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Study of southwest monsoon rainfall over Uttar Pradesh during last two decades (2001-2020)

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सार – वर्षा अंतरिक्ष और समय की एक क्रिया है और यह अंतरिक्ष और समय में अत्यधिक परिवर्तनशील है। भारत कृषि प्रधान देश है; इसकी अधिकांश आबादी प्रत्यक्ष और अप्रत्यक्ष रूप से खेती और कृषि गतिविधियों पर निर्भर करती है। भारत में वर्षा का योगदान (लगभग 75%) दक्षिण पश्चिम मॉनसून के मौसम के दौरान होता है। भारत में अधिकांश खेती योग्य भूमि वर्षा आधारित क्षेत्र के अंतर्गत आती है। इसलिए, वर्षा के इन परिवर्तनों का अध्ययन करना और योजना के उद्देश्य से परिचालनात्मक मौसम पूर्वानुमान में सुधार करना और कृषि पर निर्भर लोगों और नीति निर्माताओं तथा सरकार को प्रसारित करना बहुत महत्वपूर्ण है। इसलिए आम लोगों के कल्याण के लिए कुल वर्षा राशि का नियोजन और उचित प्रबंधन एवं उपयोग करना आवश्यक है। तदनुसार, इस शोध पत्र में, पिछले दो दशकों (2001-2020) के दौरान उत्तर प्रदेश (यू.पी.) में जून-सितंबर (JJAS) के दौरान हुई दैनिक वर्षा का विश्लेषण किया गया है क्योंकि इस राज्य ने गंगा-यमुना नदी घाटियों में उपजाऊ भूमि का विस्तार किया है।

विश्लेषण से पता चलता है किपूर्वी उत्तर प्रदेश ने 2001 से 2020 के दौरान 2003 (20%), 2008 (17%) और 2019 (02%) को छोड़कर वर्षा के नकारात्मक प्रत्यंतर का अनुभव किया और वर्ष 2015 में वर्षा में उच्चतम नकारात्मक प्रतिशत प्रत्यंतर (-47%) हुआ और पश्चिम उत्तर प्रदेश में वर्ष 2003 (32%), 2008 (03%), 2010 (0%) और 2018 (01%) को छोड़कर 2001 से 2020 तक नकारात्मक प्रत्यंतर का भी अनुभव किया गया और वर्ष 2014 में उच्चतम नकारात्मक प्रतिशत प्रत्यंतर (-56%) रहा। समूचे उत्तर प्रदेश में, वर्ष 2003 (24%), 2008 (12%) को छोड़कर वर्ष 2001 से 2020 में सामान्य से नकारात्मक प्रतिशत प्रत्यंतर रहा और वर्ष 2014 में उच्चतम नकारात्मक प्रतिशत प्रत्यंतर (-47%) रहा। इसलिए, यह निष्कर्ष निकाला जा सकता है कि केवल कुछ वर्षों को छोड़कर अधिकांश वर्षों के दौरान, उत्तर प्रदेश में पिछले दो दशकों के दौरान नकारात्मक प्रतिशत प्रत्यंतर देखा गया है, जैसा कि ऊपर उल्लेख किया गया है।

पश्चिमी उत्तर प्रदेश, पूर्वी उत्तर प्रदेश और पूरे राज्य में के संबंध में वर्षा में परिवर्तनशीलता जुलाई और अगस्त के महीनों में सबसे कम है और जून और सितंबर के महीनों में सबसे अधिक है। कुल मिलाकर, पूरे ऋतु में वर्षा परिवर्तनशीलता 30 प्रतिशत से कम है। उत्तर प्रदेश में दक्षिण-पश्चिम मॉनसून के दौरान वर्षा के दिन लगभग 59-68 दिन हैं और वर्षा की औसत तीव्रता लगभग 10 मिमी प्रति दिन है।

ABSTRACT. Rainfall is a function of space and time and highly variable in space and time. India is an agricultural country; most of its population directly and indirectly depends upon the cultivation and agricultural activities. Contribution of the rainfall in India (about 75%) is during Southwest monsoon season. Most of the cultivated land in India is under rain fed region. So, it isveryimportant to study these changesof rainfall andimprovement in operational weather forecasting for planning purpose and disseminate to the agricultural depended people and policy makers and Government.It is therefore necessary to make a planning and proper managementand utilization of total rainfall amount for the welfare of common people. Accordingly, in this paper, the daily rainfall during June-September (JJAS) of Uttar Pradesh (U. P.) during last two decades (2001-2020) is analyzedas this state has extended fertile land on Ganga-Yamuna river basins.

Analysis shows that, east U. P. experienced negative departure during 2001 to 2020 except 2003 (20%), 2008 (17%) and 2019 (02%) and highest negative percentage departure (-47%) in the year 2015 and West U.P. also experienced negative departure 2001 to 2020 except 2003 (32%), 2008 (03%), 2010 (0%) and 2018 (01%) and highest

negative percentage departure (-56%) in the year 2014. As regards, whole U.P., it received negative percentage departure from the normal for years 2001 to 2020 except during 2003 (24%), 2008 (12%) and highest negative percentage departure (-47%) in the year 2014. Hence, it may be concluded that during most of the years, Uttar Pradesh witnessed negative percentage departures during last two decades excluding only couple of years as mentioned above.

The rainfall variability in respect of west U.P., east U.P. and state as whole for the months of July and August is least and for the months for June and September is highest. Overall, for the whole season, rainfall variability is less than 30 percent. Rainy days during southwest Monsoon over U.P. are around 59-68 days and average intensity of rainfall is about 10 mm per day.

Key words – Southwest monsoon, Uttar Pradesh, Rainy days, Rainfall variability.

1. Introduction

Uttar Pradesh is the biggest state of the country in terms of population. According to India Meteorological Department (IMD), Uttar Pradesh state is divided into two meteorological sub-divisions namely West Uttar Pradesh and East Uttar Pradesh. West Uttar Pradesh is surrounded by Uttarakhand in north, Haryana, Chandigarh & Delhi in west, East Rajasthan and Madhya Pradesh in south directions. East Uttar Pradesh is surrounded by Nepal in north, Bihar in east, east Madhya Pradesh in south and also touching north Chhattisgarh and west Jharkhand in southeast directions. Agriculture sector is one of the major contributing sectors to the state and of course the country. Agriculture is heavily dependent on the monsoon rainfall. The rainfall received in any domain or parts of the country or region is an important critical factor in determining the amount of water available to meet various demands, such as agriculture, horticulture, livestock, industries and domestic water supply etc. The same is valid for the state of Uttar Pradesh also.

The southwest (SW) monsoon, which brings about 75% of the total precipitation over the country, is a main source for the availability of freshwater for drinking and irrigation. The rainfall of SW monsoon is much important for agricultural production, water resources management and overall economy of the country. The heavy concentration of rainfall in the monsoon months (June-September) results in scarcity of water in many parts of the country during the non-monsoon periods. Therefore, it will not be wrong to say that monsoonal rainfall is key source for many agricultural and economical activities in the country and also for the state as well. The above discussion shows that the analysis of southwest monsoon rainfall is very important for planning and decision purposes. Accordingly, the main goal in this paper is to analyze the monsoon rainfall of recent years and to study the mean rainfall and the rainfall variability in recent decades over the state of Uttar Pradesh.

Statistical studies of rainfall have been done in recent published literature also. Probabilities of excess and deficient southwest monsoon rainfall over different meteorological sub-divisions of India has been done in Kothawale and Munot (1998) by using monthly and seasonal rainfall data from the long homogenous series of 124 years (1871-1994) data of 29 meteorological sub-divisions of the plains of India. Their results show that in the case of excess monsoon years, the average percentage contribution of each month during monsoon period to the long term averages (1871-1994) monsoon season rainfall (JJAS) is more than that of the normal rainfall while in the case of deficient years it is less than normal value. This is found in all the 29 meteorological sub-divisions of study. From the probability analysis, it is seen that there is a rare possibility of occurrence of seasonal rainfall to be excess/deficient when the monthly rainfall of any month is deficient/excess.

Analysis of rainfall pattern and extreme events during southwest monsoon season over Varanasi for the period 1971-2010 has also been done in Bhatla *et al*. (2016). Their results show that cumulative rainfall for the period (1971-2010) is overall decreasing in southwest monsoon season (JJAS) as well as in all the individual months June-September. In general, the observed rainfall events in different categories (Non rainy day, 0-2.4 mm; Category I, 2.5-64.4; Category II, 64.5 to 124.4; Category III, 124.5 mm or more) showed a decreasing trend in all the months and monsoon season (JJAS) over the entire period. However, decadal analysis in the study reveals that in general frequency of rainfall events in almost every category is decreasing (other than August in terms of heavy rainfall case) in recent decade of their study. Different results are seen in August, as cumulative rainfall is decreasing in this month, whereas very heavy and exceptionally heavy rainfall events and their contribution have increased in recent decade as well as over total period of this study. It is important to note that July and August are the major rainfall months during the monsoon season (JJAS).

Rainfall variability analysis of Uttar Pradesh for crop planning and management has been published in Kumar *et al*. (2018). Analysis of rainfall data (1981-2012) of Uttar Pradesh has been done, their results reveal significant decreasing trend in total quantum of annual rainfall. It was also noticed that the frequency of occurrence of annual rainfall below normal was less

before 1990s while increased after 1990s. The amount of annual rainfall decreased significantly after 1996 from 1040.5 mm to 988 mm, *i.e.*, a decrease of 5 percent. A very interesting trend has been noticed for the quantum of monthly rainfall, *i.e*., it was found significantly decreased after 1996 for the months of winter season (October-February) while at par for the months of summer season except May only which was found increased as compared to before 1996. The quantum of monthly rainfall was found significantly decreased after 1996 for initial and last months of monsoon season, *i.e*., June and September while increased for the middle months, *i.e*., July and August as compared to before 1996. The study of decadal variability in annual rainfall showed that an alternate decreasing and increasing trend in all the three decades, *viz*., 1981-1990, 1991-2000 and 2001-2010.

Based on hourly rainfall data of northern and eastern parts of Uttar Pradesh, the significant trends have been done by Kant (2018). In this paper, analysis is done for the four stations Allahabad, Varanasi, Lucknow and Bareilly and concluded that there is no statistically significant trend in the hourly rainfall of northern and eastern parts of Uttar Pradesh during 1969-2014 (Kant, 2018). Spatial analysis of wet spell probability over India (1971-2005) towards agricultural planning has been done in Das *et al*. (2020). Spatial and sub-seasonal patterns of long-term trends of India summer monsoon rainfall may be seen in Kolli *et al*. (1992).

Rainfall probability analysis for the district of Allahabad in Uttar Pradesh has been done in Asim & Nath (2015) and Banjare *et al*. (2019). Their studies showed that the Gumbel distribution was found to be best model for predicting the annual rainfall (mm) for Allahabad, however, Log Normal distribution is fairly close to the observed annual rainfall (mm). Recently, an impact of rainfall variability on ground water resources for the district of Varanasi in Uttar Pradesh by using rainfall data for the period (1992-2014) has been done in Dey *et al*., 2020. In the available literature, studies on the observed trends and variability of rainfall, most of them are based on past many years (for example 100 years data) or more data and also the recent years are not included (Kumar *et al*., 2010; Guhathakurta *et al*., 2015; Guhathakurta *et al*., 2011; Guhathakurta & Rajeevan, 2008, Singh *et al*., 2021).

In the present paper, the analysis of observed rainfall patterns and trends have been done for the state of Uttar Pradesh based on recent past two decades (2001-2020) that will help to have idea of the recent changes in rainfall pattern of state. This will help in adaptation and management by different users including decision makers.

Accordingly, the main aim of this paper is to analyze daily rainfall data of Uttar Pradesh in last two decades (2001-2020). The rest of this paper is organized as follows. Section 2 is related with data and methodology; Results and Discussion is done in Section 3. The paper ends with conclusion in Section 4.

2. Study area, data and methodology

The state of Uttar Pradesh is selected for the rainfall study in this paper. According to India Meteorological Department (IMD) classification, it is divided into two meteorological sub-divisions namely west Uttar Pradesh and east Uttar Pradesh. The main motto is fixed to understand the rainfall variability in recent two decades. Accordingly in this paper, the study is concerned with the two meteorological sub-divisions and state as a whole.

The districts wise/sub-division wise/state wise rainfall data of 20 years (2001-2020) on daily/ monthly/seasonal basis for U.P. was obtained from Hydro-meteorological Division (IMD), New Delhi and Meteorological Centre, Lucknow. Then it was tabulated and monthly total rainfall calculated for every month. Total number of rainy days having rainfall amount of 2.5 mm or more were also selected and counted for every month and average rainy days and rainfall intensity for JJAS (season) is calculated based on this. This will help in understanding mean monthly rainfall were also calculated for JJAS and compared with the available long term normal from IMD for the period of 1981-2010.

Percentage departure of actual rainfall for month of JJAS and season were tabulated and plotted for JJAS for understanding the departure from both 20 years normal and also from the normal for the period of 1961-2010. For identification of mean pattern and trends of intensities of various rainfall events we used daily rainfall data. Different colour codes have also assigned for different categories of departure from normal rainfall during the period. For calculating mean and variability during the months and season, the following statistical parameters are calculated. In this paper, coefficient of variation is used for rainfall variability during monsoon season.

The statistical parameters, arithmetic mean (average), standard deviation (σ), the coefficients of variation (CV) are calculated as follows:

$$\text{Arithmetic Mean } (\bar{x}) = \frac{\sum x_i}{N}$$

$$\text{Standard Deviation } (\sigma) = \sqrt{\frac{\sum (x_i - \bar{x})^2}{N}}$$

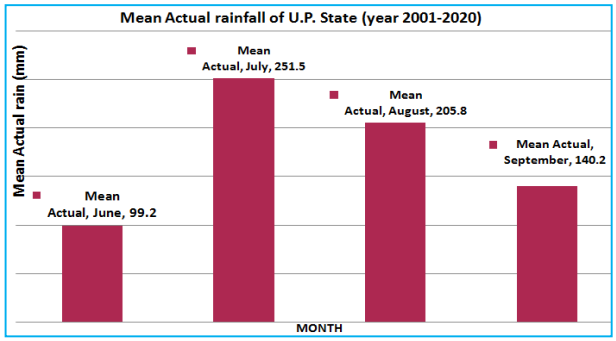

Fig. 1. Mean rainfall (mm) for the period 2001-2020

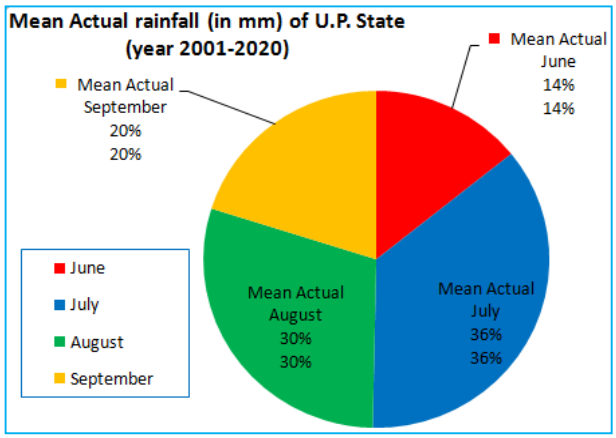

Fig. 2. Percentage of Mean seasonal rainfall (year 2001-2020)

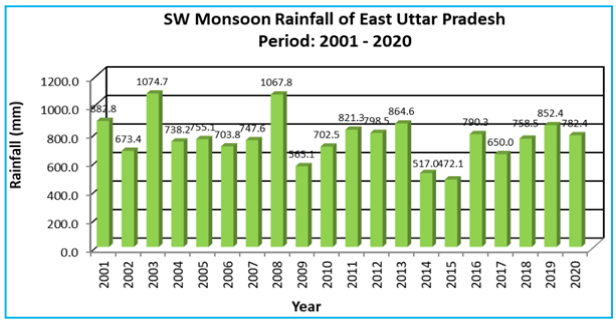

Fig. 3. Rainfall of Monsoon season of East U.P. for the period 2001-2020

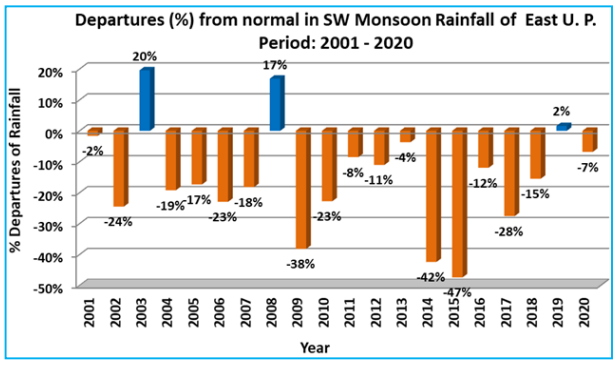

Fig. 4. Percentage departure from normal rainfall of Monsoonseason of East U.P. for the period 2001-2020

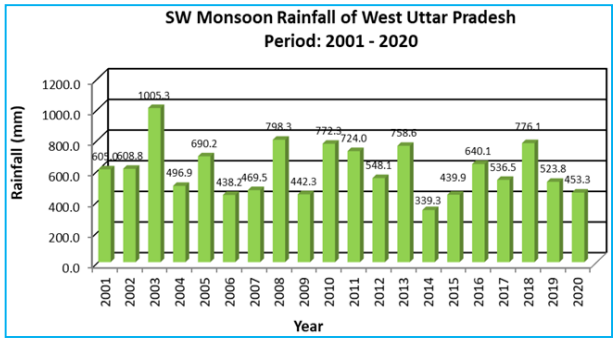

Fig. 5. Rainfall of Monsoon season of West U.P. for the period 2001-2020

TABLE 1

Mean rainfall (mm) for the period 2001-2020 and its comparison with normal rainfall and Guhathakurata *et al*., 2020

Month	Uttar Pradesh		
	Mean actual rainfall (mm)	Rainfall normal based on (1981-2010)	Mean actual rainfall (mm) Guhathakurata *et al.*, 2020
Jun	99.2	94.8	96.1
Jul	251.5	265.7	238.6
Aug	205.8	260.8	219.0
Sep	140.2	168.9	142.9

$$\text{Coefficient of variation } (\text{CV}) = \frac{\sigma}{\bar{x}} \times 100$$

3. Results and discussions

3.1. *Mean monthly rainfall*

Mean monthly rainfall for the month of JJAS on the basis of average rainfall for the period 2001-2020 as given in Table 1. Figs. 1&2 shows bar graphs and pie chart giving mean rainfall and percentage of mean seasonal rainfall for 2001-2020 and it may be observed that Uttar Pradesh was received highest rainfall in July month and least rainfall in the June month in the southwest monsoon season during 2001-2020.

From Table1, it is clear that if we compare the mean rainfall for the recent two decades with normal rainfall of 1981-2010, that for each month of July-September, the mean values are less than normal. At the same time, the normal and mean rainfall patters for different months of southwest monsoon are same. Mean and normal rainfall is lowest in the month of June; however, it is highest is the

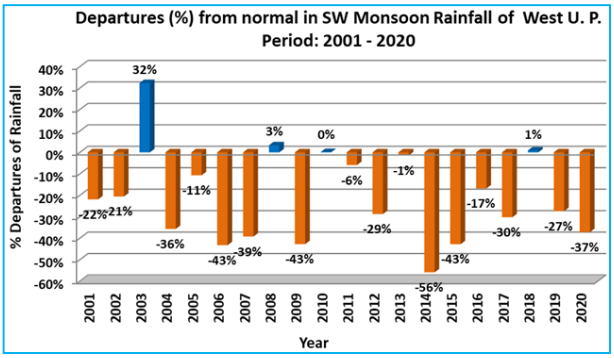

Fig. 6. Percentage departure from normal rainfall during Monsoonseasonof West U.P. for the period 2001-2020

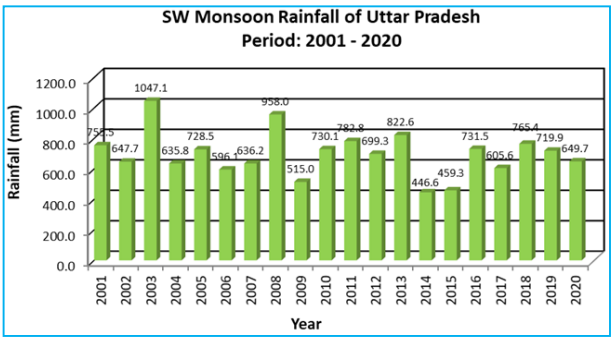

Fig. 7. Rainfall during Monsoon season of U.P. State for the period 2001-2020

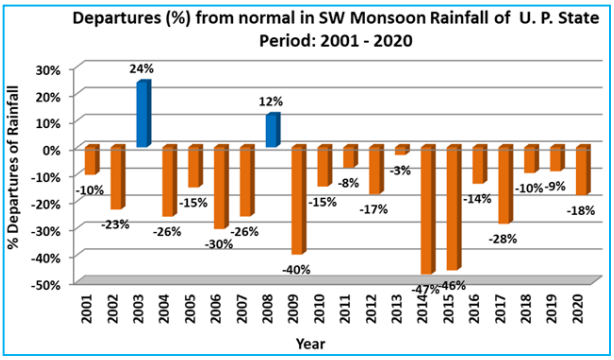

Fig. 8. Percentage departure from normal rainfall during Monsoon season of U.P. State for the period 2001-2020

month of July followed by August and September. It is an important result of further understanding of current scenario of mean rainfall of Uttar Pradesh in recent two decades.

Monthly actual, normal rainfall (in mm) and percent departure from their normal of East U.P., West U.P. and Uttar Pradesh for the month of June, July, August, September from period 2001-2020 are plotted in Figs. 3&4, Figs. 5&6 and Figs. 7&8 respectively.

TABLE 2

Rainy days and rainfall intensity of East U.P., West U.P. and U.P. State

State/Sub-division	Rainy days of SW Monsoon (Days)	Rainfall Intensity of SW Monsoon (mm/day)
East U.P.	66	11.5
West U.P.	59	10.2
Uttar Pradesh	68	10.2

3.2. *Seasonal rainfall*

Seasonal rainfall (actual and normal) and percentage departure from normal rainfall of monsoon season (June to September) for the period 2001-2020 of East U.P., West U.P and Uttar Pradesh state have been given in graphs Figs. 3-8 respectively. It may be observed that East U.P. experienced negative departure 2001 to 2020 except 2003, 2008 and 2019. West U.P. also experienced negative departure 2001 to 2020 except 2003, 2008, 2010 and 2018 and the U.P. State experienced negative departure from the normal for years 2001 to 2020 except 2003, 2008 which was excess rainfall category and highest negative % departure (47%) in the year 2014.

3.3. *Rainy days and rainfall intensity of U.P. State, East U.P. and West U.P.*

The rainy days and rainfall intensity of East U.P., West U.P. and U.P. State, has been shown in Table 2. The number of rainy days is 66 days in East U.P., 59 days in West U.P. and 68 days in U.P. State during south-west monsoon period and rainfall intensity of East U.P., West U.P. and U.P. State are 11.5 mm/day, 10.2 mm/day and 10.2 mm/day respectively for the period 2001-2020.

3.4. *Rainfall variability*

The rainfall variability is an important aspect in rainfall study. Based on the data for recent two decades (2001-2020), the rainfall variability, standard deviation and coefficient of variation has been represented in Table 3 for two meteorological sub-divisions and the state.

The coefficient of variation in respect of west Uttar Pradesh, for the months of July and August lies between 27 & 38 percent, however for the months of June and September between 78 & 83 percent. For the whole season is about 27 percent.

The coefficient of variation in respect of east Uttar Pradesh, for the months of July and August lies between

TABLE 3

The rainfall variability for west U.P., east U.P. and U.P. state

State/Sub-division	Statistical parameter	June	July	August	September	Monsoon season
West Uttar Pradesh	Mean (Average)	76.945	221.49	186.13	118.75	603.25
	Standard Deviation (SD)	63.77	82.54	62.75	93.19149	165.56
	Coefficient of variation (CV)	82.88	37.26	33.71	78.48	27.44
East Uttar Pradesh	Mean (Average)	114.57	271.80	219.33	155.21	760.91
	Standard Deviation (SD)	85.04	69.11	48.30	79.31	152.46
	Coefficient of variation (CV)	74.22	25.43	22.02	52.0	20.04
Uttar Pradesh	Mean (Average)	99.17	251.52	205.77	140.185	696.64
	Standard Deviation (SD)	73.16	65.54	48.42	77.97	146.67
	Coefficient of variation (CV)	73.77	26.06	23.53	55.67	21.05

TABLE 4

Comparison between Guhathakurata *et al*., 2020 and the present study

Uttar Pradesh	June	July	August	September	Monsoon season	Statistical parameter
Guhathakurata *et al*., 2020	96.1	238.6	219.0	142.9	696.7	Mean
	60.9	29.5	34.5	49.8	20.8	CV
Present study	99.17	251.52	205.77	140.185	696.64	Mean
	73.77	26.06	23.53	55.67	21.05	CV
The Difference	3.07	12.92	-13.23	-2.715	-0.06	Mean
	12.87	-3.44	-10.97	5.87	0.25	CV

22 & 25 percent, however for the months of June and September between 52 & 74 percent. For the whole season is about 20 percent.

The coefficient of variation in respect of Uttar Pradesh, for the months of July and August lies between 23 & 26 percent, however for the months of June and September between 55 & 74 percent. For the whole season is about 21percent.

4. Conclusions

In the available literature, studies on the observed trends and variability of rainfall, most of them are based on past many years (for example 100 years data) or more data and also the recent years are not included for example long term data for the state of Uttar Pradesh done in Met. Monograph (Guhathakurata *et al*., 2020). This Monograph brings the result of the analysis based on the recent 30 years of data (1989-2018) on the mean spatial rainfall pattern as well as mean spatial pattern of different rainfall events, trends and variability as well as extreme rainfall events during the monsoon months and annual for the state.The present study is based on recent two decades data and the same is compared with Guhathakurata *et al*., 2020.

Mean monthly rainfall amounts for month of July shows the peak month of the southwest monsoon season which gives maximum amount of rainfall of the season in Uttar Pradesh and during the month of June, the rainfall amount was less rainfall because of onset date of monsoon. At the same time, it is also important to note that July is the main month of paddy plantation in the state. Therefore, if rainfall delayed during July, this will have direct impact on paddy planation.

As regards rainy days, during the period of four months only about two months are rainy days (Rainfall 2.5mm/day) Guhathakurata *et al*., 2020. At the same time,

TABLE 5

Advance of SW Monsoon during 2001-2020

Year	Onset at Kerala	Advance at UP	Advance over Entire Country
2001	23-May	23-Jun	3-Jul
2002	29-May	19-Jul	15-Aug
2003	8-Jun	5-Jul	5-Aug
2004	18-May	18-Jun	18-Jul
2005	5-Jun	27-Jun	30-Jun
2006	26-May	9-Jul	24-Jul
2007	28-May	28-Jun	4-Jul
2008	31-May	16-Jun	10-Jul
2009	23-May	10-Jun	3-Jul
2010	31-May	5-Jul	6-Jul
2011	29-May	8-Jul	9-Jul
2012	5-Jun	7-Jul	11-Jul
2013	1-Jun	16-Jun	16-Jun
2014	6-Jun	3-Jul	17-Jul
2015	5-Jun	25-Jun	26-Jun
2016	8-Jun	2-Jul	13-Jul
2017	30-May	3-Jul	19-Jul
2018	29-May	28-Jun	29-Jun
2019	8-Jun	5-Jul	19-Jul
2020	1-Jun	25-Jun	26-Jun

TABLE 6

Withdrawal of SW Monsoon during 2001-2020

Year	Withdrawal from Raj.	With. From UP	With. From Entire Country
2001	10-Sep	27-Sep	16-Oct
2002	16-Sep	30-Sep	25-Oct
2003	17-Sep	10-Sep	15-Oct
2004	24-Sep	8-Oct	18-Oct
2005	2-Sep	7-Oct	11-Oct
2006	21-Sep	3-Oct	17-Oct
2007	30-Sep	10-Oct	22-Oct
2008	29-Sep	12-Oct	15-Oct
2009	25-Sep	12-Oct	22-Oct
2010	27-Sep	1-Oct	29-Oct
2011	23-Sep	30-Sep	24-Oct
2012	24-Sep	12-Oct	21-Oct
2013	9-Sep	19-Oct	21-Oct
2014	23-Sep	7-Oct	18-Oct
2015	4-Sep	3-Oct	19-Oct
2016	15-Sep	14-Oct	25-Oct
2017	27-Sep	15-Oct	25-Oct
2018	29-Sep	30-Oct	21-Oct
2019	9-Oct	11-Oct	16-Oct
2020	28-Sep	21-Oct	28-Oct

the average intensity of rainfall comes out to be about 10mm/dayshows the mean rainfall (mm) and coefficient of variation of the state for the monsoon months, southwest monsoon season during the period 1989-2018. It can be seen that the state gets highest rainfall (34% of south west monsoon rainfall) in July month followed by August (31% of the south west monsoon rainfall). June and September receive 14% and 21% of south west monsoon rainfall, respectively. The variability of monsoon and annual rainfall is 21%. The comparison of the present study with Guhathakurata *et al*., 2020 is done in Table 4. It is found that the variability for the monsoon season is almost same with a difference of only 0.06. However, the differences between two months June and August are the highest and the least for the months of July and September (refer Table 4).

It is also observed that East U.P. experienced negative percent departure during 2001-2020 with exception in couple of years 2003 [20%; 2008 (17%) & 2019 (02%)] and highest negative percent departure (-47%) recorded in 2015 and similarly West U.P. also experienced negative departure during the same period except 2003 (32%), 2008 (03%), 2010 (0%) and 2018 (01%) and highest negative percent departure (-56%) in 2014. The U.P. State was received negative percent departure from the normal during 2001-2020 except 2003 (24%), 2008 (12%) and highest negative percent departure (-47%) in 2014.

The rainfall variability in respect of west U.P., east U.P. and state as whole for the months of July and August is least and for the months for June and September is highest. Overall, for the whole season, rainfall variability is less than 30 percent.

East U.P. recoded in deficient and normal rainfall category in most of the years during 2001-2020 for instance deficient in 2002, 2006, 2009, 2010, 2014, 2015, 2017 and normal in rest years with one exception 2003 when excess rainfall category reported. West U.P. showed the similar pattern and the same was excess category

rainfall in 2003, normal category rainfall 2005, 2008, 2010, 2011, 2013, 2016, 2018 and in rest years which was deficient rainfall category during the same period. Accordingly, U.P. State was excess category rainfall in 2003, deficient category rainfall in 2002, 2004, 2006, 2007, 2009, 2014, 2015, 2017 and in rest years which was normal during 2001-2020.

In the year of 2003, the state of Uttar Pradesh reported excess rainfall. In the same year, the southwest monsoon advance happened over Uttar Pradesh on 5th July and withdrawal on 10th September. At the same time, if look at the list of advance and withdrawal of southwest monsoon (Tables 5 & 6), one can easily found that in the years of most deficient years 2014 & 2015, advance was early and withdrawal was delayed as compared to the excess monsoon year 2003. Therefore, it is inferred that advance and withdrawal dates are not directly related with the performance of monsoon rainfall over the state of Uttar Pradesh.

One of the possible reasons is that monsoon rainfall is not uniformly distributed. Intense spells in some days due to prevailing synoptically favorable conditions may compensate the rainfall departure and may lead to overall excess rainfall over the state. Similarly, less intense spells during peak monsoon months may be resulted in the overall deficient rainfall.

This study updates the existing literature in the area of rainfall analysis for the state of Uttar Pradesh. This study is useful for crop planning and management, other allied areas, data managers and policy makers.

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References

Asim, M. and Nath, S., 2015, "Study on Rainfall Probability Analysis at Allahabad District of Uttar Pradesh", *Journal of Biology, Agriculture and Healthcare*, **5**, 11, 214-222.

Banjare, S., Rawat, S. and Gautam, S., 2019 "Rainfall probability analysis for crop planning in Allahabad district of eastern Uttar Pradesh", *Journal of Agrometeorology*, **21**, 1, 112-113. https://doi.org/10.54386/jam.v21i1.218

Bhatla, R., Tripathi, A. and Singh, R. S., 2016, "Analysis of rainfall pattern and extreme events during southwest monsoon season over Varanasi during 1971-2010", *MAUSAM*, **67**, 4, 903-912.

Das, Prabir Kumar, Das, Dilip Kumar, Midya, Subrata Kumar, Bandyopadhyay, Soumya and Raj, Uday, 2020, "Spatial analysis of wet spell probability over India (1971-2005) towards agricultural planning", *Atmósfera*, **33**, 1, 19-31. https://doi.org/10.20937/ATM.52499.

Dey, Sangita, Bhatt, Diva, Haq, Saidul and Mall, Rajesh Kumar, 2020, "Potential impact of rainfall variability on groundwater resources: a case study in Uttar Pradesh, India", *Arab J. Geosci*., **13**, 114. https://doi.org/10.1007/s12517-020-5083-8.

Guhathakurta, P. and Rajeevan, M., 2008 "Trends in rainfall pattern over India", *International J. of Climatology*, **28**, 1453-1469.

Guhathakurta, P., Kumar, B. L., Menon, P., Prasad, A. K., Sable, S. T. and Advani, S. C., 2020, "Observed Rainfall Variability and Changes Over Uttar Pradesh State", Met Monograph No.: ESSO/IMD/HS/Rainfall Variability/27(2020)/51.

Guhathakurta, P., Rajeevan, M., Sikka, D. R. and Tyagi, A., 2015, "Observed changes in southwestmonsoon rainfall over India during 1901-2011", *Int. J. Climatol*., **35**, 1881-1898.

Guhathakurta, P., Sreejith, O. P. and Menon, P. A., 2011, "Impact of climate changes on extremerainfall events and flood risk in India", *J. Earth System Science*, **120**, 3, 359-373.

Kant,S., 2018, "Trend and variability of hourly intensity of rainfall over eastern and northern part of Uttar Pradesh during 1969-2014", *MAUSAM*, **69**, 4, 577-588. https://doi.org/10.54302/mausam.v69i4.422.

Kolli, R., Pant, G. B., Parthasarathy, B. and Sontakke, A., 1992, "Spatial and sub-seasonal patterns of long-term trends of India summer monsoon rainfall", *Int. J. Climatology*, **12**, 257-268.

Kothawale, D. R. and Munot, A., 1998, "Probabilities of excess and deficient southwest monsoon rainfall over different meteorological sub-divisions of India", *Proc. Indian Acad. Sci*. (Earth Planet. Sci.), **107**, 2, 107-119.

Kumar, A., Tripathi, P., Gupta, A., Singh, K. K., Singh, P. K., Singh, R, Singh, R. S. and Tripathi, A., 2018, "Rainfall variability analysis of Uttar Pradesh for crop planning and management", *MAUSAM*, **69**, 1, 141-146.

Kumar, V., Jain, S. K. and Singh, Y., 2010, "Analysis of long-term rainfall trends in India", *Hydrol. Sci. J*., **55**, 4, 484-496.

Singh, A., Thakur, S. and Adhikary, N. C., 2021, "Analysis of spatial and temporal rainfall characteristics of the North East region of India", *Arab J. Geosci*.,**14**, 885. https://doi.org/10.1007/s12517-021-07266-1.