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Possible future climate for rice growing regions in India: Visualising 2050 and pest-related impact thereof

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ABSTRACT

Changes in climatic variables may affect phenological phases of crops and affect plant growth and development, these changes also lead to emergence of new pests and diseases. Therefore, there is need to relate the trends of climatic parameters with rice productivity vis-á-vis the pest dynamics in the crop at different sites apart from projecting a future scenario for the crop in the country. For this long-term seasonal, monthly and weekly trends in climatic data, viz. temperature (maximum and minimum), relative humidity (morning and afternoon), rainfall and bright sunshine hours on seasonal (*kharif* or rainy season, *rabi* or post-rainy season and summer), monthly (January to December) and weekly (1-52 standard meteorological week or SMW) time scales for the period 1970–2010 at 14 different agro-climatic centers situated in rice growing regions of India were investigated. Mann–Kendall and Sen's slope estimator, non-parametric test were used for studying the magnitute as well as statistical significance of trend in climatic data. Trend analyses of the climatic variables in rice growing regions of different locations (Palampur, Chiplima, Jagdalpur, Kaul, Cuttack, Kanpur, Hyderabad, Bengaluru, Samastipur, Pantnagar, Parbhani, Varanasi, Pune and Coimbatore) in India were studied. Positive trend for maximum temperature [for *kharif* season varied from 0.006°C/yr (Pune) to 0.045°C/yr (Chiplima)] were observed at five locations, negative trends [maximum for Jagdalpur (0.047°C/yr) and minimum for Bengaluru (0.011°C / yr)] were observed at eight locations while one location showed no change in maximum temperature. Minimum temperature showed increasing trend at most of the locations in *kharif* seasons. Relative humidity in the morning and afternoon also showed increasing trend at most of the locations in *kharif*. Increase in rainfall for *kharif* season varied from 8.990 mm/yr (Chiplima) to 0.008 mm/yr (Parbhani); the decrease was highest for Jagdalpur (5.329 mm/yr) followed by Coimbatore (4.485 mm/yr) and least for Varanasi (0.213 mm/yr). Positive and negative trends for total rainfall were observed at seven locations each. In *kharif* season (23-39 SMW), weekly maximum temperature showed a rising trend except at Cuttack, Kaul, Bengaluru, Pantnagar, Parbhani and Coimbatore while minimum temperature showed the increasing trend except at Palampur, Kanpur and Parbhani. Rainfall pattern showed a falling trend except at Cuttack, Hyderabad, Chiplima, Pune and Coimbatore. Monthly analysis of maximum temperature indicates that the trends are increasing in months of February, March, April, July, August and November while the trends are decreasing in months of January, May, June, September, October and December at most of the locations. Mimimum temperature showed an increasing trend in all months except January. Rainfall showed negative trends in monthly total rainfall during June-September. In June, seven locations showed negative trends which varied from 0.246 mm/yr (Kanpur) to 3.703 mm/yr (Jagdalpur); in July, 10 locations indicated negative trends that varied from 0.231 mm/yr (Samastipur) to 2.144 mm/yr (Chiplima); in August and September eight locations had negative trends. Coimbatore showed negative trends in monthly rainfall from May to December, the decrease was highest for November (4.854 mm/yr) and least in June (0.246 mm/yr). Based on these trends in climatic variables, monthly projected mean and seasonal change till 2050 were also obtained. The changes in climatic variable can be utilised for identification of the hotspot zones of important pest of rice based on the physiological aspect of pest. These changes may lead to possible rise in blast disease of rice at Kaul, Hyderabad and Pune. There looks a possible trend in reduction of the yellow stem borer insect-pest on rice crop in Central and Peninsular India with rise in the Northern latitudes of the country. There is need to relate the trends of climatic parameters with rice productivity vis-á-vis the pest dynamics in the crop at different sites apart from projecting a future scenario for the crop in the country.

Key words: Climate variability, Mann–Kendall test, Non-parametric test, *Oryza sativa, Pyricularia oryzae, Scirpophaga incertulas,* Trend analysis

Changes in climatic variables, viz. temperature, rainfall, etc. may affect global agricultural production (Smith *et al.* 2000, IPCC 2007, Chandrappa *et al.* 2011). Increase in temperature shortens the phenological phases of crops, viz.

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planting, flowering and harvesting (Liu *et al.* 2010, Teixeira *et al.* 2013) and affects plant growth and development. Extremes of rainfall results droughts and floods which are very detrimental to rice productivity (Reid *et al.* 2007, Roudier *et al.* 2011). These extreme conditions of climate reduce rice yield significantly (Lansigan *et al.* 2000, Teixeira *et al.* 2013). High coefficient of variation in yields of *Oryza sativa* or rice crop (25-38%) is explained due to climatic (temperature, precipitation) variation with special reference to central India as compared to safer regions, viz. West Bengal (Ray *et al.* 2015). Therefore, weather patterns are critical components of agricultural production systems.

Analysis of spatial and temporal variability of the climatic variables on local scale on varied time sets (annual, seasonally and weekly) can more accurately represent the complex climate that exists in India as changing pattern of climate could lead to emergence of hitherto new pests and diseases. Historically, climate analysis has been performed on continental and global scales (Pielke *et al.* 2000). However, with such local complexities, there is need to define local climate patterns. These analyses may provide new insights into patterns in climatic variables. Effect of climate change on insect-pests and diseases of agricultural crops is multidimensional. Magnitude of this impact could vary with the type of species and their growth patterns. Vegetation exposed to extreme thermal regime, salinity regime, rising atmospheric concentration of carbon dioxide, sulphur dioxide etc may undergo special adaptive changes through the process of evolution or mutation. Intergovernmental Panel on Climate Change (IPCC) in its report of 1995 predicted that doubling the level of CO_2 in atmosphere could possibly increase yield in several crops by 30%. Observations of changing crop pest distribution over the twentieth century suggested that growing agricultural production and trade have been most important in disseminating them. But there is some evidence for a latitudinal bias in range shifts that indicates a global warming signal (Bebber 2015). The increased production could be off-set partly or entirely by the insect-pests, pathogens or weeds. It is, therefore, important to consider all the biotic components under the changing pattern of climate. Prasad *et al.* (2007) reported yield losses due to yellow stem borer (*Scirpophaga incertulas*) in rice ranging 38%-50%. In terms of grain production loss over ecosystems, 1% dead heart, or white ear head, or both phases of stem borer damage may be 108 kg/ha, 174 kg/ha and 278 kg/ha, respectively (Muralidharan and Pasalu 2006). In India, rice blast (pathogen: *Pyricularia oryzae*) appears in almost all geographical regions wherever rice is grown. About 564000 tonnes of rice is lost due to blast in Eastern India alone, nearly 50% (246000 tonnes) in the upland ecosystem (downloaded from http://www.nrcpb.org/NAIP_WEBSITE/project_trs.html on 11 Jan 2016, 23:01 hrs IST).

Several investigations addressed trends in climate change on a national and global scale, using surface observations and remote sensing platforms (Diaz and Quayle 1980). However, few researchers have studied climate on a local scale. Historically, climate researchers have used trends for single location and extrapolated these trends for a larger area (Pielke *et al.* 2000), which have looked at the trends on the country, regional scales and at the individual stations. Many attempted to determine the trend in rainfall and temperature on both country and regional scales because these two climatic variables are most important regarding climate change. Most of these studies deal with the analysis of annual and seasonal series for some individual stations or groups thereof. Jain and Kumar (2012) stated that there is no clear trend in average annual rainfall in India. Sen Roy and Balling (2004) analysed rainfall data for large number of stations in India and showed the increasing trend in a contiguous region extending from the northwestern Himalayas in Kashmir through most of the Deccan Plateau in the south with decreasing values in the eastern part of the Gangetic Plains, parts of Uttarakhand. Pal and Al-Tabbaa (2009) studied the trends in seasonal rainfall extremes in Kerala, winter and post-monsoon extreme rainfall having an increasing tendency with decreasing trends in spring seasonal extreme rainfall. Kothawale *et al.* (2010) studied the association between El Niño Southern Oscillation (ENSO) and monsoon rainfall over India and reported a strong association between El Niño events and deficient monsoon rainfall, which showed that nearly 60% of major droughts over India have occurred in association with El Niño events. Kumar *et al.* (2010) showed that the monsoon rainfall in India exhibited no significant trend over a long period of time, particularly in the all-India scale.

Pramanik and Jagannathan (1954) showed that there is no clear trend in temperature in India. Hingane *et al.* (1985) found that the mean annual temperature was increasing over the west coast, interior peninsula, north central and northeastern regions of India. Pant and Hingane (1988) observed the decreasing trend in mean annual surface air temperature over the northwest Indian region consisting of the climatic sub-divisions of Haryana, Punjab, east Rajasthan, west Rajasthan and west Madhya Pradesh. Rao (1993) showed highly significant trend of warming in the mean maximum, minimum and average mean temperatures of the Mahanadi river basin. Rupa Kumar *et al.* (1994) indicated that the maximum temperature have increasing trend in India although there was no trend for minimum temperature, resulting in rise in mean and diurnal range of temperature. Increasing trend in temperature range over the northwestern Himalayan region were reported by Bhutiyani *et al.* (2007). Pal and Al-Tabbaa (2010) revealed that monthly maximum temperature increase unevenly over the last century while changes in minimum temperature were more significant than variability in maximum temperature both temporally and spatially. Most of the researchers looked into trend analysis of temperature especially on annual and seasonal temperature for a single station or a group of stations.

Thus, there was an urgent need to study the effects of climatic change on pest scenario to predict the severity of important pathogens of major crops in real-field conditions. These changes have direct effect on growth and multiplication, spread and severity/infestation of many plant pathogens / insect-pests, which in turn are affecting the pattern of their infestation (Lamichhane *et al.* 2015, West *et al.* 2015). Weather is an important determinant in the population dynamics of the pests. Most of the earlier workers studied the weather and pest-relationship utilizing regression models (both linear and nonlinear) for insect-pest forewarning (Desai *et al.* 2004, Chattopadhyay *et al.* 2005a, 2005b, Dhar *et al.* 2007, Agrawal and Mehta 2007, Laxmi and Kumar 2011a, 2011b, Kumar *et al.* 2012 and Kumar *et al.* 2013). These studies restricts to evaluate short term relationship between weather and pest. Population dynamics of pests is dependent upon temperature and humidity among several weather factors. Small change in temperature can result in changed virulence as well as appearance of new pests in a region. Areas which are presently uncongenial for pests may become favourable to breed due to rise in temperature. However, it needs to be understood that insects (including insect-pests) and microorganisms (including crop pathogens) could adapt to slow changes in the environment (viz. increase in temperature) and thus their favourable thermal range could also shift. Any change in them, depending upon their base value, can significantly alter the scenario, which ultimately may result in yield loss.

In this study, trend analysis of the climatic variables, viz. maximum, minimum temperature, relative humidity, rainfall and bright sunshine hours for different seasons (*kharif* or rainy season, *rabi* or post-rainy season and summer), across months (January to December), and weeks (1-52 standard meteorological week or SMW) for different rice growing regions in India were investigated. Based on available projections of temperature and humidity, the possible future pests have been attempted to be foreseen.

MATERIALS AND METHODS

Observations on different climatic variables were analysed on time series across weeks, months and seasons. Data for standard meteorological weeks (SMWs) were obtained from fourteen locations, viz. Palampur (32°11'N, 76°53'E): 1980-2010; Chiplima (21°28'N, 84°01'E): 1986-2010; Jagdalpur (19°05'N, 82°04'E): 1980-2008; Kaul (28°16'N, 77°05'E): 1981-2010; Cuttack (20°28'N, 85°54'E): 1970-2009; Kanpur (26°28'N, 80°24'E): 1971-2011; Hyderabad (17°20'N, 78°30'E): 1980-2010; Bengaluru (12°58'N, 77°38'E): 1980-2010; Samastipur (25°98'N, 85°67'E): 1980-2010; Pantnagar, (28°97'N, 79°41'E): 1970-2008; Parbhani (19°08'N, 76°5'E): 1980-2010; Varanasi (25°20'N, 83°00'E): 1980-2008; Pune (18°31'N, 73°55'E): 1971-2008 and Coimbatore (11°00'N, 77°00'E): 1985-2009).

The climate variables on maximum temperature (MaxT), minimum temperature (MinT), relative humidity in the morning (RHI) and afternoon (RHII), rainfall (RF) and bright sunshine hours (BSH) were analysed. For each location 52 weekly series (1st to 52nd SMW), three seasonal (Summer season: 9-22 SMW; *kharif*: 23-39 SMW; *rabi*: 40-8 SMW) and 12 monthly series (January to December) were obtained. These data were procured from India Climatic Department, India Meteorological Department (IMD), Pune and AICRP-AM located at the ICAR: Central Research Institute for Dryland Agriculture, Hyderabad. Weekly population of yellow stem borer (YSB: *Scirpophaga incertulas*) at various experimntal stations, viz. Mandya (12°52'N, 76°9'E) (Karnataka); Raipur (20°91'N, 82°E) (Chhattisgarh); Ludhiana (30°54'N, 75°48'E) (Punjab); Chinsurah (22°91'N, 82°E) (West Bengal); Karjat (18°91'N, 73°3'E) (Maharashtra) and Aduthurai (11°N, 79°3'E) (Tamil Nadu) in India from 1995 to 2010 were utlised for developemnt of forewarning models. The data pertaining to the weather variables, viz. maximum temperature, minimum temperature, morning relative humidity, evening relative humidity and rainfall (X1 to X5) were considered as independent variables.

Analysis of a time series consists of the magnitude of trend and its statistical significance. Sen's estimator (non-parametric method) was used for obtaining the magnitude of trend in a time series data. To ascertain the presence of statistically significant trend in climatic variables with reference to climate change, non-parametric Mann–Kendall (M-K) test was employed. The total change during the observed period was obtained multiplying the slope by the number of years (Tabari and Hosseinzadeh Talaee 2011).

Mann (1945) presented a non-parametric test for randomness against time, which constitutes a particular application of Kendall's test for correlation commonly known as the Mann-Kendall test. This test is applied at the local and also at the regional scale to judge the significance of the changes detected. As stated by Zhai and Feng (2008), this test has a number of advantages: (i) relative magnitudes (ranking) are used instead of the numerical values, which allows for 'trace' or 'below detection limit' data to be included, as they are assigned a value less than the smallest measured value, (ii) the data do not need to conform to a particular distribution; thus extreme values are acceptable (Hirsch *et al.* 1993), (iii) missing values are allowed (Yu *et al.* 1993) and (iv) in time series analysis, it is not necessary to specify whether the trend is linear or not (Yu *et al.* 1993, Silva 2004). For M-K test, the null hypothesis is H_0 of no trend, i.e. the observations of series are randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. The values are evaluated as an ordered time series and each figure is compared with all subsequent data.

Sen's estimator has been widely used for determining the magnitude of trend in climatic time series data. If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated by using a simple non-parametric procedure developed by Sen (1968). The slope estimates of N pair of data are first computed by

$$T_i = \frac{x_j - x_k}{j - k} \text{ for } i = 1,2,3...N \quad (1)$$

where, x_j and x_k are data values at time j and k ($j > k$), respectively. If there are n values of x_j in the time series we get as many as N = n(n-1)/2 slope estimates T_i. The median of these *N* values of T_i is Sen's estimator (β) of slope, is calculated as:

$$\beta = \begin{cases} T_{\frac{N+2}{2}} & N \text{ is odd} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & N \text{ is even} \end{cases} \quad (2)$$

A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series. Finally, β is tested with a two-sided test at the 100 (1-α)% confidence interval and the true slope may be obtained with the non-parametric test (Partal and Kahya 2006).

For the Mann-Kendall test, the time series must be serially independent. However, in many real situations the observed data are auto-correlated. The autocorrelation in the observed data may cause misinterpretation of the trend test results. The existence of positive serial correlation will increase the possibility of rejecting the null hypothesis of no trend while it is actually true, while negative serial correlation will decrease the possibility of rejecting the null hypothesis (Yue and Hashino 2003, Yue and Wang 2002). The Durbin–Watson statistic (Durbin and Watson 1950, 1971) is widely used to determine serial correlation in the time series data. It is also used to test, if the residuals are independent, against the alternative that there is autocorrelation among them. The test statistic of the Durbin–Watson procedure is mainly denoted by "d" and is calculated as follows:

$$d = \frac{\sum_{t=2}^{n}(e_t - e_{t-1})^2}{\sum_{t=1}^{n} e_t^2} \quad (3)$$

where e_t represents the observed error term (i.e. residuals). The value of "d" lies between zero to four; zero corresponding to perfect positive correlation and four to perfect negative correlation. If the error terms, e_t and e_{t-1}, are uncorrelated, the expected value of d is 2. The calculated value of d below 2 indicates stronger evidence for the existence of positive first-order serial correlation and vice versa. If there is a serial correlation in the time series, it should be "pre-whitened" to eliminate the effect of serial correlation before applying the Mann–Kendall test.

To ascertain the presence of statistically significant trend in climatic variables, *viz.* temperature, relative humidity, rainfall and bright sunshine hour, Mann–Kendall (M-K) test a non-parametric has been employed. The M-K test checks the null hypothesis H_0 of no trend, i.e. the observations are randomly ordered in time, against the alternative hypothesis H_1, where there is increasing or decreasing trend. The statistics (*S*) is defined as:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \text{sgn}(x_j - x_i) \quad (4)$$

where, x_j and x_i are data values at time *j* and *i* (*j* > *i*) and *N* is the number of data points. Assuming the $(x_j - x_i) = \theta$, value of sgn (θ) is computed as follows:

$$\text{sgn}(\theta) = \begin{cases} 1 \text{ if } \theta > 0 \\ 0 \text{ if } \theta = 0 \\ -1 \text{ if } \theta < 0 \end{cases} \quad (5)$$

This statistics represents the number of positive differences minus the number of negative differences for all the differences considered. The test statistic τ (tau) can be computed as:

$$\tau = \frac{S}{N(N-1)/2}$$

which has a range of –1 to +1 and is analogous to the correlation coefficient in regression analysis. The null hypothesis of no trend is rejected when S and τ are significantly different from zero. If a significant trend is found, the rate of change can be calculated using the Sen's slope estimator. For large samples, the test is conducted using a normal distribution, with the mean and the variance as follows:

$$E(S) = 0 \quad (6)$$

$$\text{var}(S) = \frac{\left[N(N-1)(2N+5) - \sum_{k=1}^{m} t_k(t_k - 1)(2t_k + 5)\right]}{18} \quad (7)$$

where, *m* is the number of tied (zero difference between compared values) groups and t_k the number of data points in the k^{th} tied group. The standard normal variables Z is then computed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{var}(S)}} \text{ if } S > 0 \\ 0 \text{ if } S = 0 \\ \frac{S+1}{\sqrt{\text{var}(S)}} \text{ if } S < 0 \end{cases} \quad (8)$$

If the computed value of |Z| > zα/2, the null hypothesis (H_0) is rejected at α level of significance in a two-sided test.

A weather-based model can be an effective scientific tool to thwart the impending attack of pest by forewarning the occurrence of the menace so that timely plant protection measures can be taken up. The extent of weather influence on pest development depends not only on the total magnitude but also on the distribution of weather variables over small time intervals. However, the use of data in small time intervals increases the number of variables in the model and in turn a large number of model parameters needs to be evaluated. This requires a long series of data for precise estimation of the parameters which may not be available in practice. Thus, a technique based on relatively smaller number of model parameters and at the same time taking care of entire weather distribution was used by taking weighted accumulation of weather variables and giving weights according to their importance in different time periods. In this approach, for each weather variable two indices were developed, one as simple total value of weather variables and the other one as weighted total, weights being correlation coefficients between variable to forecast and weather variables in respective weeks. The first index represents the total amount of different weather variables prevalent during the period under consideration while the other one takes care of distribution of weather variables with special reference to its importance in different weeks in relation to the variables of forecast. Similarly, for joint effects of weather variables, weather indices were developed as weighted accumulations of product of weather variables (taken 2 weather variables at a time), weights being correlation coefficients between variable of forecast and product of weather variables considered in respective weeks (Chattopadhyay *et al.* 2005). The form of the model was

$$Y_t = a_0 + \sum_{i=1}^{p} \sum_{j=0}^{1} a_{ij} Z_{ij} + \sum_{i \neq i'}^{p} \sum_{j=0}^{1} b_{ii'j} Z_{ii'j} + e$$

$$Z_{ij} = \sum_{w=t-6}^{t-1} r^j_{iw} X_{iw}$$

$$Z_{ii'j} = \sum_{w=t-6}^{t-1} r^j_{ii'w} X_{iw} X_{i'w}$$

where, Y_t, variable of forecast; X_{iw}, value of i^{th} weather variable in w^{th} week; r_{iw}, correlation coefficient between Y and i^{th} weather variable in w^{th} week; $r_{ii'w}$, correlation coefficient between Y and product of X_i and $X_{i'}$ in w^{th} week; Y_w, is pest population in w^{th} week; P, number of weather variable; n_1, initial week for which weather data were included in the model; n_2, final week for which weather data were included in the model; e, error term.

Stepwise regression technique was used for selecting important variables to be included in the model. In this study, weather-based forewarning models have been developed for yellow stem borer of rice for different experimental stations.

RESULTS AND DISCUSSION

In India, rice is grown mostly in *kharif* season. Therefore, the trends in *kharif* seasons have been explained more elaborately. Sen's slope estimator for three different seasons [S1: Summer season (9-22 SMW); S2: *kharif* season (23-39 SMW); S3: *rabi* season (40-8 SMW)] for various climatic variables is presented in Table 1. This table reveals that, maginitude of trend, i.e. Sen's estimator had positive drift for maximum temperature in five locations, negative tendency were noted in eight locations while one location showed no change in maximum temperature. Projected increase in maximum temperature for *kharif* season varied from 0.006°C/ yr

Table 1 Sen's slope estimator for three different seasons [S1: Summer season (9-22 SMW); S2: *kharif* season (23-39 SMW); S3: *rabi* season (40-8 SMW)] for various climatic variables

Location	Cuttack	Palampur	Kaul	Jagdalpur	Hyderabad	Chiplima	Bengaluru	Kanpur	Pantnagar	Parbhani	Pune	Samastipur	Varanasi	Coimbatore
MaxT (S1)	-0.006	0.100**	0.059*	-0.041*	0.011	0.050	-0.037*	0.025	-0.032	-0.004	0.000	0.025	0.006	-0.045*
MaxT (S2)	-0.012	0.029*	-0.020	-0.047*	0.000	0.045	-0.011	0.043	-0.021	-0.025	0.006	0.043	-0.012	-0.013
MaxT (S3)	-0.003	0.100**	0.000	-0.025	0.018*	0.100*	0.000	0.025	-0.027*	-0.006	0.013	0.025	0.000	-0.016
MinT (S1)	0.006	0.026	0.045*	-0.012	0.000	0.000	-0.012	0.007	0.035*	-0.036	0.000	0.007	0.014	0.010
MinT (S2)	0.006	-0.006	0.013	-0.014	0.015*	0.000	0.028	-0.008	0.030*	-0.025	0.009	-0.008	0.005	0.011
MinT (S3)	0.023*	0.000	0.013	-0.074*	0.012	-0.012	0.007	-0.017	0.019*	-0.060*	0.028	-0.017	0.014	0.011
RHI (S1)	0.011	0.068	0.000	0.911**	0.063	-0.051	0.462	0.170	0.200*	0.457	0.159	0.170	0.469	0.292*
RHI (S2)	0.025	0.297*	0.129*	0.200*	0.023	-0.061	0.275	-0.044	-0.026	0.000	0.000	-0.044	0.146	0.203*
RHI (S3	0.050*	0.202	0.135*	0.795**	-0.053	-0.194	0.424	0.257	0.100**	0.157	0.168	0.257	0.214	0.217**
RHII (S1)	0.053	-0.168	-0.119	-0.256	0.089	-0.228	0.031	-0.126	0.148	0.216	0.058	-0.126	0.186	0.300*
RHII (S2)	0.029	0.236*	0.100	-0.272*	0.200*	-0.105	-0.193	-0.210	0.006	0.186	0.066	-0.210	0.150	0.183
RHII (S3)	0.053	0.080	0.100	-0.288	0.048	-0.074	0.043	-0.100	0.208*	0.244	0.071	-0.100	0.400*	0.204
RF (S1)	-0.056	-0.326	-0.960	-1.071	0.379	0.417	-0.400*	-0.021	0.080	0.015	-0.080	-0.021	0.046	0.070
RF (S2)	3.558	-0.727	1.033	-5.329	3.359	8.990	-0.800*	-0.733	0.053	0.008	0.335	-0.733	-0.213	-4.485*
RF (S3)	-8.940**	-0.198*	-1.213	2.178	0.511	-1.733	-0.223	-0.059	0.080	-0.028	0.025	-0.059	0.075	-2.788

*Significant at 0.05 level; **significant at 0.01 level

(Pune) to 0.045°C/yr (Chiplima); the decrease was highest for Jagdalpur (0.047°C/yr) and least for Bengaluru (0.011°C/yr). Minimum temperature showed increasing trend in most of the locations in the season. Relative humidity in the morning and afternoon also showed an increasing trend in most of the locations in *kharif* season. The increase in rainfall for *kharif* varied from 8.990 mm/yr (Chiplima) to 0.008 mm/yr (Parbhani); the decrease was highest for Jagdalpur (5.329 mm/yr) followed by Coimbatore (4.485 mm/yr) and least for Varanasi (0.213 mm/yr). For total rainfall, positive and negative trends were observed at seven locations each.

The magnitude of monthly trend for climatic variables [maximum temperature (MaxT), minimum temperature (MinT), relative humidity in the morning (RHI) and afternoon (RHII), rainfall (RF) and bright sunshine hours (BSH)] for different locations are presented in Tables 2-7 respectively. Monthly analysis of maximum temperature indicated projected increase for most of the locations in months of February, March, April, July, August and November, the highest increase being in May for Palampur (0.098°C/yr). Decreasing trends for maximum temperature were observed in January, May, June, September, October and December in most of the locations and highest decrease was found in January for Pantnagar (0.076°C/ yr). Monthly minimum temperature showed a projected increase in all months except January. Samastipur (0.083°C/yr) showed the highest increase in April while Jagdalpur (0.079°C/yr) indicated the highest decrease in February.

Most of the locations showed negative trend in monthly total rainfall from June to September. In June, seven locations showed negative trend, which varied from 0.246 mm/yr (Kanpur) to 3.703 mm/yr (Jagdalpur); in July, eleven locations indicated negative drift that varied from 0.231 mm/yr (Samastipur) to 2.144 mm/yr (Chiplima); in August and September, eight locations had negative tendency, which varied from 0.005 mm/yr (Coimbatore) to 2.208 mm/yr (Kaul) and 0.079 mm/yr (Parbhani) to 1.626 mm/yr (Bengaluru), respectively. Coimbatore projected negative trend in monthly rainfall from May to December, the decrease being highest for November (4.854 mm/yr) and the least in June (0.246 mm/yr).

Trends in Standard Meteorogical Week (1-52 SMW) (inceasing, decreasing and no changes) and weekly trends in *kharif* season (23 SMW to 39 SMW) for different climatic variables are presented in Table 8 and 9 respectively. In *kharif* season, weekly maximum temperature projected a rise in all locations except at Cuttack, Kaul, Bengaluru, Pantnagar, Parbhani and Coimbatore while minimum temperature showed anticipated increase in all locations except at Palampur, Kanpur and Parbhani. Rainfall had a falling trend in all locations except at Cuttack, Hyderabad, Chiplima, Pune and Coimbatore. Relative humidity in the morning, indicates the increasing trends in most of the weeks except at Chiplima and Samastipur while relative humidity in the evening showed the increasing trends in most of the weeks except at Jagdalpur, Chiplima, Bengaluru and Kanpur.

Based on the change (total change during the observed

Table 2 Sen's slope estimator for monthly maximum temperature (MaxT) for different locations

Location	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Cuttack	-0.008	0.013	-0.004	-0.009	-0.009	-0.025	0.010	0.011	-0.015	-0.006	0.009	0.004	-0.007
Palampur	0.083*	0.085*	0.048*	0.060*	0.094*	0.022	0.044*	0.011	0.014	0.047*	0.067*	0.098*	0.067**
Kaul	-0.060*	0.025	0.100*	0.083*	0.008	-0.075	0.022	0.000	-0.029	0.000	0.020	-0.021	0.008
Jagdalpur	-0.024	-0.067*	-0.058*	-0.071*	-0.039	-0.055	-0.045	-0.042	-0.040	-0.024	-0.017	-0.033	-0.033*
Hyderabad	0.029*	0.011	0.016	-0.008	0.011	0.033	-0.008	0.010	-0.013	0.006	0.025*	0.039*	0.009*
Chiplima	0.100	0.119	0.044	-0.020	0.065	0.010	0.024	0.041	0.096	0.100*	0.100*	0.090	0.063*
Bengaluru	0.029	-0.004	0.000	-0.033	-0.050*	-0.017	0.000	-0.011	-0.013	-0.022	-0.020	-0.013	-0.008
Kanpur	-0.008	0.037	0.056*	0.046*	-0.008	0.020	0.048	0.055**	0.051*	0.027	0.033*	0.036*	0.028*
Pantnagar	-0.076*	0.000	-0.015	0.011	-0.058	-0.054	-0.015	-0.008	-0.016	-0.027	0.000	-0.034*	-0.023*
Parbhani	-0.017	-0.012	0.000	0.010	-0.011	0.000	-0.016	-0.017	-0.040	-0.015	0.006	0.017	-0.012
Pune	0.012	0.016	0.000	0.008	0.014	0.011	0.000	0.011	0.000	0.000	0.009	0.030	0.008
Samastipur	-0.110*	-0.038	0.000	0.025	-0.011	-0.009	0.013	-0.005	-0.009	-0.067*	-0.016	-0.038	-0.022
Varanasi	-0.033	-0.040	0.024	0.009	-0.022	-0.044	0.013	0.008	0.010	0.005	0.009	-0.006	-0.025*
Coimbatore	0.028	-0.019	-0.025	-0.050*	-0.030*	-0.013	-0.010	0.000	-0.018	-0.024	-0.006	-0.017	-0.012

*Significant trend at the 0.05 level; **Significant trend at the 0.01 level

Table 3 Sen's slope estimator for monthly minimum temperature (MinT) for different locations

Location	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Cuttack	0.032	0.021	0.020	0.005	0.000	0.000	0.008	0.006	0.005	0.008	0.027	0.033	0.013*
Palampur	-0.008	0.025	0.050	0.011	0.023	-0.028	0.003	0.000	-0.006	-0.025	-0.022	-0.009	0.000
Kaul	-0.024	0.019	0.021	0.063*	0.058*	0.000	0.029*	0.015*	0.013	0.053	0.030	0.000	0.022*
Jagdalpur	-0.013*	-0.079*	-0.050*	0.000	0.009	-0.014	-0.008	-0.025	-0.013	0.000	-0.039	-0.012*	-0.037*
Hyderabad	0.007	-0.025	-0.013	-0.010	0.012	0.036*	0.014*	0.014*	0.010*	0.014	0.031	0.012	0.011
Chiplima	-0.037	0.019	0.044	0.022	0.007	-0.051	0.000	0.000	0.000	0.075	0.100	-0.017*	0.003
Bengaluru	0.015	0.000	-0.014	-0.019	-0.005	0.014	0.029*	0.030*	0.020	0.017	0.029	0.000	0.007
Kanpur	-0.033	0.018	0.020	-0.007	0.004	-0.024	0.000	-0.008	0.000	-0.031	-0.005	-0.016	-0.008
Pantnagar	0.006	0.063*	0.033	0.029	0.050*	0.033*	0.033*	0.018*	0.040*	0.029	0.007	0.033	0.029*
Parbhani	-0.092*	-0.029	-0.017	-0.036	-0.065*	-0.022	-0.024*	-0.038*	-0.037*	-0.059*	-0.050	-0.062	-0.044*
Pune	0.020	0.023	0.000	-0.013	0.014	0.006	0.011*	0.007	0.018	-0.006	0.034	0.022	0.012
Samastipur	0.054	0.056*	0.057	0.083*	0.050	0.080*	0.067*	0.067*	0.058*	0.074*	0.119*	0.081*	0.075*
Varanasi	-0.029	0.047	0.025	0.011	-0.014	-0.021	0.000	0.019	0.028	0.045	0.008	0.011	0.009
Coimbatore	-0.011	0.045	0.027	0.002	0.000	0.000	0.012	0.010	0.030	0.002	0.024	-0.041	0.013

*Significant trend at the 0.05 level; **Significant trend at the 0.01 level

Table 4 Sen's slope estimator for monthly morning relative humidity (RHI) for different locations

Location	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Cuttack	0.037	0.074	0.000	0.000	0.016	0.045	0.009	0.000	0.025	-0.009	0.076	0.080*	0.038*
Palampur	0.109	0.149	-0.074	-0.062	0.260	0.216	0.230	0.129	0.404*	0.400	0.360	0.138	0.200
Kaul	0.042	0.094	0.138	-0.255	0.135	0.250	0.114	0.000	0.160*	0.314*	0.072	0.168*	0.100*
Jagdalpur	0.729**	1.164**	1.324**	1.162**	0.623*	0.247	0.100*	0.142*	0.267*	0.580*	0.750*	0.783	0.658**
Hyderabad	-0.132*	0.009	0.120	0.230*	-0.109	-0.089	0.023	0.025	0.072	-0.030	0.012	-0.136*	0.000
Chiplima	-0.333	-0.255	-0.400	-0.042	-0.190	0.136	-0.087	-0.106	-0.125	-0.118	-0.247	-0.191	-0.100
Bengaluru	0.300**	0.667**	0.630**	0.404**	0.325**	0.263*	0.300**	0.310**	0.261**	0.375**	0.387**	0.458**	0.392**
Kanpur	0.257*	0.246	0.201	0.049	0.215	0.000	-0.024	-0.074	0.026	0.256	0.349*	0.255*	0.133
Pantnagar	0.083*	0.000	0.077	0.250*	0.333*	0.000	-0.083	-0.017	0.044	0.164**	0.117*	0.067	0.077*
Parbhani	0.037	0.500*	0.683*	0.421*	0.353*	0.000	-0.012	0.000	0.071	-0.067	0.227	0.031	0.181*
Pune	0.243**	0.185*	0.346**	0.103	0.019	0.010	-0.020	-0.018	-0.014	0.028	0.088	0.190*	0.100*
Samastipur	-0.171	-0.056	-0.138	-0.238	-0.250	-0.144	-0.175*	-0.146*	-0.081	-0.057	-0.086	-0.100	-0.122
Varanasi	-0.111	0.250	0.500*	0.667*	0.372	0.250	0.017	0.088	0.140	0.331*	0.308*	0.146	0.269*
Coimbatore	0.126	0.250*	0.306*	0.318*	0.177*	0.224	0.260	0.235*	0.060	0.069	0.209*	0.156*	0.224**

*Significant trend at the 0.05 level; **Significant trend at the 0.01 level

period was obtained multiplying the slope by the number of years) in climatic variables these trends are extrapolated for 2020, 2030, 2040 and 2050. These projected change in climatic temperature and rainfall for a *kharif* season in different locations till 2050 are presented in Tables 10-11. Five locations showed a positive change in projected maximum temperature for the rice-growing region. Kanpur showed the highest positive change (3.46°C) while Pune (0.49°C) indicated the lowest positive variation; Hyderabad did not show any alteration in maximum temperature. Eight locations showed a negative change (i.e. maximum temperature will decrease). Jagdalpur (3.26°C) showed the highest alteration in negative direction while Bengaluru and Varanasi (0.79°C) had least negative change. Eight locations indicated positive change in projected minimum temperature (Pantnagar 2.40°C showed highest positive variation in minimum temperarture, Varanasi 0.35°C showed least alteration); Chiplima showed no possible modification till 2050. Six locations trended a positive change in rainfall (highest increase in rainfall was projected at Chiplima: 584.35 mm; Parbhani could have minimal rise in rain: 0.55 mm). Seven locations indicated a negative change in projected means of rainfall. Highest decrease (373.04 mm) was projected at Jagdalpur while least (15.09 mm) reduction is expected at Varanasi.

In this study an attempt has been made for estimating monthly mean projected changes (using Sen's estimator) in climatic variables, for different locations in different

Table 5 Sen's slope estimator for monthly afternoon relative humidity (RHII) for different locations

Location	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Cuttack	0.194	0.135	-0.017	0.100	0.058	0.056	0.133	0.029	-0.042	0.023	-0.020	0.072	0.043
Palampur	-0.060	0.029	-0.383*	-0.127	0.072	0.076	0.213	0.150	0.280*	0.135	0.144	-0.035	0.089
Kaul	0.400	0.155	-0.092	-0.233*	0.143	0.250	0.027	-0.044	0.185	0.083	-0.063	0.180	0.070
Jagdalpur	-0.481	-0.019	-0.155	-0.288	-0.165	-0.350	-0.348*	-0.376*	-0.373*	-0.433	-0.300	-0.305	-0.236
Hyderabad	-0.073	-0.083	0.133	0.207*	0.000	0.046	0.174	0.173	0.331*	0.133	0.120	-0.016	0.097*
Chiplima	-0.500	-0.017	-0.200	-0.200	-0.692	0.193	-0.117	-0.154	-0.500	0.042	0.249	-0.710	-0.144
Bengaluru	-0.063	0.286	0.100	-0.025	-0.030	-0.271*	-0.295*	-0.194*	-0.231	-0.104	-0.010	0.117	-0.063
Kanpur	0.047	0.034	-0.175	-0.182	-0.115	-0.171	-0.228	-0.284*	-0.100	-0.261	-0.128	-0.171	-0.124
Pantnagar	0.436*	0.229*	0.109	0.130	0.188	0.093	-0.041	-0.111	0.138	0.183	0.213	0.250*	0.125
Parbhani	0.019	0.261*	0.319*	0.176*	0.108	0.018	0.208	0.133	0.473*	0.260	0.414*	0.083	0.227*
Pune	0.085	0.076	0.090*	0.014	0.031	0.080	0.085	0.002	0.133	0.070	0.111	0.046	0.060*
Samastipur	0.417*	0.344*	0.223	0.179	0.247	0.172	0.213	0.175	0.105	0.183	0.367*	0.192	0.245*
Varanasi	0.247	0.670*	0.207	0.070	0.260	0.280	0.004	0.083	0.200	0.433	0.235	0.367	0.233*
Coimbatore	-0.057	0.247	0.220	0.343	0.342*	0.167	0.288	0.173	0.214	0.247	0.226	0.143	0.254*

*Significant trend at the 0.05 level; **Significant trend at the 0.01 level

Table 6 Sen's slope estimator for monthly rainfall (RF) for different locations

Location	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Cuttack	0.000	0.000	-0.036	-0.397	0.389	0.197	0.565	-0.608	1.129	-1.861	-0.100	0.000	2.859
Palampur	-0.262	-0.091	-0.575	-0.190	-0.288	-0.440	-1.818	-0.100	0.376	0.065	-0.010	-0.316*	-0.316
Kaul	-0.050	-0.347	-0.289	-0.190	0.000	1.305	-0.729	-2.208	3.762*	0.000	0.000	-0.222	-0.953
Jagdalpur	0.000	0.000	0.094	0.247	-0.400	-3.703	-1.429	-1.071	-0.290	0.981	0.000	0.000	-1.976
Hyderabad	0.000	0.000	0.000	0.338	0.138	-1.076	2.508*	1.236	0.467	0.410	0.200	0.000	4.887
Chiplima	0.000	0.000	-0.073	-0.105	-0.080	1.309	-2.144	-0.009	1.386	-0.079	0.000	0.000	8.372*
Bengaluru	0.000	0.000	0.000	-0.006	-0.821*	-0.573*	-0.600*	-0.480	-1.626*	-0.745*	-0.286*	-0.030	-3.386*
Kanpur	-0.025	0.000	-0.015	0.000	0.000	-0.246	-1.081*	-1.157*	-0.553	-0.033	0.000	-0.003	-4.605
Pantnagar	0.000	0.135	-0.021	0.005	0.141	0.038	-0.558	0.654	0.441	0.000	0.000	0.000	4.050
Parbhani	0.000	0.000	0.000	0.000	0.000	-0.386	-0.492	0.200	-0.079	0.029	0.119	0.000	0.753
Pune	0.000	0.000	0.000	0.000	-0.117	0.426	0.588	0.243	-0.037	0.134	0.000	0.000	5.733
Samastipur	0.000	0.000	0.000	0.000	0.487	0.296	-0.231	0.178	-0.905	0.352*	0.000	0.000	-1.850
Varanasi	-0.057	0.229	-0.005	0.000	0.036	0.590	-0.918	0.220	-0.456	0.046	0.000	-0.005	-1.489
Coimbatore	0.000	1.088*	1.293*	0.619	-0.683	-0.246	-1.076	-0.005	-1.469	-3.164*	-4.854*	0.451	-10.400*

*Significant trend at the 0.05 level; **Significant trend at the 0.01 level

Table 7 Sen's slope estimator for monthly bright sunshine hour (BSH) for different locations

Location	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Palampur	0.000	-0.020	0.033	-0.009	-0.014	-0.037*	-0.009	-0.035z	-0.050*	-0.008	0.007	0.011	-0.009
Hyderabad	-0.039*	-0.035*	-0.042*	-0.036*	-0.013	0.000	-0.040*	-0.017	-0.034*	-0.047*	-0.053*	-0.038*	-0.031*
Bengaluru	-0.013	-0.030	-0.052*	-0.045**	-0.050*	0.014	-0.035*	-0.042*	-0.038	-0.029	-0.024	-0.042	-0.032*
Pantnagar	-0.050*	-0.044*	0.020	0.000	0.011	0.030	-0.014	0.028	-0.011	-0.009	-0.029*	-0.067*	-0.010
Parbhani	0.000	-0.020	-0.013	-0.014	0.011	0.014	-0.011	-0.005	-0.031	-0.022	-0.024	0.000	-0.006
Pune	-0.036**	-0.027*	-0.025*	-0.025*	-0.021	-0.035	-0.033	-0.013	-0.037	-0.036*	-0.031*	-0.045**	-0.200*
Varanasi	-0.076*	-0.100*	-0.025	-0.041*	-0.058*	-0.055*	0.000	-0.026	-0.018	-0.043*	-0.079*	-0.106*	-0.050*
Coimbatore	-0.154*	-0.255**	-0.232*	-0.250**	-0.251*	-0.173	-0.134*	-0.163*	-0.150*	-0.047	-0.018	-0.212*	-0.028*

*Significant trend at the 0.05 level; **Significant trend at the 0.01 level

Table 8 Trends in weekly climatic variables for different locations

Location	MaxT			MinT			RHI			RHII			RF		
	↑	↓	NC	↑	↓	NC	↑	↓	NC	↑	↓	NC	↑	↓	NC
Cuttack	15	29	8	34	8	10	36	3	23	27	11	14	13	9	30
Palampur	48	3	1	18	24	10	44	6	2	25	17	10	12	22	18
Kaul	26	24	2	34	12	6	32	8	12	28	21	3	6	9	37
Jagdalpur	15	33	4	15	33	4	51	0	1	4	43	5	7	17	28
Hyderabad	34	10	8	31	15	6	21	20	11	33	11	8	10	7	35
Chiplima	39	10	3	37	17	1	5	39	8	10	36	6	12	7	33
Bengaluru	12	34	6	38	12	2	52	0	0	19	32	1	0	27	25
Kanpur	45	7	0	16	31	5	39	13	0	6	46	0	0	12	40
Pantnagar	7	38	7	46	4	2	39	11	2	39	11	2	6	9	37
Parbhani	17	30	5	4	44	4	35	11	6	42	4	6	8	8	36
Pune	34	14	4	37	10	5	39	12	1	40	8	4	13	5	34
Samastipur	16	32	4	50	0	2	2	47	3	46	6	0	6	10	36
Varanasi	27	12	3	31	16	5	43	7	2	43	8	1	9	7	36
Coimbatore	14	35	3	26	15	11	47	5	0	40	11	1	24	12	16

(↑ showed in increasing trends; ↓ showed decreasing trends and NC showed no change; numbers in colum indicates numers of weeks)

Table 9 Trends in weekly climatic variables for different locations in *kharif* seasons (23 SMW to 39 SMW)

Location	MaxT			MinT			RHI			RHII			RF		
	↑	↓	NC	↑	↓	NC	↑	↓	NC	↑	↓	NC	↑	↓	NC
Cuttack	3	11	3	8	4	5	6	0	11	6	5	6	12	5	0
Palampur	13	3	1	4	7	6	16	1	0	12	1	4	8	8	1
Kaul	5	11	1	11	4	2	10	2	5	10	7	0	5	6	6
Jagdalpur	12	5	0	12	5	0	16	0	1	0	16	1	3	13	1
Hyderabad	9	7	1	15	0	2	7	5	5	15	1	1	10	6	1
Chiplima	10	5	2	14	3	0	3	10	4	3	11	3	11	5	1
Bengaluru	4	9	4	17	0	0	17	0	0	0	17	0	0	17	0
Kanpur	17	0	0	5	10	2	6	11	0	1	16	0	0	12	5
Pantnagar	2	12	3	16	0	1	7	10	0	7	10	0	5	9	3
Parbhani	3	13	1	0	16	1	6	7	4	11	4	2	8	8	1
Pune	10	6	1	12	2	3	7	9	1	11	3	3	11	4	2
Samastipur	7	8	2	17	0	0	1	15	1	13	4	0	5	10	2
Varanasi	10	6	1	11	5	1	15	2	0	11	6	0	7	8	2
Coimbatore	6	11	0	10	2	5	13	4	0	14	2	1	8	4	5

years (2020, 2030, 2040 and 2050), which are presented in Table 12. This table reveals, six locations projected rise in maximum temperature, highest being at Palampur (4.77°C) and least at Kaul (0.43°C). Eight locations are forecasted to reduce on maximum temperature till 2050, most reduction being at Jagdalpur (3.06°C) and least at Cuttack (0.34°C). Eleven locations are projected to see rise in minimum temperature, highest being at Samastipur (4.93°C) and least at Chiplima (0.01°C). Minimum tempertaure is also forecast to fall at five locations, least reduction being at Kanpur (0.55°C) and most at Parbhani (1.13°C). Cuttack, Bengaluru, Samastipur, Pantnagar, Varanasi and Coimbatore are projected to see opposite trends for maximum and minimum temperatures, which could affect both the rice crop and pests variedly. However, most of the locations are showing projections of fall in maximum temperature and rise in minimum temperature, which could be due to lack of proper cooling due to inadequate radiation; this could result in possible rise in mean ambient temperature.

Considering fluctuation in weather varaiables over years, six locations projected rise in annual rainfall with Hyderabad (28.49 mm/year) indicating highest upsurge while least at Samastipur (1.03 mm/ year). Eight locations indicated a decrease in projected means of rainfall over years.

Table 10 Projected change in temperature during *kharif* (rainy) season at different locations till 2050

Location	Change in maximum temperature						
	2020	2025	2030	2035	2040	2045	2050
Palampur	1.26	1.40	1.54	1.69	1.83	1.97	2.11
Chiplima	1.57	1.80	2.02	2.25	2.47	2.70	2.92
Jagdalpur	-1.86	-2.10	-2.33	-2.56	-2.80	-3.03	-3.26
Kaul	-0.80	-0.90	-1.00	-1.10	-1.20	-1.30	-1.40
Cuttack	-0.59	-0.65	-0.71	-0.76	-0.82	-0.88	-0.94
Kanpur	2.17	2.38	2.60	2.81	3.03	3.25	3.46
Hyderabad	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bengaluru	-0.46	-0.51	-0.57	-0.62	-0.68	-0.73	-0.79
Samastipur	1.73	1.95	2.17	2.38	2.60	2.81	3.03
Pantnagar	-1.05	-1.16	-1.26	-1.37	-1.47	-1.58	-1.68
Parbhani	-1.02	-1.15	-1.27	-1.40	-1.52	-1.65	-1.77
Varanasi	-0.46	-0.51	-0.57	-0.62	-0.68	-0.73	-0.79
Pune	0.31	0.34	0.37	0.40	0.43	0.46	0.49
Coimbatore	-0.47	-0.54	-0.60	-0.67	-0.73	-0.80	-0.86
	Change in minimum temperature						
Palampur	-0.27	-0.31	-0.34	-0.37	-0.40	-0.43	-0.46
Chiplima	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jagdalpur	-0.57	-0.64	-0.71	-0.79	-0.86	-0.93	-1.00
Kaul	0.50	0.56	0.62	0.69	0.75	0.81	0.87
Cuttack	0.30	0.33	0.36	0.39	0.42	0.45	0.48
Kanpur	-0.40	-0.44	-0.48	-0.52	-0.56	-0.60	-0.64
Hyderabad	0.77	0.84	0.92	0.99	1.07	1.14	1.22
Bengaluru	1.15	1.29	1.43	1.57	1.71	1.85	1.99
Samastipur	-0.32	-0.36	-0.40	-0.44	-0.48	-0.52	-0.56
Pantnagar	1.50	1.65	1.80	1.95	2.10	2.25	2.40
Parbhani	-1.03	-1.15	-1.28	-1.40	-1.53	-1.65	-1.78
Varanasi	0.20	0.23	0.25	0.28	0.30	0.33	0.35
Pune	0.44	0.49	0.53	0.58	0.62	0.67	0.71
Coimbatore	0.40	0.46	0.51	0.57	0.62	0.68	0.73

Coimbatore (44.26 mm/ year) showed the highest projected decrease while Varanasi (1.888 mm/year) displayed the least change. The projections for increase or decrease in rainfall pattern also does not seem to follow any particular trend. However, the rise in temperature and precipitation in monsoon (*kharif*) beyond optimum requirement may affect yield and cropping area (Amin *et al.* 2015) for major rice producing season apart from similar problem for summer (*boro*) crop.

Eleven locations showed increase in projected mean morning relative humidity till 2050 with Jagdalpur (46.57%) shows the highest rise while Cuttack (2.36%) presented least upsurge. Chiplima (10.61%), Smastipur (9.57%) and Hyderabad (0.04%) indicates the fall in morning relative humidity. Rise in afternoon relative humidity is projected

Table 11 Projected change in rainfall during *kharif* (rainy) season at different locations till 2050

Location	Change in rainfall						
	2020	2025	2030	2035	2040	2045	2050
Palampur	-32.00	-35.64	-39.28	-42.91	-46.55	-50.19	-53.82
Chiplima	314.65	359.60	404.55	449.50	494.45	539.40	584.35
Jagdalpur	-213.17	-239.81	-266.46	-293.10	-319.75	-346.40	-373.04
Kaul	41.33	46.50	51.67	56.83	62.00	67.17	72.33
Cuttack	177.88	195.67	213.46	231.25	249.04	266.83	284.62
Kanpur	-36.66	-40.33	-43.99	-47.66	-51.33	-54.99	-58.66
Hyderabad	171.32	188.12	204.91	221.71	238.51	255.30	272.10
Bengaluru	-32.80	-36.80	-40.80	-44.80	-48.80	-52.80	-56.80
Samastipur	-29.33	-32.99	-36.66	-40.33	-43.99	-47.66	-51.33
Pantnagar	4.00	4.40	4.80	5.20	5.60	6.00	6.40
Parbhani	0.32	0.35	0.39	0.43	0.47	0.51	0.55
Varanasi	-8.71	-9.78	-10.84	-11.90	-12.96	-14.03	-15.09
Pune	16.74	18.42	20.09	21.77	23.44	25.11	26.79
Coimbatore	-161.45	-183.87	-206.29	-228.71	-251.14	-273.56	-295.98

Table 12 The monthly means projected change in climatic variables for different locations in different years (based on non-parametric trends)

Location	Year	Maximum temperature	Minimum temperature	Morning relative humidity	Afternoon relative humidity	Rainfall
Palampur	2020	2.838	0.047	8.283	1.812	-13.377
	2030	3.483	0.057	10.165	2.224	-16.417
	2040	4.128	0.068	12.047	2.636	-19.458
	2050	4.773	0.079	13.930	3.048	-22.498
Chiplima	2020	2.530	0.008	-5.714	-7.601	0.598
	2030	3.252	0.010	-7.346	-9.772	0.768
	2040	3.975	0.013	-8.979	-11.944	0.939
	2050	4.698	0.015	-10.611	-14.116	1.110
Jagdalpur	2020	-1.766	-1.546	26.894	-12.274	-19.038
	2030	-2.197	-1.923	33.453	-15.268	-23.681
	2040	-2.627	-2.300	40.013	-18.262	-28.324
	2050	-3.058	-2.677	46.572	-21.256	-32.968
Kaul	2020	0.245	0.930	4.107	3.304	3.437
	2030	0.306	1.162	5.134	4.129	4.296
	2040	0.368	1.395	6.161	4.955	5.155
	2050	0.429	1.627	7.188	5.781	6.682
Cuttack	2020	-0.211	0.685	1.476	3.004	-3.008
	2030	-0.253	0.822	1.772	3.604	-3.609
	2040	-0.296	0.959	2.067	4.205	-4.211
	2050	-0.338	1.096	2.362	4.806	-4.812

Contd.

Table 12 (*Concluded*)

Location	Year	Maximum temperature	Minimum temperature	Morning relative humidity	Afternoon relative humidity	Rainfall
Kanpur	2020	1.636	-0.343	7.326	-7.220	-12.974
	2030	1.963	-0.411	8.791	-8.664	-15.569
	2040	2.290	-0.480	10.256	-10.108	-18.164
	2050	2.617	-0.548	11.721	-11.552	-20.759
Hyderabad	2020	0.639	0.438	-0.024	4.870	17.940
	2030	0.765	0.524	-0.029	5.824	21.458
	2040	0.890	0.610	-0.034	6.779	24.975
	2050	1.015	0.695	-0.039	7.734	28.493
Bengaluru	2020	-0.525	0.398	15.989	-2.461	-17.652
	2030	-0.653	0.495	19.889	-3.061	-21.958
	2040	-0.782	0.592	23.788	-3.661	-26.263
	2050	-0.910	0.689	27.688	-4.261	-30.569
Samastipur	2020	-0.882	2.817	-5.470	9.389	0.590
	2030	-1.102	3.522	-6.837	11.736	0.737
	2040	-1.323	4.226	-8.205	14.083	0.884
	2050	-1.543	4.930	-9.572	16.430	1.032
Pantnagar	2020	-1.222	1.557	4.312	7.568	3.482
	2030	-1.466	1.869	5.174	9.081	4.179
	2040	-1.711	2.180	6.036	10.595	4.875
	2050	-1.955	2.491	6.899	12.109	5.572
Parbhani	2020	-0.325	-1.809	7.670	8.450	-2.082
	2030	-0.405	-2.251	9.541	10.511	-2.590
	2040	-0.484	-2.692	11.412	12.572	-3.098
	2050	-0.563	-3.133	13.283	14.633	-3.606
Varanasi	2020	-0.236	0.448	10.105	10.441	-1.090
	2030	-0.293	0.558	12.570	12.988	-1.356
	2040	-0.351	0.667	15.035	15.535	-1.622
	2050	-0.408	0.776	17.499	18.081	-1.888
Pune	2020	0.458	0.569	4.829	3.429	5.157
	2030	0.550	0.682	5.795	4.115	6.188
	2040	0.641	0.796	6.760	4.801	7.220
	2050	0.733	0.910	7.726	5.487	8.251
Coimbatore	2020	-0.548	0.302	7.173	7.657	-24.140
	2030	-0.700	0.385	9.165	9.784	-30.845
	2040	-0.852	0.469	11.158	11.911	-37.551
	2050	-1.004	0.553	13.150	14.038	-44.257

at ten locations. Varanasi (18.08%) showed the highest rise while Palampur (3.05%) is projected to have least increase in afternoon relative humidity while four locations show a negative trend, least being at Bengaluru and highest at Jagdalpur till 2050. Interestingly, some locations displayed opposite trends for relative humidity morning and relative humidity evening respectively, viz. Jagdalpur, Kanpur, Hyderabad, Bengaluru and Samastipur.

The seasonal projections (up to 2050) in climatic variable for different locations are presented in Table 13. Change in maximum temperature in *kharif* season had negative trend for eight locations, positive drift for five locations while one location (Hyderabad) exhibited no change. Kanpur showed the highest change (3.46°C) in positive direction while Jagdalpur projected highest reduction (3.26°C). Kaul, Cuttack, Bengaluru, Hyderabad, Pantnagar, Varanasi, Pune and Coimbatore indicated a positive projection, whereas Palampur, Jagdalpur, Kanpur, Pune and Parbhani showed a negative trend while no change was observed for Chiplima in anticipated minimum temperature till 2050. Pantnagar (2.40°C) and Parbhani (1.78°C) showed the highest changes for projected minimum temperature in positive and negative directions till 2050, respectively. Eight locations showed a positive trend, five locations indicated negative tendency while one location showed no change in projected morning relative humidity in *kharif* season. Palampur (21.9%) showed the highest change in projected morning relative humidity for this season. Nine locations showed a positive trend while five locations indicated negative drift in projected afternoon relative humidity, whereas Palampur (17.5%) and Jagdalpur (19.1%) indicated the highest changes in positive and negative directions, respectively for projected afternoon relative humidity. For projected change in rainfall, seven locations showed negative trends and remaining locations indicated a positive tendency. This study indicated highest increase and decrease in rainfall, respectively projected by Chiplima and Jagdalpur.

In *rabi* season, six locations showed a positive trend, five locations indicated negative tendency while three locations (Hyderabad) showed no change in projected maximum temperature. For *rabi* season the projected increase in maximum temperature for Palampur may reach up to 7.4°C, which clearly indicates that winter in this region is expected to gradually get warmer. Eight locations showed a positive trend, five locations indicated negative drift while one location showed no change in projected minimum temperature for *rabi* season. Projected change in minimum temperature for Jagdalpur can go down to 5.17°C till 2050. Most of the locations showed positive trend except for Chiplima and Hyderabad in future projection for morning relative humidity for *rabi* season. Jagdalpur showed significant increase in the morning relative humidity for *rabi* season. For projected change in afternoon relative humidity, nine locations showed positive trend and remaining five locations indicated negative drift. Highest increase in afternoon relative humidity was observed at Varanasi while Jagdalpur showed the highest reduction. For projected change in rainfall, nine locations showed positive and five locations indicated negative trend. Cuttack had significant increase in projected rainfall while Jagdalpur showed significant decreasing trend.

Muralidharan and Pasalu (2006) showed that the 1%

Table 13 The seasonal projected change in climatic variables for different locations in different years (based on non-parametric trends)

Location	Year	Maximum temperature		Minimum temperature		Relative humidity in morning		Relative humidity in afternoon		Rain fall	
		Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
Palampur	2020	1.26	4.40	-0.27	NC	13.06	8.89	10.4	3.5	-32.00	-8.71
	2030	1.54	5.40	-0.34	NC	16.03	10.91	12.7	4.3	-39.28	-10.69
	2040	1.83	6.40	-0.40	NC	19.00	12.93	15.1	5.1	-46.55	-12.67
	2050	2.11	7.40	-0.46	NC	21.97	14.95	17.5	5.9	-53.82	-14.65
Chiplima	2020	1.57	3.50	NC	-0.44	-2.12	-6.81	-3.7	-2.6	314.65	-60.67
	2030	2.02	4.50	NC	-0.56	-2.73	-8.75	-4.7	-3.3	404.55	-78.00
	2040	2.47	5.50	NC	-0.69	-3.33	-10.69	-5.8	-4.1	494.45	-95.33
	2050	2.92	6.50	NC	-0.81	-3.94	-12.64	-6.8	-4.8	584.35	-112.67
Jagdalpur	2020	-1.86	-1.00	-0.57	-2.96	8.00	31.80	-10.9	-11.5	-213.17	87.13
	2030	-2.33	-1.25	-0.71	-3.69	10.00	39.74	-13.6	-14.4	-266.46	108.92
	2040	-2.80	-1.50	-0.86	-4.43	12.00	47.69	-16.3	-17.3	-319.75	130.70
	2050	-3.26	-1.75	-1.00	-5.17	14.00	55.64	-19.1	-20.2	-373.04	152.48
Kaul	2020	-0.80	NC	0.50	0.50	5.14	5.40	4.0	4.0	41.33	-48.50
	2030	-1.00	NC	0.62	0.62	6.43	6.75	5.0	5.0	51.67	-60.63
	2040	-1.20	NC	0.75	0.75	7.71	8.10	6.0	6.0	62.00	-72.75
	2050	-1.40	NC	0.87	0.87	9.00	9.45	7.0	7.0	72.33	-84.88
Cuttack	2020	-0.59	-0.17	0.30	1.15	1.25	2.50	1.4	2.7	177.88	-947.00
	2030	-0.71	-0.20	0.36	1.38	1.50	3.00	1.7	3.2	213.46	-1136.40
	2040	-0.82	-0.23	0.42	1.62	1.75	3.50	2.0	3.7	249.04	-1325.80
	2050	-0.94	-0.27	0.48	1.85	2.00	4.00	2.3	4.3	284.62	-1515.20
Kanpur	2020	2.17	1.25	-0.40	-0.83	-2.21	12.87	-10.5	-5.0	-36.66	-2.93
	2030	2.60	1.50	-0.48	-1.00	-2.65	15.45	-12.6	-6.0	-43.99	-3.51
	2040	3.03	1.75	-0.56	-1.17	-3.09	18.02	-14.7	-7.0	-51.33	-4.10
	2050	3.46	2.00	-0.64	-1.33	-3.53	20.59	-16.8	-8.0	-58.66	-4.69
Hyderabad	2020	NC	0.93	0.77	0.59	1.15	-2.72	10.2	2.5	171.32	26.07
	2030	NC	1.11	0.92	0.70	1.38	-3.25	12.2	3.0	204.91	31.18
	2040	NC	1.29	1.07	0.82	1.60	-3.79	14.2	3.4	238.51	36.29
	2050	NC	1.47	1.22	0.93	1.83	-4.32	16.2	3.9	272.10	41.40
Bengaluru	2020	-0.46	NC	1.15	0.27	11.28	17.38	-7.9	1.8	-32.80	-9.15
	2030	-0.57	NC	1.43	0.34	14.03	21.61	-9.8	2.2	-40.80	-11.38
	2040	-0.68	NC	1.71	0.41	16.78	25.85	-11.8	2.6	-48.80	-13.61
	2050	-0.79	NC	1.99	0.47	19.53	30.09	-13.7	3.0	-56.80	-15.84
Samastipur	2020	1.73	1.00	-0.32	-0.67	-1.77	10.30	-8.4	-4.0	-29.33	-2.34
	2030	2.17	1.25	-0.40	-0.83	-2.21	12.87	-10.5	-5.0	-36.66	-2.93
	2040	2.60	1.50	-0.48	-1.00	-2.65	15.45	-12.6	-6.0	-43.99	-3.51
	2050	3.03	1.75	-0.56	-1.17	-3.09	18.02	-14.7	-7.0	-51.33	-4.10
Pantnagar	2020	-1.05	-1.36	1.50	0.95	-1.30	5.00	0.3	10.4	4.00	0.38
	2030	-1.26	-1.64	1.80	1.14	-1.57	6.00	0.4	12.5	4.80	0.46
	2040	-1.47	-1.91	2.10	1.33	-1.83	7.00	0.4	14.5	5.60	0.54
	2050	-1.68	-2.18	2.40	1.52	-2.09	8.00	0.5	16.6	6.40	0.62
Parbhani	2020	-1.02	-0.23	-1.03	-2.46	NC	6.44	7.6	10.0	0.32	-1.15
	2030	-1.27	-0.28	-1.28	-3.06	NC	8.01	9.5	12.4	0.39	-1.43
	2040	-1.52	-0.34	-1.53	-3.66	NC	9.59	11.3	14.9	0.47	-1.71
	2050	-1.77	-0.39	-1.78	-4.26	NC	11.16	13.2	17.3	0.55	-1.99

Contd.

Table 13 (*Concluded*)

Location	Year	Maximum temperature		Minimum temperature		Relative humidity in morning		Relative humidity in afternoon		Rain fall	
		Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
Varanasi	2020	-0.46	NC	0.20	0.59	5.99	8.76	6.1	16.4	-8.71	3.08
	2030	-0.57	NC	0.25	0.73	7.45	10.90	7.6	20.4	-10.84	3.83
	2040	-0.68	NC	0.30	0.87	8.92	13.03	9.1	24.4	-12.96	4.58
	2050	-0.79	NC	0.35	1.01	10.38	15.17	10.6	28.4	-15.09	5.33
Pune	2020	0.31	0.67	0.44	1.39	NC	8.39	3.3	3.6	16.74	1.25
	2030	0.37	0.80	0.53	1.67	NC	10.06	4.0	4.3	20.09	1.50
	2040	0.43	0.93	0.62	1.95	NC	11.74	4.6	5.0	23.44	1.75
	2050	0.49	1.07	0.71	2.23	NC	13.42	5.3	5.7	26.79	2.00
Coimbatore	2020	-0.47	-0.58	0.40	0.41	7.31	7.83	6.6	7.4	-161.45	-100.36
	2030	-0.60	-0.74	0.51	0.53	9.34	10.00	8.4	9.4	-206.29	-128.24
	2040	-0.73	-0.90	0.62	0.64	11.36	12.18	10.3	11.4	-251.14	-156.12
	2050	-0.86	-1.06	0.73	0.75	13.39	14.35	12.1	13.5	-295.98	-183.99

dead heart and stem borer damaged may be range from 108 kg/ha to 278 kg/ha respectively. It seems that the stem borer is one of the major pest which may cause a loss in paddy crop to a great extent therefore, forewarning models for yellow stem borer in rice crop were developed for different agroclimatic zones of India, viz. Aduturai, Chinsurah. Karjat, Mandya and Raipur. The form of model along with the coefficient of determination are presented in Table 14. This table shows that minimum temperature play a significant role in infestation of yellow stem borer (YSB) in most of the experimental stations. The models indicated that the change in minimum temperature in positive direction may lead to severe infestation of YSB in all experimental stations except Aduthurai (Tamil Nadu region). Fall in minimum temperature was correlated with increase in borer population, which matched with that of Reji *et al.* (2014) for Coimbatore and could be due to proximity of the place to equator, whereby the range of minimum temperature provides comfortable conditions for the infestation of pest especially yellow stem borer. Keeping this scenario in mind Palampur, Jagdalpur, Samastipur and Parbhani, may witness a reduction in yellow stem borer on rice while in other locations, viz. Hyderabad, Bengaluru and Pantnagar could possibly observe more severe infestation of YSB in future (till 2050) as the change in minimum temperature are in positive direction. However, Jagdalpur seem to be headed for reduction in *S. incertulas* infestation while at Palampur, Kaul, Cuttack, Samastipur, Varanasi and Pune the insect-pests may be more damaging. Thus, there looks a possible trend in reduction of the insect-pests in Central and Southern Peninsular India and rise in the Northern latitudes of the country.

Table 14 Forewarning model for yellow stem borer in different agro-climatic zone in India along with coefficient of determination

Location	Model equations	R^2
Aduturai	$Y=-12147+209.352Z_{41}-2319.29Z_{21}$	0.919
Chinsurah	$Y=1798.798+70.363Z_{21}$	0.427
Karjet	$Y=896.365+94.936Z_{21}+0.341Z_{141}$	0.842
Mandya	$Y=-6842.538+143.444Z_{21}-0.420Z_{230}$	0.741
Raipur	$Y=49689+1189.677Z_{21}+2.335Z_{131}$	0.867

Z_{21}= Weighted minimum temperature; Z_{41} weighted relative humidity in evening; Z_{141} =weighted interaction of maximum temperature with relative humidity in evening; Z_{230} = unweighted interaction of minimum temperature and relative humidity in morning; Z_{131} = weighted interaction of maximum temperature and relative humidity in morning.

Weather-based forewarning model are being attempted for blast disease of rice using historical data for two agro-climatic locations, viz. Palampur and Banswara. In this model, the significant variables were minimum temperature and its interaction with rainfall for each week after transplanting. Both variables were positively correlated, which means, if they increase, the blast disease at the location may become more destructive. Thus, the disease may possibly rise at Kaul, Hyderabad and Pune, where both these parameters show increasing trends within optimal requirement of the pathogen (Kapoor *et al.* 2004).

Conclusion

The average surface temperature increased while annual and monsoon rainfall decreased in India that was reported by various researchers. However, these studies are based on individual sites or on a small number of sites. In the present study, an analysis was carried out to identify the trends in climatic variables for various rice growing regions.

The positive trend for maximum temperature in *kharif* season were observed in five locations, negative drift were noted in eight sites while one place showed no change in the variable. The minimum temperature in *kharif* season showed increasing trend in most of the locations in these seasons. Relative humidity in the morning and afternoon also showed increasing trend in most of the locations in *kharif*. The positive and negative trends for total rainfall were observed in seven locations each. Monthly analysis of maximum temperature indicated that the trends are increasing for most of the locations in months of February, March, April, July, August and November while the drifts are decreasing in the months of January, May, June, September, October and December in most of the sites. The increasing trends in monthly mimimum temperature showed increasing tendency in all months except January.

Most of locations showed negative trends in monthly total rainfall from June to September. In *kharif* season, weekly maximum temperature showed a rising trend at most locations while minimum temperature showed increasing tendency in most of the sites. Rainfall showed a falling trend in south and western Indian locations. The projected mean change in climatic variables for 2020, 2030, 2040 and 2050 were also studied. This indicates the overall increase in maximum temperature in most of the locations. For rainfall, eight locations showed decreasing trends in projected mean.

The effect of these changes in climatic variables on population dynamics of yellow stem borer (YSB), a rice pest indicates that minimum temperature plays a significant role for infestation of this pest. Keeping minimum temperature as a favorable climatic variable for infestation of YSB, these information may be linked with the other locations where trend analysis were attempted. Based on this scenario Hyderabad, Bengaluru and Pantnagar may be hotspots for YSB in future (till 2050) as the change in minimum temperature are in postitve direction. These climatic variablility may lead to possible rise in blast disease of rice at Kaul, Hyderabad and Pune. There is need to relate the trends of climatic parameters with rice productivity vis-á-vis the pest dynamics in the crop at different sites apart from projecting a future scenario for the crop in the country.

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