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To evaluate trends in weather variables in Haryana using Mann Kendall test and Sen's slope estimator

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Abstract**—***Over the 35-year period from 1985 to 2020, an extensive analysis of rainfall and temperature trends across several cities in Haryana, including Hisar, Rewari, Ambala, Karnal, and Rohtak, was conducted. Hisar exhibited a significant yearly increase in May rainfall, while the monsoon season showed a non-significant decreasing trend. Rewari experienced notable rises in March rainfall but insignificant changes during monsoon, while Ambala saw an overall decrease in rainfall, particularly in September. Karnal indicated significant January rainfall increases but insignificant changes during monsoon. Rohtak displayed noteworthy reductions in February and August rainfall but insignificant changes during monsoon. Temperature trends varied across cities, with consistent increases observed in minimum temperatures and sporadic changes in maximum temperatures. Understanding these patterns is crucial for evaluating regional climate variations and devising appropriate adaptation strategies. This comprehensive research provides valuable insights into the complex interplay between rainfall and temperature dynamics, offering essential information for policymakers and stakeholders tasked with addressing climate change challenges in the Haryana region.*

Keywords**—*Climate change, Haryana, Monsoon, Rainfall, Temperature***

I. INTRODUCTION

Land constitutes a valuable asset encompassing natural elements such as terrain, weather, soil, water, and plants. Humanity relies on this resource for sustenance, textiles, and energy, leading to a swift expansion of farming areas. The growth of agriculture paved the way for the surge in industrialization, akin to how the agricultural revolution preceded the industrial revolution spanning from 18th-century England to 19th-century Japan (World Development Report 2008). The adoption of contemporary farming techniques in the 1970s, notably recognized as the Green Revolution, in Haryana state brought about remarkable advancement over the past 40-50 years. This progress stands as an unparalleled instance in the annals of global agricultural development. (Rangi and Sidhu 1998).

Hussain *et al.,* (2021) examined monthly minimum temperature (T_{min}), maximum temperature (T_{max}), and precipitation from nine Upper Indus Basin (UIB) meteorological stations to study the spatiotemporal variations of temperature and precipitation on month to month, seasonal, and yearly scales. Mondal *et al.,* (2015) studied alterations in the trends of rainfall and temperature for 141 (1871-2011) and 107 years (1901-2007) respectively in India. Pal *et al.,* (2011) documented the protracted trends for the four yearly, seasonal and precipitation types in India's main climatological areas and sub-regions.

Despite the remarkable advancements in agricultural technology over the past few years, the weather and climate still play a significant role in agricultural production. The net primary productivity of plants will raise as CO_2 concentrations rise, but climate change and the concomitant changes in disturbance regimes could result in either an increase or a decrease in net ecosystem production. The hydrologic cycle and groundwater recharge, which regulate waterlogging and salinity

distribution of shallow aquifer systems and consequently impact the amount of land that can be used for agriculture, can be considerably altered by changes in climatic variables. A number of significant weather abnormalities that occur in the State have a negative impact on crop production, including insufficient rains, excessive rains that fall at the wrong time, heat waves, cold waves, high and hot winds during the summer (known locally as "loo"), dust storms, fog, frost, and hail. The south-westerly monsoon and north-westerly cold winds have a significant impact on Haryana's climate. From July to September, only the tails of the summer monsoon depressions are experienced.

II. MATERIAL AND METHODS

For evaluation of climate change, 5 districts are selected in such a way that whole Haryana is represented. These 5 districts are- Ambala, Rohtak, Hisar, Karnal and Rewari. The geographical area is 1569 km^2 of Ambala, 1745 km^2 of Rohtak, 3083 km^2 of Hisar, 2520 km^2 of Karnal and 1594 km^2 of Rewari.

To analyze the trend in weather variables, three parameters have been taken i.e., Maximum temperature, Minimum temperature and Rainfall for five districts (Ambala, Rohtak, Hisar, Karnal and Rewari). To evaluate climate change at all districts, climatic data of 35 years (1985-2020) has been taken of their respective district. Data was taken from Department of Agricultural Meteorology, CCSHAU, Hisar and IMD.

Trends in long term weather data will be carried out by the widely accepted non-parametric test for weather variables working with time series trends i.e. Mann Kendall test and Sen's slope estimator using MAKESENS programme. Where Mann- Kendall Test shows the trend analysis and the value of Sen's slope estimator gives the magnitude of the trend.

III. RESULTS AND DISCUSSION

Five districts data has been tabulated and precessed through the MAKESENS programme and the results have been discussed below:

3.1 Weather variables at Hisar

During the period of 1985-2020 at Hisar, May month observed significant increasing trend in rainfall @ 0.23 mm/year. Whereas during monsoon, there is a non-significant decreasing trend with rainfall decreasing @ 0.04mm/year. Yearly trend at Hisar observed increasing trend in rainfall @ 1.31 mm/year.

The results revealed that during the last 35 years (1985-2020), the annual mean maximum temperature of Hisar had shown a non-significant increasing trend by 0.01°C/year, while in January, the mean maximum temperature had shown a significant decreasing trend and decreased by 0.04°C (Table 1). Meanwhile, in September, the mean maximum temperature had shown a significant increasing trend and increased by 0.03°C.

The average minimum temperature exhibited a noteworthy upward trend throughout each month. On an annual basis, there was a significant increase in the minimum temperature, reaching 0.02°C per year. Similarly, February, April, and August experienced notable rising trends, with temperature increments of 0.03°C, 0.04°C, and 0.02°C, respectively, at Hisar during the period of 1985-2020.

3.2 Weather variables at Rewari

The findings indicate that over the past 35 years (1985-2020) in Rewari, there has been a notable rise in rainfall during the month of March, with an increase of 0.17 mm per year. Conversely, during the monsoon season, there is a slight, albeit statistically insignificant, upward trend in rainfall, which amounts to an increase of 2.09 mm per year. Overall, the annual trend in rainfall at Rewari demonstrates a significant increase of 2.65 mm per year.

During the period of 35 years (1985-2020), the average maximum temperature in Rewari showed no change at all. However, in January, there was a notable and significant decrease in the mean maximum temperature, with a decrease of 0.05°C (Table 2). Similarly, in November, there was also a significant decrease observed in the mean maximum temperature, with a decrease of 0.03°C.

The mean minimum temperature in Rewari displayed a considerable upward trend across all months. Annually, there was a significant rise in the minimum temperature, amounting to 0.02°C per year. Similarly, February, April, August, and September witnessed noticeable increasing trends, with temperature increments of 0.03°C, 0.04°C, 0.02°C, and 0.02°C, respectively.

3.3 Weather variables at Ambala

The results suggest that in Ambala over the past 35 years (1985-2020), there was a considerable increase in rainfall during April, averaging a rise of 0.36 mm per year. However, in September, there was a significant decrease noted, amounting to 2.91 mm per year. Conversely, during the monsoon season, there was a slight, yet statistically significant, decline in rainfall, equating to a decrease of 10.94 mm per year. Overall, the annual trend in rainfall for Ambala indicated a significant decrease of 10.52 mm per year.

During the last 35 years (1985-2020), the mean maximum temperature in Ambala showed a non-significant annual increase of 0.01°C. However, July stood out with a significant and noticeable rise in the mean maximum temperature, amounting to an increase of 0.03°C (Table 3). Similarly, in August, September, and October, there was also a significant increase observed in the mean maximum temperature, each with an increase of 0.03°C.

The average minimum temperature in Ambala exhibited a considerable upward trend across all months. Annually, there was a significant rise in the minimum temperature, amounting to 0.02°C per year. Similarly, February, April, July, August, September, October, and November experienced noticeable increasing trends, with temperature increments of 0.03°C, 0.03°C, 0.02°C, 0.02°C, 0.02°C, 0.03°C, and 0.02°C, respectively.

3.4 Weather variables at Karnal

The findings indicate that in Karnal during the last 35 years (1985-2020), there has been a significant rise in rainfall during January, averaging an increase of 0.31 mm per year. However, during the monsoon season, there is a slight but statistically insignificant decrease in rainfall, amounting to a decline of 0.97 mm per year. Overall, the annual trend in rainfall for Karnal suggests an insignificant decrease of 0.61 mm per year.

Over the past 35 years (1985-2020), the average maximum temperature in Karnal exhibited a non-significant annual rise of 0.01°C. However, October notably demonstrates a significant and conspicuous increase in the mean maximum temperature, with a rise of 0.03°C (Table 4).

The average minimum temperature in Karnal exhibited a notable upward trend throughout each month. On an annual basis, there was a significant increase in the minimum temperature, reaching 0.02°C per year. Similarly, February, April, July, August, and September experienced observable rising trends, with temperature increments of 0.03°C, 0.04°C, 0.02°C, 0.03°C, and 0.02°C, respectively.

3.5 Weather variables at Rohtak

The results suggest that over the past 35 years (1985-2020) in Rohtak, there has been a noteworthy reduction in rainfall during February and August, averaging decreases of 0.15 mm and 2.66 mm per year, respectively. However, during the monsoon season, there is a slight but statistically insignificant decrease in rainfall, with a decline of 4.71 mm per year. Overall, the annual trend in rainfall for Rohtak indicates an insignificant decrease of 5.58 mm per year.

Mean maximum temperature in Rohtak showed no change in the trend annually during the last 35 years (1985-2020). However, January and November stood out with significant and noticeable decreases in the mean maximum temperature, with declines of 0.05°C and 0.03°C, respectively (Table 5).

The mean minimum temperature in Rohtak exhibited a noticeable upward trend across all months. Annually, there was a significant rise in the minimum temperature, reaching 0.02°C per year. Similarly, February, April, August, and September experienced observable significant increases, with temperature increments of 0.03°C, 0.04°C, 0.02°C, and 0.02°C, respectively.

IV. FIGURES AND TABLES

Table 1: Monthly Significant trends in weather variables at Hisar

Weather Parameters	Months	Mann-Kendall Trend (Test Z)	Sen's slope estimation (Q)
Rainfall			
	MAY	1.98*	0.23
	S-W MONSOON	-0.09	-0.04
	ANNUAL	0.67	1.31
Maximum Temperature			

	JANUARY	-1.70 +	-0.04
	SEPTEMBER	1.68 +	0.03
	ANNUAL	0.69	0.01
Minimum Temperature			
	FEBRUARY	1.81 +	0.03
	APRIL	1.76 +	0.04
	AUGUST	2.77 **	0.02
	ANNUAL	2.38 *	0.02

Table 2: Monthly Significant trends in weather variables at Rewari

Weather Parameters	Months	Mann-Kendall Trend (Test Z)	Sen's slope estimation (Q)
Rainfall			
	MARCH	2.05 *	0.17
	S-W MONSOON	0.59	2.09
	ANNUAL	0.69	2.65
Maximum Temperature			
	JANUARY	-1.92 +	-0.05
	NOVEMBER	-1.87 +	-0.03
	ANNUAL	-0.40	0.00
Minimum Temperature			
	FEBRUARY	1.81 +	0.03
	APRIL	1.76 +	0.04
	AUGUST	1.88 +	0.02
	SEPTEMBER	2.04 *	0.02
	ANNUAL	2.08 *	0.02

Table 3: Monthly Significant trends in weather variables at Ambala

Weather Parameters	Months	Mann-Kendall Trend (Test Z)	Sen's slope estimation (Q)
Rainfall			
	APRIL	2.52 *	0.36
	SEPTEMBER	-1.87 +	-2.91
	S-W MONSOON	-2.49 **	-10.94
	ANNUAL	-2.74 *	-10.52
Maximum Temperature			
	JULY	1.76 +	0.03

	AUGUST	2.11 *	0.03
	SEPTEMBER	2.03 *	0.03
	OCTOBER	1.70 +	0.03
	ANNUAL	0.94	0.01
Minimum Temperature			
	FBRUARY	1.68 +	0.03
	APRIL	1.68 +	0.03
	JULY	1.89 +	0.02
	AUGUST	3.17 **	0.02
	SEPTEMBER	2.03 *	0.02
	OCTOBER	2.44 *	0.03
	NOVEMBER	1.73 +	0.02
	ANNUAL	2.68 *	0.02

Table 4: Monthly Significant trends in weather variables at Karnal

Weather Parameters	Months	Mann-Kendall Trend (Test Z)	Sen's slope estimation (Q)
Rainfall			
	JANUARY	1.90 +	0.31
	S-W MONSOON	-0.29	-0.97
	ANNUAL	-0.26	-0.61
Maximum Temperature			
	OCTOBER	2.06 *	0.03
	ANNUAL	1.13	0.01
Minimum Temperature			
	FEBRUARY	1.81 +	0.03
	APRI	1.89 +	0.04
	JULY	1.70 +	0.02
	AUGUST	3.42 ***	0.03
	SEPTEMBER	2.36 *	0.02
	ANNUAL	2.74 **	0.02

Table 5: Monthly Significant trends in weather variables at Rohtak

Weather Parameters	Months	Mann-Kendall Trend (Test Z)	Sen's slope estimation (Q)
Rainfall			
	FEBRUARY	-1.74 +	-0.15
	AUGUST	-2.06 *	-2.66

	S-W MONSOON	-1.51	-4.71
	ANNUAL	-1.46	-5.58
Maximum Temperature			
	JANUARY	-1.92 +	-0.05
	NOVEMBER	-1.87 +	-0.03
	ANNUAL	-0.40	0.00
Minimum Temperature			
	FEBRUARY	1.81 +	0.03
	APRIL	1.76 +	0.04
	AUGUST	2.47 *	0.02
	SEPTEMBER	2.19 *	0.02
	ANNUAL	2.08 *	0.02

V. CONCLUSION

Over the 35-year period from 1985 to 2020, analysis of weather patterns in various cities of Haryana reveals significant trends. Hisar experienced increasing rainfall in May and yearly, but a non-significant decrease during monsoon. Rewari saw notable rises in March and overall rainfall, with stable maximum temperatures but notable increases in minimum temperatures. Ambala witnessed mixed rainfall trends, notably decreasing in September. Karnal showed rising rainfall in January but a slight decrease during monsoon, with stable maximum temperatures and significant increases in minimum temperatures. Rohtak displayed reduced rainfall in February and August, stable maximum temperatures, and significant rises in minimum temperatures throughout the year. These trends reflect complex climate dynamics requiring continued monitoring and adaptation efforts.

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