Extreme Weather Events and Its Impacts on Rice Production in Coastal Odisha Region of India

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Abstract

The study investigates trend in extreme daily precipitation and temperature over coastal Odisha, India. 18 weather indices (8 related to temperature and 10 related to rainfall) were calculated using RClimDex software package for the period 1980–2010. Trend analysis was carried out using linear regression and non-parametric Mann-Kendall test to find out the statistical significance of various indices. Results indicated, a strong and significant trend in temperature indices while the weak and non-significant trend in precipitation indices. The positive trend in $T_{\max}$ mean, $T_{\min}$ mean, TN90p (warm nights), TX90p (warm days), diurnal temperature range (DTR), warm spell duration indicator (WSDI), consecutive dry days (CDD) indicates increasing the frequency of warming events in coastal Odisha. Similarly, positive trend in highest maximum 1-day precipitation (RX1), highest maximum 2 consecutive day precipitation (RX2), highest maximum 3 consecutive day precipitation (RX3), highest maximum 5 consecutive day precipitation (RX5), number of heavy precipitation days ($\geq 64.5\text{mm}$), number of very heavy precipitation days ($\geq 124.5\text{mm}$) and negative trend in the number of rainy days ($R2.5\text{mm}$), consecutive wet days (CWD) indicate changes toward the more intense and poor distribution of precipitation in coastal Odisha. The combined effect of precipitation and temperature extreme events showed negative effects on rice grain yield. With the increasing number of extreme events there was sharp decline in rice grain yield was observed in the same year in all the coastal districts. This study emphasizes the need for new technology/management practice to minimize the impacts of extreme weather events on rice yield.

1 Introduction

The change in the frequency of extreme weather events is considered an indicator of climatic variability. The frequency of extreme events like flood, drought, heatwaves and cold waves were increased in India especially in Odisha (De et al. 2005). A small change in the mean climate condition can cause large changes in agriculture production systems (Cruz et al. 2007). A precise spatial and temporal understanding of changes in the frequency of extreme weather events is of great importance because of their large impact on agriculture and its allied sectors. The second report of the Intergovernmental Panel on Climate Change (IPCC) has highlighted the lack of information on climate trends and variability, and daily climate extremes, between regions and globally (IPCC 1995). The IPCC emphasizes that a comprehensive assessment and understanding of the vulnerability of an area is critical for developing adaptive measures and resilience building (IPCC 2007). The trend analysis helps in understanding events of the past, and predict future events.

Natural disaster, become regular phenomena in coastal Odisha which harms standing crop and causes yield loss. The state's fluctuating weather conditions suggest that it is reeling under climatic chaos. For more than a decade now, it has experienced contrasting extreme weather conditions: from heat waves to cyclones, from droughts to floods (Mishra 2015). The frequency of cyclones has increased on the Odisha coast. Multiple cyclones hit the state in quick succession. Odisha has encountered with catastrophic events like flood, drought and cyclone in almost all the years since 1965. Between the period 1965 to 2004, floods have occurred 17 times, droughts 19 times, and cyclones have hit the state 7 times (OSDMA

2011). Since, 1965, these extreme events not only become more frequent, they are striking areas that have never experienced such conditions before. For instance, a heatwave in 1998 killed around 2,200 people most of the casualties were from coastal Odisha, a region known for its moderate climate (Jena 2018). Since 1998, almost 3,000 people have died due to heatstroke. Earlier, in eastern India, the western Odisha was a known calamity hotspot, but now the coastal areas are also considered as calamity hotspot due to regular occurrence of a tropical cyclone, drought, flood, heat waves etc (Ray et al. 2015). Now this region is considered as the most vulnerable to all kind of weather extremes due to frequent occurrence of weather extremes. Recently on May 3, 2019, Odisha has been battered by one of the strongest cyclone (Fani) to have hit India in the last 20 years, caused extensive damage and impacted life and property of more than 1.65 crore people in 14 districts of the state. At least Rs 1,00,000 crore (\$14 billion) is required to rebuild the damaged houses and public infrastructure (The Hindu Business Line 2019). The most affected people are the poor and socially disadvantaged groups and the least equipped to cope with the sudden, adverse effects. The small and marginal farmers account 70% of the total farming community in Odisha (Hartmann et al. 2013). The coastal Odisha which is the most fertile region in Odisha and account 40 per cent of the total rice produced every year in the state. This signifies the contribution of coastal Odisha region to the state food basket.

The study on changes in extreme weather events is highly imperative for better disaster management and agricultural planning. In the recent past, many studies on weather extremes were undertaken using ETCCDI indices in India as well as globally (Hasib and Saiful Islam 2012; Keggenhoff et al. 2014; Gbode et al. 2015). Several regional studies have been done to study recent trends and variability in various climate variables in India. Most of the study in India has been carried out on rainfall and only a few studies have been done in temperature extremes (Revadekar et al. 2012). Only, very little work has been carried out on the climate extremes at regional level especially in eastern India and no study available for Odisha coast due to absence of relatively long term historical weather data sets in the past. Keeping in view an attempt has been made to analyze the trend in the temperature and rainfall extremes over coastal districts of Odisha from 1980 to 2010 using ETCCDI indices. The objectives of our work were (1) to assess changes and trends in precipitation and temperature through computing different extreme indices and (2) to assess the impact of the precipitation and temperature extreme on rice grain yield over coastal Odisha

2 Materials And Methods

2.1 Study area

Odisha state is situated in the Eastern part of India. The vast area of its border (480 km) is shared with the Bay of Bengal. The coastal district lies in the eastern part of the state between the latitudes 19.63°N and 21.48°N and between longitudes 85.00°E and 86.81°E and plays a major role in the state economy (Fig. 1). The soil in this region is highly fertile and formed through the soils of the river valleys (alluvial). Agriculture is the major sector providing employment and livelihood security to the people (Sahu et al. 2015). The major crops cultivated in coastal Odisha are rice, pulses, oilseeds, coconut etc. Coastal

Odisha is characterized by smallholder farming systems and high levels of poverty. Climatically, this region is classified as tropical and characterized by high temperature, medium to high rainfall, high humidity and short and mild winters. The average annual rainfall of the coastal districts is 1482 mm. Due to tropical monsoon climate and change in climatic variables, this region is affected by extreme climatic events like a tropical cyclone, coastal erosion, heatwaves, flood, and drought very frequently (Prabhakar et al. 2019).

2.2 Weather data and trend analysis

The daily observed data of maximum temperature, minimum temperature and rainfall were collected from India Meteorological Department (IMD) for the 5 coastal districts (Baleshwar, Bhadrak, Jagatsingpur, Puri, Ganjam) of Odisha for 31 years (1980-2010) used to calculate various extreme climate indices and their trends. The collected data were scrutinized for assessing the data quality using RClimdex software.<http://etccdi.pacificclimate.org/> RClimDex is a program script written in R language developed at the Meteorological Service of Canada (Zhang and Yang, 2004). The data was checked for invalid data (negative value of rainfall, maximum temperature which was less than or equal to minimum temperature) and removal of outliers by threshold values defined by the user in the form of standard deviation. The threshold for outliers in this investigation was defined as the mean $\pm$ 3 times standard deviations, based on previous studies. Sheikh et al. (2009) and Manikandan et al. (2019) also used 3-sigma for their studies. After quality checking, 18 indices were computed out of which 8 were related to temperature and 10 were related to rainfall (Table 1). The indices and their trends were worked out using RClimDex statistical modelling toolkit. Indices which are proposed in RClimDex are a standard set of globally accepted indices for climate extremes to facilitate comparison in changes in any part of the world. While, in India according to India Meteorological Department (IMD), when a day receive rainfall of ≥ 2.5 mm, 64.5 mm and 124.5 mm is known as a rainy day, heavy precipitation day and very heavy precipitation day, respectively. The computed year-wise extreme weather events were plotted with respective district rice yield to understand the relationship between extreme events and rice yield. However, the relationship graph was plotted only for 18 years (1993 to 2010) due to lack of historical rice yield data for all the districts from 1980 to 1992.

2.3 Statistics

Trend analysis of various indices was carried out by a simple linear regression method. Linear regression method is a parametric test. It requires the assumptions of normality of residuals, constant variance and true linearity of relationship (Helsel and Hirsch 1992). The model for Y (e.g. temperature or rainfall) can be described by an equation of the form:

$$Y = ax + b$$

where Y is variable of interest (temperature or rainfall); x is time (year); a is slope coefficient, indicating the rate of change per year for the variable in question; and b is a least-squares estimate of the intercept. The slope coefficient indicates the annual average rate of change in the variable of interest (temperature

or rainfall). The statistical significance of the climatic indices was found out through the Mann-Kendall test (MK test) based on the frequency of occurrence and using Trend Toolkit software (Chiew et al. 2005). The statistical significance of the observed trends was defined at the 99% ($p\text{-value} \leq 0.01$), 95% ($0.01 < p\text{-value} \leq 0.05$) and 90% ($0.05 < p\text{-value} \leq 0.10$) significant level in this study. If the slope is significantly different, it interprets there is a real change occurring over time. The sign of the slope defines the direction of the trend of the variable of interest: increasing if the sign is positive, and decreasing if the sign is negative. The trend calculations were performed for the period 1980–2010 to optimize significant results.

3 Results

3.1 Temperature indices

Various climatic indices slope and p-value for linear regression; Z value and its significance level for MK test were shown in Table 2 & 3, respectively. The annual mean maximum temperature (mean $T_{\max}$) of coastal Odisha showed an increasing trend significantly (at 0.05% level) in Balasore, Bhadrak and Jagatsingpur, and non-significant increasing trend in Ganjam and Puri districts (Fig. 2). The mean $T_{\max}$ in Odisha coast is increased at the rate of 0.003-0.044 °C/year from 1980 to 2010. Similarly, the annual mean minimum temperature (mean $T_{\min}$) of coastal Odisha showed an increasing trend significantly (at 0.05% level) in Bhadrak, Jagatsingpur and Puri district, whereas the non-significant increasing trend in Balasore and Ganjam districts (Fig. 3). The rate of increase of mean $T_{\min}$ was found between 0.006-0.065 °C/year respectively during the period 1980–2010. The comparison between mean $T_{\max}$ and mean $T_{\min}$ shows the magnitude of temperature increase was high in mean $T_{\min}$ over mean $T_{\max}$. In Puri district, the mean $T_{\max}$ showed a significant increase trend and mean $T_{\min}$ showed non-significant increasing trend while the reverse trend of significantly increasing mean $T_{\min}$ and non-significant increase in $T_{\max}$ was found in Balasore district. Among the five coastal districts, only Ganjam district showed a non-significant increasing trend of mean $T_{\max}$ and mean $T_{\min}$ and the highest warming was found in Bhadrak district based on mean $T_{\max}$ and mean $T_{\min}$.

The number of warm nights (TN90p) found increasing (0.156-0.461 days/year) in coastal Odisha (Table 2 & 3). The TN90p found increasing significantly (at 0.05% level) in Bhadrak (0.461 days/year), Jagatsingpur (0.399 days/year) and Puri (0.293 days/year) districts, whereas it showed a non-significant increase in Balasore (0.201 days/year) and Ganjam (0.156 days/year) districts (Fig. 4). Similar to warm nights, the number of warm days (TX90p) found increasing significantly (at 0.01% level) in all the coastal districts of Odisha at the rate of 0.269-0.498 days/year except Puri (0.152 days/year) where it showed a non-significant increasing trend (Fig. 5). The warm spell duration indicator (WSDI) is increasing in all the coastal district at the rate of 0.056 to 0.43 days/year (Table 2 & 3). The WSDI found increasing significantly (at 0.05% level) in Balasore (0.415 days/year), Bhadrak (0.43 days/year) and Ganjam (0.221 days/year) districts, while the non-significant increasing trend in Jagatsingpur (0.235 days/year) and Puri (0.056 days/year) districts (Fig. 6). It is interesting to note that, the mean $T_{\max}$, mean $T_{\min}$ and TN90P

showed a non-significant increase in Ganjam district, while the warm days (TX90P) and WSDI showed a significantly increasing trend.

Cold spell duration indicator (CSDI) showed non-significant decreasing tendency (Fig. 7) in all the coastal districts except Bhadrak where it showed decreasing significantly (at 0.1% level) at the rate of -0.538 days (Table 2 & 3). The number of cool nights (TN10p) in the coastal district found decreasing at the rate of -0.075 to -0.596 days. However, the significant (at 0.1% level) decrease was observed only in Jagatsingpur, Bhadrak and Puri districts only (Fig. 8). The diurnal temperature range (DTR) was found to change in the range of -0.018 to 0.009 °C in coastal Odisha (Table 2 & 3). Only in Puri district, the DTR showed significant (at 0.05% level) decreasing trend (-0.018 °C) whereas in the remaining district it showed non-significant decreasing trend except Balasore (Fig. 9).

3.2 Rainfall indices

The analysis of rainfall-related climate indices reveals predominantly weak and insignificant trend (Table 2 & 3). The trend analysis of total annual precipitation (PRCPTOT) showed the non-significant increasing trend in all the coastal districts except Ganjam where it was decreased by 4.7 mm/year during the study period (Fig. 10). The highest increase in total annual precipitation was recorded in Jagatsingpur (7.3 mm/year) district followed by Bhadrak (5.3 mm/year). In our investigation, the number of rainy days (R2.5) per year showed a non-significant decreasing trend in all the districts except Ganjam where it was found to increase by 0.263 days/year (Fig. 11). The decreased number of rainy days shows the poor distribution of rainfall. The rate of change of rainy day in coastal Odisha was found between -1.043 -0.263 days per year. The number of heavy rainy days (R64.5) showed exactly the opposite trend to rainy day (R2.5) (Table 2 & 3). The R64.5 showed an increasing trend in all the districts except Ganjam (Fig. 12). In Ganjam, the R64.5 showed a non-significant decreasing (-0.074 days/year) trend. The rate of change of heavy rainy days was found between -0.074 - 1.289 days per year. The number of very heavy rainy days (R124.5) showed an increasing trend in Bhadrak, Jagatsingpur and Puri district, whereas decreasing trend was noticed in Balasore and Ganjam districts (Fig. 13). However, R124.5 was found increasing significantly only in Bhadrak district by 1.794 days/year. This clearly shows that the increased annual precipitation is mainly because of the increased number of heavy rainy days and very heavy rainy days.

The Consecutive Dry Days (CDD) showed a significant increasing tendency in Ganjam district (2.116 days/year) (Table 2) and non-significant increasing tendency in all other coastal districts (Fig. 14). Simple daily intensity index (SDII) is computed by taking annual total precipitation divided by the number of wet days in the year. The computation of SDII showed a significant (at 0.05% level) increasing tendency in Balasore at the rate of 0.115; Jagatsingpur at the rate of 0.15, and non-significant increasing tendency in Puri & Bhadrak district while in Ganjam it showed a non-significant decreasing tendency (Fig 15). Maximum 2-day consecutive precipitation (RX2day), maximum 3-day consecutive precipitation (RX3day) and maximum 5-day consecutive precipitation (RX5day) showed a non-significant increasing trend in Bhadrak, Jagatsingpur, Puri (Fig. 16-18) and a decreasing trend in Ganjam (Fig. 19). In Balasore, the maximum 2-day consecutive precipitation (RX2day) showed a non-significant decreasing trend,

whereas maximum 3-day consecutive precipitation (RX3day) and maximum 5-day consecutive precipitation (RX5day) showed a non-significant increasing trend (Fig. 20). It shows, the consecutive day precipitation in coastal districts is increasing except Ganjam.

4 Discussion

4.1 Extreme temperature events and their impacts on rice

The increasing trends of temperature (mean $T_{\max}$, mean $T_{\min}$) in coastal Odisha will harm soil health and agriculture production (Brevik, 2013; Karmakar et al 2016). The rise in mean temperature is a cause of concern especially night temperature as it affects agricultural crop growth and yield (Cruz et al., 2007). Many studies have proven that the increasing minimum temperature (night temperature) affect respiration in rice plants, and can potentially reduce biomass accumulation and crop yield through increasing plant respiration (Hatfield et al., 2011; Das et al. 2014; Wanju Shi et al 2017). Drought stress during flowering stage could cause upto 80% yield loss in rice (Nimai Senapati et al. 2019). The increasing warm nights and warm days will bring early crop maturity thereby reduce the effective grain filling period in crops and affect the crop yield and quality (Akter and Islam, 2017). For example, the extremely high temperature in 2010 after heading significantly reduced rice grain quality in many rice-growing regions of Japan (Morita et al., 2016). Plants exposed to high nighttime temperatures during the grain development period experienced lower productivity and reduced quality (Hatfield et al. 2014). The exposure of rice crop to heat stress (warm days & warm nights) during grain filling stage will increase chalkiness of the grains by increasing the air spaces between amyloplasts as a result of loosely packed starch granules (Ashida et al., 2009) which could result in a higher percentage of broken grains and significantly lower market value of the rice grain (Lyman et al., 2013; Zhao and Fitzgerald, 2013). The decreasing CSDI and cool night signify, shortening of winter and widening of summer in coastal districts. This result is even supported by the fact that increasing mean $T_{\max}$, mean $T_{\min}$ and WSDI in coastal Odisha. The negative value of DTR signifies narrowing down of the difference between the maximum and minimum temperatures. The reduced diurnal temperature range has been shown to affect crop growth and development of rice crop (Peng et al., 2004; IPCC, 2007; Bahuguna and Jagadish, 2015).

4.2 Extreme rainfall events and their impacts on rice

Though coastal Odisha receives higher rainfall than its country average, its distribution is not good especially during the cropping season. In general, the total annual rainfall in coastal Odisha is increasing over a year. The increasing trend of heavy precipitation (R64.5), very heavy precipitation (R124.5) and decreasing trend of R2.5 makes clear that the increased annual precipitation is mainly because of the increased number of heavy rainy days and very heavy rainy days. It is obvious from the result that, the distribution of rainfall in the coastal district of Odisha is changed, due to decreased number of rainy days and increased heavy precipitation, very heavy precipitation day and SDII which intern responsible for the increased number of CDD, and frequency of drought and floods. A similar result of increasing total annual rainfall in coastal districts of Odisha is also reported by Sahu et al (2015). The increasing number

of R64.5 and R124.5 and decreasing number of rainy days (R2.5) may also be correlated with an increased number of flood events in coastal districts.

SDII indicates the mean precipitation in wet days and the results shows, increasing mean precipitation amount during wet days. The decreased number of rainy days and increasing trend of SDII, heavy rainfall, very heavy rainfall signifies poor distribution of rainfall. The probability for drought is more with increasing CDD, similarly, the probability for flood is more with increasing CWD. It is obvious from the result that, the decreased number of rainy days and increased heavy precipitation and very heavy precipitation day and which intern increased CDD, and frequency of drought and floods. The increasing frequency of drought and flood in coastal Odisha intern reduces the agriculture production and causes huge economic loss.

The calculation of consecutive precipitation amount is more important to overcome the adverse effect of heavy and very heavy rainfall on agriculture production. The success/failure of agriculture crop during a rainy period is largely controlled by consecutive day precipitation (rainfall distribution). If the precipitation in consecutive days is more than it causes flooding in the crop field. However, the impact of flooding on the crop depends on so many factors like soil characteristics (initial soil moisture, slope, texture, organic matter), crop characteristics (stage of the crop, crop root zone depth, crop canopy cover) and environment (temperature, wind, relative humidity). The high water table in rice weakened root, stem and leaves (Dahiya, 2018).

In general, the consecutive day precipitation in coastal districts is increasing. The increased consecutive day precipitation causes flooding in rice and reduces the grain yield. The effect of consecutive days rainfall is more pronounced in clay soil and, less pronounced in sandy soil since the later soil has more permeability than earlier one (Witheetrirong et al 2011). In coastal Odisha, rice is established by two methods *viz.*, direct seeding and conventional transplanting. Direct seeded rice (DSR) is sown during the first fortnight of June, whereas transplanting of rice is done during the second fortnight of July to first fortnight of August. In DSR the flowering of rice occurs from the second fortnight of September to first fortnight of October. Similarly, in transplanted rice flowering occur in October (Das, 2012). Though rice is tolerant of a waterlogging for a short period, the consecutive heavy rain during flowering causes lodging of crop plants and chaffy grains (Rawson and Macpherson, 2000). Germination and flowering periods are the most vulnerable to rainfall anomalies (Bacci, 2017). Flowering time is a critical stage of development in the life cycle of rice plants because the seed number is determined (Bacci, 2017). There are many methods to compute effective rainfall. In this study, we consider Indian-2 method and Vietnam method assumption for computing effective rainfall. According to Vietnam method, a daily rainfall < 5 mm and > 50 mm is considered as ineffective. Similarly, two-days and three-days successive rainfall of > 60 mm and 70 mm is considered as ineffective rainfall respectively (Ali and Mubarak, 2017). In Indian-2 method, a daily rainfall < 6.25 mm and ten-days consecutive rainfall of > 125 mm is treated as ineffective (Ali and Mubarak, 2017). Month wise computation of consecutive rainfall in coastal districts shows the amount of rainfall received during June to October in all the coastal district is mostly > 100 mm. In coastal

districts flowering generally coincide in the month August and most vulnerable to moisture stress. Flood during flowering will cause lodging of the rice plant and yield loss.

4.3 Relationship between rice grain yield and extreme events

The rice yield and extreme events graph clearly show the negative relationship between grain yield and number of extreme events of different types. The rice yield in all the districts decreased sharply when the number of extreme events increased (Fig. 21). The graph shows the decreasing grain yield is not just function one or two extreme events instead it is often the cumulative effect of multiple stress events during the crop growing period. It also shows that even in the normal rainfall years the grain yield is reduced if the distribution of rainfall is uneven. The reduced grain yield is observed even in normal rainfall years having increased number of heavy precipitation, very heavy precipitation, and higher consecutive day rainfall events. The increasing number of CDD shows the increasing chance of moisture stress and poor distribution of rainfall. In case of normal rainfall years, high-temperature stress *viz.*, warm days and warm night have reduced the rice grain yield significantly. The climate smart technology including tolerant varieties is suggested for ensuring the resilience of the production system.

5 Conclusions

The earlier studies on trend analysis are mostly concentrated on precipitation event only. For a more detailed understanding of extreme weather events impacts on agriculture, together analysis of precipitation and temperature trend is very important. The results from this study clearly show the increasing trend of extreme weather events of rainfall and temperature in coastal Odisha. Distribution of rainfall is changed more in all the coastal districts. Increasing annual rainfall, heavy and very heavy precipitation and decreasing number of rainy days show the poor distribution of rainfall. Similarly, the frequency and number of warm nights, warm days and consecutive dry days are increasing in coastal Odisha. These extreme weather events affect the rice crop growth and grain yield negatively. The increasing frequency of drought and flood in coastal Odisha is the combined effects of temperature and rainfall extremes events rather than low or high rainfall. Farmers, Scientist and researchers should develop new technology/management practice to cope with the changing climate. Policymakers can utilize this study results to develop an appropriate policy to minimize the impacts of extreme weather events.

Declarations

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Conflict of interest

No potential conflict of interest was reported by the authors.

Availability of data and material

Data used in the experiment is collected from IMD, Pune. Authors have made self-declaration to IMD that data will not be shared to any person/organization without taking proper permission form IMD.

Code availability

Not applicable

Ethics approval

Not applicable

Consent to participate

Not applicable

Consent for publication

The required permission for publication is obtained from PME cell, NRRI, Cuttack, Odisha.

Authors contribution

S Vijayakumar – Data collection, manuscript preparation

A.K. Nayak – Concept, manuscript revision

N. Manikandan – Statistical analysis, manuscript revision

Suchismita Pattanaik – Data arrangement, and it quality checking

Rahul Tripathi - Manuscript revision

C K Swain - Data arrangement, and it quality checking

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Table 1. Summary of temperature and rainfall indices used in this study

ID	Indicator name	Definition	Unit
mean T _{max}	Annual mean maximum temperature		°C
mean T _{min}	Annual mean minimum temperature		°C
TN10p	Cool nights	Percentage of days when TN<10 th percentile	Days
TN90p	Warm nights	Percentage of days when TN>90 th percentile	Days
TX90p	Warm days	Percentage of days when TX>90 th percentile	Days
WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when TX>90 th percentile	Days
CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when TN<10 th percentile	Days
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	°C
RX1day	Max 1-day precipitation amount	Highest maximum 1-day precipitation in a year	mm
RX2day	Max 2-day precipitation amount	Highest maximum consecutive 2-day precipitation in a year	mm
RX3day	Max 3-day precipitation amount	Highest maximum consecutive 3-day precipitation in a year	mm
RX5day	Max 5-day precipitation amount	Highest maximum consecutive 5-day precipitation in a year	mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as PRCP>=1.0mm) in the year	mm/day
R64.5	IMD-heavy precipitation days	Annual count of days when PRCP>=64.5mm	Days
R124.5	IMD-very heavy precipitation days	Annual count of days when PRCP>=124.5mm	Days
CDD	Consecutive dry days	Maximum number of consecutive days with RR<1mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR>=1mm	Days
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR>=1mm)	mm

Table 2. Trend and statistical significance of climatic indices by linear regression

Districts	Balasore		Bhadrak		Ganjam		Jagatsingpur		Puri	
Indices	Slope	P Value	Slope	P Value	Slope	P Value	Slope	P Value	Slope	P Value
mean T _{max}	0.021	0.028**	0.044	0***	0.007	0.175	0.028	0***	0.003	0.591
T _{min} mean	0.012	0.116	0.065	0.003***	0.006	0.458	0.046	0.011***	0.02	0.01**
TX90p	0.331	0.003***	0.498	0***	0.269	0.003***	0.414	0.01***	0.152	0.204
TN10p	-0.074	0.398	-0.596	0.016**	-0.075	0.515	-0.407	0.097*	-0.285	0.016**
TN90p	0.201	0.118	0.461	0.031**	0.156	0.188	0.399	0.001***	0.293	0.011**
WSDI	0.415	0.002***	0.43	0.006***	0.221	0.019**	0.235	0.255	0.056	0.788
CSDI	-0.006	0.931	-0.538	0.087*	-0.093	0.49	-0.466	0.376	-0.102	0.357
DTR	0.009	0.38	-0.021	0.34	0.001	0.921	-0.018	0.276	-0.018	0.048**
RX1day	-0.617	0.69	1.159	0.428	-1.977	0.171	0.134	0.907	1.621	0.212
RX2day	-0.034	1.699	1.241	1.699	-1.113	1.699	0.332	1.699	1.186	1.699
RX3day	0.498	1.699	1.467	1.699	-1.053	1.699	0.332	1.699	1.343	1.699
RX5day	1.921	0.284	3.076	0.279	-1.453	0.469	0.466	0.81	2.955	0.251
SDII	0.115	0.013**	0.078	0.28	-0.063	0.437	0.15	0.029**	0.035	0.659
R2.5	-1.043	1.699	-0.233	1.699	0.263	1.699	-1.028	1.699	-0.568	1.699
R64.5	0.536	1.699	0.902	1.699	-0.074	1.699	1.289	1.699	0	1.699
R124.5	-0.237	1.699	1.794	1.699*	-1.679	1.699	0.536	1.699	0.617	1.699
CDD	0.985	0.102	1.066	0.112	2.116	0.02**	1.271	0.12	-0.347	0.574
CWD	-0.026	0.522	0.031	0.698	-0.019	0.682	-0.001	0.992	-0.031	0.405
PRCPTOT	3.783	0.526	5.251	0.465	-4.747	0.553	7.328	0.308	2.266	0.766

NS-non-significant, *Significant at 10% level, **significant at 5% level, ***significant at 1% level, T_{max} mean - Annual mean maximum temperature, T_{min} mean - Annual mean minimum temperature, TN10p - Cool nights, TN90p - Warm nights, TX90p - Warm days, WSDI - Warm spell duration indicator, CSDI - Cold spell duration indicator, DTR - Diurnal temperature range, RX1day -Max 1-day precipitation amount, RX2day - Max 2-day precipitation amount, RX3day - Max 3-day precipitation amount, RX5day - Max 5-day precipitation amount, SDII - Simple daily intensity index, R64.5 - IMD-heavy precipitation days, R124.5 - IMD-very heavy precipitation days, CDD - Consecutive dry days, CWD - Consecutive wet days, PRCPTOT - Annual total wet-day precipitation

Table 3. Trend and statistical significance of climatic indices by MK test

Districts	Balasore		Bhadrak		Ganjam		Jagatsingpur		Puri	
Indices	Z value	Sig. lev	Z value	Sig. lev	Z value	Sig. lev	Z value	Sig. lev	Z value	Sig. lev
TMAXmean	1.87	*	4.419	***	1.258	NS	3.722	***	0.68	NS
TMINmean	1.377	NS	3.008	***	1.309	NS	2.957	***	1.989	**
TX90p	2.278	**	4.198	***	2.821	***	3.161	***	2.295	**
TN10p	-0.425	NS	-2.091	**	-1.394	NS	-2.515	**	-1.972	**
TN90p	1.7	*	2.77	***	1.19	NS	3.161	***	2.583	***
WSDI	2.481	**	2.498	**	2.261	**	0.578	NS	0.816	NS
CSDI	0.238	NS	-1.105	NS	-0.527	NS	-0.969	NS	-0.238	NS
DTR	0.867	NS	-0.595	NS	-0.272	NS	-1.054	NS	-1.853	*
RX1day	0.051	NS	0.952	NS	-0.476	NS	-0.017	NS	1.513	NS
RX2day	0.646	NS	0.952	NS	-1.054	NS	0.476	NS	1.428	NS
RX3day	0.748	NS	1.088	NS	-0.748	NS	0.204	NS	1.53	NS
RX5day	1.156	NS	0.646	NS	-0.544	NS	0.391	NS	1.224	NS
SDII	2.634	***	0.952	NS	-0.102	NS	2.379	**	0.476	NS
R2.5	-0.884	NS	-0.221	NS	0.068	NS	-1.105	NS	0.068	NS
R64.5	0.884	NS	1.037	NS	0.136	NS	0.901	NS	0.068	NS
R124.5	-0.153	NS	1.377	NS	-1.207	NS	0.544	NS	0.612	NS
CDD	1.479	NS	1.462	NS	2.142	**	1.7	*	0.068	NS
PRCPTOT	0.612	NS	0.85	NS	0	NS	1.292	NS	0.578	NS

NS-non-significant, *Significant at 10% level, **significant at 5% level, ***significant at 1% level, T_{max} mean - Annual mean maximum temperature, T_{min} mean - Annual mean minimum temperature, TN10p - Cool nights, TN90p - Warm nights, TX90p - Warm days, WSDI - Warm spell duration indicator, CSDI - Cold spell duration indicator, DTR - Diurnal temperature range, RX1day -Max 1-day precipitation amount, RX2day - Max 2-day precipitation amount, RX3day - Max 3-day precipitation amount, RX5day - Max 5-day precipitation amount, SDII - Simple daily intensity index, R64.5 - IMD-heavy precipitation days, R124.5 - IMD-very heavy precipitation days, CDD - Consecutive dry days, CWD - Consecutive wet days, PRCPTOT - Annual total wet-day precipitation

Figures

Figure 1

Map showing location of the study area

Figure 2

Annual mean maximum temperature (Tmax mean)

Figure 3

Annual mean minimum temperature (Tmin mean)

Figure 4

Warm nights (TN90p)

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Warm days (TX90p)

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Warm spell duration indicator (days/year)

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Cold spell duration indicator (CSDI)

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Cool night (TN10p)

Figure 9

Diurnal temperature range (DTR)

Figure 10

Annual precipitation (PRCPTOT)

Figure 11

Number of rainy days (R2.5)/year

Figure 12

Number of heavy rainy days (R64.5)/year

Figure 13

Number of very heavy rainy days (R124.5)/year

Figure 14

Consecutive dry days (CDD)

Figure 15

Simple daily intensity index (SDII)

Figure 16

Highest 1-day precipitation (RX1day), Highest maximum consecutive 2-day precipitation in a year (RX2day), Highest maximum consecutive 5-day precipitation in a year (RX5day) of Bhadrak district

Figure 17

Highest 1-day precipitation (RX1day), Highest maximum consecutive 2-day precipitation in a year (RX2day), Highest maximum consecutive 5-day precipitation in a year (RX5day) of Jagatsinghpur district

Figure 18

Highest 1-day precipitation (RX1day), Highest maximum consecutive 2-day precipitation in a year (RX2day), Highest maximum consecutive 5-day precipitation in a year (RX5day) of Puri district

Figure 19

Highest 1-day precipitation (RX1day), Highest maximum consecutive 2-day precipitation in a year (RX2day), Highest maximum consecutive 5-day precipitation in a year (RX5day) of Ganjam district

Figure 20

Highest 1-day precipitation (RX1day), Highest maximum consecutive 2-day precipitation in a year (RX2day), Highest maximum consecutive 5-day precipitation in a year (RX5day) of Balasore district

Figure 21

Relationship between grain yield and type and number of extreme events a) Balasore b) Bhadrak c) Jagatsingpur d) Puri e) Ganjam. Note: RX1day - Max 1-day precipitation amount; WS - Warm spell duration indicator; RX2day - Max 2 consecutive day precipitation amount; RX3day - Max 3 consecutive day precipitation amount; RX5day - Max 5 consecutive day precipitation amount; R64.5 - IMD heavy precipitation days; R124.5 – IMD very heavy precipitation days; CDD - Consecutive dry days; LR – Low rainfall; HR – High rainfall; WD – Warm days; WN – Warm nights