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Study of the Precipitation Concentration Index for Rahuri tehsil in Ahmednagar district, Maharashtra

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Abstract
The Precipitation Concentration Index (PCI) is a crucial parameter for assessing rainfall variability, as well as flood and drought conditions in any region. Given that Rahuri tehsil lies in a scarcity zone, determining PCI values is essential. Using monthly and annual data from 1975 to 2021, PCI values were calculated. The annual PCI values revealed variations in precipitation distribution: 36 years (78.26%) exhibited strong irregularity, 7 years (15.21%) showed irregular distribution, and 3 years (6.52%) had moderate precipitation distribution, with no instances of uniform distribution. Seasonal PCI values (June to September) indicated 100% strong irregularity in precipitation distribution, with no years showing irregular, moderate, or uniform distribution patterns. These findings demonstrate that seasonal PCI values fluctuate annually, highlighting an inconsistent rainfall pattern. The analysis of PCI can aid in crop planning based on annual and seasonal precipitation patterns for Rahuri tehsil. Additionally, PCI assessments are valuable for understanding rainfall variability, conducting hydrological studies, planning crops, and managing floods and droughts. They can also contribute to evaluating soil erosion and loss by analysing rainfall variability.

Keywords: Drought, flood, irregularity precipitation concentration index, rainfall pattern

1. Introduction
The climate of India varies due to changing monsoon and weather conditions due to its varied topography and large geographic extent in the tropic region. Extreme climate change is the biggest existential threat to the earth (Fattah *et al.*, 2024) [3]. Understanding the impacts of climate change and global warming is of paramount importance as these phenomena transcends geographical and societal boundaries. (Kinzler *et al.*, 2023) [7] Approximately 80% of the rainfall occur during the monsoon months of June to September (Nandargi and Aman, 2018 and Rahase *et al.*, 2023) [11, 17]. Rainfall is an important variable in monsoons throughout the world and the amount can vary significantly within a week or month or year (Labde *et al.*, 2024) [8]. Rainfall is generally not very abundant but spatiotemporally concentrated causing extreme and violent floods. (Salhi *et al.*, 2019) [18]. Rainfall prediction is a challenging task and the results should be accurate. (Lokesh, 2021) [9]. The Precipitation Concentration Index (PCI) is a crucial metric used in climatological studies to assess the distribution and variability of rainfall over a specific period, typically monthly, seasonally, or annually. It provides insights into the uniformity or irregularity of rainfall events, which are essential for understanding hydrological processes, managing water resources, and assessing climate variability. Accurately predicting precipitation trends is a great concern to the hydrologists and water resource planers from the past centuries as the economy, development, and livelihood of the nation greatly depend on the water resource availability of that region (Gajbhiye *et al.*, 2016) [5]. Because of the changing pattern of rainfall, some areas experience severe flooding while others experience drought conditions. As a result, the intensity and duration of rainfall play a significant role in the variability of rainfall across the country. This study used to analyse and compare the concentration of rainfall because it emphasizes on the relative distribution of rainfall irrespective of total rainfall received (Nandgude *et al.*, 2013) [12]. Some studies found that rainfall amounts and seasonal distribution have changed over the last few decades, owing to urbanization, industrial development, and

drastic changes in the environment. The precipitation concentration index is such a useful method to know the actual rainfall in that region and also to provide suitable conservation measures. The PCI is widely applied in studies related to climate change, drought monitoring, hydrological modelling, and environmental risk assessment (da Silva *et al.*,2012) [2]. Its relevance continues to grow in understanding the impacts of global climate anomalies.

2. Materials and Methodology

2.1 Study area

The main rainfall characteristics of the study area's rainfall are that it is uncertain and uneven in nature. On the basis of the last 50 years of meteorological data of Rahuri recorded by the Department of Irrigation and Drainage Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri, the area falls under the semi-arid and sub-tropical zone. (Veer *et al.*, 2024) [19] The study area located between Latitude 19°24'and Longitude 74°39'. (Rajmane *et al.*, 2023a and Viswanatha *et al.*, 2019) [14, 20].

2.2 Data acquisition

The historical data on different weather parameters was collected from:

1. Department of Irrigation and Drainage Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri
2. India Meteorological Department, Pune (https://dsp.imdpune.gov.in/data_supply_service.php; Rajmane *et al.*, 2023b) [15]
3. Department of Agricultural Meteorology, College of Agriculture, Pune.

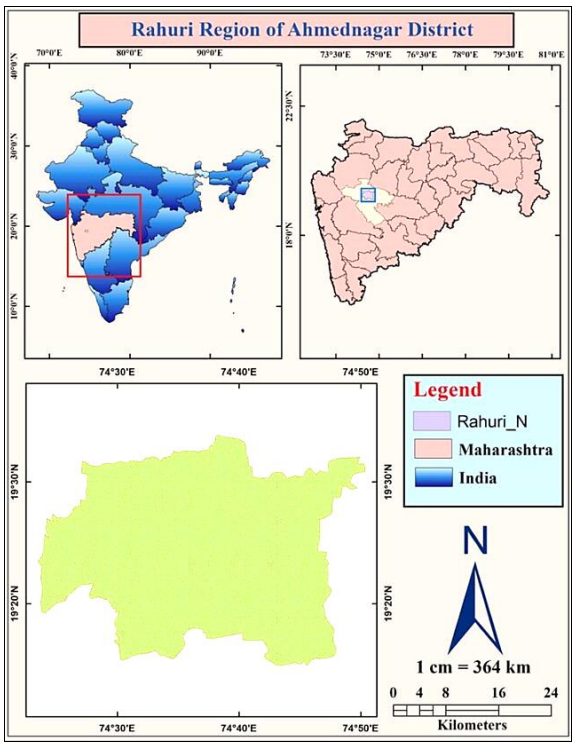

Fig 1: Study Area

2.3 Determination of Precipitation Concentration Index

Monthly rainfall data for the period 1975-2023 has been used in the analysis of the PCI Index. The seasonal (Jun-Sept) and annual PCI were estimated for the Rahuri on the basis of rainfall data to know the concentration and variation of rainfall. The PCI was estimated on an annual and seasonal scale, using a modified version of PCI to estimate the monthly heterogeneity of rainfall (Oliver, 1980) [13]. Proposed the precipitation concentration index (PCI), Uniform Precipitation distribution was denoted if the PCI Values are less than or equal to 10 and Moderate Precipitation Distribution is considered as if the values are between 10 to 15, and irregular precipitation distribution is denoted as the PCI Values between 16 to 20 and strong Irregular precipitation distribution considered if the PCI Values are more than 20. The long-term variability in the rainfall amount on the seasonal and annual scale was obtained through PCI and it was calculated using the following equations:

$$PCI\ annual = \frac{\sum_{i=1}^{12} Pi^2}{\left(\sum_{i=1}^{12} Pi^2\right)} * 100$$

$$PCI\ seasonal = \frac{\sum_{i=1}^{4} Pi^2}{\left(\sum_{i=1}^{4} Pi^2\right)} * 33.33$$

Where- P_i is the monthly precipitation in a month i.

The number 100 in the formula for the annual PCI (eq.1) represents 12 months of the year signifying 100% and the number 33 for the seasonal PCI (eq.2) represents the four monsoon months in each season, which equals 33%.

2.4 Trend detection test

In this study, the modified Mann–Kendall test (MMK), which is a nonparametric test, was used for detecting the trends in both seasonal and annual precipitation, and SPCI and APCI series. In the ordinary form of MK test, the S statistics defined as follows (Mann, 1945; Kendall, 1975) [10, 6]:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k)$$

where n is the data set length, xj is the value of jth data and sgn(x) is the sign function which is defined as follows:

$$\mathrm{sgn}(x) = \begin{cases} +1 & if\,(x_j - x_k) > 0 \\ 0 & if\,(x_j - x_k) = 0 \\ -1 & if\,(x_j - x_k) < 0 \end{cases}$$

when n C 8, the S statistic is almost normally distributed with the mean of E(S) = 0 and following variance:

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

where m presents the number of tied groups, and t_i is the size of the i^{th} tied group. The test statistic of MK (Z_{MK}) can be computed as:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\,S > 0 \\ 0 & if\,S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if\,S < 0 \end{cases}$$

The MMK was proposed by Hamed and Ramachandra Rao (1998) and has been employed in a wide number of studies of trend analyzing very often (Dinpashoh *et al.*, 2013; *Gajbhiye et al.*, 2015; Akinsanola and Ogunjobi, 2015; Zamani *et al.*, 2016) [4, 5, 1, 21]. In this version of MK test, the impact of all considerable autocorrelation structure is eliminated from the data set. Therefore, Var(S)* as the modified variance is defined as:

$$Var(S)^* = Var(S)\frac{n}{n^*}$$

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)(n-2)}\sum_{i=1}^{n-1}(n-i)(n-i-1)(n-i-2)r_i$$

where n is the actual number of observations, n* is the sample size, which is effective, and r_i is the lag-i significant autocorrelation coefficient of the i^{th} rank of time series and defined as:

$$r_i = \frac{\frac{1}{n-i}\sum_{j=1}^{n-i}(x_j - \bar{x})(x_{j+i} - \bar{x})}{\frac{1}{n}\sum_{j=1}^{n}(x_j - \bar{x})^2}$$

where n is the data set length, x_j is the value of j^{th} data and x the average value of the data set.

The Z statistic of MMK is computed by substituting Var(S)* in eq.6. It is noteworthy that when $-Z_{1-\alpha/2} <= Z <= Z_{1-\alpha/2}$, the null hypothesis (no trend) is accepted at the significance level of a. Else, the null hypothesis will be unacceptable and the other possible hypothesis will be taken at the significance level of a (Dinpashoh *et al.*, 2013) [4].

2.5 Software used for Analysis

For the analysis, we utilized R software (R studio 2024.04.2) to perform the Mann-Kendall test, which helped in identifying trends within the precipitation data. Additionally, R was used for graph plotting to visualize temporal variations and trends effectively. Microsoft Excel was employed for data organization, basic calculations, and preliminary statistical assessments. Furthermore, Weather Cock software was used for the conversion of daily precipitation data into seasonal, monthly, and annual datasets, ensuring accurate aggregation and facilitating further analysis of precipitation distribution patterns.

3. Results and Discussion

3.1 Statistical analysis of rainfall data

Table 1 shows the statistical parameters of rainfall data of 52 years (i.e. 1975 to 2023) for the Rahuri tehsil in Ahmednagar district. September month shows the highest monthly rainfall followed by June, August, and July. The average annual rainfall of Rahuri is about 599.82 mm. The standard deviation and range of September, June, August and July has a high value which shows high uncertainty in rainfall data. The coefficient of variance of June, July, August, and September is less than 0.7 which indicates lower variability from the mean. The coefficient of variance of annual rainfall is 0.05 which is less. It indicates a high reliability of the experiment like trend analysis, forecasting, etc. All positive kurtosis value of data indicates a peaked distribution of rainfall data. Also, all positive values for the skewness indicate that data are skewed to the right to normal distribution.

Table 1: Statistical summary of rainfall data for Rahuri tehsil in Ahmednagar district

Parameters	Mean	S.D.	C.V.	Skewness	Kurtosis
January	2.13	5.04	2.36	2.78	7.14
February	2.31	8.03	3.48	4.85	26.50
March	5.97	10.33	1.73	2.25	5.79
April	5.63	12.31	2.19	3.17	10.24
May	16.96	27.31	1.61	2.36	6.06
June	112.33	75.51	0.67	0.95	0.72
July	88.49	58.22	0.66	0.75	0.29
August	94.43	66.98	0.71	0.68	-0.35
September	162.26	109.32	0.67	0.45	-0.86
October	76.36	76.84	1.01	1.67	3.40
November	24.22	34.92	1.44	1.81	2.82
December	8.75	27.20	3.11	4.36	21.48
Annual	599.82	32.45	0.05	2.17	6.94

3.2 Precipitation Concentration Index

3.2.1 Annual Precipitation Concentration Index

Table 2: Percentage of total years of PCI ranges for annual precipitation concentration index.

Sr. No.	Remark	PCI Values	No. of years	Per cent of total years
1	Uniform Precipitation Distribution	< 10	0	0
2	Moderate Precipitation Distribution	10 to 15	0	0
3	Irregular Precipitation Distribution	16 to 20	19	38.77
4	Strong Irregularity Precipitation Distribution	> 20	30	61.23
	Total		49	100.00

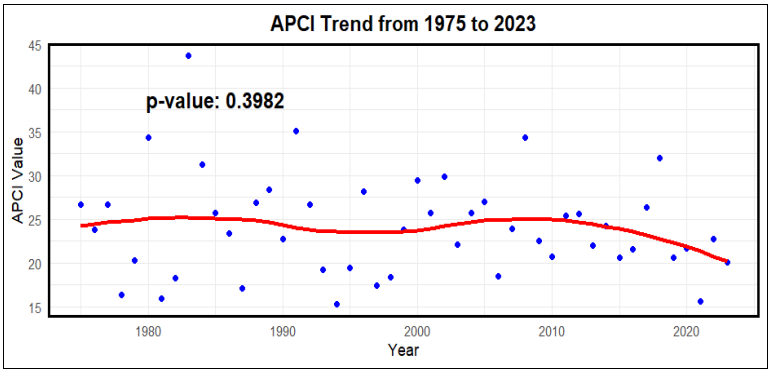

Fig 2: Annual Precipitation Concentration Index

3.2.2 Seasonal Precipitation Concentration Index

Table 3: Percentage of total years of PCI ranges for seasonal precipitation concentration index.

Sr. No.	Remark	PCI Values	No. of years	Per cent of total years
1	Uniform Precipitation Distribution	< 10	0	0
2	Moderate Precipitation Distribution	10 to 15	0	0
3	Irregular Precipitation Distribution	16 to 20	0	0
4	Strong Irregularity Precipitation Distribution	> 20	49	100
	Total		49	100

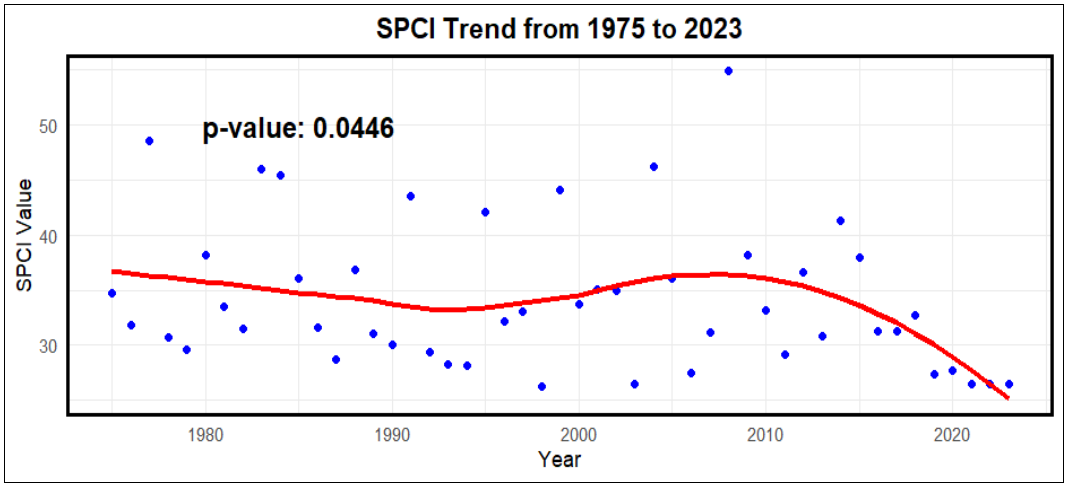

Fig 3: Seasonal Precipitation Concentration Index

3.2.2 Comparison of Annual and Seasonal Precipitation Concentration Index

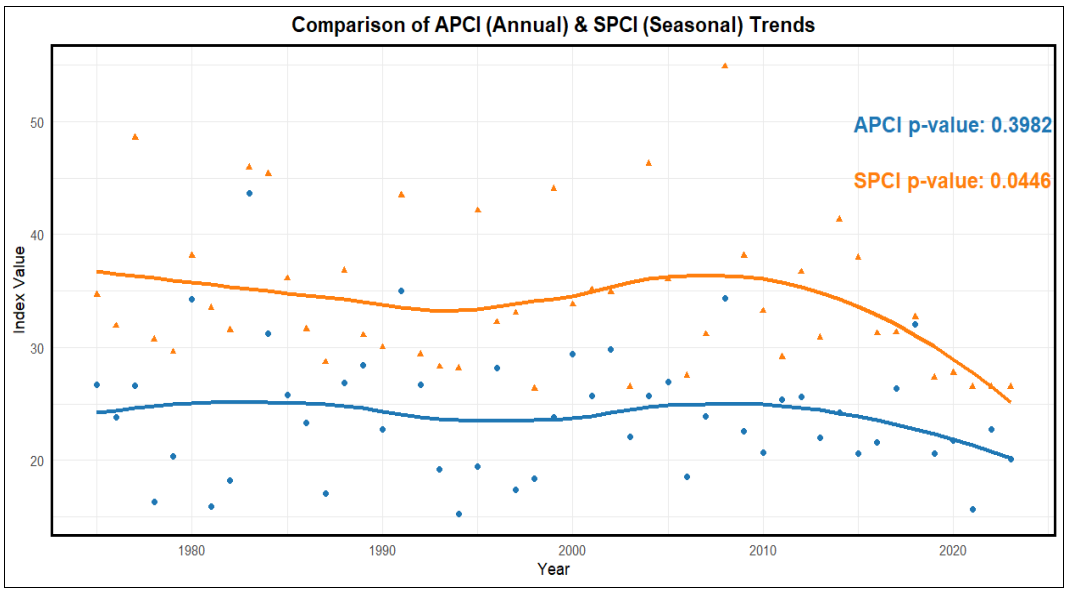

Fig 4: Comparison of APCI (Annual) and SPCI (Seasonal) Trends

4. Conclusion

Using monthly and annual data from 1975 to 2021 PCI values were estimated. Annual PCI values show variation in PCI ranges. The Annual PCI index contains 30 years of strong irregularity of precipitation distribution having 61.23% of total years, 19 years of irregular precipitation distribution having 38.77% total years of total years and no uniformity range found while seasonal (Jun-Sept) shows 100% strong irregularity of precipitation distribution. It means there was no irregular precipitation distribution, no moderate precipitation distribution, and no uniform precipitation distribution. It is seen that seasonal values of PCI varies yearly and have irregularity in rainfall pattern. Analysis of PCI will help in crop planning accordingly annual and seasonal PCI ranges for the Rahuri tehsil.

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