



ASSESSMENT OF HISTORICAL METROLOGICAL DROUGHT AND RAINFALL VARIABILITY OVER NASHIK DISTRICT MAHARASHTRA, INDIA

AHER M.C.

Assistant Professor, Civil Engineering Department, Maratha Vidya Prasarak Samaj's
Karmaveer Advocate Baburao Ganpatrao Thakare College of Engineering, Nashik,
Maharashtra, 422013, India

(*) *madhura.aher@gmail.com*

Research Article – Available at <http://larhyss.net/ojs/index.php/larhyss/index>
Received September 27, 2025, Received in revised form July 23, 2026, Accepted July 27, 2026

ABSTRACT

The long-term spatio-temporal variation in rainfall pattern significantly affects the socio-economical activities. Specially, the developing country like India, having agriculturally based economy demands a great concern about the intensity and magnitude of rainfall. Study of historical trends and variability in rainfall provides vital information about the changing climate over particular area. Additionally, changes in rainfall pattern also creates the drought situations. Maharashtra state is one of the semi-arid region in India. In this region agriculture activities are highly depending on the Monsoon (June-September) rainfall. Present study aims to assess the metrological drought characteristics using Standardised Precipitation Index (SPI), Rainfall Anomaly Index (RAI), Percentage Departure and Rainfall Variability Index (RVI). Trend analysis is carried out using Innovative Trend Analysis (ITA) technique. The monthly, seasonal and annual rainfall data was used for period of 100 years. Decreasing trend in medium and high rainfall regime is observed at seasonal and annual. Nashik district experiences mild, moderate and severe metrological drought for 34, 7 and 8 times respectively. Five Severe droughts were observed in first two decades i.e., from 1901- 1910 and 1911- 1920. The results of the study will help policy makers to minimize the impact of drought in coming future.

Keywords: Nashik district, rainfall, Standardised Precipitation Index, Innovative Trend Analysis, Rainfall Anomaly Index, Rainfall Variability Index.

Abbreviation

SPI Standardised Precipitation Index

RAI Rainfall Anomaly Index

RVI	Rainfall Variability Index
ITA	Innovative Trend Analysis
PDSI	Palmer Drought Severity Index
MK	Mann-Kendall
IMD	India Metrological Department
WMO	World Metrological Organization
IPCC	Inter-panel Government on Climate Change
GRB	Godavari River Basin
CMI	Crop Moisture Index

INTRODUCTION

Climate variability and climate change have become major challenges for the sustainable management of water resources, particularly in regions where water availability is strongly controlled by the temporal and spatial distribution of precipitation. Rainfall constitutes the principal climatic input to the hydrological cycle and controls, either directly or indirectly, surface runoff, groundwater recharge, reservoir inflows, soil-moisture availability and agricultural production. Consequently, changes in rainfall amount, timing, frequency and spatial distribution can profoundly alter the hydrological functioning of watersheds and the reliability of available water resources. Numerous studies published in *Larhyss Journal* have emphasized the importance of investigating rainfall variability and its hydrological consequences at different spatial and temporal scales (Abdi and Meddi, 2015; Adja et al., 2021; Djellouli et al., 2015; Lazri et al., 2007; Zeggane et al., 2021). Long-term rainfall records are therefore particularly valuable because they make it possible to distinguish persistent hydroclimatic tendencies from short-term fluctuations and to identify changes that may progressively increase the vulnerability of water-resource systems.

This issue becomes particularly critical in arid and semi-arid environments, where rainfall is inherently irregular and water resources are exposed simultaneously to climatic variability, increasing demand and anthropogenic pressure. Studies conducted under different hydroclimatic settings have demonstrated that climatic fluctuations may influence groundwater recharge, runoff generation, aquifer conditions, reservoir behavior and the overall balance between water availability and demand (Bahir et al., 2015; Chibane and Ali-Rahmani, 2015; Khemmoudj et al., 2016; Ouis, 2012; Ouhamdouch et al., 2016). Climate-change impacts on water resources have consequently received increasing attention, ranging from changes in watershed response and groundwater systems to the broader challenges of water-resource engineering, adaptation and water security (Assemian et al., 2021; Chadee et al., 2023; Choukrani et al., 2018; El Fellah Idrissi et al., 2017; Nichane and Khelil, 2015; Remini, 2020d; Remini, 2024; Lalwani et

al., 2026). These investigations collectively highlight the need to understand historical hydroclimatic behavior before reliable adaptation and water-management strategies can be formulated.

Among the manifestations of hydroclimatic variability, drought is particularly important because it develops progressively, can persist over extended periods and may simultaneously affect agriculture, surface-water resources, groundwater reserves and socio-economic activities. Meteorological drought, which originates from a sustained precipitation deficit relative to normal climatic conditions, represents an essential first stage in understanding the propagation of water scarcity through the hydrological system. Research in semi-arid regions has shown that drought characteristics can vary considerably in frequency, duration and severity, reinforcing the necessity of long-term and region-specific assessments (Boubakeur, 2018; Bouguerra and Benslimane, 2017; Benali Khodja and Ferdjouni, 2024). The application of standardized drought indicators further provides an objective framework for identifying dry periods and comparing drought conditions through time. In this context, SPI- and SPEI-based investigations have demonstrated their usefulness for characterizing meteorological drought and evaluating its temporal evolution under contrasting climatic conditions (N'guessan Bi et al., 2020; Koussa, 2025).

Rainfall variability should nevertheless not be considered independently of other components of the hydrological system. Variations in precipitation affect rainfall-runoff relationships, catchment response, extreme flows, reservoir operation and groundwater recharge, while changes in land use and water demand may further amplify hydrological stress. Rainfall-runoff investigations and watershed modelling have consequently become important tools for understanding these interactions (Atallah et al., 2024; Kherde et al., 2024; Koua et al., 2019; Mehta and Yadav, 2024). Likewise, statistical analyses of rainfall provide essential information for detecting temporal tendencies, evaluating extremes and identifying changes in rainfall regimes (Benkaci et al., 2020; Bong et al., 2023; Houichi, 2017; Nassa et al., 2021). Spatial and temporal characterization is equally important because changes in annual rainfall totals may conceal contrasting behavior among seasons, rainfall classes and geographical areas (Doumounia et al., 2020; Kouao et al., 2020; Nakou et al., 2023; Oga et al., 2016; Zeggane et al., 2021).

The implications of these changes extend beyond the characterization of climate itself. Reduced or increasingly irregular precipitation may intensify competition for water, increase pressure on groundwater and reservoirs, and compromise the reliability of water supplies, particularly where agricultural production depends strongly on seasonal rainfall. Sustainable water management therefore requires an integrated understanding of climatic variability, hydrological response and the capacity of water-resource systems to withstand prolonged deficits (Aroua, 2018; Faye, 2016; Rouissat and Smail, 2022; Morsli and Habi, 2026). The growing concern regarding water scarcity under changing climatic conditions further emphasizes the strategic importance of monitoring long-term precipitation behavior and identifying recurrent drought episodes before their impacts become critical (Zella and Smadhi, 2010; Remini, 2020d; Remini, 2024).

This scientific context is particularly relevant to India, where monsoon rainfall governs a substantial part of surface-water availability, groundwater replenishment and agricultural activity. Recent studies carried out in Indian basins have also demonstrated the importance of hydrological modelling, reservoir management and long-term assessment of basin-scale changes for sustainable water-resource planning (Panchal and Suryanarayana, 2025; Rajput et al., 2023; Verma et al., 2023; Patil et al., 2026). Accordingly, the simultaneous examination of historical rainfall variability, temporal trends and meteorological drought provides a particularly valuable framework for identifying hydroclimatic changes and evaluating the long-term vulnerability of rainfall-dependent regions. Such an approach is especially pertinent for Nashik district, where the strong dependence on monsoon rainfall and agriculture makes the identification of long-term changes in rainfall regimes and drought occurrence essential for future water-resource planning and drought-risk management.

The recent changes in climate are more visible through extreme rainfall events, increased heat islands, flooding in urban areas and increased droughts conditions. One of the important elements of hydrological cycle is rainfall. The spatial and temporal variations in rainfall pattern becomes more important from socio-economic point of view. Specially, in countries like India where agriculture sector has contribution of 17-18 % in total GDP, rainfall plays a vital role. The increased or decreased rainfall in a specific year have a great impact on the agricultural production. One of the concerns of climate is about change in the total and deviations in the rainfall, will become more severe across the globe (Zamani et al., 2018). In developing countries like India, rapid increase in population as well as industrial and agricultural growth creates additional demand of requirement of fresh water. Due to this exploitation of water resources have been occurred beyond the sustainable limit which ultimately create human induced droughts in several areas (Van Loon et al., 2016). Drought is extremely complex and hence least understood natural hazard, that happens recurrently in many regions across the world (Mehta et al., 2023). Drought can be considered as a normal element of climate. This phenomenon is quite common in arid and semi-arid regions and can be extended for a particular season or a year too. Effects of drought can be accumulated slowly for considerable time period (Mishra and Singh, 2010). The foot prints of droughts are more hazardous than any other natural hazard like flood and earthquakes. Droughts can be characterized on the basis of its severity, duration for which it persists and locations. It affects the availability of surface as well as groundwater eventually leading to disaster conditions in many areas. Adverse effect of droughts can be seen on agriculture and food security, generation of hydropower, physical and economic health of society, security of women and even access to education of girls. To have clear understanding drought can be classified as Agricultural, Meteorological, Hydrological, and socio-economic drought (Kallis, 2008; Khaniya et al., 2020; Pastagia et al., 2022; Mehta et al., 2022; Mehta et al., 2023).

Analysis of trend and variability of various climatic parameters such as rainfall helps in drought studies and hence always used by many researchers (Perera et al., 2020; Anushka and Upaka, 2020; Mellak and Souag-Gamane, 2020; Aher and Yadav, 2021; Poornima et.al., 2023). The trend in rainfall data series can be examined by different methods like Mann-Kendall (MK) trend test, Innovative trend analysis (ITA), Spearman's correlation

test etc. (Aher and Yadav, 2021; Shaikh et al., 2022). Further, to evaluate drought events several indices can be used. In the recent past decades, several scientific studies on drought indices have been increased. Additionally, more focus has been made on comparative studies of different indices such as Rainfall Anomaly Index (RAI), Standardised precipitation Index (SPI), Crop Moisture Index (CMI), Palmer Drought Severity index (PDSI), Mooley Drought Index, Rainfall Variability Index (RVI), FAO Water Satisfaction Index, Bhalme and Mooley Drought Index, Index of Moisture Adequacy etc. (Palmer, 1965; Palmer, 1968; Frere and Popov, 1979; Bhalme and Mooley, 1980; Sastri, 1993; Aher and Yadav, 2021; Ndayiragije and Li, 2023). Out of several indices SPI is most effective, reliable and commonly used index which is also recommended by World Metrological Organization (WMO, 2016).

According to Inter-panel government on Climate change (IPCC) upcoming climate change will have supposed to increase recurrence of extreme droughts in various regions of the world (IPCC, 2007; Dai, 2011). According to, global warming might not increase drought events, but their frequency and severity may increase. Past observations indicates that frequency of severe drought has been increased in the recent decades over India. India Meteorological Department (IMD) testified 27 drought events that occurred between 1875 and 2005 (Shewale and Kumar, 2005). More than 300 million people becomes victims of severe drought occurred in 2002 (Bhat, 2006). Similarly, Gangetic region and Maharashtra experienced severe water shortage in 2014 and 2015, affecting millions of people in these regions (Mishra et al., 2016). The significant spatial and temporal variability in rainfall and temperature will further enhance the drought events. For instance, Barmer district of Rajasthan indicates increasing trend in south-west rainfall while Jalore district indicates decreasing trend in South-West rainfall for the period of 121 years (Mehta and Yadav, 2021a; Mehta and Yadav 2021b). Similarly, Marathwada, Madhya Maharashtra and Vidarbha regions in India indicates diverse nature of trend in seasonal and annual rainfall (Aher and Yadav, 2021).

From the socio-economic point of view, the study of historical drought is essential for any region. Further from climate perspective, it is also important to address the long-term trends and patterns in rainfall. Such studies have their own implication in both the agriculture and health sectors. The study in past so far were not reported on climatic parameters such as rainfall or temperature as well as on drought of Nashik city. To the best of our knowledge, no study is concentrated at micro level analysis of drought and rainfall at monthly, seasonal and annual basis in past. The objectives of the present study are i. To detect trend in monthly, seasonal and annual rainfall of 100 years (1901 to 2000) using ITA technique. ii. To analyse long-term temporal variability in rainfall. iii. To carry out temporal analysis of metrological drought characteristics of Nashik district.

STUDY AREA

Nashik is located between 19.9975° N, 73.7898° E at Northern side of Maharashtra state that occupies 15,582 Sq. area. The second largest river in India i.e., Godavari originates from Trimbakeshwar about 24 km from Nashik. Some of the important rivers like Darana,

Vaitarana, Kashyapi, Bhima and Girana, flow across the city. The population of Nashik city is 61,09,052, which makes Nashik as a third largest city in Maharashtra. The Western part of the district is surrounded with Sahyadri ranges. The average temperature of Nashik varies from 18^o C to 39^o C. Nashik district receives 80% of annual rainfall through South-West monsoon. The average annual rainfall of Nashik is 1134 mm. Overall; Nashik has a very pleasant weather throughout the year. Near about 24 dams were located in different rivers across Nashik district. Out of which Bhandardara dam located on Pravara River which is tributary of Godavari, is one of the oldest dam in India constructed in 1926 with 11TMC capacity. Nashik district has an agriculturally based economy and total cultivated area is 864,000 ha. Nashik is well known for production of grapes. Along with grapes, onion and pomegranate are primary crops in district. District soil formations is very fertile and categorized in four classes viz., lateritic black soil (Kali), reddish brown soil (Mal), coarse shallow reddish black soil (Koral), medium light brownish black soil (Barad). The location and boundary of Nashik district in Maharashtra, India is shown in Fig. 1. The India Metrological department (IMD) has created Thirty-six different metrological sub-divisions of India. Out of which Madhya Maharashtra region is one of the sub-division. Nashik district falls in Madhya Maharashtra sub-division. The annual, seasonal and monthly rainfall of Nashik district was collected from IMD, Pune. The historical record of rainfall for past hundred years i.e. from 1901 to 2000 is utilized for the analysis.

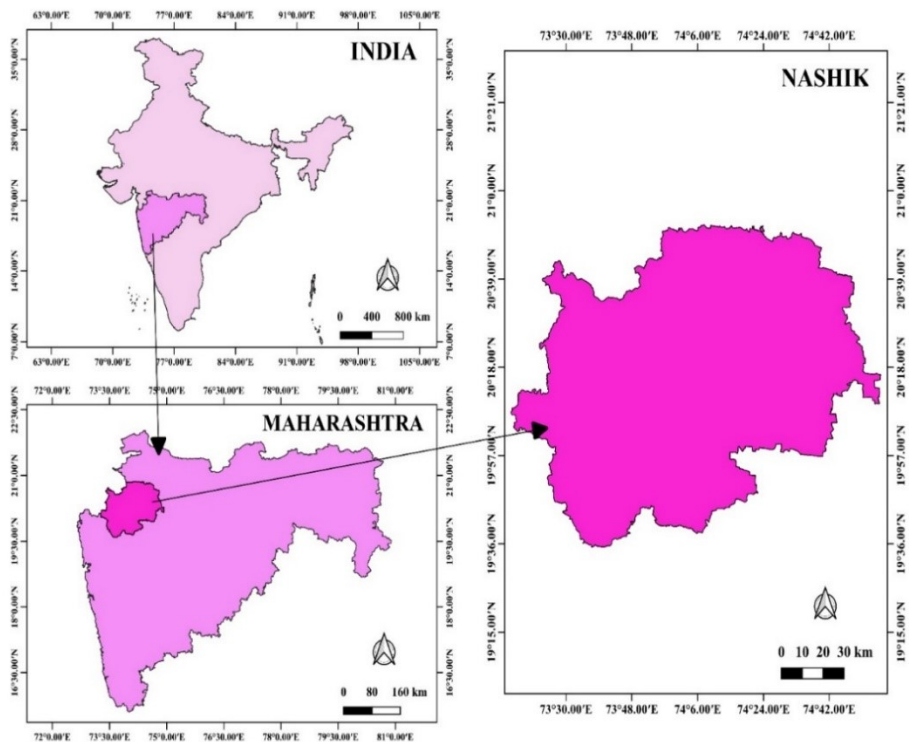


Figure 1: Location and boundary of Nashik district in Maharashtra, India

METHODOLOGY

Present study incorporates various statistical and graphical methods to assess trend and variation in rainfall and drought of Nashik district. The rainfall trend was assessed through Innovative Trend Analysis (ITA) technique and Rainfall Variability Index (RVI) technique is used to assess temporal variation in rainfall. The drought assessment was carried out using Standard Precipitation Index (SPI), Rainfall Anomaly Index (RAI) And Departure Analysis of rainfall. Drought analysis is carried out for four seasons i.e. Monsoon (June-September), Post-Monsoon (October-December), Winter (January-February) and Pre-monsoon i.e. (March-May). Study attempts analysis of historical rainfall along with drought through number of well-known techniques. Very few studies reported combine analysis of drought and rainfall analysis at seasonal and annual scale earlier.

INNOVATIVE TREND ANALYSIS (ITA)

Sen (2011) recommended a novel method to identifying nature of trend in the time series. This method consist of 1:1 (45°) as the straight line on the Cartesian coordinate system. To check the trend, time series is separated into two identical sub-series. Identical sub-series is then arranged in the ascending order. First of the time series is plotted as abscissa against the second as ordinate based on the Cartesian coordinate system. The data points collected on 1:1 straight line shows no trend in the data. When data falls in the upper part of 1:1 straight line, it shows positive trend in the time series. While reverse of the scenario shows negative trend. The technique also detects low, medium and high trends in different hydrologic regimes.

RAINFALL VARIABILITY INDEX (RVI)

The rainfall variability index represents standard departure in the precipitation data and helps to segregate the existing data into normal, wet, very wet, dry and very dry climatic year (L'Hote et al., 2002). The rainfall variability index (D_i) is calculated from the equation (1) given as:

$$D_i = \frac{P_i - \mu}{\sigma} \quad (1)$$

Where, D_i represents the rainfall variability index for year i , and P_i is the annual rainfall of year i . σ and μ are the standard deviation and mean of the annual precipitation series respectively, for duration under the study at the given station. The value of D_i is within ± 0.5 , between $+ 0.5$ to $+ 1$, more than $+ 1$ is categorized as a normal; wet and very wet climatic year, respectively. Correspondingly, when the value of D_i lies in between -0.5 to -1 and less than -1 indicates the dry and very dry, climatic year, respectively (L'Hôte et al., 2002).

STANDARD PRECIPITATION INDEX (SPI)

There are four types of droughts viz. metrological, agricultural, hydrological and socio-economic drought. Out of which this study focus on metrological drought that occurs due to lack in the magnitude and duration of precipitation as compared with regional normal precipitation. WMO recommended SPI as the main meteorological drought index that countries should use to monitor and follow drought conditions (Hayes, 2011). It uses historical precipitation records for any location to develop a probability of precipitation that can be calculated at any timescales. SPI can be calculated for 20 years, but preferably the time series should have a minimum of 30 years, even when missing data are accounted for. For accurate analysis and predictions, it is important to have reliable and continuous data series. In this study there were no missing data and hence test results obtained are quite reliable. Depending on the drought impact in question, SPI values for 3 months or less might be useful for basic drought monitoring, values for 6 months or less for monitoring agricultural impacts and values for 12 months or longer for hydrological impacts. SPI is applicable on gridded data, that supports wider scope than just working with station data. SPI is applicable in all climate regimes, and SPI values for very different climates can be compared. The SPI is widely used for defining and monitoring meteorological droughts. It is evident that many researchers across the world has used this technique to study droughts. In this technique drought is categorised in seven classes from extremely wet to severe drought based on average values of SPI. The classification of drought is given in Table 1 below.

Table 1: State of metrological drought based on SPI

SPI Range	Drought Class
> 2	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
0 to 0.99	Near Normal
0 to -0.99	Mild drought
-1 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought

RAINFALL ANOMALY INDEX (RAI)

RAI segregates rainfall regime in to nine classes i.e. from extremely wet to extremely dry. Based on RAI rainfall regime is classified as shown in Table 2. It uses normalized precipitation data of the rain gauge station located at a particular location. RAI is flexible to analyse monthly, seasonal and annual precipitation data. Comparison to the current period puts the output into a historical perspective. The application of RAI technique is to check the effect of drought on agriculture, water resources and other related sectors. Van Rooy has given an equation 2 as mentioned below.

$$RAI = \pm 3 \frac{P - \bar{P}}{\bar{E} - \bar{P}} \quad (2)$$

where P = measured precipitation, $\bar{P}$ = mean precipitation, and $\bar{E}$ = average of 10 extrema (mean of ten highest precipitation records in the period). RAI values ranges from +3 to - 3. Positive values of RAI are indication of wet conditions whereas negative values show dry conditions. And hence rainfall is segregated from extremely wet to extremely dry conditions. RAI is one of the well-known technique deployed by several researchers to study rainfall regimes.

Table 2: Rainfall regime based on RAI

RAI values	Rainfall Regime
> 3	Extremely wet
2.0–2.99	Very wet
1.0 -1.99	Moderately wet
0.50– 0.99	Slightly wet
+ 0.49 to -0.49	Near normal
- 0.50 to - 0.99	Slightly dry
- 1 to - 1.99	Moderately dry
- 2 to - 2.99	Very dry
< - 3	Extremely dry

PERCENTAGE DEPARTURE ANALYSIS (% DA)

If, annual rainfall is less than 75% of mean rainfall, then it is called a drought year and % percentage departure analysis is calculated using equation given below.

$$D(\%) = \frac{X_i - X_m}{X_m} \quad (3)$$

where, X_m = mean annual rainfall from the annual rainfall series X_i .

RESULTS AND DISCUSSION

Temporal analysis of monthly, seasonal and annual rainfall over Nashik district using ITA

Preliminary analysis of rainfall data from year 1901 to 2000, shows significant variation on monthly seasonal and annual scale also (Table 3). For non-monsoonal months the minimum rainfall was observed to be zero, whereas for monsoon season the minimum values was observed to vary from 25.6 mm to 80.5 mm. in past 100 years the August month was contributing good amount of rainfall as compared with other monsoonal

months. At seasonal time scale the minimum rainfall in Monsoon month was 386.4mm. While for pre-monsoon, post-monsoon and winter season the minimum rainfall values was zero. Which is quite oblivious as Nashik region in Maharashtra always experiences good rainfall from South-West monsoon only. In view of non-monsoonal months May month observed maximum rainfall of 118.7mm and other non-monsoonal months i.e. January, February, march and April indicates maximum rainfall of 40.4 mm. 13mm. 21.9 mm and 35.1 mm respectively.

Table 3: Rainfall statistics at monthly, seasonal and annual time scale

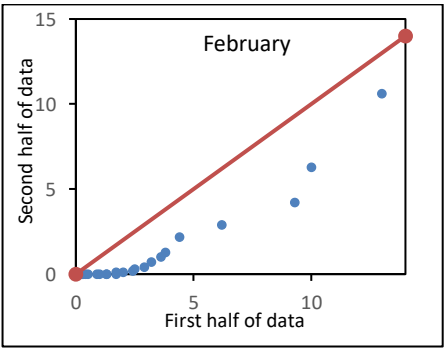
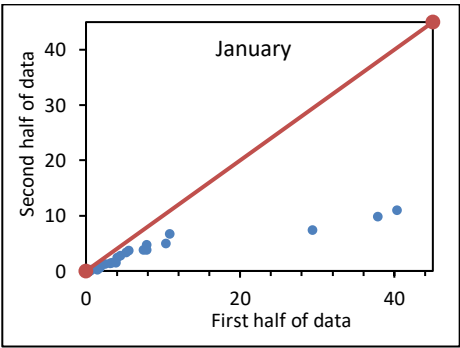
Time scale	Minimum	Maximum	Mean	SD	CV
Jan	0	40.4	2.7	6.5	244.7
Feb	0	13	1	2.4	230.3
March	0	21.9	1.7	4.2	242.9
April	0	35.1	5.1	7.8	151.7
May	0	118.7	17.2	23.8	138.1
June	28.9	353.1	149.7	73.4	49
July	68.4	695.4	309	117.2	37.9
August	80.5	465.4	227.6	87.6	38.5
September	25.6	510.4	174	92.9	53.4
October	0	325.1	62.4	61.4	98.4
November	0	205.9	24	37.8	157.2
December	0	66.1	4.8	10.3	215.1
Pre-Monsoon	0	119.4	24.1	25.3	105.2
Monsoon	386.4	1365.3	860.4	194.6	22.6
Post-Monsoon	0	409.6	86.4	71.4	82.6
Winter	0	66.1	8.5	11.9	139.5
Annual	479.1	1641.3	979.4	224.1	22.9

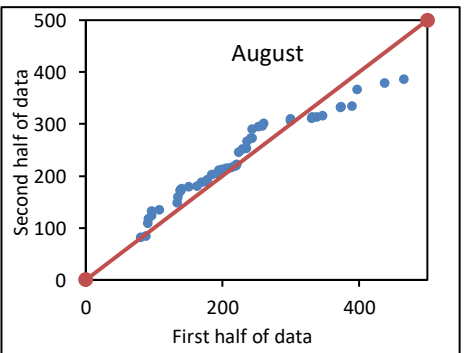
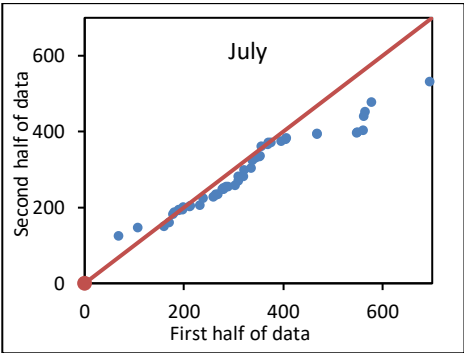
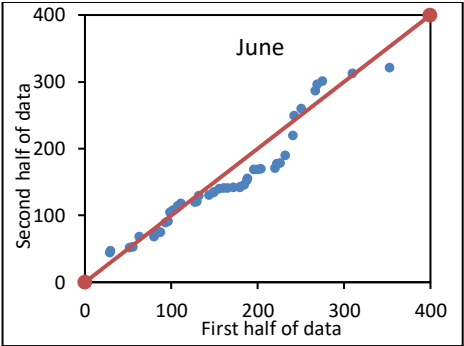
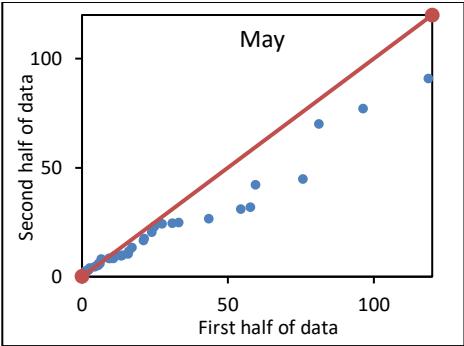
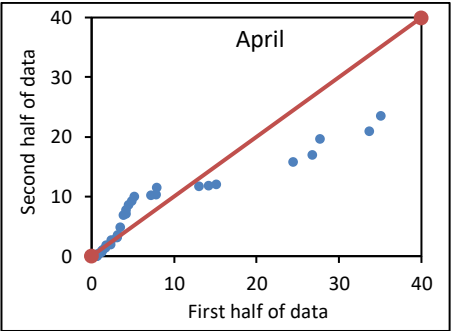
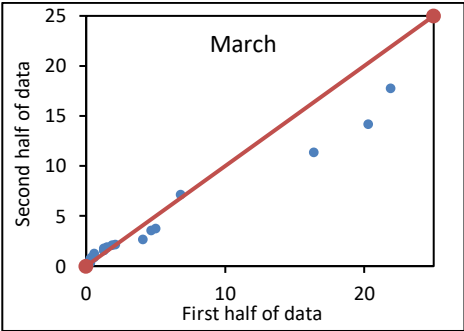
Considerable variation in non-monsoonal as well as monsoonal months was observed in maximum values of rainfall. Similar is the observation for Monsoonal months also. The average rainfall for June, July, August and September month was 149.7 mm, 309 mm, 227.6 mm and 174 mm respectively. For Monsoon season the average rainfall was 860.4mm and annual average rainfall was 979.4 mm. As compared with Pre-monsoon season Post-monsoon season contribute good amount of rainfall of 71.4 mm. After analyzing basic statistics of 100-year historical rainfall, trend analysis was carried out using ITA technique, which is very good to understand pattern of rainfall in low, medium and high regime. This technique is broadly used by many researchers across the world to study rainfall trend. ITA is graphical method to analyze particular trend in rainfall. The ITA result for monthly, seasonal and annual scale is shown in Table 4. For January, February and May months, decreasing trend is observed in low, medium and high regime. Whereas for March and April months mix trend of increasing, decreasing and no trend was noticed. in case of Monsoonal months also mix trend is observed in all three regimes. It is observed that in July month, medium and high rainfall shows decreasing trend vice versa August month shows increasing trend in low and medium regime and decreasing

trend in high rainfall regime. As September month is an important month when Nashik district receives considerable amount of rainfall, no particular trend was noticed in low and high rainfall regime as shown in Fig. 2.

Table 4: Trend analysis of monthly, seasonal and annual rainfall

Time scale	Low	Medium	Low
Jan	↓	↓	↓
Feb	↓	↓	↓
March	↑	○	↓
April	○	↑	↓
May	↓	↓	↓
June	○	↓	↑
July	↑	↓	↓
August	↑	↑	↓
September	○	↓	○
October	↑	↑	↓
November	↑	↓	↓
December	○	↑	↑
Pre-Monsoon	○	↓	↓
Monsoon	○	↓	↓
Post-Monsoon	○	○	↓
Winter	↓	↓	↓
Annual	○	↓	↓





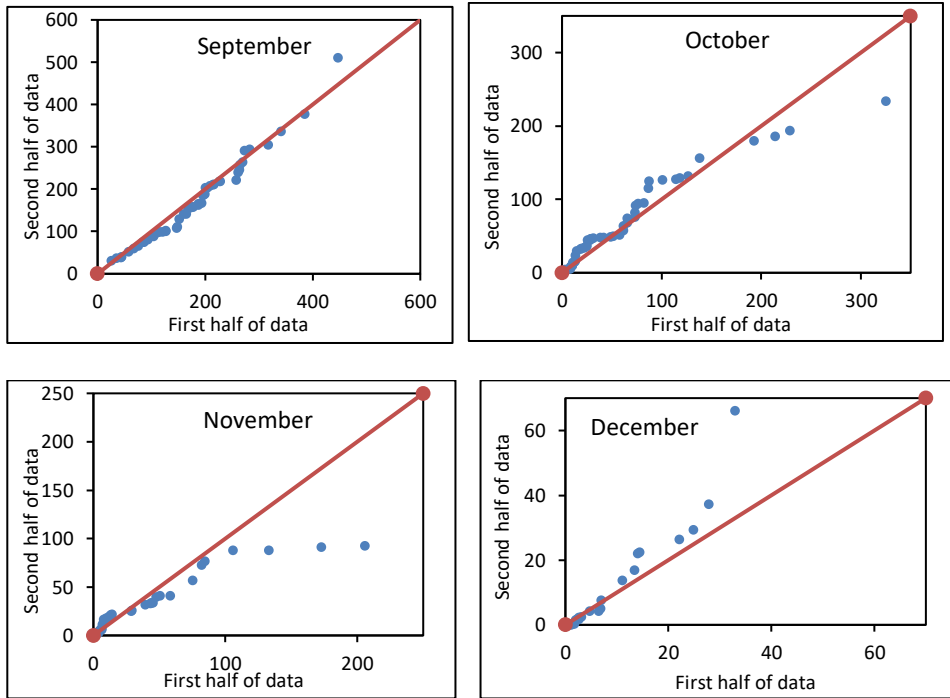


Figure 2: ITA plots for monthly rainfall data of Nashik District

At seasonal scale, it is noticed that pre-monsoon and monsoon rainfall was decreased in medium and high regime. While winter rainfall was decreased in all three regimes. Post monsoon season shows no trend in low and medium regime and decreasing trend in high rainfall regime. The annual rainfall shows decreasing trend in medium and high rainfall regime, whereas no specific trend was noticed in low rainfall regime. Overall, it is observed that at seasonal scale rainfall shows decreasing trend in high regime. Whereas at monthly scale rainfall exhibits mixed trend. Therefore, no specific trend was there in monthly rainfall of Nashik district for past 100 years as shown in Fig. 3. But annual rainfall shows decreasing trend. Now this decreasing trend in seasonal and annual rainfall has significant impact on the agricultural sector, specifically for the crops which were grown in Rabi and Kharif season. Specifically, those fields which are non-irrigated and completely depend on the monsoon season. As in majority of the study area land use/land cover is agricultural area, decreased trend in rainfall will affect the local economy also. Similarly, large variation in the minimum, maximum and average value of rainfall have significant impact on planning of existing water resources.

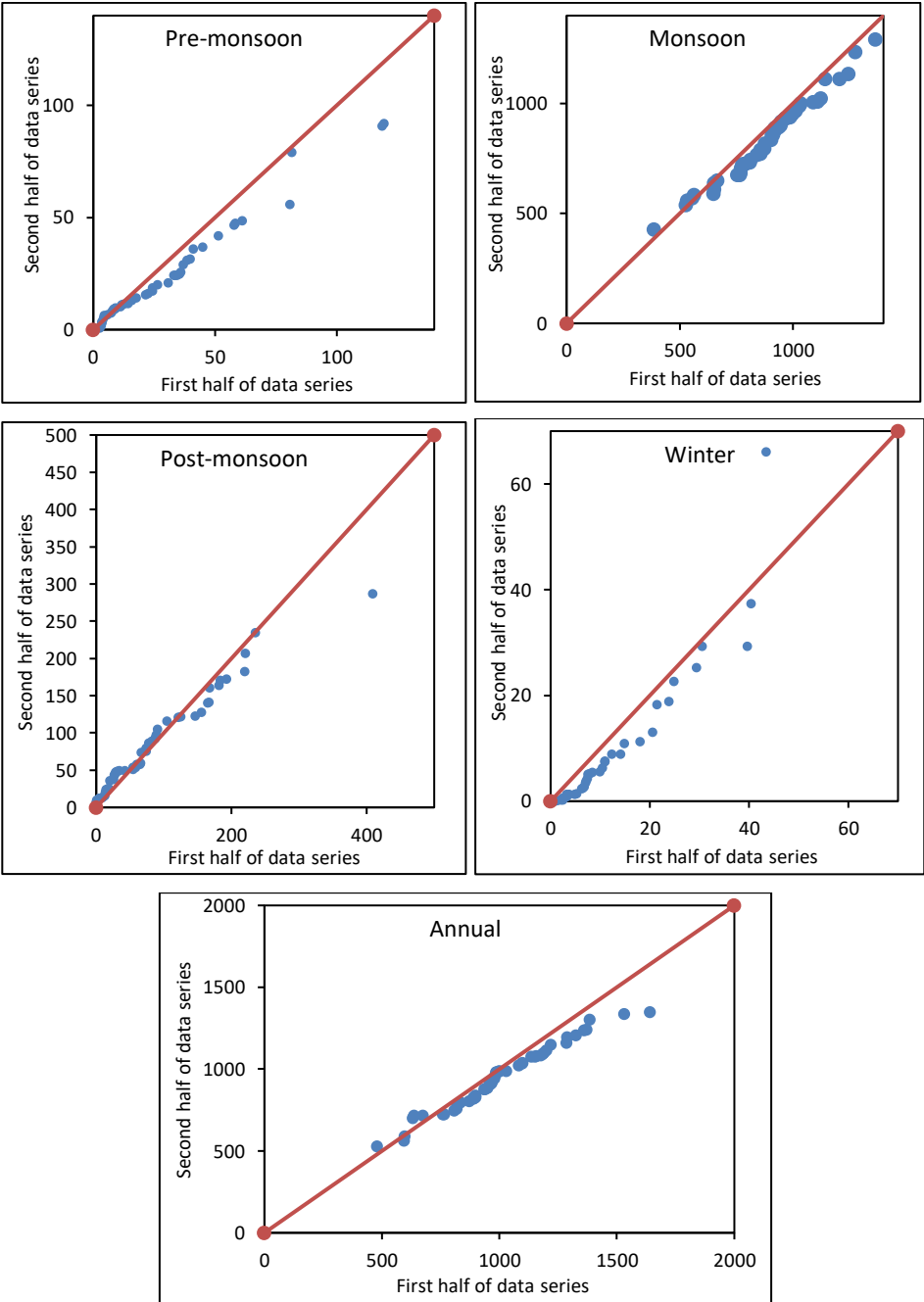
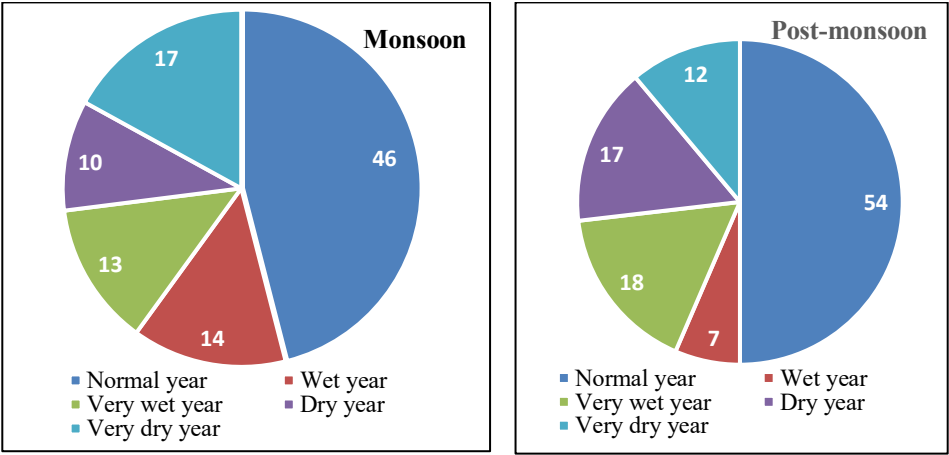


Figure 3: ITA plots for seasonal and annual rainfall data of Nashik District

Rainfall variability over Nashik district

After analyzing basic statistics and rainfall trend, the next step was to see the rainfall variability over Nashik district. This was analyzed with RAI, that represents standard departure in the precipitation data and helps to segregate the existing data into normal, wet, very wet, dry and very dry climatic year. To check variability in rainfall monsoon, Potts monsoon and annual rainfall data was used. As it was observed that pre-monsoon and Winter season does not contribute that significant amount of rainfall, was excluded. It was observed that, Nashik district experienced normal year for 46 % of time whereas 17 % of time Very dry year and 13 % of time very wet was observed in monsoon season. In post-monsoon season, district was experienced normal year, wet year, very wet year, dry year and very dry year for 54%, 7%, 18%, 17% and 12% respectively. This shows that Nashik district experiences normal rainfall for majority of time in past 100 years. And very dry year very few in past 100 years. As mentioned earlier, that being a significant agricultural dominant region in Maharashtra that depends on South- West monsoon and receiving normal rainfall plays important role. In addition, Nashik district experience annual normal rainfall for 42 % of time as shown in Fig. 4. Assessment of rainfall variability is extremely important to plan and manage the available water resources. This will provide a base to take necessary actions for supply of water that is required for various sectors like, industry, agriculture and for drinking. Indications of past normal years will reflect that there is probability of normal rainfall in coming future for most of the time. This will serve as a guide line for policy makers to deal with the uncertainty in rainfall.



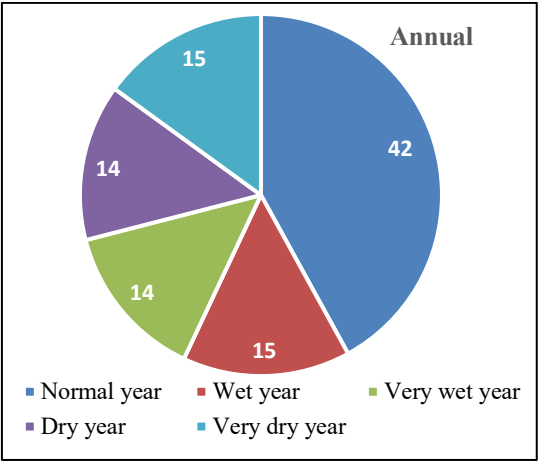


Figure 4: Rainfall variability index plots for Monsoon, Post-monsoon and annual rainfall

Metrological drought analysis using SPI

Metrological drought occurs when significant and abnormal dry weather is noticed similarly short fall of precipitation is observed as compared with long term regional average precipitation. The key characteristics of metrological droughts are shortfall in precipitation in magnitude as well as duration, it is very much region specific and it is the primary stage in the water scarcity. And if actions are not taken on the metrological drought this will prolong and develop more serious conditions in future. Hence it is important to evaluate metrological drought at early phase only. SPI is one the easy and effective tool in the evaluation process that is recommended by WMO also. This method uses precipitation records for minimum 20 years. But it is always good to have at least 30 years records to arrive at a specific conclusion. In this study past 100 years annual and seasonal precipitation records were utilized to classify time series in to wet and dry years.

The results indicate that extremely wet, very wet, moderately wet, near normal, mild drought, moderate drought and severe drought conditions occurred for 2, 5, 7, 34, 34, 7, 8 years respectively in the district (Table 5). It has been also observed that no severe drought conditions are seen in the district after year 1989. Similarly, moderate drought is not seen after year 2000. Majority of moderate and severe drought conditions were seen after year 1908 and 1904 respectively. In addition, it has been observed that in 1904 and 1905 severe drought conditions for subsequent two years. Similar pattern in severe drought was seen in year 1918 and 1920.

Table 5: Classification of wet and dry year through SPI

Sr. No	Extremely wet	Very wet	Moderately wet	Near Normal	Mild drought	Moderate drought	Severe drought
1	1931	1930	1914	1907	1902	1908	1904
2	1933	1938	1927	1910	1903	1957	1905
3	-	1944	1932	1916	1906	1975	1911
4	-	1954	1958	1917	1909	1982	1918
5	-	1956	1976	1919	1912	1985	1920
6	-	-	1990	1926	1913	1986	1952
7	-	-	1994	1928	1915	2000	1972
8	-	-	-	1935	1921	-	1989
9	-	-	-	1937	1922	-	-
10	-	-	-	1940	1923	-	-
11	-	-	-	1941	1924	-	-
12	-	-	-	1943	1925	-	-
13	-	-	-	1947	1929	-	-
14	-	-	-	1948	1934	-	-
15	-	-	-	1949	1936	-	-
16	-	-	-	1950	1939	-	-
17	-	-	-	1955	1942	-	-
18	-	-	-	1959	1951	-	--
19	-	-	-	1963	1953	-	-
20	-	-	-	1964	1960	-	-
21	-	-	-	1967	1961	-	-
22	-	-	-	1968	1962	-	-
23	-	-	-	1969	1965	-	-
24	-	-	-	1970	1966	-	-
25	-	-	-	1973	1971	-	-
26	-	-	-	1979	1974	-	-
27	-	-	-	1981	1977	-	-
28	-	-	-	1988	1978	-	-
29	-	-	-	1991	1980	-	-
30	-	-	-	1993	1983	-	-
31	-	-	-	1996	1984	-	-
32	-	-	-	1997	1987	-	--
33	-	-	-	1998	1992	-	-
34	-	-	-	1999	1995	-	-

Segregation of rainfall regime using RAI

RAI is another technique that measures how rainfall is differs in a particular area than long term average rainfall. It is a simple but effective technique that can be apply on monthly, seasonal and annual rainfall time series. One of the weaknesses of this method is requirement of serially complete data set and no missing data. The application of RAI technique is to check the effect of drought on agriculture, water resources and other related sectors. The analysis of annual rainfall shows that 1933 was only extremely dry year for Nashik district as shown in Table 6.

Table 6: Rainfall Regime over Nashik district

Sr. No	Slightly dry	Moderately dry	Extremely dry
1	1913	1901	1933
2	1915	1904	-
3	1921	1905	-
4	1923	1908	-
5	1929	1911	-
6	1934	1918	-
7	1951	1920	-
8	1960	1925	-
9	1962	1952	-
10	1966	1957	-
11	1971	1965	-
12	1974	1972	-
13	1978	1975	-
14	1984	1978	-
15	1987	1982	-
16	1995	1985	-
17	-	1986	-
18	-	1987	-
19	-	1989	-
20	-	2000	-

After 1933 district has not face any extreme dry conditions. Moderately dry conditions were prevailed for 20 years, out of 100 years. And slightly dry conditions were there for 16 years. Amount of rainfall that a particular region receives have a great impact on occurrence of drought. As Nashik district comes in the path of South-West Monsoon the requirement of water from domestic, industry and agriculture is highly affected by the extent of rainfall that district receives. In addition to this a second largest river in India originates in the Trimbakeshwar hills. Godavari river flows through the middle of Nashik and serves as a lifeline to all sectors that depends on water. Near about 21 dams were constructed on this river in and around the Nashik district. The extent of water store in

the dams is also depended on the amount of rainfall that occurs in the catchment area of Godavari River basin (GRB). The rainfall regime in slight dry, moderately dry and extreme dry segregates rainfall and allow to take actions in advance to cope up with probable droughts. It is evident that drought have serious impact on society and demands special attention to handle droughts very sensitively. The majority of people impacted by such conditions are from low-income group and will face struggle in daily fulfillment of fresh water for drinking purpose. The results of RAI technique show no drought and serious rainfall deficit occurs in the district. From socio-economic point of view good amount of rainfall is an indication of prosperity specially where agriculture is primary occupation of the majority of people. Specially in the country like India where likelihood of majority of people is agricultural and allied based business This will have a good impact on agricultural sector and positive impact on local economy.

Percentage departure of annual rainfall over Nashik district

Percentage departure in rainfall was deployed on annual rainfall of Nashik district. The method categorize rainfall in to three categories viz. normal, deficit and excess rainfall. The results show that 62 % of time district have received normal rainfall, 20 % of time deficit rainfall and 18 % of the excess rainfall as shown in Fig. 5. The indication of normal rainfall in the district, reflects ample amount of availability of water in the district that can be analysed through the dam storage data too. As in the Nashik district more than 20 dams were constructed in past five decades, this district is rich in water perspective. As Nashik district is known for majority of dams in the state of Maharashtra, daily requirement of fresh water gets fulfilled through the reservoir storage. When normal rainfall conditions are prevailed for more than 60% of time in the past 100 years, the reservoir operations will not be a crucial job for water management perspective. Nashik district is also well known for considerable production of agricultural crops like Onion, Grapes and Pomegranate. Economy of the district is highly influence by the agricultural sectors and majority of the likelihood id depending on this particular sector. Similarly, 18 % of excess rainfall for some of the years reflects the flooding conditions. As Godavari River originates and flows through the district, in the recent past many flood events due to extreme rainfall are quite evident. Past 100 years' study of annual rainfall, will serve as a prediction tool in near future. And not only use as a prediction tools, this will help policy makers to in decision making in reservoir operations, schedule irrigation for crops, and other uses.

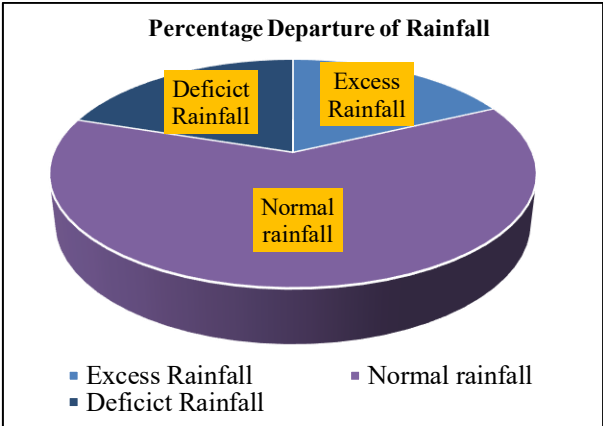


Figure 5: Percentage departure of annual rainfall

CONCLUSION

One of the important elements of hydrological cycle is rainfall. The spatial and temporal variations in rainfall pattern becomes more important from socio-economic point of view. Specially, the developing country like India, having agriculturally based economy demands a great concern about the intensity and magnitude of rainfall. Study of historical trends and variability in rainfall provides vital information about the changing climate over particular area. In this study hydrological and metrological droughts were assessed using various techniques. The monthly, seasonal and annual precipitation data of Nashik district was utilized for assessment. Overall, it is observed that at seasonal scale rainfall shows decreasing trend in high regime. Whereas at monthly scale rainfall exhibits mixed trend. So, no specific trend was there in monthly rainfall of Nashik district for past 100 years. But annual rainfall shows decreeing trend. Nashik district experiences normal rainfall for majority of time in past 100 years. And very dry year very few in past 100 years. As mentioned earlier, that being a significant agricultural dominant region in Maharashtra that depends on South- West monsoon and receiving normal rainfall plays important role. Metrological drought analysis shows that extremely wet, very wet, moderately wet, near normal, mild drought, moderate drought and severe drought conditions occurred for 2, 5, 7, 34, 34,7, 8 years respectively in the district. The results of RAI technique show no drought and serious rainfall deficit occurs in the district. Percentage departure in rainfall also shows that no serious drought conditions was occurred in the past 100 years and the rainfall was normal for 62 % of time. The result of the study provides deep insights about the historical hydrological and metrological droughts. The results will help policy makers to understand past rainfall patterns. The results can be utilized in the current scenario of rainfall to assess existing water resources in the district. The study will help engineers, researchers and policy makers to understand historical droughts.

Acknowledgments

The author gratefully acknowledges the India Meteorological Department (IMD) for providing rainfall data for the selected study area of Nashik, Maharashtra, India. The authors also thank the reviewers and editors for their constructive comments, which improved the manuscript.

Declaration of competing interest

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.

REFERENCES

- AADHAR S., MISHRA V. (2018). Impact of Climate Change on Drought Frequency over India, Climate Change and Water Resources in India, Ministry of Environment, Forest and Climate Change, Vol. 1, No 2, pp. 117-129.
- ABDI I., MEDDI M. (2015). Rainfall-runoff modeling distributed in two watersheds in eastern Algeria, Larhyss Journal, No 23, pp. 7-22. (In French)
- ADJA M.G., ASSANDE A.A., DJEMIN E.J., SORO S.I., JOURDA J.P. (2021). Contribution of a GIS to mapping and spatial-temporal characterization of rainfall variability: case of the northern part of Ivory Coast, Larhyss Journal, No 47, pp. 119-132.
- AHER M.C., YADAV S.M. (2021). Assessment of rainfall trend and variability of semi-arid regions of Upper and Middle Godavari basin, India, Journal of water and climate change, Vol. 12, No 8, pp. 3992-4006.
- AROUA N. (2018). Water resources in SNAT 2030. between economic needs and ecological requirements, Larhyss Journal, No 35, pp. 153-168. (In French)
- ASSEMIAN A.E., DJE BI DOUTIN S., SAMAKÉ Y. (2021). Consequences of the effects of climate change on water resources in a humid tropical zone of central eastern Côte d'Ivoire, Larhyss Journal, No 45, pp. 95-105.
- ATALLAH M., DJELLOULI F., HAZZEB A. (2024). Rainfall-runoff modeling using the HEC-HMS model for the Mekerra wadi watershed (N-W Algeria), Larhyss Journal, No 57, pp. 187-208.
- BAHIR M., EL MOUKHAYAR R., CARREIRA P., SOUHEL A. (2015). Isotopic tools for groundwater management in semi-arid area: case of the wadi Ouazzi basin (Morocco), Larhyss Journal, No 23, pp. 23-39.
- BENALI KHODJA M., FERDJOUNI N. (2024). Assessment of the meteorological drought in the northern part of Algeria "case of the Isser wadi watershed, Larhyss Journal, No 58, pp. 39-54.

- BENKACI T., MEZENNER N., DECHEMI N. (2020). Exploration of maximum likelihood method in extreme rainfall forecasting using four probability distributions - the case of northern Algeria, *Larhyss Journal*, No 43, pp. 57-72.
- BHALME H.N., MOOLEY D.A. (1980). Large-scale droughts/floods and monsoon circulation, *Monthly Weather Review*, Vol. 108, No 1, pp. 1197-1211.
- BHAT G.S. (2006). The Indian drought of 2002-a sub-seasonal phenomenon?, *Quarterly Journal of the Royal Meteorological Society*, Vol.132, No 621, pp. 2583-2602.
- BONG C.H.J., LIEW S.C., SIM J.E., TEO F.Y. (2023). Trend and statistical analysis of annual maximum daily rainfall (AMDR) for Sarawak River basin, Sarawak, Malaysia, *Larhyss Journal*, No 53, pp. 183-197.
- BOUBAKEUR G. (2018). Climatic drought in the semi-arid region of Djelfa –Algeria (analyses of the rainfall data from 1975 to 2016), *Larhyss Journal*, No 33, pp. 123-140.
- BOUGUERRA S.A., BENSLIMANE N. (2017). Characterization of drought weather in climate semiarid: case of watershed wadi Boumessaoud (N-W Algeria), *Larhyss Journal*, No 29, pp. 95-110. (In French)
- CHADEE A., NARRA M., MEHTA D., ANDREW J., AZAMATHULLA H. (2023). Impact of climate change on water resource engineering in Trinidad and Tobago, *Larhyss Journal*, No 55, pp. 215-229.
- CHIBANE B., ALI-RAHMANI S.E. (2015). Hydrological based model to estimate groundwater recharge, real-evapotranspiration and runoff in semi-arid area, *Larhyss Journal*, No 23, pp. 231-242.
- CHOUKRANI G., HAMIMSA A., SAIDI M.E., BABQIQI A. (2018). Diagnosis and future projection of climate change in arid zone. case of Marrakech-Safi region (Morocco), *Larhyss Journal*, No 36, pp. 49-63. (In French)
- DAI A. (2011). Drought under global warming: A review, *Wiley Interdisciplinary Reviews, Climate Change*, Vol.2, No 1, pp. 45-65.
- DJELLOULI F., BOUANANI A., BABA-HAMED K. (2015). Hydrological characterization of the Oued Louza basin using a global rainfall-flow model, *Larhyss Journal*, No 23, pp. 275-286. (In French)
- DOUMOUNIA A., ZEBE A., DAMIBA L., ZOUGMORE F., NIKIEMA M. (2020). Climate variability analysis in the Nouhao sub-basin in eastern center of Burkina Faso, *Larhyss Journal*, No 41, pp. 57-69.
- EL FELLAH IDRISSE B., CHERAI B., HINAJE S., MEHDI K. (2017). Climatic variability and its influence on water resources in the northern part of the middle atlas Moroccan: the case of the Sefrou and the Anocour causses, *Larhyss Journal*, No 32, pp. 155-179. (In French)

- FAYE C. (2016). Management of water resources in the local of Ndondol: study of community management of water resources and water use conflicts in Mbomboye villages (Senegal), Larhyss Journal, No 25, pp. 219-240. (In French)
- FRERE M., POPOV G.F. (1979). Agrometeorological crop monitoring and forecasting, Food and Agriculture Organization of the United Nations, No 17, pp. 64.
- HAYES M.J., SVOBODA M.D., WIIHITE D.A., VANYARKH O.V. (1999). Monitoring the 1996 drought using the standardized precipitation index, Bulletin of the American Meteorological Society, Vol. 80, No 3, pp. 429-438.
- HOUICHI L. (2017). Appropriate formula for estimating rainfall intensity of selected duration and frequency: a case study, Larhyss Journal, No 30, pp. 67-87. (In French)
- IPCC (Intergovernmental Panel on Climate Change). (2007). Climate Change 2007: Synthesis report. Contribution of working group I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change, pp.1-22.
- KALLIS G. (2008). Droughts, Annual Review of Environment and Resources, Vol.33, pp. 85-118.
- KHANIYAB., PRIYANTHAH.G., BADUGEN., AZAMATHULLA H.M., RATHNAYAKE U. (2020). Impact of climate variability on hydropower generation: a case study from Sri Lanka, Indian Society for Hydraulics (ISH) Journal of Hydraulic Engineering, Vol. 2, No 3, pp. 301–309.
- KHEMMOUDJ K., BENDADOUCHE H., MERABET S. (2016). Water resources in semi-arid and sustainable development, case Djemila northeast Algerian region, Larhyss Journal, No 26, pp. 249-258. (In French)
- KHERDE R.V., MEHTA D.J., MORE K.C., SAWANT P.H. (2024). Dynamic watershed modelling: HEC-HMS analysis of a tropical watershed, Larhyss Journal, No 60, pp. 87-111.
- KOUA T., ANOH K., EBLIN S., KOUASSI K., KOUAME K. (2019). Rainfall and runoff study in climate change context in the buyo lake watershed (southwest Côte d'Ivoire), Larhyss Journal, No 39, pp. 229-258. (In French)
- KOUAO J.M., KOUASSI A.M., DEKOULA S.C., ASSEUFI B.D. (2020). Analysis of the climate regionalization of the ivory coast in a changing climate context, Larhyss Journal, No 41, pp. 233-259. (In French)
- KOUSSA M. (2025). Application of SPI and SPEI indices for the analysis and evaluation of the drought phenomenon in the Ain Oussera plain, Algeria, Larhyss Journal, No 61, pp. 111-139.
- L'HOTE Y., MAHÉ G., SOMÉ B., TRIBOULET J.P. (2002). Analysis of a Sahelian annual rainfall index from 1896 to 2000; the drought continues, Hydrological Sciences Journal, Vol.47, No 4, pp. 563-572.

- LALWANI P.K., PATEL V.M., CHADEE A.A., JHA S., TRIPATHI R. (2026). Assessing the impact of climate change on river systems - a review of hydrological modeling approaches, *Larhyss Journal*, No 65, pp. 7-26.
- LAZRI M., AMEUR S., HADDAD B. (2007). Analysis of precipitation data using the Markovian approach, *Larhyss Journal*, No 6, pp. 7-20. (In French)
- MEHTA D., YADAV S. (2024). Rainfall runoff modelling using HEC-HMS model: case study of Purna river basin, *Larhyss Journal*, No 59, pp. 101-118.
- MEHTA D., YADAV S.M. (2021a). Temporal analysis of rainfall and drought characteristics over Jalore District of S-W Rajasthan, *Water Practice & Technology*, IWA Publishing, Vol 17, No 1, pp. 254-267.
- MEHTA, D., YADAV, S.M. (2021b). An analysis of rainfall variability and drought over Barmer District of Rajasthan, Northwest India, *Water Supply*, Vol. 21, No 5, pp. 2505-2517.
- MEHTA, D.J., YADAV, S.M. (2022). Long-term trend analysis of climate variables for arid and semi-arid regions of an Indian State Rajasthan, *International Journal of Hydrology Science and Technology*, Vol. 13, No 2, pp. 191-214.
- MEHTA, D.J., YADAV, S.M. (2023). Meteorological drought analysis in Pali District of Rajasthan State using standard precipitation index, *International Journal of Hydrology Science and Technology*, Vol. 15, No 1, pp. 1-10.
- MISHRA A.K., SINGH V.P. (2010). A review of drought concepts, *Journal of Hydrology*, Vol. 391, pp. 202-216.
- MISHRA V., AADHAR S., ASOKA A., PAI, S., KUMAR R. (2016). On the frequency of the 2015 monsoon season drought in the Indo-Gangetic Plain, *Geophysics Research Letters*, Vol.43, No 23, pp.102-112.
- MORSLI S., HABI M. (2026). Performance and assessment of future water management using the WEAP and RRV indicators in Maghnia municipality, northwestern Algeria, *Larhyss Journal*, No 66, pp. 265-295.
- N'GUESSAN BI V.H., ADJAKPA T.T., ALLECHY F.B., YOUAN TA M., ASSA Y.F. (2020). Characterization of the drought by the SPI and SPEI indices in the west center of Côte d'Ivoire case of the Lobo basin, *Larhyss Journal*, No 43, pp. 23-39.
- NAKOU T.R., SENOU L., ELEGBEDE B., CODO F.P. (2023). Climate variability and its impact on water resources in the lower mono river valley in Benin from 1960 to 2018, *Larhyss Journal*, No 56, pp. 215-234.
- NASSA R.A.K., KOUASSI A.M., BOSSA S.J. (2021). Analysis of climate change impact on the statistical adjustment models of extreme rainfall case of Ivory Coast, *Larhyss Journal*, No 46, pp. 21-48.

- NDAYIRAGIJE J.M., LI F. (2022). Monitoring and Analysis of Drought Characteristics Based on Climate Change in Burundi Using Standardized Precipitation Evapotranspiration, *Water*, Vol. 14, No 1, pp. 2511-2521.
- NICHANE M., KHELIL M.A. (2015). Climate change and water resources in Algeria - vulnerability, impact and adaptation strategy, *Larhyss Journal*, No 21, pp. 25-33. (In French)
- OGA Y.M.S., ADJA M., YAPI A.F., KPAN J.G., BAKA D. (2016). Projection of climate variability by 2050 in the coastal area in the southeast of ivory coast (Abidjan in Aboisso), *Larhyss Journal*, No 25, pp. 67-81. (In French)
- OUHAMDOUCH S., BAHIR M., CARREIRA P., CHKIR N., GOUMIH A. (2016). Climate change impact on Hauterivian aquifer of Essaouira basin (Morocco), *Larhyss Journal*, No 25, pp. 269-283. (In French)
- OUIS S. (2012). Impact of climatic fluctuations on the quantity and quality of groundwater in a semi-arid region: case of the Ghriss plain (northwest Algeria), *Larhyss Journal*, No 11, pp. 119-131. (In French)
- PALMER WC. (1965). Meteorological drought, *Weather Bureau Research No. 45*, US Dept. of Commerce, Washington DC, United States, pp. 1-58.
- PALMER WC. (1968). Keeping track of index, *Weather-wise*, Vol. 2, pp.156-161.
- PANCHAL S.L., SURYANARAYANA T.M.V. (2025). Optimized operation of a multipurpose reservoir by evolutionary algorithm for Panam reservoir project in eastern Gujarat, India, *Larhyss Journal*, No 61, pp. 31-52.
- PASTAGIA, J., MEHTA, D. (2022). Application of innovative trend analysis on rainfall time series over Rajsamand district of Rajasthan state, *Water Supply*, Vol. 22, No 9, pp. 7189-7196.
- PATIL G., KHERDE R., MEHTA D.J. (2026). Spatio temporal assessment of LULC change impacts on basin hydrology in the Indian upper Godavari basin, *Larhyss Journal*, No 66, pp. 217-234.
- POORNIMA S., PUSHPALATHA M., JANA R.B., PATTI L.A. (2023). Rainfall Forecast and Drought Analysis for Recent and Forthcoming Years in India, *Water*, Vol. 15, No 592, pp. 1-17.
- RAJPUT D.C., MISTRY K.P., BHORANIYA J.K., UMRIGAR J.N., WAIKHOM S.I. (2023). Assessing the decadal groundwater level fluctuation-a case study of Gujarat, India, *Larhyss Journal*, No 54, pp. 175-191.
- REMINI B. (2020d). Algeria: the climate is changing, the water is becoming scarce, what to do? *Larhyss Journal*, No 41, pp. 181-221. (In French)
- REMINI B. (2024). Can we ensure water security in the era of climate change? *Larhyss Journal*, No 60, pp. 297-308.

- ROUISSAT B., SMAIL N. (2022). Contribution of water resource systems analysis for the dynamics of territorial rebalancing, case of Tafna system, Algeria, *Larhyss Journal*, No 50, pp. 69-94.
- SASTRI A. (1993). Agricultural drought management strategies to alleviate impacts: examples from the arid and sub humid regions of the Indian Subcontinent, Wilhite DA (ed) *Drought assessment, management, and planning, Theory and case studies*, Kluwer Academic, Dordrecht, pp. 65-86.
- SHAIKH, M.M., LODHA, P., LALWANI, P., MEHTA, D. (2022). Climatic projections of Western India using global and regional climate models, *Water Practice & Technology*, Vol. 17, No 9, pp. 1818-1825.
- SHEWALE M. P., KUMAR S. (2005). Climatological features of drought incidences in India, *Meteorological Monograph*, National Climate Centre, IMD, Delhi, India.
- VERMA S., SAHU R.T., PRASAD A.D., VERMA M.K. (2023). Reservoir operation optimization using ant colony optimization a case study of Mahanadi reservoir project complex Chhattisgarh – India, *Larhyss Journal*, No 53, pp. 73-93.
- WILHITE D.A. (2000). Drought as a natural hazard, Concepts and definitions, *Drought: A Global Assessment*, pp 3-18.
- WMO (World Meteorological Organization) and GWP (Global Water Partnership). (2016). *Handbook of Drought Indicators and Indices* (M. Svoboda and B.A. Fuchs), (IDMP) Integrated Drought Management Programme, Integrated Drought Management Tools and Guidelines Series, No 2, pp.1-52.
- ZAMANI R., MIRABBASI R., GAJBHIYE N., MESHRAM M., AHMADI F. (2018). Spatio-temporal analysis of daily, seasonal and annual precipitation concentration in Jharkhand state, India. *Stochastic Environmental Research and Risk Assessment*, Vol. 43, No 4, pp.1085-1097.
- ZEGGANE H., GHERNAOUT R., BOUTOUTAOU D., ABDULLAH S.S., REMINI B. (2021). Multidimensional analysis of precipitation in central-northern region of Algeria, *Larhyss Journal*, No 47, pp. 209-231.
- ZELLA L., SMADHI D. (2010). Water shortage in Arab countries and the need for the use of non-conventional water, *Larhyss Journal*, No 8, pp. 149-166. (In French)