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RESEARCH ARTICLE

Analysis of seasonal variations and trends in rainfall patterns of the Aliyar sub-basin

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Abstract

Climate change is a major issue around worldwide caused by anthropogenic activities, leading to changes in climatic parameters such as rainfall, temperature and other hydrometeorological events. Assessing regional rainfall pattern changes is essential for effective water management and agricultural planning. Rainfall data obtained from the India Meteorological Department (IMD) dataset was analysed to determine the annual and seasonal trends from 1981 to 2023. This study investigated the trends and change point analysis of rainfall data for 43 years in the Aliyar sub-basin. The analysis was carried out by using Mann-Kendall (MK), Modified Mann-Kendall (MMK), Innovative Trend Analysis (ITA) and Innovative Polygon Trend Analysis (IPTA) methods. Pettit's test was used to assess the data homogeneity. The result showed that the mean annual rainfall of the sub-basin is 1421.65 mm, with a significant increase in rainfall pattern per year. Seasonal analysis revealed a consistent increasing trend across all seasons with the southwest monsoon season showing the major rainfall contribution in that region. A notable shift in the annual rainfall was observed in 2004, highlighting the impact of climate change. The findings give valuable insights into planning of water resource management practices and planting of short duration crops with rice-based cropping systems and controlled soil loss measures at the regional level and underscore the need for sustainable agriculture production by proper irrigation management strategies to alleviate the effects of climate change in the sub-basin.

Keywords: climate change; innovative trend analysis; rainfall; sub-basin; trend analysis

Introduction

Water resource plays a major role in developing activities and planning for effective water resource management. During the past years, aberrant weather conditions, floods and drought have been a major concern. Climate change causes variability in the frequency and pattern of hydrometeorological events driven by burning fossil fuel and large areas of deforestation (1). Rainfall is an important climate variable component of the water cycle and is closely associated with drought and flood, which can affect the supply of water, agriculture purpose and socio-economic development (2). Alteration of the rainfall events is majorly influenced by climate change (3). Greenhouse gas is released into the atmosphere due to the cause of anthropogenic activity and it is the primary cause of the increase in average surface temperature by 1.1 °C (4, 5). Continuous rising temperature trends lead to significant changes in rainfall patterns, which will continue to increase in upcoming decades and cause a high risk of water-related issues (4). Rainfall is one of the important components of the hydrological cycle, it is used for the prediction of the variation in climate change. Assessing the magnitude of the rainfall at the regional level is a challenging task, for precipitation indices are developed by researchers to identify the variation in the weather patterns due to climate change (6). Rainfall is the major climatic factor that directly affects agricultural production. Several studies also proved that climate change is the major cause of the change in rainfall patterns (7-9). A decline in rainfall was observed in many parts of the world (10). In recent years, India has been affected by significant changes in the climate, caused by abnormal temperatures and shifting rainfall patterns (11). Several studies have been conducted in India to identify the spatiotemporal variation in the rainfall at the state level and country level concerning climate change (12-15). The average amount of rainfall fell between 1951 to 2015 and the annual mean, maximum and minimum temperatures were 0.15, 0.15 and 0.13 °C (16). In India, long-term rainfall variation was observed in different parts and observed that climate change significantly affects the rainfall pattern (17). In recent decades in the northern and southern parts of India experienced a decline in rainfall events and severe drought incidents have occurred (18). Variability in climate change altered the rainfall dynamics around the globe. Observing and predicting climate change is one of the most challenging climatological tasks. Trend analysis of climatic data using long-term meteorological data is very important for climate change studies.

The Parambikulam Aliyar (PAP) basin is an important hydrological unit located in the southern part of India covering the area in Tamil Nadu and Kerala. The PAP basin comprises of four sub-basins *viz*., Aliyar, Sholaiyar, Palar, Valaiyar. In that Aliyar sub-basin region, it supports a diverse range of ecosystem and agricultural activities. The sub-basin is experiencing an average rainfall of 650 mm, which has an impact on the hydrological unit. Due to climate change, water availability and distribution are affected by the both global scale and regional scale. Therefore, the study was conducted to assess the variation in the rainfall patterns in the Aliyar sub -basin, aiming to understand the impacts of climate change and changes in the rainfall patterns for better water resource planning and management.

Material and Methods

Study area and data sources

The Aliyar sub-basin is in the southwestern part of Peninsular India covering the area in Tamil Nadu (Fig. 1). This sub-basin area lies within the coordinates of North latitude between 10°18'44" to 10°42'58" and East longitudes 76°48'37" to 77°8'8" with elevation ranging from 155 to 2504 m above mean sea level. The total area of the sub-basin is 564.54 km^2. The sub-basin predominantly covers the major areas of the Coimbatore district, with minor areas of Tiruppur district. The study area covers diverse ecosystems such as agricultural land, forest area, water bodies, human settlements and barren lands which play an important role in the hydrology of the region. The sub-basin is characterized by a semi-arid climate; it is more susceptible to climate change and makes it ideal for the study of changing rainfall patterns under climate-changing conditions. Daily rainfall data for the period 1981-2023 (43 years) was obtained from the India Meteorological Department (IMD) (19).

Descriptive statistics

Descriptive statistics include measures such as the mean, variance, standard deviation, skewness, kurtosis, minimum and maximum values of rainfall and total rainfall. The mean, or average represents the central tendency of the data. Standard deviation is a measure used to quantify the dispersion of the mean, giving indications about the variability and reliability of the rainfall pattern. The higher the standard deviation, the more volatile the rainfall has been and the opposite, the lower the deviation, the more consistent the rainfall. The skewness gives a measure of how symmetrical the data is, while kurtosis determines the sharpness or flatness of the data distribution in comparison with a normal distribution. The above-mentioned metrics allow for determining if the data has a normal distribution.

Precipitation Concentration Index (PCI)

The Precipitation Concentration Index was utilized to identify the annual and seasonal rainfall distribution. The PCI value of less than 10 represents a uniform distribution of precipitation. If the PCI value falls within 10-16, then it is considered as a moderate concentration of rainfall. In the study area, if the value lies between 16 and 20, then it would represent an irregular distribution of rainfall. A PCI value above 20 indicates a very irregular rainfall distribution in the region (20). The PCI is computed from the equation:

$$\text{PCI} = \frac{\sum_{i=1}^{12} P_i}{(\sum_{i=1}^{12} P_i)^2} \times 100 \qquad \text{Eqn. (1)}$$

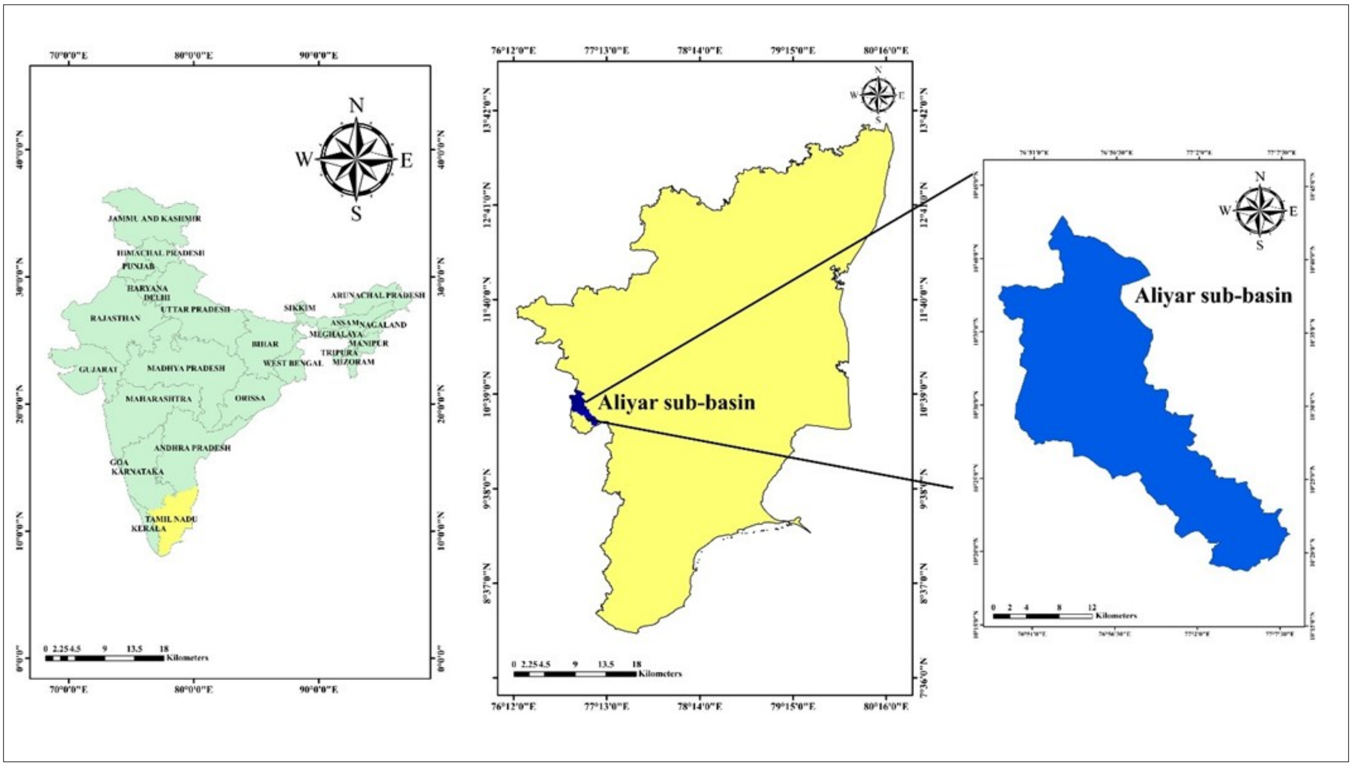

Fig. 1. Location map of the study area.

Rainfall Anomaly Index (RAI)

The Rainfall Anomaly Index (RAI), introduced by Van Rooy (1965) (21), it employs a ranking method to quantify the magnitude of positive and negative precipitation anomalies. It is calculated as:

$$\mathrm{RAI} = \pm 3\frac{\mathrm{P}-\overline{\mathrm{P}}}{\overline{\mathrm{E}}-\overline{\mathrm{P}}} \qquad \text{Eqn. (2)}$$

In this calculation, P represents the observed precipitation, $\bar{P}$ is the mean precipitation and $\bar{E}$ indicates the average of 10 extreme highest values (positive anomalies) or lowest (negative anomalies) precipitation values in the series. The RAI values are categorized into nine classes, ranging from "extremely wet" to "extremely dry" (Table 1). Positive value of RAI denotes the above normal rainfall (wet anomaly) and negative RAI indicates the below normal rainfall (dry anomaly). RAI is useful for identifying extreme hydrological events such as droughts or floods over time.

Table 1. Rainfall Anomaly Index

Ranges of values	Classification	Number of years
≤ - 3.00	Extremely dry	4
-2.00 to - 2.99	Very dry	1
-1.00 to -1.99	Moderately dry	7
-0.50 to - 0.99	Slightly dry	4
0.49 to - 0.49	Near normal	11
0.50 - 0.99	Slightly wet	2
1.00 - 1.99	Moderately wet	6
2.00 - 2.99	Very wet	4
≥3.00	Extremely wet	4

Trend analysis

Trend analysis plays an important role in hydrological studies, for effective planning and managing the water resources. The study was carried out to assess the annual and seasonal dynamics of precipitation using different nonparametric tests. The study area comprises four seasons: southwest monsoon (June-September), northeast monsoon (October-December), winter (January- February) and summer (March-May). By using R software 4.4.2 version trend analysis was carried out with the significance at 5 %.

Innovative trend analysis

Innovative trend analysis (ITA) is majorly used in hydro-meteorological studies to detect the trend proposed by (22). The first step is to categorize the hydro-metrological time series data into two equal sub-series and rank each data independently in ascending order. ITA applied to analyze the long-term time series of Aliyar sub-basin rainfall data from 1984 to 2023. ITA has the major advantage over the parametric and non-parametric tests viz., Mann-Kendall, Sen's slope test, etc. (Fig. 2). This method involves dividing the data series into two equal parts and comparing them. Data is arranged in ascending and descending order. The first subseries (x_i) is represented on the x-axis and the other sub-series (y_i) is represented on the y-axis. Data is plotted on the 1:1 line (45°) straight line on them. If data is plotted on a straight line, it indicates no trend and if data falls under a straight line, it indicates a negative trend (23, 24). Data points gathered above and below the straight line represent increasing and decreasing trends respectively. The trend slope is calculated by,

$$S = \frac{1}{n}\sum_{i=1}^{n}\frac{10\,(y-x)}{n} \qquad \text{Eqn. (3)}$$

where 'S' is the trend indicator, representing positive value indicates an increasing trend and a negative value indicates a decreasing trend. 'x' and 'y' represent the arithmetic averages of the first sub-series and second sub-subseries respectively. 'n' denotes the number of collected data points. The indicator is multiplied by 10 to facilitate comparison with Mann- Kendall (MK) test (25).

Innovative Polygon Trend Analysis

IPTA is an advanced method developed by Sen (2012) (22), which is derived from the framework of ITA. It was created to modify some limitations of the Mann-Kendall test and to extend some principles of ITA. In this case, polygons are constructed on statistical parameters such as the mean, minimum, maximum, standard deviation and skewness applied across multiple time scales. It can be analysed at the monthly scale whereby the process is dividing critical parameter values such as the mean or maximum into two equal parts that will form the base for the analysis. There are five systematic steps carried out during the IPTA test. They include;(1) Dividing the data series into two equal parts (2) Calculating the necessary statistical parameters of the data series (3) Plotting one-half of the data on the horizontal axis and the other half on the vertical axis. (4) Connecting consecutive data points with straight lines to create a polygonal structure. (5) Measuring the slope and length of each line segment, which are then used to determine the trend slope and segment lengths.

$$|AB| = \sqrt{(X_2 - X_1) + (Y_2 - Y_1)^2} \qquad \text{Eqn. (4)}$$

$$S = \frac{Y_2 - Y_1}{X_2 - X_1} \qquad \text{Eqn. (5)}$$

In the IPTA method, 'S" denotes the trend slope, while the trend length is represented as |AB|. The variables 'X_1' and 'X_2' correspond to consecutive points in the first part plotted on the horizontal axis, whereas 'Y_1' and 'Y_2' represent the equivalent points in the second part on the vertical axis. If the data point lies above the 1:1 trend line, that indicates a positive trend that is, the trend of increase and vice versa below the trend line, the negative or declining trend. This polygon form helps to picture the nature of the behaviour of time series over the year. Lines connecting two consecutive months reflect month-wise changes. In the case of steady lines, this means monthly variations exert less influence over the general average trend.

Mann-Kendall test

The Mann-Kendall test is used worldwide to investigate the time series data trend, especially in hydrological and environmental studies. This test is resistant to the influence of the outliers and does not assume any specific data distribution, this makes it suitable for the various types of trend analysis. This test identifies the occurrence of monotonic trends in time series data. Mann-Kendall test assumes two hypotheses: time series data and randomly ordered data. S statistics used in the Mann-Kendall test, it shows the positive and negative differences between data pairs.

Fig. 2. Framework for analyzing the seasonal variations and trends in rainfall patterns.

$$S = \sum_{i=1}^{n-1} \sum_{j=k+1}^{n} sign\,(x_j - x_i) \quad \text{Eqn. (6)}$$

where, x_j and x_i data points at time j and i, respectively, n' length of the time series and sign (x_j and x_i) is a function. Additionally, the distribution of S statistic is impacted by tied values in time series data and variance must be calculated as follows:

$$Var(S) = \frac{n(n+1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \quad \text{Eqn. (7)}$$

Where t_i is the number of tied values in the i^{th} tied group, m is the number of tied groups and n is the number of data points. Likewise, the test statistic (Z) is computed using the following method to determine the trend's significance.

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & if\ S > 0 \\ 0, & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & if\ S < 0 \end{cases} \quad \text{Eqn. (8)}$$

Sen's slope estimator

The Sen's slope estimator is one of the non-parametric techniques used for trend analysis, which is specially used to determine the trend's slope in time series data. It is resistant to extreme values and in the meantime, it does not require data to satisfy the specific distribution assumptions. Sen's slope estimator, which determines the slope as the median of all possible slopes between observation pairs in the dataset, was applied to assess the magnitude of rainfall trends in the study area.

$$\text{Slope } (\beta) = \text{Median } \left(\frac{x_i - x_j}{i - j}\right) \text{ for all } i > j \quad \text{Eqn. (9)}$$

Where, x_i and x_j denotes the rainfall values in years i and j, respectively.

Change point analysis

Pettitt's test is a statistical method used to identify the change point where the median of a time series data significantly shifts. It is a nonparametric test primarily used to detect abrupt changes in the mean of time series data. The change point analysis for annual and seasonal rainfall datasets was performed using R software. The test statistic (U_t,k) is calculated as follows,

$$U_{t,k} = \sum_{i=1}^{k} \sum_{j=k+1}^{n} sign\,(x_j - x_i) \quad \text{Eqn. (10)}$$

where,

x_j and x_i - data points at time j and i, respectively,

k - year in which change take place,

t - length of time series and sign (x_j - x_i) is the function that returns +1 if x >0, 0 if x = 0 and -1 if x <0.

Subsequently, the Pettitt test detects the most possible change point (K_T) as the point where the absolute value of $U_{t,m}$ is maximized.

$$K_T = \max_{1 \le k < n} |U_{t,k}| \quad \text{Eqn. (11)}$$

The significance of the change point is statistically evaluated using approximate p-value and indicates the presence of data shift when P > 0.05 or vice versa.

$$P \approx 2\exp[(-6U^2(K_T))/(n^3 + n^2)] \quad \text{Eqn. (12)}$$

Inverse distance weighted (IDW) method

The IDW method is used for tasks like spatial interpolation of temperature, air quality, rainfall, or any other continuous variable observed at multiple places in different areas, *viz.,* environmental science, geography and geostatistics. It is a well-known method in spatial interpolation, in this method by keeping the values of known locations, the unknown location values are identified (26). IDW gives weights to neighboring known data points based on their distances from the unknown location (target location). The resulting weights are used to compute the average, which estimates the value at the targeted location. The data points closer to the target location have a greater impact than the points away from the location (27). IDW is estimated by using the following equation:

$$W(x,y) = \sum_{i=1}^{N} \lambda_i \omega_i$$

$$\lambda_i = \frac{(1/d_i)^P}{\sum_{K=1}^{N}(1/d_i)^P} \quad \text{Eqn. (13)}$$

where,

W- estimated value at location (x,y)

N- no.of known locations nearby (x,y)

λ_i- weight assigned to the known values ω_i (x_i,y_i)

d_i- Euclidean distance between each point in locations (x,y) and (x_i and y_i)

P- power impacted by weight ω_i on ω

Results and Discussion

Summary of the descriptive statistics for the data

The descriptive statistical analysis of the rainfall data was conducted for the Aliyar sub-basin for the years 1981-2023 (Table 2). The annual rainfall varied from 385.75 mm to 2178.61 mm, with an average normal rainfall of 1421.65 mm. The standard deviations for each month varied between 20.62 mm and 117.49 mm. The coefficient of variation (CV) was calculated to identify the spatial pattern of interannual variability of monthly rainfall in the sub-basin. The CV varied from 45.56 % in July to 197.24 % in January. The CV of the annual rainfall over the study period was 26.88 %, indicating moderate rainfall contribution in the sub-basin. For the individual months, the CV values were highest in January and February (>150 %), indicating high rainfall variations, while months such as June to October observed relatively low CV values (<50 %), showing less rainfall variation over the years. The moderate rainfall variation was observed in April and November with variations of 63.46 % and 66.83 %, respectively. Among seasons, the southwest monsoon (SWM) dominates rainfall patterns in the sub-basin, contributing 55.67 % to the annual rainfall, but it shows moderate variation in rainfall pattern of 34.62 %. The

Table 2. Descriptive statistics of months and annual rainfall

Month	Min (mm)	Max (mm)	Mean (mm)	SD	CV	Contribution (%)
January	0.00	140.85	15.25	30.08	197.24	1.07
February	0.00	68.50	13.64	20.62	151.14	0.96
March	0.00	223.39	34.61	40.26	116.31	2.43
April	18.08	198.44	75.63	47.99	63.46	5.32
May	18.27	261.66	97.11	55.65	57.31	6.83
Jun	40.77	532.55	193.55	92.30	47.69	13.62
July	44.53	535.98	244.25	111.27	45.56	17.18
August	38.29	513.32	203.64	117.49	57.70	14.33
September	21.76	302.63	150.07	74.96	49.95	10.56
October	38.41	412.05	183.50	87.93	47.92	12.91
November	24.50	359.02	148.70	99.37	66.83	10.46
December	0.04	247.37	61.71	58.48	94.77	4.34
SWM	164.97	1474.32	791.50	273.99	34.62	55.67
NEM	126.49	751.26	393.91	170.20	43.21	27.71
Winter	0.12	141.49	28.89	36.95	127.89	2.03
Summer	63.14	438.13	207.35	91.55	44.15	14.59
Annual	385.75	2178.61	1421.65	379.33	26.68	100

SWM - South west monsoon, NEM - North east monsoon

northeast monsoon (NEM) follows, contributing 27.71 % to the annual rainfall, with a mean of 393.91 mm and a maximum of 751.26 mm. The NEM shows higher variability than the SWM, with a variation of 43.21%. As earlier this study was confirmed in previous literature (28). Southwest monsoon and month of September recorded the major contributor month of rainfall in Bengaluru. Winter rainfall, while minimal at 2.03 % of the total, averages 28.89 mm with a peak of 141.49 mm and exhibits the highest variability among seasons. The summer season accounts for 14.59 % of the annual rainfall, with a mean of 207.35 mm and a peak of 438.13 mm, demonstrating moderate variation in rainfall (44.15 %). Annually, the sub-basin receives an average rainfall of 1,421.65 mm, with significant inter-annual variability as indicated by a standard deviation of 379.33 mm. The maximum annual rainfall of 2,178.61 mm highlights the occurrence of wet years, while the minimum of 385.75 mm underscores periods of drought. The SWM is the major contributor to the annual rainfall. In Tamil Nadu's Western Agro-climatic zone, South West Monsoon and North East Monsoon contributed significantly to annual rainfall, with high dependability status indicated by the appropriate coefficient of variation levels (29, 30). In contrast, the limited and high variation in rainfall patterns in the winter season makes necessary action for supplemental irrigation for crops, while summer rainfall can support short-duration crops or early sowing with proper water budgeting. These variations emphasize the region's vulnerability to climate extremes and highlight the need for effective water resource management and adaptive strategies to mitigate the impacts of rainfall variability on agriculture and water availability.

Precipitation Concentration Index (PCI)

Precipitation Concentration Index analysis shows that nearly 7 % of the years (eg.1984, 2005 and 2021) had equally distributed precipitation (PCI <10) (Fig. 3). Based on the classification (Oliver, 1980) about 70 % of the years fall in the category, 1981, 1986, 1993 and 2013 with a moderate concentration of rainfall (PCI between 10 and 16), which means that in those years, the amount of rainfall received was relatively the same, only a slight variation was seen over the years. In addition, 20 % of the years (e.g., 1991, 1999, 2019) were marked by an uneven distribution of rainfall (PCI between 16 and 20), which clearly shows that the sub-basin receives strong rainfall concentration in fewer months. Finally, approximately 3 % of the years (e.g., 2019) had a very uneven distribution of rainfall (PCI > 20), which indicates extreme variations in precipitation, caused by the changing climatic conditions. Mohamed et al. (2022) (31) reported that 89.9 % of the rainfall pattern of Upper Blue Nile basin shows the irregular to strongly irregular distribution rainfall pattern. Tropical cyclones are formed during the pre-monsoon and post-monsoon season the North Indian Ocean; the major intensity of the rainfall was observed during the Southwest Monsoon season (32). These findings show that the sub-basin mostly experiences a moderate rainfall distribution, with irregular instances of uniform or unequal distribution.

Rainfall Anomaly Index (RAI)

The Rainfall Anomaly Index (RAI) analysis is also shows that the annual variability of rainfall is highly variable (Fig. 4). Extremely dry years (drought years) were recorded in 2001, 2002 and 2003, while very dry years (below average rainfall) were recorded in 1995 and 2016. Moderately dry years were recorded

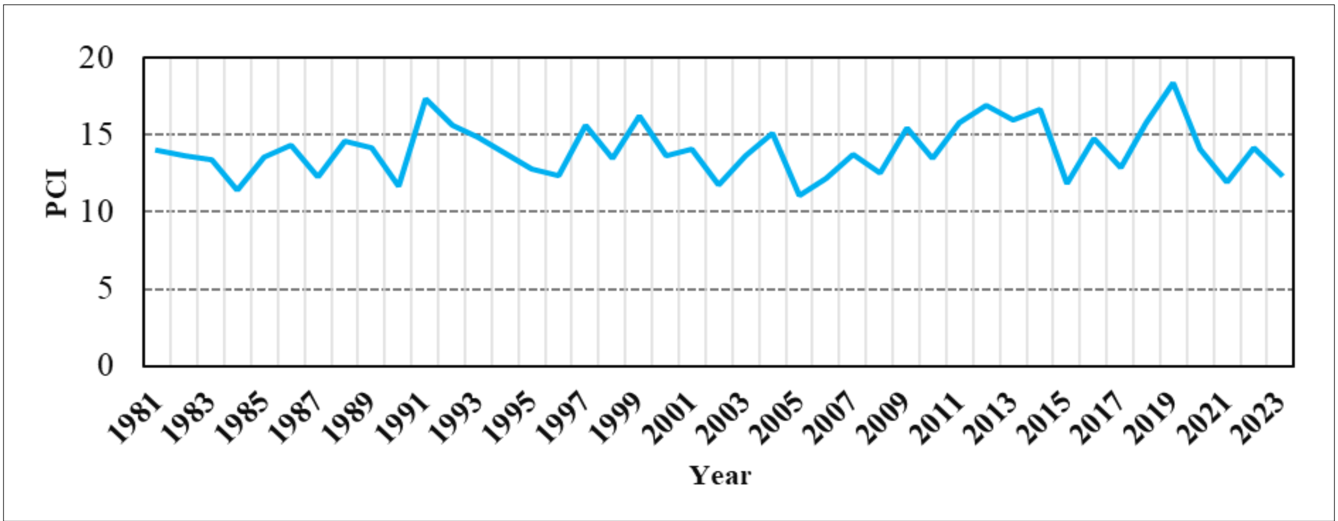

Fig. 3. Precipitation Concentration Index (PCI) for the Aliyar sub-basin (1981-2023).

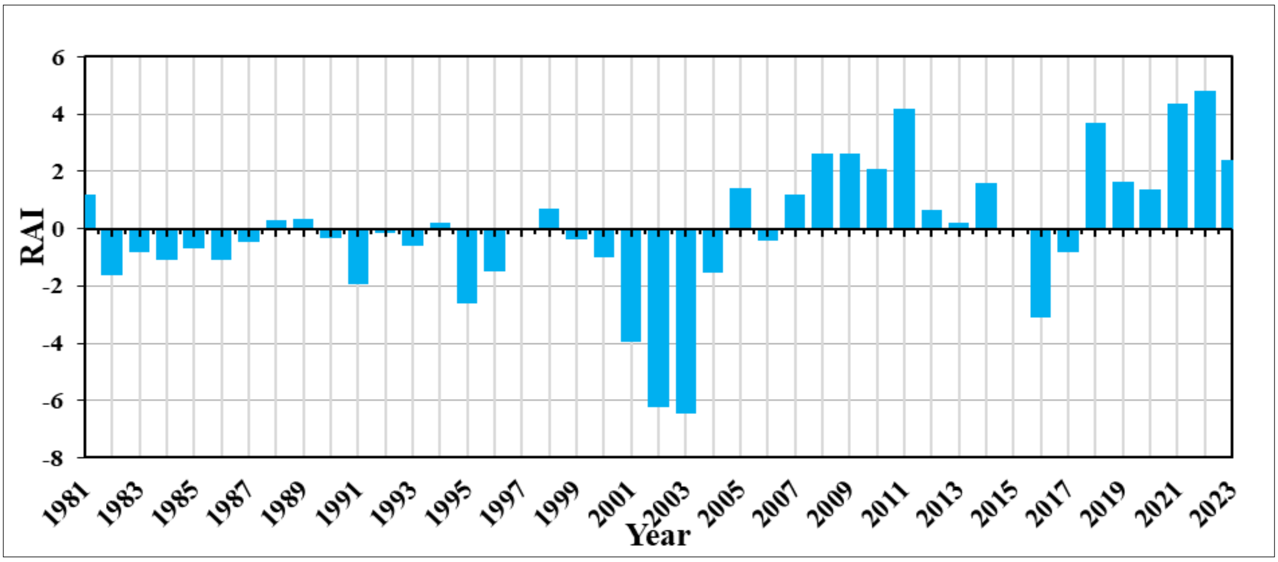

Fig. 4. Rainfall Anomaly Index (RAI) for the Aliyar sub-basin (1981-2023).

in 1982, 1984, 1991, 1996 and 2004, indicates that deficit in rainfall over the years and slightly dry years were recorded in 1983, 1985, 1987, 1990 and 2017, represents that sub-basin experiences slightly lower than average rainfall. Near-normal years were relatively frequent and were recorded in 1988, 1989, 1993 and 2013, those years receives the rainfall within normal range. Slightly wet years were recorded in 1998 and 2012 this year receives rainfall above average, while moderately wet years were recorded in 1981, 2005, 2007, 2014, 2019 and 2020, which receives moderate surplus rainfall in the years. Very wet years indicate that sub-basin received above average rainfall in the years was recorded in 2008, 2009and 2010. Extremely wet years have be endominant in the last few years, including 2011, 2018, 2021 and 2022,showinganincreasein extreme wet conditions in recent decades in the study area, possible for sudden downpour leads to flooding. The Rainfall Anomaly Index (RAI) analysis highlights significant annual rainfall variability in the study area. Dry conditions were frequent in the past, with extremely dry years (2001-2003) and very dry years (1995, 2016) observed. Near-normal years were relatively common, while wet conditions have become more prevalent in recent decades. Extremely wet years, including 2011, 2018, 2021 and 2022 indicate an increasing trend of extreme wet conditions. The extreme RAI over the years is the influence of the Sea Surface Temperature deviation, which favours the low and high rainfall pattern in the basin and confirming that the Pacific and Atlantic Ocean are the major influences of the regulation of the extreme weather changes in the region (33). These findings emphasize the growing variability in rainfall patterns and the need for proactive measures to manage the risks associated with both dry and wet extremes.

Trend analysis

The innovative trend analysis (ITA) and innovative polygon trend analysis (IPTA) techniques on seasonal and annual rainfall times series of the Aliyar sub-basin was used for analysis (Table 3). It is most important to know the impact of climate change over the sub-basin area; it gives an idea about the distribution of the rainfall pattern. The ITA plots are grouped into three types: low, medium and high. The NEM, SWM, Summer and Annual rainfall shows positive trends, whereas the winter rainfall is a negative trend in low regimes (Fig. 5). The medium regime was reported in summer with a positive trend. The high rainfall regime was observed in SWM and annual rainfall with a positive trend. No trend is observed in both annual and seasonal rainfall patterns. The results showed that a seasonal negative trend was observed in winter in low regimes. The IPTA polygon of the mean seasonal values shows significant variations in both distance and slope parameters during 1981-2023. The Winter and NEM season shows no variation during the study period in the sub-basin, which denotes that this season experiences a shortage of water due to elevated temperatures, higher evaporation rates and lowered groundwater recharge. However, the SWM and Summer show a moderate variation and an increased trend, which indicates the increased rainfall pattern in the sub-basin. Effective water management practices and conservation measures are carried out during this season to keep the water source for the next season of cropping. Winter shows no trends and NEM shows slight deviation from the trend line, effective water management practices were followed to overcome the water-scarce conditions.

Table 3. Innovative trend analysis of seasonal and annual rainfall over Aliyar sub-basin

Season	Low	Medium	High
SWM	O	O	↑
NEM	↑	O	O
Winter	↓	O	O
Summer	O	↑	O
Annual	O	O	↑

↑ - Raising trend, ↓ - Falling trend, O - no trend

Temporal analysis of rainfall trends

Table 4 shows the results of trend analysis for seasonal and annual rainfall patterns in the Aliyar sub-basin over 43 years, from 1981-2023. The MK test and SS estimator were applied to identify the magnitude of the trend at 5 % level of significance. There observed an upward tendency during the annual, southwest monsoon and summer rainfall. The MK test and SS estimator outcomes for rainfall reveal a significantly increasing trend observed for annual (Z= 0.339), SWM (Z=0.218) and summer (Z=0.224) at a 0.05 % level of significance with an

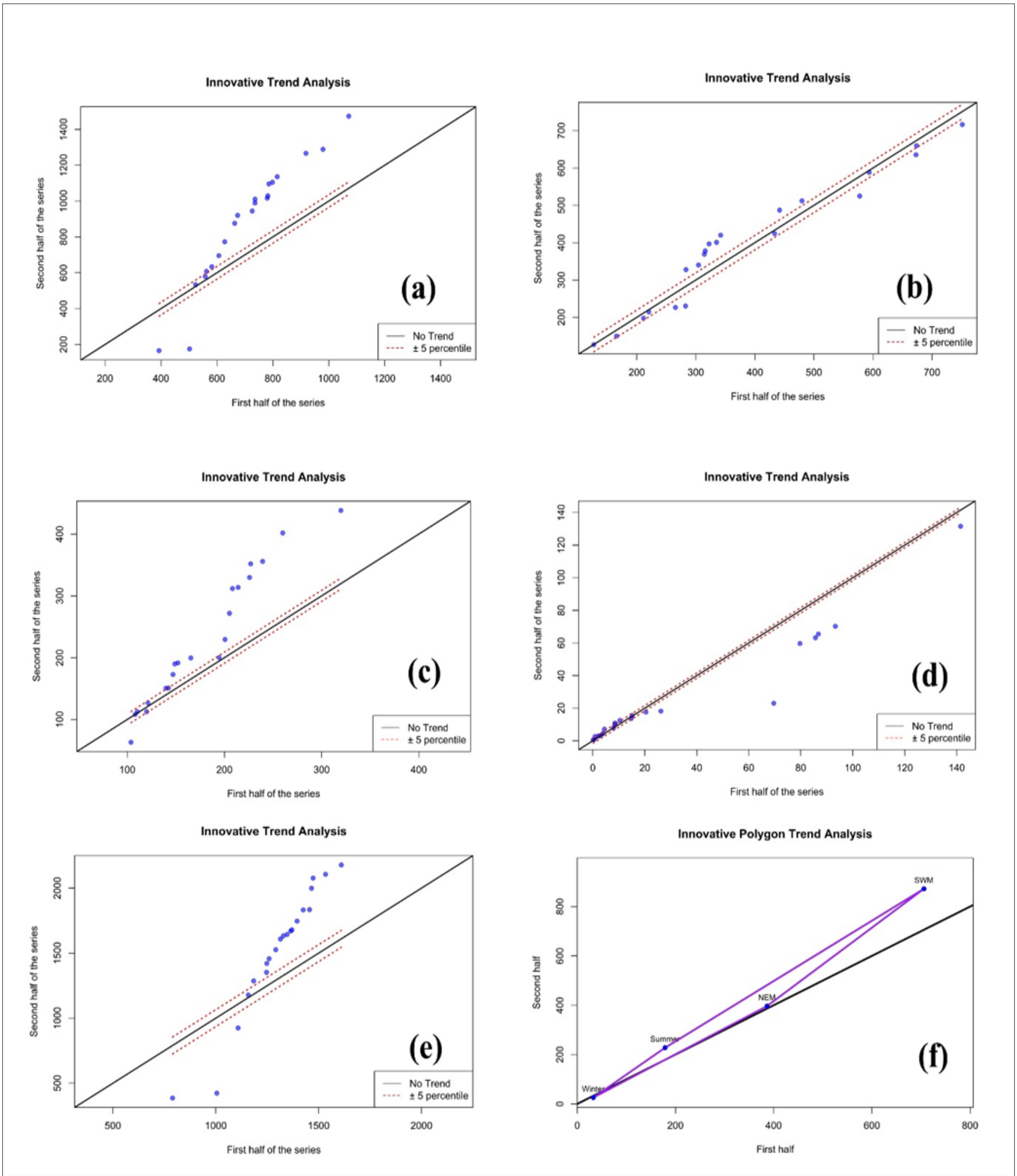

Fig. 5. ITA (a) Southwest monsoon (b) Northeast monsoon (c) Winter (d) Summer (e) Annual and IPTA (f) Seasonal.

Table 4. Trend analysis results of seasonal and annual rainfall in Aliyar sub-basin (1981-2023) at 5 % level of significance

Season	MK test (*Z*)	Sen's slope (*Q*)	*p*- value	Trend
SWM	0.218	7.273	0.040	Increasing
NEM	0.096	2.033	0.368	No trend
Winter	0.029	0.033	0.785	No trend
Summer	0.224	2.325	0.034	Increasing
Annual	0.339	12.578	0.001	Increasing

annual magnitude of 12.577 mm, 7.273 mm and 2.325 mm respectively. The *p* values of SWM and annual is about 0.040 and 0.001, respectively.

The positive trend in the annual rainfall pattern suggests that the Aliyar sub-basin may be experiencing an increase in overall rainfall patterns due to the major contribution of rainfall during SWM and summer season, which could help plan agriculture and water-dependent activities. The southwest monsoon season is the major contributor of rainfall in the sub-basin region. No trend was observed during the northwest monsoon season and winter season with a magnitude of 2.033 and 0.033 mm. This indicated a stable rainfall pattern throughout the study period. NEM and winter seasons are not influenced due to climate change. After the southwest monsoon and summer season, the rainfall pattern was constant. During this period, the groundwater recharge operation and water conserving measures are taken to use the water effectively. Monsoons are influenced by various factors, including sea surface temperatures, atmospheric circulation and land-sea temperature (34). The pre-monsoon may increase due to variations in sea surface temperature and ocean currents, caused by the El Nino-Southern Oscillation (ENSO) (35).

Table 5. Comparative trend analysis of precipitation between M-K test, SS estimator and ITA

Season	MK	SS	ITA
SWM	Increasing	Increasing	Increasing
NEM	No Trend	No Trend	No Trend
Winter	No Trend	No Trend	Decreasing
Summer	Increasing	Increasing	Increasing
Annual	Increasing	Increasing	Increasing

Comparative analysis of rainfall between MK test, SS estimator and ITA method

In this research, trends in annual and seasonal time series of precipitation are obtained by employing the MK test and SS estimator and compared with the ITA method. Table 5 shows the comparative trend analysis of rainfall results between the three methods. By comparing results among these methods, it is observed that annual rainfall for all three methods (MK test, SS estimator and ITA) shows an increasing trend. Also, SWM and winter seasons are observed with an increasing trend in all three methods. The results were found to be similar with earlier findings (35). Moreover, the NEM reveals no trend in all three methods. Winter season recorded no trend in the two methods (MK test and SS estimator), but in the ITA method winter season shows a decreasing trend.

Change point analysis

A changing point shows that there is a significant shift in the data and results in a prolonged alteration in distribution. Changes in annual and seasonal trends in rainfall records for the Aliyar sub-basin were detected using Pettitt's test. It is used to identify the trends and from which year the shift begins. Graphical representation of annual and seasonal rainfall records is acquired by performing Pettitt's test are presented in (Fig. 6). The change point for the NEM, SWM, summer, winter and annual were 2003, 2004, 2006, 2013. Significant changes

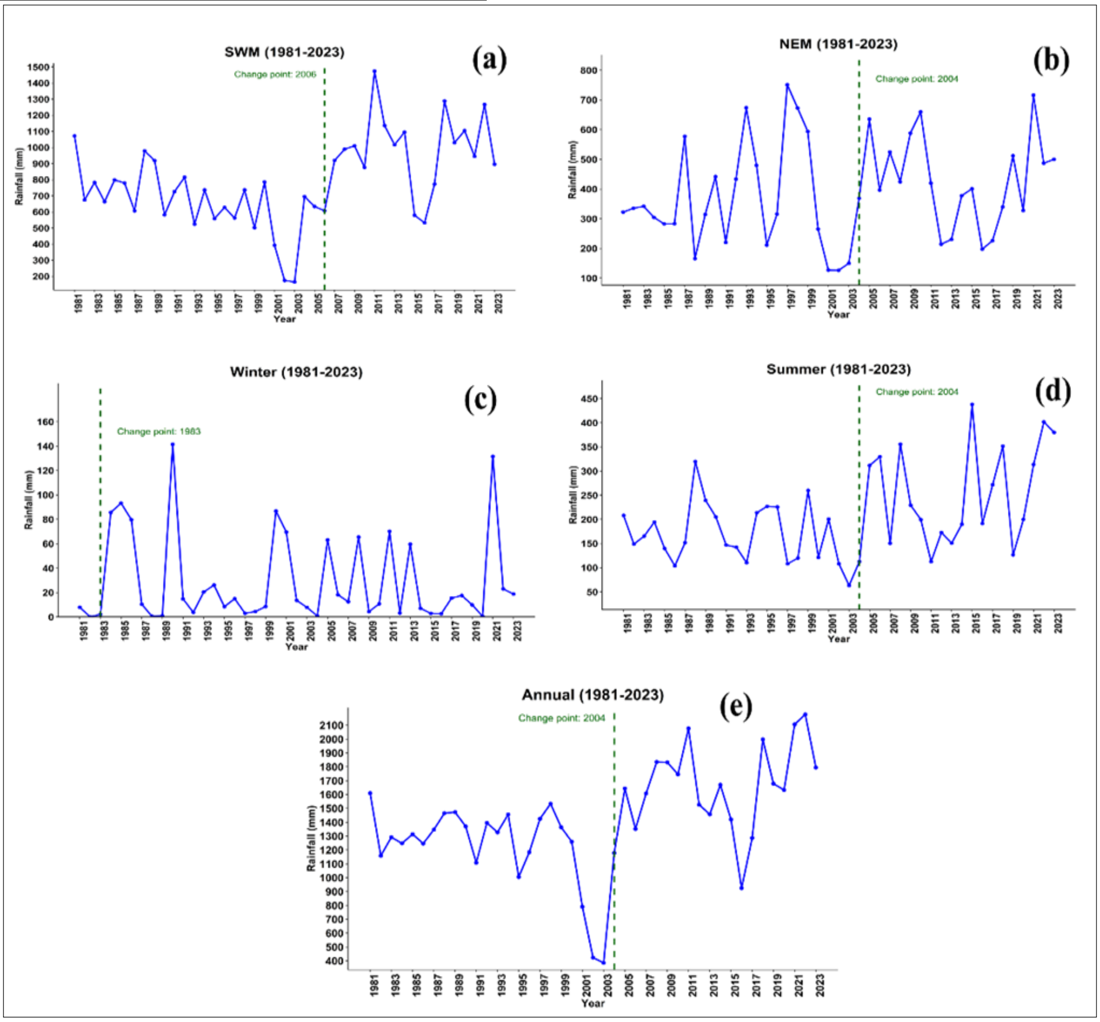

Fig. 6. Change Point Analysis (a) Southwest monsoon (b) Northeast monsoon (c) Winter (d) Summer (e) Annual.

were observed in 2013 (May), 2006 (July, SWM), 2003 (September) and 2004 (summer, annual), indicating significant changes in rainfall patterns during these months. Significant changes in rainfall were found in July. Likewise, a significant change in August and November was observed in previous scientific studies (36, 37). In contrast, no significant changes were found in seasons like January, February, March, April, June, October, November, Winter and Northeast Monsoon (2003-2004), showing that stable rainfall pattern across the sub-basin during these months. The results suggest that while some years experienced noticeable changes in specific periods (e.g., 2006 for July and SWM, 2004 for annual and summer), other seasons did not show any statistically significant shifts. On an annual scale, a significant change point was detected in 2004, showing a major shift in overall rainfall patterns. This shift is due to the major contribution of rainfall in the monsoon periods. Similarly, during the summer season shows significant change in rainfall pattern was observed, so it may require proper cropping pattern strategies in the sub-basin to avoid flooding and crop damage. On the contrary, stable rainfall patterns occur in seasons like NEM and winter, giving better decisions for consistent crop planning during that season over the years. Similar studies were done which provides relevant methodology like the Aliyar sub-basin analysis (38, 26). Previous study found that minimal rainfall shifts but significant post 1900's warming trends in urban areas of southwest Iran, aligning with the Aliyar study's observation of limited rainfall change points (38). Kumar et al. (2023) analysed 115 years of rainfall in the Kosi River Basin, identified monsoon change points linked to ENSO and elevation like Aliyar's station specific shifts (e.g. 2004 annual, 2006 southwest monsoon rainfall) (26). The analysis's outcome highlights the fact that change points are not uniform for all seasons; some periods exhibit more remarkable variability than others, necessitating season-specific water and crop management interventions.

Inverse distance weighted (IDW) method

The IDW method is a key interpolation component used in the spatial change analysis. The IDW maps given in (Fig. 7-10), respectively, show the spatial distribution of seasonal and monthly rainfall in the Aliyar sub-basin. It gives valuable insights into rainfall's geographical and temporal shifts in the sub-basin. The analysis shows the region receiving less than 25 mm rainfall was increased after the year 2004 in the sub-basin. This study found an increasing rainfall trend during the monsoon season. Additionally, the sub-basin received over 1000 mm of rainfall during the monsoon season and declined after the monsoon season, with the declining maximum average rainfall from 1623 mm to 1311 mm after the year 2004. In terms of monthly rainfall, January months shows a declining trend, with areas receiving more than 20 mm of rainfall get decreased and the regions receiving 5 mm of rainfall is expanded. However, February, March and April month observed an increasing rainfall pattern, with increasing rainfall receiving area of above 5 mm. During the SWM season, significant change in the rainfall pattern, in June month the area receives rainfall of about 50-100 mm is witnessed as a decreased, thereby expanding the area receives rainfall of about 100 mm to 200 mm. The maximum average rainfall declines from 204 mm to 186 mm. Similarly, July and August month observe that decline in the average rainfall of about 400 mm from the year (1981-2023). Likewise, September and December month showed decreasing rainfall patterns, in September rainfall receiving areas of about 200 mm reduced thereby increasing the area receiving less than 100 mm of rainfall. Similar patterns were observed in October, November and December, where during this period the sub-basin receives a low amount of rainfall. December month predominantly receives rainfall of less than 5 mm during the NEM monsoon periods. During the SEM monsoon season, the area that receives rainfall above 400 mm is encountered in July and August, while the area receiving less than 300 mm has increased over the years in the sub-basin. The frequency of the rainfall pattern is reduced and causes an increase in area of below 300 mm rainfall. It was confirmed in the previous research studies that the southwest monsoon (SWM) is the major contributor to annual rainfall (39). In the winter season, the area receiving 25 mm of rainfall getting expanded, while the rainfall range of about 50 mm in receiving areas was reduced. The cropping pattern is modified according to the rainfall trend in winter in the sub-basin, due to the low amount of rainfall received during this season. Annual rainfall shows a significant change in the rainfall pattern. Region receiving rainfall less than 1000 mm expanded after 2004. Simultaneously, a significant reduction in the annual rainfall pattern in the sub-basin with areas of receiving rainfall more than 1250 mm. The considerable change in the annual rainfall pattern caused the decline in the maximum average annual rainfall, which reduced from 1769 mm (1981-2004) to 1401 mm after 2004.

The study findings on rainfall variability gives an idea for developing climate-resilient agriculture strategies in the Aliyar sub-basin. The increase in southwest monsoon rainfall after 2006 suggests the farmers to adopt system of rice intensification during June-September period. By adopting this approach would maximize yields from the sudden downpour of rainfall and minimizing the risk of waterlogging in the rice field. Short-duration rice varieties should replace long duration rice cultivars to accommodate variable monsoon onsets. After 2004, PCI is more than 15, it indicates that irregular occurrence of the wet and dry spells, for that planning of intercropping drought tolerant millets with pulses, along with the organic mulches can overcome the wet and dry spell effects. Additionally rising in summer rainfall (+2.3 mm/year) creates the opportunities for growing the short-duration varieties such as green gram between March and May. Meanwhile, the average low winter rainfall (28.9 mm) indicates the need for micro-irrigation systems for perennial horticultural crops. Due to the drastic climate changes in rainfall patterns, traditional farming methods followed by the farmers is no longer effective, to overcome this farmer need to adjust their farming techniques with these new changing climatic conditions.

Conclusion

The present study evaluated the trends of annual and seasonal rainfall patterns in the Aliyar sub-basin over 43 years and gave critical insights into sub-basin hydroclimatic dynamics. The findings show an increasing trend in both annual and seasonal rainfall patterns. The southwest monsoon is the major contributor to the annual rainfall pattern, resulting in excess

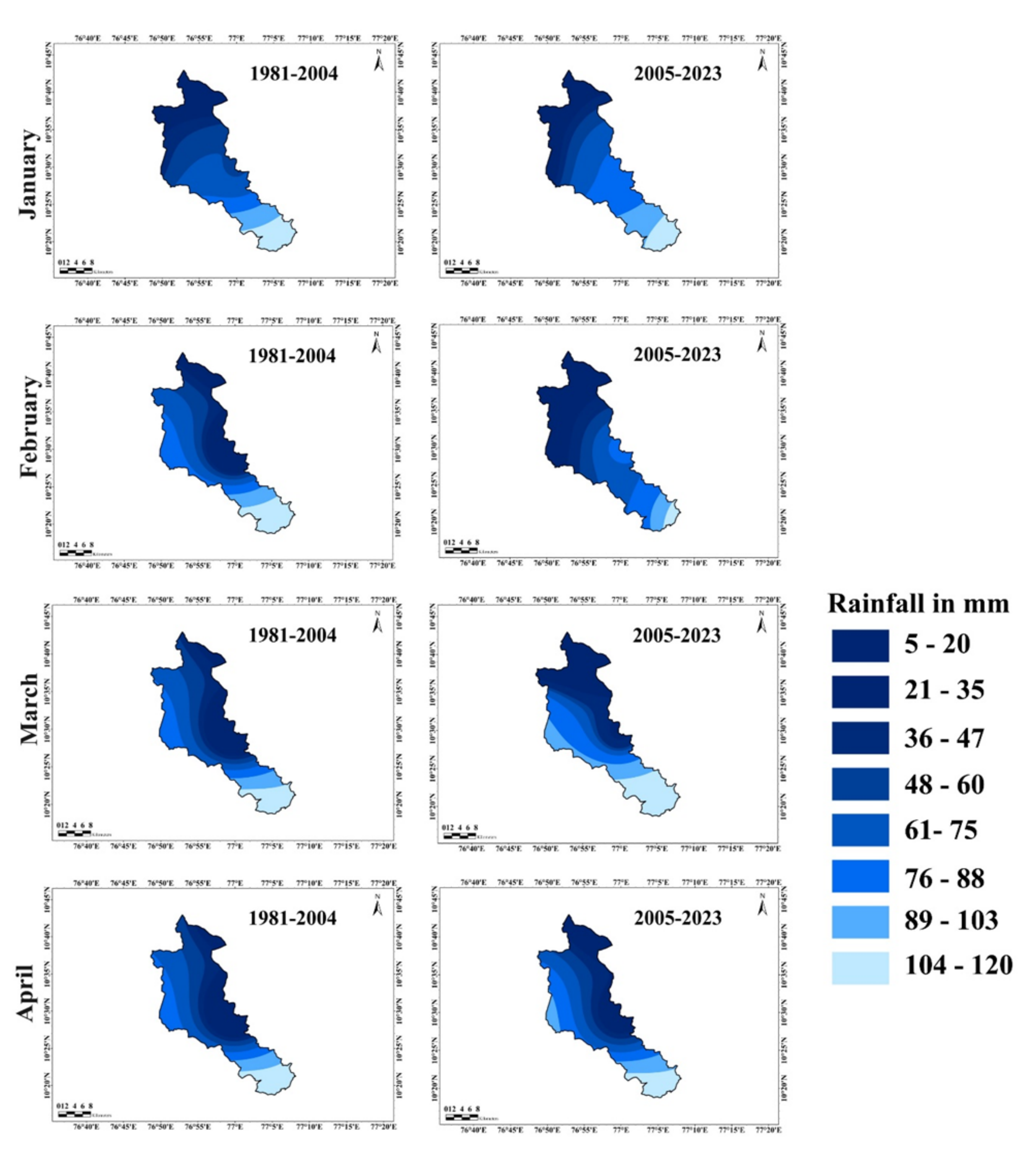

Fig. 7. Monthly (January - April) rainfall distribution in the Aliyar sub-basin.

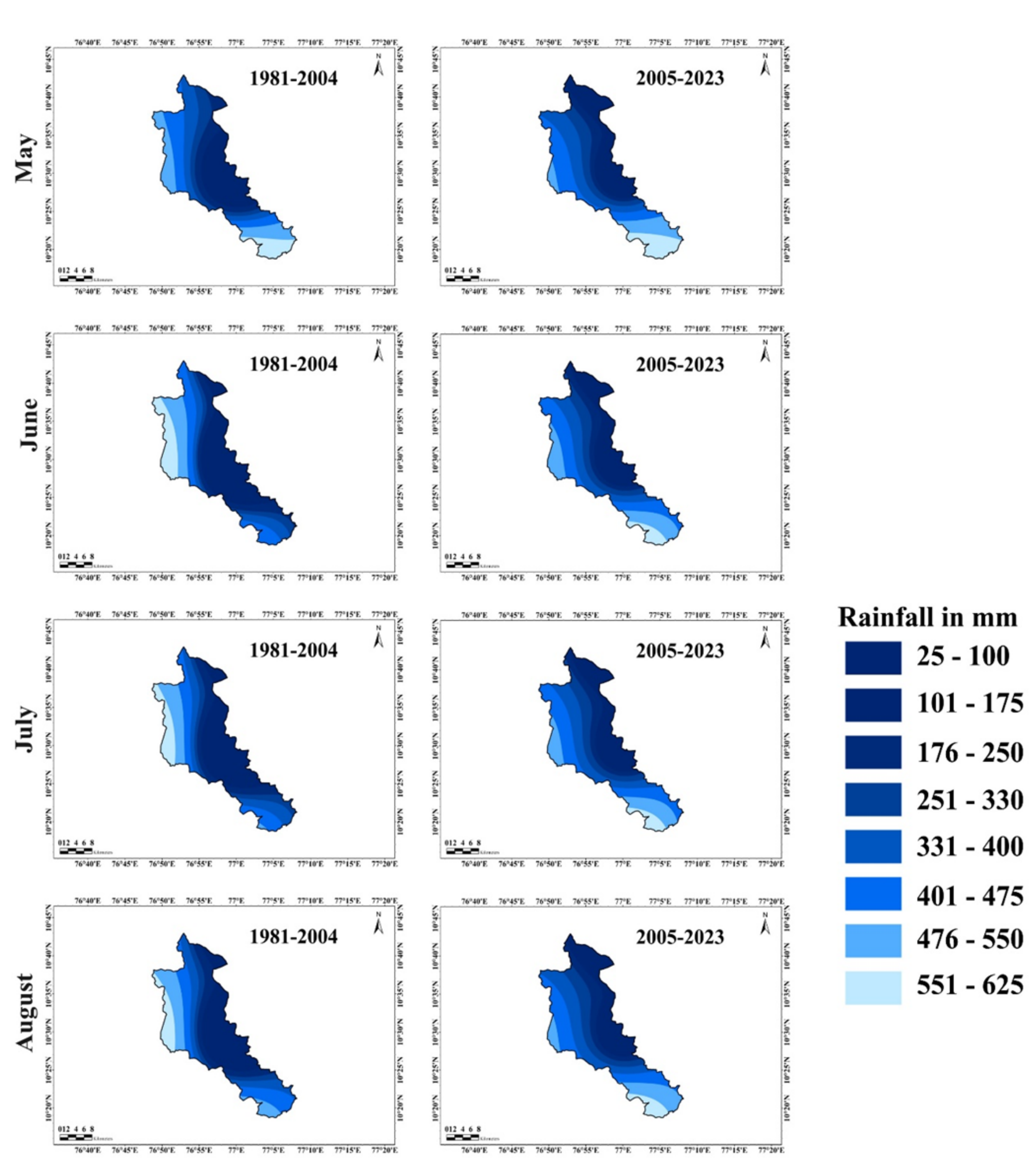

Fig. 8. Monthly (May-August) rainfall distribution in the Aliyar sub-basin.

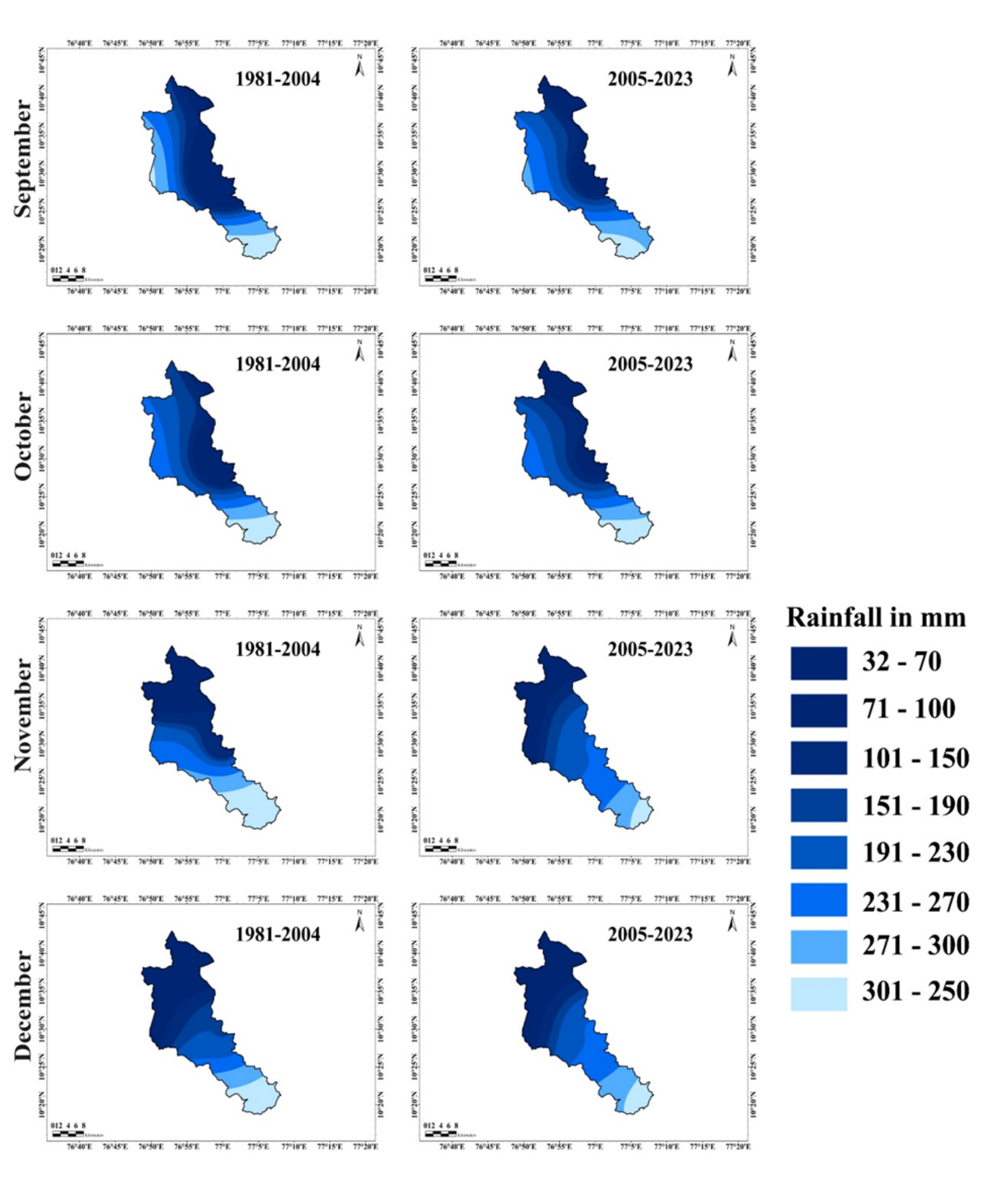

Fig. 9. Monthly (September-December) rainfall distribution in the Aliyar sub-basin.

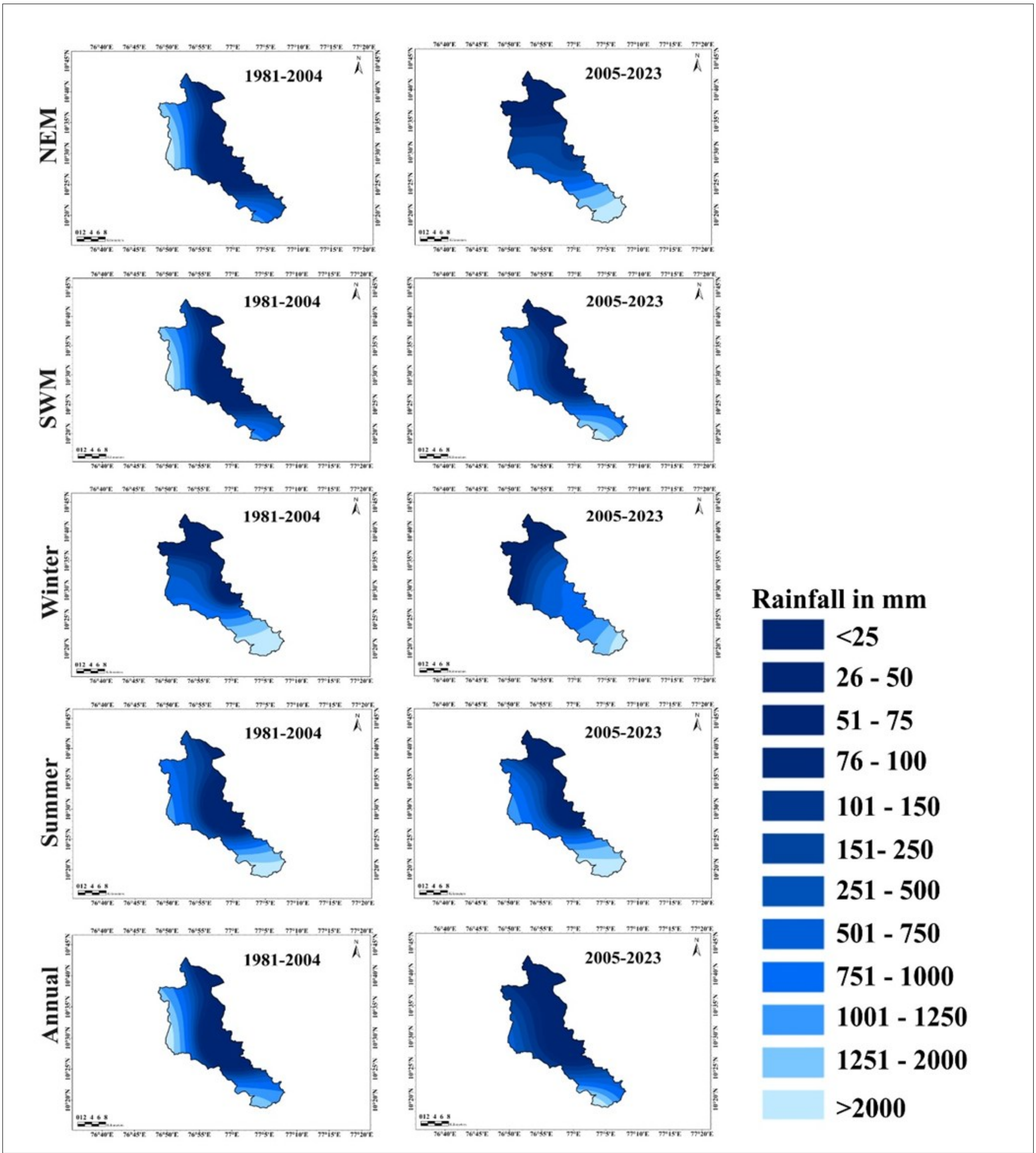

Fig. 10. Seasonal and Annual rainfall distribution in the Aliyar sub-basin.

water availability during the season and poses significant implications for water resource management. The positive rainfall trends have a significant implication for agricultural productivity, water availability and overall ecological balance within the Aliyar sub-basin. The high rainfall occurred during the southwest monsoon season are indicated by the relatively higher PCI values over the years, the increased rainfall is due to the major association of cyclone in the Indian Ocean. The trend detections like MK, ITA and IPTA are used for the analysis of the rainfall variable and it shows a positive trend over the study period (1981 - 2023). A change point was applied to detect the rainfall pattern change. The change points for Annual, SWM, NEM, Winter and Summer were 2004, 2006, 2004, 1983 and 2004 respectively. The ITA and IPTA were used to find out the transition of the rainfall pattern from one area to another area, identified by slopes and trends, SWM and summer seasons show the variation in the trend line and receive the high rainfall volumes compared to the other seasons like Winter and NEM, which shows no trend line variation. Furthermore, the study findings pave the way for the proper planning of the water management strategies like rainwater harvesting structures, proper drainage systems and establishing ground water recharge units, which helpful under the dry periods with deficit rainfall conditions. The planning of short duration crops pulses with rice-based cropping systems. Soil erosion control measures like cover crops, contour farming is adopted to limit the soil loss under high rainfall intensity conditions. By adopting these measures, farmers in the Aliyar sub-basin can ensure the sustainable agricultural productivity, effective water management and adapting the farming practices under the changing climatic conditions in the region.

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Authors' contributions

AKM and RM participated in conceptualization and wrote the original draft of the paper. RM supervised and wrote carried out the review part. SP, SS, RS and KR reviewed the contents and edited the manuscript. SS carried out the statistical analysis part. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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