CHAPTER 5

Evaluation of Temporal Variability of Meteorological Variable

5.1 Overview

The assessment of climate variables through trend analysis is critical in understanding the state of a region's climate and the changes occurring in its variables. Trend analysis is particularly useful in identifying extreme events such as droughts and heat wave that have significant implications for public health, agriculture, and water resources. The climate in Uttar Pradesh, India, is heterogenous and ranges from humid to sub-arid, with inhomogeneous distribution of rainfall causing extreme events. The variability of meteorological variables is crucial for socio-economic reasons, yet no studies have focused on their variability over the entire state at the divisional level. This chapter aims to investigate the trend characteristics of precipitation, temperature, and potential evapotranspiration (PET) across 18 synoptic locations in Uttar Pradesh, India, for the period of 48 years from 1971 to 2018. The study evaluates the trend of rainfall on a monthly, seasonal, and annual timescale, as well as the average temperature and potential evapotranspiration (PET) on a monthly timescale. The Mann-Kendall (MK) test is used to estimate the trends in meteorological variables at a 5% significance level. The magnitude of the trend is then calculated using Sen's Slope tests.

5.1.1 Temporal variability of annual and seasonal precipitation

The changing rainfall pattern is a topic within this field that requires immediate and systematic attention because it affects both freshwater availability and food production (Dore, 2005). It governs the agricultural enterprise's overall cropping pattern, productivity, and long-term viability. The distribution of average monsoon rainfall as a proportion of average annual precipitation for investigated stations over 48 years shows that the monsoon contributed an average of 88.8% to average annual rainfall. Trend assessment of annual and seasonal precipitation was conducted over the study period to understand the temporal variability of precipitation over the study period.

Long-term precipitation time series were analysed using the MK test (Z_{MK}) and Sen's slope estimator test method for nearly half-decade (1971 to 2018) over the 18 synoptic stations of Uttar Pradesh. The MK test is used to evaluate monotonic change, while Sen's slope estimates the magnitude of change over time. Trend has been evaluated at a significance level $\alpha = 0.05$. All timeseries were investigated for no serial correlation before applying the MK test. Table 5.1-5.5 shows the Z_{MK} value, significance level (P-value), and Sen's slope value for precipitation over 48 years for different seasons and annually.

5.1.2 Trend assessment of annual precipitation

The precipitation time series for different seasons and annuals were created using a simple summing procedure from monthly time series data obtained from 1971 to 2018. Table 5.1 displays the mean and standard deviation (SD) of annual precipitation over the 18 synoptic stations of Uttar Pradesh, India. Monsoon precipitation accounts for 89% of the annual precipitation of Uttar Pradesh. The months with the most rainfall are July and August (34% of monsoon rainfall), followed by June and September (31% of monsoon rainfall). Basti district has the highest annual rainfall of 967.41mm with SD (251 mm), while Aligarh division has the lowest annual rainfall of 671 mm with SD (172mm). The lowest annual precipitation was recorded in Agra, Aligarh, Kanpur, and Meerut, varying from 671-680 mm with SD ranging from 172-198 mm, and the highest annual precipitation was recorded in Basti, Gorakhpur, and Gonda (900-980 mm), with SD ranging from 200 to 290mm. The MK (Z_{MK}) test applied over the annual precipitation time series at a 5% significance level ranges from -3.24 to 2.66, as shown in Table 5.1. Figure 5.1 depicts the trend assessment result, which depicts the Z_{MK} value and Sen's slope value of annual precipitation time series from 18 synoptic locations in Uttar Pradesh. A significant decreasing trend was observed over the 13 synoptic locations, whereas Bareilly, Basti, Lucknow, Meerut, and Moradabad stations exhibit a non-significant but decreasing trend.

At the Saharanpur station, positive Z_{MK} value (Z_{MK} =2.62) indicate a significantly increasing trend for annual precipitation. The magnitude of the annual precipitation trend was estimated using Sen's slope ranges from -8.24 mmyr^{-1} to 7.11 mmyr^{-1} as shown in Table 5.1. Ninety-nine percent of the synoptic location experience decreasing annual rainfall rates over the study period, except at location Saharanpur which shows increasing annual precipitation with the slope of 7.11 mmyr^{-1}. Higher rates of decline in annual precipitation were observed in Jhansi (-8.24 mmyr^{-1}), Kanpur (-7.31 mmyr^{-1}), and Chitrakoot (-7.21 mmyr^{-1}), followed by Allahabad (Prayagraj), with a decrease of -6.09 mmyr^{-1}.

Table 5.1 Result of trend characteristics of annual precipitation of the study area

Districts	Mean (mm)	SD (mm)	Kendall's Statistics (Z_{MK})	P-value	Sen's Slope	Trend
Agra	673.83	198.1	-2.24	0.025	-4.83	Decreasing
Aligarh	671	172.5	-1.40	0.05	-2.4	Decreasing
Allahabad	904.66	290.56	-2.2	0.02	-6.09	Decreasing
Azamgarh	844.42	202.2	-3.02	0.001	-6.9	Decreasing
Bareilly	856.48	226.63	-0.07	0.13	-0.29	Decreasing
Basti	967.41	251.49	-0.33	0.12	-0.85	Decreasing
Chitrakoot	953.2	289.9	-2.5	0.01	-7.23	Decreasing
Gonda	918.8	221.62	-1.59	0.05	-3.15	Decreasing
Faizabad	868.1	220.16	-1.60	0.05	-3.8	Decreasing
Gorakhpur	923.3	212.01	-2.40	0.01	-5.74	Decreasing
Jhansi	859.2	261.64	-3.24	0.03	-8.24	Decreasing
Kanpur	778.7	229.16	-2.87	0.004	-7.31	Decreasing
Lucknow	849.1	232.42	-0.61	0.15	-1.42	Decreasing
Meerut	735.1	192.03	-0.73	0.1	-1.77	Decreasing
Mirzapur	960.2	245.88	-2.62	0.008	-6.57	Decreasing
Moradabad	809.8	237.84	-1.18	0.2	-2.64	Decreasing
Saharanpur	892.4	284.64	2.62	0.008	7.11	Increasing
Varanasi	896.1	218.52	-2.99	0.002	-6.58	Decreasing

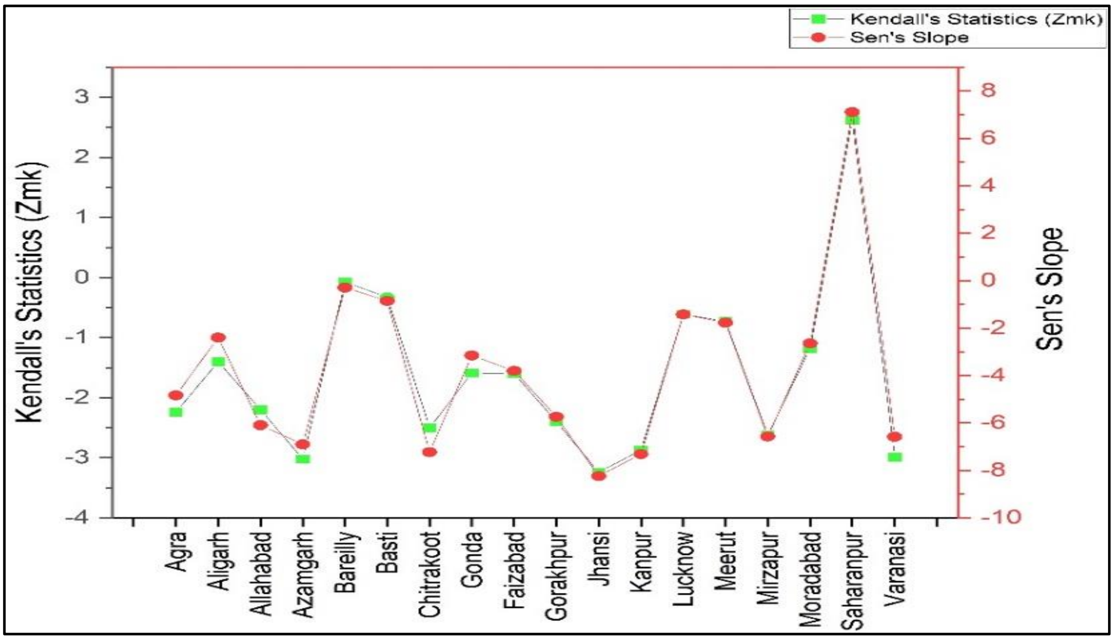

Figure 5. 1 Results of MK test (Z_{MK}) and Sen's slope test assessmemts of annual precipitation, where Z_{MK} stands for the standardized MK trend statistics

5.1.3 Trend assessment of pre-monsoon precipitation

The pre-monsoon season (Summer) begins in March and lasts until mid-June. The hot weather arrives in March and lasts until June 20th. During the summer, the study region experiences dust storms and dust-raising winds, and during April and May, the hot winds (loo) prevailed over the study region, where it blew at an average speed of 8-16 km/h. Table 5.2 summarizes the trend characteristics of precipitation during the pre-monsoon season over the study area for 48 years from 1971 to 2016. Rainfall during this season barely contributes to the overall amount of precipitation over the study area, with Saharanpur recording the g highest average rainfall of 59.6 mm with an SD of 36 mm. Figure 5.2 depicts the trend assessment result, which depicts the Z_{MK} value and Sen's slope value of the pre-monsoon precipitation time series from 18 synoptic locations in Uttar Pradesh. Applying the MK test and Sen's slope estimator over pre-monsoon season revealed that Z_{MK} values vary from 2.4 to -0.18, and Sen's slope output ranges between 0.55 mmyr^{-1} to -1.9 mmyr^{-1}. At a 5% significance level, 66% of the synoptic locations in the research region show increasing rainfall in this season. A significant declining trend was seen at the synoptic location Chitrakoot, whereas a non-significant but persistent decreasing trend was found at stations Moradabad and Mirzapur.

The highest magnitude of the trend was recorded at Basti (Z_{MK} = 2.4, Sen's slope of 0.47 mmyr^{-1}), whereas Bareilly exhibited a non-significant downward trend (Z_{MK} = -0.18, Sen's slope of 0.03 mmyr^{-1}) pre-monsoon rainfall over the study period.

Table 5.2 Result of trend characteristics of pre-monsoon precipitation of the study area

Districts	Mean (mm)	SD (mm)	Kendall's Statistics (Z_{MK})	P-value	Sen's Slope	Trend
Agra	24.5	19.668	0.38	0.05	0.05	Increasing
Aligarh	32.75	20.59	1.40	0.01	0.2	Increasing
Allahabad	23.98	20.25	0.071	0.04	0.02	Increasing
Azamgarh	26.734	19.01	0.72	0.04	0.135	Increasing
Bareilly	38.851	21.96	-0.18	0.09	-0.03	Decreasing
Basti	34.36	23.9	2.40	0.01	0.47	Increasing
Chitrakoot	22.47	20.71	-0.64	0.05	-0.8	Decreasing
Gonda	34	22.5	1.00	0.03	0.3	Increasing
Faizabad	28.9	21.01	1.35	0.01	0.28	Increasing
Gorakhpur	38.3	25.1	1.50	0.01	0.35	Increasing
Jhansi	18.4	13.9	0.41	0.03	0.051	Increasing
Kanpur	21.1	18.46	0.87	0.1	0.095	Increasing
Lucknow	27.7	21.25	1.60	0.04	0.36	Increasing
Meerut	46.4	31.55	0.76	0.24	0.19	Increasing
Mirzapur	27.9	19.34	-0.49	0.23	-0.019	Decreasing
Moradabad	40.7	24.52	-0.37	0.3	-1.9	Decreasing
Saharanpur	59.6	36.01	1.70	0.04	0.55	Increasing
Varanasi	27.9	19.87	0.023	0.14	0.049	Increasing

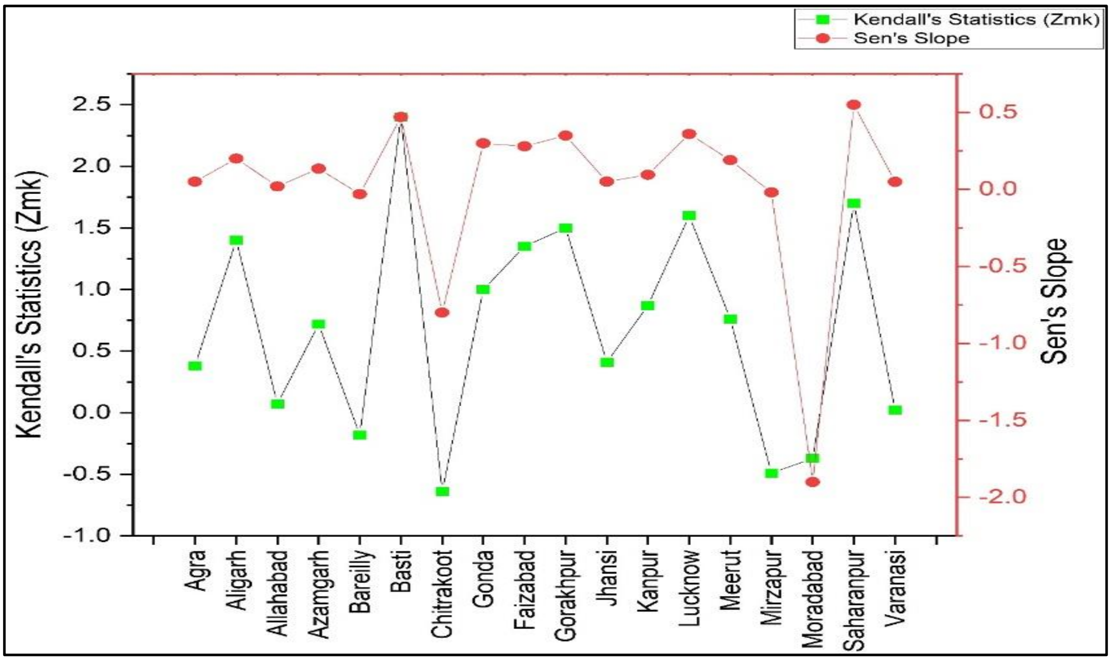

Figure 5.2 Results of MK test (Z_{MK}) and Sen's slope test assessments of pre-monsoon precipitation, where Z_{MK} stands for the standardized MK trend statistic

5.1.4 Trend assessment of monsoon precipitation

The monsoon season starts in mid-June and lasts through the end of September. The monsoon season receives the majority of precipitation (between 60 and 89 %) due to the southwest monsoon. The monsoon season begins when the water-laden storm from the Bay of Bengal crosses over a study area. The commencement of the monsoon may be as early as the last week of May or as delayed as the second week of July. The rainy season usually begins in June. The wettest months are July and August. The southwest monsoon causes rain in the study area. The present study analyses monthly rainfall data from 18 synoptic locations to study the monsoon season trend and variability of rainfall. The variability of monsoon precipitation is demonstrated in Table 5.3. Table 5.3 summarizes the mean, standard deviation (SD), Z_{MK} trend value, and its significance value (P-value) as well the slope's median (Sen's slope). Figure 5.3 illustrate the trend assessment result, which portrayed the Z_{MK} value and Sen's slope value of monsoon precipitation time series from 18 synoptic locations in Uttar Pradesh. The average monsoon rainfall is lower in the western part of the study region as compared to the other stations, such as Aligarh, Agra, and Meerut. The northeastern region of the study area received a higher average rainfall during the monsoon, such as Basti, Gonda, and Gorakhpur. The application of the nonparametric MK trend test and Sen's slope estimator over the monsoon rainfall over Uttar Pradesh reveals a statistically significant negative trend in monsoon rainfall over 14 synoptic locations. The monsoon rainfall exhibits a significant negative trend with higher magnitude observed at synoptic location Jhansi Z_{MK} = 2.07 with Sen's slope of 8.16 mmyr^{-1} followed by Azamgarh Z_{MK} = 2.80 with Sen's slope of 6.60 mmyr^{-1} whereas synoptic location Basti, Bareilly, and Lucknow exhibiting non-significant decreasing trend over the considered period. Saharanpur is the only location showing a positive trend of Z_{MK} = 2.07 with the Sen's slope of 5.79 mmyr^{-1}. The overall study region is experiencing a decrease in monsoon rainfall across the study region, which is a cause for concern for the state government.

Table 5.3 Result of trend assessment of monsoon precipitation of the study area

Districts	Mean (mm)	SD (mm)	Kendall's Statistics (Z_{MK})	P-value	Sen's Slope	Trend
Agra	606.66	198.09	-2.2	0.02	-4.76	Decreasing
Aligarh	589.57	181.26	-1.26	0.04	-2.71	Decreasing
Allahabad	798.81	283.39	-1.90	0.05	-5.67	Decreasing
Azamgarh	748.63	195.88	-2.80	0.004	-6.6	Decreasing
Bareilly	753.89	225.4	-0.16	0.23	-0.25	Decreasing
Basti	858.2	252.33	-0.372	0.2	-1.15	Decreasing
Chitrakoot	845	285.57	-2.38	0.01	-6.2	Decreasing
Gonda	810.7	217.49	-1.30	0.01	-2.59	Decreasing
Faizabad	768.2	222.22	-1.43	0.04	-3.36	Decreasing
Gorakhpur	812	210.43	-2.70	0.006	-4.9	Decreasing
Jhansi	773.95	253.216	-2.90	0.002	-8.16	Decreasing
Kanpur	687.5	228.61	-2.70	0.006	-7.05	Decreasing
Lucknow	747.5	232.14	-0.71	0.17	-1.54	Decreasing
Meerut	625.8	191.04	-1.06	0.02	-2.15	Decreasing
Mirzapur	845	236.66	-2.12	0.03	-5.23	Decreasing
Moradabad	707.6	236.84	-1.17	0.02	-2.96	Decreasing
Saharanpur	755	266.09	2.07	0.03	5.79	Increasing
Varanasi	786.3	205.98	-2.49	0.02	-6.02	Decreasing

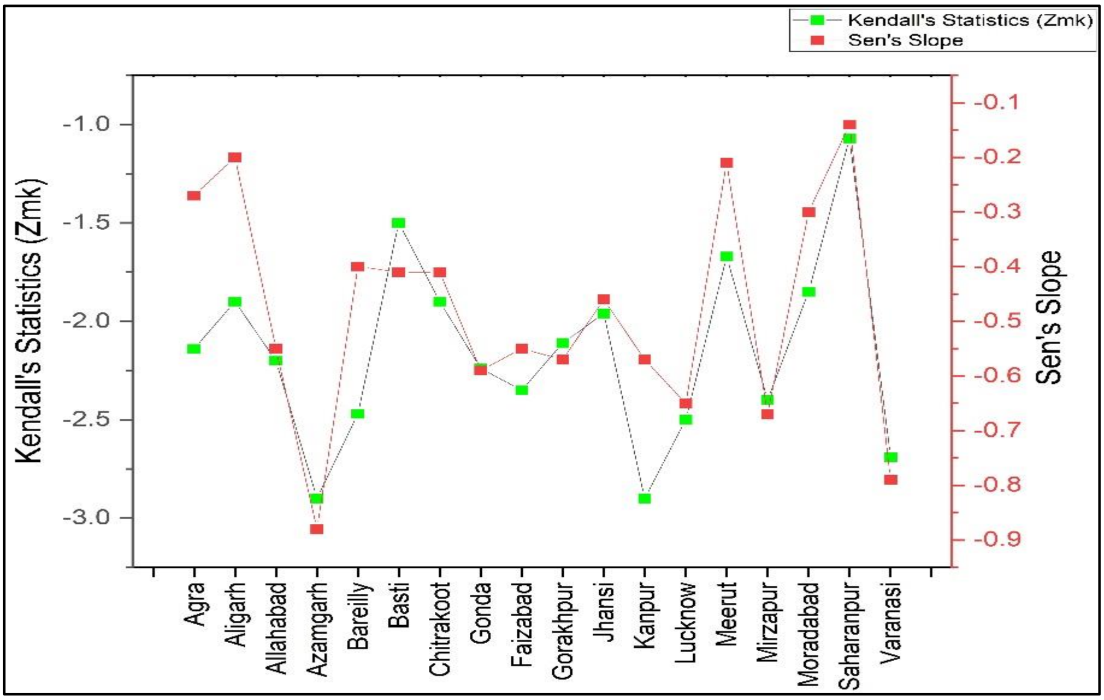

Figure 5. 3 Results of MK test (Z_{MK}) and Sen's slope test assessments of monsoon precipitation, where Z_{MK} stands for the standardized MK trend statistics

5.1.5 Trend assessment of post-monsoon precipitation

The post-monsoon seasons begin in October and continue through November. This season is especially notable for the invasion of tropical cyclones that originate in the Bay of Bengal, which is an important feature of the retreating monsoon season in the area under study. Table 5.4 summarizes the result of the trend assessment over the 18 synoptic locations of the study area. Figure 5.4 depicts the trend assessment result, which depicts the Z_{MK} value and Sen's slope value of the post-monsoon precipitation time series from 18 synoptic locations in Uttar Pradesh. At a significance level of 5%, the significantly declining trend with negative Sens slope values estimates at 83 % of the synoptic locations exhibit a during the post-monsoon rainfall. Therefore, it is possible to conclude that the entire study area experienced a decrease in post-monsoon rainfall.

Table 5.4 Result of trend characteristics of post-monsoon precipitation of the study area

Districts	Mean (mm)	SD (mm)	Kendall's Statistics (Z_{MK})	P-value	Sen's Slope	Trend
Agra	22.38	25.28	-2.14	0.031	-0.27	Decreasing
Aligarh	19.014	20.12	-1.90	0.05	-0.2	Decreasing
Allahabad	39.65	40.85	-2.20	0.02	-0.55	Decreasing
Azamgarh	40.69	38.96	-2.90	0.002	-0.88	Decreasing
Bareilly	26.81	31.13	-2.47	0.01	-0.4	Decreasing
Basti	45.08	43.72	-1.50	0.11	-0.41	Decreasing
Chitrakoot	39	38.54	-1.90	0.05	-0.41	Decreasing
Gonda	41.2	41.91	-2.24	0.02	-0.59	Decreasing
Faizabad	39.7	40.8	-2.35	0.01	-0.55	Decreasing
Gorakhpur	45	44.12	-2.11	0.03	-0.57	Decreasing
Jhansi	35.6	38.17	-1.96	0.04	-0.46	Decreasing
Kanpur	34.8	32.04	-2.90	0.009	-0.57	Decreasing
Lucknow	37.3	40.8	-2.50	0.01	-0.65	Decreasing
Meerut	17.2	17.87	-1.67	0.09	-0.21	Decreasing
Mirzapur	41.3	33.94	-2.40	0.01	-0.67	Decreasing
Moradabad	21.4	23.37	-1.85	0.06	-0.3	Decreasing
Saharanpur	18.3	16.06	-1.07	0.28	-0.14	Decreasing
Varanasi	41.6	37.62	-2.69	0.007	-0.79	Decreasing

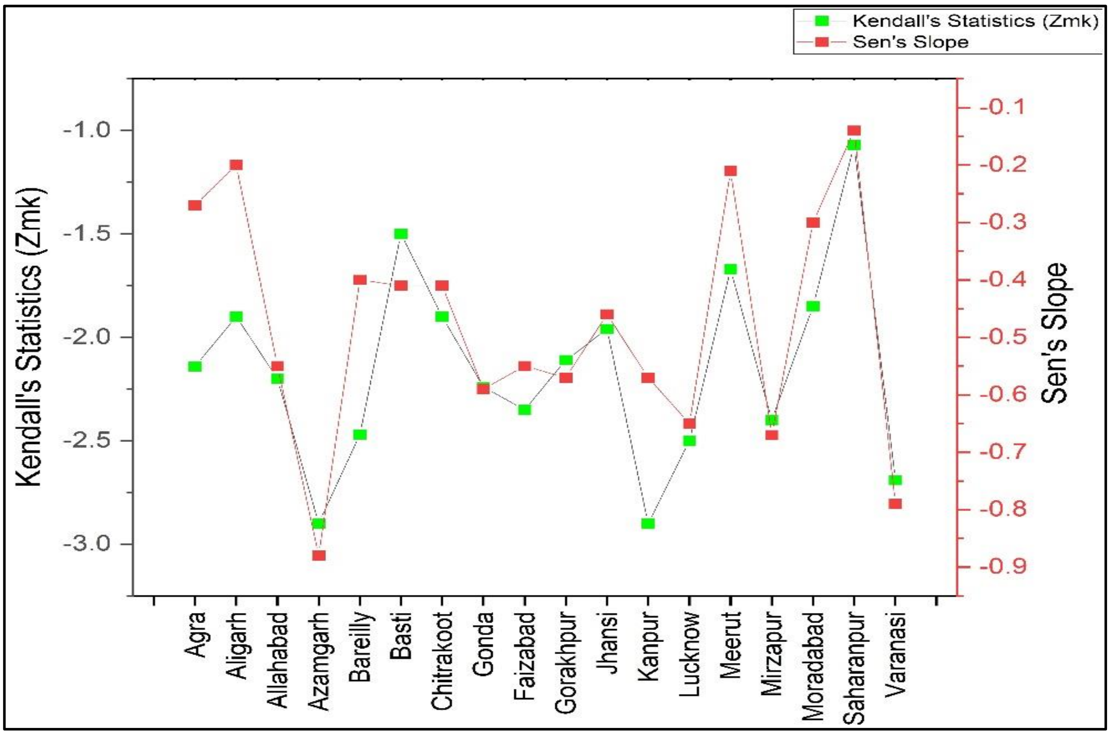

Figure 5.4 Results of MK test (Z_{MK}) and Sen's slope test assessments of post-monsoon precipitation, where Z_{MK} stands for the standardized MK trend statistic

5.1.6 Trend assessment of winter precipitation

Early November marks the beginning of the cold season, which lasts until the end of February in this part of the country. Air temperatures drop immediately after sunset, and a piercing chill replaces the day's heat. The winter temperatures typically range from 2° C to 10° C. The study area also has a record low temperature of -2° C in its data collection. For winter rainfall, mean rainfall, SD, the Z_{MK} trend value and its significance, and median slope (Sen's slope) were calculated and presented in Table 5.4. Figure 5.5 represents the trend assessment result, which represents the Z_{MK} value and Sen's slope value of winter precipitation time series from 18 synoptic locations in Uttar Pradesh. The winter rainfall shows a significant positive trend at stations Saharanpur, Bareilly, Gonda, and Moradabad with a low magnitude of Sen's slope values, whereas other stations indicate a significant negative trend of winter rainfall over the study area. Therefore, it can be broadly generalized that the study region experienced a decrease in winter rainfall during this period.

Table 5.5 Result of trend assessment of winter precipitation of the study area

Districts	Mean (mm)	SD (mm)	Kendall's Statistics (Z_{MK})	P-value	Sen's Slope	Trend
Agra	20.21	16.27	-0.27	0.07	-0.047	Decreasing
Aligarh	18.47	20.27	1.12	0.02	0.21	Increasing
Allahabad	42.53	33.776	-1.16	0.01	-0.511	Decreasing
Azamgarh	28.36	20.77	-2.26	0.08	-0.55	Decreasing
Bareilly	36.94	20.26	0.25	0.02	0.036	Increasing
Basti	29.71	18.54	-1.04	0.02	-0.19	Decreasing
Chitrakoot	46.8	37.11	-1.24	0.21	-0.45	Decreasing
Gonda	32.8	21.76	0.69	0.04	-0.21	Increasing
Faizabad	31.2	19.75	-0.85	0.03	-0.16	Decreasing
Gorakhpur	27.9	18	-2.02	0.04	-3.81	Decreasing
Jhansi	31.2	28.17	-1.3	0.01	-0.31	Decreasing
Kanpur	35.2	25.64	-0.51	0.05	-0.11	Decreasing
Lucknow	36.7	25.02	-0.198	0.04	-0.036	Decreasing
Meerut	45.7	35.11	0.93	0.03	0.311	Decreasing
Mirzapur	45.9	31.88	-1.62	0.01	-0.53	Decreasing
Moradabad	40.1	27.27	0.43	0.04	0.14	Increasing
Saharanpur	59.5	47.58	0.95	0.03	0.34	Increasing
Varanasi	40.4	28.87	-1.87	0.06	-0.57	Decreasing

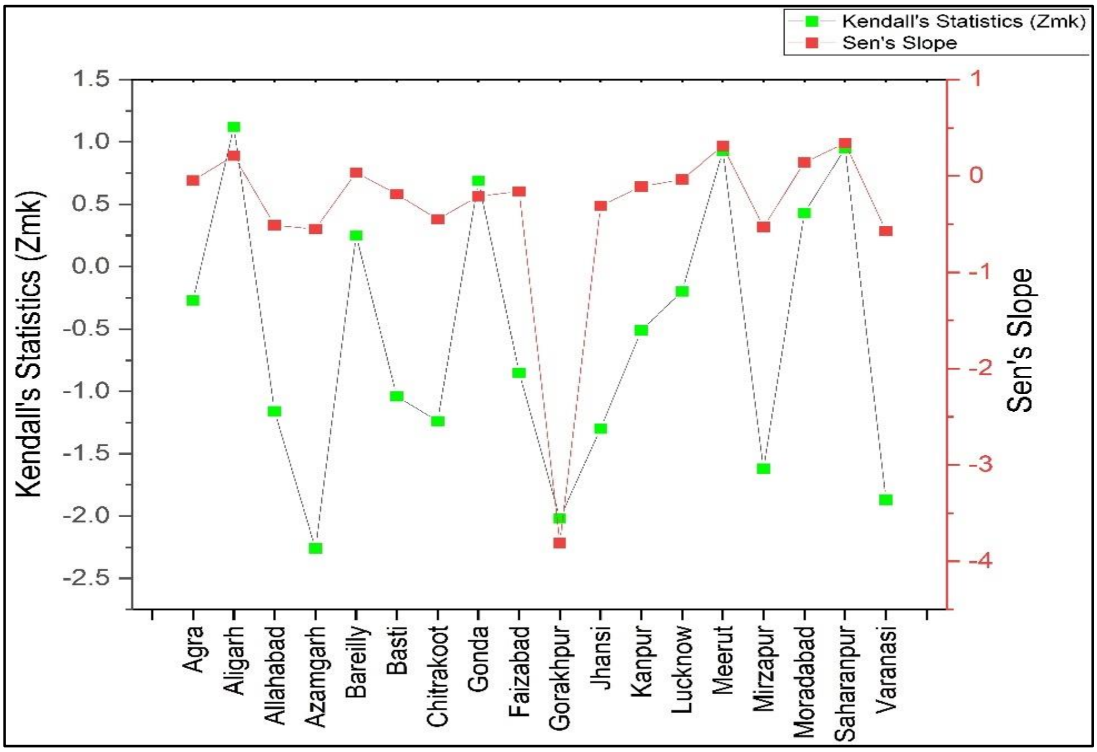

Figure 5. 5 Results of MK test (Z_{MK}) and Sen's slope test assessment of winter precipitation, where Z_{MK} stands for the standardized MK trend statistic

5.1.7 Trend assessment of temperature

Temporal variability of average temperature was investigated on a monthly scale for the 18 synoptic locations of Uttar Pradesh for the period of 48 years from 1971 to 2018. Table 5.6 shows the maximum, minimum, and mean of monthly temperature, the Z_{MK} trend value, and its significance value (P-value) for temperature in Uttar Pradesh. Figure 5.6 depicts the trend assessment result, which shows the Z_{MK} value of the monthly temperature time series from 18 synoptic locations in Uttar Pradesh. The highest maximum temperature (Tmax) was recorded in the western part of the state at stations Jhansi, Agra, and Jhansi. Whereas, over the Indo-Gangetic plain Tmax was recorded at locations Kanpur, Aligarh, and Allahabad (Prayagraj). The lowest minimum temperature (Tmin) was recorded over Saharanpur, Gonda, and Bareilly. The Mann-Kendall test examined the trend variation of the average temperature on a monthly timescale for 48 years, from 1971 to 2018. the magnitude of Z_{MK} values ranges from -0.11 to 0.05. A significant increasing trend has occurred at Agra, Azamgarh, Allahabad (Prayagraj), Aligarh, Bareilly, Basti Meerut, Chitrakoot, Jhansi, Varanasi, and Mirzapur locations. A significant decreasing trend of monthly temperature occurred at locations Azamgarh, Gonda, Faizabad, Gorakhpur, and Lucknow, whereas an insignificant downward trend was observed at Kanpur locations. The magnitude of the trend was estimated from Sen's slope estimator, showing a small magnitude of ranges from -0.05 to 0.05 for the monthly average temperature over this study period.

Table 5.6 Result of trend assessment of monthly temperature of the study area

Districts	Tmax (°C)	Tmin (°C)	Mean (°C)	Kendall's Statistics (Z_{MK})	P-Value	Trend
Agra	44.503	17.87	32.27	0.05	0.006	Increasing
Aligarh	44.394	16.926	32.19	0.04	0.007	Increasing
Allahabad	44.343	19.206	32.18	0.011	0.003	Increasing
Azamgarh	43.115	17.023	32.23	-0.017	0.001	Decreasing
Bareilly	43.682	15.258	31.09	-0.03	0.01	Decreasing
Basti	42.671	17.584	32.22	-0.04	0.007	Decreasing
Chitrakoot	43.912	20.013	32	0.019	0.001	Increasing
Gonda	42.66	16.403	31.96	-0.007	0.005	Decreasing
Faizabad	43.186	17.584	32.23	-0.04	0.007	Decreasing
Gorakhpur	42.012	17.023	32.06	-0.007	0.005	Decreasing
Jhansi	44.029	19.877	32.31	0.016	0.001	Increasing
Kanpur	44.553	18.365	32.53	-0.11	0.2	Decreasing
Lucknow	43.938	17.413	32.29	-0.08	0.004	Decreasing
Meerut	42.853	16.584	31.42	0.04	0.07	Increasing
Mirzapur	43.273	18.587	31.88	0.012	0.002	Increasing
Moradabad	43.548	16.603	31.46	-0.05	0.006	Increasing
Saharanpur	41.818	15.49	30.29	-0.03	0.01	Increasing
Varanasi	43.244	18.51	31.97	0.02	0.008	Increasing

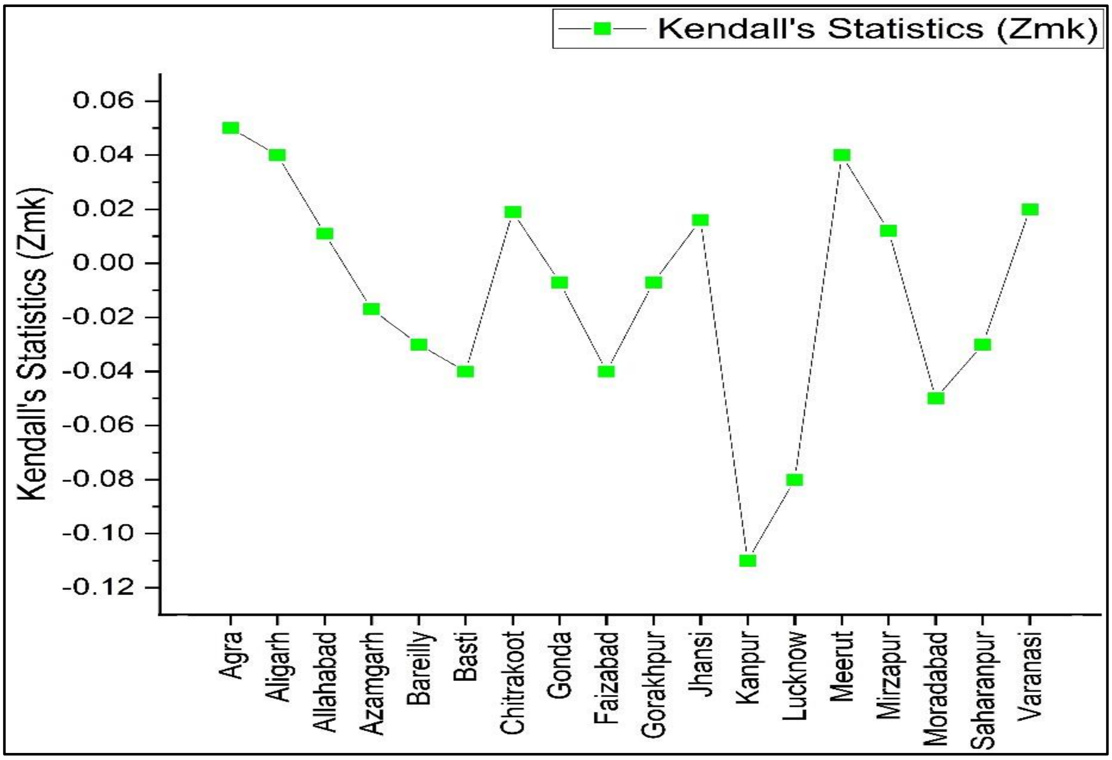

Figure 5. 6 Results of MK test (Z_{MK}) of monthly temperature, where Z_{MK} stands for the standardized MK trend statistic

5.1.8 Trend assessment potential evapotranspiration (PET)

Monthly potential evapotranspiration (PET) was estimated using the Thornthwaite equation described in section 4.4.2 (i) for the 18 synoptic locations of the study area for the observed period from 1971 to 2018. The MK test was used to investigate the trend variation of the average PET on a monthly timescale for 48 years, from 1971 to 2018. Table 5.7 shows the monthly PET mean, SD, Z_{MK} value, and its significance value (P-value). Figure 5.7 depicts the trend assessment result, which shows the Z_{MK} value of monthly PET time series from 18 synoptic locations in Uttar Pradesh. The higher monthly PET is estimated at synoptic locations Kanpur, Agra, Aligarh, and Jhansi. The magnitude of Z_{MK} values ranges from -3.04 to 1.80. The highest magnitude of positive Z_{MK} value occurred at the location Allahabad (Prayagraj) (Z_{MK} = 1.58), followed by Jhansi (Z_{MK} = 1.07). A significant increasing trend was observed in monthly PET at synoptic locations Chitrakoot, Allahabad (Prayagraj), Agra, Jhansi, Meerut, Mirzapur, Gonda, Varanasi, and Aligarh. A significant decreasing trend was observed at Moradabad, Saharanpur, Azamgarh, Bareilly, Gonda, Faizabad, Gorakhpur, and Kanpur locations.

Table 5.7 Result of trend assessment of potential evapotranspiration (PET) of the study area

Districts	Mean	S.D.	Kendall's Statistics (Z_{MK})	P-Value	Trend
Agra	636.62	685.63	0.449	0.05	Increasing
Aligarh	623.16	655.97	0.39	0.04	Increasing
Allahabad	576	625.49	1.07	0.02	Increasing
Azamgarh	558.41	559.49	-1.53	0.02	Decreasing
Bareilly	452.04	444.71	-3.04	0.002	Increasing
Basti	548.05	534.74	0.70	0.04	Increasing
Chitrakoot	544.86	601.04	1.80	0.05	Increasing
Gonda	527.49	509.57	-0.60	0.05	Decreasing
Faizabad	567.819	565.97	-0.39	0.04	Decreasing
Gorakhpur	518.69	482.97	-1.80	0.02	Decreasing
Jhansi	615.4	692.5	1.58	0.01	Increasing
Kanpur	667.65	741.22	-0.11	0.04	Decreasing
Lucknow	602.31	630.8	-0.73	0.04	Decreasing
Meerut	503.31	485.0165	0.34	0.04	Increasing
Mirzapur	505.61	488.45	0.09	0.02	Increasing
Moradabad	501.04	488.23	-0.5	0.05	Decreasing
Saharanpur	380.246	348.08	-2.84	0.004	Decreasing
Varanasi	527.08	538.62	0.176	0.03	Increasing

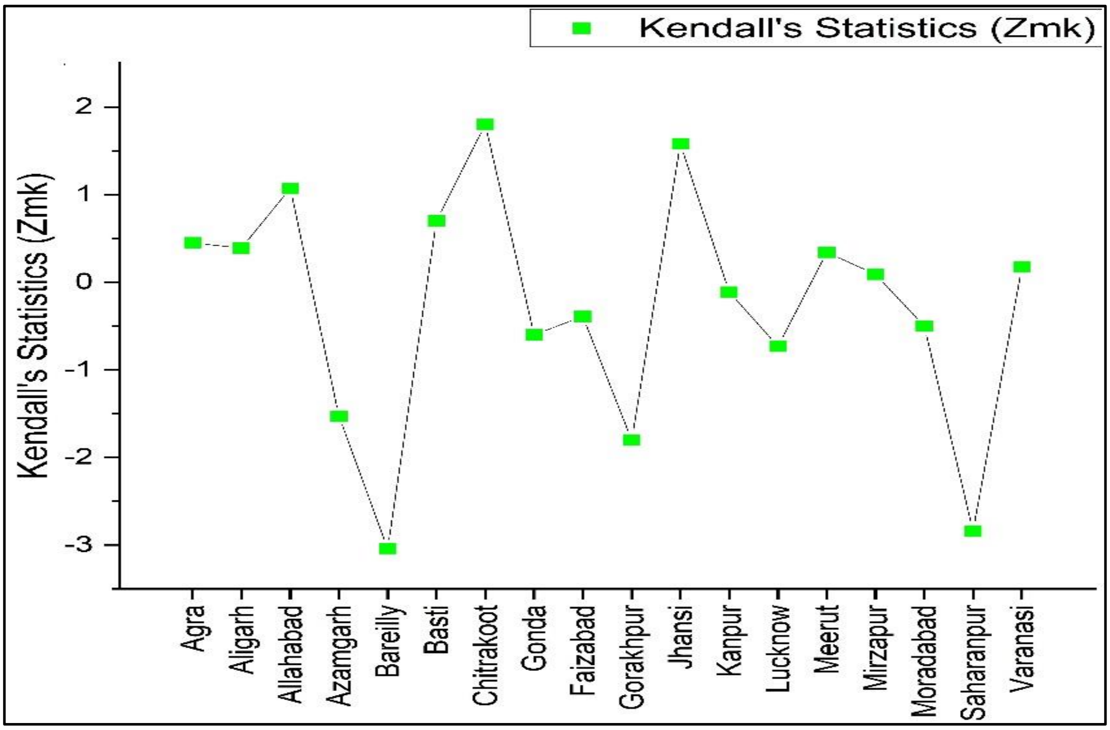

Figure 5. 7 Results of MK test (Z_{MK}) of potential evapotranspiration (PET), where Z_{MK} stands for the standardized MK trend statistics

5.2 Summary

Non-parametric MK tests at the significance level of 5% were used in this chapter to investigate trend in meteorological variables from 1971 to 2018 in the 18 synoptic locations of Uttar Pradesh, India. The magnitude of precipitation, temperature, and PET trend was determined using Sen’s slope test. The trend analyses for the monsoon season and annual time series of rainfall show a significant decreasing trend observed at 14 locations, except for Saharanpur, whereas Bareilly, Basti, and Lucknow exhibited a non-significant but decreasing trend. The synoptic location over the western part of the study area was identified with a higher magnitude of a negative trend. The increasing trend of rainfall was observed over the state during the pre-monsoon season except at locations Chitrakoot, Moradabad, and Mirzapur. The post-monsoon rainfall declines significantly at all stations, with a negative Sens slope. Consequently, it is possible to conclude that post-monsoon rainfall decreased across the entire study area. While most stations in the research area show a significant negative trend with smaller Sen's slope values, Saharanpur, Bareilly, Gonda, and Moradabad show a significant positive trend in winter rainfall. The trend assessment of monthly temperature was analysed and indicated an increasing trend observed at Agra, Azamgarh, Allahabad (Prayagraj), Aligarh, Bareilly, Basti Meerut, Chitrakoot, Jhansi, Varanasi, and Mirzapur locations. The magnitude of Sen's slope ranges between 0.01 to 0.05 overall synoptic locations. The monthly temperature trend significantly decreasing over Gonda, Faizabad, Gorakhpur, and Lucknow, while a non-significant decreasing trend was observed at Kanpur. The PET trend investigation on a monthly scale revealed a significant increasing trend in the majority of locations, including Chitrakoot, Allahabad (Prayagraj), Agra, Jhansi, Meerut, Mirzapur Gonda, Varanasi, and Aligarh.

The significant decrease in precipitation and temperature rise created the ideal conditions for hydrologic extremes like drought. Reduced rainfall combined with higher temperatures causes less storage and more significant water stress, exacerbating the severity of extreme climatic conditions like drought and creating difficult living conditions. Assessing trends in precipitation and temperature in Uttar Pradesh, India can provide valuable insights into the impacts of climate change on the region. Researchers can refine climate models and predict future scenarios by studying climate patterns. The outcomes of this study have significant implications for water resource management, particularly in terms of seasonal and annual planning. This can also provide guidance to policymakers in developing appropriate strategies for adapting to and mitigating the effects of climate change and variability. However, to ensure robust results, future research should consider utilizing all available observed station data, employing various trend analysis techniques, and examining different timescales, such as decadal periods. Additionally, using relevant indices such as the SPEI and other relevant drought indices can aid in monitoring droughts in Uttar Pradesh, India.