Seasonal rainfall trend analysis during 1951 – 2020 in Madhya Pradesh, India

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Abstract – In this study, we investigated the spatial and temporal changes of rainfall using high resolution gridded dataset over Madhya Pradesh. For statistical trend analysis used long term 70 years (1951 - 2020) time series and Mann Kendall test for trend analysis and Sen's slope estimator for detection of change in magnitude of rainfall. With the help of 'Pre whitening' technique remove the serial correlation in time series then applied Modified Mann Kendall test. In our study all the test is done at 5% significance level. The change in magnitude of rainfall found in seasonal basis. For temporal study the time series is divided into pre industrial (1951 - 1985) and post industrial (1986 - 2020) time period and compare the both. For trend analysis we used R studio and two open source packages 'trend' and 'modifiedmk' and for representation of spatial distribution in maps we used Arc GIS 10.3.1 and also represent significance level of trend.

In seasonal study, pre monsoon season pre industrial time series shows the increasing trend as compare to post industrial and maximum changes in magnitude is occurred in Barwani and Balaghat district. In monsoon time period Madhya Pradesh region shows the mixed trend all over region, some district shows increasing trend and some shows decreasing trend. When we compare pre industrial time period to post industrial period, the post industrial shows the increasing trend. Maximum change (+0.3922 mm/yr) occurred in Dhar district in Post industrial time and maximum decreases (-0.3286 mm/yr) in Bhind district in pre industrial time. The spatial – temporal maps of variability of rainfall can provided invaluable information to water resources management policy makers & decision makers, also helpful for planning and management of water resources as well as hydrological study in Madhya Pradesh

1. Introduction

Rainfall is the most important hydro-climatic parameter, which spatial and temporal variability affects the hydrological cycle and environment. Trend analysis is helpful for detection of magnitude of climate change and also useful for hydro-meteorological studies. The spatio-temporal rainfall trend analysis is important to deal with water resources planning

& management, drought & flood assessment, agricultural planning etc (Tabari, 2011). Trend analysis can be defined as detection, prediction and estimation of trend associated with physical and statistical significance. Time series a collection of value of particular variable over a time in sequential manner (Hann, 1977). The time interval for a hydrological data is hourly, daily, monthly, seasonal or yearly. Time series analysis would describe the time dependent characteristics of hydrological variables and also helpful for prediction of the future values. Four steps involved in time series analysis (McCuen, 2003).

(a) Detection, (b) Analysis, (c) Synthesis, (d) Verification.

Apart from statistical analysis of hydrological time series, the application of analysis includes development of mathematical models, to forecast the extreme event, identify trend, missing value observation etc. (Salas, 1993).

Rainfall is the primary components of the hydrological cycle and understanding the patterns of its variability plays a vital role in understanding the aspects of hydrological, meteorological, climatological and agricultural studies worldwide. The spatial and temporal rainfall trend analysis is an important measure in analysis of rainfall pattern and detection of change point of rainfall pattern and detect the shift of monsoon period. For different climate studies the rainfall and temperature impact the hydrological process and rainfall trend analysis on different spatial scale (local & regional scale) will help in development of future climate scenarios (Panda, 2019). This is mainly done on the seasonal and monthly basis for detecting the change in magnitude. Understanding the uncertainties about rainfall pattern and changes will give idea for better management of water resources in agricultural field, policy decision regarding the cropping pattern, sowing date etc.(Jaiswal, 2015, 2017, 2018) and useful for the study about extreme events like flood and droughts (Harsha, 2017). Analysis of spatial and temporal changes of long-term rainfall distribution at a local scale is very important for the prevention & mitigation of water-related disasters (flood, drought, cyclones etc.) (Jaiswal, 2021).

According to India Meteorological Department (IMD) season over India are (https://www.imdpune.gov.in/Weather/Reports/glossary) –

1. Winter Season – January, February
2. Pre monsoon season – March, April, May
3. South – west monsoon season – June, July, August, September
4. Post monsoon season - October, November, December

Trend analysis is quantification of changes occurs in a region over a long time period using different statistical methods. Trend occurs in two ways – 1. Monotonic trend, 2. Step trend. Monotonic trend shows a gradual change over a time period and step trend shows the abrupt shift at a specific point in time (Donald, 2011).

Mainly two types of tests for trend analysis: - (Padhiary, 2018)

1. Parametric test
2. Non parametric test

Parametric test – In this test data have normally distributed and multiple points have same variance. Example - Pearson's correlation coefficient, regression analysis etc.

Non parametric test – In this test data does not follow normal distribution, so the variance is not same at multiple points, it includes missing values which are encourage in hydrological time series analysis (Duhan, 2012). Example – Mann Kendall test, Modified Mann – Kendall test, Sen's slope test, Spearman's rank correlation etc. Various researcher prefers non parametric test over parametric. Some of the advantages of non-parametric test –

- Assumption of normality and homogeneity is not required.
- Compare median rather than mean.
- Due to skewed distribution greater power achieved.
- Transformation of data not required (Helsel, 1987).

South – west monsoon dominated in India and about 80% rainfall occurs in four months (June, July, August, September) of monsoon period. In India, north India shows rainfall decreasing trend except Saurashtra, Haryana and western part of Rajasthan shows increasing trend & south India also shows increasing trend except middle Maharashtra and Kerala (Basistha, 2007). Chhattisgarh, East Madhya Pradesh and Vidarbha experienced decreasing rainfall trend (Kumar, 2010). Due to the climate change frequency and magnitude of extreme rainfall event increases and decreases the moderate rainfall events. The summer monsoon rainfall over India decreases by 6% and central India shows in increases in extreme precipitation events. In Madhya Pradesh western MP shows increasing trend and east MP shows the decreasing rainfall. Maximum decreases in rainfall in Balaghat and minimum in Shahdol (Duhan, 2012).

This paper focuses on understanding the long term (1951-2020) rainfall trend in seasonal basis, also compare pre industrial (1951-1985) and post industrial (1986-2020) trend at regional scale utilizing the high-resolution gridded data (0.25° X 0.25°, 515 grids) over Madhya Pradesh.

2. Study area and data used

2.1 Study area – The Madhya Pradesh is heart of the India and its situated north – central part of Peninsular plateau and has ten major rivers. These rivers are follows: - Narmada, Ken, Betwa, Chambal, Son, Mahanadi, Tapi, Mahi, Wainganga and Kunwari sindha. Narmada is the longest river in MP.

Table 1 Geographical structure of Madhya Pradesh

Area	308252 Km^2
Latitude	21°60' - 26°30'
Longitude	74°59' - 82°66'
District	52
Major crops	Rice, Wheat, Jowar, Soyabean, Cotton

The rainfall of Madhya Pradesh depends on south – west monsoon. During monsoon period MP receives 85% of rainfall i.e. 100 -125 c.m. The hilly and plateau region receives more rainfall compare to plains. Table 2 shows the rainfall distribution in Madhya Pradesh.

Table 2 Rainfall distribution on the basis of intensity of rainfall

Area with excess rainfall (More than 150 cm)	South – Eastern area of Madhya Pradesh – Pachmarhi (Highest – 215 cm), Mandla, Sidhi, Balaghat
More than average (125 – 150 cm)	Eastern area of Madhya Pradesh - Betul, Chhindwara, Seoni, Narsinghpu
Areas with Average Rainfall (75 – 100 cm)	North-Eastern part - Central highlands, plateau of Bundelkhand, Rewa-Panna plateau
Areas with Minimum Rainfall (50 – 75 cm)	Western areas - Neemuch, Mandsaur, Ratlam, Dhar, Jhabua, Bhind (Lowest rainfall)

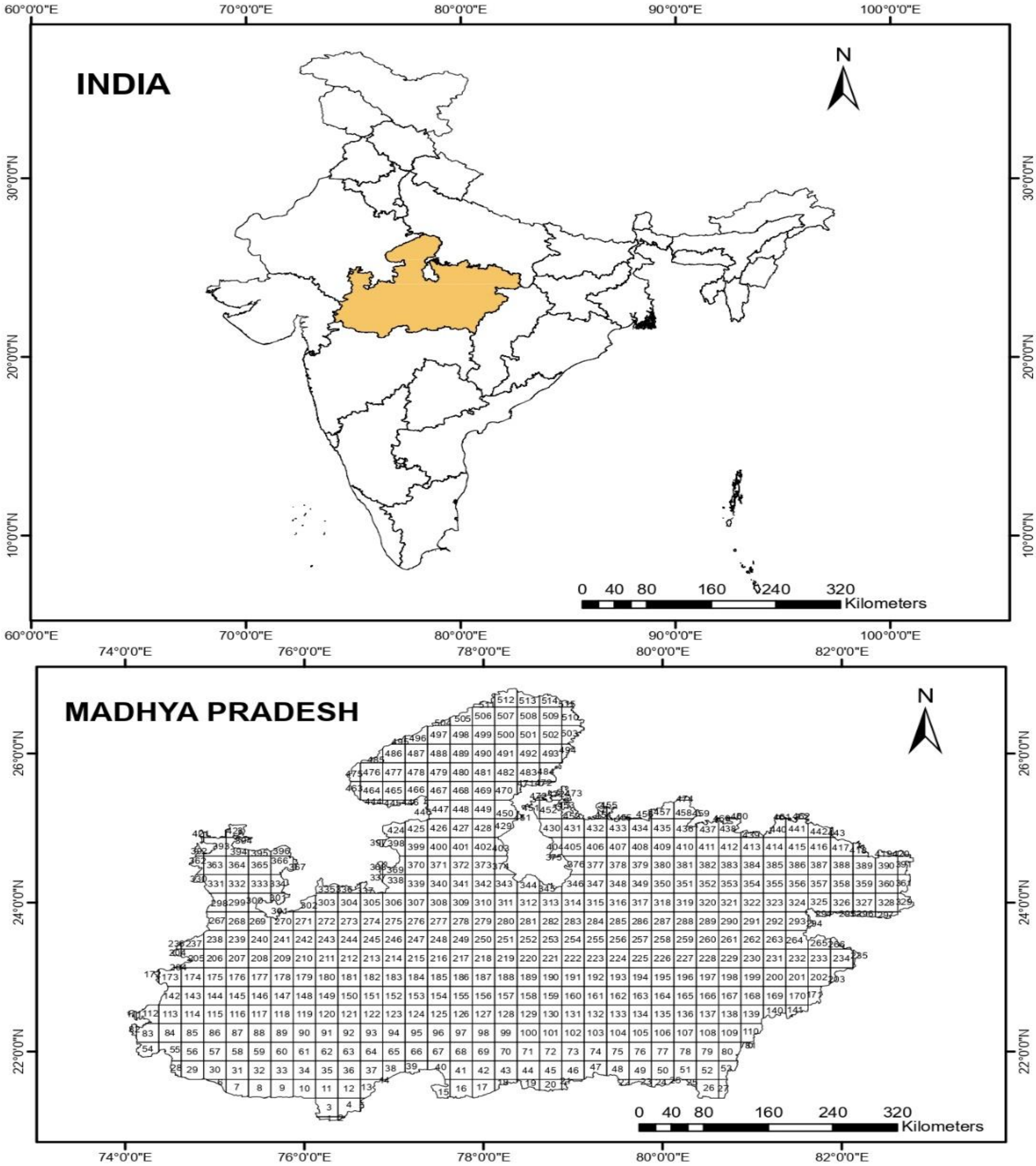

Figure 1 – Index map of Madhya Pradesh (Gridded map - 0.25° X 0.25°)

In winter the mean minimum temperature is 10 °C and its drops as low 1 °C and rise to mean maximum temperature is 25 °C. In the summer season, the temperature in the entire Madhya Pradesh above 29.4 °C. The region like Gwalior, Datia & Morena record temperature over 42°C and eastern part of Madhya Pradesh are warmer than western parts. The highest temperature reaches 49 °C in some parts of Madhya Pradesh.

2.2 Data collection - The high spatial resolution gridded daily precipitation dataset (0.25° x 0.25°) was obtained from Indian Meteorological Department. The Madhya Pradesh region consist of total 515 grid points (shown in figure 3.2). Daily rainfall data from 1951 to 2020 was used for the trend analysis and mean rainfall pattern. For trend analysis daily rainfall data converted into monthly and seasonal time series for each grid points.

The complete dataset is divided into two parts: -

1. Pre industrial (1951 - 1985)
2. Post Industrial (1986 - 2020)

About IMD dataset (Pai 2014, Rajeevan 2008, Srivastava 2009) –

- Before releasing dataset, IMD checks the standard quality measure which consists of extreme value check, homogeneity, missing data check and duplicate station check etc.
- Inverse weighted interpolation technique is used for interpolation of rain gauge values and 6955 rain gauge station was used for construction of gridded dataset.

3. Methodology –

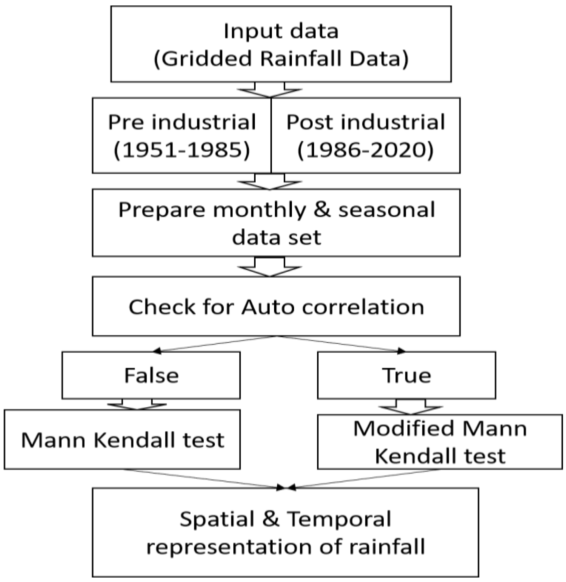

Figure 2 - Methodology

Figure 2 represented the methodology adopted in research work. Mann – Kendall, Modified Mann – Kendall & Sen's slope estimator used for trend detection.

3.1 Mann Kendall test

Mann Kendall test is the non-parametric test for exploring the trend of the time series. Mann (1945) used the test and Kendall (1975) derived the test statistics distribution. This this is widely used for hydrological time series analysis and excellent tool for trend detection.

If the null hypothesis H_o of trend test is accepted that there is no trend and data are independent and random. If the alternative hypothesis H_1 is accepted then trend is present in time series which depend on test statistics.

The Mann Kendall test statistics calculated as –

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\ (x_j - x_i)$$

Where

Time series $X_i = x_1, x_2, x_3, \dots \dots.., x_n$

n = Number of data points

x_j and x_i = Data values in time series i and j ($j > i$)

$sign\ (x_j - x_i)$ is the sign function as

$$\text{Sign}\ (x_j - x_i) = \begin{cases} -1 & if \quad (x_j - x_i) < 0 \\ 0 & if \quad (x_j - x_i) = 0 \\ -1 & if \quad (x_j - x_i) > 0 \end{cases}$$

Variance V(S) as given below:

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{m} t_k(k)(k-1)(2k+5)}{18}$$

m = number of tied groups

t_k = number of ties of extent k (Tied group is set of data with same values)

Standardized test statistic Z given below

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{var(S)}} \ if\ S > 0 \\ \quad 0 \quad if\ S = 0 \\ \dfrac{S+1}{\sqrt{var(S)}} \ if\ S > 0 \end{cases}$$

A positive sign of the Z indicates an increasing trend and a negative sign indicates a decreasing trend. When Z > $Z_{1-\alpha/2}$ the null hypothesis is rejected then a significant trend exists in the time series $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table.

3.2 Theil-Sen approach

The Theil Sen's slope estimator is developed by Theil (1950) and Sen (1968). The Kendall slope (β) is initially given by Sen for finding the trend magnitude. This test is also known as Sen's slope estimator. This test is widely used for the finding of trend magnitude of hydro-meteorological time series. Following steps involved in Theil Sen approach –

- The interval between time series is equally spaced at data points.
- Data is shorted in ascending order, then the Sen's slope is calculated as,

$$\beta_i = \frac{x_j - x_k}{j-k}, \ \mathrm{k} \leq j \ and \ i = 1,2,\ldots\ldots,n$$

- The total N values β_i of are ranked from smallest to largest and the median of Sen's estimator of slope β computed as

$$\beta = \begin{cases} \dfrac{\beta_{\frac{N+1}{2}}}{2}, & if\ N\ is\ odd \\ \dfrac{\beta_{\frac{N}{2}} + \beta_{\frac{N+2}{2}}}{2}, & if\ N\ is\ even \end{cases}$$

The sign of β reflect the trend of time series. If positive then increasing trend or negative shows the decreasing trend.

3.3 Removal of serial correlation effect (Modified Mann Kendall test)

In Mann Kendall test required that the time series is serially independent but some time serial correlation is presented in dataset. When serial correlation is present in data, the null hypothesis to be falsely rejected and significance level increased when positive serial correlation in time series (Von storch, 1995). If the significance level to be underestimated, then the negative serial correlation present in data (Yue, 2002). A pre whitening method is used for removal of serial correlation (Yue, 2002). This is used for removal of lag 1 auto correlation. The following steps are adopted for detection and removal of serial correlation: -

- Find the lag 1 serial coefficient (r_1) using auto correlation function of sample data X_i. It can be calculated by

$$r_1 = \frac{\frac{1}{n-1}\sum_{i=1}^{n-1}(x_i - E(x_i))(x_{i+1} - E(x_i))}{\frac{1}{n}\sum_{i=1}^{n}(x_i - E(x_i))^2}$$

$$E(X_i) = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Where

$E(X_i)$ = mean of sample data

N = number of observations in the data.

Using the following range for finding serial correlation (Salas, 1980).

$$\frac{-1-1.645\sqrt{n-2}}{n-1} \leq r_1 \leq \frac{-1+1.645\sqrt{n-2}}{n-1}$$

- If the r_1 lies inside the above interval, then the time series is independent.
- In case r_1 outside, the data is serially correlated.
- If the data is independent MKT is applied, if serially correlated then used MMKT and 'Pre whitened' time series may be obtained (von Storch, 1995). ($x_2 - r_1x_1,\ x_3 - r_1x_2$...........)

4. Results and discussion

4.1 Spatial Seasonal Trend Analysis –

Figures 3 and 4 represent the seasonal rainfall variation and compare with pre-industrial and post- industrial time period.

Figure 3 represents winter and pre monsoon season rainfall variability. In winter the change in magnitude of rainfall is negligible except south – east part of MP in post-industrial time period shows decreasing trend as compare to pre-industrial time period. In pre monsoon season MP shows no change in rainfall.

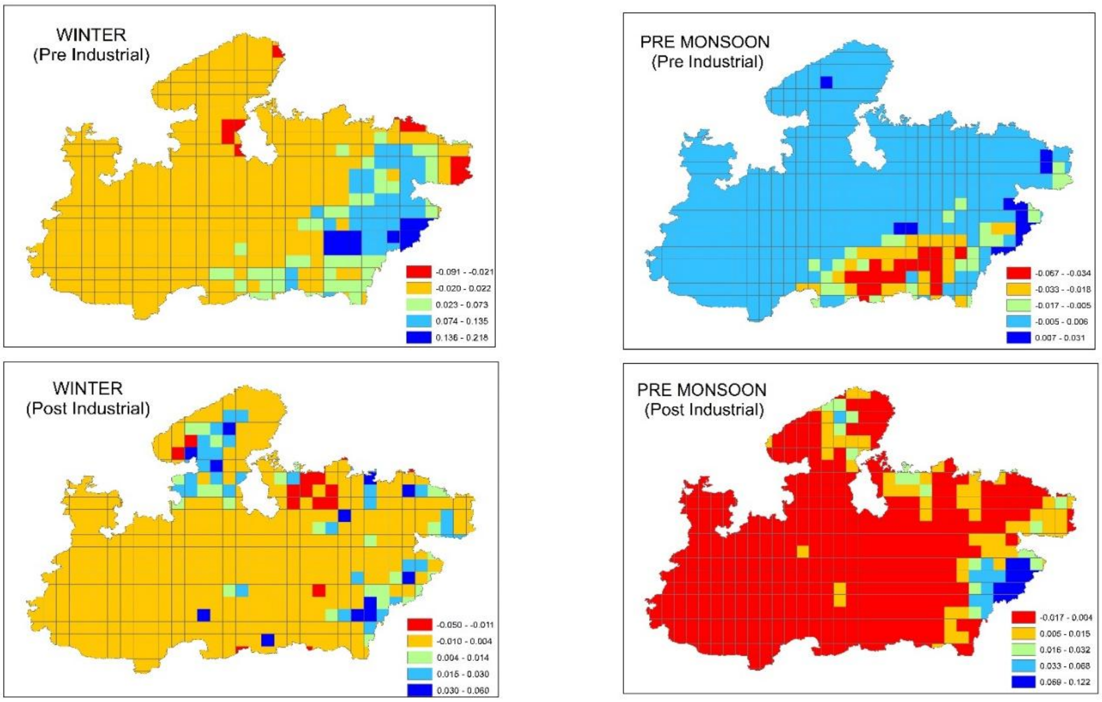

Figure 3 - Change in magnitude of rainfall in Winter & Pre monsoon season over Madhya Pradesh region

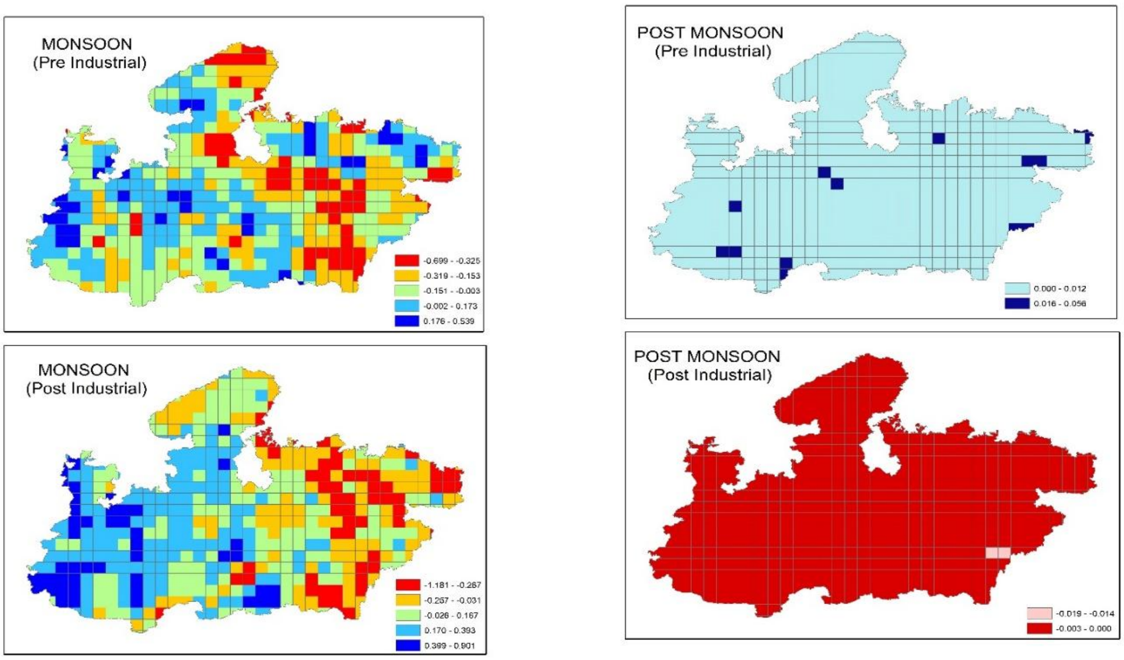

Figure 4 - Change in magnitude of rainfall in Monsoon & Post Monsoon season over Madhya Pradesh region

Figure 4 shows monsoon and post monsoon season. In monsoon season shows mixed trend except west part of MP indicate increasing trend in post-industrial time period compare with pre- industrial period and north MP shows the decreasing trend. In post monsoon no change in magnitude of rainfall.

4.2 Temporal Trend Analysis of Rainfall –

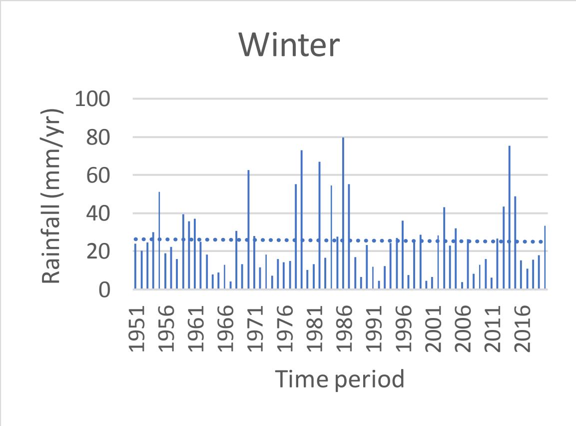

Figure 5 - Long term rainfall trend in Winter

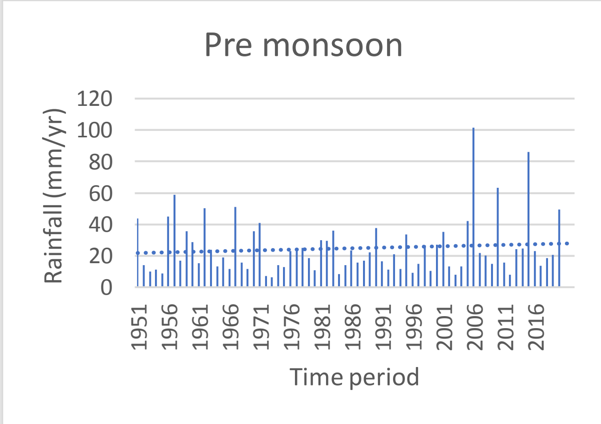

Figure 6 - Long term rainfall trend in Pre-Monsoon

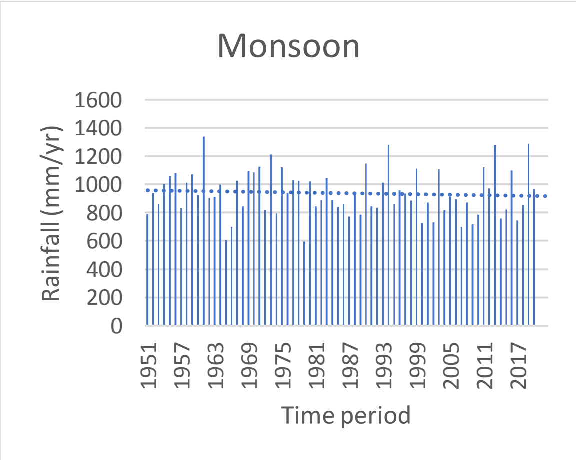

Figure 7 - Long term rainfall trend in Monsoon

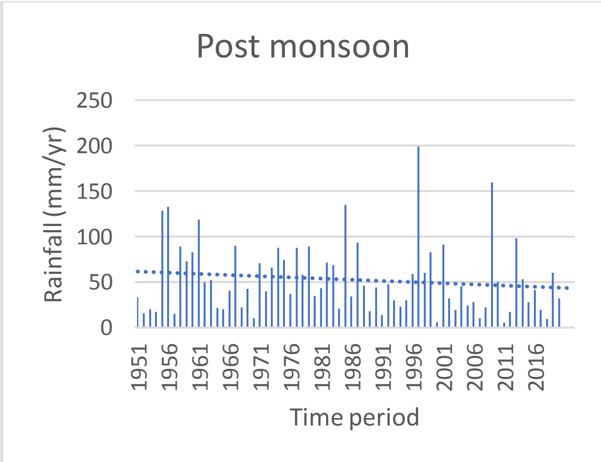

Figure 8 - Long term rainfall trend in Post-monsoon

Figure 5, 6, 7 and 8 represented the long-term rainfall pattern of season winter, pre monsoon, monsoon & post monsoon respectively. Linear dotted trend line shows the pattern of rainfall. In winter shows the slightly decreasing pattern of rainfall and maximum rainfall occurs in 1987. In pre monsoon season the increasing trend of rainfall is shown & last two decade the intensity of rainfall increases. In monsoon period the rainfall intensity decreases in long term time period. Post monsoon season also represent the decreasing trend.

4.3 Seasonal change in magnitude of rainfall -

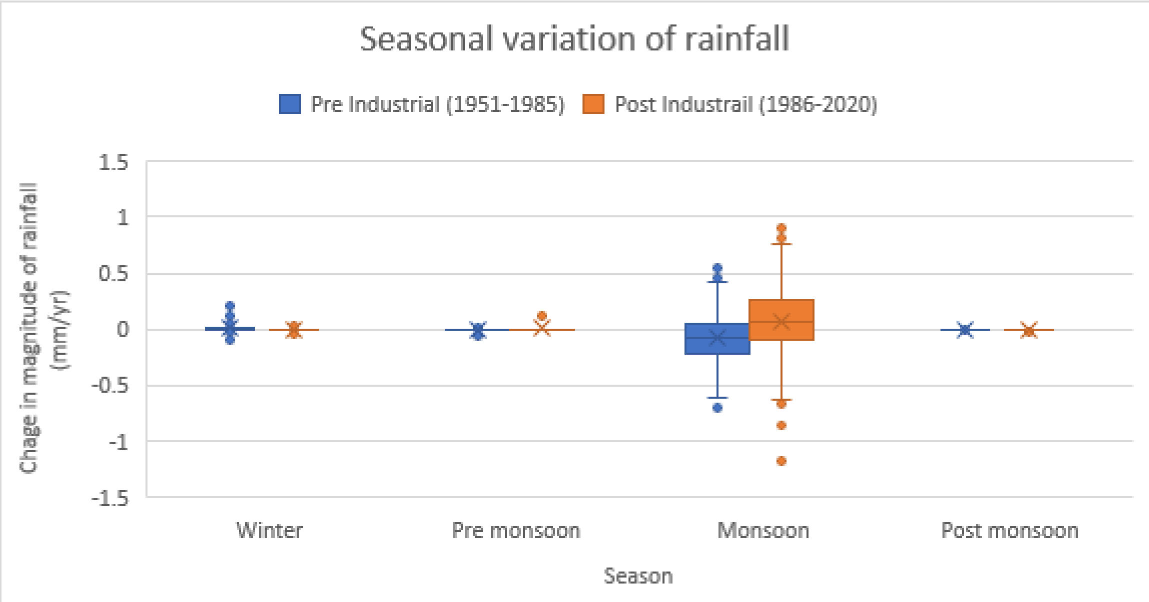

Figure 9 Long term change in magnitude of rainfall (Seasonal)

Figure 9 represented the seasonal analysis of change in magnitude of rainfall. In winter season, positive change in magnitude of rainfall decreases in post industrial period as compared to pre industrial period. Pre monsoon season and monsoon season shows the positive rainfall trend in post industrial time period. Post monsoon season shows no variation in rainfall trend.

5. Conclusion

In the present study we have investigated the rainfall variability and pattern and also find the change in magnitude of rainfall based on 70 years long term time series. In this analysis we considered seasonal and monthly scale. For temporal we considered 70 years rainfall data and again divided into two parts pre-industrial and post-industrial. In pre monsoon season pre industrial time period shows the increasing rainfall trend as compare to post industrial time period. The maximum increase (+0.2814 mm/yr) in change in magnitude of rainfall shows in Barwani district in post industrial time period & maximum decrease (-0.2812 mm/yr) in Balaghar in post industrial time period. In monsoon time period Madhya Pradesh region shows the mixed trend all over region, some district shows increasing trend and some shows decreasing trend. When we compare pre industrial time period to post industrial period, the post industrial shows the increasing trend. Maximum change (+0.3922 mm/yr) occurred in Dhar district in Post industrial time and maximum decreases (-0.3286 mm/yr) in Bhind district in pre industrial time. In post monsoon and winter season shows the negligible change in magnitude of rainfall. This study is limited with rainfall trend analysis using long term time series. For future work we considered the other climatic factors like temperature, heat waves, stream flow pattern and analyzed the extreme rainfall pattern (flood & drought events), these factors helpful for better understanding about climate condition.

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