RESEARCH ARTICLE

# STUDY OF SOUTH-WEST MONSOON RAINFALL SCENARIO IN MEERUT DISTRICT

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**Abstract:** Rainfall is one of the most important climatic variables and renewable natural source of water on the earth. Meerut District is the part of Upper Ganga-Yamuna doaba which lies between $28^0$.98' & $29^0$.15' north latitude and between $77^0$.45' & $77^0$.07' east longitude. The objective is to compute properties of a long period of time series is broken into separate components and analyzed individually to understand the pattern of rainfall. The annual and monthly rainfall data used for observed trend during long period. Analysis of rainfall data of a century (1916-2015) over Meerut plays a significant role in the agricultural and urbanization contribution and in the overall growth of the District. The data of annual rainfall and S-W rainfall is 689.6mm and 587.2mm respectively. The monthly south-west monsoon rainfall variability in years is observed maximum after 21th century. It is most important period of rainfall seasonal cycle. The analysis data of S-W monsoon observed highest rainfall 85.2% and lowest rainfall in post monsoon season 4.4%. The anomalous departures from the mean were observed the highest positive and negative departure from the mean of approximately -459.1 & 457.5 in year 2009 and 1933 respectively. The analysis included variability of rainfall, trends in rainfall pattern and changes in spatial and temporal patterns of Precipitation Ratio (PR) and Monsoon Precipitation Index (MPI). The maximum abnormality 2.46 and -2.04 in annual rainfall was recorded during 1933 & 2009. It is seen that the average MPI varied from 0.63 to 0.77. The trend in the annual rainfall showed that the rainfall decreasing in the area whereas south-west rainfall declined pattern of 3% changes was also observed in the century. The standardized anomalies results obtained show a fluctuating rainfall pattern across the years over Meerut District which makes it hard to freely forecast rainfall trend for a future season. The rainfall data analysis of Meerut District for a period of 100 years (1916 to 2015) reveals variation in the rainfall amount and points out a negative trend of rainfall in future. The information is useful for agriculturists and policy makers on critical issues is it affects seasonal agricultural practices such application of agricultural inputs, water resources maintenance and management practices. The global climate and the local environmental changes are the chief factors for the variation in rainfall over the recent times. The knowledge of current situation of weather and climate change related pattern and adaptation of technology is maintend trend. Uncertainty on the dates of monsoon onset and its withdrawal also puts a great problem before the farmers.

**Keywords:** Anomalies, Climate change, MPI, PR & South-west monsoon

## INTRODUCTION

Rainfall is one of the most important climatic variables and renewable natural source of water on the earth. The rainfall patterns have temporal and spatial variability due to seasonal atmospheric phenomenon and geographical factors respectively. The rainfall received maximum coverage area during south west monsoon season: June to September month (Attri & Tyagi, 2010). The variations in rainfall patterns are vital to understand the climate change variations. The variability in rainfall may affect the agriculture production, water supply, transportation, the entire economy of the region, and the existence of its people.

The assessment of climate change is done through statistical analysis of certain meteorological parameters such as annual, seasonal rainfall. Climate change has become big threat for agriculture, livestock, and biodiversity environment. Meerut district has main season in a year (IMD's season). These are: the winter season (January- February.), Pre –Monsoon season (March- May), South West Monsoon season (June-September) and, the Post Monsoon Season (October- December). The south westerly wind flow occurring over most parts of India and Indian seas gives rise to south west monsoon over India from June to September. South-west monsoon provides a major part of India's annual rainfall, and the quantum varies widely across space (GOI, 1999). In most places, growing crops require artificial provision of water during non-monsoon season and in some places even during the monsoon. Weather parameters mainly rainfall, its distribution pattern and quantum play an important role in productivity crops. The prediction of rainfall further helps in planning the activities of agriculturists, water supply professionals or engineers, and others.

### Study Area

Meerut District is the part of Upper Ganga- Yamuna doaba which lies between $28^0$.98' & $29^0$.15' north latitude and between $77^0$.45' & $77^0$.07' east longitude (Abst. & Souv., 2016). The altitude / elevation (above sea level) of the city are 224.6 m (Fig.1). The

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district is spread across 2564 square kilometer .The land of district is very fertile which is known as alluvial soil or loamy soil deposits by Ganga. Meerut has humid subtropical type climate which is characterized by cool winters and very hot summers. The average annual rainfall of Meerut is about 805.98 mm (Kumar *et al*., 2009). About 80% of the rainfall is received during the south west monsoon (Jain &Kumar, 2012)). The monsoon begin by the end of June and last till the end of September.

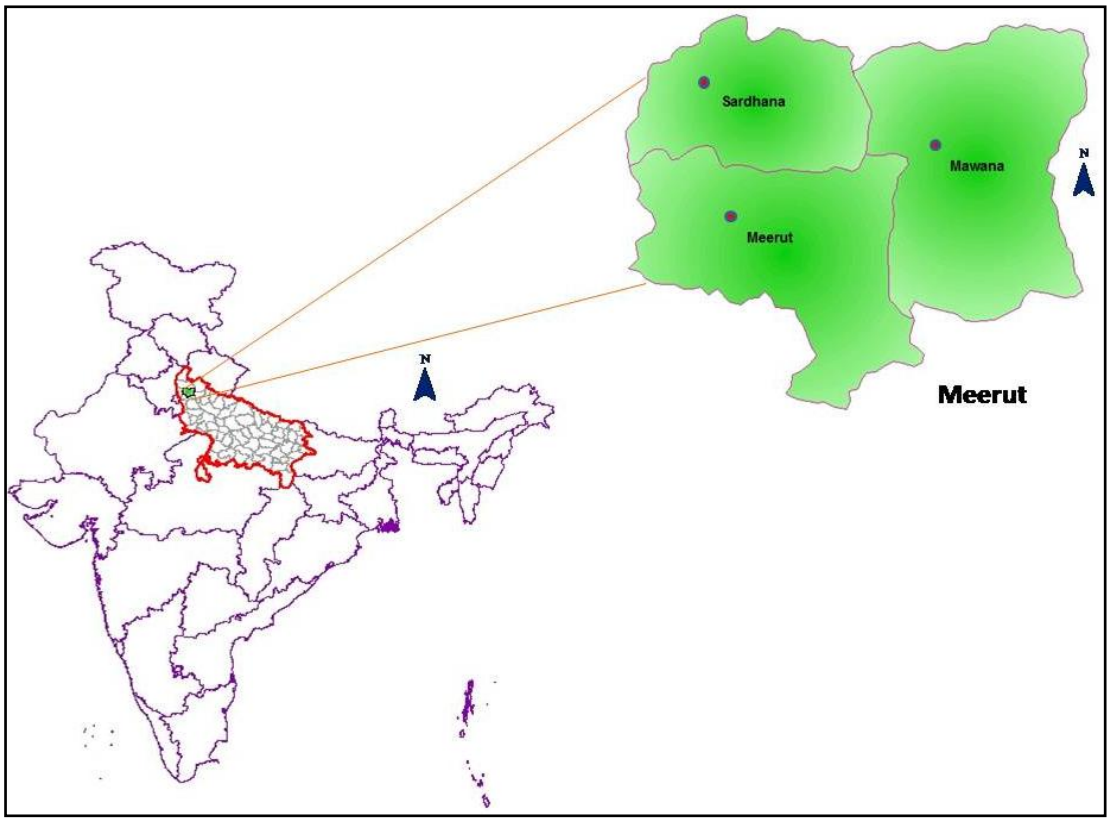


**Fig. 1.** Study area

**Objectives**

The objective is to generate data having properties of the observed long period record. To compute properties of a long period of time series is broken into separate components and analyzed individually to understand the pattern of rainfall. The annual and monthly rainfall data used for observed trend during long period.

## MATERIAL AND METHOD

The present study is based on secondary sources of time series data (rainfall) data of seasonal rainfall. The climatic data (annual and monthly rainfall) of Meerut for continuous 100 years 1916 to 2015 data were obtained from India water portal website, IMD, New Delhi & NASA POWER (1901-2002, 2003, 2004-06 &2007-13 & 2014-15) (Rainfall data Info: a,b,c,d & e). The data set used in this study is derived from the time series of annual and monthly precipitation of Meerut district, Uttar Pradesh. The S-W rainfall data analysis to observed pattern of trend and develop forecasting model for future scenario. The different type of statistical data analysis *viz.* Coefficient of Variation (CV), Standard deviation, Correlation of Coefficient ($R^2$), Departure and Cumulative departur**e** and Trend Analysis to given important scenario of change pattern of time series data in MS Excel.

The Following formula has been used for determining Mean, Standard Deviation and Co-efficient of Variation.

(a) Mean $(\bar{x}) = \frac{\sum x}{N}$

Where,

x = rainfall variables, N= number of years

(b) Standard Deviation $(\sigma) = \frac{\sum(x-\bar{x})^2}{N}$

Where,

$\bar{x}$ = the mean value as is defined above.

In computing the deviation score $(\bar{x} - x)$ and the standardized anomaly, formula *viz.*

(c) Standardirzed anomaly $= \frac{(x-\bar{x})}{STD}$

Where,

x is the annual rainfall totals, $\bar{x}$ is the mean of the entire series and

STD is the standard deviation from the mean of the series.

(d) Coefficient of variation $= \frac{\text{Standard Deviation}}{\text{Mean}} x100$

It is also referred to as the coefficient of mean deviation, is defined as the ratio of the standard deviation to the mean of the data set.
(e) Median: It is the middle value when the data is arranged in order of size.
(f) Coefficient of Skewness: The coefficient of skewness measures the skewness of a distribution. It is based on the notion of the moment of the distribution.

$$\text{Skewness} = \frac{\bar{x} - \text{Mode}}{\text{Standard Deviation}} x100$$

Where,
$\bar{x}$ represents the arithmetic mean
This measure is equal to zero if the data are distributed symmetrically.
The Monsoon Precipitation Index (MPI) and Precipitation Ratio have also been worked out using respective formula.

## RESULT AND DISCUSSION

The mathematical and statistical analyses of South-west rainfall (S-W rainfall) are discussed in below:

### Variation of monthly rainfall

The average monthly rainfall of 100 years (1916-2015) for Meerut district is observed 587.2mm and the intensity of rainfall increasing from June to September (South-west Monsoon), and suddenly decreasing trend noticed from October to December (Post- monsoon). The analysis of 100 years monthly data observed 108.2mm in the month of September, 218.6mm in August 202.6mm in July, and 57.8mm in June. The lowest rainfall was observed 7.3mm in the month of November and its maximum rainfall is 218.6mm in the month of August. The coefficient of variation for monthly mean rainfall observed highest in the month of November and it is 151% whereas coefficient of variation is minimum for the month of August and it is 46.6% for the Meerut district. This shows that rainfall is more stable in the month of August and is more variable in the month of November for the Meerut district. The scenario of seasonal rainfall data observed South-west monsoon has maximum rainfall then other seasonal rainfall (Table-1).

**Table 1.** Statistical summary of seasonal (month wise) rainfall of Meerut district (1916-2015)

| Season | Month | Mean | Std. Dev. | C.V. % | MIN. | MAX. | MEDIAN | COFF. OF SKEWNESS | Distribution % of Rainfall |
|---|---|---|---|---|---|---|---|---|---|
| Winter | January | 18.1 | 15 | 82.7 | 0.1 | 58.3 | 16.1 | 0.8 | 5.1 |
| | February | 16.8 | 17 | 101.2 | 0 | 100.4 | 12.8 | 1.8 | |
| Pre-Monsoon | March | 13.2 | 14.9 | 112.7 | 0 | 98 | 9.2 | 2.6 | 5.4 |
| | April | 8.8 | 10.1 | 115.7 | 0 | 44.3 | 5.0 | 1.9 | |
| | May | 15.5 | 14.5 | 93.9 | 0.2 | 67.9 | 10.3 | 1.3 | |
| South-west Monsoon | June | 57.8 | 41 | 70.9 | 0.3 | 254.9 | 47.1 | 1.7 | 85.2 |
| | July | 202.6 | 97.2 | 48 | 35.5 | 475.7 | 196.6 | 0.6 | |
| | August | 218.6 | 101.8 | 46.6 | 16 | 500.1 | 203.9 | 0.6 | |
| | September | 108.2 | 71.8 | 66.4 | 7.9 | 289.7 | 94.3 | 0.5 | |
| Post-monsoon | October | 14.4 | 18 | 125.2 | 0 | 82.7 | 6.1 | 1.7 | 4.4 |
| | November | 7.3 | 11 | 151 | 0 | 50 | 3.0 | 2.4 | |
| | December | 8.3 | 9.6 | 115.7 | 0 | 41.8 | 5.4 | 1.8 | |
| Total (Jan. to Dec.) | | 689.6 | 187.5 | 27.5 | 223.7 | 1140 | 674 | 0.1 | |

The Post monsoon season is more stable then South-west monsoon. The $R^2$ value 0.030 means that only 3.0 percent variation in rainfall is explained by time. The highly intensity trends noticed in the month of June to September month get highest rainfall in August month and it reaches its maximum peak and also its start to decreasing from month of October and lowest rainfall in the month of November (Fig. 2).

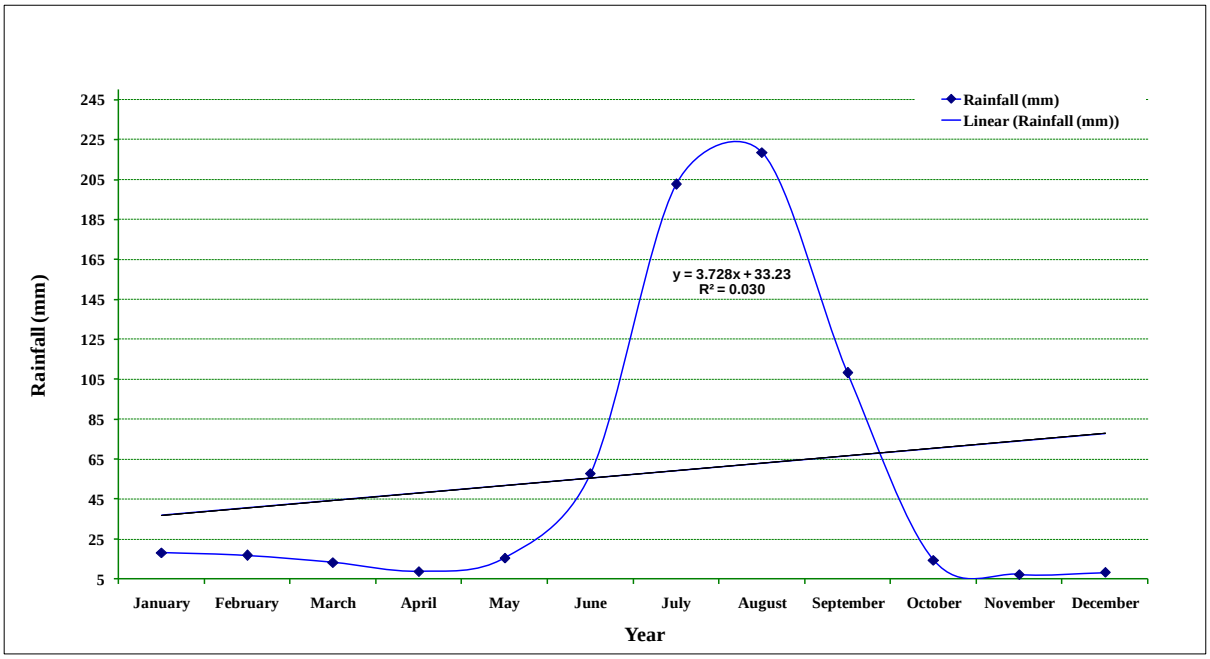


**Fig. 2:** Average Monthly rainfall of Meerut (1916-2015)

**Monthly variation of South west monsoon**

The long term data analysis of month wise June, July August and September contributes 10.7%, 33.3%, 38.3% and 17.8% in south west monsoon rainfall season respectively, the results of the analysis are given in Table 5. The mean maximum rainfall is 224.9mm observed in August month whereas minimum rainfall is 62.6mm observed in June month. The minimum rainfall is observed in June , July, August and September month 0.30mm, 36.4mm, 16mm and 9.7mm in year 2012, 2004, 2006 and 1974 respectively, whereas the maximum rainfall is observed 157.8mm, 419.8mm, 500.1mm and 289.7mm in year 2013, 2003, 1995 and 2005 respectively (Table 2 & Fig.3). The monthly south-west monsoon rainfall variability in years is observed maximum after 21th century. It is most important period of rainfall seasonal cycle.

**Table 2.** Computation of statistical parameters of decadal south-west rainfall data of Meerut district

| Monsoon (June-July-Aug-Sept) | | | | | | Decadal Distribution % of Rainfall |
|---|---|---|---|---|---|---|
| **Decade** | **Mean (mm)** | **SD (mm)** | **CV (%)** | **Max (mm)** | **Min (mm)** | |
| 1916-1925 | 587.3 | 140.9 | 24 | 732.4 | 289.3 | 100 |
| 1926-1935 | 552.9 | 204.3 | 37 | 1033.3 | 254.2 | 94 |
| 1936-1945 | 539 | 188.5 | 35 | 915.2 | 302.9 | 92 |
| 1946-1955 | 587.3 | 150.3 | 25.6 | 817.5 | 363.6 | 100 |
| 1956-1965 | 669.7 | 170 | 25.4 | 989 | 486.9 | 114 |
| 1966-1975 | 661.1 | 160.9 | 24.3 | 958 | 459.7 | 113 |
| 1976-1985 | 672.9 | 172.5 | 25.6 | 871.1 | 326.3 | 115 |
| 1986-1995 | 607.8 | 216.6 | 35.6 | 896.7 | 248.1 | 104 |
| 1996-2005 | 566.8 | 175.3 | 30.9 | 885.8 | 336.6 | 97 |
| 2006-2015 | 427 | 161.5 | 37.8 | 696.3 | 216.1 | 73 |
| **1916-2015** | **587.2** | **74.2314** | **12.6419** | **1033.3** | **216.1** | |


**Fig. 3.** Decadal Average South-west rainfall (Monsoon season) of Meerut (1916-2015)

## Decadal rainfall pattern

**Table 3.** Computation of statistical parameters of decadal rainfall data of Meerut district

| Decade | Total rainfall decadal | | | | | |
|---|---|---|---|---|---|---|
| | **Annual Av. Rainfall (mm)** | **SD (mm)** | **CV (%)** | **Max. Rainfall (mm)** | **Min. Rainfall (mm)** | **Precipitation ratio (%)** |
| **1916-1925** | 667 | 153.9 | 23.1 | 845.5 | 333.1 | 76.8 |
| **1926-1935** | 648.1 | 202.9 | 31.3 | 1140.3 | 397.1 | 114.7 |
| **1936-1945** | 622.9 | 198.8 | 31.9 | 1010 | 384.1 | 100.5 |
| **1946-1955** | 671.6 | 141.3 | 21 | 873.8 | 482 | 58.3 |
| **1956-1965** | 762.9 | 169 | 22.1 | 1033.2 | 541.6 | 64.4 |
| **1966-1975** | 745.9 | 169 | 22.7 | 1035.4 | 497.3 | 72.1 |
| **1976-1985** | 786.7 | 159.8 | 20.3 | 956.8 | 437.4 | 66 |
| **1986-1995** | 709.6 | 205.6 | 29 | 970.5 | 355.9 | 86.6 |
| **1996-2005** | 689.9 | 191.3 | 27.7 | 1056.2 | 407.7 | 94 |
| **2006-2015** | 523 | 206.1 | 39.4 | 923.8 | 223.7 | 133.9 |
| **1916-2015** | **682.8** | **76.4** | **11.2** | **1140.3** | **223.7** | **134.2** |

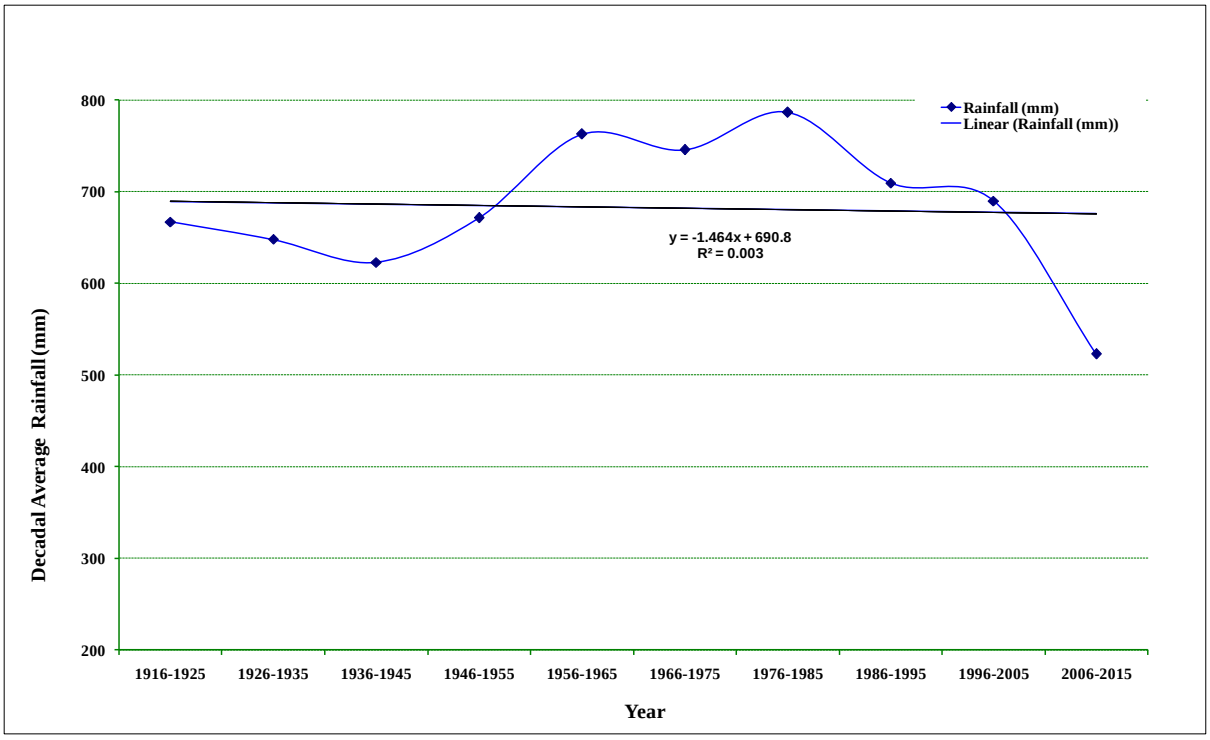


**Fig. 4.** Decadal Average Annual rainfall of Meerut (1916-2015)

During the 100 year period (1916 to 2015), divide in equal ten decadal rainfall periods for understanding of rainfall data pattern were observed as indicated in Table 3. The analysis of table observed maximum average rainfall 786.7 mm in decadal year 1976-85 and lowest rainfall 523 mm in year 2006-15. The maximum coefficient of variation 39.4% observed in year 2006-2015 whereas minimum coefficient of variation 20.3% observed in decadal year 1976-85. The regression analysis indicates $R^2$ value of 0.003 for decadal rainfall is observed (Fig.4). The rainfall data variability observed in a decadal period's analysis due to changing of rainfall trend in Meerut.

**Precipitation ratio (%)**

The abnormalities of rainfall at any location may be brought by a simple ratio of precipitation. It is the difference between maximum and minimum rainfall of the annual rainfall series expressed in terms of mean.

$$P_R = \frac{(P_{Max} - P_{Min})}{P_{Mar}} x100$$

Where,

PR = Precipitation Ratio

$P_{Max}$ = Maximum mean annual rainfall

$P_{Min}$ = Minimum mean annual rainfall

$P_{MAR}$ = Mean annual rainfall

This ratio may give the stability of rainfall with special relationship. Higher the ratio, higher is the abnormality in rainfall and vice versa (Rathod and Aruchamy, 2010). The minimum and maximum precipitation ratios for different decades were worked out for Meerut District is given in Table 3.

In Meerut district, maximum abnormality (i.e. 133.9%) was recorded during 2006-15 (Tables 4) decade during which the district as a whole recorded less annual rainfall. In Meerut, maximum abnormality was recorded during 1946-55 period during which the district recorded very less annual rainfall in precipitation ratio of 58.3%. The overall period (1916-2015) for precipitation ratio was observed 134.2%.

**Rainfall departure and cumulative departure of south west rainfall**

The departure and cumulative departure from average rainfall for the study area has been depicted in Table.4. The trend of annual departure from the computed value of average annual rainfall reveals that;

(a) Years showing annual positive departure with respect to average annual rainfall were 1916-17, 1921-24, 1926, 1933-34, 1936, 1942, 1944-45, 1948-1950, 1953, 1955, 1957-58, 1960-61, 1963-1964, 1966-67, 1969, 1971-72, 1975-1978, 1980, 1982-83, 1985, 1988, 1990, 1993-96, 1998, 2000, 2003-04, 2010 & 2013. The positive trend of rainfall shows the favourable conditions for recharge.

(b) Years showing annual negative departure with respect to average annual rainfall were 1918-1920,1925, 1927-32, 1935, 1937-1941, 1943, 1946-47, 1951-52, 1954, 1956, 1959, 1962, 1965,1968,1970,1973-74,1979,1981,1984,1986-87,1989,1991-92,1997, 1999, 2001-04, 2005-09, 2011-12 & 2014-15. The negative trend of rainfall shows the unfavourable conditions for recharge.

**Table 4.** South –west rainfall data and its departure and cumulative departure from average South-west rainfall in Meerut district (1916-2015)

| South-west rainfall (mm) (June-July-August-September) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1916-2015 | | | | | | | | | |
| **Year** | **Standardized rainfall anomaly** | **Departure from average rainfall** | **Cumulative departure from average rainfall** | **Season Trend** | **Year** | **Standardized rainfall anomaly** | **Departure from average rainfall** | **Cumulative departure from average rainfall** | **Season Trend** |
| **1916** | 0.77 | 96.8 | -96.8 | 605.3 | **1966** | 0.14 | 24.8 | -582.4 | 587 |
| **1917** | 0.8 | 162.7 | 65.9 | 604.9 | **1967** | 1.35 | 260.8 | -321.6 | 586.6 |
| **1918** | -1.64 | -349.7 | -283.8 | 604.5 | **1968** | -0.32 | -97.6 | -419.2 | 586.3 |
| **1919** | -0.82 | -146.1 | -429.9 | 604.2 | **1969** | 0.39 | 33.2 | -386 | 585.9 |
| **1920** | -0.46 | -124.2 | -554.1 | 603.8 | **1970** | -0.51 | -36.3 | -422.3 | 585.5 |
| **1921** | 0.35 | 21.3 | -532.8 | 603.4 | **1971** | 1.18 | 230.2 | -192.1 | 585.2 |
| **1922** | 0.41 | 39.3 | -493.5 | 603.1 | **1972** | 0.53 | 64.9 | -127.2 | 584.8 |
| **1923** | -0.02 | 22 | -471.5 | 602.7 | **1973** | -0.05 | -15.7 | -142.9 | 584.4 |
| **1924** | 0.56 | 134.5 | -337 | 602.3 | **1974** | -0.7 | -185.5 | -328.4 | 584.1 |
| **1925** | 0.05 | -14.5 | -351.5 | 602 | **1975** | 2.04 | 352.7 | 24.3 | 583.7 |
| **1926** | 0.16 | 23.9 | -327.6 | 601.6 | **1976** | 1.54 | 274 | 298.3 | 583.3 |
| **1927** | -0.58 | -78.6 | -406.2 | 601.3 | **1977** | 0.48 | 117.8 | 416.1 | 583 |
| **1928** | -1.83 | -285.6 | -691.9 | 600.9 | **1978** | 1.56 | 246.7 | 662.8 | 582.6 |
| **1929** | -1.17 | -233.9 | -925.8 | 600.5 | **1979** | -1.44 | -245.3 | 417.4 | 582.3 |
| **1930** | -0.37 | -65.9 | -991.6 | 600.2 | **1980** | 1.28 | 201.9 | 619.4 | 581.9 |
| **1931** | -0.05 | -6.7 | -998.3 | 599.8 | **1981** | -0.35 | -27.4 | 592 | 581.5 |
| **1932** | -0.48 | -142.6 | -1140.9 | 599.4 | **1982** | -0.08 | 89.2 | 681.2 | 581.2 |
| **1933** | 2.46 | 457.5 | -683.4 | 599.1 | **1983** | 0.44 | 179 | 860.2 | 580.8 |
| **1934** | 0.35 | 44.6 | -638.8 | 598.7 | **1984** | 0.17 | -11.8 | 848.4 | 580.4 |
| **1935** | -0.38 | -59.5 | -698.3 | 598.3 | **1985** | 1.11 | 215.2 | 1063.5 | 580.1 |
| **1936** | 1.81 | 327.3 | -371 | 598 | **1986** | -0.64 | -85.9 | 977.7 | 579.7 |
| **1937** | -0.62 | -110.1 | -481.1 | 597.6 | **1987** | -1.87 | -326.9 | 650.8 | 579.3 |
| **1938** | -1.15 | -228.6 | -709.8 | 597.2 | **1988** | 1.7 | 287.7 | 938.5 | 579 |
| **1939** | -1.05 | -236.7 | -946.5 | 596.9 | **1989** | -1.08 | -179.4 | 759.1 | 578.6 |
| **1940** | -0.7 | -132.1 | -1078.6 | 596.5 | **1990** | 1 | 207.7 | 966.8 | 578.2 |
| **1941** | -1.56 | -298.6 | -1377.2 | 596.1 | **1991** | -0.25 | -24.8 | 942 | 577.9 |
| **1942** | 0.76 | 117.2 | -1260 | 595.8 | **1992** | -0.8 | -128.6 | 813.4 | 577.5 |
| **1943** | -0.68 | -181.8 | -1441.8 | 595.4 | **1993** | 1.13 | 161.4 | 974.8 | 577.1 |
| **1944** | -0.01 | 79.1 | -1362.6 | 595 | **1994** | 0.76 | 114.6 | 1089.4 | 576.8 |
| **1945** | 0.57 | 65.7 | -1296.9 | 594.7 | **1995** | 1.18 | 242.9 | 1332.3 | 576.4 |
| **1946** | -0.17 | -68.1 | -1365 | 594.3 | **1996** | 1.13 | 184.7 | 1517 | 576 |
| **1947** | -0.56 | -132 | -1497 | 593.9 | **1997** | -0.58 | -35.6 | 1481.4 | 575.7 |
| **1948** | 0.92 | 173.2 | -1323.8 | 593.6 | **1998** | 0.58 | 136.6 | 1618 | 575.3 |
| **1949** | 0.74 | 89.4 | -1234.4 | 593.2 | **1999** | -1.38 | -275 | 1342.9 | 574.9 |
| **1950** | 1.27 | 191 | -1043.4 | 592.8 | **2000** | -0.07 | 8.2 | 1351.1 | 574.6 |
| **1951** | -1.23 | -200.8 | -1244.2 | 592.5 | **2001** | -0.62 | -99.4 | 1251.8 | 574.2 |
| **1952** | -0.82 | -156.4 | -1400.6 | 592.1 | **2002** | -1 | -217.8 | 1034 | 573.8 |
| **1953** | 0.26 | 17.4 | -1383.1 | 591.8 | **2003** | 1.64 | 373.4 | 1407.4 | 573.5 |
| **1954** | -0.7 | -110.1 | -1493.3 | 591.4 | **2004** | -0.75 | 39.5 | 1447 | 573.1 |
| **1955** | 0.3 | 84.4 | -1408.9 | 591 | **2005** | -0.08 | -43.4 | 1403.6 | 572.8 |
| **1956** | -0.2 | -10.8 | -1419.7 | 590.7 | **2006** | -1.73 | -330.1 | 1073.5 | 572.4 |
| **1957** | 0.11 | 70.5 | -1349.2 | 590.3 | **2007** | -1.64 | -309.1 | 764.5 | 572 |
| **1958** | 1.53 | 258.5 | -1090.7 | 589.9 | **2008** | -1.13 | -245.4 | 519.1 | 571.7 |
| **1959** | -0.3 | -62.4 | -1153.1 | 589.6 | **2009** | -2.04 | -459.1 | 60 | 571.3 |
| **1960** | -0.01 | 5.5 | -1147.6 | 589.2 | **2010** | 0.41 | 19.1 | 79.2 | 570.9 |
| **1961** | 1.44 | 314 | -833.6 | 588.8 | **2011** | -0.49 | -126.6 | -47.4 | 570.6 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1962** | -0.11 | -35.9 | -869.4 | 588.5 | **2012** | -1.43 | -287.4 | -334.8 | 570.2 |
| **1963** | 0.43 | 52.9 | -816.5 | 588.1 | **2013** | 0.6 | 241 | -93.7 | 569.8 |
| **1964** | 2.21 | 350.5 | -466 | 587.7 | **2014** | -0.75 | -48.1 | -141.8 | 569.5 |
| **1965** | -0.55 | -141.1 | -607.2 | 587.4 | **2015** | -0.62 | -51.8 | -193.6 | 569.1 |

**Standardized rainfall anomaly**

Table 4 depicts the computed annual mean rainfall , departure & cumulative departure of rainfall , seasonal trend and standardized anomalies within the year under consideration (1915-2016) over Meerut District. Fig. 5. shows the standardized rainfall deviations *viz.* 1916-17, 1921-22, 1924-26, 1933-34, 1936, 1942, 1945, 1948-50, 1953, 1955, 1957-58, 1961, 1963-64, 1966-67, 1969, 1971-72, 1975-78, 1980, 1983-85, 1988, 1990, 1993-96, 1998, 2003, 2010 & 2013 are years with above average rainfall with 1933 showing the highest positive rainfall anomaly while the other years show rainfall below normal with 2009 showing the lowest negative rainfall deviation.

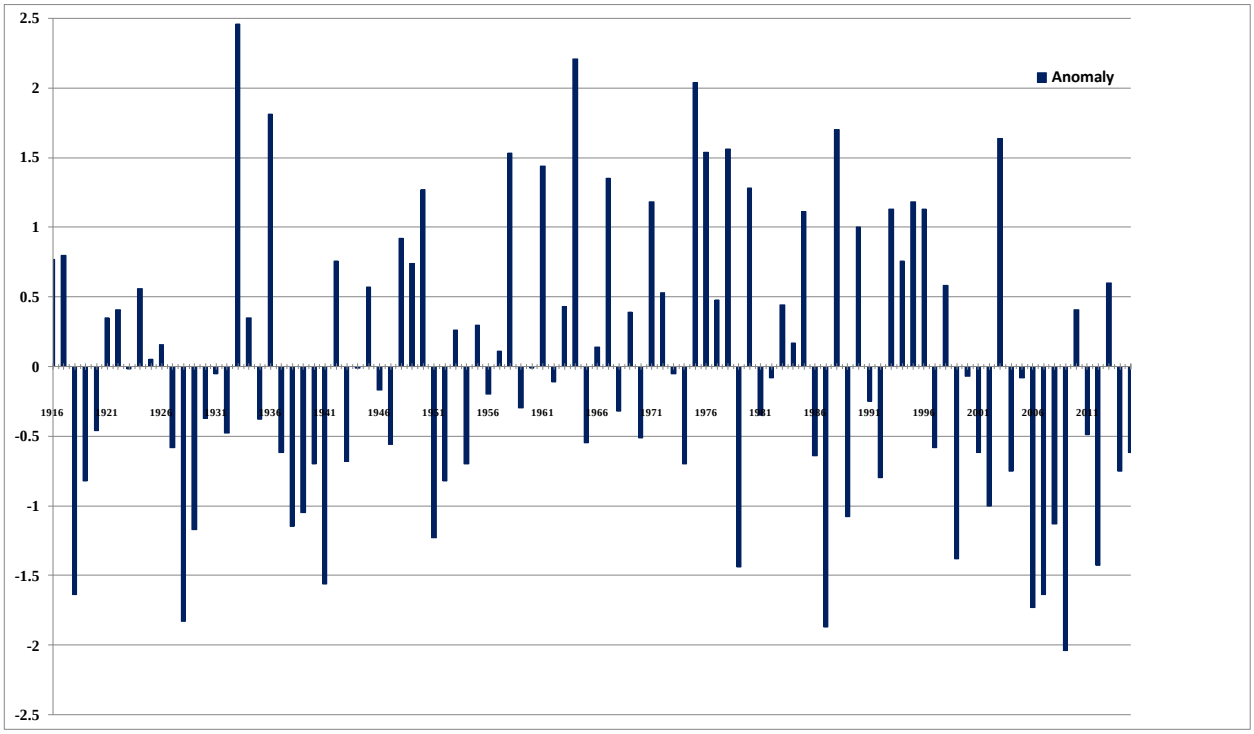


**Fig. 5.** Standardized rainfall anomaly over Meerut District from 1916-2015

**Trend analysis of south-west rainfall (Monsoon season)**

A trend analysis of the average south west rainfall of Meerut district for 100 year period from 1916 to 2015 was statistical test MS Excel in Fig. 6 shows the plots of annual and south-west rainfall for the study area; trends lines for the data have also been drawn. The monsoon season (S-W) is least scatter then annual rainfall. It does not show much scatter. It gives valuable trend information of series observations. Trend analysis was also performed on seasonal scale to examine if there are trends in the data at this scale. The trend analysis helps to measure the deviation from the trend and also provides information pertaining to the nature of trend. The analysis can be used as a tool to forecast the future behaviour of the trend. The method of least square fit for straight line has been used for trend analysis of the behaviour of annual rainfall, south west rainfall and rice yield. After trend analysis of data observed rainfall trend is going to decline pattern.

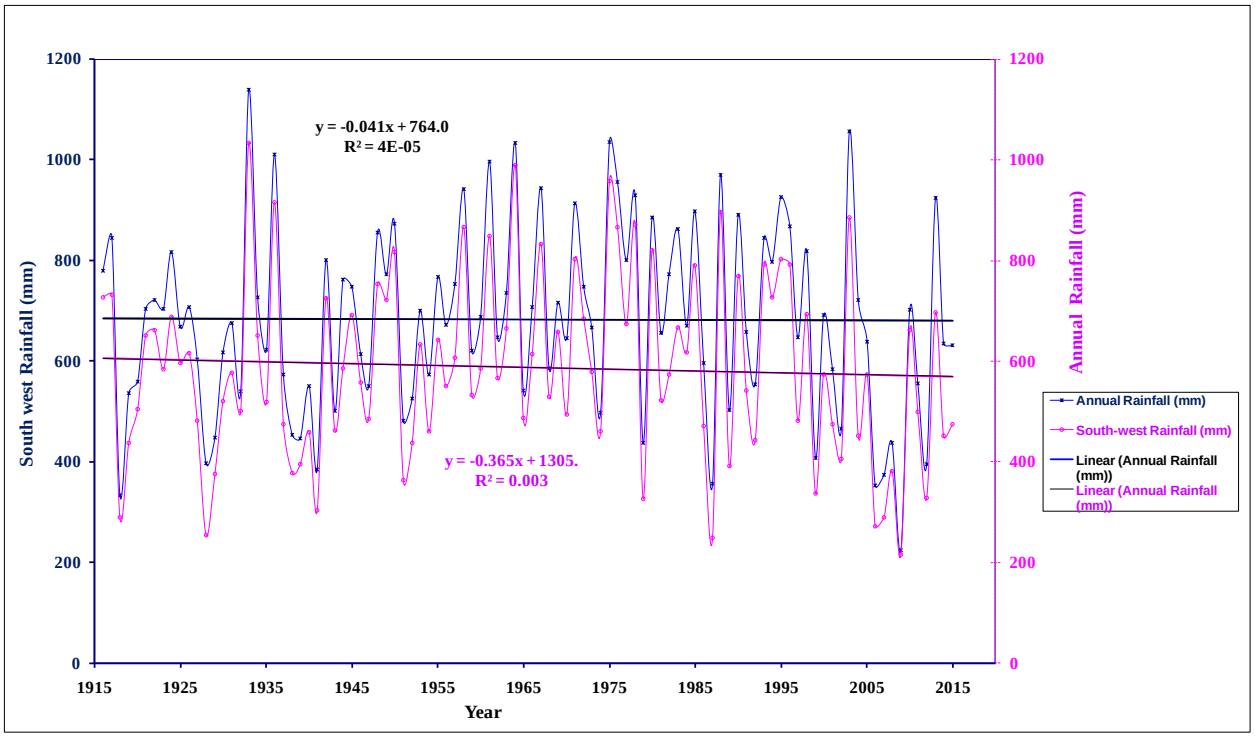


**Fig. 6.** Trend of rainfall in Meerut district (1916-2015)

**Monsoon Precipitation Index (MPI)**

Moetasim Ashfaq *et al.* (2009) defined the precipitation index as the departure of rainfall from the climatological means (1961–1990), averaged over land points between 70º - 90ºE and 5º–25ºN. Calculation of MPI is useful for both agricultural and hydrological applications. Since MPI is not adversely affected by the topography it gives us an idea about spatial variation of monsoon rainfall over different topographical regions. Higher the MPI, lesser is the rainfall variation at individual district. In the present study on the basis of available monthly rainfall data, monsoon precipitation index (MPI) has been calculated as,

Monsoon Precipitation Index

$$(\text{MPI} = \frac{\text{Annual Range}}{\text{Total Annual Rainfall}}$$

Where, Annual Range = (Monsoon rainfall – Non-monsoon rainfall)

MPI in case of Meerut mostly varied from 0.71 to 0.76 except in the decadal year 1996-2005 & 2006-05 it was 0.64 and 0.63 respectively (Table 5). The lowest MPI of 0.64 to 0.63 was recorded due to district received less rainfall during the monsoon months.

**Table 5.** Decadal Monsoon Precipitation Index (MPI) of Meerut

| Sl. No. | Decade | MPI VALUE |
|---|---|---|
| 1 | 1916-1925 | 0.76 |
| 2 | 1926-1935 | 0.71 |
| 3 | 1936-1945 | 0.73 |
| 4 | 1946-1955 | 0.75 |
| 5 | 1956-1965 | 0.76 |
| 6 | 1966-1975 | 0.77 |
| 7 | 1976-1985 | 0.71 |
| 8 | 1986-1995 | 0.71 |
| 9 | 1996-2005 | 0.64 |
| 10 | 2006-2015 | 0.63 |
| **1916-2015** | | **0.72** |

**Forecasting of annual rainfall and S-W rainfall**

On the basis, the future forecast of rainfall and yield amount for a period of ten years from 2016 to 2026 has been made (Table 6), which shows a negative trend for the coming years. In future, expected annual and south west rainfall may be less in year

2026 observed 680.3mm and 565.1mm in Meerut district. The expected annual rainfall in year 2016 to 2026 rainfall patterns are declining stage. The trend analysis gives the scenario of current to expected future situation. Monsoon rainfall is one of the key factor play vital role in Indian agriculture. Our statistical result indicates that monsoon rainfall is affecting the kharif season in the study area.

**Table 6.** Expected future Annual & South-west rainfall (mm) of Meerut District

| Year | Expected future rainfall trend (mm) | |
|---|---|---|
| | **Annual** | **South-west Monsoon** |
| **2016** | 680.7 | 568.7 |
| **2017** | 680.6 | 568.4 |
| **2018** | 680.6 | 568.0 |
| **2019** | 680.6 | 567.6 |
| **2020** | 680.5 | 567.3 |
| **2021** | 680.5 | 566.9 |
| **2022** | 680.4 | 566.5 |
| **2023** | 680.4 | 566.2 |
| **2024** | 680.3 | 565.8 |
| **2025** | 680.3 | 565.4 |
| **2026** | 680.3 | 565.1 |

## CONCLUSION

Water is a vital component and rainfall is major source of irrigation especially for south west monsoon for Kharif. Analysis of rainfall data of a century (1916-2015) over Meerut plays a significant role in the agricultural and urbanization contribution and in the overall growth of the District. The impacts of climate changes on temporal and spatial patterns are clearly noticed in this analysis. In the century based rainfall data analysis observe in maximum rainfall 115% in decadal period year 1976-85 whereas in decadal period year 2006 to 2015 only 73% monsoon rainfall was observed.

The data of annual rainfall and S-W rainfall is 689.6mm and 587.2mm respectively. The monthly south-west monsoon rainfall variability in years is observed maximum after 21th century. It is most important period of rainfall seasonal cycle. The analysis data of S-W monsoon observed highest rainfall 85.2% and lowest rainfall in post monsoon season 4.4%. The analysis of trend of rainfall and observed rainfall is declining. The District experienced irregular pattern rainfall which adversely affected the agriculture production and yield. There is increase in annual and South-west Monsoon season CV for all the decades during 1915-2016 periods ranging between 27.5 for annual and 12.6 for monsoon rainfall.

Statistical indicators viz. coefficient of skewness showed that the frequency of low precipitation is high in Meerut during winter and pre monsoon more or less equal but south west rainfall more than other season and average post-monsoon season has very low rainfall.

The anomalous departures from the mean were observed the highest positive and negative departure from the mean of approximately -459.1 & 457.5 in year 2009 and 1933 respectively.

The analysis included variability of rainfall, trends in rainfall pattern and changes in spatial and temporal patterns of Precipitation Ratio and Monsoon Precipitation Index. Due to plain topography, the annual and seasonal rainfall in the district has been estimated by a simple ratio of precipitation. The maximum abnormality 2.46 and -2.04 in annual rainfall was recorded during 1933 & 2009. It is seen that the average MPI varied from 0.63 to 0.77.

The trend in the annual rainfall showed that the rainfall decreasing in the area whereas south-west rainfall declined pattern of 3% changes was also observed in the century.

The standardized anomalies results obtained show a fluctuating rainfall pattern across the years over Meerut District which makes it hard to freely forecast rainfall trend for a future season. The information is useful for agriculturists and policy makers on critical issues is it affects seasonal

agricultural practices such application of agricultural inputs, water resources maintenance and management practices. The rainfall data analysis of Meerut District for a period of 100 years (1916 to 2015) reveals variation in the rainfall amount and points out a negative trend of rainfall in future. The global climate and the local environmental changes are the chief factors for the variation in rainfall over the recent times. The knowledge of current situation of weather and climate change related pattern and adaptation of technology is maintend trend. Uncertainty on the dates of monsoon onset and its withdrawal also puts a great problem before the farmers.

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**Rainfall data info (a,b,c,d & e):**

a. Rainfall data of Meerut (1901 to 2002): http://www.indiawaterportal.org/articles/meteorological-datasets-download-entire-datasets-various-meteorological-indicators-1901 to 2002

b.Rainfall year 2003: http://shodhganga.inflibnet.ac.in/bitstream/10603/41261/6/06_chapter%202.pdf

c.Rainfall data of Meerut (2004 to 06): http://www.indiawaterportal.org/met_data/

d. IMD (Indian meteorology Department, New Delhi (2007 to2013): Hydromet Division, India Meteorological Department, District rainfall (mm) for last five years (2007 to 2013)

e. NASA/POWER Agroclimatology Daily Averaged Data: (2014-15): http://power.larc.nasa.gov/common/AgroclimatologyMethodology/Agro1d0_Methodology_Content.html & http://power.larc.nasa.gov

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