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Observed rainfall events and outgoing longwave radiation over contrasting river basins in Bihar, India

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सार – जल ग्रहण क्षेत्र मापक्रम पर दीर्घकालिक अत्यधिक वर्षा की घटना का विश्लेषण बाढ़ जैसी स्थितियों और जल संसाधन प्रबंधन के प्रशमन और रोकथाम के लिए महत्वपूर्ण है। यह अध्ययन 1979-2018 की अवधि के लिए 0.25° × 0.25° विभेदन के ग्रिडेड वर्षा डेटा का उपयोग करके निचले कोसी और पुनपुन नदी बेसिन पर भारत मौसम विज्ञान विभाग (IMD) द्वारा वर्गीकृत वर्षा की विभिन्न घटनाओं का मूल्यांकन करता है। इसके अलावा बहिर्गामी दीर्घतरंग विकिरण (OLR) और वर्षा की घटनाओं के बीच संबंध की जाँच की जाती है। पुनपुन बेसिन की तुलना में दैनिक संचित वर्षा कोसी नदी बेसिन पर बहुत विविधता दर्शाती है। निचली कोसी नदी पर मध्यम और भारी वर्षा के दिनों की सख्या में काफी कमी आई है। इसके अलावा, पुनपुन नदी पर हल्की और मध्यम वर्षा में भी कमी आई है, हालाँकि यह महत्वपूर्ण नहीं है। दोनों नदियों के बेसिन में बहुत भारी वर्षा में कोई महत्वपूर्ण प्रवृत्ति नहीं पाई गई है। यह देखा गया है कि मध्यम वर्षा की घटनाओं में दिनों की सख्या बेसिनों पर बहिर्गामी दीर्घतरंग विकिरण (ओएलआर) के साथ एक स्वीकार्य नकारात्मक सहसंबंध दर्शाती है। यह अध्ययन बदलते मौसम में आपदाओं के प्रशमन और रोकथाम तथा स्थायी जल संसाधन प्रबंधन के लिए सहायक होगा।

ABSTRACT. The long term extreme rainfall event analysis at the catchment scale is crucial for mitigation and prevention of flood like situations and water resource management. This study evaluates the different rainfall events categorized by the India Meteorological Department (IMD) over the lower Kosi and Punpun river basin using the gridded rainfall data of 0.25° × 0.25° resolution for the period of 1979-2018. Further, the linkage between Outgoing Longwave Radiation (OLR) and rainfall events is examined. The daily accumulated rainfall shows large variation over the Kosi river basin in compare to the Punpun basin. The number of days of moderate and heavy rainfall over the lower Kosi River has significantly decreased. In addition, light and moderate rainfall over Punpun River has also decreased; however, it is non-significant. No significant trend in very heavy rainfall is found for both the river basin. It is observed that the number of days in moderate rainfall events shows an acceptable negative correlation with Outgoing Longwave Radiation (OLR) over basins. This study will be helpful for the mitigation and prevention of disasters and sustainable water resource management under changing climate.

Key words – Rainfall event, India Meteorological Department (IMD), Kosi river basin, Punpun river basin, Outgoing Longwave Radiation (OLR).

1. Introduction

In India, the rainfall events over a river basin, an area of land drained by a series of streams and rivers coming together and feeding into a larger river, are key factors in deciding the river runoff and flood condition over the floodplains. The eastern part of the river Ganga in eastern India receives a large amount of rainfall during June-July-August-September (JJAS), *i.e.*, Summer Monsoon Season and accumulated rainfall lies in the range of 102-109 cm. Because of the large temporal variations in JJAS rainfall over the state of Bihar, India, there is wide fluctuation in the flow characteristics of the rivers and sometimes, high rainfall leads to flood conditions during the monsoon period. The persisting rainfall events of different category in terms of rainfall amount controls the flood risk in flood plains of the river basins of Bihar.

Researchers have been examined the observed rainfall events over different periods and locations in India

(Rakhecha and Soman, 1994; Sinha Ray and Srivastava, 2000; Sen Roy and Balling, 2004; Goswami *et al*., 2006; Rajeevan *et al*., 2008; Ghosh *et al*., 2009; Pattanaik and Rajeevan, 2010) and found an increased risk on flood conditions (Guhathakurta *et al*., 2011; Gupta and Nair, 2011; Mishra and Shah, 2018). In the past, attempts have been made to determine rainfall variability at the station, grid points, regional and international scales and seasonal to annual time scales. Such studies on changes in rainfall pattern over India summarized that there is no clear increasing or decreasing trend in average annual rainfall over the country (Mooley and Parthasarathy, 1984; Sarker and Thapliyal, 1988; Thapliyal and Kulshrestha, 1991; Lal, 2001) as well as in all India Summer Monsoon Rainfall (ISMR). However, there may be pockets of significant long-term changes in rainfall (Koteswaram and Alvi, 1969; Jagannathan and Parthasarathy, 1973; Raghavendra, 1974; Chaudhary and Abhyankar, 1979; Kumar *et al*., 2005; Dash *et al*., 2007; Kumar and Jain, 2009; Rupa Kumar *et al*., 1992; Srivastava *et al*., 1998; Sinha Ray and De, 2003; Sinha Ray and Srivastava, 1999; Kripalani *et al*., 2003). A significant rising trend in the frequency and magnitude of extreme rain events and a significant decreasing trend in the frequency of moderate events over Central India during the monsoon seasons from 1951 to 2000 is discussed (Goswami *et al*., 2006). Similarly, the rainfall distribution over 30 sub-divisions in India using the rainfall data from 1871 to 2005 is examined (Kumar *et al*., 2010). The analysis is carried out on monthly seasonal and annual time scales and an increasing/decreasing trend is shown on different time scales over different sub-divisions. Over the Asia region, recent studies (Khan *et al*., 2000; Shrestha *et al*., 2000; Mirza, 2002; Lal, 2003; Min *et al*., 2003) suggested that the frequency of more intense has been increased, while the number of rainy days and the total annual amount of precipitation has been decreased.

Over the river basins in India, the rainfall is analyzed to fulfill the various purposes of water resources. Jain and Kumar (2010) have been analyzed the trends (using Sen's estimator) in observed rainfall of IMD ($1° \times 1°$ resolution) over different river basins of India. They found that the Six (6) river basins have an increasing trend in annual rainfall and Fifteen (15) river basins showthe opposite trend; the Ganga basin could not show the trend. Annual rainfall over two (2) basins has shown a significant trend, while the majority of the basins have indicated a non-significant trend. In the case of annual rainy days, four (4) river basins showed an increasing trend, fifteen (15) river basins showed a decreasing trend and three (3) showed no change. Analysis of seasonal trends has been shown an increase in monsoon rainfall over six (6) basins and a decrease over sixteen (16) basins. Specifically, over the Ganga basin, the rainfall of 236 districts during the 1901-2000 is analyzed by using the Mann-Kendall test and Sen's slope estimation (Behra, 2017). Almost half of the districts showed a decreasing trend in annual rainfall and thirty-nine (39) districts showed a statistically significant decreasing trend. During January to May, 78% of the total districts showed a decreasing trend. Districts under the Kosi, Gandak and Sone sub-basins showed a significant negative trend in annual, pre-monsoon and post-monsoon seasons. Deshpandeand Singh (2010) studied five wet periods that contribute in different percentages to the annual rainfall over major river basins in India. Spatial and temporal variations in the parameters such as starting date, duration and rainfall intensity using daily gridded rainfall data for the period of 1951-2007.

The above cited literature and discussion focus on rainfall analysis of different categories over different locations, including river basins. The researchers have shown that the rainfall variability can be linked to the Outgoing Longwave Radiation (OLR). The low value of OLR is associated withstrong convection, whereas a high value of OLR corresponds to cloud free atmosphere (Prasad and Bansod, 2000). Studies (Prasad and Verma, 1985; Arkin *et al*., 1989; Xie and Arkin, 1998; Prasad *et al*., 2000) have been shown that the OLR can play an important role in deciding the variability of Indian Summer Monsoon Rainfall (ISMR). Kumar *et al*. (2021) haveshown that the total precipitation (PRCPTOT), Cumulative Dry Days (daily rainfall $\leq$ 1 mm), Cumulative Wet Days (daily rainfall $\geq$ 1mm), Rx10 (daily rainfall $\geq$ 10 mm) and Rx20 (daily rainfall $\geq$ 20mm) follows an increasing/decreasing trend at a 95% confidence level. Further, they have also found that the rainfall indices CDD and CWD have positive and negative correlationswith OLR over the meteorological sub-divisions of Bihar, Eastern and Western Uttar Pradesh, India.

Considering the above discussion, the different rainfall events during the summer monsoon season, as mentioned by IMD, are not earlier discussed over the flood causing rivers, especially over Bihar, India. Therefore, it is aimed to examine the (a) rainfall events such as light, moderate, heavy and very heavy rainfall over the lower river basins of the Kosi and the Punpun, known for the devastating flood in Bihar and (b) the association of these rainfall events to the OLR over these basins. Such analysis of rainfall events over both river basins will be useful for water resource planning in the state.

2. Study area, data and methodology

The study area is shown in Fig. 1, comprising the lower Kosi and Punpun River basins located in the

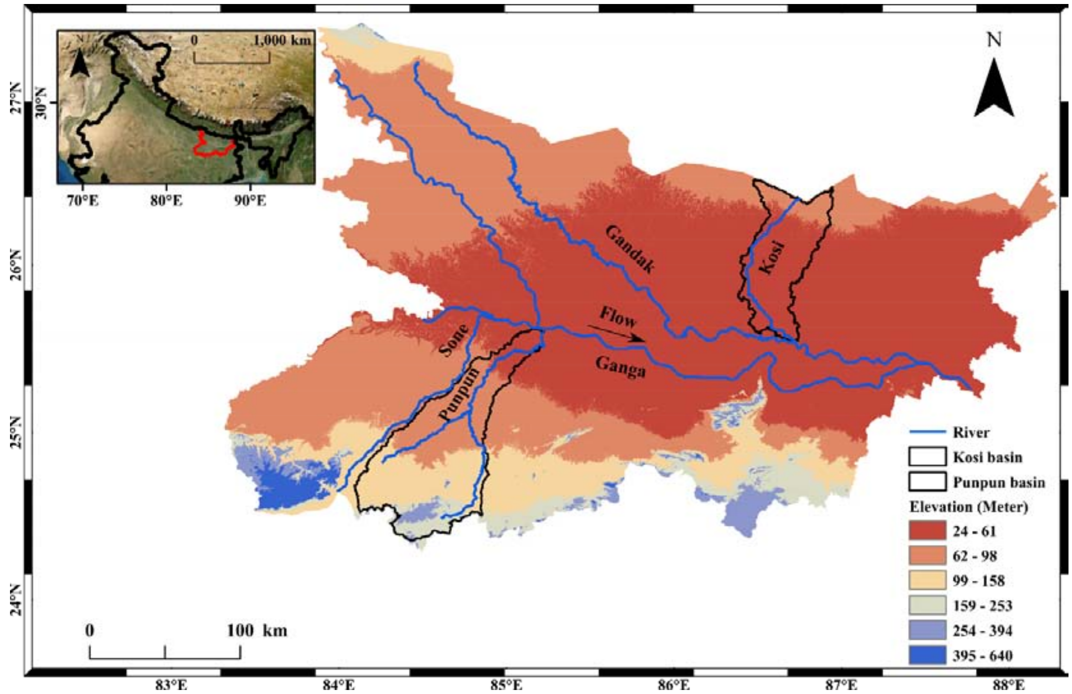


Fig. 1. Location of lower Kosi and Punpun River basin in Gangetic plain of Bihar. Major rivers and variation in topography are shown in the background

TABLE 1

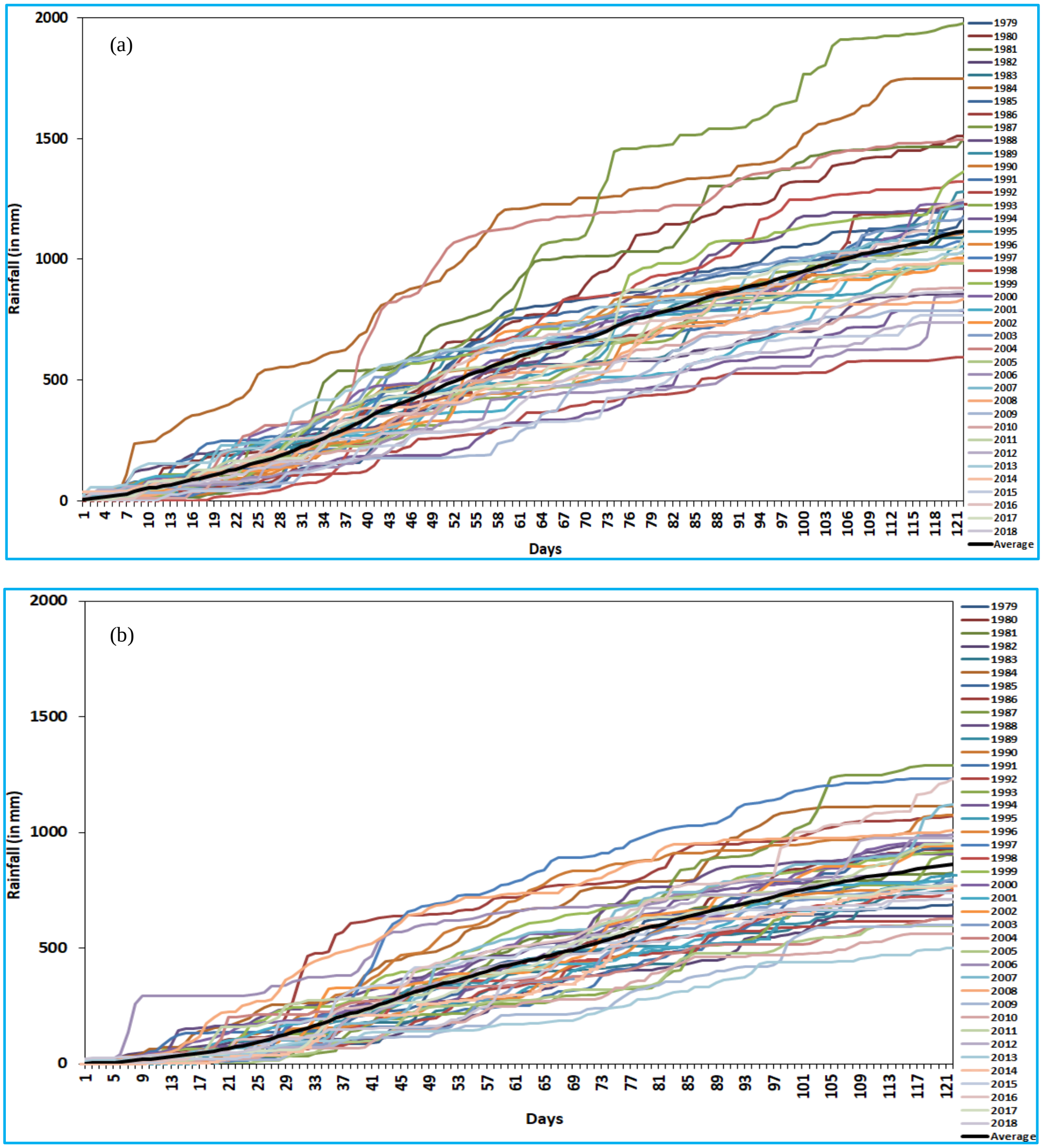
Rainfall events considered over the study area

Indices	Definitions	Units
Light rainfall	Rainfall amount realised in a day is between 2.5 to 15.5 mm	Days
Moderate rainfall	Rainfall amount realised in a day is between 15.6 to 64.4 mm	Days
Heavy rainfall	Rainfall amount realised in a day is between 64.5 to 115.5 mm	Days
Very Heavy rainfall	Rainfall amount realised in a day is between 115.6 to 204.4 mm	Days

Gangetic plain of Bihar. The Kosi is of the Himalayan origin (formed by the confluence of three streams, namely the Sun Kosi, the Arun Kosi and the Amur Kosi) river; however, the Punpun is a cratonic (hills of the Chottanagpur) originated riverfrom the Palamu district of Jharkhand. Both rivers are different in nature. The Kosi River flows from a high elevation of the north to the lower elevation of the south direction in the north Bihar region, while the Punpun River flows from a high elevation of the south to the lower elevation of the north in the south Bihar region. The total area of the lower Kosi and Punpun river basins in Bihar are 3267 and 6362 km^2, respectively. Both river basins create devastating floods during the summer monsoon season when there are either long spells of a good amount of rainfall or heavy rainfall events; however, the flood is relatively more dangerous in the Kosi river basin. The IMD defined criteria of Light rainfall, Moderate rainfall, Heavy rainfall, Very heavy rainfall and Very to very heavy rainfall are considered (Table 1) in the observed rainfall of IMD at the resolution of 0.25° × 0.25° for the time period of 1979-2018. The Outgoing Longwave Radiations (OLR) data from National Centers for Environmental Prediction (NCEP)/National Centerfor Atmospheric Research (NCAR) at a resolution of 0.25° × 0.25° for the same time period is taken.

The standardized anomaly is calculated by an anomaly divided by a standard deviation (Scheuerer and Büermann, 2014) by using the formula $\left(x-\overline{x}\right)/\sigma_x$. The long term trend in observed rainfall events has determined by using a non-parametric Mann Kendall (MK) test (Mavromatis *et al.*, 2011; Onoz *et al.*, 2012). Themathematical expression of the Man-Kendall test is given as follows :

$$\text{MK Test Statistic (S)} = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \text{sign}\left(x_j - x_i\right)$$



Figs. 2(a&b). Daily accumulated rainfall in JJAS during the time period of 1979-2018over (a) the Kosi and (b) the Punpun River basin, respectively (black line represents mean over the years)

Sign $(x_j - x_i) = 1$,if $x_j - x_i > 0$
$= 0$,if$x_j - x_i = 0$
$= -1$, if $x_j - x_i < 0$

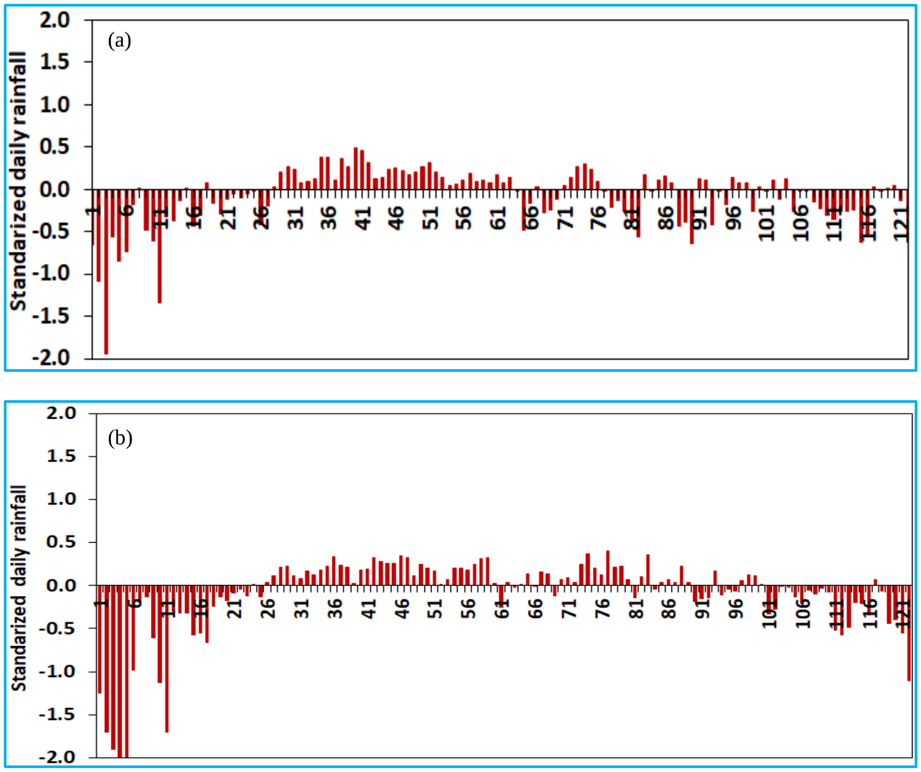
A positive (negative) value of the MK Test indicates an increasing (decreasing) trend in rainfall data.

3. Results and discussion

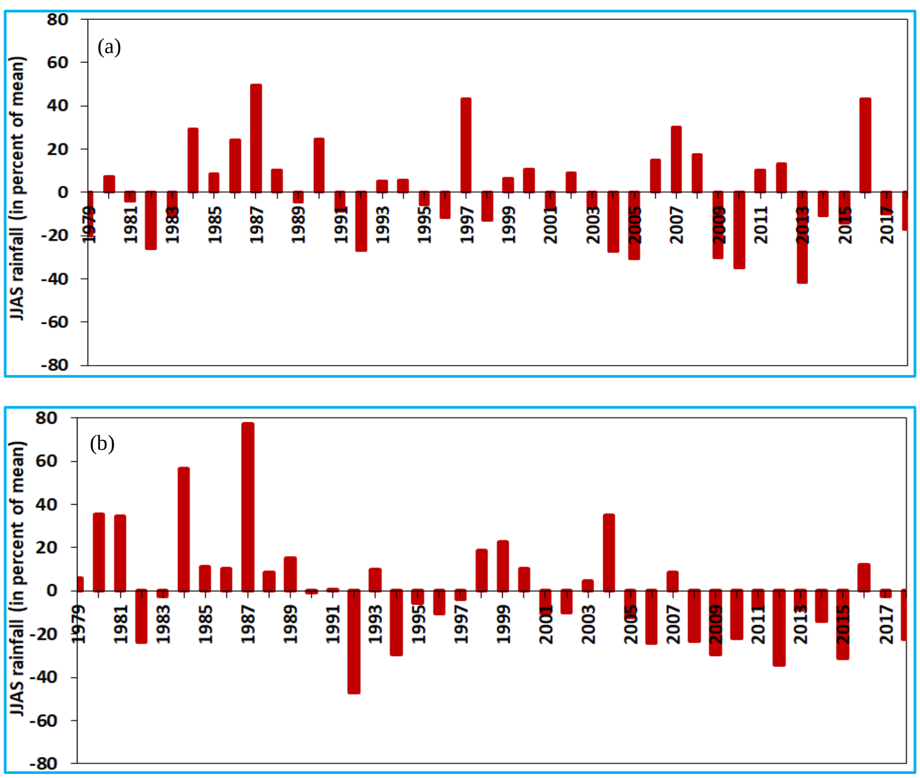
Over the lower Kosi and Punpun river basins, only few grid points (5 and 9 grids over the Kosi and the Punpun, respectively) are available at a grid resolution of 0.25° × 0.25°. Therefore spatial distribution analysis may not be suitable and therefore only temporal analysis is carried out.

3.1. *Temporal variation of rainfall events*

The daily accumulated JJAS rainfall over the time period of 1979-2018 for thelower Kosi and the Punpun basinis shown in Figs. 2(a&b). There is a wide variation of daily accumulated rainfall following the years over the lower Kosi basinin comparison to that of the lower Punpun basin. The range of variation is 600-2000 mm and 500-1300 mm over the lower Kosi and the Punpun basins, respectively. The standardized daily rainfall climatology



Figs. 3(a&b). Standardized daily rainfall during JJAS for the time period of 1979-2018 over (a) the Kosi and (b) the Punpun River basin, respectively

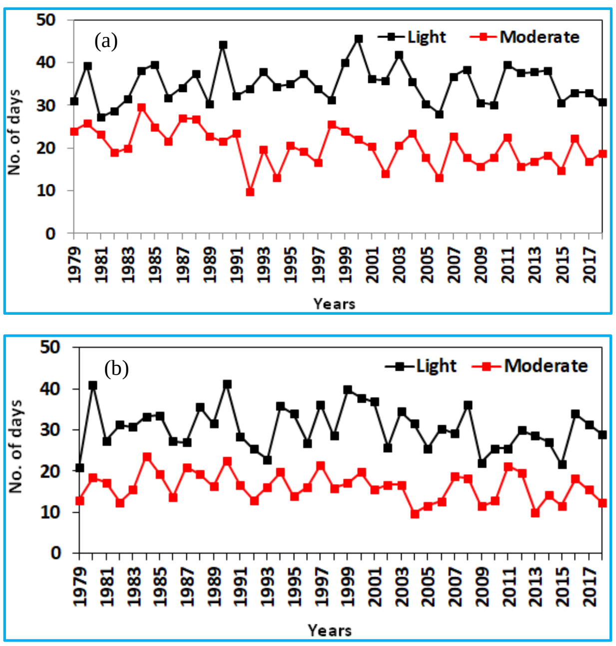


Figs. 4(a&b). JJAS rainfall in percent departure from the mean for the time period of 1979-2018 over (a) the Kosi and (b) the Punpun River basins, respectively

TABLE 2

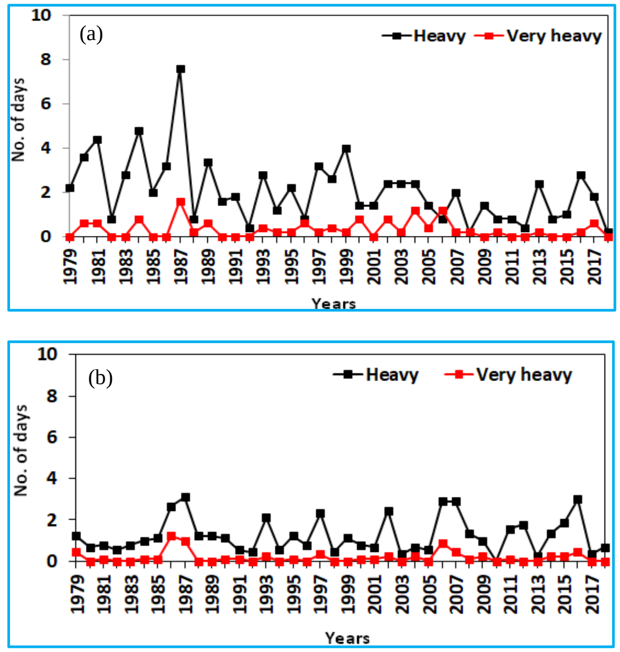
Trend (P value < 0.05 at 95% confidence level in Mann Kendal Test) of rainfall events during 1979-2018 over the Kosi and Punpun river basins

River Basin	Rainfall events	Trend
Kosi	Light rainfall	Increasing
	Moderate rainfall	Decreasing*
	Heavy rainfall	Decreasing*
	Very heavy rainfall	No trend
Punpun		
	Light rainfall	Decreasing
	Moderate rainfall	Decreasing
	Heavy rainfall	Increasing
	Very heavy rainfall	No trend



Figs. 5(a&b). Number of days of Light and moderate rainfall events during JJAS for the time period of 1979-2018 over (a) the Kosi and (b) the Punpun River basins, respectively

(1979-2018) over the lower Kosi and the Punpun is shown in Figs. 3(a&b). Over each basin, out of 122 days in JJAS, the first thirty (30) days (June month) shows negative standardized rainfall anomaly; the next 31-100 days (July and August months) corresponds to positive standardized rainfall anomaly and remaining days (100-122) (September month) showsnegative standardized rainfall anomaly. The percentage departure from the mean value of JJAS rainfall over the river basins of the lower Kosi and the Punpun is shown in Figs. 4(a&b) and no increasing or decreasing trend is seen over the Kosi basin while there is a signal of a positive/negative departure

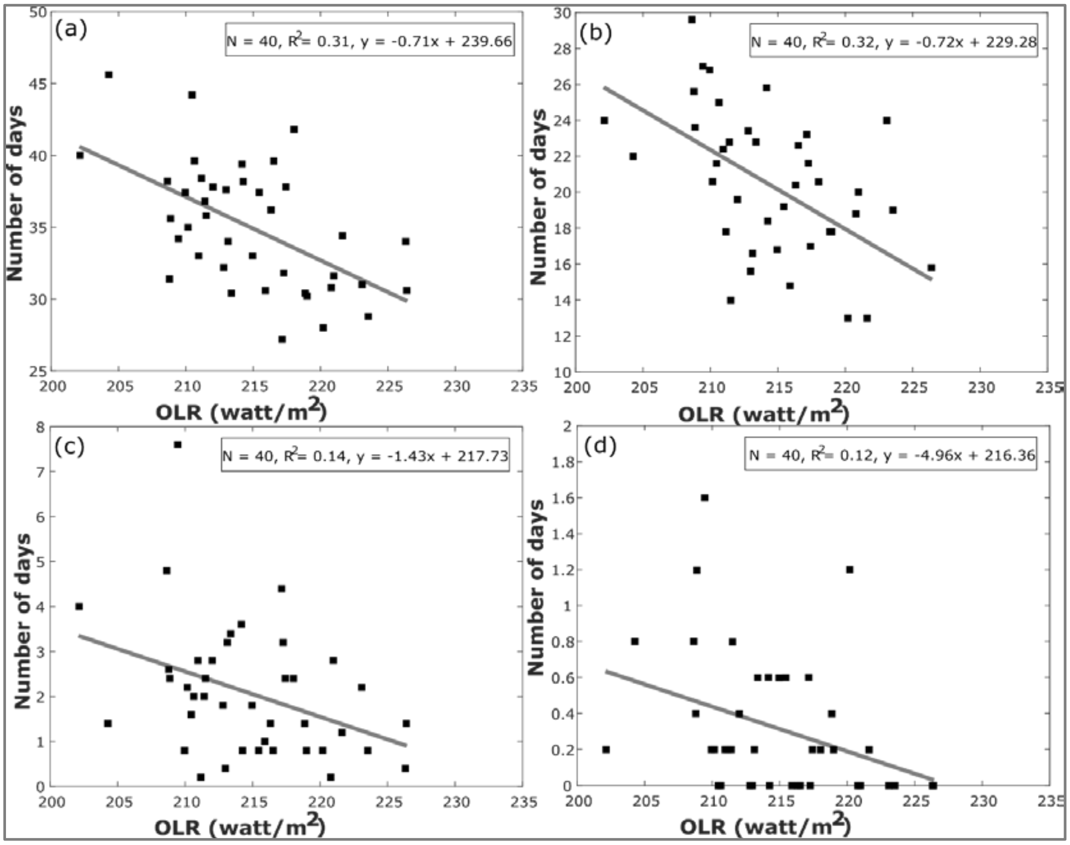


Figs. 6(a&b). Number of days of heavy and very heavy rainfall during JJAS for the time period of 1979-2018 over (a) the Kosi and (b) the Punpun river basins, respectively

over 9-10 years is noticed over the Punpun basin. In recent decades, a negative departure from the JJAS mean is dominating over these basins.

The following section discusses the number of days receiving light, moderate, heavy and very heavy rainfall, as mentioned by IMD (Table 1), over each basin. The number of days of a particular event is counted over each grid falling overariver basinand then it is averaged. Figs. 5(a&b) shows the number of days receiving light and moderate rainfall events during JJAS (1979-2018) over the lower Kosi and the Punpun basins, respectively.

The number of days of light rainfallis relatively more with respect to the moderate rainfall over each basin. Out of 122 days (during JJAS), the number of days of light rainfall is in the range (on average) of 27-46 days (22-37% of 122 days) and 21-41 days (17-33% of 122 days) over the lower Kosi and the Punpun basins, respectively. Similarly, the days of moderate rainfall lie between 10-30 days (8-30% of 122 days) and 10-24 (8-19% of 122 days) days over the lower Kosi and the Punpun basins, respectively. The number of days (or percent) of light and moderate rainfall over these two basins does not show much change. However, light and moderate rainfall jointly contribute a maximum of 50-60% of 122 days during JJAS. In Figs. 6(a&b), the number of days receiving heavy and very heavy rainfall events during the time period of 1979-2018 over the Kosi and Punpunis depicted. The number of days of heavy rainfall events is more than



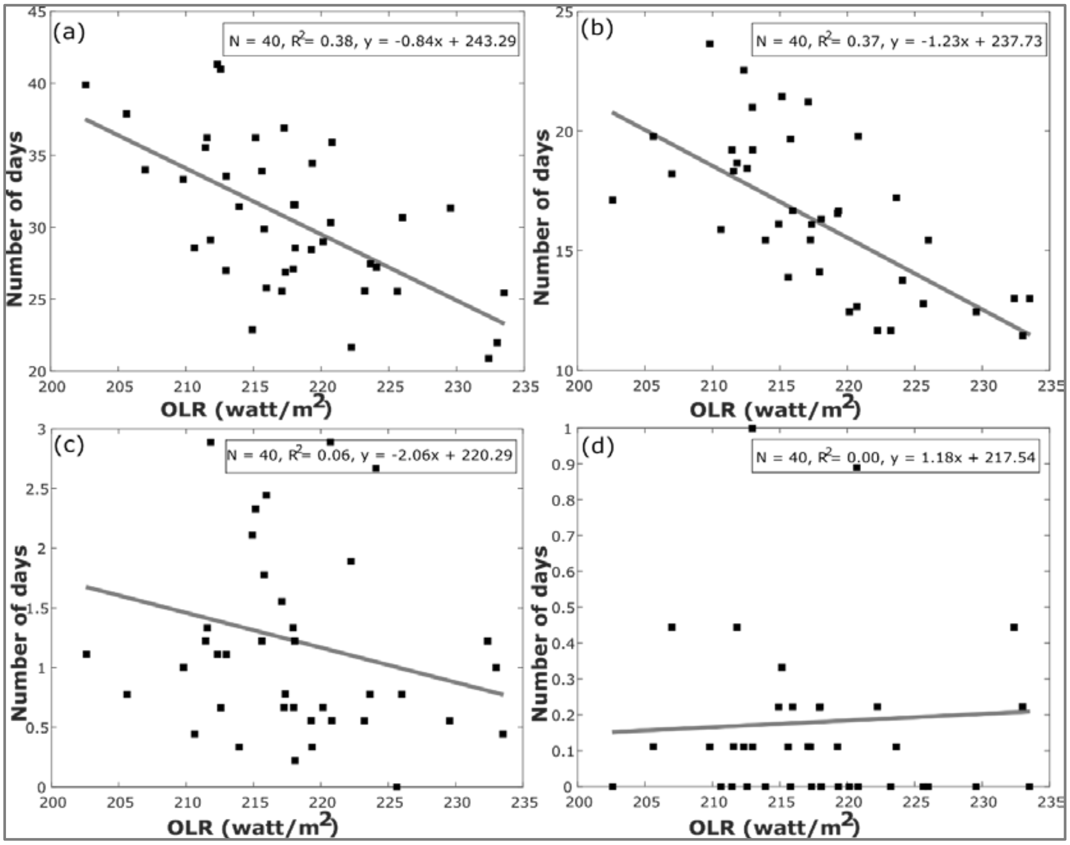
Figs. 7(a-d). Scatter diagram between OLR and number of days of (a) light, (b) moderate, (c) heavy and (d) very heavy rainfall events during JJAS for the period of 1979-2018 over the Kosi river basin

that of very heavy events over each basin. The number of days receiving heavy rainfall events is a maximum of 8 and 3 days (only 6 and 3% of 122 days) over the lower Kosi and the Punpun basins, respectively. The number of days of very heavy rainfall events lies below 2 and 1 days on average over the lower Kosi and the Punpun basins, respectively and did not show much change over each river basin. MK test at 95% confidence level is performed for the number of days of each category of rainfall for the time period of 1979-2018 over each basin. Over the lower Kosi, a significant decreasing trend in the number of days receiving moderate and heavy and anon-significant increasing trend in the number of days in light is noticed (Table 1). Over the lower Punpun basin, a non-significant decreasing trend in the number of days receiving light and moderate rainfall events and a non-significant increasing trend is estimated (Table 1).

The above discussion onrainfall events (light, moderate, heavy and very heavy rainfall events) (Guhathakurta, 2011) may be linked to the north and south shifting of summer monsoon trough from its normal position in July and August in Bihar (Srinivasan *et al*., 1972; Pathan, 1993). It is believed that during the summer monsoon season, atmospheric air over the Bihar and the adjoining area becomes warm and humid, producing a sufficient amount of latent instability and leadingto the convective type of clouds and rainfall (Srinivasan *et al*., 1972; Mishra *et al*., 1988) and therefore the position of monsoon trough has a close link to rainbelt as well as rainfall events and convection (Jin-Hai, 2009). So, in the next section, a possible connection between number of days receiving different rainfall events and the OLR over the river basins is discussed.

3.2. *Rainfall events and OLR*

The mean JJAS OLR and number of days of light, moderate, heavy and very heavy rainfall events during the time period of 1979-2018 over the lower Kosi and the Punpun is presented by the scatter diagram in Figs. 7(a-d) and Figs. 8(a-d). Over the lower Kosi basin, the OLR lies in the range of 210-225 Watt/m^{*2}. Over the lower Kosi basin, the value of the coefficient of determination between OLR and light/moderate rainfall (0.32/0.31) is relatively better against the relation between OLR and heavy/very heavy rainfall (0.14/0.12). It reveals that the light/moderate rainfall events may be better



Figs. 8(a-d). Scatter diagram between OLR and number of days of (a) light, (b) moderate, (c) heavy and (d) very heavy rainfall during JJAS for the period of 1979-2018 over the Punpun river basin

TABLE 3

Correlation between OLR and rainfall events

River basins	Correlation between parameter	Correlation coefficients
Kosi	OLR and Light rainfall	-0.56
	OLR and Moderate rainfall	-0.56
	OLR and Heavy rainfall	-0.37
	OLR and Very heavy rainfall	-0.35
Punpun	**OLR and Light rainfall**	**-0.62**
	OLR and Moderate rainfall	**-0.60**
	OLR and Heavy rainfall	-0.24
	OLR and Very heavy rainfall	0.04

explained by OLR. In Table 3, an acceptable degree of negative correlation (0.56) between OLR and days of light/moderate rainfall events suggest the dependency of these events on OLR.

Over the lower Punpun basin Figs. 8(a-d), the increasing number of days in different rainfall eventsis found when the OLR is in the range of 205-234 Watt/m^{*2}. The value of the coefficient of determination (R^{*2}) is relatively better in the case of OLR and light/moderate rainfall (0.38/0.37) over the lower Punpun basin. However, it is poorly correlated in the case of OLR and the number of days of heavy/very heavy rainfall events. OLR can be used as proxy rainfall prediction (Kriplani *et al*., 1991; Krishnan *et al*., 2000; Prasad and Bansod, 2000; Pai *et al*., 2016). It seems that OLR may be used for light and moderate rainfall prediction over the lower Kosi and the Punpun basins. Earlier, it is shown that the rainfall episodes of >2.5 mm/day, the probability of occurrence of OLR is 0.9 (Kriplani *et al*., 1991). Similarly, the positive (negative) anomalies of OLR are associated with no or little rainfall (good rainfall) over the core monsoon or central India (Krishnan *et al*., 2000). The regions of 70°E to 80°E show a negative correlation between Indian Summer Monsoon Rainfall (ISMR) and OLR (Prasad and Bansod, 2000). The changes in the distribution of daily rainfall events of various intensities associated with break and active events and OLR are examined (Pai *et al*., 2016). The above-cited studies strengthen the negative correlation (>0.6) between OLR and moderate intensity (7.6 to 35.5 mm) of rainfall over the considered river basins. During the summer monsoon season, OLR anomalies have a strong dependence in poor or excess monsoon rainfall (Haque and Lal, 1991). Recently Kumar *et al*. (2021) highlighted the relation between rainfall indices and OLR over the state of Bihar. Based on the above discussion, it can be summarized that the light/ moderate rainfall events are relatively better explained based on OLR over the Kosi and Punpun river basins.

4. Conclusions

The summer monsoon rainfall distribution over the river basin in the state of Bihar, India, influences the risk in flood conditions during the season and, therefore,the distribution of summer monsoon rainfall over the twocontrasting rivers, namely the lower Kosi and the Punpun located over the north and south of the river Ganga, respectively is analyzed. The daily accumulated rainfall of 600-2000 mm and 500-1300 mm (1979-2018) over the lower Kosi and the Punpun basins, respectively, shows a positive standardized daily rainfall anomaly in July and August while the remaining months show negative standardized anomaly. The number of days of light and moderate rainfall events seems to be contributing 27-54% of 122 days during JJAS over both basins. A significant/non-significant decreasing trend in the observed number of moderate rainfall days is noticed over the lower Kosi/Punpun basin. The non-significant increasing/decreasing trend in the number of days of light rainfall over the lower Kosi/Punpun is estimated. Over the lower Kosi basin, the number of days of heavy rainfall is shown a significant decreasing trend. The relation between the OLR (convective activity) is a good degree of negatively correlated with moderate rainfall events over both basins and shows more dependency on each other; however large number of days of rainfall events in all four cases remain in the OLR of the range of 205-234 Watt/m^{*2}.

Disclaimer : The contents and views expressed in this studyare the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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