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Research Article

Trends of Extreme Weather Events and Their Impact on Crops in Bihar

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ABSTRACT

Trend of heat and cold waves, extreme rainfall and their impacts on crops were studied. The trends were analysed based on the long term daily temperature and rainfall data collected from four different stations representing four agro-ecological zones of Bihar. The Mann-Kendall test was used, assuming the observation in time series are serially independent, and there is no correlation. The test determines whether the observations in the data trend to increase or decrease with time. There is significant decreasing trend in heat waves for Pusa and Sabour stations. But for Purnea and Patna stations, it showed increasing but non-significant change. Moderate and total cold waves showed significant decreasing trend for all the stations. In Sabour, there is also decreasing trend in severe cold waves though other stations shows marginal decrease. There is also marginal increasing trend of frequency of extreme rainfall (75-100 mm and > 100 mm rainfall) in Sabour station and 75-100 mm rainfall in Pusa. Warming temperatures and a greater incidence and intensity of extreme weather events may lead to significant reductions in crop yields.

Key words: Climatic extremes, Heat wave, Cold wave, Extreme rainfall, Frequency, Crops

Introduction

There is general agreement that changes in the frequency or intensity of extreme weather and climate events would have profound impacts on both human society and the natural environment. A climate extreme can be considered an ecological disturbance in semi-natural terrestrial ecosystems, and they are implicated as mechanistic drivers of species diversity, nutrientcycling or carbon (C) stocks (Parmesan *et al.,* 2000). The frequency and types of extreme climatic events have significant damagepotentials at the local and at the regional scales under today's climate. But their importancecould increase over time, because warming trends and increasing temperature extremes have been observed across most of the Asian region over the past century (Sattar *et al*., 2017; Saikia and Sharma, 2017). Increasing numbers of warm days and decreasing numbers of cold days have been observed, with the warming trend continuing into the new millennium. Precipitation trends including extremes are characterized by strong variability, with both increasing and decreasing trends observed in different parts and seasons of Asia. Extreme climate events will have an increasing impact on human health, security, livelihoods, and poverty, with the type and magnitude of impact varying across Asia. More frequent and intense heat waves in Asia will increase mortality and morbidity in vulnerable groups. Increases in floods and droughts will exacerbate rural poverty in parts of Asia as a result of negative impacts on the rice crop and resulting increases in food prices and the cost of

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living (IPCC, 2014). The link between climatic extremes andclimatic change is elusive because a few isolated events are difficult to relate in a statisticallymeaningful way to changes in mean climatic conditions (e.g., Frei and Schaer, 2001; Beniston and Stephenson, 2004). Climate extremes can be characterized based ontheir socio-economic and/or ecological relevance, which implies the definition of specificthresholds beyond which serious impacts may occur in the systems concerned (Meehl *et al*., 2000). Regardless of the definition used, the characteristics of what is called an 'extreme weather event' may vary from place to place. Extreme positive departure from normal maximum temperature results in heat wave during summer season (De *et al.,* 2005). These are called heat waves because the spells of hot weather are often seen to move from one region to another (Chaudhary *et al*., 2000).Hence understanding the pattern and frequency of heat waves and cold waves is essential for forecasting and management of extreme temperature conditions. The cold waves mainly affect the areas to the north of 20° N but in association with large amplitude troughs, cold wave conditions are sometimes reported from States like Maharashtra and Karnataka as well. The maximum number of cold waves occurs in Jammu and Kashmir followed by Rajasthan and Uttar Pradesh. It may be seen that number of cold waves in Gujarat and Maharashtra are almost one per year though these states are located in more southern location. In recent years due to deterioration of the air quality in urban locations of India the deaths and discomfort from cold waves have been substantial (De and Sinha Ray, 2000). Their study showed that in states of Uttar Pradesh and Bihar the number of deaths from extreme events in the cold weather season during 1978-1999 was 957 and 2307 respectively. These two States rank the highest in terms of casualties from cold wave. In recent years 1978-99 highest number of deaths from severe cold waves has been in Bihar. In the 1st week of January 2000 the deadly cold spell resulted in the death of 363 persons of which 152 were from Uttar Pradesh and 154 were from Bihar.Extreme rainfall events cause damages in the form of landslides, flash floods, crop loss, etc., which further have impacts on society as well as the environment. Rajeevan *et al.* (2008) used 104 years of gridded dataset over central India and examined the variability and long-term trends of extreme rainfall events. A proper assessment of likely incidences of such events and their trends would be helpful to the planners in their disaster mitigation and implementations.

Materials and Methods

Study area

Bihar is located in the alluvial plains of India. The state is situated between 24° N and 27° N, 83° E and 88° E with a height of 52 m amsl, having total geographic area of 9.36 m ha with cultivable land of 0.58 lakh ha and normal rainfall of 1243.7 mm. It is divided into three agro-ecological zones: zone I (North West alluvial plains), zone II (north east alluvial plains) and zone III (South Bihar alluvial plains). Zone III is further subdivided into categories A and B. Gross cropped area is maximum (30.07 lakh ha) for zone I and minimum (6.21 lakh ha) for zone III B and irrigated area ranges from 3.68 to 18.41 lakh ha. Zone II receives highest annual rainfall (1466.7 mm). Zone III B receives least annual rainfall (1031.0 mm) and is the warmest (average temperature: 22.4°C). Average minimum temperature (7.7°C) is least for zone I. Four different stations were selected representing different zones (Pusa zone I; Purnea zone II; Sabour zone III A; Patna zone III B) (Table 1).

A committee was set up by the Director General of India Meteorological Department (IMD) under the chairmanship of Dr M. Rajeevan, Sci.G and Advisor MoES, with Shri B.P. Yadav, DDGM(S), IMD as the convener, to review the present terms and terminologies being used in operational weather forecasts and to recommend changes for implementation (Forecasting Circular No. 5/2015 (3.7) IMD, 2015). The following changes were made in the existing criteria to be used from 1st January 2016.

(1) The wind chill factor may not be used for declaring cold waves.

Table 1. Selected meteorological stations representing different agro-ecological zones of Bihar

Station	Agro-ecological zone	Latitude (°N)	Longitude (°E)	Elevation (m)	Weather data
Pusa	I	25.85	85.78	47	1955-2012
Purnea	II	25.98	87.80	53	1969-2012
Sabour	III A	26.10	87.70	37	1955-2012
Patna	III B	25.58	85.25	41	1969-2012

(2) Since the heat wave, hot day, warm night, cold wave, cold day etc. are distinct phenomena, these may co-exist in the 'weather warnings' as against the present practice.

(3) To declare heat and cold waves, the following criteria should be met at least in 2 stations in a Meteorological sub-division for at least two consecutive daysand it would be declared on the second day.

(4) Forecasts of heat and cold waves over a sub-division would be issued only if at least two stations in the sub-division are expected to experience such conditions.

A) Heat wave

Heat wave is considered if maximum temperature of a station reaches at least 40°C or more for Plains and at least 30°C or more for Hilly regions.

Based on Departure from Normal

Heat Wave: Departure from normal is 4.5°C to 6.4°C

Severe Heat Wave: Departure from normal is >6.4°C

Based on Actual Maximum Temperature

Heat Wave: When actual maximum temperature ≥ 45°C

Severe Heat Wave: When actual maximum temperature ≥ 47°C

Criteria for describing *Heat Wave* for coastal stations

When maximum temperature departure is 4.5°C or more from normal, *Heat Wave* may be described provided actual maximum temperature is 37°C or more.

(B) Cold wave

It should be based on the actual minimum temperature of a station. Cold Wave is considered when minimum temperature of a station is 10°C or less for plains and 0°C or less for Hilly regions.

Based on Departure

Cold Wave: Negative Departure from normal is 4.5°C to 6.4°C

Severe Cold Wave: Negative Departure from normal is more than 6.4°C

Based on Actual Minimum Temperature (For plain stations only)

Cold Wave: When minimum temperature is ≤ 04°C

Severe Cold Wave: When minimum temperature is ≤ 02°C

Cold Wave conditions for coastal stations

When minimum temperature departure is -4.5°C or less over a station, *"Cold Wave"* may be described if the minimum temperature is 15°C or less.

Daily data for air temperature and rainfallfrom four representative stations were collected for the period 1955-2012 for Pusa and Sabour and 1969-2012 for Purnea and Patna to calculate heat wave, cold waves and extreme rainfall. The Mann-Kendall test was used, assuming the observation in time series are serially independent and there is no correlation. The test determines whether the observations in the data trend to increase or decrease with time. The significance of each trend was examined at 95% confidence level.

Results and Discussion

Trends in heat waves

There is significant decreasing trend of moderate and total heat waves for Pusa station whereas for Purnea station, there is increasing trend in moderate and total heat waves but statistically they are non-significant. For Sabour station, there is significant decreasing trend in moderate, severe and total heat waves (Table 2). For Patna station, there is increasing trend in moderate, severe and total heat waves but are statistically non-significant.

Trends in cold waves

For all the stations, Pusa, Purnea, Sabour and Patna, there is significant decreasing trend in moderate and total cold waves but there is non-significant decreasing trend in severe cold waves for all the stations except Sabour, where it is significantly decreasing (Table 3).

Trends in extreme rainfall

There is increasing trend in frequency of extreme rainfall (75-100 mm rainfall and more than 100 mm rainfall) for Sabour station but statistically non-significant (Table 4). There is also increasing trend in frequency of 75-100 mm rainfall in a year for Pusa station but statistically non-significant. For other stations, there is non-significant decreasing trend in frequency of extreme rainfall in a year.

Table 4. Mann Kendall test (Kendall's tau) with trends of extreme rainfall

Station	Rainfall 75-100 mm		Rainfall >100 mm	
	tau	Trend	tau	Trend
Pusa	0.066	0.008	-0.054	-0.005
Purnea	-0.063	-0.014	-0.03	-0.002
Sabour	0.101	0.017	0.092	0.009
Patna	-0.052	-0.002	-0.094	-0.012

Impact on crops

Besidesdirect effects of heat on plants, high temperatures stimulate potential evapotranspiration (Calanca *et al.,* 2006), which contributes to more rapid soil water depletion.Temperatures above the optimum for growth can be deleterious, causing injury or irreversible damage, whichis generally called 'heat stress' whichis a function of the magnitude and rate of temperature increase,as well as the duration of exposure to the raised temperature (Wahid *et al.,* 2007).Rice and Wheat both are very sensitive to high

Table 2. Mann Kendall test (Kendall's tau) with trends of heat waves

Station	Moderate heat waves		Severe heat waves		Total heat waves	
	tau	Trend	tau	Trend	tau	Trend
Pusa	-0.228	-0.111*	-0.118	-0.004	-0.210	-0.107*
Purnea	0.103	0.010	-0.019	-0.006	0.07	0.004
Sabour	-0.338	-0.144*	-0.272	-0.060*	-0.345	-0.205*
Patna	0.055	0.052	0.058	0.055	0.037	0.106

*Significant at 5%

Table 3. Mann Kendall test (Kendall's tau) with trends of cold waves

Station	Moderate cold waves		Severe cold waves		Total cold waves	
	tau	Trend	tau	Trend	tau	Trend
Pusa	-0.43	-0.058*	-0.028	-0.001	-0.39	-0.057*
Purnea	-0.495	-0.157*	-0.139	-0.007	-0.492	-0.164*
Sabour	-0.433	-0.128*	-0.232	-0.012*	-0.430	-0.141*
Patna	-0.243	-0.063*	-0.18	-0.009	-0.262	-0.072*

*Significant at 5%

temperature and experiences heat stress to varying degreesat different phenological stages, but heat stress during the reproductive phase is more harmful than during the vegetative phasedue to the direct effect on grain number and dry weight (Wollenweber *et al*., 2003). Heat stress during the reproductive phase can cause pollen sterility, tissue dehydration, lower CO_2 assimilation and increased photorespiration.When temperatures areelevated between anthesis to grain maturity, grain yield is reducedbecause of the reduced time to capture resources by oxidative stress, may also reduce the rate of leaf photosynthesis. Oxidative stressmay induce lipid peroxidation leading toprotein degradation, membrane rupture and enzyme inactivation (Sairam *et al.,* 2000). Increased daily minimum temperature appears to have greater impact on wheat production as grain yield is more strongly negatively correlatedwith increasing minimum temperatures than maximum temperatures (Lobell *et al.,* 2005). Extreme rainfall damages the crops making the field flooded.

Management strategies

Agronomic strategies for mediating future increases in ambient temperature include practices that conserve water (e.g., no tillage and stubble retention), fertilization during critical growth stages and timing of sowing. Continuous water supply to heat-stressed wheat helped sustain grain-filling rate, duration and size and application of nitrogen, phosphorus and potassium improve plant growth under moderate heat stress (Dupont *et al.,* 2006). Application of some micronutrients such as zinc, can also improve heat tolerancein wheat (Graham and McDonald, 2001). The timing ofnutrient application to coincide with key developmental stagesis already regularly practiced, such as nitrogen application when the spike is 1 cm in length. Time of sowing is another important management strategyin some regions. Although periods of elevated temperature may occur during the growing season, grain filling usually occurs when seasonal temperatures are increasing. Early planting mayavoid terminal heat stress so that grain filling occurs during cooler temperatures. A good drainage facility can reduce the loss of crop yield at the time of extreme rainfall.

Conclusions

Human activities are causing the augmentation of the natural atmospheric greenhouse effect. Climate change will gradually (and, at some point, may be even abruptly) affect regional and global food production. Significant decreasing trend of heat and cold waves in Pusa and Sabour stations showed that there is no worry about the extreme temperature events for these stations but it is only frequencies of occurrence not duration of these events which mostly effect the crop growth and yield. In two stations Purnea and Patna, frequency is increasing though it is statistically non-significant. Cold waves showed significant decreasing trend for all the stations which may be due to gradually warming up of the atmosphere. There is no significant increasing/decreasing trend in extreme rainfall for all the stations. Warming temperatures and a greater incidence and intensity of extreme weather events may lead to significant reductions in crop yields.

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