > 33.70 °C (RCP 4.5), > 33.80 °C (RCP 6.0) and > 34.50 °C (RCP 8.5). By 2080, the average annual maximum temperature (higher side) is expected to be > 33.40 °C under RCP 2.6, > 34.50 °C under the RCP 4.5, > 36.10 °C, both under the RCP 6.0 and RCP 8.5 emission scenarios. Similarly, the average

Table 4 The trend in annual minimum temperature of 115 years (1901–2016) of the 15 districts of Madhya Pradesh state of central India under study as per Mann–Kendall test and Sen's estimator showing a significant increasing trend for minimum temperature in all the selected 15 districts of Madhya Pradesh except Chhatarpur district

Districts	Mann–Kendall statistics	Tau	*P*-value	Sen's slope	Probable change
Balaghat	2166	0.324	0.000	0.006	50 (1950)
Bhind	2170	0.325	0.000	0.008	84 (1984)
Bhopal	1596	0.239	0.000	0.005	63 (1963)
Chhatarpur	24	0.003	0.956	0.000	102 (2002)
Chhindwara	1098	0.164	0.008	0.003	50 (1950)
Guna	2116	0.317	0.000	0.007	78 (1978)
Gwalior	2286	0.342	0.000	0.008	83 (1983)
Hoshangabad	2907	0.435	0.000	0.008	75 (1975)
Indore	2138	0.320	0.000	0.006	63 (1963)
Jabalpur	2810	0.421	0.000	0.007	63 (1963)
Khargone	3408	0.510	0.000	0.012	75 (1975)
Neemuch	1900	0.284	0.000	0.007	78 (1978)
Rewa	2850	0.427	0.000	0.009	84 (1984)
Sagar	2212	0.331	0.000	0.007	63 (1963)
Tikamgarh	2648	0.397	0.000	0.008	84 (1984)

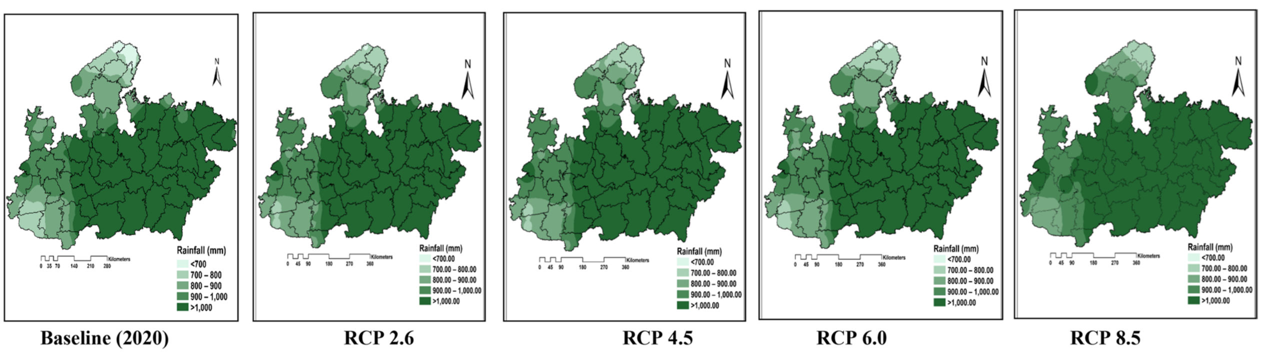

Fig. 5 Predicted change in the precipitation relative to baseline over the whole Madhya Pradesh state under different RCP scenarios of 2050

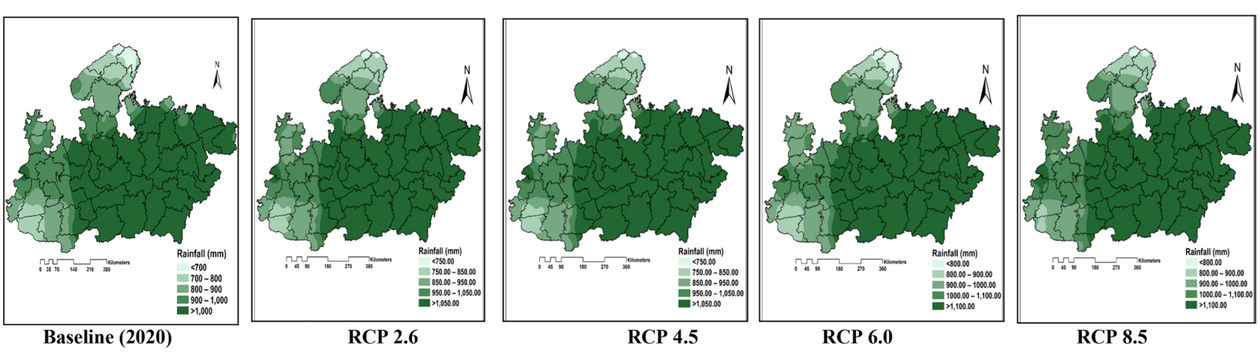

Fig. 6 Predicted change in the precipitation relative to baseline over the whole Madhya Pradesh state under different RCP scenarios of 2080

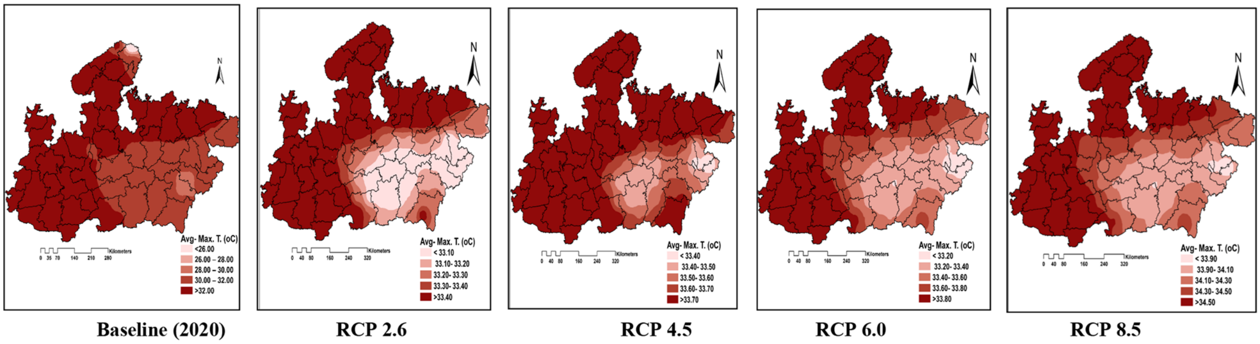

Fig. 7 Predicted change in the maximum temperature relative to baseline over the whole Madhya Pradesh state under different RCP scenarios 2050. Under all the RCP scenarios, the average maximum temperature is projected to increase

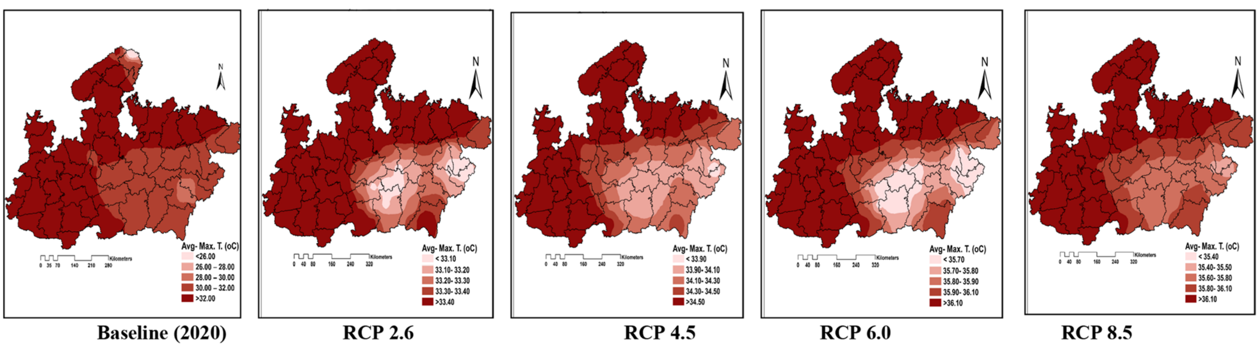

Fig. 8 Predicted change in the maximum temperature relative to baseline over the whole Madhya Pradesh state under different RCP scenarios of 2080. Under all the RCP scenarios, the average maximum temperature is projected to increase

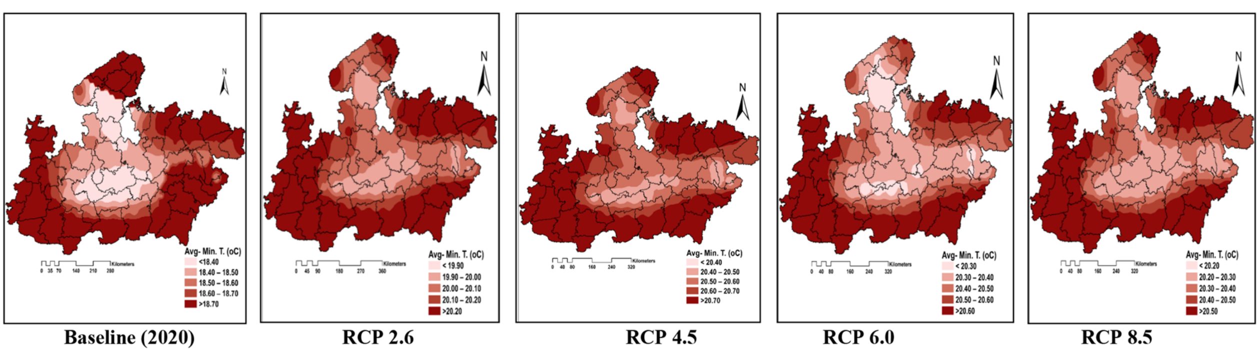

Fig. 9 Predicted change in the minimum temperature relative to baseline over the whole Madhya Pradesh state under different RCP scenarios of 2050. Under all the RCP scenarios, the average minimum temperature is projected to increase

annual minimum temperature (higher side) is also projected to increase in 2050 with the RCP 2.6, 4.5, 6.0, and 8.5 (> 20.20 °C, > 20.70 °C, > 20.60 °C, and > 20.50 °C, respectively). The annual average minimum temperature (higher side) predictions for the four emission scenarios in 2080 are > 20.15 °C (RCP 2.6), > 20.20 °C (RCP 4.5), > 21.60 °C (RCP 6.0) and > 23.35 °C (RCP 8.5). Compared with the baseline temperature, it can be projected that average maximum temperature rise may vary between 1.4 and 2.5 °C under different RCP scenarios in 2050 and between 1.4 and 4.1 °C in 2080. Similarly, a rise in average minimum temperature of 1.5 to 2.0 °C is projected

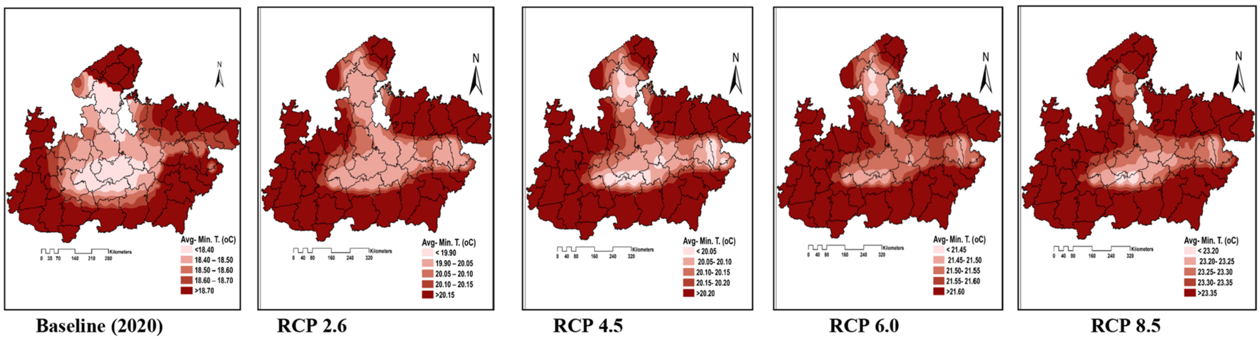

Fig. 10 Predicted change in the minimum temperature relative to baseline over the whole Madhya Pradesh state under different RCP scenarios of 2080. Under all the RCP scenarios, the average minimum temperature is projected to increase

under different RCP scenarios in 2050 and between 1.45 and 4.65 °C in 2080. The Madhya Pradesh State Action Plan on Climate Change also reported that the average surface daily maximum temperature in Madhya Pradesh in the 2030s is projected to rise by 1.8–2.0 °C while the minimum temperature may rise between 2.0 and 2.4 °C (MPSAPCC 2012). By 2080s, average maximum temperature is projected to rise by 3.4–4.4 °C, with the northern region of the state warming the most. The average minimum temperature is likely to rise by more than 4.4 °C across the whole of Madhya Pradesh. It is expected that the north-western half of the state will experience more rise in the maximum temperature than the eastern half, whereas the minimum temperature will rise in the southern, western, and some pockets of the eastern part of the state. This prediction is in line with the temperature data and trend discussed earlier. There is a distinct rise in minimum temperatures in the northern part of the state in 2080 compared to 2050 for the RCP 8.5 scenario. It is also reported that even moderate warming may lead to yield decline in horticultural crops as higher temperature leads to higher rate of respiration thereby altering the photosynthesis rate which could result in altering of phenology, flowering and fruiting duration, ripening and senescence ultimately reducing the yield (Malhotra 2017).

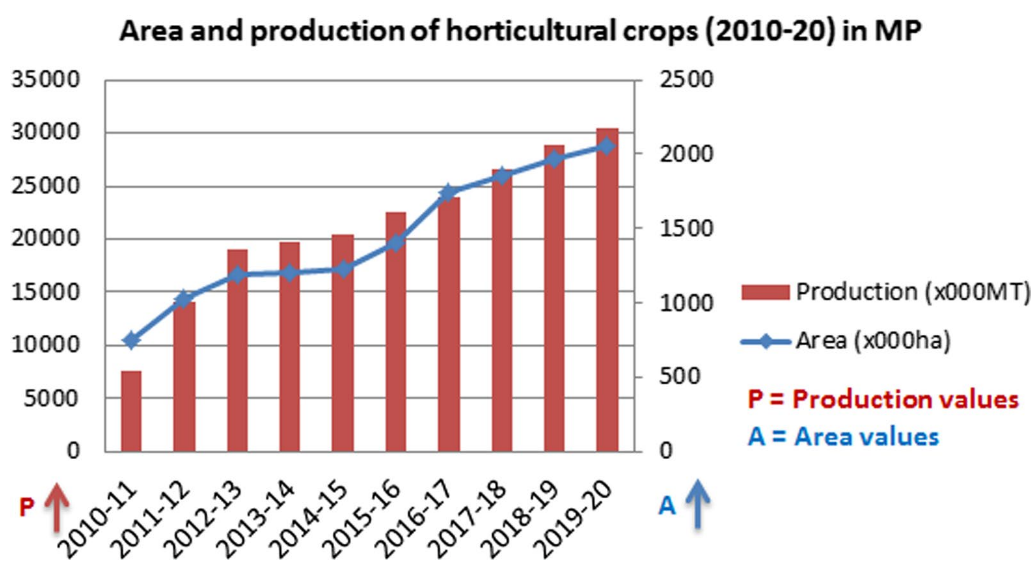

Fig. 11 Decadal growth in area and production of horticultural crops in Madhya Pradesh during 2010–2020. The blue line depicts the area cultivated, whereas the bars show the combined production of horticultural crops of the year. The figure shows that area and production of horticultural crops has grown in the last decade in the state

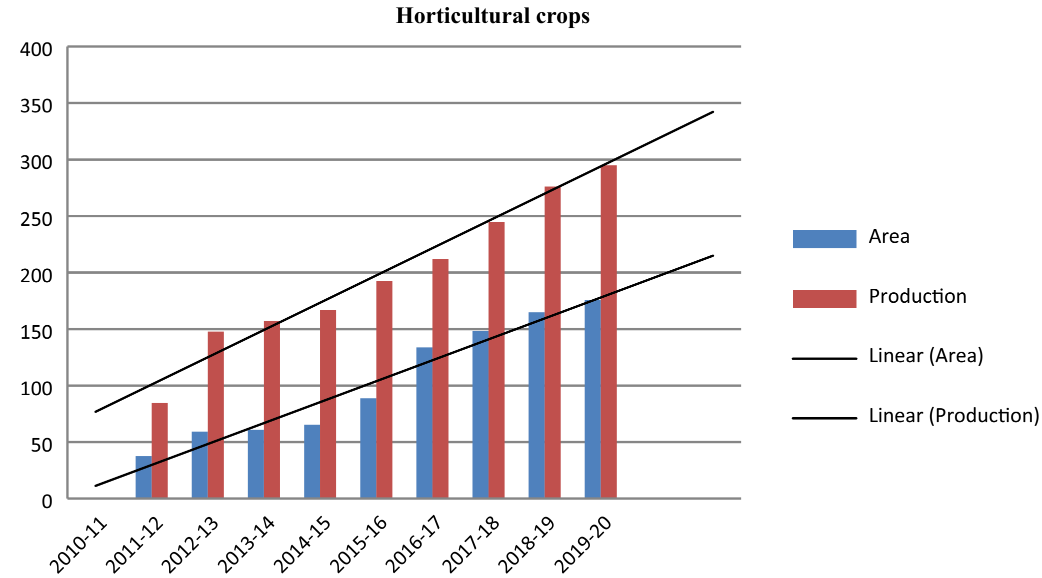

Fig. 12 Growth rate (%) in area and production of horticultural crops in Madhya Pradesh state during the decade 2010–2020 depict a continuous and consistent increase in the growth rate per year in the area under these crops and its linear forecast points towards a positive growth trend in future as well

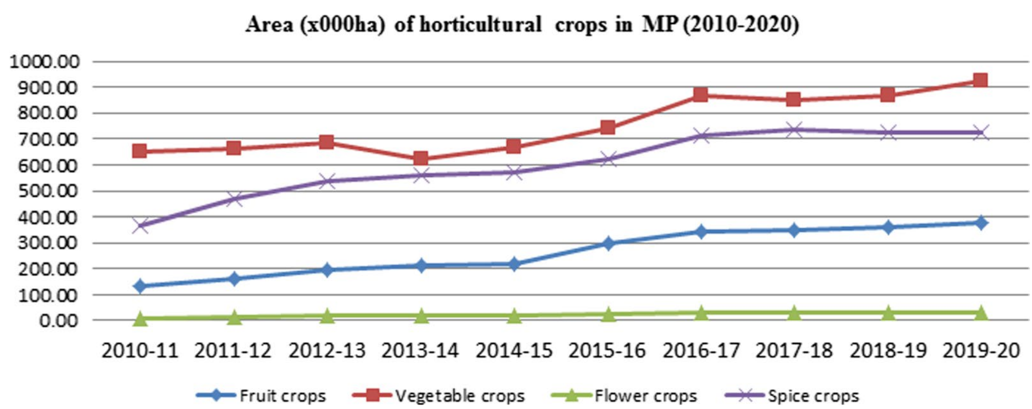

Fig. 13 Decadal growth in the area of fruit, vegetable, flower and spice crops in Madhya Pradesh during 2010 to 2020 indicate a rise in the cultivated area of the horticultural crops

Decadal growth trend of horticulture in Madhya Pradesh

The area and production of horticultural crops were studied for 10 years of the preceding decade (2010–2020). The study shows that region's area and production of horticultural crops has grown in the last decade (Fig. 11). There has been a continuous and consistent increase in the growth rate per year in the area under these crops (Fig. 12). The area under horticultural crops grew by 175.47% between 2010 and 2020, with an absolute increase from 0.745 to 2.05 million ha, respectively. Within the horticultural crops (Figs. 13 and 14), fruit crops had a continuous increase over the years. The area of fruit crops grew by 183.81%, from 0.132 million ha (2010–2011) to 0.375 million ha (2019–2020). In the case of vegetable crops, the area increased from 0.651 million ha (2010–2011) to 0.922 million ha (2020–2021), with a growth of 41.62%. Under floriculture, the area increased from 0.007 to 0.03 million ha during the period 2010–2020, with a growth of 299.87%. Similarly, a continuous and consistent increase in the area of spice crops was noticed. The area under spice crops increased from 0.365 to 0.723 million ha, from 2010–2011 to 2019–2020, which grew at 97.75%. It can be inferred that there has been no noticeable adverse effect on the growth in the area of horticultural crops of all the major horticultural crops in the last decade in Madhya Pradesh.

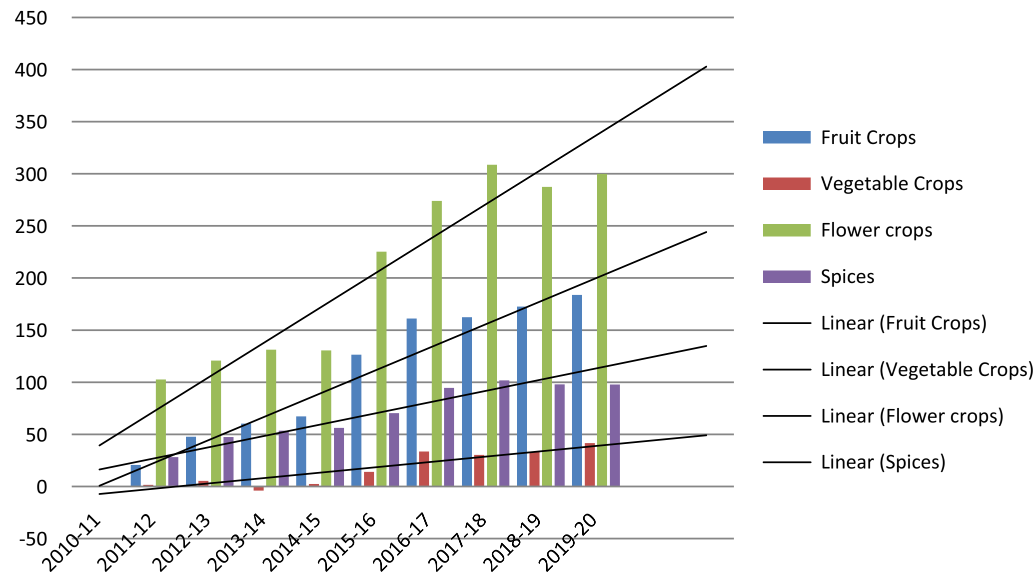

Fig. 14 Per cent growth rate of fruit, vegetable, flower and spice crop area during 2010–2020 suggests a general increased growth trend in area and its linear forecast also indicates a positive growth trend in Madhya Pradesh

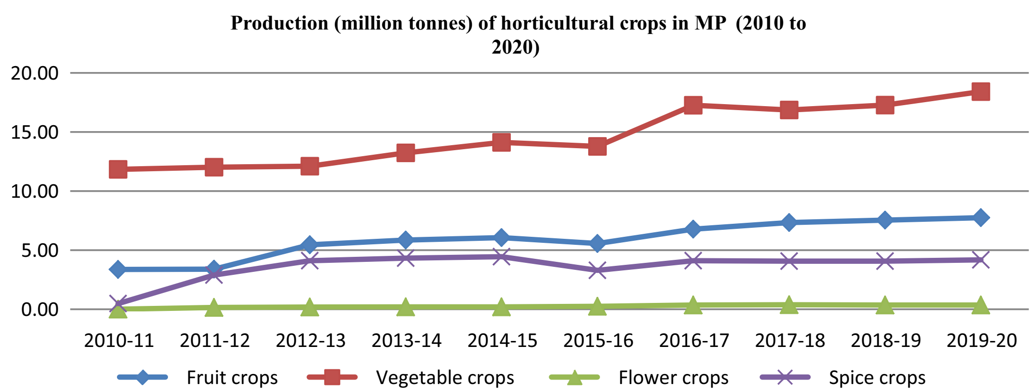

Fig. 15 Decadal growth in the production of fruit, vegetable, flower and spices in Madhya Pradesh during 2010–2020 indicates a rise in the production of all the horticultural crops

Also from Figs. 11 and 12, it can be seen that horticultural production has grown in the last decade. The horticultural production (combined) increased by 294.85% between 2010 and 2020, with an absolute increase from 7.69 to 30.37 million tonnes. Figures 15 and 16 clearly show that fruit production increased from 3.37 to 7.75 million tonnes between 2010 and 2020 with a growth of 129.97%. The vegetable production also increased from 11.84 million tonnes (2010–2011) to 18.42 million tonnes (2019–2020) with a growth of 55.57% even though there was a slight decline in the area during 2013–2014. Interestingly, the production of flowers has grown a whopping 500% between 2010 and 2020 with an absolute increase from 0.006 to 0.36 million tonnes. Similarly, spices production recorded a growth of 770.83% between 2010 and 2020, with an increase in production from 0.48 to 4.18 million tonnes. It can be seen that the production of horticultural crops in the last decade has been on the rise and is more or less showing a consistent trend. However, a sudden decline in the production of fruits and spices was noticed in the year 2015–2016 as compared to the preceding year, but overall horticultural crop production has increased. The decline in the production of

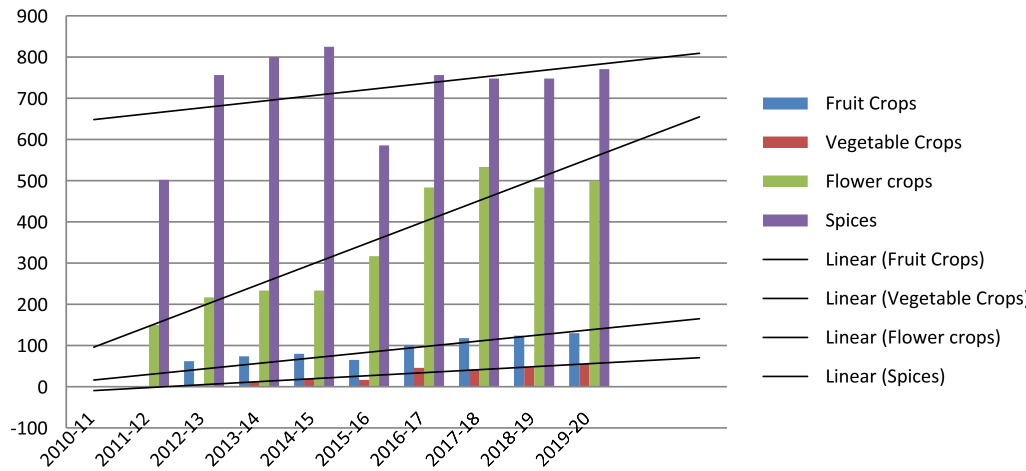

Fig. 16 Per cent growth rate of fruit, vegetable, flower and spices production during 2010–2020 shows an increasing value and its linear forecast also indicates a positive growth trend in Madhya Pradesh

above mentioned crops in the said years may have been due to early or delayed flowering, multiple reproductive flushes, fruit and bud drop, abnormal flower and bud setting as affected by climate change.

Based on the analysis of the last ten years, the linear forecast of the growth trend of horticultural crops (combined) indicates further rise in the area and production (Fig. 12) as well as of individual horticultural crops viz., fruits, vegetables, flowers and spices (Figs. 14 and 15). Further, Fig. 14 points out towards a general increased growth trend in area, except in the year 2013–2014, wherein there was a decline in area (− 3.94%) in vegetable crops.

Case study on horticultural crops in the 15 districts

To get indication of the current crop yield trend, comparison of long-term average yield (2000–2015) of the four selected horticultural crops, i.e. potato, onion, chillies and garlic was done with the 5-year average yield of the previous decade (2005–2006 to 2009–2010), i.e. phase I and the first 5-year average yield data of the preceding decade (2010–2011 to 2014–2015), i.e. phase II.

District-wise average crop yield

The average yield over the years within the district was assessed for the selected crops and presented through Figs. 17, 18, 19, and 20. In potato, the districts noticed

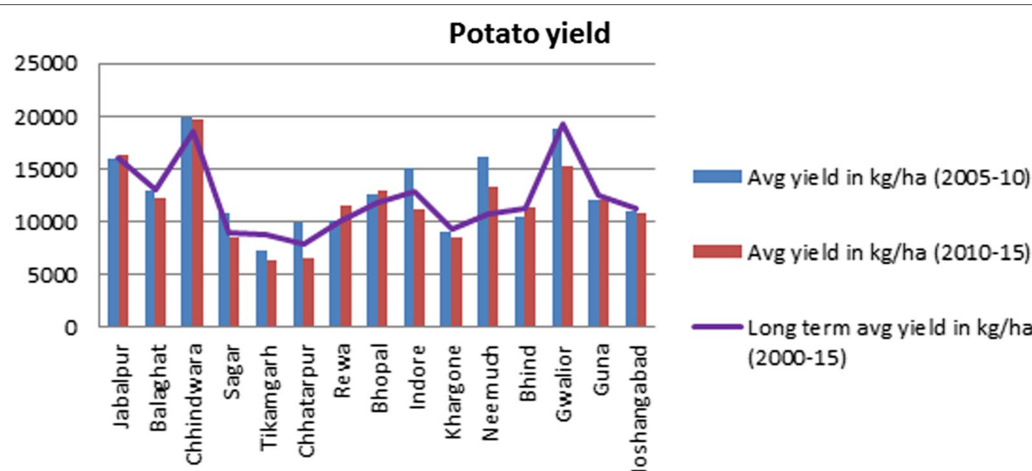

Fig. 17 Comparison of the long-term average potato yield with the average yield during the years 2005–2010 (phase I) and 2010–2015 (phase II) and also among phase I and II yield in the selected districts of Madhya Pradesh

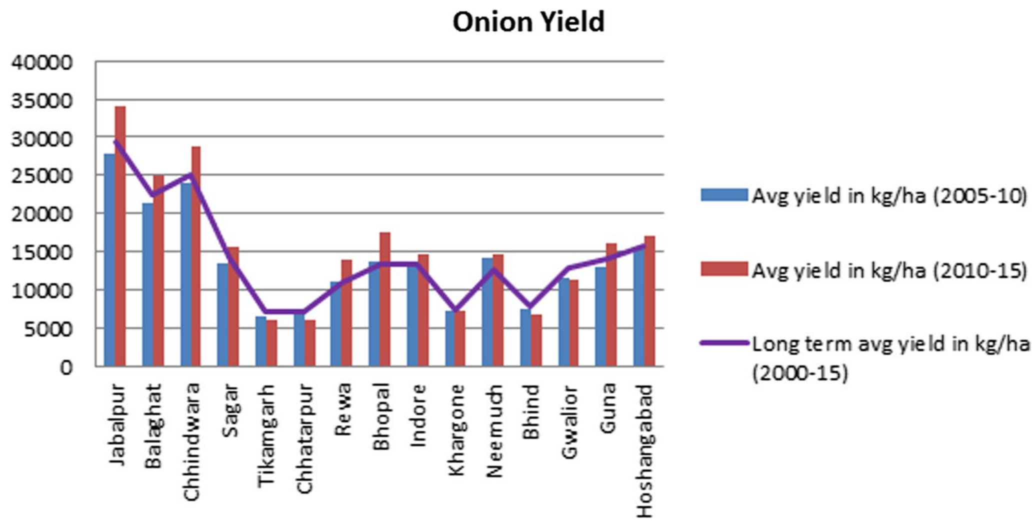

Fig. 18 Comparison of the long-term average onion yield with the average yield during the years 2005–2010 (phase I) and 2010–2015 (phase II) and also among phase I and II yield in the selected districts of Madhya Pradesh

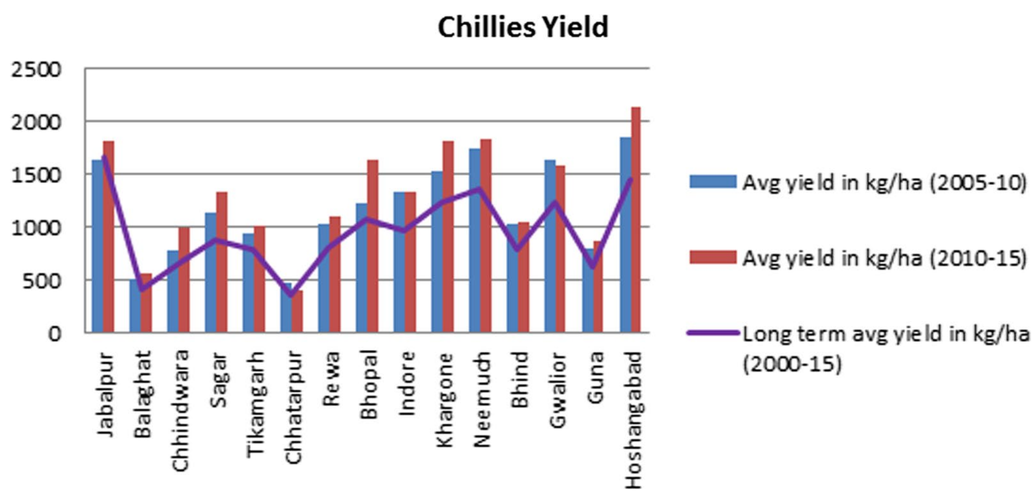

Fig. 19 Comparison of the long-term average chillies yield with the average yield during the years 2005–2010 (phase I) and 2010–2015 (phase II) and also among phase I and II yield in the selected districts of Madhya Pradesh

with average yield less than the long-term average yield (2000–2015) in phases I and II are Tikamgarh, Gwalior, Khargone, Balaghat, Guna and Hoshangabad. Also, decline in average potato yield per hectare (2010–2015) has been noticed in phase II as compared to the 5-year average yield (2005–2010) of phase I in majority of the districts except Rewa, Bhopal and Jabalpur. Similarly, in onion, the districts with lower yield in both I and II phases as compared to long-term average yield are Bhind, Tikamgarh, Khargone, Gwalior and Chhatarpur, whereas major decline in phase II has been noticed in the districts Tikamgarh, Bhind and Chhatarpur. In case of chillies, interestingly all the districts had an average yield of more than the long-term average yield in both the phases, however, yield decline in phase II has been noticed only in the districts Chhatarpur, Gwalior and Indore as compared to phase I. In case of garlic, the yield decline in phase II is observed in all the districts except Bhopal. In general, there was decline in potato and garlic average yield in phase II and in onion and chillies in phase I.

Effect of climate variables on crop yield

There has been increase in the average yield in all crops when compared to long-term average yield except for

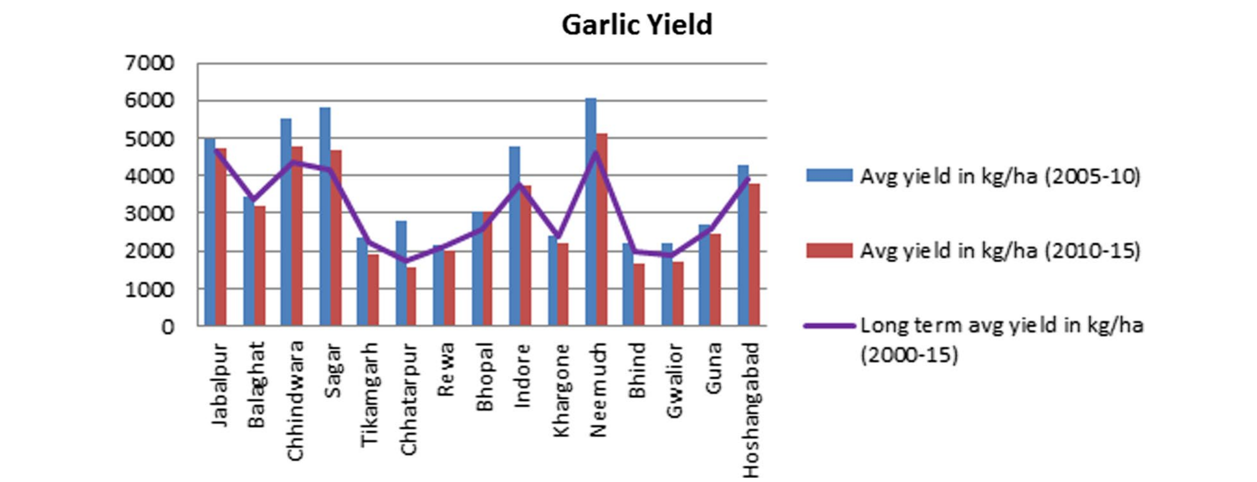

Fig. 20 Comparison of the long-term average garlic yield with the average yield during the years 2005–2010 (phase I) and 2010–2015 (phase II) and also among phase I and II yield in the selected districts of Madhya Pradesh

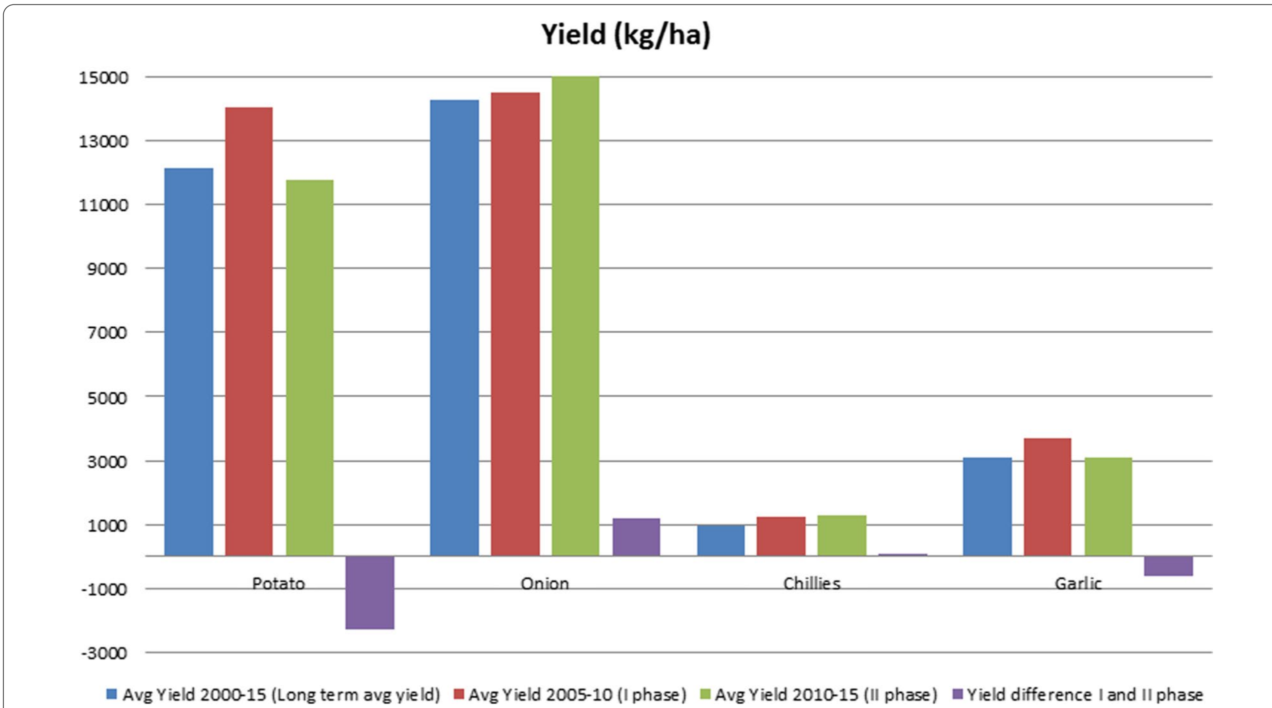

Fig. 21 Comparison of the average crop yield of 2005–2010 (phase I) and 2010–2015 (phase II) with long-term yield average (2000–15) and yield difference between phase I and II average yield and the yield difference between the two phases

potato in II phase (Fig. 21). On comparison of the average yield data of phase I with phase II, it is observed that there has been a visible decrease in the yield of potato and garlic in phase II. Yield when seen on yearly basis, as visible from Fig. 22, in potato, as compared to the long-term average yield there has been decrease in the yield in the years 2000–2001, 2007–2008, 2008–2009, 2009–2010, 2011–2012 and 2013–2014. In onion, decline in yield is observed in the years 2001–2002, 2002–2003, 2003–2004, 2005–2006, 2007–2008, 2008–2009, 2010–2011 and 2014–2015 when compared to long-term average yield. In case of chillies, a yield decline is evident in the years 2000–2001 to 2003–2004 and 2014–2015 when compared with long-term average yield. In garlic, there has been decrease in the yield in the years 2000–2001 to 2005–2006, 2007–2008,

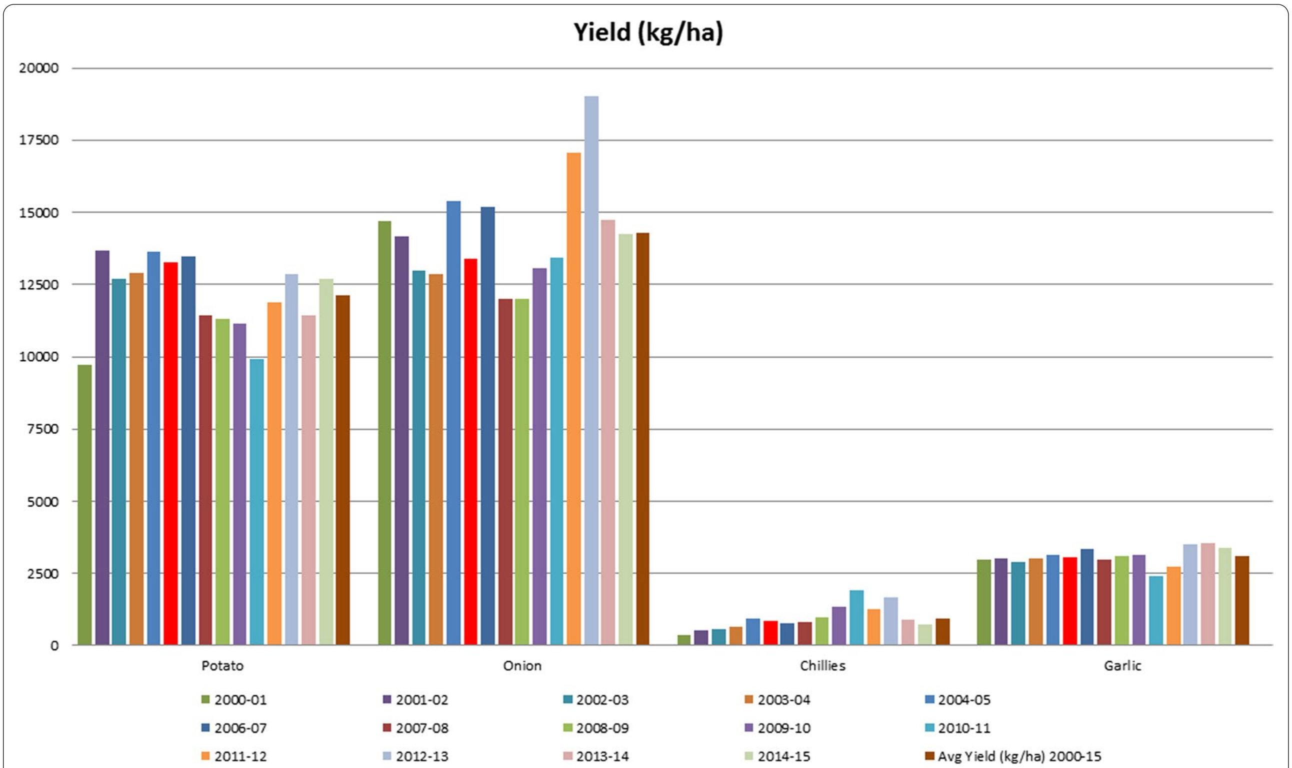

Fig. 22 Comparison of yearly crop yield of potato, onion, chillies, garlic during 2000 to 2015 along with its long-term average yield

Table 5 Correlation between climatic variables and crop yield indicates a significant relationship between the climatic change and the yield of crops

Crop	Temperature	Precipitation
Onion	− 0.2355 (0.0004)	0.5702 (0.0000)
Garlic	− 0.2077 (0.0017)	0.3834 (0.0000)
Chillies	0.2201 (0.0009)	0.1160 (0.0825)
Potato	− 0.2106 (0.0015)	0.0179 (0.7890)

Values in parenthesis denote the *p* value

2010–2011 and 2011–2012. It is evident that in the year 2001–2002 to 2003–2004, yield decline was noted in all the horticultural crops studied.

Climate–crop yield relationship

The correlation analysis results reveal that there is a significant relationship between the climatic change and the yield of crops as depicted in Table 5. A significantly positive correlation was obtained between temperature and chillies yield (+ 0.2201), whereas a significantly negative correlation was obtained between temperature and the yield of onion (− 0.2355), potato (− 0.2106) and garlic (− 0.2077). Significantly positive correlation was

Table 6 Linear regression analysis between climate variables (precipitation and temperature) and average production (kg/ha) during 2000–2015 shows that variation in the chillies, garlic, potato and onion crop yield is significantly impacted by climate variables

Crop	R^2	Pr (> *F*)	Coefficient		*P*-value	
			Temperature	Precipitation	Temperature	Precipitation
Onion	0.3547	0.000	− 1688.74	15.57	0.0016	0.000
Garlic	0.1743	0.000	− 265.83	1.69	0.0072	0.000
Chillies	0.0485	0.009	176.62	–	0.0009	–
Potato	0.0444	0.001	− 1150.42	–	0.0015	–

obtained between precipitation and onion (+0.5702) and garlic yield (+0.3834), whereas a positive correlation was obtained between the chillies yield (+0.1160), potato yield (+0.0179) and precipitation.

Crop yield variation due to climatic variable

The linear regression analysis results (Table 6 and Fig. 23) for the horticultural crops show that variation in the crop yield as impacted by climate variables (precipitation and temperature) is significantly affected in chillies, garlic, potato and onion. Further, it suggests that temperature significantly affected the yield in all the crops, whereas precipitation significantly affected the garlic and onion yield. The variation in the crop yield from a minimum of 4.44% (0.0444) in case of chillies to maximum of 35.47% (0.3547) in onion can be explained by the climatic variables. The regression analysis for onion indicates an R^2 value of 0.3547, implying that the climate variables

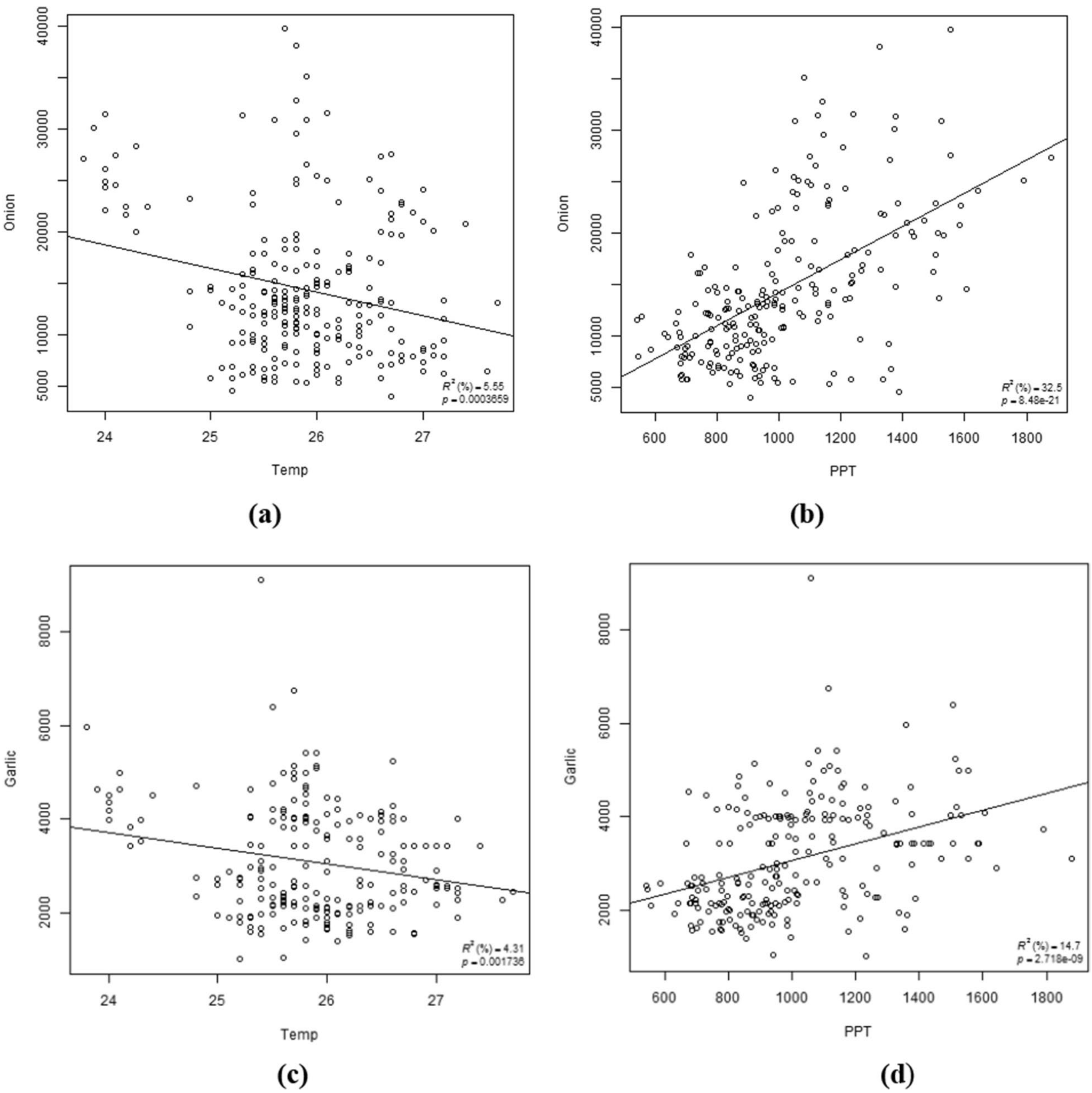

Fig. 23 Scatter diagram of the linear regression analysis of **a** onion yield with temperature, **b** onion yield with precipitation, **c** garlic yield with temperature, **d** garlic yield with precipitation, **e** chillies yield with temperature, **f** chillies yield with precipitation, **g** potato yield with temperature, **h** potato yield with precipitation

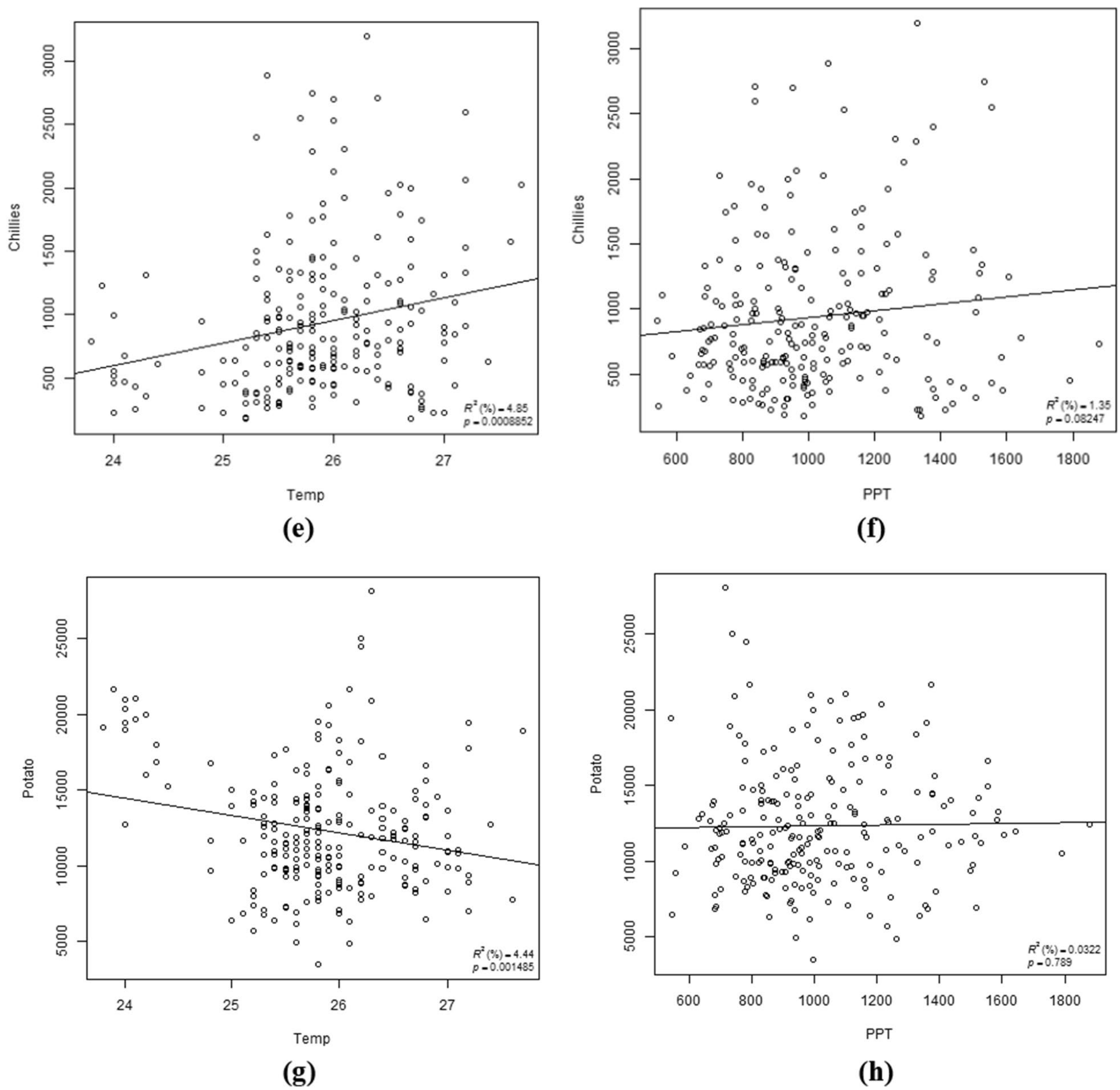

Fig. 23 continued

impact accounts for 35.47% of the yield changes, while the rest per cent of the variation in yield is due to various other non-climate influences viz, agro-technologies used, crop management, technical know-how, etc. Also, the sign of the coefficients suggests the direction of change in the yield versus climate variable changes. There is a direct relationship between temperature and chillies yield, whereas in all other crops there is inverse relation. Similarly, direct relationship between precipitation and crop yield was observed (Fig. 23).

The fitted models are as follows:

$$\text{Onion} = 42{,}302.24 - 1688.74 \times \text{Temp} + 15.57 \times \text{PPT}$$
$$\text{Garlic} = 8266.56 - 265.83 \times \text{Temp} + 1.69 \times \text{PPT}$$
$$\text{Chillies} = -3635.20 + 176.62 \times \text{Temp}$$
$$\text{Potato} = 42{,}075.41 - 1150.42 \times \text{Temp}$$

where ‘Temp’ is temperature and ‘PPT’ is precipitation.

Discussion

Based on the above results, it can be said that the upward trend in maximum and minimum temperature as indicated by Mann–Kendall statistics may pose challenges in the horticultural production in Madhya Pradesh in the coming time. Presently, horticultural crops grown in Khargone, Balaghat and Bhind are vulnerable due to high mean temperature and low rainfall. Significant increasing trend of mean temperature obtained from Mann–Kendall test for Hoshangabad, Jabalpur, Sagar and Rewa districts makes these districts even more vulnerable for horticultural crops. The projected rise in temperature is of concern as it may directly influence the flowering in fruit crops like mango and guava as with increase in temperature, the vegetative bias of the fruit crop increases and it adversely affects the flower phenology (Malhotra 2017). High temperature along with low relative humidity during the peak blooming period in mango leads to higher transpiration rate resulting in dehydration injury to panicles thereby reducing the yield. Further, in guava there are chances of increase in pests and diseases due to hot and humid conditions particularly the infestation of insects like fruit fly. However, higher temperature (>30 °C), is reported to increase the plant maturity rate in banana, thus it will shorten the bunch development period (Turner et al. 2007). Vegetables will be even more susceptible to high temperature because of their succulent nature. In tomato, high temperatures can cause yield losses due to reduced fruit set and smaller size. Fruit set failure at high temperatures in tomato including bud drop, abnormal flower development, poor pollen production, dehiscence, and viability, ovule abortion and poor viability, reduced carbohydrate availability, and other reproductive abnormalities has also been reported by Hazra et al. (2007). Pre-anthesis temperature stress is associated with changes in the anthers like irregularities in the epidermis and endothesium, lack of opening of stomium and poor pollen formation (Sato et al. 2002). In cucumber, low temperatures favours female flower production, whereas high temperatures lead to production of more male flowers which is not much desirable (Wien 1997). High temperature shortens the duration of onion and bulb size leading to reduced yields (Malhotra 2017). In short term, the commercial varieties of vegetables may perform poorly due to aberration of climate. It is expected that the winters will get warmer and lead to the shortening of growing period causing reduction in production of horticultural crops. Due to rise in the temperature availability of suitable growing period particularly for rabi season cash crops like vegetable peas, flowers and spices is likely to be impacted in the state. Potato is another cash crop which is likely to be affected by climate change due to adverse effect on physiological processes (Dua et al. 2018; Kondinya et al. 2014). The rise in high temperature will lead to more physiological disorders in horticultural crops like spongy tissue of mango, fruit cracking of litchi, flower and fruit abscission in solanaceous vegetables and improper flower development in flower crops.

Under a warmer climate, the horticultural crops may experience severe water stress due to the decline in soil moisture and increase in evapotranspiration, leading to severe crop water-stress conditions. The vulnerability to crop stress depends on the temperature and rainfall coupled with the water availability in these districts. Gosain and Rao (2016) have analysed that under the present scenario, in Madhya Pradesh, 13 districts belong to very high water resource vulnerability category, and out of these, four districts from this present study viz., Khargone, Hoshangabad, Chhindwara, Balaghat are included in it, whereas one district Chhatarpur lies in the least vulnerable category. Water deficit is known to retard the plant growth and its effects may be visible only after several months of drought (Stover 1972). Soil water stress will especially affect fruit crops like banana causing poor bunch formation, lower number and small-size fingers, poor filling of fingers and lower bunch weight. Higher temperature coupled with water stress will also lead to choking of bunches in banana in these districts (Malhotra 2017). However, by mid-century, Balaghat will downgrade to the high vulnerable category from the very high vulnerability indicating that this district will become less vulnerable in the end century as compared to mid-century. Though by the end of century, the districts in the least vulnerable category will decrease but districts like Gwalior will downgrade to least vulnerable cluster from the moderate in the mid-century (Gosain and Rao 2016).

The projected increase in precipitation in some regions may be due to warmer atmosphere causing an increase in evaporation rate resulting in higher amount of moisture. Rise in the untimely winter rains will adversely affect production by promotion of vegetative flushes in crops like citrus and mango instead of flowering flushes. Excessive moisture or flooding also causes stress to the vegetable crops like tomato and onion, which are very sensitive to excessive moisture. In case of tomato, flood situation has been reported to cause accumulation of endogenous ethylene which may cause damage to the plants (Malhotra 2017). The severity of flooding symptoms such as wilting and death of plants increases with high temperature (Kuo et al. 1982). However, the rainfall data as obtained by the Mann–Kendall test indicated a non-significant trend analysis, but it pointed towards a general declining pattern in majority of districts. In particular, the Mann–Kendall test revealed increase in annual precipitation in Khargone but a decrease in the annual rainfall for Rewa district which is of concern. Moisture stress in vegetables will be one of the major causes of low yield particularly in onion, tomato and chilli in the climate change scenario. Significant changes in climate will have impact on the production of spices as well viz., small cardamom, seed spices and black pepper and other spices (Muthusami et al. 2012).

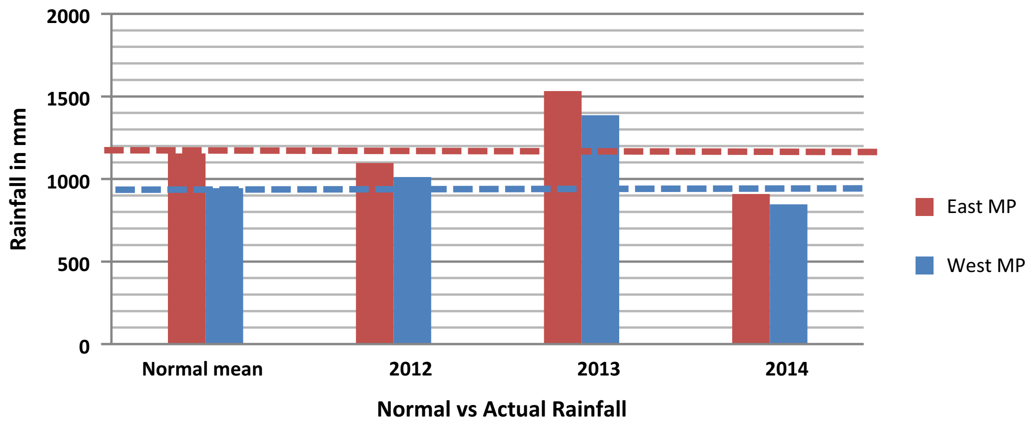

Fig. 24 Rainfall pattern (2012, 2013 and 2014) as compared to normal mean in Madhya Pradesh. The blue and maroon dash line shows that the actual rainfall in the year 2013 in West and East MP, respectively, was much higher than the normal mean rainfall

Though there has been growth in area and production of horticultural crops, the decline in vegetable area in 2013 may have been as a result of excessive rainfall in that year probably causing non-timely planting of vegetable crops (Fig. 24). Also, the fastest growth is in floriculture and slowest in vegetable crops. This may be due to the fact that vegetable cultivation is already being done since long in Madhya Pradesh with addition of some area each year, whereas the increase in the area of floriculture may be due to sudden diversion towards these crops because of high profitability per unit area, increase in availability of water resources and also domestic demand of flowers at the district levels. Similarly, in case of production of fruits, vegetables, flowers and spices, the linear forecast of the growth trend indicates further rise in the production level with fastest growth rate in spices and slowest again in vegetables. As improved open pollinated or hybrid varieties of vegetables are grown in maximum area, it reduces the chance of major quantum jump in the production. Therefore, under present situation, though horticultural crops are growing at considerable growth in the state but by the mid of century the crops may become susceptible to climate change. It has been earlier reported that erratic rainfall patterns and high-temperature spells have far-reaching implications on horticulture and consequently reduce crop productivity (Bhati et al. 2018).

In line with the above discussions, the case study also reveals that there has been increase in temperature in all the years when compared to long-term average temperature (2000–2015) but erratic rainfall, particularly, less than the long-term average in phase I (2005–2010). There has been yield increase in all the crops selected in case study (potato, onion, chillies and garlic) when compared to long-term average yield except for potato in phase II (2010–2015). Also, on comparison of the average yield data of phase I with phase II, it is observed that there has been a visible decrease in the yield of potato and garlic in phase II. When correlating

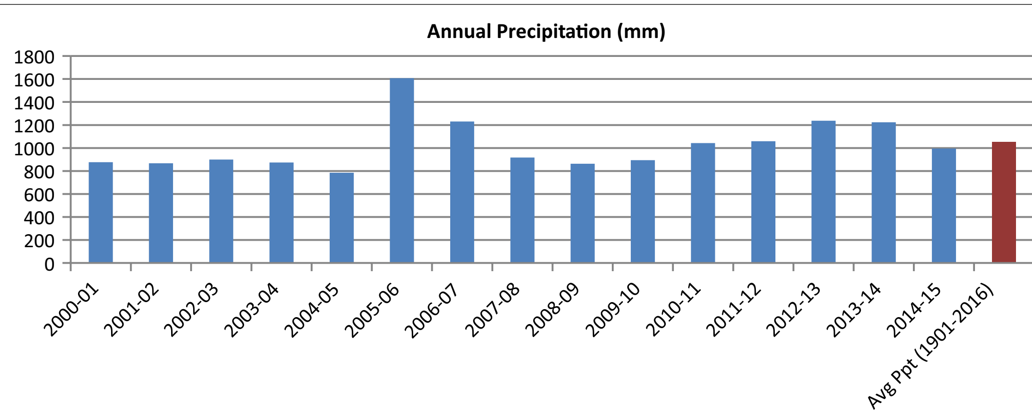

Fig. 25 Comparison of annual and average precipitation (mm) from 2000 to 2015 during the study period

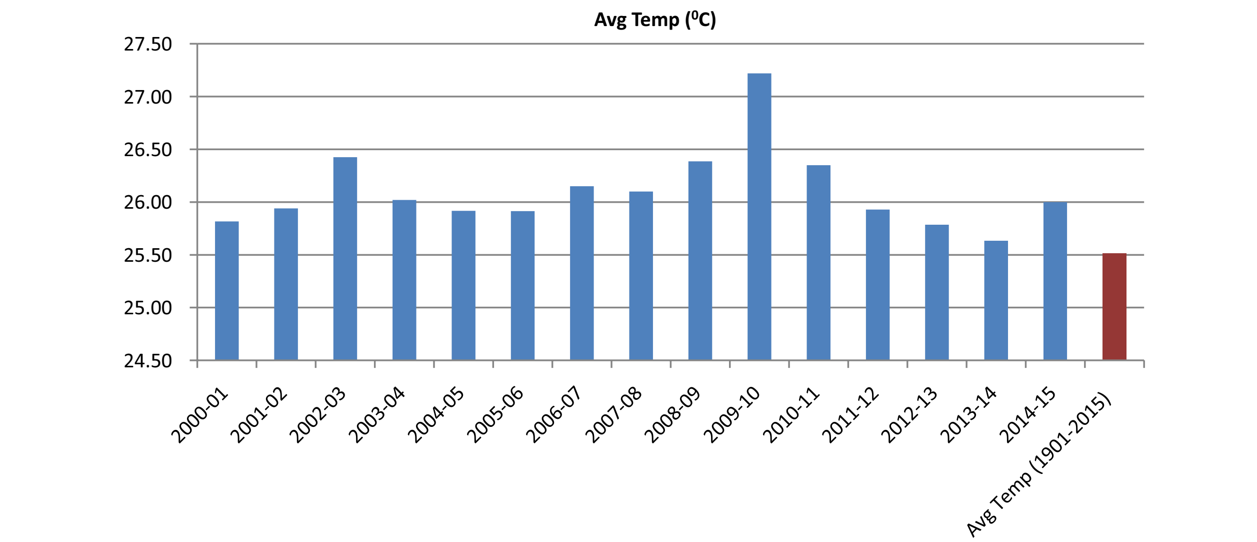

Fig. 26 Comparison of annual average temperature (°C) from 2000 to 2015 and its average during the study period

Table 7 Year-wise crop yield and average annual precipitation and temperature

Crop	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15
The coloured boxes represent lower Yield															
Potato	■							■	■	■		■		■	
Onion		■	■	■		■		■	■		■				■
Chillies	■	■	■	■											■
Garlic	■	■	■	■	■	■		■			■	■			
The coloured boxes represent higher value of climate variables															
Ppt*						■	■				■	■	■	■	
Temp*	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Ppt: Precipitation

Temp: Temperature

*Compared to long term average (2000-15)

The yield has been low when the rainfall has been lower and temperature higher than the average of 15 years. However, average temperature was higher in all the years as compared to the long-term average

Ppt: precipitation; Temp: temperature

* Compared to long-term average (2000–2015)

with climate variables (Figs. 25 and 26), there was lower average rainfall from 2007–2008 to 2009–2010 (phase I) and 2014–2015 and higher rainfall in phase II (2010–2011 to 2013–2014) which clearly reflects in the crop yield. The correlation studies also suggest that there is a significantly positive correlation between precipitation and potato as well as garlic yield, but a significantly negative correlation between temperature and potato as well as garlic yield. The regression studies suggest that temperature affected the yield in all the crops. All the districts recorded higher yield in chillies when compared to the long-term average yield. This

Table 8 Major horticultural crops along with the districts in which they are grown

Major crop	Major districts in which crop grown
Fruit crops	
Citrus (oranges)	Neemuch*, Mandsaur, Hoshangabad*, Chhindwara
Mango	Rewa*, Jabalpur*, Chhindwara, Balaghat, Indore
Guava	Rewa*, Sagar*, Jabalpur*, Hoshangabad*, Indore, Khargone*
Banana	Khargone*, Balaghat, Jabalpur*
Pomegranate	Mandsaur, Khargone*, Bhopal, Chhindwara
Vegetable crops	
Onion	Sagar*, Chhindwara, Rewa*, Indore
Tomato	Chhatarpur, Sagar*, Hoshangabad*, Rewa*, Jabalpur*, Chhindwara
Potato	Gwalior, Sagar*, Chhindwara, Rewa*, Indore*
Peas	Gwalior, Tikamgarh, Sagar*, Chhindwara, Jabalpur*, Indore
Spice crops	
Garlic	Guna, Sagar*, Chhindwara, Chhatarpur, Indore, Neemuch*, Mandsaur
Chilli	Gwalior, Tikamgarh, Chhatarpur, Chhindwara, Jabalpur*, Rewa*, Hoshangabad, Neemuch*, Khargone*
Coriander	Gwalior, Guna, Sagar*, Rewa*, Jabalpur*, Neemuch*, Mandsaur
Flower crop	
Marigold	Bhopal, Indore, Gwalior, Jabalpur*, Mandsaur

The districts with the asterisk mark are the predicted vulnerable districts for climate change. The horticultural crops grown in these districts may be adversely affected

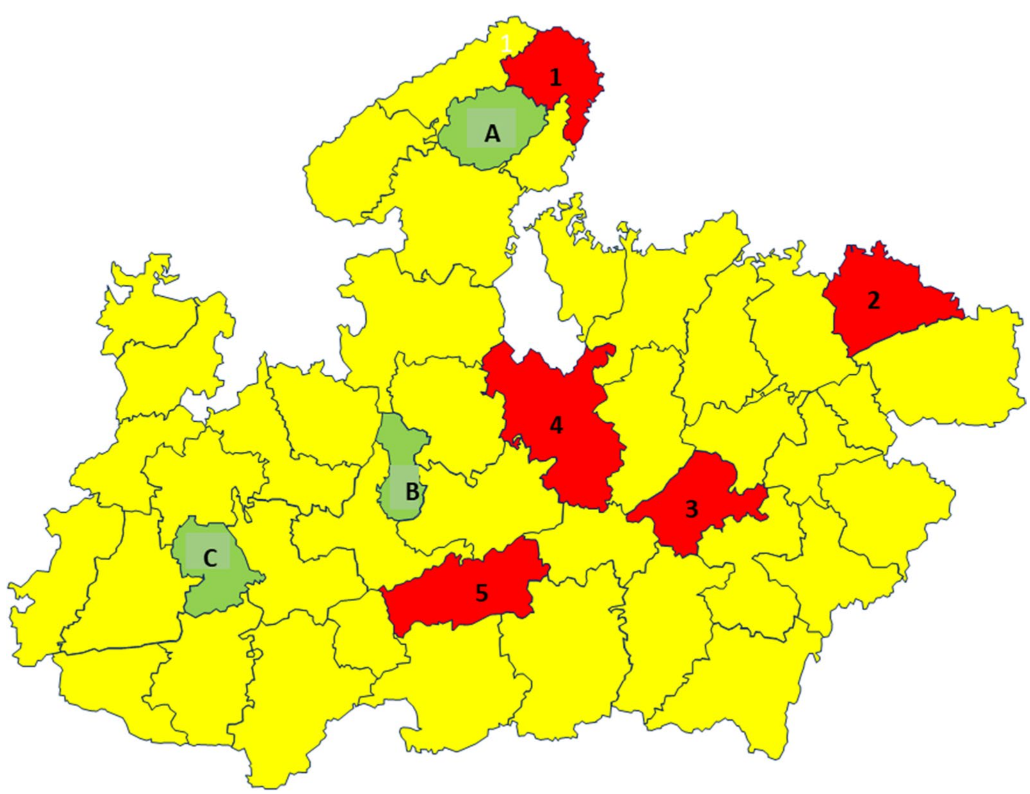

Fig. 27 Predicted vulnerable districts (1-Bhind, 2-Rewa, 3-Jabalpur, 4-Sagar, 5-Hoshangabad) and less vulnerable districts (A-Gwalior, B-Bhopal, C-Indore) for Horticultural crops. The red coloured districts are more vulnerable to climate change, therefore crop production will be at risk, whereas the green coloured districts are at the least risk

may be attributed to fact that there is a direct relationship between average temperature and chillies yield, whereas in all other crops there is inverse relation. The loss in yield in certain years may be attributed to higher temperature coupled with lower rainfall (Table 7) as compared to the long-term average temperature and precipitation. Lower precipitation particularly affected the potato and garlic yield. Similarly, the increase in temperature creates severe water loss due to evaporation which adversely affected the crop production.

The major horticultural crops and the climate vulnerable districts likely to be affected by climate change are given in Table 8. Under climate change scenario, the impact of these stresses would be compounded. Therefore, based on the future climatic predictions, it is important to become proactive and go for climate-resilient and adaptive techniques in horticultural crop production to mitigate climate change specially in the districts of Rewa, Bhind, Hoshangabad, Jabalpur and Sagar of Madhya Pradesh (Fig. 27). Also, the climatic variability will influence the soil fertility status, pest and disease occurrences, host- pathogen interactions, soil microbial population and behaviour of the pollinators which affect the crop yield. Strategies like development of cultivars tolerant to high temperature, moisture stress, pests and disease resistant, short duration and high yielding, as well as technologies like precision horticulture will help in addressing these challenge (Bhati et al. 2018). Indeterminate crops and varieties will need to be developed as these are less sensitive to heat stress conditions due to extended flowering as compared to determinate crops.

The study confirms that Madhya Pradesh is one of the vulnerable states in India and that horticulture sector may be adversely affected in the districts vulnerable to climate change.

The study is based on the basic premise that if all other factors (viz. environmental and socio-economic) remain the same, then how the horticultural production responds to the climatic changes. While this study is able to interpret the effects of climatic factors such as temperature and available moisture on production, there is further scope to reflect the complex relationships between different climate variables as part of the natural ecosystem. Various environmental factors contribute to the crop production including weather, soil type, pests, diseases, and farm-management practices, extreme events and also the availability of inputs like fertilisers, pesticides, etc., which depends on farmers' socio-economic characteristics, contributes to defining the crop yields (Smith and Kurtz 2018; Gadedjisso-Tossou et al. 2021).

Conclusion

The present study indicates that districts of Bhind, Khargone, Gwalior and Neemuch with history of low precipitation and high mean temperature are more sensitive to climate change.

The Mann–Kendall test and Sen's slope indicated a non-significant change in long-term trend for precipitation except for the Khargone and Rewa districts, wherein there was a significant increasing change in precipitation for the Khargone but a significant decreasing change for Rewa district. However, significant increasing trend of average temperature obtained from Mann–Kendall test for Hoshangabad, Jabalpur, Sagar and Rewa districts makes these districts even more vulnerable for horticultural crops. The Sen's slope indicates an increase of 0.005 to 0.009 °C in annual maximum temperature and 0.005 to 0.012 °C rise in minimum temperature annually. The rainfall projections indicate no major abnormal variation in the precipitation in all the RCP 2050 and 2080 scenarios. Furthermore, it is projected from this study that average maximum temperature rise may vary between 1.4 and 2.5 °C under different RCP scenarios in 2050 and between 1.4 and 4.1 °C in 2080. Similarly, a rise in average minimum temperature of 1.5 to 2 °C is projected under different RCP scenarios in 2050 and between 1.45 and 4.65 °C in 2080. The study shows that region's area and production of horticultural crops has grown in the last decade (2010–2020), even though there was a slight decline in the area during 2013–2014 and in the production in 2015–2016. There has been yield increase in all the crops selected in case study (potato, onion, chillies and garlic) when compared to long-term average yield (2000–2015) except for potato which recorded a decreased yield between 2010 and 2015 (phase II).

Therefore, this study shows that Madhya Pradesh state is susceptible to climate change and the trends obtained as per statistical tools and projections do not deny the fact that climate change is occurring. There is a need to have a proactive approach to cope with future climate change that may lessen the extent of horticultural losses in the state.

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Author contributions

GS conceived the idea, performed the study design, data collection, interpretation and writing manuscript. AS and SKT did the conceptualization, draft review and edited the manuscript. NKS performed the statistical analysis of results. OPS contributed in data collection and assisted in analysis. AKP edited and approved the final manuscript. AS and AK wrote the rough draft of manuscript. BS and MKS contributed in data collection of horticultural crops and graph deigning and illustrations. All authors read and approved the final manuscript.

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Availability of data and materials
The data of this study are derived from the following resources available in the public domain: district-wise mean monthly temperature and precipitation from ClimateCharts.net—an interactive climate analysis web platform, International Journal of Digital Earth, https://doi.org/10.1080/17538947.2020.1829112; Area and production of horticultural crops in Madhya Pradesh from http://nhb.gov.in/Statistics.aspx?enc=WkegdyuHokljEtehnJoq0KWLU79sOQCy+W4MfOk01GFOWQSEvtp9tNHHoiv3p49g, https://agricoop.nic.in/sites/default/files/area_horticulture11_12_1.pdf, https://eands.dacnet.nic.in/Publication1212012/Agriculture_at_a_Glance%202012/Pages173-241.pdf and http://www.mphorticulture.gov.in/en/related-to-department/statistics; Major horticultural crops grown in the districts from http://www.mphorticulture.gov.in/sites/default/files/Coffee%20Table%20Book.pdf; Map of India from https://cpwd.gov.in/panindia.aspx and map of Madhya Pradesh from http://inst.mhrd.gov.in; Vulnerable districts map drawn from https://gramener.com/indiamap/.

Declarations

Ethics approval and consent to participant
Not applicable.

Consent to publication
All authors agreed and approved the manuscript for publication in *Ecological Processes*.

Competing interests
The authors have no competing interest to declare.

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