CHAPTER 5

APPLICATION OF STATISTICAL TECHNIQUES FOR TREND ANALYSIS

5.1 General

Statistical methods are mathematical formulas, models, and techniques used in the statistical analysis of raw research data. The application of statistical methods extracts information from research data and provides different ways to assess the robustness of research outputs. Various statistical tools have been applied in the obtained time series data from various sources and analyses the output obtained after implementing the various statistical techniques in this study.

5.1.1 Distribution of Average Rainfall

The distribution of average rainfall of the monsoon season over 118 years as a proportion of average annual rainfall distribution for studied stations shows that the monsoon contributed an average of 85.48% to the total average annual rainfall in Uttar Pradesh and Jharkhand. Individual stations experienced not less than 74.39% of their rainfall during the monsoon. The other seasons did not make a significant contribution to the average annual rainfall. Hence, further trend analysis was carried out for annual and monsoon rainfall time series.

5.2 Trend Analysis for Uttar Pradesh

Statistical analysis for the trend of several climatic variables (rainfall, temperature, and PET) was considered seasonally and annually to understand the temporal changes in the climate for Uttar Pradesh. Firstly, in this case, the station exhibits significant persistence, then the effect of serial correlation is eliminated by pre-whitening of data before trend analysis at significance levels 1, 5, and 10 %.

5.2.1 Temporal Variability in Rainfall

Rainfall time series data were analyzed seasonally and annually for a long-term period (1901–2018) for the divisional study stations such as Agra, Aligarh, Allahabad (Prayagraj), Azamgarh, Bareilly, Basti, Chitrakoot, Gonda, Ayodhya, Gorakhpur, Jhansi, Kanpur, Lucknow, Meerut, Mirzapur, Moradabad, Saharanpur, and Varanasi. The Z_{MK} trend value and its significance, Kendall's tau, the spearman's rho (S.Rho), and median of slope (Sen's slope) have been carried out for rainfall for Uttar Pradesh and presented in Table 5.1-5.5. Before applying the MK test, we have checked the serial correlation for all the study stations.

The data from the various stations for 1901 to 2018 were utilized to create the time series for months, seasons, and annum by a simple summation process. Thus, the length of the data series for every district is 118. The magnitude of annual precipitation for each district was calculated from monthly data and analyzed using various statistical techniques, and the result is presented in Table 5.1. The spatial variation of annual precipitation trend value obtained from the MK test is demonstrated in Figure 5.1. Uttar Pradesh gets about 89% of its annual rainfall in the monsoon season. The highest rainfall (34% of monsoon rainfall) is received in July, followed by August (31% of the monsoon rainfall). The highest annual rainfall (1374.5 mm) is observed over Gorakhpur district, and the lowest annual rainfall (431.3 mm) is observed over the districts of Chitrakoot division. Gorakhpur and Gonda received the maximum amount of rainfall in annual time scale (1089-1374.5 mm), and divisions with a minimum amount of rainfall in annual time scale are Agra, Kanpur, Lucknow, Chitrakoot (431.3-798.6 mm). In annual time scale, a significant increasing trend in Bareilly, Kanpur, Meerut, Faizabad, Mirzapur, and Varanasi and a significant decreasing trend in Saharanpur, Meerut, Chitrakoot, Allahabad, Gonda, Basti, and Gorakhpur districts are seen.

Table 5.1 Trend characteristics of annual precipitation for various divisions of Uttar Pradesh

Districts	M.K Statistics (S)	Kendall's Statistics (Z)	Kendall's Tau (τ)	S. Rho	Sen's Slope
Agra	-468	-1.0726	-0.0667	-0.9706	-0.6809
Aligarh	429	0.9830	0.0611	0.9853	0.4921
Allahabad	-1058	-2.4227	-0.1507	-2.689	-1.726
Azamgarh	-1952	-4.513	-0.2964	-4.4884	-2.484
Bareilly	167	0.3813	0.0238	0.4301	0.2604
Basti	867	1.989	0.1235	2.0691	1.2097
Chitrakoot	-1235	-2.861	-0.1983	-3.135	-2.222
Gonda	-1317	-3.6234	-0.2198	-3.2162	-1.7031
Faizabad	-1387	-3.2681	-0.1937	-3.4565	-1.7924
Gorakhpur	-1671	-3.8231	-0.2168	-4.1978	-2.1717

Jhansi	-1028	-2.4239	-0.1127	-2.6839	-1.6833
Kanpur	-1011	-2.3169	-0.0958	-2.5343	-1.5641
Lucknow	-681	-1.5618	-0.097	-1.6562	-0.8991
Meerut	887	2.0349	0.1263	2.1098	1.0215
Mirzapur	-1243	-2.962	-0.1893	-3.0626	-1.9086
Moradabad	923	0.0184	0.0013	0.0884	0.0227
Saharanpur	1829	4.215	0.02984	4.5111	2.3236
Varanasi	-1603	-3.756	-0.2136	-4.1165	-2.0737

As per IMD, four climatological seasons with some local adjustments: season 1 refers to the pre-monsoon (summer) season (March to May); season 2 resembles the monsoon (rainy) season (June to September); season 3 resembles the post-monsoon season (October to November), and season 4 resembles the winter season (December to February) and annually (January to December) are considered for statistical analysis.

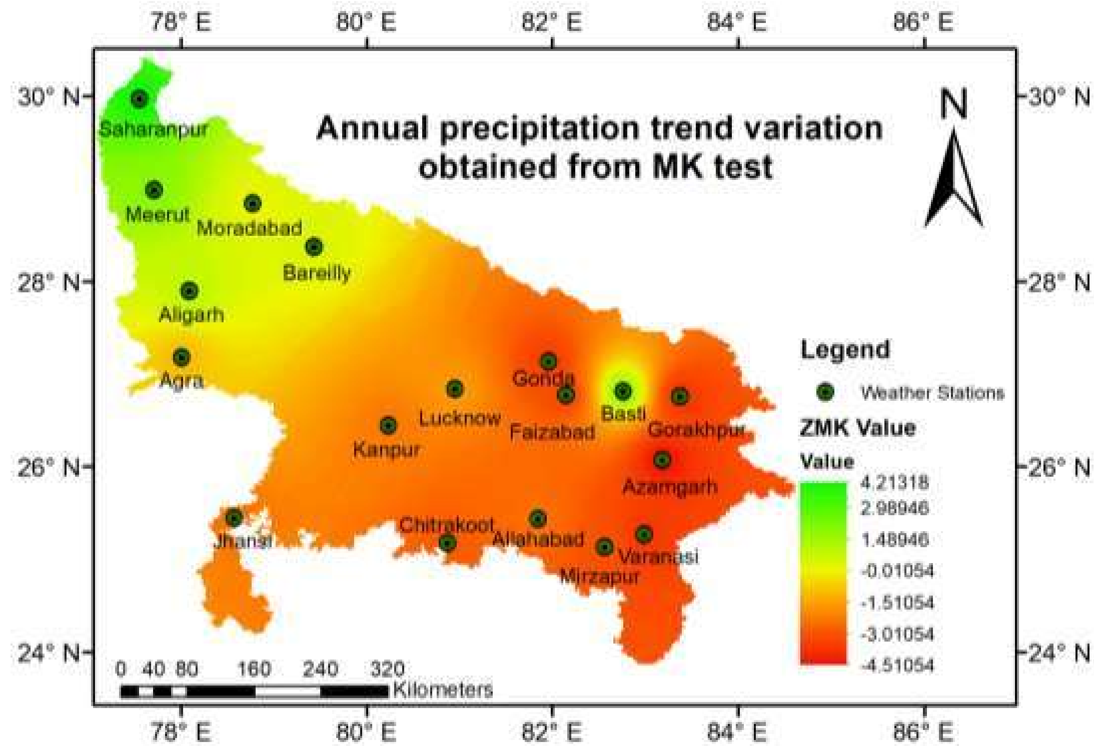

Figure 5.1 Trend characteristics of annual precipitation for various divisions of Uttar Pradesh

5.2.2 Pre-monsoon

The hot weather sets in March and lasts until the middle of June. The highest temperature in the study area is often recorded in May, the hottest month in the state. Like the rest of northern India, the study area also experiences dust-storms and dust-raising winds during the summer season. Dust storms with a 48-64 km/hour velocity are most frequent in May and with the second maximum in April and June. The hot winds (loo) of UP plains blow during April and May with an average velocity of 8-16 km/hour. This hot wind hugely affects human comfort during this season. The Z_{MK} trend value and its significance, Kendall's tau, the spearman's rho (*S.Rho*), and median of slope (Sen's slope) have been carried out for pre-monsoon rainfall for Uttar Pradesh and presented in Table 5.2. The spatial variation of annual precipitation trend value obtained from the MK test is demonstrated in Figure 5.2.

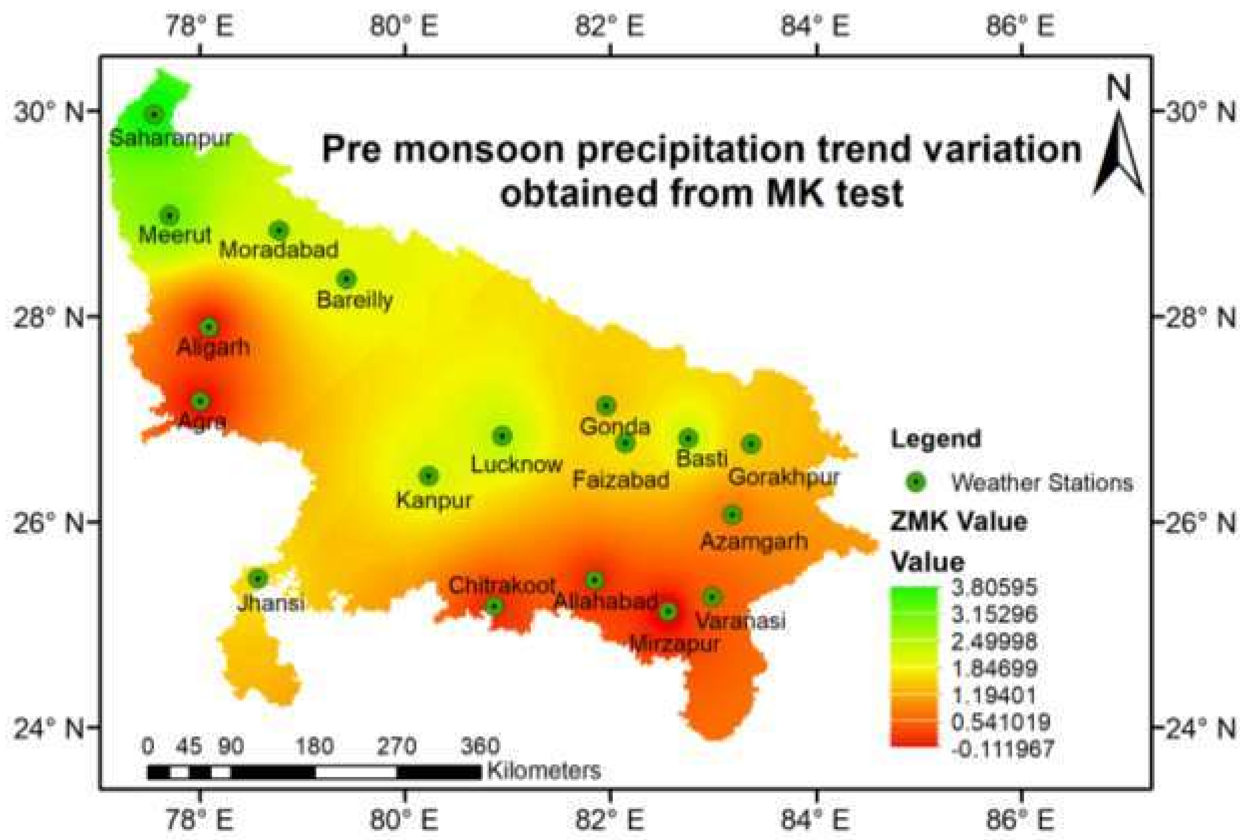

Figure 5.2 Trend characteristics of pre-monsoon precipitation for various divisions of Uttar Pradesh

Table 5.2 Trend characteristics of pre-monsoon precipitation for various divisions of Uttar Pradesh

Districts	M.K Statistics (S)	Kendall's Statistics (Z)	Kendall's Tau (τ)	S Rho	Sen's Slope
Agra	1247	0.0029	0.0062	3.0026	0.1022
Aligarh	173	0.0040	0.0002	4.0704	0.1722
Allahabad	50	0.1125	0.0071	0.1857	0.0048
Azamgarh	320	0.7327	0.0456	0.6891	0.0271
Bareilly	887	2.034	0.1263	1.9284	0.1022
Basti	1012	2.267	0.01389	2.2697	0.0934
Chitrakoot	58	0.1309	0.0083	0.3315	0.0041
Gonda	617	1.4148	0.0879	1.3097	0.0682
Faizabad	754	1.7295	0.1074	1.6360	0.0664
Gorakhpur	635	1.4562	0.0904	1.4550	0.0733

Jhansi	724	1.6606	0.1031	1.6687	0.0406
Kanpur	927	2.1268	0.132	2.1661	0.0705
Lucknow	1047	2.4163	0.0013	2.3994	0.0980
Meerut	1354	3.0596	0.0267	3.1123	0.1526
Mirzapur	-50	-0.1125	-0.0071	-0.083	-0.0066
Moradabad	973	2.2325	0.1386	2.1048	0.1166
Saharanpur	1649	3.8068	0.2196	3.8144	2.371
Varanasi	213	0.4869	0.0303	0.4761	0.0236

5.2.3 Monsoon

Soon after mid-June, the rainy season commences, and it continues until the end of September. 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 wet months are July and August. The southwest monsoon causes rain in the study area. The Z_{MK} trend value and its significance, Kendall's tau, the Spearman's Rho (*S.Rho*), and median of slope (Sen's slope) has been carried out for monsoon rainfall for Uttar Pradesh and presented in Table 5.3. The spatial variation of annual precipitation trend value obtained from the MK test is demonstrated in Figure 5.3.

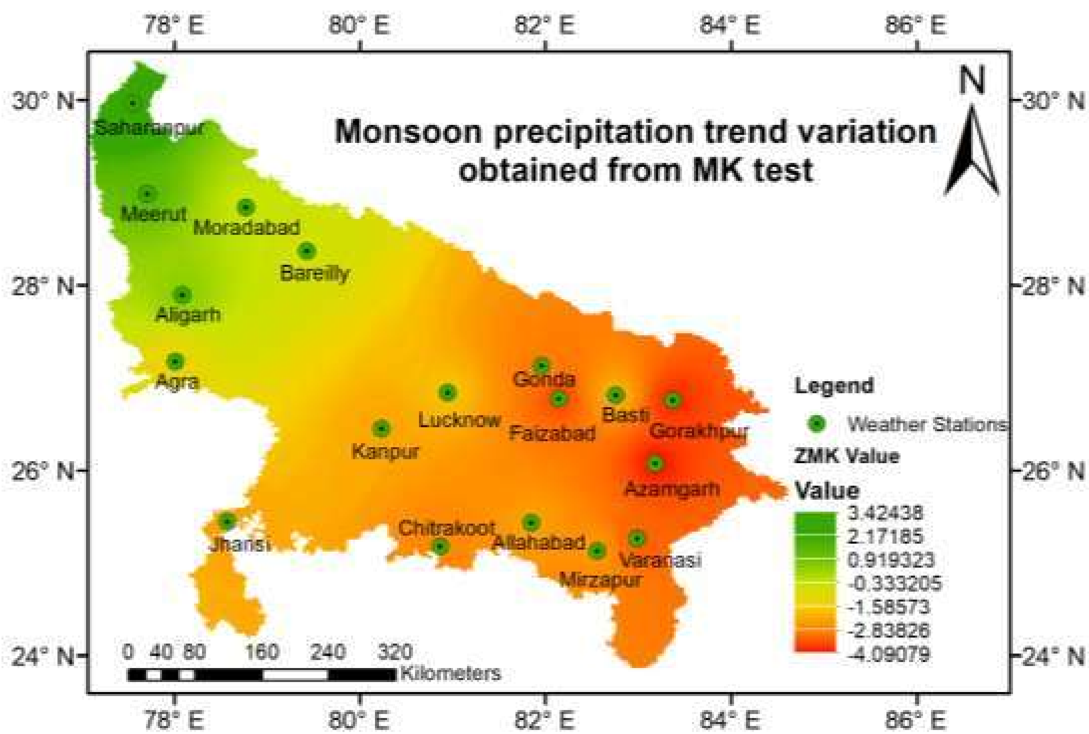

Figure 5.3 Trend characteristics of monsoon precipitation for various divisions of Uttar Pradesh

The monsoon season rainfall and the annual rainfall showed significant decreasing trends. In monsoon, there is a significant increasing trend in Bareilly, Gonda, and Varanasi and a significant decreasing trend in Saharanpur, Ghaziabad, Meerut, Agra, Chitrakoot, Azamgarh, and Basti.

Table 5.3 Trend characteristics of monsoon precipitation for various divisions of Uttar Pradesh

Districts	M.K Statistics (S)	Kendall's Statistics (Z)	Kendall's Tau (τ)	S Rho	Sen's Slope
Agra	-628	-1.4401	-0.0894	-1.393	-0.8183
Aligarh	237	0.542	0.338	0.5677	0.2449
Allahabad	-1046	-2.361	-0.103	-2.521	-1.541
Azamgarh	-1802	-4.092	-0.032	-4.554	-2.321
Bareilly	-275	-0.6293	-0.0392	-0.566	-0.3487
Basti	-903	-2.0717	-0.128	-2.193	-1.166
Chitrakoot	-1225	-2.812	-0.1976	-3.088	-1.999
Gonda	-1275	-2.9192	0.0298	-3148	-1.4775
Faizabad	-1317	-3.6234	0.2193	-3.266	-1.5719

Gorakhpur	-1681	-3.9287	-0.1963	-4.235	-2.1507
Jhansi	-1054	-2.4297	-0.1873	-2.725	-1.6752
Kanpur	-1007	-2.3268	-0.1249	-2.642	-1.453
Lucknow	-781	-1.7915	-0.1112	-1.945	-0.897
Meerut	547	1.254	0.0779	1.2627	0.6312
Mirzapur	-1103	-2.527	-0.2149	-2.757	-1.5998
Moradabad	-183	-0.418	-0.0261	-0.387	-0.259
Saharanpur	1499	3.4261	0.0296	3.5797	1.8455
Varanasi	-1459	-3.347	-0.2169	-3.767	-1.977

5.2.4 Post-monsoon

An important feature of the retreating monsoon season in the study area is the invasion of tropical cyclones originating in the Bay of Bengal at about 12° N latitude. The study area is also influenced by the typhoons originating in the South China Sea. The maximum frequency of the tropical cyclones in the study area is from September to November, especially during the asterism called Hathiya. However, these cyclones appear necessary for the maturity of paddy and are required to moisten the soil to cultivate Rabi crops. The Z_{MK} trend value and its significance, Kendall's tau, the Spearman's Rho (*S.Rho*), and median of slope (Sen's slope) has been carried out for post-monsoon rainfall for Uttar Pradesh and presented in Table 5.4. The spatial variation of annual precipitation trend value obtained from the MK test is demonstrated in Figure 5.4.

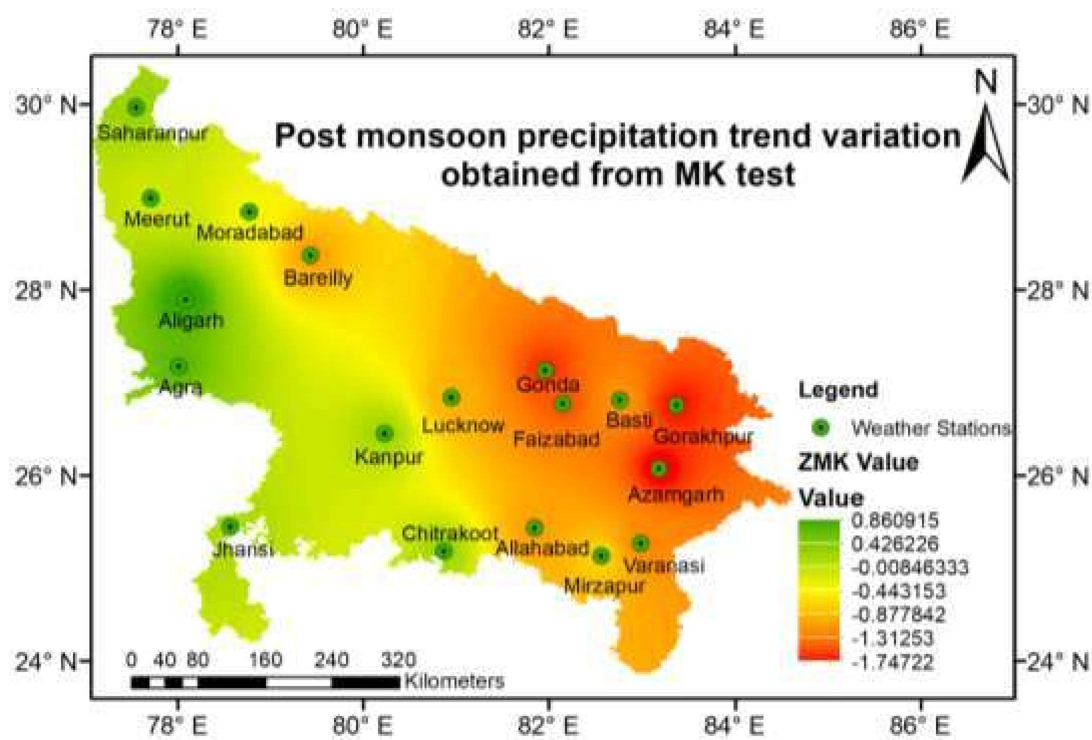

Figure 5.4 Trend characteristics of post-monsoon precipitation for various divisions of Uttar Pradesh

Table 5.4 Trend characteristics of post-monsoon precipitation for various divisions of Uttar Pradesh

Districts	M.K Statistics (S)	Kendall's Statistics (Z)	Kendall's Tau (τ)	S Rho	Sen's Slope
Agra	257	0.5880	0.0366	0.5795	0.0094
Aligarh	376	0.8613	0.0536	0.9700	0.0178
Allahabad	-480	-1.079	-0.0683	-0.377	-0.037
Azamgarh	-762	-1.7478	-0.1085	-1.642	-0.1209
Bareilly	-475	-1.0887	-0.0677	-1.119	-0.0477
Basti	-493	-1.1326	-0.0702	-1.168	-0.0738
Chitrakoot	107	0.2435	0.0152	0.0078	0.0078
Gonda	-703	-1.6123	-0.1001	-1.589	-0.110
Faizabad	-641	-1.4699	-0.0913	-1.475	-0.0828
Gorakhpur	-701	-1.6677	-0.0998	-1.596	-0.1179

Jhansi	54	0.1217	0.0077	0.0907	0.0048
Kanpur	86	0.1952	0.0122	0.1635	0.0072
Lucknow	-417	-0.9555	-0.0594	-0.911	-0.0595
Meerut	-64	-0.1447	-0.091	-0.171	-0.0025
Mirzapur	-290	-0.6638	-0.0413	-0.517	-0.045
Moradabad	-186	-0.4249	-0.0265	-0.518	-0.0148
Saharanpur	114	0.2595	0.0162	0.2545	0.0071
Varanasi	-545	-1.2494	-0.0776	-1.086	-0.0932

5.2.5 Winter

The cold weather in the study area commences early in November and ends in late February. The climate in October and November is quite comfortable. The days are bright and warm, but the sun hours are not too hot. As soon as the sun sets, air temperature starts falling, and a sharp, bracing cold replaces the day's heat. The winter temperature in the study area normally ranges from 2 to 10 °C. December and January are usually the coldest months. The study area also holds a record low of -2° Celsius temperature in its data series. The Z_{MK} trend value and its significance, Kendall's tau, the spearman's rho (S.Rho), and median of slope (Sen's slope) have been carried out for winter rainfall for Uttar Pradesh and presented in Table 5.5. The spatial variation of annual precipitation trend value obtained from the MK test is demonstrated in Figure 5.5.

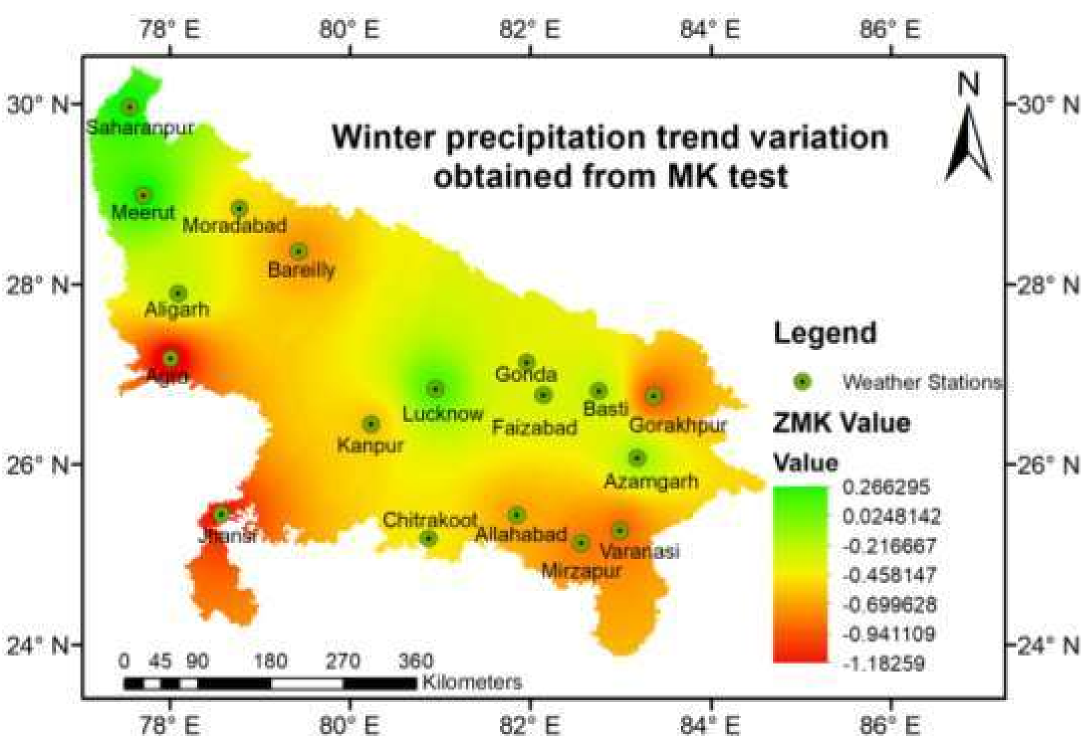

Figure 5.5 Trend characteristics of winter precipitation for various divisions of Uttar Pradesh

Table 5.5 Trend characteristics of winter precipitation for various divisions of Uttar Pradesh

Districts	M.K Statistics (S)	Kendall's Statistics(Z)	Kendall's Tau (τ)	S Rho	Sen's Slope
Agra	-516	-1.1828	-0.0735	-1.1471	-0.0455
Aligarh	-101	-0.2297	-0.0144	-0.2325	-0.0125
Allahabad	-304	-0.6959	-0.0433	-0.4002	-0.0575
Azamgarh	-620	-0.0883	-1.4217	-1.4087	-0.0772
Bareilly	-332	-0.7602	-0.0473	-0.7335	-0.0476
Basti	-87	-0.1975	-0.0124	-0.2513	-0.0102
Chitrakoot	-204	-0.4662	-0.0291	-0.5119	-0.0363
Gonda	-169	-0.3859	-0.0241	-0.4512	-0.0218
Faizabad	-143	-0.3261	-0.0204	-0.3434	-0.0140
Gorakhpur	-424	-0.9715	-0.0604	-0.9771	-0.450

Jhansi	-474	-1.0864	-0.0675	-1.1153	-0.0597
Kanpur	-254	-0.5811	-0.0362	-0.5209	-0.0389
Lucknow	73	0.1654	0.0104	0.9101	0.0595
Meerut	117	0.2664	0.0167	0.2324	0.0195
Mirzapur	-363	-0.8314	-0.0517	-0.7591	-0.0712
Moradabad	-231	-0.5283	-0.0329	-0.5697	-0.0324
Saharanpur	117	0.2664	0.0167	0.2632	0.0194
Varanasi	-391	-0.8957	-0.0557	-0.8080	-0.0603

Table 5.6 Mann-Kendall test and percentage change of annual and seasonal rainfall during 1901-2018 for the Uttar Pradesh

Time	1901-2018		
	T_i	Z value	Change (%)
Annual	-2.67	-3.02	-19.83
Pre-Monsoon	0.12	0.42	9.42
Monsoon	-2.91	-3.73	-22.71
Post-Monsoon	0.18	0.69	15.14
Winter	0.07	0.17	4.19

5.3 Temporal Variability in Temperature

Temperature minima were analyzed seasonally and annually between 1901 and 2018 for the divisional study stations such as Agra, Aligarh, Allahabad (Prayagraj), Azamgarh, Bareilly, Basti, Chitrakoot, Gonda, Ayodhya, Gorakhpur, Jhansi, Kanpur, Lucknow, Meerut, Mirzapur, Moradabad, Saharanpur, and Varanasi. The mean, Z_{MK} trend value and its significance, Kendall's tau, the spearman's rho (*S.Rho*), and median of slope (Sen's slope) have been carried out for temperature for Uttar Pradesh and presented in Table 5.7. Based on the average normal value of MK test statistic (*S*) and persistence, the study area has revealed no persistence and trend in pre-monsoon, whereas significant persistence with insignificant trend was observed during monsoon season. However, a noteworthy persistence with decreasing trends was found in the post-monsoon and winter season. The magnitude of trend and PC is quite low for the station.

The trend analysis of minimum temperature conducted for the winter season (December-February) projects a colder drift in the central regions, with a decrease of 0.37-0.78 °C. The annual average temperature fluctuates with a decrease of 0.78-0.37 °C in the winter season to an increase of 0.42-0.71 °C in the summer season. The study also points that the duration of the winter season has decreased, with a lowering of the minimum temperature. The intensity of chilliness is also observed to have increased in the winter season over the central regions of northern-central India.

Table 5.7 Trend characteristics of Temperature for various divisions of Uttar Pradesh

Districts	Mean	M.K Statistics (S)	Kendall's Statistics (Z)	Kendall's Tau (τ)	S Rho	Sen's Slope
Agra	31.87	361	1.0409	0.0701	0.2540	0.0018
Aligarh	32.08	587	1.6493	0.1140	2.2878	0.0329
Allahabad	32.66	1064	3.0764	0.2066	4.4534	0.0489
Azamgarh	32.05	1105	3.1921	0.2145	1.4023	0.0512
Bareilly	29.57	583	1.6828	0.1132	2.6439	0.0316
Basti	32.28	1113	3.2152	0.2161	0.0573	0.0543
Chitrakoot	32.60	1145	3.3077	0.2223	6.4641	0.0540
Gonda	32.45	1057	3.0533	0.2025	2.2212	0.0538
Faizabad	32.97	1103	3.1892	0.2141	2.8477	0.0529
Gorakhpur	32.90	1095	3.1631	0.2126	2.8164	0.0484
Jhansi	32.97	1035	2.9897	0.2009	5.7001	0.0506

Kanpur	32.90	806	2.3275	0.1565	2.5254	0.0404
Lucknow	31.96	1047	3.0244	0.2033	0.3340	0.0512
Meerut	30.56	715	2.0673	0.1388	4.7236	0.0398
Mirzapur	31.72	1129	3.2615	0.2192	0.6980	0.0508
Moradabad	30.90	613	1.7724	0.1190	1.7038	0.0372
Saharanpur	31.78	467	1.3503	0.0907	2.9137	0.0263
Varanasi	32.33	1064	3.0735	0.2066	0.9424	0.0486

5.3.1 Temporal Variability in Potential Evapotranspiration (PET)

PET was analyzed seasonally and annually for a long-term period of 1901 to 2018 for the divisional study stations such as Agra, Aligarh, Allahabad (Prayagraj), Azamgarh, Bareilly, Basti, Chitrakoot, Gonda, Ayodhya, Gorakhpur, Jhansi, Kanpur, Lucknow, Meerut, Mirzapur, Moradabad, Saharanpur, and Varanasi. The Z_{MK} trend value and its significance, Kendall's tau, the spearman's rho (*S.Rho*), and median of slope (Sen's slope), and proportionate change has been carried out for PET and presented in Table 5.8. In this case, no significant persistence and trend was observed for pre-monsoon and post-monsoon season, but during monsoon season as well as yearly, significant persistence with decreasing trend of 0.0004-0.0013 mm/year was found, whereas winter data have persistence with the negligible trend with a little value of the magnitude of a trend. PET shows an insignificant trend during the winter season; conversely, a progressive trend for temperature maxima and minima was observed. It is because of the dependency of PET on metrological variables other than temperature also. These variables may be wind speed, solar radiation, and sunshine hour, which affect PET and are not considered for carrying out the present research work.

It reveals that, for the Pre-monsoon season, no significant serial correlation and trend was observed across the stations, but in the case of monsoon season station showed a little value of persistence with a noteworthy downward trend. The station revealed no significant persistence but an increasing trend during post-monsoon, whereas the study station perceived no significant persistence with an insignificant decreasing trend during the winter season.

Table 5.8 Trend characteristics of Evapo-transpiration for various divisions of Uttar Pradesh

Districts	M.K Statistics (S)	Kendall's Statistics (Z)	Kendall's Tau (τ)	S Rho	Sen's Slope
Agra	-516	-1.1828	-0.0735	-1.1471	-0.0455
Aligarh	-101	-0.2297	-0.0144	-0.2325	-0.0125
Allahabad	-304	-0.6959	-0.0433	-0.4002	-0.0575
Azamgarh	-620	-0.0883	-1.4217	-1.4087	-0.0772
Bareilly	-332	-0.7602	-0.0473	-0.7335	-0.0476
Basti	-87	-0.1975	-0.0124	-0.2513	-0.0102
Chitrakoot	-204	-0.4662	-0.0291	-0.5119	-0.0363
Gonda	-169	-0.3859	-0.0241	-0.4512	-0.0218
Faizabad	-143	-0.3261	-0.0204	-0.3434	-0.0140
Gorakhpur	-424	-0.9715	-0.0604	-0.9771	-0.450
Jhansi	-474	-1.0864	-0.0675	-1.1153	-0.0597

Kanpur	-254	-0.5811	-0.0362	-0.5209	-0.0389
Lucknow	73	0.1654	0.0104	0.9101	0.0595
Meerut	117	0.2664	0.0167	0.2324	0.0195
Mirzapur	-363	-0.8314	-0.0517	-0.7591	-0.0712
Moradabad	-231	-0.5283	-0.0329	-0.5697	-0.0324
Saharanpur	117	0.2664	0.0167	0.2632	0.0194
Varanasi	-391	-0.8957	-0.0557	-0.8080	-0.0603

The Median slope, such as the magnitude of a linear trend, is calculated by Sen's slope estimator seasonally and annually, as represented in Table 5.1-5.5. The disproportionate trend was detected in the pre-monsoon and winter seasons, although rainfall is decreased by 1.09-2.3 mm/year during monsoon season and 1.2- 2.4 mm/year annually.

The significant long-term trends for monsoon rainfall are possibly recognized in descending manner beginning in the early 1960s till the remaining period. Similarly, the descending long-term trend in annual rainfall started during the early 1960s till the late 20th century. A maximum decreasing % change in annual rainfall was found in southern Uttar Pradesh (-16.5%). The cause for a significant variable rainfall pattern in the state of Uttar Pradesh may be credited to several factors like North Atlantic Sea Surface Temperature (SST), Equatorial SE Indian ocean SST, East Asia mean sea level pressure, North Atlantic mean sea level pressure, and Northcentral pacific wind at 1.5 km above sea level. As per (Roxy and Tanimoto 2007), the regional warming of SST over the Indian Ocean is likely to impact the Indian monsoon circulations and reduce precipitation over northeast India state Uttar Pradesh. The decreasing nature of trends in precipitation during the monsoon season may distress the surface and subsurface water resources, which directly affect the water requirement of an industrial zone and for agriculture purposes.

5.4 Trend Analysis for Jharkhand

Statistical analysis for the trend of several climatic variables (rainfall, temperature minima-maxima, and PET) was considered seasonally and annually to understand the temporal changes in the climate for the Jharkhand (Gupta et al. 2021). Firstly, in this case, the station exhibits significant persistence, then the effect of serial correlation is eliminated by pre-whitening of data before trend analysis at significance levels 1, 5, and 10 %.

5.4.1 Temporal Variability in Rainfall

Rainfall time series data were analyzed seasonally and annually for a long-term period (1901–2018) for the synoptic study stations such as Palamu, Ranchi, Hazaribagh, Dumka, and West Singhbhum. The coefficient of serial correlation for lag1 (ρ_1), the Z_{MK} trend value and its significance, the median of slope (β), intersection point, and proportionate change have been carried out for rainfall and presented in Table 5.9. Before applying the MK test, we have checked the serial correlation, and it reveals that, for the Pre-monsoon season, no significant serial correlation and trend was observed across the stations, but in the case of monsoon season station showed a little value of persistence with a noteworthy downward trend. The station revealed no significant persistence but an increasing trend during post-monsoon, whereas the study station perceived no significant persistence with an insignificant decreasing trend during the winter season. The Median slope, such as the magnitude of a linear trend, is calculated by Sen's slope estimator seasonally and annually, as represented in Table 5.9. The disproportionate trend was detected in the pre-monsoon and winter seasons, although rainfall is decreased by 1.09- 2.3 mm/year during monsoon season and 1.2- 2.4 mm/year annually. The SQMK statistics is used for determining the approximate year of the starting of a significant trend. It is derived from a forward analysis illustrated by solid line *u(t)* and backward analysis demonstrated as dashed line *u'(t)* of the MK rank correlation and the confidence interval at 5% significant level of sequential MK represented by the horizontal dashed line shown in Figure 5.6 and Figure 5.7. If they cross each other and diverge beyond the specific threshold value or converge to a point then cross each other, there is a statistically significant trend. The point where they cross each other indicates the approximate year at which the trend occurs. Herein, *u(t)* is a standardized variable that has zero mean and unit standard deviation. Therefore, its sequential behavior fluctuates around zero levels. *u(t)* is the same as the z values found from the first to last data point. The graphs of two stations, Palamu and Ranchi stations, from the study region are plotted in Figure 5.6 and Figure 5.7 as examples, respectively. The negligible or no trend was detected in the pre-monsoon, post-monsoon, and winter season, although in monsoon season, it is demonstrated that the converging of graphical plots at the end of the 1940s signifies the trend's beginning point.

The forward and backward series crosses multiple times; therefore, there is an insignificant trend for the post-monsoon season. The significant long-term trends for monsoon rainfall are possibly recognized in descending manner beginning in the early 1960s till the remaining period. Similarly, the descending long-term trend in annual rainfall started during the early 1960s till the late 20^{th} century. A maximum decreasing % change in annual rainfall was found at Palamu and Dumka (-15.3%). The cause for a significant variable rainfall pattern in the state of Jharkhand may be credited to several factors like North Atlantic Sea Surface Temperature (SST), Equatorial SE Indian ocean SST, East Asia mean sea level pressure, North Atlantic mean sea level pressure, and Northcentral pacific wind at 1.5 km above sea level(Krishnakumar et al. 2009). As per (Roxy and Tanimoto 2007) the regional warming of SST over the Indian Ocean is likely to impact the Indian monsoon circulations and reduce precipitation over northeast India state Jharkhand.

Table 5.9 Statistical analysis for rainfall for the selected synoptic stations of Jharkhand

Stations	Palamu					Ranchi				
Season	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual
ρ1	0.048	0.108	0.069	0.076	0.087	0.051	0.082	0.072	0.069	0.087
Z_{MK}	-0.166	-2.131	0.726	-0.321	-1.975	0.249	-1.623	0.946	-0.682	-1.762
Trend	0	-1	0	0	-1	0	-1	0	0	-1
β-value	-0.0165	-1.643	0.121	-0.037	-1.742	0.282	-1.079	0.196	-0.091	-1.248
Intercept	53.456	945.68	67.329	55.628	1307.3	82.826	1126.2	73.19	61.468	1341.7
PC	2.8921	-20.68	35.126	-36.91	-16.5	3.480	-10.1	20.41	-16.77	-9.743
Stations	Hazaribagh					Dumka				
Season	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual
ρ1	0.0568	0.0925	0.0628	0.0692	0.0798	0.0479	0.0852	0.0782	0.0927	0.0841
Z_{MK}	0.0713	-1.706	1.093	-0.883	-1.877	0.1241	-2.981	2.089	-1.796	-2.672

Trend	0	-1	0	0	-1	0	-1	0	0	-1
β-value	0.0202	-1.0759	0.2037	-0.0972	-1.1084	0.0301	-2.199	0.349	-1.461	-2.168
Intercept	95.521	1176.3	81.546	62.362	1349.8	102.61	1203.5	86.983	49.776	1435.2
PC	0.2237	-9.8253	22.703	-17.952	-8.3263	2.8911	-20.42	35.101	-36.97	-16.42

Stations	West Singhbhum				
Season	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual
ρ1	0.0625	0.0856	0.0718	0.0692	0.0834
Z_{MK}	0.2769	-1.271	1.115	-0.8326	-1.299
Trend	0	-1	0	0	-1
β-value	0.0576	-0.5871	0.1739	-1.030	-0.668
Intercept	101.46	1068	75.679	60.074	1370.3
PC	5.5229	-5.886	21.625	-19.73	-5.386

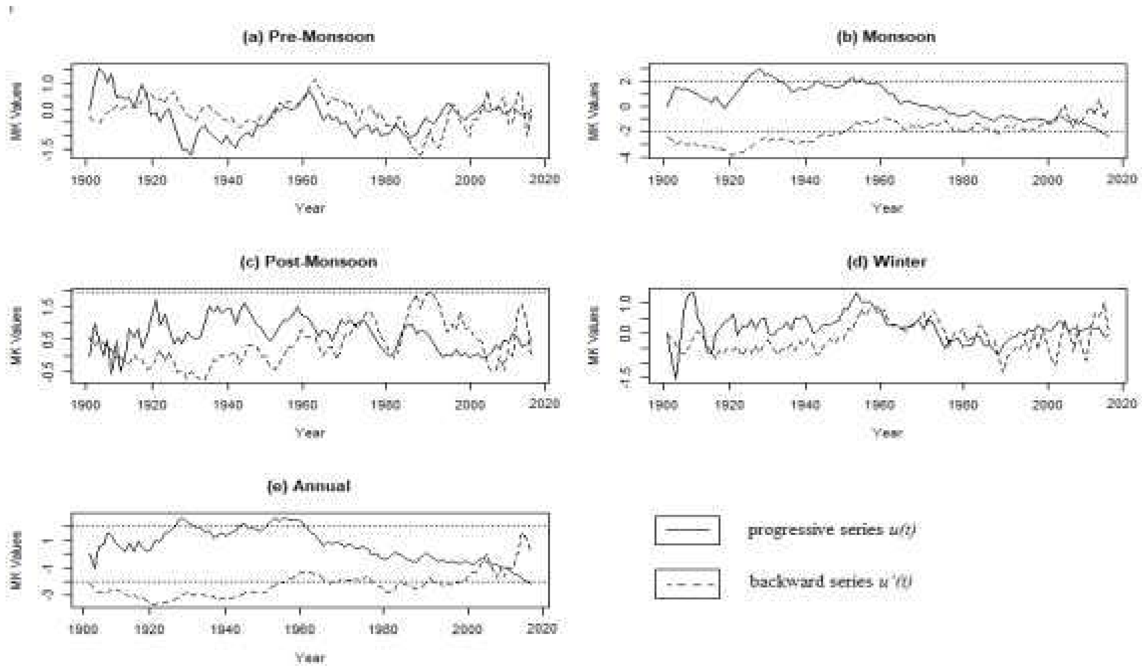

Figure 5.6 Sequential progressive (u (t)) and backward values (u'(t)) for (a) Pre-Monsoon, (b) Monsoon, (c) Post-Monsoon, (d) Winter and (e) Annual rainfall for Palamu

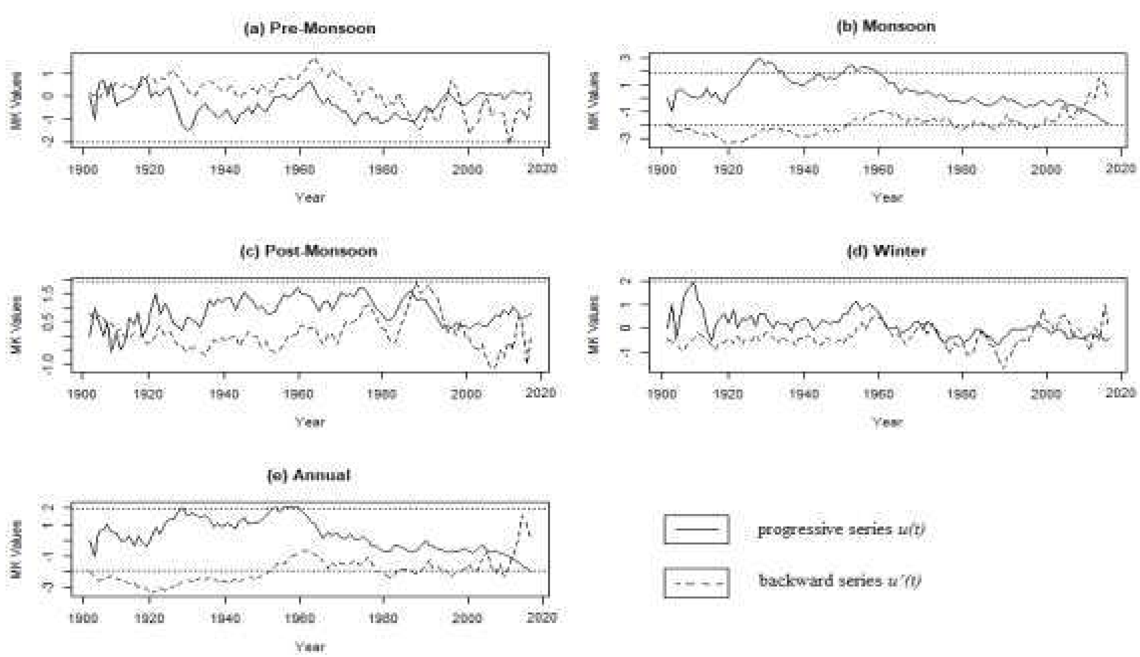

Figure 5.7 Sequential progressive (u (t)) and backward values (u'(t)) for (a) Pre-Monsoon, (b) Monsoon, (c) Post-Monsoon, (d) Winter and (e) Annual rainfall for Ranchi

5.4.2 Temporal Variability in Minimum Temperature

Temperature minima were analyzed seasonally and annually between 1901 and 2018 for the synoptic study stations such as Palamu, Ranchi, Hazaribagh, Dumka, and West Singhbhum. The coefficient of serial correlation for lag1 (ρ_1), the Z_{MK} trend value and its significance, a median of slope (β), intersection point, and proportionate change have been carried out for minima temperature and presented in Table 5.10. Based on the average normal value of MK test statistic (S) and persistence, the study area has revealed no persistence and trend in pre-monsoon, whereas significant persistence with the insignificant trend during monsoon season was observed. The magnitude of trend and PC is quite low for the station. The graphs of two stations, Palamu and Ranchi stations, from the study region are plotted in Figure 5.8 and Figure 5.9 as examples, respectively. The graphical representation of SQMK progressive series *u(t)* and backward series *u'(t)* displayed in Figure 5.8 and Figure 5.9 for minima temperature has multiple intersection points or overlaps several times for pre-monsoon significant trend was not detected for monsoon season. However, when examining the trace corresponding to *u(t)* and *u'(t)* in post-monsoon and winter season as well as annual, significant trends in extended duration may perhaps be recognized in increasing manner originating in the early 1915s and terminating in prompt to 1945s, and instantly after again in a progressive manner till late 1975s. The trend analysis of minimum temperature conducted for the winter season (December-February) and pre-monsoon season (March-May) projects a colder drift in the central regions, particularly Palamu and Ranchi, with a decrease of 0.37-0.78 °C. The annual minimum temperature fluctuates with a decrease of 0.79-0.39 °C in the Palamu and Ranchi to an increase of 0.59-0.41 °C in Hazaribag, Dumka, and West Singhbhum. The study also points that the duration of the winter season has decreased, with a lowering of the minimum temperature. The intensity of chilliness is also observed to have increased in the winter season over the central regions of the state of Jharkhand.

Table 5.10 Statistical parameter analysis for temperature minima for selected synoptic stations

Stations	Palamu					Ranchi				
Season	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual
ρ1	0.2121	0.326	0.472	0.395	0.518	0.198	0.219	0.186	0.5109	0.562
Z_{MK}	-0.5147	1.041	6.190	-1.594	-4.04	-1.335	1.72	5.881	-1.629	-4.12
Trend	1	0	1	1	1	0	0	1	1	1
β-value	-0.0014	0.0015	0.0193	-0.0121	-0.0058	-0.0037	0.0022	0.0169	-0.012	-0.055
Intercept	22.582	21.055	9.0498	10.546	17.688	23.905	21.086	11.113	12.791	19.179
PC	-0.6260	0.7174	19.5399	-6.073	-3.295	-1.5651	1.0196	14.295	-8.776	-2.913
Stations	Hazaribag					Dumka				
Season	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual
ρ1	0.0835	0.3635	0.4655	0.4146	0.5277	0.0582	0.3725	0.1923	0.4238	0.6186
Z_{MK}	0.1301	1.8038	6.0248	5.9302	4.8691	-0.06	3.365	6.1702	5.843	4.958

Trend	1	0	1	1	1	0	1	1	1	1
β-value	0.0004	0.0025	0.0195	0.0124	0.0062	-0.0002	0.0045	0.0198	0.0138	0.0073
Intercept	23.428	21.663	10.172	11.433	18.547	24.37	23.59	11.879	13.452	20.247
PC	-0.1929	1.1694	17.172	10.433	3.3391	-0.0830	1.9355	15.7124	9.5033	3.6424

Stations	West Singhbhum				
Season	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual
ρ1	0.261	0.327	0.2163	0.3861	0.551
Z_{MK}	-1.5093	1.818	5.4907	5.606	4.02
Trend	-1	1	1	1	1
β-value	-0.0039	0.0022	0.0153	0.0111	0.0051
Intercept	24.38	22.317	19.788	13.796	12.063
PC	-1.623	1.0224	12.087	7.8838	2.599

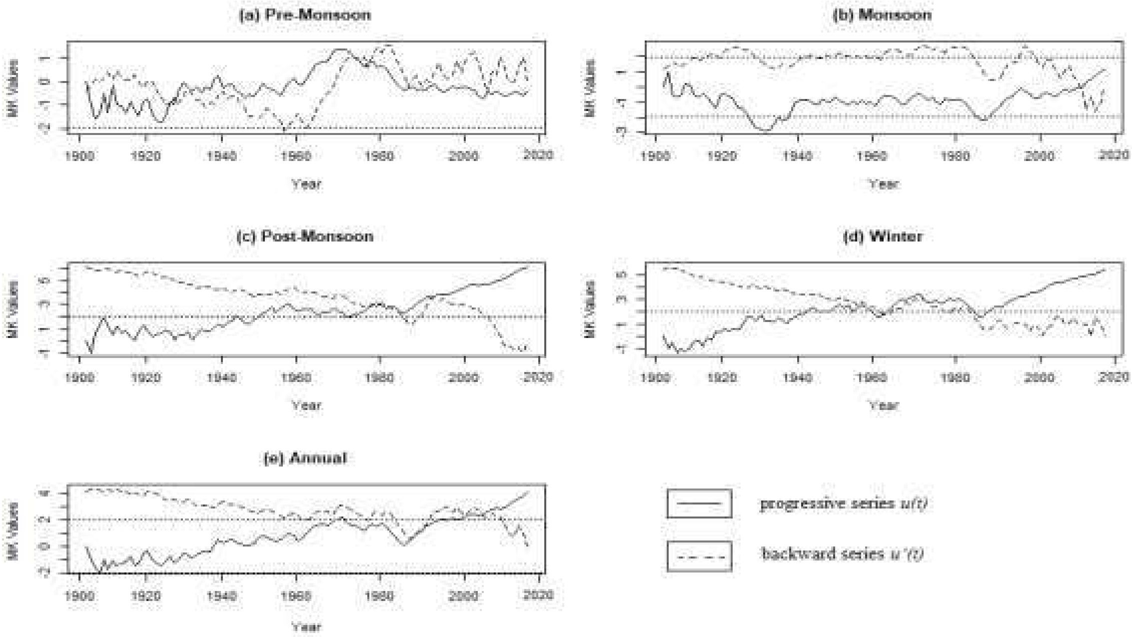

Figure 5.8 Sequential progressive (u (t)) and backward values (u'(t)) for (a) Pre-Monsoon, (b) Monsoon, (c) Post-Monsoon, (d) Winter and (e) Annual temperature minima for Palamu

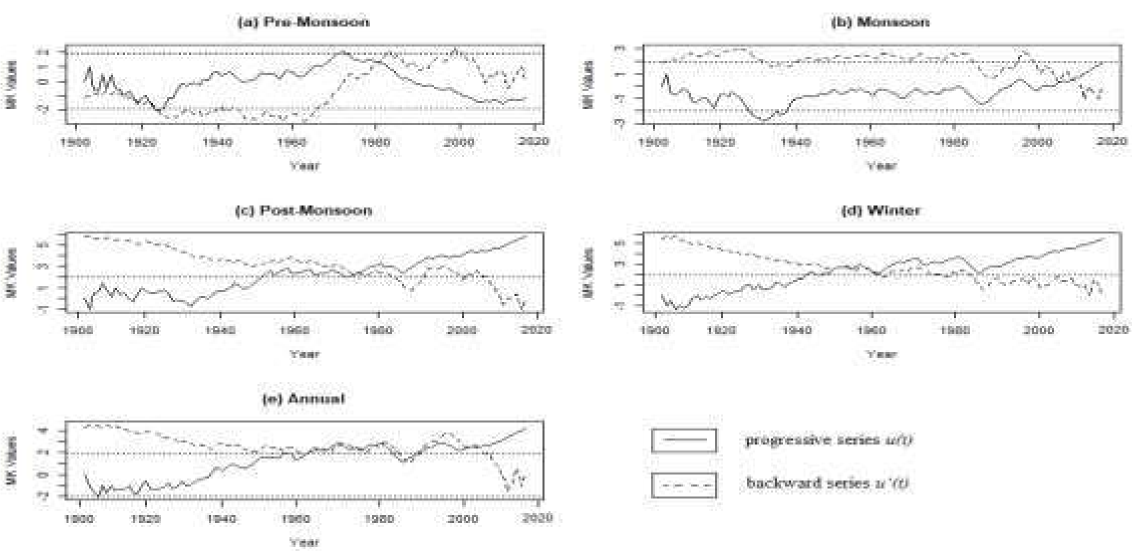

Figure 5.9 Sequential progressive (u (t)) and backward values (u'(t)) for (a) Pre-Monsoon, (b) Monsoon, (c) Post-Monsoon, (d) Winter and (e) Annual temperature minima for Ranchi

5.4.3 Temporal Variability in Maximum Temperature

The coefficient of serial correlation for lag1 (ρ_1), the Z_{MK} trend value and its significance, the median of slope (β), intersection point, and proportionate change was carried out for maximum temperature between 1901 and 2018 presented in Table 5.11. The pre-monsoon and monsoon seasons did not exhibit any substantial persistence and trend. However, a significant persistence and positive trend were observed during the pre-monsoon and monsoon seasons. Compared to minimum temperature, the magnitude of trend and proportionate values of maximum temperature is quite low for the stations. The graphs of two stations, Palamu and Ranchi stations, from the study region are plotted in Figure 5.10 and Figure 5.11 as examples, respectively. The SQMK statistics, derived from a progressive series *u(t)* and backward series *u'(t)*, of the MK rank correlation, are represented in Figure 5.10 and Figure 5.11. The results indicate a significant increasing trend was observed during pre-monsoon and monsoon seasons. However, in the post-monsoon season, the SQMK curve converges in the late 1970s according to a graphical representation, indicating the starting point of fluctuation in maximum temperature. Two functions start converging in the late 1935s, indicating the starting of a long-term trend.

Ascending mode of notorious long-term trends is commencing in the last 1945s until remaining time zone annually. It is observed from the analysis that pre-monsoon and monsoon season has become warmer, and its intensity has severed for most parts of the state. The average maximum temperature trend shows a significant increasing trend and is particularly prevalent in the north-western districts of Jharkhand, where an increasing trend is observed from 1-1.5 °C in the north-western region. The maximum temperature is observed to fluctuate with an increase of 0.55-1.5 °C in the Palamu, Hazaribagh, and part of Ranchi to a minor fluctuation of 0.82-0.14 °C in the north-eastern (Dumka) and southern part of

Jharkhand (West Singhbhum). An overall increasing trend of maximum temperature during pre-monsoon (March-May) and monsoon season (June-September) over Jharkhand is extremely noteworthy. Apart from the high increase of up to 1.5 °C in the north-western part, a moderate increase of temperature with 0.14-0.82 °C is observed in the northern and south-western parts of the state, which may lead to water scarcity in the area. There is an increase in the mean warming of the atmosphere due to progressive trends in pre-monsoon and monsoon season for temperature maxima which in turn causes the formation of clouds and ultimately pacifies the precipitation phenomenon. The rising trend in maximum temperature in the winter season imitates the water balance and impacts on rabi crop accordingly.

Table 5.11 Statistical analysis for temperature maxima for selected synoptic stations of Jharkhand

Stations	Palamu					Ranchi				
Season	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual
ρ1	0.269	0.196	0.109	0.332	0.345	0.376	0.183	0.163	0.291	0.367
Z_{MK}	6.45	3.964	-0.6188	0.211	2.874	5.99	3.764	-1.263	0.154	2.515
Trend	1	1	-1	0	1	1	1	-1	0	1
β-value	0.0191	0.0090	-0.0022	0.0003	0.0041	0.0161	0.0087	-0.0036	0.0019	0.0034
Intercept	23.415	25.904	36.795	29.445	30.085	24.656	27.478	37.383	29.867	30.898
PC	8.0144	3.4805	-0.5119	0.1282	1.3972	6.4675	3.1752	-0.9707	0.0663	1.1318
Stations	Hazaribagh					Dumka				
Season	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual
ρ1	0.2591	0.3442	0.0903	0.0665	0.2752	0.329	0.267	0.0812	0.0637	0.475
Z_{MK}	6.8662	3.1809	-0.7135	0.5985	2.795	6.216	3.414	-0.335	1.289	1.59

Trend	1	1	0	0	1	1	1	0	1	1
β-value	0.0184	0.0097	-0.0024	0.0011	0.0039	0.0185	0.0095	-0.0009	0.0019	0.0055
Intercept	23.383	26.352	38.946	29.298	30.071	31.457	28.655	37.53	31.98	25.871
PC	7.6725	3.4125	-0.6719	0.0037	1.3425	7.0398	3.3179	-0.2705	0.6162	1.7324

Stations	West Singhbhum				
Season	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual
ρ1	0.279	0.218	0.1.83	0.132	0.315
Z_{MK}	5.508	3.550	-1.41	0.46	2.41
Trend	1	1	-1	0	1
β-value	0.0144	0.0080	-0.0041	0.0007	0.0031
Intercept	25.517	28.399	37.652	30.2	31.416
PC	5.5843	2.8337	-1.112	0.255	0.9998

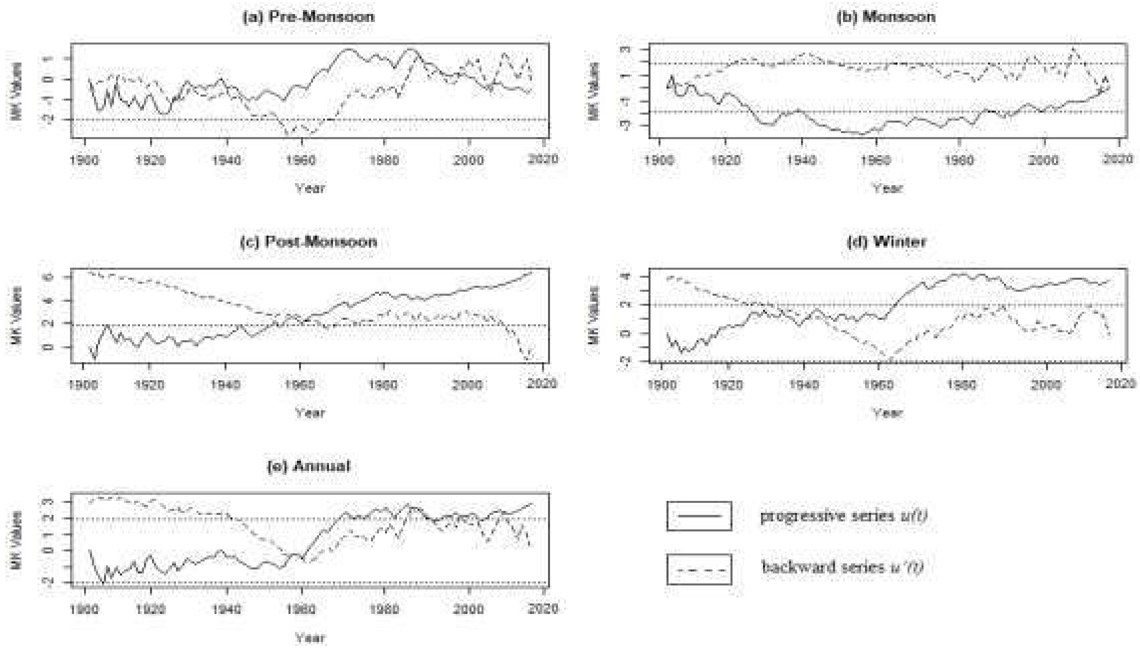

Figure 5.10 Sequential progressive (u (t)) and backward values (u'(t)) for (a) Pre-Monsoon, (b) Monsoon, (c) Post-Monsoon, (d) Winter and (e) Annual temperature maxima for Palamu

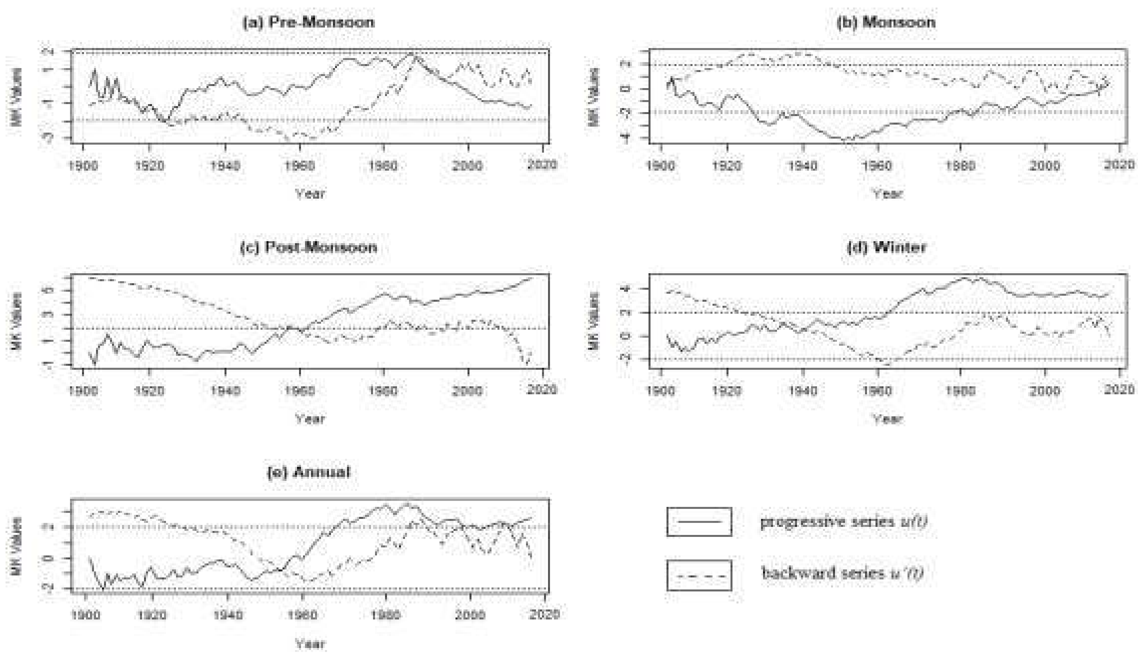

Figure 5.11 Sequential progressive (u (t)) and backward values (u'(t)) for (a) Pre-Monsoon, (b) Monsoon, (c) Post-Monsoon, (d) Winter and (e) Annual temperature maxima for Ranchi

5.3.4 Temporal Variability in Potential Evapotranspiration (PET)

PET was analyzed seasonally and annually for a long-term period of 1901 to 2018 for the synoptic study stations such as Palamu, Ranchi, Hazaribagh, Dumka, and West Singhbhum. The coefficient of serial correlation for lag1 (ρ_1), the Z_{MK} trend value and its significance, the median of slope (β), intersection point, and proportionate change have been carried out for PET and presented in Table 12. In this case, no significant persistence and trend were observed for pre-monsoon and post-monsoon season, but during monsoon season as well as yearly, significant persistence with decreasing trend of 0.0003-0.0012 mm/year was found, whereas winter data have persistence with the negligible trend with a little value of the magnitude of a trend. The graphs of two stations, Palamu and Ranchi stations, from the study region are plotted in Figure 5.12 and Figure 5.13 as examples, respectively. SQMK test's outcomes for PET show no significant trend in the pre-monsoon, post-monsoon, and winter season and are presented in Figure 5.12 and Figure 5.13. However, during monsoon season and annually, it is noted that the graphical trace of *u(t)* and *u'(t)* starts to deviate in the late 1990s, designating the trend's beginning point. PET shows an insignificant trend during the winter season; conversely, a progressive trend for temperature maxima and minima was observed. It is because of the dependency of PET on metrological variables other than temperature also. These variables may be wind speed, solar radiation, and sunshine hour, which affect PET and are not considered for carrying out the present research work.

Table 5.12 Statistical analysis for PET for selected synoptic stations of Jharkhand state

Stations	Palamu					Ranchi				
Season	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual
ρ1	0.172	0.483	0.0109	0.4231	0.485	0.216	0.396	0.0091	0.418	0.392
Z_{MK}	0.523	-2.376	0.8963	2.385	-0.399	0.016	-2.252	0.7315	1.168	-0.743
Trend	0	-1	1	1	0	0	-1	1	1	0
β-value	0.0013	-0.0011	0.0009	0.0012	-0.000	0.0001	-0.001	-0.0012	0.0008	-0.0011
Intercept	7.984	5.948	5.733	5.216	6.238	7.918	5.7855	5.6049	5.3272	6.1739
PC	0.2582	-1.7601	0.7607	1.1346	-0.119	0.0573	-1.996	0.6665	0.7250	-0.2926
Stations	Hazaribagh					Dumka				
Season	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual
ρ1	0.168	0.526	0.0091	0.4353	0.421	0.204	0.442	0.0083	0.398	0.402
Z_{MK}	0.1648	-2.1107	0.4568	1.0409	-0.673	-0.367	-1.879	0.456	1.460	-0.647

Trend	0	-1	0	0	-1	0	-1	0	1	-1
β-value	0.0011	-0.0012	0.0002	0.0004	-0.0003	0.0002	0.0005	-0.0011	0.0003	-0.0012
Intercept	7.8032	5.7311	5.5288	5.1465	6.068	7.802	5.7903	5.5545	5.2843	6.1129
PC	0.1457	-2.2081	0.5295	0.9328	-0.554	-1.112	0.255	5.5843	2.8337	0.9998

Station	West Singhbhum				
Season	Pre-Monsoon	Monsoon	Post-Monsoon	Winter	Annual
ρ1	0.186	0.451	0.0081	0.294	0.319
Z_{MK}	0.101	-1.908	0.332	0.864	-0.396
Trend	0	-1	0	1	0
β-value	0.0001	-0.0009	0.0002	0.0011	-0.0003
Intercept	7.917	5.7653	5.6048	5.4299	6.1926
PC	0.1024	-1.458	0.3789	0.5675	-0.196

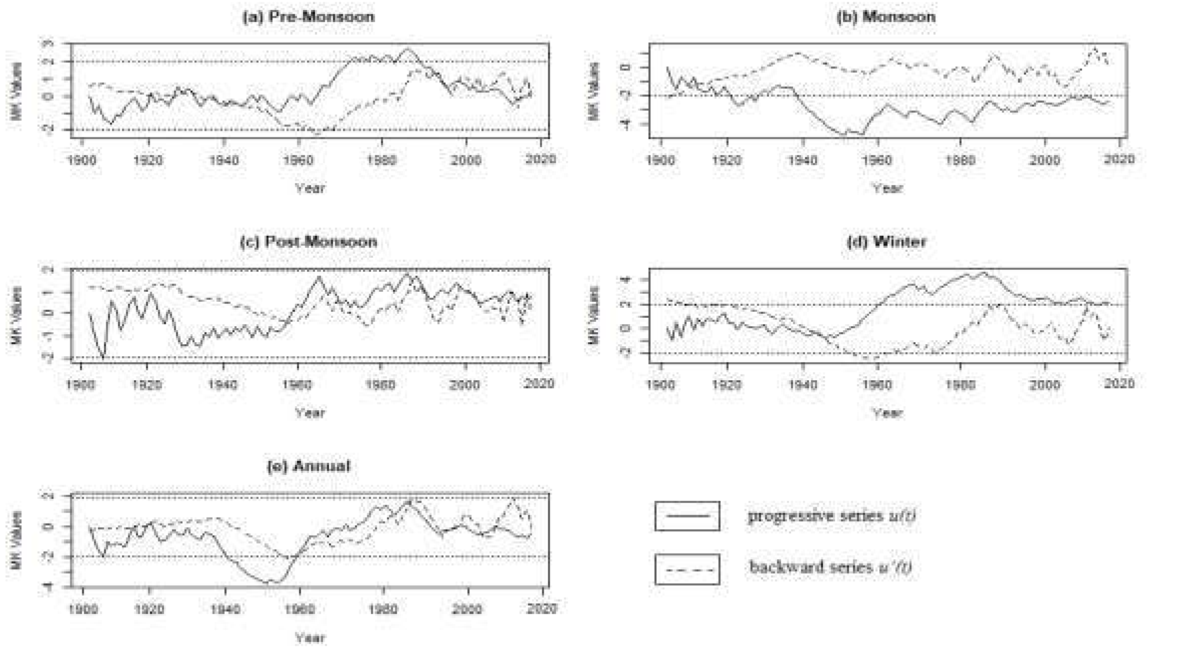

Figure 5.12 Sequential progressive (u(t)) and backward values (u'(t)) for (a) Pre-Monsoon, (b) Monsoon, (c) Post-Monsoon, (d) Winter and (e) Annual PET for Palamu

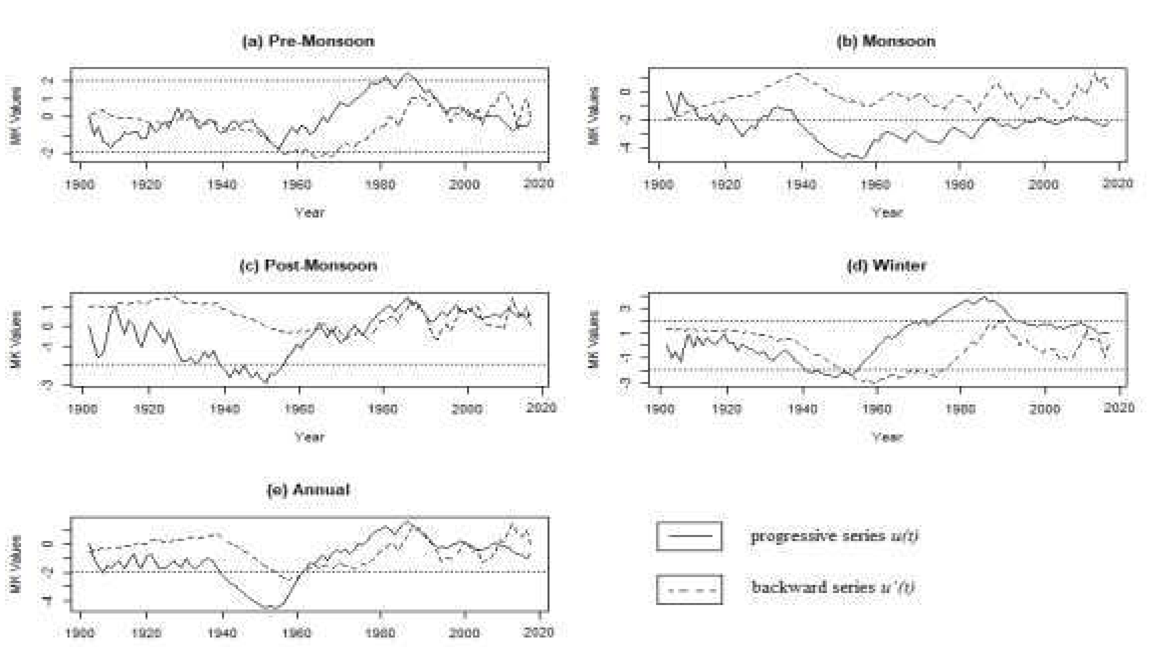

Figure 5.13 Sequential progressive (u(t)) and backward values (u'(t)) for (a) Pre-Monsoon, (b) Monsoon, (c) Post-Monsoon, (d) Winter and (e) Annual PET for Ranchi

5.3.5 Spatial Variability of Climate Variables

The spatial distribution of long-term Mann-Kendall value (ZMK) of annual time series during 118 years for all the climatic variables (Precipitation, temperature, and evapotranspiration) is illustrated in Figure 5.14. The color variation of the studied stations is according to the Z_{MK} value. The Z_{MK} value varies from -1.2 to -2.6 for the precipitation, which signifies the decreasing trend, whereas the temperature increases with the Z_{MK} value from 2.4 to 4.9. Evapotranspiration is also a crucial climatic variable; the Z_{MK} value varies from -0.3 to -0.74. The size of the arrow depends on the Z_{MK} values. The bigger the size of the arrow higher the Z_{MK} values, and the size decreases with the Z_{MK} values. The Mann Kendall trend test indicated that the seasonal and annual precipitation were characterized by decreasing trends in almost all localities depending upon geographical features concerning forest coverage and water bodies and maintains. However, the meaningful change of precipitation observed merely in two locations, Kolhan and Santhal Parganas divisions, and the significant change in temperature and evapotranspiration is observed in Palamu and Kolhan divisions (Figure 5.14). Overall, it can be concluded that a decrease in rainfall has occurred over the entire time period. The negative values in the trend analysis map (Figure 5.14) show the magnitude of decrease, whereas the positive values show the magnitude of increase. The color spectrum shows the color from blue (negative Z_{MK} values) to red (positive Z_{MK} values) with intermediate color followed by cyan, green and yellow. The spatial distribution map of rainfall and evapotranspiration illustrates a significant decreasing trend. In contrast, the spatial distribution map of average temperature trend demonstrates a significant increasing trend and is particularly prevalent in the Santhal Parganas division of Jharkhand (Figure 5.14), where an increasing trend was observed from 1-1.5 °C in the north-western region. Apart from the high increase of up to 1.5 °C in the north-western part, a moderate increase of temperature with 0.14-0.82 °C is observed in the northern and south-western parts of the state, which may lead to water scarcity in the area. The findings of this study will help in spatially accessing the zones severely affected due to the rising trend of maximum temperature and decreasing trend of rainfall that help government personnel to provide relief instantly. The further increasing trend may severely affect agricultural productivity under warmer climates as arid and semiarid regions could experience severe water stress due to a decline of soil moisture due to high temperatures.

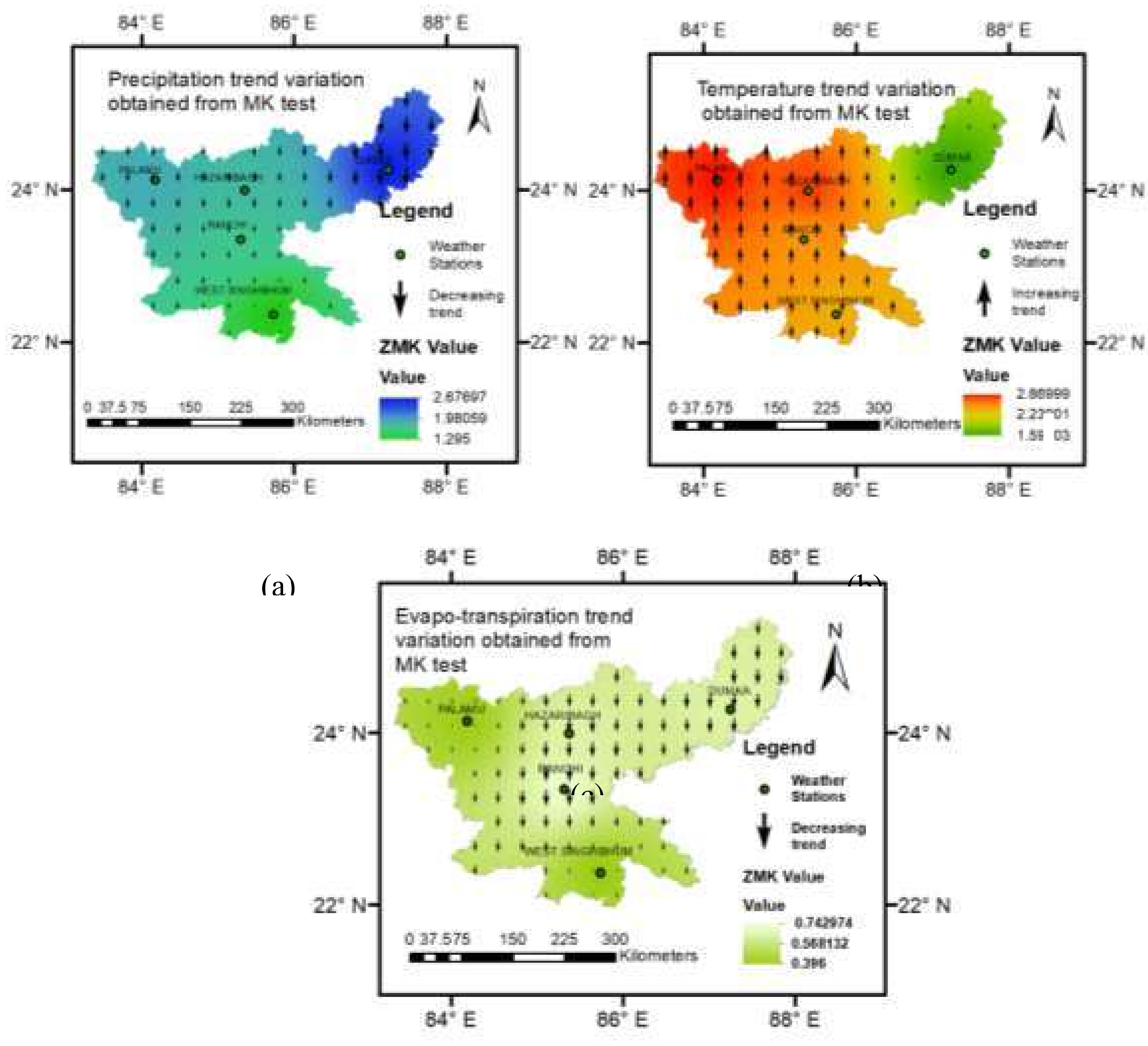

Figure 5.14 Spatial distribution of trend (ZMK values) from 1901-2018 of the synoptic study stations for climatic variables (a) Precipitation (b) Temperature and (c) Evapotranspiration respectively in Jharkhand state, India

5.5 Summary

Four predetermined climatic variables, namely rainfall, evapotranspiration, maximum temperature, and minimum temperature over Uttar Pradesh and Jharkhand of the Indian subcontinent, were systematically explored. The persistence effect has been removed before the statistical approach for trend analysis. The trend analyses for seasonal and annual time series were analyzed. Monotonicity in trend was detected in the pre-monsoon and winter season for rainfall whereas, a positive and upward trend in the immediate study area was observed for the post-monsoon season. The significant decreasing trend for rainfall was perceived during the monsoon season and annually. The decreasing rate of the trend for selected synoptic stations was observed in between 1.09-2.3 mm/year during the monsoon season and 1.2-2.4 mm/year annually. Considering temperature effects, the result of trend analysis of minimum temperature conducted for the winter season (December-February) and pre-monsoon season (March-May) projects a colder drift in the central regions, particularly in Palamu and Ranchi, with a decrease of 0.39-0.79 °C. A significant decreasing trend was observed for annual minimum temperature, which fluctuates with a decrease of 0.78-0.37 °C in the Palamu and Ranchi and an increasing trend with an increase of 0.59-0.41 °C in Hazaribagh, Dumka, and West Singhbhum. An overall increasing trend of maximum temperature during pre-monsoon (March-May) and monsoon season (June-September) over Jharkhand is extremely noteworthy. Apart from the high increase of up to 1.5 °C in the northwestern part, a moderate increase of temperature with 0.14–0.82 °C is observed in the state's northern and southwestern parts evapotranspiration and relative humidity of the study region. However, the underlying persistence effect observed in all seasons and throughout the year for all climatic parameters resulted in the time series with low-frequency fluctuations. Sequential Mann–Kendall test exhibits the periodic fluctuation of trends, which are more prominent in pre-monsoon and monsoon seasons. Severe restoration of water bodies is a challenge faced by climatologists. The decrease in rainfall, coupled with elevated temperature levels, implies lesser storage and more significant water stress and thereby exaggerates the severity of the extreme climatic conditions and inflicts harsh living situations. The close insights of these climatic variables used in the study can help achieve devastating results for the study region.