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Innovative Polygon Trend Analysis Method: A Case Study of the South Gujarat Region

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ABSTRACT. The unpredictability of precipitation can have dramatic impacts on agriculture, ecosystems, and water resource management. It is needed to study the change in trends of precipitation due to climate change. The present aims to assess the impact of climate change, trend analysis using the Innovative polygon trend analysis (IPTA) method considering monthly precipitation data of 120 years for seven districts of South Gujarat. Further comparison is carried out with the trends predicted by the well accepted Mann-Kendall (M-K) method. IPTA method shows increasing trends during the monsoon season (June and August) but decreasing trends for the monthly precipitation of July for all seven districts. It can be said that over the period of years, less precipitation occurs in the month of July. Decreasing trends are observed for the post-monsoon and pre-monsoon seasons. No trend is observed for the monthly precipitation of February which demands preparedness in the water Management system. Interestingly, monthly variation of trends is observed for Dang District for both monsoon and post-monsoon seasons. However, a variation in trends in the monsoon season leads to difficulties in the water management system, and sometimes flood events occur. Trends predicted by the Mann-Kendall method show decreasing trends in the post-monsoon season and increasing trends for the monsoon season. Whereas Tapi and Bharuch districts show decreasing trends in the month of June. No trend is predicted in the pre-monsoon season. Comparative analysis of trends predicted by IPTA and M-K method shows similar results for Post Monsoon. IPTA predicts decreasing trends in pre-monsoon season whereas the M-K test shows no trends in pre-monsoon season. The monthly prediction by IPTA may bring useful information for water utility sectors and decision-makers in the study area.

Keywords: climate change, innovative polygon trend analysis, precipitation, Mann-Kendall, rainfall pattern

1. Introduction

Climate change can have considerable impacts on the variability in hydro-meteorological variables such as precipitation, temperature, and evaporation (Emadi et al., 2021; Hirca et al., 2022). Lack of precipitation poses a serious hazard to both humans and wildlife in arid and semiarid areas (Mehta and Yadav, 2021a, 2022a, b; Pastagia and Mehta, 2022). The central problem in arid places is not necessarily a lack of precipitation, but the large differences in that precipitation over the period, location, intensity, and duration (Şen 2012; Ceribasi et al., 2021; Mehta and Yadav, 2021b; Pastagia and Mehta 2022).

Precipitation is one of the key factors that is usually used to determine the scope and intensity of climate variability (Achite et al., 2021). In the production of hydroelectric power, irrigation techniques, groundwater recharge, and water delivery, hydro-meteorological data analysis is crucial. Planning these actions, in particular, benefits from the analysis of this data set using the mean and standard deviation (Ceribasi et al., 2021). The most popular techniques for analysing such a data collection are those that involve trend analysis. When data is analysed using trend analysis techniques, the analysis's findings are typically interpreted as either increasing or decreasing. In addition, the data set's trend analysis results are typically classified as three different sorts, including high, medium, and low (Ahmed et al., 2022; Akçay et al., 2022).

The Intergovernmental Panel on Climate Change (IPCC) claimed in its fifth assessment synthesis report that the warming of the climate system is undeniable and that many of the changes that have occurred since the 1950s are unprecedented. There is no doubt that humans have an impact on the climate system (IPCC, 2014). The regional climate projection suggests that in the 2030s, the summer monsoon precipitation will increase by 3 ~ 7%. This is according to Indian Network for Climate Change Assessment (INCCA) report II. While a diminishing trend for summer and winter precipitation will be shown over the same period, a similar pattern will be seen for western coastal regions. India's temperature has significantly increased by 0.51°C between the years 1901 and 2007 in terms of temperature (Mehta and Yadav, 2021c; Mehta et al., 2022c; Shaikh et al., 2022).

Trend analysis is one of the techniques used to investigate this variability. The purpose behind using the innovative trend analysis for rainfall is to identify and quantify the trends and patterns in rainfall data over time. The rainfall is the important factor of the hydrological cycle. Thus, its variations have direct

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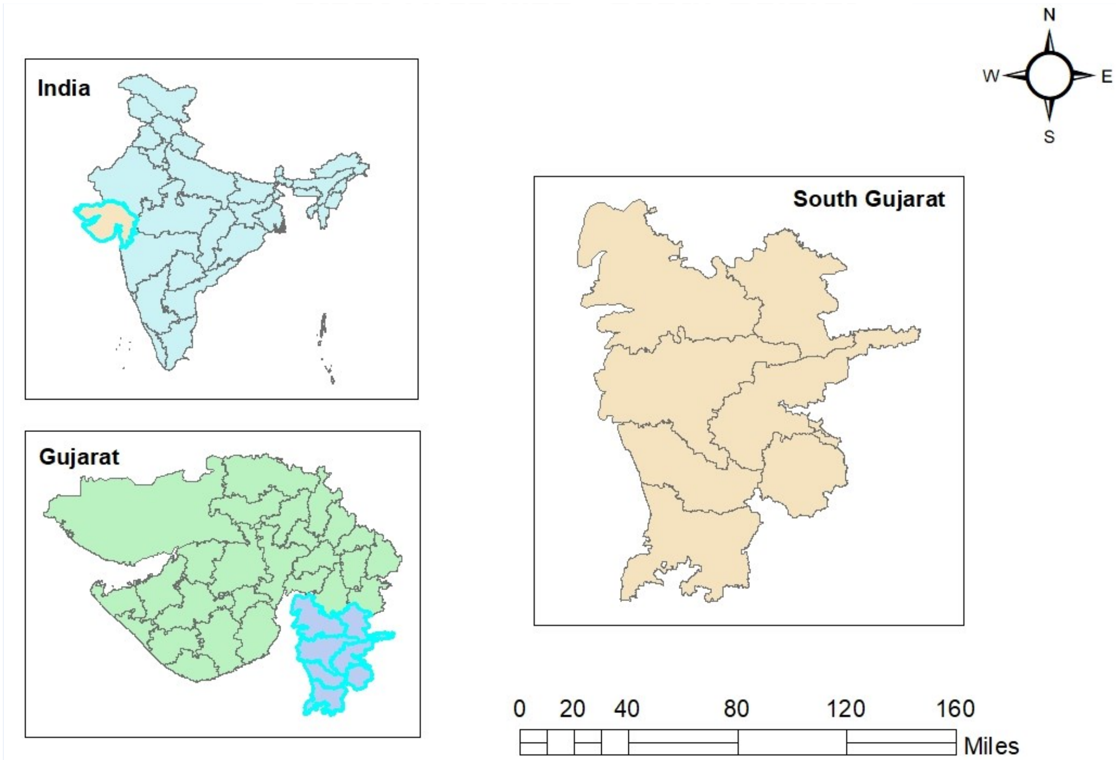

Figure 1. Location map of the study area (South Gujarat District).

impact on the agricultural activity, demand of water supply, occurrence of flood as well as to drought (Perera et al., 2020; Mehta and Yadav, 2023; Sharma et al., 2023).

Recent years have seen a significant increase in the importance of studying climate change brought on by global warming because existing water resources are significantly impacted by climate change. Examples of this climate change include the decline in the percentage of water in dams, the major withdrawal of drinking-water-producing lakes from their shorelines, and the total drying out of minor streams. On the other hand, one of the repercussions of climate change is the foods that arise as a result of excessive rainfall in certain locations. In order to mitigate the detrimental effects of these studies, early warning systems should be implemented together with expanded hydro-meteorological data investigations (Ceribasi et al., 2021). A trend is typically defined as a consistently rising or falling average tendency in a time series that has a general direction. Sen's innovation method, innovative triangular trend analysis (ITTA), and innovative polygon trend analysis (IPTA) are now the most popular trend analysis techniques utilized in academic studies (Sen et al., 2019). The hydrological cycle is primarily influenced by rainfall, and changes in this component can directly affect both the frequency of floods and droughts as well as agricultural productivity. In order to plan and manage water resources and to create effective plans to deal with floods and drought situations, it is vital to analyze rainfall variation (Perera et al., 2020). One method used to analyze this Variability is trend analysis. The goal of trend analysis is to forecast the future using systematic, objective, and quantitative techniques for detection, identification, and prediction (Sen et al., 2019). Trend detection analysis has a specific place in every statistical research of hydro-meteorological, economic, geophysical, quality-control, and related time series investigations. Traditional trend approaches like holistic trend identification are important but do not identify periodic changes like monthly ones (Sen et al., 2019). Therefore, trend traits are essential for illustrating seasonal trend behaviour. A novel method called IPTA has been put out by Sen et al., (2019) to enhance the ITTA process because seasonal trend detection can help regulate or manage agriculture and irrigation activities, as well as water resources systems. For the south Gujarat region, we used the IPTA approach for analyzing the rainfall trends. The objective of this study is to investigate the patterns of monthly total precipitation data for the South Gujarat region from 1902 to 2021. To achieve the objective, Mann-Kendall test and the IPTA method were used.

2. Study Area

In this research, the South Gujarat region is selected as the study area which is located between a latitude of 21.1995° N and a longitude of 73.2765° E. This is one of India's wettest regions. It is divided into two parts: Western and Eastern. The eastern part is also known as the mountain party almost hilly and spans from 100 to 1000 meters ranges with the highest peak at Saputara in the Dangs District of South Gujarat. During the months of June to September, South Gujarat receives 97 percent of its rainfall from the southwest monsoon (between 24

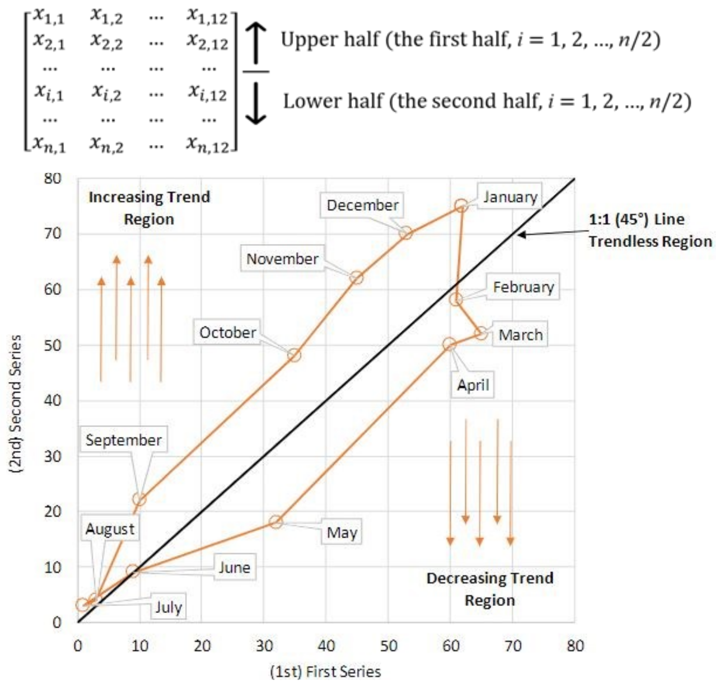

Figure 2. An innovative polygon trend analysis (IPTA) template for monthly records.

and 32 standard weeks. The total area of the south Gujarat region is 17,500 km^2 and largest city in this region is Surat. Figure 1 shows the location map of study area.

3. Data Collection

For trend analysis of rainfall, monthly rainfall data of Surat, Bharuch, Navsari, Dang, Valsad, Narmada, and Tapi Districts for the period 120 years (i.e., 1902 ~ 2021) were collected from the India WRIS. Figure 2 shows the outline of the methodology adopted to assess the trend in the study area.

Mann-Kendall Test: The Mann-Kendall (M-K) test is one the commonly used non-parametric tests to detect monotonic trends in precipitation time series data. The null hypothesis, H_0 is that the data come from a population with independent realizations and are identically distributed. The alternative hypothesis, H_A, is that the data follow a monotonic trend (Wu et al., 2022). The M-K test (S) statistic is calculated using Equations (1) and (2):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(X_j - X_k) \tag{1}$$

$$Sgn(x) \begin{cases} 1, \ x > 0 \\ 0, \ x = 0 \\ -1, \ x < 0 \end{cases} \tag{2}$$

The variance σ^2 is determined using Equation (3), where the mean of S is zero:

$$\sigma^2 = \{n(n-1)(2n+5) - \sum_{j=1}^{p} (tj(tj-1)(2tj+5))\} / 18 \tag{3}$$

where p is tied group, t_p a number of observations in a p^{th} group, a sign (Σ) expresses summation of all a tied group. A standardized test statistic (Z) can be determined by utilizing the following Equation (4):

$$Z = \begin{cases} \dfrac{S-1}{\sigma}, \ S > 0 \\ 0, \ S = 0 \\ \dfrac{S+1}{\sigma}, \ S < 0 \end{cases} \tag{4}$$

Calculate the probability associated with this normalized test statistic. The probability density function for a normal distribution with a mean = 0 and a standard deviation = 1 is given by the Equation (5):

$$f(Z) = \frac{1}{\sqrt{2\pi}} e^{\frac{-Z^2}{2}} \tag{5}$$

If Z is negative and the computed probability exceeds the level of significance, the trend is considered to be decreasing. If the Z is positive and the computed probability exceeds the level of significance, the trend is said to be rising. There is no trend if the determined probability is lower than the level of significance.

A statistical test called Sen's slope estimator test calculates the level of the trend as determined by the M-K test (Sen, 1968). The remaining variations of the data, which are constant across time, may be computed as follows to determine the slope of the trend in this test.

Table 1. Result of M-K Test for Precipitation Trend Data (1902 ~ 2021 over Surat and Navsari) District

Month	Surat District				Navsari District			
	P value	*Z* value	Sen's Slope	Nature of Trend	*P* value	*Z* value	Sen's Slope	Nature of Trend
January	0.058	–0.130	0.000	Decreasing	0.065	–0.128	0.000	Decreasing
February	<0.0001	–0.2771	0.000	No Trend	0.002	–0.211	0.000	No Trend
March	0.023	–0.158	0.000	No Trend	0.196	–0.091	0.000	Decreasing
April	0.017	–0.161	0.000	No Trend	0.074	–0.124	0.000	Decreasing
May	0.159	–0.092	0.000	Decreasing	0.235	–0.078	0.000	Decreasing
June	0.679	0.026	0.159	Increasing	0.748	0.020	0.155	Increasing
July	0.610	–0.032	–0.286	Decreasing	0.831	–0.013	–0.185	Decreasing
August	0.019	0.146	1.027	No Trend	0.115	0.098	0.957	Increasing
September	0.195	0.080	0.472	Increasing	0.181	0.083	0.603	Increasing
October	0.379	0.055	0.017	Increasing	0.244	0.072	0.059	Increasing
November	0.645	–0.031	0.000	Decreasing	0.994	0.001	0.000	Increasing
December	0.261	–0.078	0.000	Decreasing	0.747	–0.023	0.000	Decreasing
Annual	0.142	0.091	0.128	Increasing	0.293	0.065	0.117	Increasing

Table 2. Result of M-K Test for Precipitation Trend Data (1902 ~ 2021 over Dang and Bharuch) District

Month	Dang District				Bharuch District			
	P value	*Z* value	Sen's Slope	Nature of Trend	*P* value	*Z* value	Sen's Slope	Nature of Trend
January	0.138	–0.101	0.000	Decreasing	0.057	–0.132	0.000	Decreasing
February	0.009	–0.182	0.000	No Trend	0.004	–0.204	0.000	No Trend
March	0.439	–0.052	0.000	Decreasing	0.035	–0.149	0.000	No Trend
April	0.069	–0.121	0.000	Decreasing	0.057	–0.130	0.000	Decreasing
May	0.147	–0.092	–0.001	Decreasing	0.068	–0.120	0.000	Decreasing
June	0.594	–0.033	–0.147	Decreasing	0.532	–0.039	–0.154	Decreasing
July	0.916	0.007	0.074	Increasing	0.138	–0.092	–0.568	Decreasing
August	0.086	0.107	0.823	Increasing	0.068	0.113	0.664	Increasing
September	0.748	0.020	0.118	Increasing	0.457	0.046	0.214	Increasing
October	0.085	0.107	0.137	Increasing	0.662	0.027	0.002	Increasing
November	0.989	–0.001	0.000	Decreasing	0.990	–0.001	0.000	Decreasing
December	0.467	–0.049	0.000	Decreasing	0.648	–0.032	0.000	Decreasing
Annual	0.366	0.056	0.071	Increasing	0.326	0.061	0.062	Increasing

4. Innovative Polygon Trend Analysis Method

Sen introduced the innovation trend analysis approach in the years 2012 (Sen, 2012). This progress resulted in the emergence of the IPTA method. Data time scales in this method might be daily, monthly, or annual. Row data will consist of monthly data over the period of a year if the IPTA technique is used to monthly data presented in matrix format.

X_1, X_2, X_i, …, X_n are the monthly meteorological data, where i is the number of months and n is the number of years. The stated matrix is transformed into a matrix format by splitting it into two equal series at the top and bottom. Each data series' mean and standard deviation are computed after being divided into 2 equal parts. The X-axis and Y-axis of the Cartesian system are used to represent the means of the upper and lower series, respectively. Each month's trend polygon endpoint is made, as seen in Figure 2.

The polygonal end points of each month are joined, as seen in Figure 3. Information about trends is given by each line that joins all points. The distribution of points in the graph varies depending on how hydro-meteorological events affect it. Figure 3 depicts the polygon with decreasing lines after ascending lines. These line modifications describe how hydro-meteorological data changed throughout the period of the months. In Figure 3, for instance, February, March, April, and May all exhibit a rising tendency, but January, December, November, October, September, August, July, and June show a falling trend. The polygon cycle is accomplished in this manner. If the data are homogenous in form, the analysis's result will be a single polygon. However, the analysis may use more complex and many polygons depending on how complex the data is. In this study, there are five processing steps for adopting IPTA to monthly data (Şen et al., 2019; Şan et al., 2021):

(1) A monthly time series is split into two equal parts.

(2) For each month in both time periods, basic statistics (like mean and maximum) or specified criteria (like uncertainty) are calculated.

(3) On the scatter chart's horizontal (vertical) axis, the first (second) period is located, and 12 dots are drawn to represent 12 months.

(4) A polygon is created by connecting the points of con-

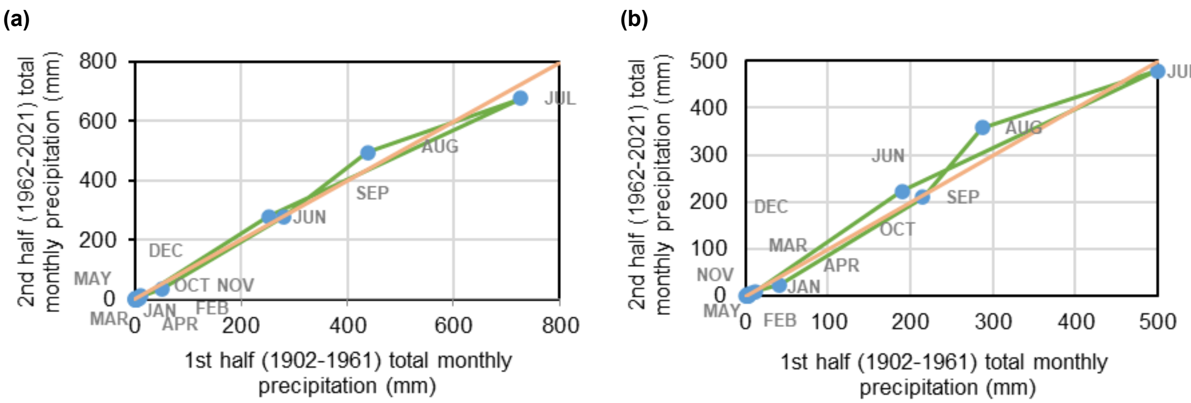

Figure 3. Graphical representation of arithmetic mean analysis over (a) Surat and (b) Navsari districts.

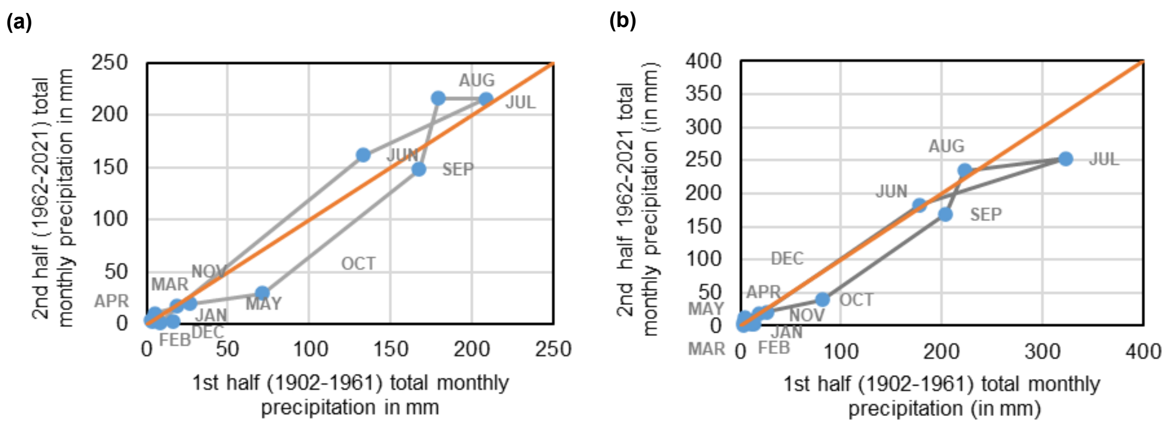

Figure 4. Graphical representation of standard deviation analysis over (a) Surat and (b) Navsari districts.

Table 3. Summary of the Arithmetic Mean Analysis of All Districts

Region	January	February	March	April	May	June	July	August	September	October	November	December
Surat	↘	→	↘	↘	↘	↗	↘	↗	↗	↘	↘	↘
Navsari	↘	→	↘	↗	↘	↗	↘	↗	↗	↘	↘	↘
Dang	↘	→	↘	→	↘	↗	↘	↗	↘	↗	↗	↘
Bharuch	↘	→	↘	↘	↗	↗	↘	↗	↘	↘	↘	↘
Tapi	↘	→	↗	↘	↘	↗	↘	↗	↘	↘	↘	↗
Narmada	↘	→	↘	↘	→	↗	↘	↗	↘	↘	↗	↘
Valsad	↘	↘	→	↘	↘	↗	↘	↗	↘	↘	↘	↗

Note: increasing trend (↗), no trend (→), and decreasing trend (↘).

Table 4. Summary of the Standard Deviation Analysis of All Districts

Region	January	February	March	April	May	June	July	August	September	October	November	December
Surat	↘	→	↘	↘	↘	↗	↗	↗	↘	↘	↘	↗
Navsari	↘	→	↘	↘	→	↗	↘	↗	↘	↘	↘	↗
Dang	↘	→	↘	↘	↘	↗	↗	↗	↗	↘	↘	↗
Bharuch	↘	→	↗	→	↘	↗	↗	↗	↘	↘	↗	↗
Tapi	↘	→	↘	↘	↘	↗	↗	↗	↘	↘	↘	↗
Narmada	↘	→	→	↘	↘	↗	↗	↗	↘	↘	↘	↗
Valsad	↘	→	↘	↘	↘	↗	↗	↗	↘	↘	↘	↗

Note: increasing trend (↗), no trend (→), and decreasing trend (↘).

Table 5. Result of M-K Test for Precipitation Trend Data (1902 ~ 2021 over Tapi and Narmada) District

Month	Tapi District				Narmada District			
	P value	*Z* value	Sen's Slope	Nature of Trend	*P* value	*Z* value	Sen's Slope	Nature of Trend
January	0.097	–0.111	0.000	Decreasing	0.057	–0.130	0.000	Decreasing
February	0.001	–0.225	0.000	No Trend	<0.0001	–0.270	0.000	No Trend
March	0.126	–0.104	0.000	Decreasing	0.002	–0.218	0.000	No Trend
April	0.044	–0.133	0.000	No Trend	0.006	–0.186	0.000	No Trend
May	0.014	–0.156	–0.005	No Trend	0.002	–0.198	–0.004	No Trend
June	0.720	–0.022	–0.113	Decreasing	0.581	–0.034	–0.145	Decreasing
July	0.666	–0.027	–0.230	Decreasing	0.253	–0.071	–0.561	Decreasing
August	0.032	0.133	0.988	No Trend	0.050	0.122	0.870	No Trend
September	0.666	0.027	0.149	Increasing	0.580	0.034	0.199	Increasing
October	0.484	0.044	0.031	Increasing	0.578	0.035	0.008	Increasing
November	0.439	–0.050	0.000	Decreasing	0.408	–0.054	0.000	Decreasing
December	0.109	–0.108	0.000	Decreasing	0.093	–0.114	0.000	Decreasing
Annual	0.435	0.049	0.065	Increasing	0.843	0.012	0.015	Increasing

secutive months with straight lines.

(5) Calculations are carried out to determine the length and slope of the line connecting two successive locations. Using Equations (6) and (7) trend slope and length can be calculated as follows:

$$\left|AB\right| = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{6}$$

$$S = \frac{(y_2 - x_2)}{(x_2 - x_1)} \tag{7}$$

where S is the slope, $|AB|$ is the length, x_1, and x_2, y_1 and y_2 are 2 sequential points in the second section, while y_1 and y_2 are two sequential points in the first half of the horizontal.

A 1:1 (45°) line depicting a decreasing (growing) trend is created in the Cartesian coordinate system with the points below (above) the line. Data on the changes between the following months is given by the straight lines connecting the points (Ceribasi et al., 2021; Ceribasi and Ceyhunlu, 2021). The percentage of monthly variations that contribute to the mean change in the hydrometeorological series is large and vice versa if the slopes of the lines connecting consecutive months are far from one another. The polygon results show how the hydrometeorological series behaves over a year. The chance of occurrence of complicated polygons is directly related to the dynamics and diversity of the hydrometeorological event (Şen et al., 2019; Ceribasi and Ceyhunlu, 2021; Şan et al., 2021).

5. Results and Discussions

5.1. Precipitation Trend Analysis Using the Mann-Kendall Test

Monthly precipitation data were used in 1902 ~ 2021 in the south Gujarat region. For finding trends XLSTAT was used. After performing the data in XLSTAT, the Z (Kendall's tau) value was obtained. If Z is positive, it indicates an increasing trend and if Z is negative, it indicates a decreasing trend. A 5% significant level is used for the M-K method. After the M-K test, it is observed from Tables 1 to 4, that there is no trend in February month in all 7 districts. In March, there is no trend in Surat, Bharuch, and Narmada district; while in April there is no trend in Surat, Tapi, Narmada, and Valsad district. Similarly, in May no trend is observed in the Tapi and Narmada districts, whereas in August there is no trend in Surat, Tapi, and Narmada districts. It is also observed that there is an increasing trend in September, October, and Annual in all districts while decreasing trends in January, July, November, and December.

5.2. Precipitation Trend Analysis Using IPTA Method

The IPTA method was used to analyze the total monthly precipitation data for the region of South Gujarat. Data of seven monthly precipitation data (Surat, Navsari, Dang, Bharuch, Tapi, Narmada, and Valsad) in the South Gujarat region were used. Table 5 shows the summary of the arithmetic mean analysis for each district of the South Gujarat region based on Figures 3, S1, S2, and S3. Based on the analysis, results reveal that each station's polygons are complex and irregular, due to the invariable data, and the arithmetic mean is not constant. Data on precipitation are not uniform and isotropic at each station. At any station, not a single polygon was created. This demonstrates the instability of the precipitation data.

5.3. Arithmetic Mean

From the graph of the Surat district, it is clear that February shows no trend, while June, August, and September show rising trends and January, March, April, May, June, July, October, November, and December show falling trends. From the graph of Navsari district, it is clear that February shows no trend. April, June, August, and September show a rising trend, though. In January, March, May, July, October, November, and December, falling trends are observed as shown in Figure 3.

From the graph of Dang district, it is observed that there is no trend between February and April. In contrast, a rising trend is shown in June, August, October, and November while it shows a falling trend in January, March, May, July, September, and December. From the graph of Bharuch district, it is observed

Table 6. Result of M-K Test for Precipitation Trend Data (1902 ~ 2021 over Valsad) District

Month	Valsad District			
	P value	*Z* value	Sen's Slope	Nature of Trend
January	0.055	–0.133	0.000	Decreasing
February	0.002	–0.213	0.000	No Trend
March	0.626	–0.033	0.000	Decreasing
April	0.026	–0.147	0.000	No Trend
May	0.736	–0.022	0.000	Decreasing
June	0.621	0.031	0.231	Increasing
July	0.925	–0.006	–0.079	Decreasing
August	0.187	0.082	0.910	Increasing
September	0.130	0.094	0.705	Increasing
October	0.185	0.082	0.098	Increasing
November	0.733	0.022	0.000	Increasing
December	0.510	–0.045	0.000	Decreasing
Annual	0.418	0.050	0.106	Increasing

Table 7. Statistical Values of Arithmetic Mean and Standard Deviation of All the Districts

Month			Jan. ~ Feb.	Feb.~ Mar.	Mar.~ Apr.	Apr.~ May	May ~ Jun.	Jun.~ Jul.	Jul.~ Aug.	Aug.~ Sep.	Sep.~ Oct.	Oct.~ Nov.	Nov.~ Dec.	Dec.~ Jan.
SUR	Mean	TL	1.83	0.67	0.68	7.20	283.77	402.44	244.10	164.51	255.10	33.32	11.22	2.86
		TS	0.12	–0.65	–0.96	0.72	1.20	0.83	0.57	2.03	1.08	0.47	0.68	–1.39
	SD	TL	12.50	2.10	6.53	18.26	184.55	91.99	28.78	69.24	152.33	45.61	23.90	13.30
		TS	0.04	–2.13	–0.44	1.52	1.26	0.71	–0.03	5.62	1.23	0.22	0.43	–0.64
NAV	Mean	TL	1.58	0.78	1.45	8.01	366.01	620.12	340.96	268.68	333.59	47.06	12.01	3.37
		TS	0.31	–1.28	–0.35	0.84	1.12	0.84	0.63	1.38	1.06	0.61	0.72	–3.31
	SD	TL	10.10	4.40	8.50	17.40	229.80	160.90	102.40	68.20	178.30	58.50	22.40	13.80
		TS	0.13	–39.11	–0.40	2.00	1.04	0.48	0.19	3.59	1.05	0.34	0.35	–1.30
DAN	Mean	TL	2.90	0.80	3.30	9.10	253.80	450.40	170.90	228.70	259.00	53.70	17.50	3.30
		TS	0.36	1.10	0.17	0.48	1.18	0.93	0.44	1.66	1.05	1.11	0.54	–3.62
	SD	TL	12.20	1.40	7.20	15.90	153.50	164.70	82.60	60.10	115.40	46.80	30.80	11.00
		TS	0.18	1.01	0.13	0.43	1.87	0.43	0.13	2.21	1.21	0.89	0.47	–0.88
BHA	Mean	TL	1.70	0.70	1.30	5.30	192.00	272.80	153.20	106.90	193.70	28.20	8.70	2.60
		TS	0.23	–1.97	–0.36	1.07	1.04	0.77	0.39	2.27	1.02	0.31	0.97	–0.97
	SD	TL	10.02	3.60	10.53	11.00	138.03	56.96	24.76	28.55	120.56	42.20	20.83	11.05
		TS	0.08	51.36	–0.30	5.94	1.16	0.50	–0.23	–12.64	1.29	0.08	0.96	–0.51
TAP	Mean	TL	2.59	0.37	1.05	8.32	247.21	402.98	185.17	197.26	244.16	35.47	13.72	2.92
		TS	0.21	4.47	–0.07	0.53	1.19	0.86	0.45	1.89	1.05	0.62	0.57	–3.50
	SD	TL	12.22	0.85	2.33	18.65	156.58	102.38	37.90	56.39	126.21	31.24	27.66	12.06
		TS	0.07	1.98	–0.13	0.82	1.66	0.33	–0.03	2.18	1.36	0.26	0.40	–0.86
NAR	Mean	TL	1.92	0.88	0.39	7.58	208.52	339.59	144.78	178.48	226.65	27.37	10.55	2.80
		TS	0.24	9.18	–6.37	0.53	1.13	0.80	0.22	2.21	1.00	0.38	0.88	–1.81
	SD	TL	9.69	4.49	2.94	15.59	139.08	85.91	45.00	42.80	150.99	32.98	20.70	11.81
		TS	0.11	2.95	–2.29	1.16	1.44	0.25	–1.12	–16.73	1.20	0.11	0.58	–0.89
VAL	Mean	TL	1.21	0.97	2.21	9.93	415.25	758.31	373.84	389.89	358.72	61.51	14.19	3.36
		TS	0.33	–0.24	–0.01	0.69	1.05	0.82	0.53	1.21	1.12	0.62	0.77	–4.75
	SD	TL	6.28	1.54	10.48	18.83	259.49	185.00	134.57	72.54	183.15	74.51	22.36	11.70
		TS	0.15	–0.66	–0.05	1.47	0.87	0.60	0.23	1.43	1.33	0.36	0.40	–1.85

Note: Surat (SUR); Navsari (NAV); Dang (DAN); Bharuch (BHA); Tapi (TAP); Narmada (NAR); Valsad (VAL).

a rising trend while January, March, April, May, July, September, October, November, and December all show falling trends as shown in Figure S1.

From the graph of Tapi district, it is clear that February shows no trend. In contrast, there is a rising trend in March, June, August, and December, while January, April, May, July, September, October, and November all show falling trends. From the graph of the Narmada district, it is observed that there is no trend in February and May, while June, August, and November show a rising trend. January, March, April, July, September, October, and December show falling trends as shown in Figure S2.

From the graph of the Valsad district, it is clear that there is no trend in March while a rising trend is seen in June, August, and December. In January, February, April, May, July, September, October, and November, falling trends are observed as shown in Figure S3.

5.4. Standard Deviation

From the graphical representation, it is observed that in Surat district there is no trend in February. while a rising trend is observed in Jun, July, August, and December and falling trends are observed in January, March, April, May, September, October and November. From the graphical representation, it is observed that in Navsari district there is no trend in February and May, while a rising trend is observed in June, August, and December and falling trends are observed in January, March, April, July, September, October, and November, respectively, as shown in Figure 4.

From the graphical representation, it is observed that in Dang district there is no trend in February while a rising trend is observed in June, July, August, September, and December and falling trends are observed in January, March, April, May, October, and November. From the graphical representation, it is observed that in Bharuch district there is no trend in February and April, while a rising trend is observed in March, June, July, August, November, and December and falling trends are observed in January, May, September, and October respectively as shown in Figure S4.

From the graphical representation, it is observed that in Tapi district there is no trend in February while a rising trend is observed in Jun, July, August, and December and falling trends are observed in January, March, April, May, September, October, and November, respectively. From the graphical representation, it is observed that in Narmada district there is no trend in February and March while a rising trend is observed in Jun, July, August, and December and falling trends are observed in January, March, April, May, September, October, and November, respectively, as shown in Figure S5.

From the graphical representation, it is observed that in the Valsad district, there is no trend in February while a rising trend is observed in Jun, July, August, and December and decreasing trends are observed in January, April, May, September, October, and November, respectively, as shown in Figure S6.

Figures 4, S4, S5, and S6 show the graph representation of the standard deviation in the IPTA method. Table 6 shows the overall evaluation of the standard deviation results for each station based on Figures 4, S4, S5, and S6, respectively. Based on the analysis, results reveal that each station's polygons are complex and irregular, due to invariable data, and the arithmetic mean is not constant. Data on precipitation are not uniform and isotropic at each station. At any station, not a single polygon was created. This demonstrates the instability of the precipitation data.

Statistical values of the arithmetic mean and standard deviation of seven districts are shown in Table 7. The results shown in Table 5 indicate the transition between months. In Surat district, the maximum trend length of the arithmetic means, and standard deviation is 402.44 and 184.55 mm, whereas the maximum trend slope is 2.030 and –2.13 mm. In Navsari district, the maximum trend length is 620.12 and 229.8 mm, whereas the maximum slope is –3.31 and –39.11 mm. In Dang district maximum trend length is 450.4 and 164.7 mm, whereas the maximum trend slope is –3.62 and 2.21 mm. In the Bharuch district, the maximum trend length is 272.8 and 138.03mm, whereas the maximum trend slope is 2.27 and 51.36 mm. In the Tapi district, the maximum trend length is 402.98 and 156.68 mm, whereas the maximum trend slope is 4.47 and 2.18 mm. In the Narmada district, the maximum trend length is 339.59 and 150.99 mm whereas the maximum trend slope is 9.18 and –16.73 mm. In the Valsad district, the maximum trend length is 758.31 and 259.49 mm, whereas the maximum trend slope is –4.75 and –1.85 mm respectively.

6. Conclusions

In this study, the M-K and IPTA method was used to assess the monthly precipitation data of seven districts of the South Gujarat Region (Surat, Navsari, Dang, Bharuch, Tapi, Narmada, and Valsad). The 120-year (1902 ~ 2021) monthly precipitation data was used. In this study, IPTA graphs were prepared for seven districts of the south Gujarat region. The monthly total precipitation trend length and trend slopes for each district were also determined. The M-K test was used in this study to assess the nature of the trend. IPTA gives monthly transitions between the months that can lead to deep analysis behaviours of analyzed data. M-K does not give monthly transition. IPTA does not provide any numerical value of the trend, but the M-K test provides a numerical value for the trend. IPTA gives a trend slope, but the M-K method does not give a trend slope. It gives a holistic trend. IPTA is very simple to use compared to the M-K test. For each district, the IPTA plots do not show a regular polygon; instead, they show how the precipitation data fluctuates by year. The size of trend lengths and trend slopes demonstrates the degree of month-to-month variation. For instance, the greatest trend length and slope in the Valsad district are 758.31 and 259.49 mm, respectively. These numbers demonstrate that climate change may be to blame for the changeover between the previous two months and this one. The result of M-K is quite similar to the IPTA method. The direction of the trend is the same in most cases in both methods. From the analysis, the maximum transition occurs in June and July. Based on the above analysis, it is also observed that the trend has increased in June, July, and August. The variance between months is shown by the size of trend lengths and trend slopes. In seasonal Analysis, monsoon shows maximum lengths for the arithmetic mean and standard deviation. The outcome of research work will be beneficial for numerous engineering applications including irrigation techniques, water supply, and the production of hydroelecpower.

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