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STUDY & ANALYSIS OF TRENDS & VARIABILITY OF RAINFALL OVER GANGETIC WEST BENGAL

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ABSTRACT

The scope of this study is to analyse the trends and variability in the rainfall pattern over the **Gangetic West Bengal** using non parametric Mann-Kendall test & Sen's slope estimator. Analysis has been carried out for monthly, seasonal and annual rainfall series of 19 meteorological sub-divisions of West Bengal using monthly rainfall data of 117 years (1901-2017) as obtained from IMD, Govt. of India. From the statistics obtained from the study, the increasing and decreasing trends, as and when applicable in the rainfall pattern over the said region has been clearly reflected.

KEYWORDS: Rainfall variability, Statistical data analysis, Mann-Kendall test, Sen's slope, Trend analysis, Climate Change, Gangetic West Bengal (GWB)

I. INTRODUCTION

The increase in the global temperature owing to several phenomena such as global warming in association with the global climate change has been one of the most discussed issues in the light of threatened human existence in the near future. Needless to mention, it is also considered to be among the major challenges of the 21st century. This climate change has not only an influencing role over the water resources of a region but also has a significant and a long time impact on the agriculture based country's economy. Lot of changes in the climatic factors such as rainfall, temperature, etc in different parts of the world has been witnessed since the last century. Day to day the changing pattern in rainfall is becoming serious problem all over the world, which is seriously affecting the fresh water availability and thereby causing floods in some part and droughts in other parts. The Indian subcontinent, and especially to mention, the Gangetic West Bengal is an agricultural region whose economic well being and prosperity exclusively depends to a large extent on the timely arrival and withdrawal of monsoon and the rainfall received during the four monsoon months of June to September. It is, therefore, essential to study different aspects of monsoon rainfall which is unique every time and visualize any climate change impact of it on water resources planning, agricultural production, etc.

On the basis of observed temperature and rainfall data, it has been inferred that there is a decreasing trend in rainfall during the monsoon season as against the increasing trend in the pre-monsoon and post-monsoon season. Drought frequency and intensity analysis showed that the western and the central parts of the West Bengal were more prone to drought during 1973-2005. Using IMD's long period data (1961-1990) it is found that Krishnanagar, Malda and Purulia experienced relatively lower rainfall (< 1333 mm) during this period. It also showed that extreme northern part has also been reeling under drought in recent years. Using daily gridded data for 1971- 2005 of four rainfall stations surrounding the Purulia district spatial pattern of meteorological drought was analysed and the Standardized Precipitation Index (SPI) graphs showed high SPI values (i.e. extreme drought) for three stations in 1993. The years 1976, 1979, 1980, 1982, 1983, 1985, 2001, 2003 were found to be the worst drought years. Central part of the district experienced mild to moderate droughts whereas northeast, northwest and southwest parts experienced severe and extreme droughts. In this increasing trend of sea surface temperature (SST) scenario and increase or decrease in the frequency of low pressure systems during the last century, long term rainfall trend analysis over the Gangetic West Bengal will definitely be useful in knowing the rainfall variations and hydro-economic conditions over the said region.

II. MATERIALS

Study Area: The West Bengal State situated in the eastern part of India covers an area 88752 km² which is about 3% of the total area of the Indian region. It is bounded to the east by Bangladesh, to the south by the Bay of Bengal, to the southwest by Orissa state, the state of Jharkhand to west, to the northwest by the Bihar state and Nepal, to the north by Sikkim state and Bhutan and Assam in the northeast. The state experiences inherent climate diversity because of its vast physiographic features. The major part of the state falls in the Gangetic West Bengal (GWB) covering thirteen districts: Murshidabad, Birbhum, Bardhaman, Nadia, Purulia, Bankura, Hooghly, Howrah, East Midnapore, West Midnapore, North 24 Parganas , South 24 Parganas, Kolkata. Southwest monsoon (Jun-September) advances over the state by June 7 and withdraws around October 10 comprising of nearly 125 monsoon days. The average seasonal rainfall over GWB is in the range of 73%-81%. These districts of GWB in the Gangetic plains experience different types of climatic conditions all through the year. Therefore, in order to assess spatial and temporal distribution of rainfall pattern, district wise rainfall variation has been studied.

Data Source: Long term monthly rainfall data for the districts of the GWB Sub-division of the state for the period of 1901 to 2017 obtained from the India Meteorology Department (IMD) forms the major data source.

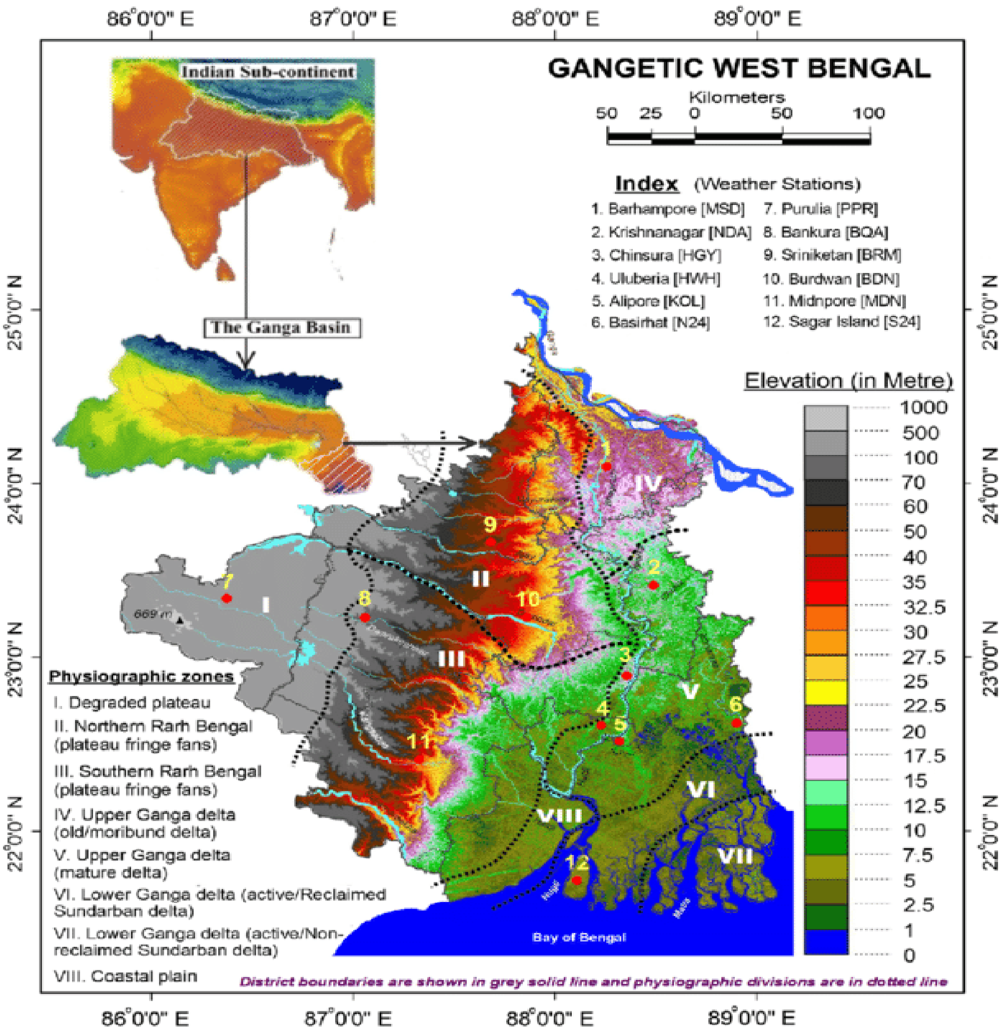

Fig-1: Study Area: Gangetic West Bengal

III. METHODOLOGY

In order to assess a trend in the given time series generally parametric or non-parametric distribution are fitted. In the present study the annual and seasonal time series was subjected to normal, log-normal, Gamma Type II, Poisson and Pearson Type III distributions. The magnitude of the trend in the time series is determined by Sen's Slope estimator (Sen, 1968).

$$T_i = \frac{x_j - x_k}{j - k}, \text{ for } i = 1, 2, \ldots, N \ (j > k) \ldots \quad (1)$$

where T_i is Sen's Slope, x_j and x_k are data values of the same observational unit at time j and k respectively. The median of these N values of T_i is represented as Sen's estimator of slope which is given as:

$$Q_{median} = \left.\begin{array}{ll} \frac{T_{(N+1)}}{2}, & \text{if N is odd} \\ \frac{\frac{T_N}{2} + \frac{T_{(N+2)}}{2}}{2}, & \text{if N is even} \end{array}\right\} \ldots \quad (2)$$

The sign of Q_{median} reflects the data trend direction and its value gives the magnitude of slope of the trend. A positive value indicates increasing and negative value indicate decreasing trend in the time series. The rainfall time series is further subjected to a popular Mann-Kendall non parametric test to determine any statistically significant trend as illustrated below-

Null Hypothesis: There is no trend in the series meaning data are independent and randomly selected. S statistic is calculated as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sign}(\chi_j - \chi_i), \text{ for } j > 1 \ \ldots \quad (3)$$

where, x_i and x_j are the values of the data at time i = 1,2…., n-1 and j = i+1, 2,…., n respectively. The null hypothesis is rejected when the test is two sides at a level of significance. Each of the data point x_i is taken as a reference point which is compared with the rest of the data points x_j so that,

$$\text{sign}(\chi_j - \chi_i) = \left.\begin{array}{ll} -1, & \text{for } x_j - x_i < 0 \\ 0, & \text{for } x_j - x_i = 0 \\ +1, & \text{for } x_j - x_i > 0 \end{array}\right\} \ldots \quad (4)$$

When n ≥ 8, the statistic S is approximately normally distributed with the mean E(S) = 0 and variance is given as

$$\text{Var}(S) = \frac{1}{18} n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5) \ \ldots \quad (5)$$

where, t_p is the number of ties for the pth values and q is the number of tied values. The test statistics Zc which is known as Kendall's Tau (τ) (Kendall, 1975) is computed as

$$Z_c = \left.\begin{array}{ll} \frac{S-1}{\sqrt{\text{Var}(S)}}, & \text{if } S > 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}}, & \text{if } S = 0 \\ 0, & \text{if } S < 0 \end{array}\right\} \ldots \quad (6)$$

Here Zc follows a standard normal distribution. A positive value of Z signifies an increasing trend and negative value as decreasing trend. Kendall's tau is comparable to the correlation coefficient in regression analysis and varies between -1 to +1. The drawback of the Mann-Kendall test (distribution free test) is that it is only able to detect monotonic trend in the data. In order to assess the trend in the large variable data set of rainfall series from 1901-2017 for the districts in West Bengal, second degree polynomial was found to be best fit indicating increase and decreasing periods in the given time series. The percentage change has been computed by

$$\text{Percentage change (\%)} = \frac{\beta * \text{Peroid of length}}{\text{Mean}} \times 100 \ \ldots \quad (7)$$

Computation of monthly data for trend analysis and descriptive statistical analysis was done using SCILAB 2016 and MS Excel.

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IV. RESULTS AND DISCUSSION

Table-1: Average annual and seasonal rainfall (in mm) in the districts of Gangetic West Bengal (GWB)

SL. NO.	DISTRICTS	JAN-FEB	MAR-MAY	JUN-SEP	OCT-DEC	AVERAGE ANNUAL	JUN-SEP AS % OF ANNUAL
1.	Murshidabad	26.5	179.4	1045.2	123.7	1374.5	76
2.	Birbhum	29.4	154.5	1071.7	121.6	1377.1	78
3.	Bardhaman	32.0	167.7	1034.0	115.8	1349.6	77
4.	Nadia	30.8	198.9	956.3	125.4	1309.3	73
5.	Purulia	38.9	112.4	1073.0	103.9	1328.3	81
6.	Bankura	33.7	145.4	1032.4	110.3	1321.9	78
7.	Hooghly	37.5	201.2	1042.5	127.1	1408.0	74
8.	Howrah	35.5	197.0	1150.8	147.3	1530.8	75
9.	East Midnapore	40.2	189.5	1173.9	176.8	1579.8	74
10.	West Midnapore	40.0	200.4	1149.5	141.3	1530.5	75
11.	North 24 Parganas	35.9	226.5	1176.2	158.3	1596.6	74
12.	South 24 Parganas	36.1	191.7	1328.1	210.0	1765.3	75
13.	Kolkata	37.9	209.5	1263.8	180.9	1692.3	75

Table-2: Descriptive statistics of annual rainfall (in mm) in the districts of Gangetic West Bengal (GWB)

SL. NO.	DISTRICTS	MEAN	STANDARD DEVIATION (SD)	CV (%)	RANGE	STANDARD ERROR	COEFF. OF SKEWNESS	COEFF. OF KURTOSIS
1.	Murshidabad	1374.50	310.27	22.6	1721.10	28.68	0.62	1.05
2.	Birbhum	1377.15	278.46	20.2	1301.00	25.74	0.34	-0.27
3.	Bardhaman	1349.58	235.75	17.5	1154.40	21.79	0.43	-0.04
4.	Nadia	1309.32	317.18	24.2	1687.80	29.45	0.19	0.23
5.	Purulia	1328.17	244.90	18.4	1369.40	22.64	0.28	-0.03
6.	Bankura	1321.87	274.83	20.8	1670.10	25.41	0.21	0.77
7.	Hooghly	1408.03	314.30	22.3	1889.40	29.06	0.19	0.93
8.	Howrah	1530.80	377.47	24.7	1881.00	35.67	0.03	-0.06
9.	East Midnapore	1591.24	323.41	21.8	1619.80	30.03	0.56	0.07
10.	West Midnapore	1530.50	273.93	17.9	1440.00	25.43	0.61	0.14

11.	North 24 Parganas	1596.57	326.04	20.4	1647.70	30.14	0.42	0.11
12.	South 24 Parganas	1765.31	424.42	24.0	2694.20	39.24	1.59	4.64
13.	Kolkata	1692.26	317.08	18.7	1687.40	29.44	0.45	0.08
AVERAGE ANNUAL		1475.02	309.08	21.0	1674.10	28.67	0.45	0.59

Table-3: Descriptive statistics of seasonal rainfall (Jun-Sep) (in mm) in the districts of Gangetic West Bengal (GWB)

SL. NO.	DISTRICTS	MEAN	STANDARD DEVIATION (SD)	CV (%)	RANGE	STANDARD ERROR	COEFF. OF SKEWNESS	COEFF. OF KURTOSIS
1.	Murshidabad	1045.17	270.72	25.9	1664.70	25.03	0.62	1.09
2.	Birbhum	1071.66	242.82	22.7	1213.80	22.45	0.61	0.25
3.	Bardhaman	1033.98	211.15	20.4	1114.60	19.52	0.75	0.59
4.	Nadia	956.32	257.47	26.9	1568.40	24.01	0.87	1.55
5.	Purulia	1073.03	217.83	20.3	1070.70	20.14	0.34	-0.19
6.	Bankura	1032.44	228.43	22.1	1255.60	21.12	0.46	0.27
7.	Hooghly	1042.53	253.24	24.3	1471.00	23.41	0.15	0.47
8.	Howrah	1150.78	328.06	28.5	1678.70	31.00	0.06	-0.01
9.	East Midnapore	1182.76	246.50	22.5	1353.50	22.89	0.48	0.47
10.	West Midnapore	1149.50	236.13	20.5	1128.90	21.92	0.90	0.96
11.	North 24 Parganas	1176.17	281.12	23.9	1526.80	25.99	0.61	0.26
12.	South 24 Parganas	1328.13	324.75	24.5	2142.00	30.02	1.30	4.09
13.	Kolkata	1263.85	282.77	22.4	1264.30	26.25	0.61	-0.24
AVERAGE JUN-SEP		1115.87	260.08	23.5	1419.46	24.13	0.59	0.74

Table-4: Results of Mann-Kendall test with Sen's slope (Q,mm/year) for annual rainfall over the districts of Gangetic West Bengal (GWB)

SL. NO.	DISTRICTS	KENDALL'S TAU (τ)	p-VALUE	SEN'S SLOPE (Q)	MK TEST (Z)	TREND
1.	Murshidabad	-0.024	0.696	-0.37	-0.39	Decreasing
2.	Birbhum	0.108	0.085	1.39	1.72	Increasing
3.	Bardhaman	0.009	0.886	0.09	0.14	Increasing
4.	Nadia	-0.083	0.186	-1.33	-1.32	Decreasing

5.	Purulia	0.020	0.747	0.21	0.32	Increasing
6.	Bankura	0.053	0.399	0.68	0.84	Increasing
7.	Hooghly	-0.099	0.114	-1.23	-1.58	Decreasing
8.	Howrah	-0.072	0.261	-1.14	-1.12	Decreasing
9.	East Midnapore	0.104	0.097	1.37	1.66	Increasing
10.	West Midnapore	0.100	0.110	1.05	1.60	Increasing
11.	North 24 Parganas	0.057	0.359	0.83	0.91	Increasing
12.	South 24 Parganas	0.220	0.000	3.38	3.52	Increasing
13.	Kolkata	0.161	0.010	2.07	2.57	Increasing

Table-5: Results of Mann-Kendall test with Sen's slope (Q,mm/year) for seasonal rainfall (Jun-Sep) over the districts of Gangetic West Bengal (GWB)

SL. NO.	DISTRICTS	KENDALL'S TAU (τ)	p-VALUE	SEN'S SLOPE (Q)	MK TEST (Z)	TREND
1.	Murshidabad	0.016	0.799	0.18	0.25	Increasing
2.	Birbhum	0.088	0.159	0.91	1.41	Increasing
3.	Bardhaman	0.069	0.271	0.61	1.10	Increasing
4.	Nadia	-0.048	0.449	-0.55	-0.75	Decreasing
5.	Purulia	0.001	0.983	0.01	0.02	Increasing
6.	Bankura	0.075	0.232	0.84	1.19	Increasing
7.	Hooghly	-0.027	0.665	-0.26	-0.43	Decreasing
8.	Howrah	-0.028	0.660	-0.36	-0.44	Decreasing
9.	East Midnapore	0.125	0.047	1.34	1.98	Increasing
10.	West Midnapore	0.114	0.070	1.12	1.81	Increasing
11.	North 24 Parganas	0.069	0.270	0.75	1.10	Increasing
12.	South 24 Parganas	0.235	0.000	2.96	3.75	Increasing
13.	Kolkata	0.140	0.026	1.52	2.22	Increasing

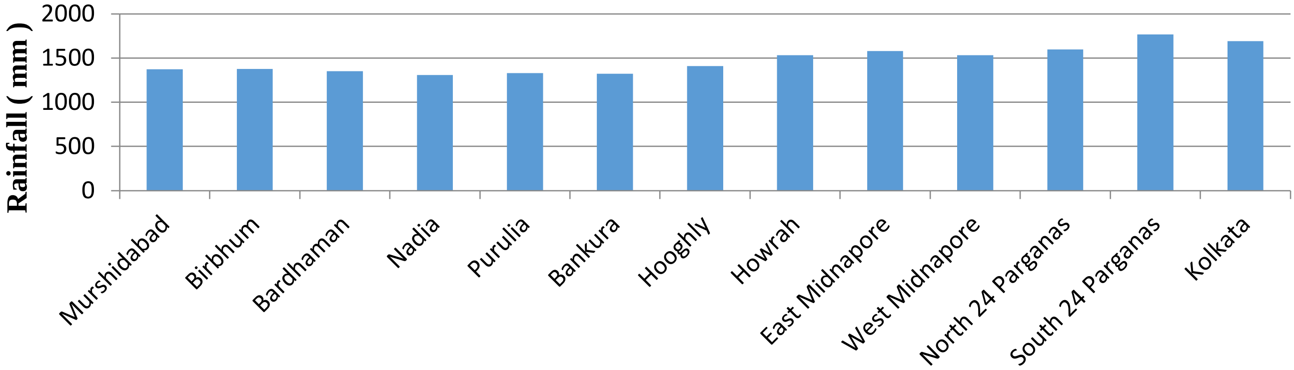

Fig-2: Annual Rainfall Variations in the districts of Gangetic West Bengal

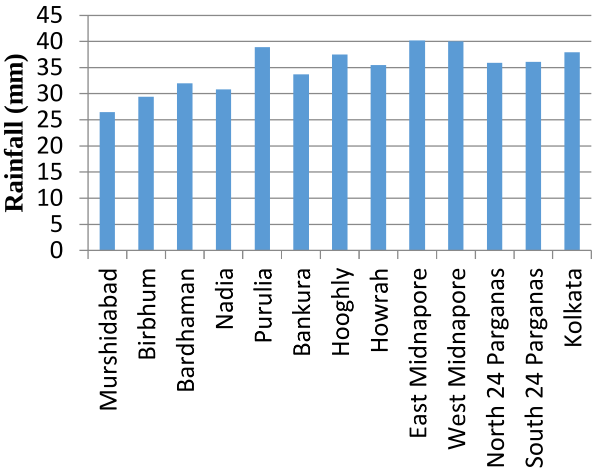

Fig-3: Seasonal Rainfall Variations (Jan-Feb) in the districts of Gangetic West Bengal

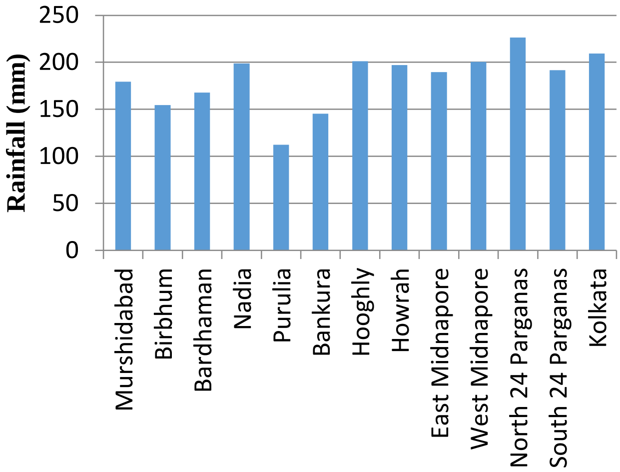

Fig-4: Seasonal Rainfall Variations (Mar-May) in the districts of Gangetic West Bengal

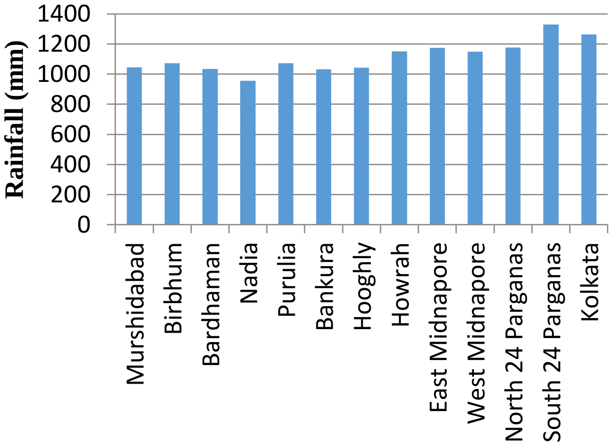

Fig-5: Seasonal Rainfall Variations (Jun-Sep) in the districts of Gangetic West Bengal

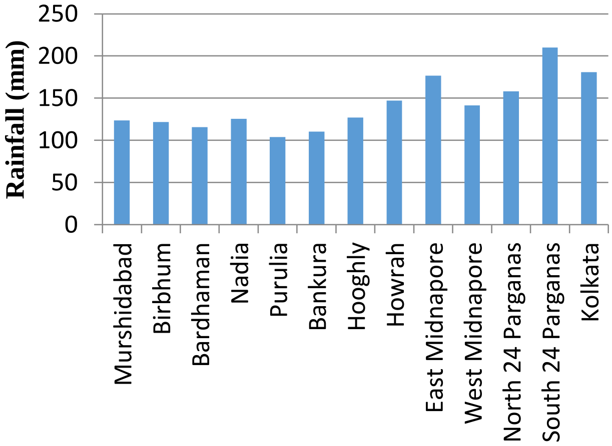

Fig-6: Seasonal Rainfall Variations (Oct-Dec) in the districts of Gangetic West Bengal

On the basis of 117 years monthly rainfall data, mean monthly, seasonal and annual rainfall has been estimated for all the districts falling under Gangetic West Bengal Sub-Division. The average annual and seasonal maximum rainfall is noted by 24 Parganas (S) district (1765 mm and 1328 mm respectively) and minimum by Nadia district (1309 mm and 956 mm respectively). It has been observed that around 74 to 81% of the annual rainfall is contributed by Jun-Sept rainfall. It is also seen that the pre-monsoon months of Mar-May and post-monsoon months Oct-Dec also substantially contribute to total annual rainfall. This is mostly related to thunderstorm activity during the pre-monsoon months locally known as 'Kal Baisakhi' (norwesters). High variation in annual and seasonal rainfall is seen in Nadia, Howrah and 24 Parganas (S) districts and low variation in Bardhaman, Purulia and Midnapore (W) districts.

In GWB sub-division, 24 Parganas (S) and Kolkata districts showed significant increasing trend during monsoon (2.96 mm/year and 1.52 mm/year respectively) and annual (3.38 mm/year and 2.07 mm/year respectively) rainfall supported by the Sen's slope estimator. The other districts which showed increasing trend in seasonal and annual rainfall are Birbhum, Bardhaman, Bankura from 1981 onwards, Midnapore East and West, 24 Parganas (N) from 1940 onwards. Slightly decreasing trend was noticed in the Nadia and Howrah districts. This is because in these districts, numbers of excess and deficient years were found to be more or less same. Seasonal and annual rainfall for 1901-2017 showed noteworthy decreasing trend in Hoogly district after 1970. Slightly decreasing trend is noted for Murshidabad and Howrah district with negative Sen's slope for annual rainfall series. However Murshidabad district showed increasing trend during Jun-Sept monsoon season. Although no significant trend was seen for Nadia district, Mann-Kendall tests showed negative trend to the higher side than the other three districts mentioned above.

Percentage change in annual rainfall series showed > -10% change in Nadia and Hooghly districts. Positive increase >10% is seen in Birbhum, Midnapore (E), 24 Parganas (S) and Kolkata districts of GWB. Seasonal rainfall series showed positive percentage change increase >10% in Midnapore (E), Midnapore (W), 24 Parganas (S) and Kolkata districts of GWB. Nadia and Hooghly districts showed high negative percentage change due to decrease in rainfall activity during Jun-Sept monsoon months.

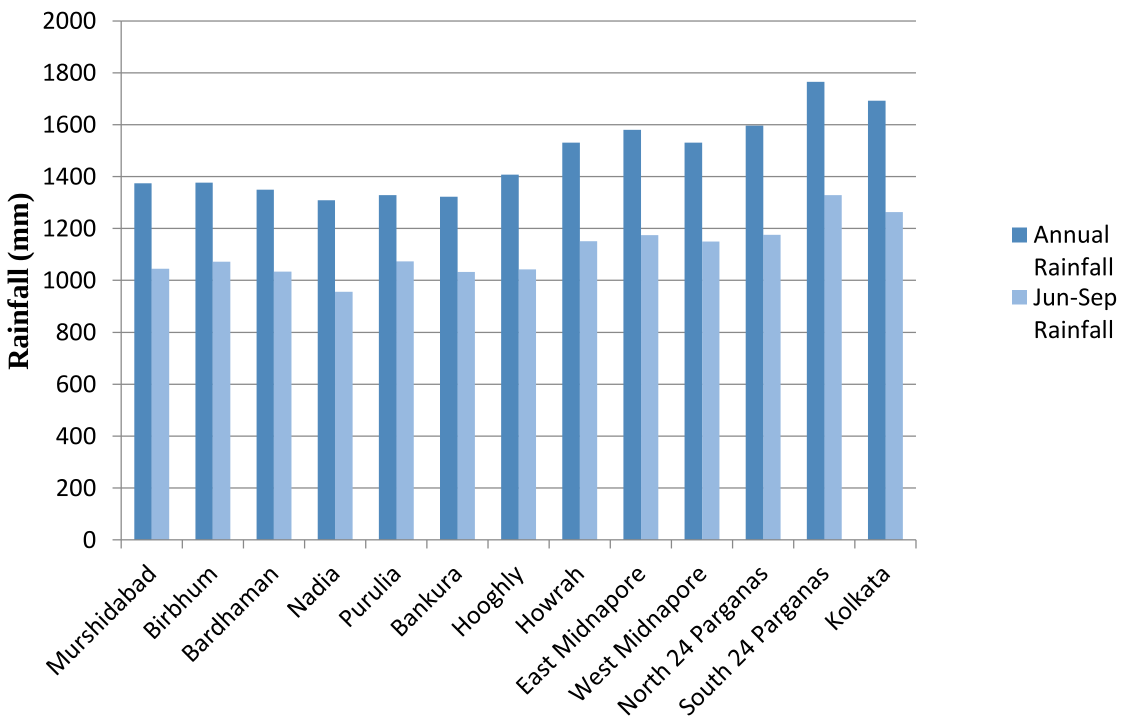

Fig-7: Annual and Monsoonal (Jun-Sep) Rainfall Variations in the districts of Gangetic West Bengal

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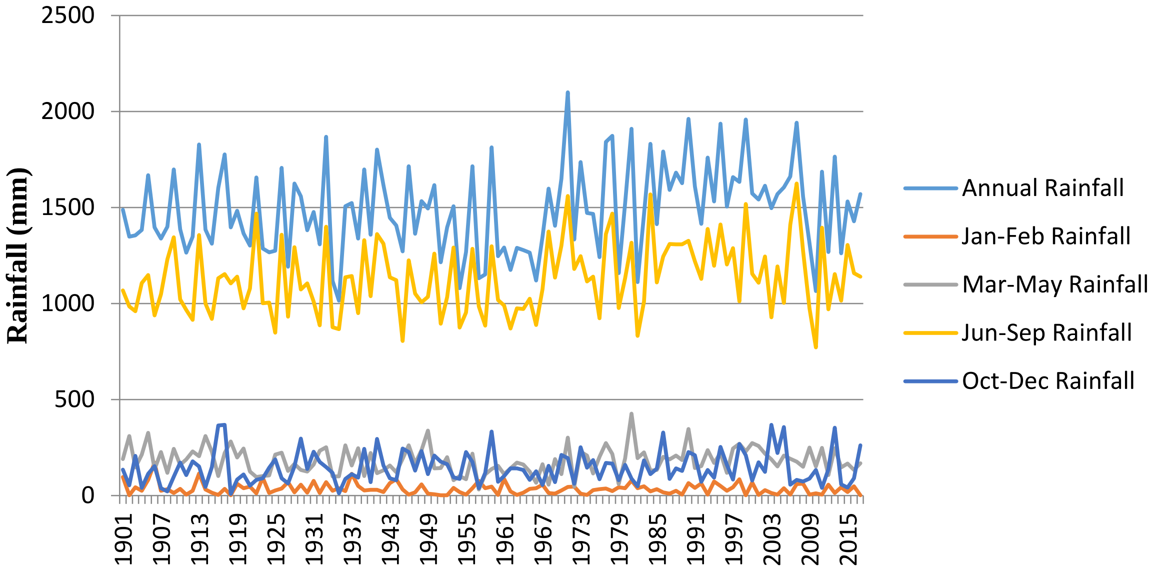

Fig-8: Annual and Seasonal Rainfall Variations for the entire Gangetic West Bengal for the period 1901-2017

Rainfall Trend Pattern: If we look at the rainfall trend, then the result shows that, in case of annual average rainfall most of the districts have a definite trend. But if we look at the seasonal trend of rainfall, then we can see that during pre-monsoon, rain-fall is decreasing in the GWB except Purulia and it is completely reversed during post-monsoon period. During winter season, the entire Gangetic West Bengal has a downward trend of rainfall except the two 24 Parganas. Monsoon period shows a very contrasting picture of rainfall during the last century. The central districts are showing a very fluctuating trend which is insignificant at the 95% level but still as per the Kendall' S and Sen's slope (β) these districts have a negative trend. The rainfall is increasing at the rate of 0.344 mm per year in North 24 Parganas during monsoon (Jun-Sep). In case of annual average rainfall trend also, North 24 Parganas has the highest increasing trend (0.158 mm. per year) during the last century.

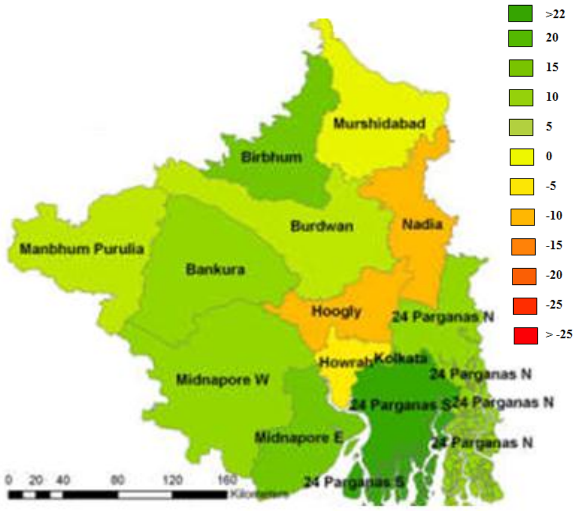

Fig-9: Percentage change in the annual rainfall series in the districts of Gangetic West Bengal

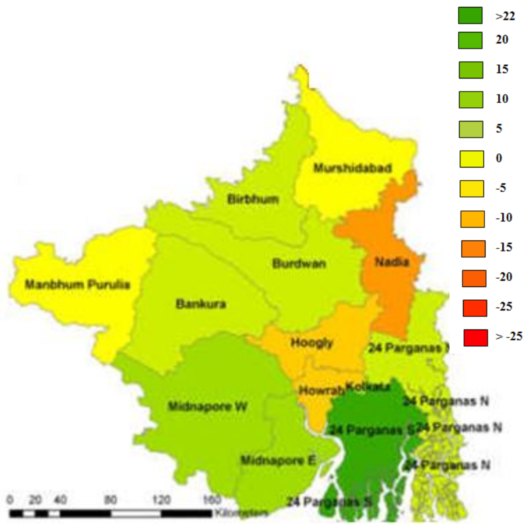

Fig-10: Percentage change in the seasonal rainfall (Jun-Sep) series in the districts of Gangetic West Bengal

V. CONCLUSION

In the light of climate change, it is essential to study rainfall variation at small regional scale for better water management, understanding hydrology and agriculture of the region from administrative point of view. The present study highlights the results of the trend analysis using monthly rainfall data for 117 years (1901-2017) of the 13 districts falling under Gangetic West Bengal at seasonal and annual scale because more than 75% of rainfall is received during the monsoon season. Alternative positive and negative trend in the rainfall pattern, equal number of excess and deficient years etc show mixed scenario in rainfall trend indicating the climate change in rainfall variation over the West Bengal state. Out of 13 districts, 10 of them showed decreasing trend in rainfall pattern hence it is high time for undertaking some alternative measures to overcome the situation. The Report of the Regional Meteorological Centre Kolkata under IMD, Govt. Of India on the seasonal rainfall distribution for the period 01.06.2019-27.07.2019, reveals that during the Monsoon season (Jun-Sep) for the year 2019, out of the 13 districts of the Gangetic West Bengal, the rainfall deficiency will be in the range of -20% to -59% for the 10 districts (viz., Murshidabad, Birbhum, Bardhaman, Nadia, Purulia, Bankura, Hooghly, East Midnapore , West Midnapore and South 24 Parganas) and that of -60% to -99% for the remaining 3 districts (viz., North 24 Parganas, Kolkata and Howrah).

As per the above study, it is quite evident that there is a mixed scenario of rainfall trend in West Bengal. Although majority of districts are having decreasing trend of rainfall. As monsoon rainfall has prime significance in the production of crops, therefore the districts of central West Bengal which are suffering from decreasing trend and hence drought conditions must think about alternative measures of irrigation. Similarly, increasing trend in the post-monsoon rainfall over entire state except the North-Bengal has become a concern for flood probability and crop loss.

West Bengal is an agrarian economy based state where rice is the major crop. In the central part along the riverine flood plain, agriculture is highly practiced. But monsoon rainfall is decreasing more or less in this area whereas post-monsoon rainfall is increasing. So, crop calendar must be revised for this part of the state. During pre-monsoon, rainfall is increasing in the North Bengal whereas it is decreasing in the South Bengal. So, we can understand that Boro cultivation will be preferable in the North Bengal than the South Bengal. If we have to do it in the fertile plains of South Bengal then irrigation facility must be provided in this season.

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