

APPLICATION OF THE IPTA METHOD FOR DETECTING PRECIPITATION CHANGES UNDER A CHANGING CLIMATE A CASE STUDY APPROACH

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ABSTRACT

It is well known that hydro-meteorological variables' intensity, frequency, and variability increase irregularly under climate change. One of the most important hydrometeorological variables is precipitation. One of the best methods for assessing climate change effects on any time series is trend analysis. A new graphical technique has recently challenged the traditional trend analysis method. Precipitation data for 120 years were applied for analysis. Gujarat's Navsari District is located in the southern portion of the state and is bordered by the Valsad District borders the south, the east, and the north by the Surat District, and to the west by the Arabian Sea. The study aims to check the possibility of changes in monthly precipitation. Based on the results, IPTA determined an increasing trend for August and September precipitation. The polygon of standard deviation and mean graphs created by IPTA provides a monthly cycle, providing useful data for the study area's decision-makers and water utility sectors. As a result of the survey, it can be seen that the precipitation data varies from year to year because the IPTA graph of each station does not have a regular polygon. The findings of this study are important for assessing drought and flood risk and managing water resources sustainably in the study area.

Keywords: Trend analysis, IPTA, Graphical method, Ambica River, Precipitation

Abbreviation

IPTA Innovative Polygon Trend Analysis

IPCC Intergovernmental Panel on Climate Change INCCA Indian Network for Climate Change Assessment

MK Mann Kendall

ITTA Innovative Triangular Trend Analysis

ITA Innovative Trend Analysis
HKH Hindukush-Karakoram-Himalaya
VGTBRB Vu Gia-Thu Bon River Basin

IITM Indian Institute of Technology Madras IMD Indian Meteorological Department

HO Hydrological Observations CWC Central Water Commission

WRIS Water Resource Information System

sq.km Square Kilometer SD Standard Deviation

INTRODUCTION

Variability in hydro-meteorological variables, including precipitation, water resources, temperature, and evaporation, can be significantly impacted by climate change (Nichane and Khelil, 2015; Choukrani et al., 2018; Boutoutaou et al., 2020; Nassa et al., 2021; Mah et al., 2024). In arid and semiarid regions, the lack of precipitation presents a major risk to both people and wildlife (Mehta and Yadav, 2021a; Mehta and Yadav, 2022a; 2022b; Pastagia and Mehta, 2022). The central problem in arid places is not necessarily a lack of precipitation, but the large differences in precipitation over the period, location, intensity, and duration (Şen, 2012; Patakamuri et al., 2020; Ceribasi et al., 2021; Zeggane et al., 2021; Mehta and Yadav, 2021a; Pastagia and Mehta, 2022; Mehta and Yadav, 2022a).

Extremes of droughts, high air temperatures, strong wind speeds that cause major evapotranspiration (Chibane and Ali-Rahmani, 2015; Hamimed et al., 2017; Soro et al., 2018), and low and erratic precipitation magnitudes are all features of the semi-arid region of the country (Bouguerra and Benslimane, 2017; N'Guessan Bi et al., 2020; Benali Khodja and Ferdjouni, 2024; Koussa, 2025). One of the key factors in calculating the water balance is precipitation, and changes in precipitation trends may have an impact on the region's hydrological properties (Houichi, 2017; Smadhi et al., 2021; Bong et al., 2023). Detecting changes in hydrological time series trends helps to mitigate the effects of climate change (Hachemi and Benkhaled, 2016; Patakamuri et al., 2020; Baria and Yadav, 2021; Mehta and Yadav, 2021a; Verma et al., 2021; Pastagia and Mehta, 2022; Verma et al., 2022a; 2022b). Any change in the climate over time, whether brought on by manmade or natural factors, is referred to as climate change. IPCC (Intergovernmental Panel on Climate Change) has given particular emphasis to climate change and its wide variability caused by anthropogenic impact (IPCC, 2001). Additionally, it was stated clearly in the IPCC's fourth assessment report that the evidence for the global warming

of the climate system derives from observations of extensive melting of snow and ice, rises in global warming air and ocean temperatures (Thakur et al., 2020; Baudhanwala et al., 2024).

The 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 the 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 (Sridhara et al., 2020; Yaman and Ertuğrul, 2021).

Global warming's influence on climate change is seen everywhere in the world. Several freely accessible papers in the literature analyse long-term climate trends, including temperature rise and rainfall decline, and quantifies their effects on evapotranspiration, runoff, and groundwater recharge with statistical methods (Gaaloul, 2015; El Moukhayar et a., 2015; Bemmoussat et al., 2017; Remini, 2019; Qureshi et al., 2024), providing clear examples of global warming's regional impacts on water resources (El Fellah Idrissi et al., 2017; Aroua, 2018; Assemian et al., 2021). The studies reveal increasing drought frequency and rising temperatures over four decades, demonstrating the real-world imprint of global warming on regional climate patterns (Boubakeur, 2018; Pang and Tan, 2023).

Water is scarce in certain places, while floods have been seen in other places (Mehta and Yadav, 2022b). Climate change is intensifying the global water crisis by altering precipitation patterns, reducing freshwater availability, and exacerbating drought frequency and severity. These disruptions are especially pronounced in arid and semi-arid regions, where water scarcity is becoming a chronic challenge (Remini, 2020). In response, the adoption of non-conventional water sources, such as wastewater reuse and seawater desalination, has emerged as a strategic imperative (Aroua-Berkat and Aroua, 2022; Remini and Amitouche, 2023a; 2023b). While desalination provides a reliable supply of potable water, it must be implemented responsibly. The discharge of hypersaline brine into marine environments poses ecological risks, potentially damaging aquatic ecosystems and biodiversity (Belkacem et al., 2017; Amitouche et al., 2017). Therefore, any large-scale desalination initiative must include robust environmental safeguards to mitigate the impact of brine discharge. Similarly, wastewater reuse offers a sustainable and circular approach to water management, helping to close the loop between consumption and supply. However, its success hinges on advanced treatment technologies, public acceptance, and strict regulatory oversight. Together, these alternative solutions can help build climate-resilient water system, provided that they are deployed within a framework that prioritizes both resource security and environmental stewardship. In addition, adopting robust and transparent water governance frameworks is essential to ensuring equitable access, sustainable resource and real-smart water supply managements (Paulo Monteiro and Costa Manuel, 2004; Bahir et al., 2015; Pandey et al.,

2022), and long-term resilience against the growing pressures of water scarcity and climate variability (Ayari and Ayari, 2017). The imperative adoption of robust water laws and comprehensive policy frameworks is essential to safeguard water quality – a crucial aspect of public health, ensuring equitable access, preventing conflicts among users, and preserving aquatic ecosystems in the face of growing environmental pressures and competing demands (Faye, 2016; 2017).

The most significant and useful method used by researchers to conduct verbal analysis is the trend test (Mehta and Yadav, 2022a; Patel et al., 2023). Therefore, trend features are essential for illustrating seasonal trend behaviour. The new technique, IPTA, has been developed by Sen et al. (2019) to improve the ITA process, in particular since the identification of seasonal trends can be used to control or manage irrigation, agriculture, and water resource systems (Pastagia and Mehta, 2022; Chadee et al., 2023). They asserted that, in addition to helping to identify a trend in a particular order, the IPTA approach also produces the trend polygon, which can be used to improve verbal and numerical interpretation.

The most popular technique for detecting temporal changes in hydro climatological events is trend analysis. These analyses can be used to assess overall changes in many environmental factors (Achite et al., 2021; Pastagia and Mehta 2023). Additionally, they are crucial, particularly in arid regions where there is a high chance of droughts; therefore, understanding the behaviour of hydro-meteorological events can be applied to the management and planning of water resources. In general, non-parametric tests like the MK test or Sen's slope estimator are used in trend analysis because they are more suited than parametric tests to deal with data that is not regularly distributed (Chadee et al., 2024). The null hypothesis (H₀), which implies a serial correlation of the data, is one of the test's limitations. Numerous studies on precipitation variations around the world have suggested and used innovative trend analyses. Because of the wide use of the ITA (Azharuddin et al, 2021; Mehta et al., 2023), certain improvements of this methodology, like the ITTA (Innovative Triangular Trend Analysis) and the IPTA, have recently been proposed.

The IPTA Sen (2019) methodology, in particular, is a method that helps in determining trends within a given series as well as trends that change between succeeding portions of two equal segments from the initial hydro-meteorological time series that resulting in a trend polygon. As a result, it serves as a valuable basis for more in-depth analyses using extrapolations from a certain time series using verbal and numerical interpretations (Ceribasi et al., 2021; Azharuddin et al., 2022). Climate change caused by global warming has recently become a very important issue to be researched. Climate change affects existing water resources negatively. Examples of this climate change are the decrease in the water occupancy rate in dams, the withdrawal of lakes used as drinking water, substantially from the shore, and the complete drying of small streams. On the other hand, foods that occur due to excessive rainfall in different regions are among the effects of climate change. Therefore, studies on hydro-meteorological data should be increased, and early warning systems should be used against the negative consequences of these studies (Ceribasi et al., 2021; Shaikh et al., 2022).

A common definition of a trend can be generally directional and in the form of a steadily increasing or decreasing average tendency in a time series. Recently, the most common trend analysis methods used in academic studies are Innovative Trend Analysis (ITA), Sen's Innovation Method, Innovative Triangular Trend Analysis (ITTA), and Innovative Polygon Trend Analysis (IPTA) (Sen, 2019). The primary and fundamental goal of IPTA is to firmly build a strong and stable link between the datasets. Because this technique aids in defining the strategy during the seasonal change. Achite et al. (2021) applied precipitation trend detection at seven stations located in the Wadi Sly basin, in Algeria, for 50 years (1968-2018). They were used separately for both arithmetic mean and standard deviation and then compared with the results of trend analysis based on the Mann-Kendall test and Sen's slope estimator. Sen (2019) explained a non-parametric approach to avoid almost all these difficulties by a simple methodology, which is referred to as the Innovative Polygonal Trend Analysis (IPTA). Such an approach not only identifies the trend in a given series but also trend transitions between successive sections of the two equal segments from the original hydro-meteorological time series, leading to a trend polygon, which provides a productive basis for finer interpretation with linguistic and numerical interpretations and inferences from a given time series. Ceribasi et al. (2021) analyzed monthly average temperature data by using this two-polygon method for the period of 22 years (1996-2017). Ahmed et al. (2021) explored the changes in monthly streamflow in the Hindukush-Karakoram-Himalaya (HKH) region within Pakistan using the recently developed trend analysis method known as Innovative Polygon Trend Analysis (IPTA). They have also used the Pettitt test to check the homogeneity of the time series for 34 gauging stations. San et al. (2020) compared the IPTA and ITA with the Significance Test and Mann-Kendall (MK) methods. To achieve this, they have used monthly total rainfall trends of 15 stations in the Vu Gia-Thu Bon River Basin (VGTBRB) of Vietnam for the period 1979-2016. As a result, the current study is to project, explain, and analyze the IPTA approach as well as the variability and trends in the Ambica River's minimum, maximum, and rainfall for the years 1901–2021. The IPTA from (Sen, 2012), a recently introduced assumptions-free method to calculate trends, was used in this research to assess the patterns in rainfall across the Ambica River. This study investigated the changes in monthly and seasonal precipitation for the period of 1901-2021.

STUDY AREA AND DATA COLLECTION

Gujarat's Navsari district is located in the southern portion of the state and is bordered to the north by Surat, the east by Dang, the south by Valsad, and the west by the Arabian Sea. Navsari, Jalalpore, Gandevi, Chikli, and Bansda are the five talukas that make up its 2210.97 sq. km geographical area. The major rivers draining the district are Purna, Ambica, Kaveri, and Khapar and their tributaries (Mehta and Yadav, 2020). The district receives rainfall mainly from the Southwest monsoon, i.e., between June to October, and is about 1210 mm (Varun and Mehta, 2021).

Located between 20°31′ and 20°57′ North Latitude and 72°48′ and 73°52′ East Longitude, the Ambica is one of Gujarat's major west-flowing rivers. After running for 136 kilometers, it drains into the Arabian Sea (Mehta and Yadav 2020). It starts in the Maharashtra Saputara hill ranges. Nasik, Valsad, Dang, and Navsari district falls under the drainage area of the Ambica River. The area is situated at heights that range from 1050m to 100m. The river has a catchment area of 2715 km². lying in Gujarat and Maharashtra. In the Ambica basin, there is only one H.O. (Hydrological Observation) station of CWC (Central Water Commission) at Gadat and a total of 25 rain gauge stations. The southwest monsoon provides the majority of the rainfall to the Ambica River basin from June to September (Mehta et al. 2021b). IITM (Indian Institute of Technology Madras) has described how they select the network of rain gauge stations: A network was selected which would provide one representative station per district having a reliable record for the longest possible period (Thakur et al., 2020; Banda et al., 2021; Ramkar and Yadav, 2018). The rainfall data is collected from the Indian Meteorological Department (IMD) or Indian Water Portal & WRIS (Mehta and Yadav, 2022b; Pastagia and Mehta, 2022). The monthly precipitation data for the years 1901-2021 are collected from the India Water Resource Information System (WRIS) portal for the Navsari district.

METHODOLOGY

IPTA can be applied on several time scales (i.e., daily, monthly, annual, etc.). There are some advantages of using the IPTA method., (i) IPTA helps in spotting trends in specific sequences, (ii) IPTA results in the trend polygon, which offers a working system for more accurate verbal and numerical interpretation and trend derivation, (iii) It is possible to measure the hydrological balance over a year, (iv) It is non-parametric and unaffected by time serial dependency and (v) Assessing seasonal trends can be very useful for managing irrigation, agricultural, and water resource systems (Achite et al., 2021; Dhiwar et al., 2022). Data time scales in this method might be daily, monthly, or annual. Data will consist of monthly data over a year if the IPTA technique is used for monthly data, which is presented in matrix format (Ceribasi et al., 2021; Şan et al., 2021; Chadee et al., 2024).

X₁, X₂, X..., X_i, n are the monthly meteorological data, i is the month, and n is the year. The stated matrix is transformed into a matrix format by splitting it into two equal series at the bottom and top (Şen et al., 2019). Each data series' mean and standard deviation are computed after being divided into 2 equal parts (Ceribasi et al., 2021; Şen, 2012; Şan et al., 2021; Ahmed et al., 2022).

In this study, there are five processing steps for adopting IPTA to monthly data (Şen, 2012; Şan et al., 2021).

- (1) A monthly time series is split into two equal parts.
- (2) For each month in both 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 consecutive months with straight lines.
- (5) Calculations are carried out to determine the length and slope of the line connecting two successive locations. Using the following Eqs. (1) and (2), length and trend slope can be calculated, respectively.

$$|AB| = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$
 (1)

$$S = \frac{y_2 - x_2}{x_2 - x_1} \tag{2}$$

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

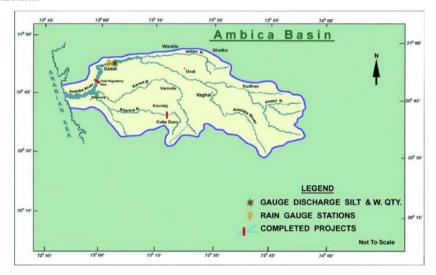


Figure 1: Study area map, Ambica River Basin (Source: www.cwc. gov.in)

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; Mehta et al., 2024; Ceribasi and Ceyhunlu, 2021). The percentage of monthly variations that contribute to the mean change in the hydro-meteorological series is large, and vice versa if the slopes of the lines connecting consecutive months are far from one another. The polygon that results shows how the hydro-meteorological series behaves over a year. The chance of occurrence of complicated Polygons is directly related to the dynamics and diversity of the hydro-meteorological event (Ceribasi et al., 2021; Tandel et al., 2023; Şen, 2012; Şan et al., 2021).

RESULTS AND DISCUSSIONS

In the present study, data on monthly average temperatures were applied to IPTA. Arithmetic means and the standard deviation data were calculated using these techniques.

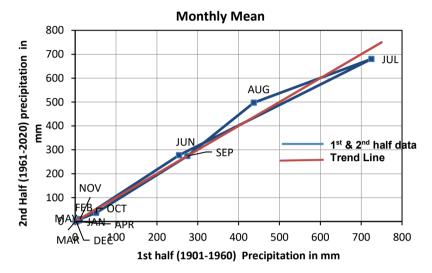


Figure 2: Graphical representation of arithmetic mean analysis for Monthly Mean Rainfall

Figs. 2 and 3 present the findings from the IPTA method's analysis of the arithmetic mean. Tables 1 and 2 provide a general assessment of the findings and statistical values related to the arithmetic mean analysis for the Ambica River. The IPTA template in Fig. 2 illustrates the arithmetic mean of the monthly Ambica River, displaying a regular polygon with three limbs indicating decreasing trends in March, July, and October, followed by a rising limb in February, August, and September. Additionally, there are transitions from increasing to decreasing areas and vice versa in the arithmetic mean as shown in Fig. 2. Green arrows indicate no trend, orange arrows represent a rising trend, and purple arrows denote a falling trend.

Table 1: General analysis of arithmetic mean results for the Monthly mean rainfall

Region	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Ambica River	—	/	_	_	 		/		→		A	-

Table 2: Statistical values of the arithmetic mean for the Monthly rainfall

	Jan	Feb	Mar	Apr	May	June
Length	1.66	0.776	1.48	7.52	367.45	619.09
Slope	0.16	-1.29	-0.34	0.62	1.11	0.85

	Jul	Aug	Sep	Oct	Nov	Dec
Length	340.70	276.21	326.61	47.06	12.24	2.55
Slope	0.63	1.37	1.07	0.65	0.76	-2.0

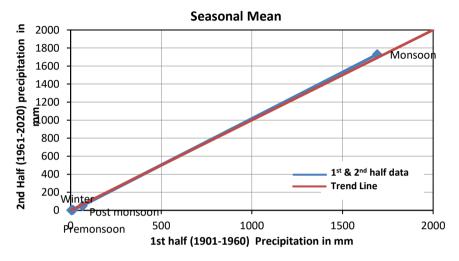


Figure 3: Graphical representation of arithmetic mean analysis for Seasonal Mean Rainfall

The IPTA template in Fig. 3 for the arithmetic mean of seasonal Ambica River has a regular polygon with three limbs, as no trends in winter, Pre-monsoon, and Postmonsoon, and then a rising limb in monsoon. There are also transitions from the increase to the decrease area and vice versa in the arithmetic mean, as in Fig. 3. Table 3 shows the general analysis of arithmetic mean results for seasonal mean rainfall. Table 4 summarizes the numerical values of these graphs. Green arrows show no trend, Orange arrows show a rising trend, and purple arrows show a falling trend.

Table 3: General analysis of arithmetic mean results for Seasonal mean rainfall

Region	Winter	Pre-Monsoon	Monsoon	Post-Monsoon
Ambica River	→			

Table 4: Statistical values of the arithmetic mean for Seasonal rainfall

	Winter	Pre-Monsoon	Monsoon	Post-Monsoon
Length	7.67	1678.96	2373.87	77.76
Slope	1.58	0.97	0.97	1.25

Figs. 2 and 3 show the outcomes of the IPTA method used on the data for the arithmetic mean. The basin does not show as a regular polygon on IPTA charts. This is because the data do not vary systematically, and the total average of the monthly total precipitation data is not constant.

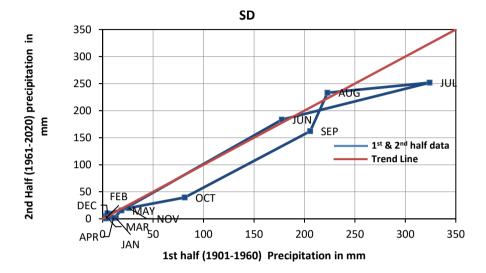


Figure 4: Graphs of the IPTA method of the Standard deviation analysis results for the Monthly Rainfall

Standard deviations have typically trended upward in June, August, November, and December. In April, when the majority of the stations showed no trends, the conditions were steadier which as shown in Fig. 4. As a result, the study of monthly precipitation standard deviation trends revealed pronounced variability typical of the Mediterranean climate. Tables 5 and 6 show a general assessment of the findings and statistical values of the standard deviation for the Ambica River. Green arrows show no trend, Orange arrows show rising trend, and purple arrows show falling trend (Achite et al., 2021; Pingale et al., 2016).

Table 5: General analysis of Standard Deviation results for each district for the Monthly rainfall

Region	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Ambica River	—	· →	·	7		~	7		→	' \	*	

Table 6: Statistical values of the Standard deviation for Monthly rainfall

	Jan	Feb	Mar	Apr	May	June
Length	10.05	4.36	8.46	15.49	231.36	161.53
Slope	0.07	-38.6	-0.4	1.71	1.05	0.46
	Jul	Aug	Sep	Oct	Nov	Dec
Length	102.87	73.03	174.59	58.78	23.35	11.99
Slope	0.18	4.12	0.98	0.35	0.47	-1.01

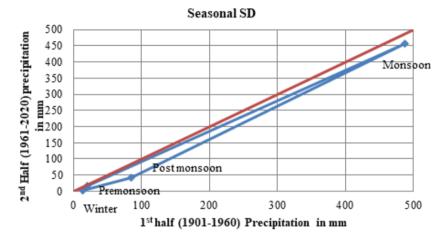


Figure 5: Graphs of the IPTA method of Standard deviation analysis results for Monthly Rainfall

Standard deviations have typically trended downward throughout all season. As a result, the study of monthly precipitation standard deviation trends revealed pronounced variability typical of the Mediterranean climate. Table 7 shows the general analysis of standard deviation results for seasonal mean rainfall. Table 8 summarizes the numerical values of these graphs. Green arrows show no trend, Orange arrows show a rising trend, and purple arrows show a falling trend.

Table 7: General analysis of Standard Deviation results for each district for Seasonal rainfall

Region	Winter	Pre-Monsoon	Monsoon	Post-Monsoon
Ambica River	1			

Table 5: Statistical values of the Standard deviation for Seasonal rainfall

	Winter	Pre-Monsoon	Monsoon	Post-Monsoon
Length	6.97	467.27	609.20	83.19
Slope	0.46	1.05	0.96	1.75

Based on the above analysis, shows that an increasing trend is observed in February, June, August, and September, and a decreasing trend are observed in the remaining 3 months. This complicated pattern of precipitation can be explained by the impact of atmospheric circulation and the basin's location in the Mediterranean, which experiences mid-latitude weather in the winter and persistent subtropical dryness in the summer (Ceribasi et al., 2021).

Tables 7 and 8 provide a general assessment of the findings of the arithmetic mean analysis for the Ambica River. The IPTA method's outcomes for the standard deviation data of the Ambica River are shown in Figs. 4 and 5. Monthly precipitation is not shown in a regular polygon in Figs. 4 and 5. This is because there is no regular change in the data, and the monthly precipitation standard deviation is not constant. However, the fact that there is just one non-regular standard deviation polygon in the seasonal analysis of the data suggests that the standard deviation of the seasonal precipitation data is stable.

Tables 2, 4, 6, and 8, respectively, provide statistical values for the arithmetic mean and standard deviation results for the Ambica river basin whereas Tables 1, 3, 5, and 7 respectively, provide the general analysis or assessment for the arithmetic mean and standard deviation results for the Ambica river basin. Results show a change in the months. The maximum values are seen as an abrupt transition between two months.

A detailed analysis of the statistical data for the arithmetic means for the Ambica River shows that the longest trend length occurs in the transition from June to July and has a maximum trend slope of 1.37. In terms of the standard deviation, the longest trend length of 231.36 mm and the largest trend slope of 4.12 were found in May-June and August-September, respectively. On a monthly scale, rainfall there is no single or regular polygon observed in ITPA graphics, which means that average rainfall data varies by year, and they don't have homogeneous and isotropic behavior. It is seen that this change increases in some stations and decreases in others.

CONCLUSIONS

In this study, monthly and seasonal precipitation data for the Ambica River basin over 120 years (1901–2021) were analyzed using the IPTA (Innovative Polygon Trend Analysis) method. This analysis included examining monthly total precipitation trend lengths and slopes across the basin. The findings reveal significant variance between months, as shown by the size of the trend lengths and trend slopes. During seasonal analysis, the monsoon season displayed the highest values for both arithmetic mean and standard deviation, indicating increased precipitation variability. The IPTA method enabled detailed monthly transitions, allowing for an in-depth understanding of the precipitation trends and variability in the region. However, the IPTA graphs did not form a regular polygon for each district, indicating uneven distribution and potential influences from local factors. The observed variability, with trends of increasing and decreasing precipitation, is likely driven by climate change, which has substantial implications for water resource management. These trends are critical for various engineering

applications, including irrigation systems, water supply planning, and hydroelectric power generation.

To mitigate the impacts of climate change, several recommendations are proposed. Regular monitoring of carbon emissions from local industrial factories should be implemented to help manage greenhouse gas levels in the study area. Public awareness campaigns can encourage the community to reduce fossil fuel usage, helping to minimize carbon footprints locally. Additionally, as industrialization and population growth expand, the development of green residential areas could help absorb greenhouse gases, contributing to improved air quality. Protecting local water resources and educating the public on efficient water use are also essential measures to lessen climate change and safeguard water availability. Applying the IPTA method to other meteorological parameters in future studies could enhance water resource planning and agricultural practices, providing valuable insights for sustainable management strategies.

Limitations and future scope of the present study

The present study employs the Innovative Polygon Trend Analysis (IPTA) method for analyzing precipitation data in a selected case study area. While the IPTA technique offers a novel approach to identifying trends in precipitation patterns, certain limitations must be acknowledged. One of the primary constraints is the reliance on historical precipitation datasets, which may contain inconsistencies due to missing or inaccurate records. Such discrepancies can influence the accuracy and reliability of the trend analysis.

Additionally, the application of the IPTA method in this study is limited to a specific geographical region, which may restrict the generalizability of the findings. Climatic variability and local topographical influences unique to the study area may not reflect broader regional or global patterns. Furthermore, the method primarily focuses on trend detection and does not account for potential causes or contributing factors behind the observed variations, such as land use changes, urbanization, or climate change impacts.

Despite these limitations, the study opens up several promising directions for future research. Expanding the application of IPTA to multiple regions with diverse climatic conditions can help validate its effectiveness and adaptability. Integrating IPTA with other statistical or machine learning techniques may enhance its analytical capabilities, allowing for deeper insights into precipitation dynamics. Moreover, coupling precipitation trend analysis with hydrological modeling can support better water resource planning and disaster risk management.

Further studies may also explore the incorporation of satellite-based precipitation data and high-resolution climate models to improve data quality and spatial coverage. Overall, the IPTA method demonstrates potential as a valuable tool in climate data analysis, and with continued refinement, it can significantly contribute to long-term hydrological and environmental assessments.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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