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Research Article

Evaluation of Climate Change Impact on Rainfall Variation in West Bengal

SS Nandargi[1]* and K Barman[2]

[1]*Scientist, Indian Institute of Tropical Meteorology, Pashan, Pune, India*

[2]*M.Sc Geoinformatics, Bharati Vidyapeeth Deemed University, Institute of Environment Education and Research, Pune, India*

***Corresponding Author:** SS Nandargi, Scientist, Short Term Variation and Climate Prediction Department, Indian Institute of Tropical Meteorology, Pashan, Pune, India.

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Abstract

Rainfall is an important parameter of weather and climatology. Being located in close vicinity of Bay of Bengal, West Bengal experiences large vagaries in the monsoon and annual rainfall. In view of this, in the present study different aspects of monsoon and annual rainfall variation for the two meteorological sub-divisions are studied with reference to Standardized rainfall anomaly index, Precipitation concentration index, and coefficient of variation using monthly rainfall data (1901 - 2016) of West Bengal. The analysis revealed that the spatial and temporal analysis are influenced by climate change especially 1990 onward showing increase in percentage of dry years in Gangetic West Bengal (75% to 97%) although increase in rainfall is seen during 2001 - 2016. Even southern districts of Sub-Himalayan West Bengal showed increase in dry year's percentage (69% to 84%). This is serious condition from agricultural as well as water resources planning point of view.

Keywords: West Bengal; Climate Change; Rainfall Variability; Statistical Analysis; Precipitation Ratio; Standardized Rainfall Anomaly Index

Introduction

In order to understand the impact of climate variability, it is essential to examine the behaviour of the principle elements of hydrological cycle viz. precipitation and temperature because both the parameters highly variable in space and time at local, regional and global scale [1]. The report of Intergovernmental Panel on Climate Change [2] has also mentioned about the observed trends in seasonal, annual and spatial distribution in rainfall during the past decades all over Asia. In India also due its large size complex geography, in last century summer monsoon rainfall has showed decreasing trend and increasing trend during pre-monsoon and post-monsoon months of monsoon season [3]. Increasing trend in the monsoon seasonal rainfall was indicated by Kumar., *et al.* [4] in north-west India, along the west coast, and north Andhra Pradesh whereas decreasing trend was observed over north-east India, east Madhya Pradesh and adjoining areas, and parts of Gujarat and Kerala. Guhathakurta and Rajeevan [5] study on southwest monsoon rainfall of 1901 - 2003 period showed that three subdivisions viz. Jharkhand, Chhattisgarh and Kerala experienced significant decreasing trend of rainfall whereas eight subdivisions viz. Gangetic West Bengal, West Uttar Pradesh, Jammu and Kashmir, Konkan and Goa, Madhya Maharashtra, Rayalaseema, Coastal Andhra Pradesh and North Interior Karnataka showed significant increasing trends in rainfall pattern. Such variations in rainfall pattern at local, regional scale and fluctuations from place to place emphasize to study this climate parameter with more attention and carefully at local, district level, basin level, etc. IMD (2013) reported an increasing trend of averaged monsoon season rainfall in West Bengal during 1950- 2010 (State Level Climate Change Trends in India, 2013).

India, being an agricultural country, planning for water resources development in a basin or a region requires careful assessment of the available water resources and reasonable needs of the basin/region in foreseeable future for various purposes such as drinking, irrigation, crop production, hydro-power generation, industries, navigation, etc. More than 75% of rainfall occurs during the monsoon season however, monsoon rainfall is uneven both in time and space, so it forms an important factor to evolve the rainfall analysis. Due to change in climate, the frequency of rain has become unpredictable causing floods in one part and drought in the other part of the country. Hydrological studies are carried out to estimate the available quantity of water in a given time distribution, on long term as well as short-term basis. Therefore, to ensure the success of any project, it is necessary to plan it in such a way that desired quantity of water will be available most of the time to meet the needs.

It is known to everyone that West Bengal is located in lower reaches of Ganga basin, very close to the Bay of Bengal. Therefore the climate of the state is influenced by gigantic wet monsoon air streams (known as low pressure systems) from the south to south-east Bay of Bengal during the monsoon season. These low pressure systems are responsible for causing heavy to very heavy rainfall over the state causing very often serious floods in the Sundarbans region or deltaic region of Ganga-Hooghly river. Considering this, it is decided to analyse rainfall characteristics of the West Bengal for the period 1901 - 2016 in the recent past. The study includes the temporal and spatial distribution of rainfall and its variability through different seasons, trend analysis which may be useful for better water management practices in the state.

Material and Methodology

Study Area

The West Bengal State situated in the eastern part of India with its geographical spread over 21°30' to 27°30' N and 85°30' and 89°45' E covering an areas of 88752 sq.km 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 Odisha 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 (Figure 1).

The unique feature of geography of the state is that its northern part is in the Himalayan Range known as Sub-Himalayan West Bengal (SHWB), southern part is formed of Gangetic plains (called as Gangetic West Bengal -GWB), and the extreme southern part touches the Bay of Bengal and is covered by the active Delta of the Sundarbans Mangrove forest. Mount Kanchenjunga located in adjacent Sikkim dominates the landscape of the area, particularly in Darjeeling of Sub-Himalayan West Bengal. The SHWB is a part of Tarai lowland belt between the Himalayan ranges and the plain area. The plain of GWB contains fertile alluvial soil that is deposited by the Ganga and its tributaries (Figure 1). There are numerous marshes and shallow lakes in the plain area. The elevation of the plain increases slowly toward the west and there is markedly rise near the Chota Nagpur Plateau located in neighbouring Jharkhand state.

Figure 1: District map of West Bengal showing physiographic features and river system.

The SHWB river system consists of the Teesta, the Torsa and the Jaldhaka river which are the major tributaries of the river Brahmaputra. In the south, the river Ganga and the Hooghly are the main rivers. The Ganga drains into the Bay of Bengal forming the famous delta of Indian Sundarbans. It is one of the biggest deltas formed by the combination of two major rivers of India, the Ganga and the Brahmaputra and their tributaries. Major part of the delta is located in Bangladesh, while about 65000 sq.km area lies in the South West Bengal. In addition to these, rivers Ajoy, Barakar, Bhagirathi, Bhairab, Damodar, Jalangi N, Mahananda and Subarnarekha also flow through the state. Different parts of West Bengal are vulnerable to the natural calamities like Flood, Cyclonic Storms, Earthquake, Landslide, Drought and Embankment Erosion. In fact there are multiple High Risk Multi Hazard Zones.

West Bengal broadly experiences hot and wet tropical monsoon climate. It varies from moist- tropical in the south-east to dry tropical in the south west and from sub-tropical to temperate in the mountains of north. The climate is cooler in the northern mountains than in the southern plains. Broadly the state experiences four marked seasons:

i) The hot and dry season (March to early June), with dry hot and humid days and frequent thunderstorms;

ii) The hot and wet season (mid-June to September), when rain-bearing monsoon winds blow from the south to southeast; and

iii) The post monsoon (Autumn) season (October to November), when days are dry and clear and stable atmospheric conditions prevail.

iv) The cold, dry winter from December to February in the plains and up to mid-March in Darjeeling Himalayas. The winter months are generally pleasant in the southern part of the state. Snowfall is limited to the Himalayan region.

Southwest monsoon (July to September) plays important role in the climate of West Bengal. It advances over the state by 7th June and withdraws by 10th October constituting total 125 rainfall days. 75% to 80% of the annual rainfall is received during monsoon season. Throughout West Bengal there is a pronounced seasonal variation in rainfall e.g. average annual rainfall of Kolkata is about 1625 mm of which 330 mm fall in August and < 25 mm in December. The state is also subject to considerable variability from year to year. In the sub-Himalayan region, rainfall is considerably greater.

Data used

Sub-divisional and district monthly rainfall data for the period of 1901 to 2016 obtained from the National Data Centre (NDC), India Meteorology Department (IMD) forms the major data source.

Methodology

Statistical analysis: On the basis of the monthly rainfall data for the state, long term mean monthly, seasonal and annual rainfall was calculated for the districts and the two sub-divisions, North and South West Bengal along with the standard deviation and coefficient of variability for the period of 1901 to 2016 and their spatial distribution have been shown using GIS technique.

Precipitation Ratio: The abnormalities of rainfall at any location are worked out by a simple ratio of precipitation which is expressed as:

$$P_R = \frac{(P_{Max} - P_{min})}{P_{MAR}} \times 100 \quad \ldots\ldots\ldots\ (1)$$

Where, P_R= Precipitation Ratio; P_{Max}= Maximum mean annual rainfall; P_{Min}= Minimum mean annual rainfall; P_{MAR}= Mean annual rainfall

Standardized Rainfall Anomaly Index (SRAI)

$$z = \frac{x - \mu}{\sigma} \quad \ldots\ldots\ldots\ (2)$$

Where,Z = Standardized Rainfall Anomaly Index (SRAI); X = Annual rainfall total of a given year; μ = Mean annual rainfall of a period considered; σ = Standard deviation of a period considered

Results and Discussion

Impacts of changes in the rainfall (pattern and magnitude) and temperature as well as an increase in extreme events have profound effect on food availability and socio-economic conditions of a region. Long period monthly rainfall can be used to assess the regional response to climate change for any water resources systems and it is also useful in deriving water availability in the large river catchments. As mentioned earlier, the water resource in the river basins of West Bengal state is mainly due to the monsoon rainfall during Jun to Sept and is largely affected by the monsoon vagaries, resulting in floods during some years and droughts during others. Due to the increase number of such disasters and their high impact on economical and human life, it is necessary for the state administration to have district rainfall climatology and information about temporal variability of rainfall at the district levels for better disaster and water managements and planning. Considering this, attempts have been made to study temporal and spatial variability of the monsoon rainfall on monthly, seasonal, annual and decadal scales and the changing pattern of rainfall using 1901 to 2016 rainfall data for all the districts of the West Bengal state.

Monthly rainfall variation

The distribution of precipitation throughout the seasonal cycle is as important as the total annual amount of monthly or annual precipitation when evaluating its impact on hydrology, ecology, agriculture or in water use. As already stated, West Bengal's climate is transitional between tropical wet-dry in the southern portions and humid subtropical in the north. The variation of monthly rainfall over the two sub- divisions of West Bengal showed that the intensity of rainfall gradually goes on increasing from mid- March to July (see Figure 2). This is mostly due to the thunderstorm activity (well known as "Kal Baisakhi") during pre-monsoon months of

March-May and later enhancement of southwest monsoon activity over the region. It decreases sharply till the month of October. July is the highest rainfall recording month in all the districts of both the sub-divisions.

Figure 2: Average monthly rainfall (mm) for the two sub-divisions of West Bengal.

All the districts in SHWB show two peaks in monthly rainfall, one in July and second in September. There is decrease in rainfall activity in the month of August (Figure 2). In GWB, Nadia and Murshidabad districts showed slight decrease in August month rainfall. This can be illustrated as during August low pressure areas develop in lower latitudes of central Bay of Bengal. Districts in SHWB recorded 77% (Dist. Cooch Behar) to 80% (Districts Darjeeling and Dinajpur N) of their respective annual rainfall during Jun-Sept monsoon months in association with the Himalayan topography in this region. Low Pressure system when cross Cooch Behar comes in the sway of high altitude Himalayan range shading heavy rainfall over Jalpaiguri (> 950 mm) district compare to Cooch Behar (756 mm). There is again decrease in rainfall when the moist current reach over the Darjeeling (795 mm) at still higher altitude wherein some of the rain gets converted into snow and therefore experience less rainfall.

Districts in the GWB experienced Jun-Sept rainfall varying from 73% in Nadia and 81% in Purulia districts. In the southern plain area comparatively less average July rainfall is observed varying between 276 mm (Dist. Nadia) to 394 mm 24 Pargana-S. As stated earlier orography again plays an important role. It is interesting to mention that pre-monsoon (Mar-May) rainfall percentage in all the districts is more than that of post-monsoon rainfall (see figure 3) in association with the thunderstorm activity. Eastern parts of the state receive heavy rainfall during post-monsoon season due to northeast monsoon rainfall. As seen from figure 3 in the pre-monsoon months, Jalpaiguri and Cooch Behar districts recorded > 500 mm of average rainfall in the SHWB whereas average pre-monsoon rainfall in the plains of GWB restricted between 120 to 300 mm except Purulia district which recorded < 120 mm of rainfall. There is increase in magnitude of rainfall during monsoon season (Figure 3).

Figure 2: Average monthly rainfall (mm) for the two sub-divisions of West Bengal.

Figure 3: Spatial distribution of average Mar-May and Jun-Sept. rainfall over the West Bengal.

Except Nadia district, rest of the districts recorded more than 1000 mm of rainfall in GWB. Districts in GWB recorded average 1000 mm to 2000 mm rainfall in June-September months. The highest June-September rainfall was recorded in the Jalpaiguri district (3846.4 mm) followed by Cooch Behar and Darjeeling districts (2500 to 3000 mm) in SHWB. This is mostly associated with the topography of the region. This is also followed in annual distribution (Figure 4) also but with increase in rainfall magnitude. Substantial decrease in rainfall is seen in post-monsoon period with highest rainfall in 24 Parganas S (> 200 mm) and rests were having rainfall < 150 mm (Figure 4) in GWB whereas SHWB districts recorded rainfall between 150 mm-200 mm.

Annual and Seasonal Rainfall Variation (1901-2016)

Average annual and Jun-Sept rainfall go hand in only there is increase in magnitude of rainfall in annual. As stated earlier SHWB recorded more rainfall than the GWB. The variation in rainfall showed an increasing trend from 1930 to 1970 thereafter there is decrease in rainfall (Figure 5 and 6) in the SHWB. However in GWB, there was decrease in rainfall activity during 1930 to 1980 period especially in Murshidabad, Birbhum, Bardhaman, Bankura, Midnapur E and Kolkata districts. Significant increase in rainfall is shown by 24 Pargana S district only which comes in direct flow of monsoon wind currents.

Figure 4: Spatial distribution of average Oct-Dec. and Annual rainfall over the West Bengal.

Figure 5: Average annual and seasonal rainfall variation in SHWB (1901-2016).

The variation in annual and seasonal average rainfall in 1901 to 1950 and 1951 to 2000 and 2001 to 2016 periods showed that there is equal or slight increase in rainfall (see figure 7). Except Cooch Behar district, in SHWB all the districts, especially hilly districts of Jalpaiguri, Cooch Behar and Darjeeling showed increase in rainfall during annual and monsoon season during 1901 - 1950 and noteworthy decrease is seen during 2001-2016 period.

Figure 6: Average annual and seasonal rainfall variation in GWB (1901-2016).

Figure 7: Average annual and seasonal rainfall variation in the districts of SHWB.

In GWB, 1951 - 2000 has contributed more annual and monsoon rainfall in the districts of Murshidabad, Bankura, Midnapore East and West, 24 Parganas North and South and Kolkata. However, there is noteworthy increase in rainfall is seen during 2001 to 2016 (Figure 8A and 8B) in the districts of Bardhaman, Midnapore East and West and Kolkata whereas 24 Parganas North and South districts showed increase in rainfall in 1951-2000 period during monsoon season. Nadia district has recorded less rainfall than the other districts in all the three categories. The comparative spatial distribution of rainfall during different periods is shown in figure 9.

It is seen from figure 9 that during 1901-1950 Nadia district in Jun-Sept and Bankura district in annual rainfall show less than 1000 mm and 1400 mm of rainfall respectively. In 1951-2000 Dinajpur N and Nadia districts recorded less rainfall in Jun-Sept, whereas in annual Dinajpur N, Nadia, Murshidabad, Purulia, Burdwan, Bankura and Hooghly districts recorded less rainfall. This can be linked with the reason that 1971 - 1980 decade which recorded less rainfall. During Jul-Sept of 2001-2016 rainfall has increased almost in all the districts except Bankura and Hooghly. But the annual picture shows less rainfall in Murshidabad, Nadia, Bardhaman, Hooghly, and Purulia districts. This may be due to the rainfall received in other months having contributed less to annual rainfall.

Figure 8: Average annual and seasonal rainfall variation in the districts of GWB.

Figure 9: Comparison of Average annual and Jun-Sept rainfall (mm) during the period 1901-1950, 1951-2000 and 2001-2016.

Annual and Seasonal Maximum Rainfall Variation

Maximum annual rainfall values have occurred almost in all the months of the year. However, their magnitude and intensity is higher during the monsoon season. The time and duration of the seasons' high rainfall at a place or watershed is most important for the planning and design of agriculture or water managements. Figure 10 and 11 show the spatial distribution of seasonal and annual maximum rainfall for all districts in West Bengal. It is seen from these figures that highest seasonal (Mar-May, Jun-Sept and Oct- Dec) and annual maximum rainfall has been recorded by Cooch Behar and Jalpaiguri districts of SHWB and 24 Parganas S of GWB which are located in the extreme north or extreme south of the state (Table 1). Therefore these districts are more vulnerable to flood situations.

Figure 10: Spatial distribution of Mar-May and Jun-Sept maximum rainfall (mm).

Figure 11: Spatial distribution of Oct-Dec and Annual maximum rainfall (mm).

Sub-divisions	Districts	Seasons			
		Mar-May	Jun-Sept	Oct-Dec	Annual
SHWB	Cooch Behar, Jalpaiguri	>1300 mm	> 5000 mm	> 500 mm	> 6000 mm
GWB	24 Parganas S	500 - 1000 mm	2000 - 3000 mm	> 500 mm	> 3000 mm

Table 1: Highest seasonal and annual maximum rainfall recorded in two sub-divisions.

The low and high values of annual maximum rainfall during different months and seasons along with their year of occurrences and the districts are given in table 2.

Season	Months	Annual Maximum Rainfall (mm)	
		Low	High
Winter	January	64.0 (1944, Burdwan)	164.6 (1957, Darjeeling)
	February	57.6 (1906, Dinajpur N)	202.3 (1906, Kolkata)
Pre-monsoon	March	100.6 (1920, Murshidaba)	385.3 (1990, 24 Pargana S)
	April	134.9 (1971, Birbhum)	411.4 (1949, Jalpaiguri)
	May	264.6 (1938, Birbhum)	1039.0 (1921, Jalpaiguri)
Monsoon	June	507.3 (1913, Birbhum)	1501.3 (1967, Jalpaiguri)
	July	594.0 (1905, Burdwan)	1890.8 (1955, Jalpaiguri)
	August	577.2 (1909, Nadia)	2895.8 (1990, Cooch Behar)
	September	576.5 (1986, Midnapore W)	1345.5 (1984, Cooch Behar)
Post-monsoon	October	341.8 (1970, Hooghly)	990.7 (1937, Dinajpur S)
	November	123.9 (1932, Malda)	312.8 (1995, 24 Pargana S)
	December	43.3 (1979, Cooch Behar)	205.1 (1991, Bankura)

Table 2: Monthly/Seasonal annual maximum rainfall (mm) range.

Precipitation Ratio (PR)

From the foregoing temporal and spatial distribution of rainfall over the West Bengal, it is seen that rainfall is highly variable in space and time. The abnormalities of rainfall at any location may be brought by a simple ratio of precipitation (see Section 2.1).

This ratio may give the stability of rainfall with special relationship. Higher the ratio, higher is the abnormality in rainfall and vice versa [6]. Precipitation ratio i.e. maximum abnormality for annual rainfall ranged from 13.3 (2011 - 2016, Darjeeling) to 199.4 (1971 - 1980, Dinajpur N) and for seasonal (Jun-Sept) it ranged from 26.2 (2011 - 2016, Jalpaiguri) to 186.9 (1991 - 2000, Dinajpur N) in SHWB. This is mostly associated with the topography of the region. Similarly, in GWB precipitation ratio for annual rainfall, ranged from 12.9 (1901 - 1910, Midnapore E) to 167.0 (1971-1980, Midnapore E) and for Jun-Sept from 20.5 (1901 - 1910, Midnapore E) to 157.2 (1971 - 1980, Midnapore E). Therefore, it can be said that as stated earlier, 1971 - 1980 decade proved to be the low rainfall receipt decade. Whereas 2011 - 2016 period has given good amount of rainfall although this period has experienced four severe drought years. This is because the region receives rainfall due to north to northeast moving low pressure systems as well as due to topography and sinking of lower end of the monsoon trough near Kolkata.

Standardized Rainfall Anomaly Index (SRAI) for Wet and Dry years

There are different indices to describe the rainfall variability based on monsoon and annual rainfall, maximum and minimum rainfall, CV as the percentage ratio of standard deviation to the mean rainfall for a given period, etc. In a similar manner, Standardized Rainfall Anomaly Index is used to determine dry and wet years in the 116 years data of West Bengal using the formula [7].

By using McKee [8] classification, calculated SRAI values are categorized into dry and wet years for all the districts of West Bengal. These dry and wet years were also compared with the IMD's classification of deficient, normal and excess rainfall years and given in table 3. The detailed classification SRAI values are given in table 4. Broadly the ratio of dry to wet years is 41:16 indicating alarming situation from agriculture point of view. Ratio for deficient, normal and excess rainfall for Annual D:N:E is 1:4:1 and Jun- Sept D:N:E is 1:3:1.

SRAI demonstrates the intensity and frequency of drought and inter-annual variation at various time scales and area. The percentage of negative anomaly is less in SHWB during monsoon season whereas exactly reverse condition is seen in GWB (Figure 12). This is because annual rainfall in GWB is also contributed by pre-monsoon (Mar-May) and post-monsoon (Oct-Dec) seasons whereas very heavy rainfall occurs over the SHWB during the monsoon season itself as it is located in the foot hills of the Himalayan ranges.

District	As per SRAI years of		As per IMD years of		
	Dry	Wet	Excess	Normal	Deficient
Sub-Himalayan West Bengal					
Darjeeling	0	116	13	91	12
Jalpaiguri	1	115	34	86	16
Cooch Behar	1	115	25	71	20
Dinajpur N	80	21	23	50	27
Dinajpur S	89	24	25	58	30
Malda	98	17	19	67	29
Gangetic West Bengal					
Murshidabad	108	8	23	65	28
Birbhum	110	6	19	73	24
Burdwan	112	4	20	73	23
Nadia	112	3	29	57	29
Manbhum Purulia	111	5	21	74	21
Bankura	110	6	21	74	22
Hoogly	112	4	26	67	23
Howrah	95	17	28	56	28
Midnapore E	105	11	25	75	20
Midnapore W	105	10	22	77	16
24 Parganas N	97	19	25	65	25
24 Parganas S	85	31	24	69	31
Kolkata	87	26	24	68	21

Table 3: Dry and Wet years (SRAI) and Excess, Deficient and Normal Rainfall years.

Figure 12: Annual and Seasonal SRAI variation over the two sub-divisions of West Bengal.

Conclusion

Analysis of rainfall data of 116 years (1901 - 2016) over West Bengal plays a significant role in the industrial and agricultural contribution and in the overall growth of the country. The analysis included variability of rainfall, trends in rainfall pattern and changes in spatial and temporal patterns of dry and wet year index. The impact of climate changes on temporal and spatial patterns over smaller spatial scales is clearly noticed in this analysis. In the 1970 to 1980 decade, the state experienced very low and uneven rainfall which adversely affected the agriculture production. Due to varied topography, the abnormalities of annual and seasonal rainfall in all the districts have been estimated by a simple ratio of precipitation. The maximum abnormality (> 100%) in annual and seasonal rainfall was recorded during 1971-80, 1981-90 decades. SRAI showed that numbers of dry years are increasing which is an alarming situation from water resources planning and agricultural point of view.

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Conflicts of Interest

There is no conflict of interest.

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