

Variability and trend detection of temperature and rainfall: A case study of Bengal Duars

KOYEL SAM and NAMITA CHAKMA

Department of Geography, The University of Burdwan, West Bengal, India

(Received 8 June 2017, Accepted 26 July 2019)

e mail : koyelsam04@gmail.com

सार - हिमालय की तलहटी का सौंदर्य बंगाल द्वार है जो तीस्ता नदी से लेकर संकोश तक वन आवरण से भरपूर एक अद्वितीय परिदृश्य संयोजन के रूप में फैला हुआ है। वर्तमान अध्ययन में, बंगाल द्वार के 100 से अधिक वर्षों के जलवायु डेटा के आधार पर वार्षिक और मौसमी परिवर्तनशीलता तथा तापमान एवं वर्षा की प्रवृत्ति का पता लगाया गया है। अध्ययन से पता चला है कि उष्णता की डिग्री सभी मौसमों में प्रमुख है। लेकिन वर्षा की प्रवृत्ति विभिन्न मौसमों में भिन्न रही है। यहाँ विसंगतियों की गणना करके जलवायु में परिवर्तनशीलता का अध्ययन किया गया है, जहां लंबी अवधि के दौरान दोलन की प्रवृत्ति देखी गई है। लेकिन 1985 के बाद से वार्षिक औसत तापमान में महत्वपूर्ण रूप से वृद्धि की प्रवृत्ति देखी गई है, वहीं दूसरी ओर 1990 के दशक के बाद से वर्षा का प्रतिशत 5% अधिक हो गया है।

ABSTRACT. The Bengal Duars, a beauty of Himalayan foothills extended from river Tista to Sankosh as a unique landscape assemblage with forest cover. In the present study, the annual and seasonal variability and trend of temperature and rainfall in Bengal Duars based on more than 100 years' climatic data is explored. The study revealed that the degree of warming is prominent over all seasons. But the trend of rainfall varies in different seasons. The variability in climate has studied by calculating anomalies, where the oscillating trend has observed throughout the long period. But the significant rising trend of annual average temperature is noticed from 1985 onwards. On the other hand, rainfall extreme become 5% higher since the 1990's.

Key words – Bengal Duars, Variability, Trend, Anomaly.

1. Introduction

In the recent era of *Anthropocene*, human beings technocentric acts in the name of development of civilisation have resulted in havoc change in the earth's natural climatic system. This has started since the time of industrial revolution, late in the 18th century. Being the most rational terrestrial creature humans started to collect ecosystem services rapidly from the terrestrial ecosystems by clearing forest cover, changing land use pattern in the 20th century and has been continued the pace in the 21st century too. Anthropogenic drivers are detected throughout the climate system and are likely to be the dominant cause of the observed warming since the mid-20th century (IPCC, 2014). The earth's average surface temperature had risen by 0.76 °C since 1850 and most of the warming over the last 50 years is likely to be caused by anthropogenic activities (Somorin, 2010). In India, the mean annual temperature increase at the rate of 0.57 °C in the last century (Pant and Kumar, 1997). Rabindranath *et al.* (2011) reported that the Indian Sub-continent is likely to experience a warming of over 3 to 5 °C with a significant change in flood and drought frequency and intensity. Radhakrishnan *et al.* (2017) studied a significant

positive trend of temperature and declining rainfall of India in the last 30 years (1901-2014) with seasonal variability. On the other hand, a decreasing trend of annual rainfall (1901-2013) has observed over 8% of the area and significant increasing show over 10% of the area in India by Kaur *et al.* (2017). Rajendran *et al.* (2013) projected spatially varying increasing trend of Indian summer monsoon rainfall over Indo-Gangetic plain and North East India during the period of 1979-2003 by using high-resolution model.

Nature and changing characteristics of rainfall and temperature is not uniform all around the world, rather regional variation is apparently clear in climatically different regions (Yue and Hashino, 2003). A comprehensive understanding about changing the pattern of temperature and rainfall is very essential for the development of a particular landscape. North-east India popular for its forest and agricultural resource bases and considered as a separate macro-region (Winstanley, 1973; Parthasarathy *et al.*, 1987). The strategic location, geo-ecological fragility, socio-economic instability makes this region highly prone to climate change (Laskar *et al.*, 2014). The Bengal Duars region located in the foothill of

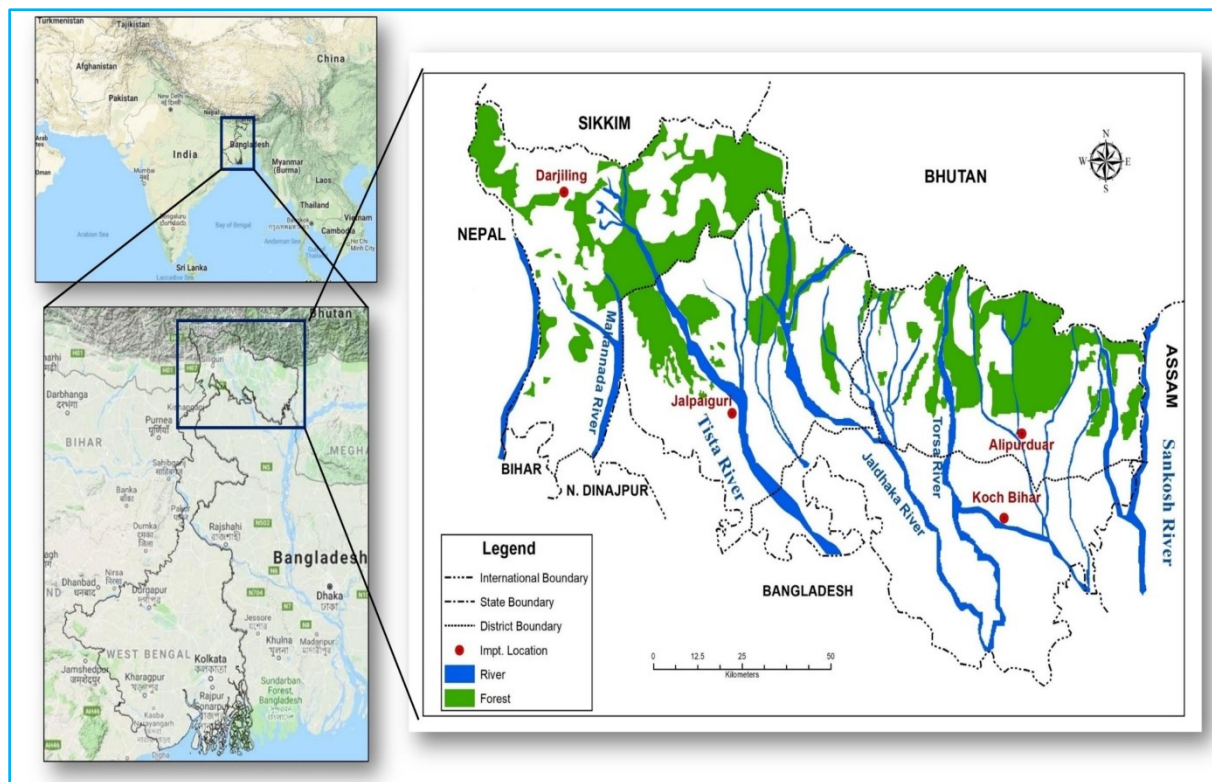


Fig. 1. Spatial distribution of Bengal Duars

Eastern Himalaya and received highest amount of rainfall in West Bengal. The climatic variability and trend of Bengal Duars is still less academically searched by the researchers. Therefore, the present study intends to explore the long-term climatic variability of the Bengal Duars region by using high-resolution climatic data to depict a comprehensible view of annual and seasonal variability and trend.

2. Bengal Duars; a beauty of Himalayan foothills

Duars is located along the foothill of the Himalayas extending from the river Tista in Bengal to the river Dhunseri in Assam. The narrow strip of land, with a breadth of 20 to 30 miles and about 180 miles in length, assemblage with forest cover stretching between the river Sankosh in the east and the river Tista in the west, forms the northern boundary of West Bengal is known as Bengal Duars or Western Duars and other parts in Assam District is popularised as Assam Duars or Eastern Duars (Gruning, 1911). This region acts like an ecotone of sub-Himalayan physiography and the Brahmaputra plain. The immense beauty of nature with an assemblage of forestry and biodiversity acts as an umbrella on the head of West Bengal. The study area, Bengal Duars extends from $26^{\circ}30'0''$ N to $27^{\circ}11'20''$ N and $88^{\circ}25'18''$ E to $89^{\circ}52'40''$ E

and now it covers a large portion of Jalpaiguri, Alipurduar and Kalimpong district and a small part of Koch Bihar District (Fig. 1).

The climate of Duars region owing to its proximity to the hills, the rainfall is much heavier and temperatures seldom excessive (Gruning, 1911) The region receive an annual rainfall of 3000 mm out of these, 1800 mm of rainfall occur in the monsoon months only (Jana, 2002). Therefore, trend analysis of extreme rainfall events is important, considering the flood vulnerability of this region.

3. Data sources and methodology

Daily and monthly climatic data of rainfall (1901-2015) and temperature (1951-2014) were extracted from a gridded dataset of India Meteorological Department (IMD), Pune and temperature data (1901-1950) also collected from this web link http://www.indiawaterportal.org/met_data/.

3.1. Multi-decadal oscillations analysis

Ntegeka and Willems (2008) and William (2013a,b) have analysed the recent trends and the multi-decadal oscillations of precipitation intensities, this was done by means of a technique identifying anomalies in extreme

quantiles. The same method is applied in the present study to investigate multi-decadal oscillations and anomalies in climatic events.

An anomaly is a study of relative change of climatic parameters (e.g., temperature, rainfall) in comparison to the long-term average. In the present study, continuous anomalies are calculated through 15 or 30 years' interval, corresponds to the whole periods. After converting individual anomaly in percentage, it has plotted against the middle of a particular block length. Percentages of anomalies help to identify the rate of changes in decadal and centurion term. The above which the values are considered as an "extreme" is called as a threshold, which corresponds to a specific frequency of occurrence in time or a specific mean recurrence interval. On the other hand, the 95% confidence intervals are calculated from the whole historical series. Such for example, 100 random samples (same size as historical series) are generated. For each random sample, anomaly calculation is repeated and leading to generate 100 values of each year of historical series. After ranking the 100 values, 25th and 75th sample values define the 95% confidence interval for each particular year.

3.2. Analysis of climatic trends

The non-parametric Mann-Kendall Trends test is applied to determine whether there exists any trend or not in the data series. It is valid for a sequential dataset of independent and identical distributed values $x_i, i = 1, n$ under the null hypothesis (H0) of no trend in the data. The Mann-Kendall test statistics value is computed as:

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

where, by $\text{sgn} (x) = -1$ for $x < 0$, $\text{sgn} (x) = 0$ for $x = 0$ and $\text{sgn} (x) = 1$ for $x > 0$. A positive value indicates an increasing trend and a negative value denotes a decreasing trend.

If, sample size ≥ 8 , the test statistics S is approximately normally and variance of S as follows:

$$V(S) = 1/18 [n(n - 1)(2n + 5)] \tag{2}$$

where, n denote the length of the time series and standardized statistical test Z is computed as:

$$\begin{aligned} Z &= S-1 / \sqrt{V(S)} \text{ if, } S > 0, \\ &= S+1 / \sqrt{V(S)} \text{ if, } S < 0 \end{aligned} \tag{3}$$

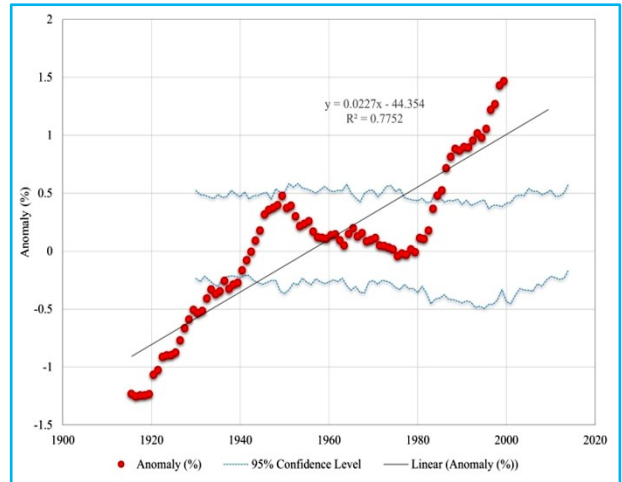


Fig. 2. Anomalies in annual temperature (1901-2014) using 30 years moving average

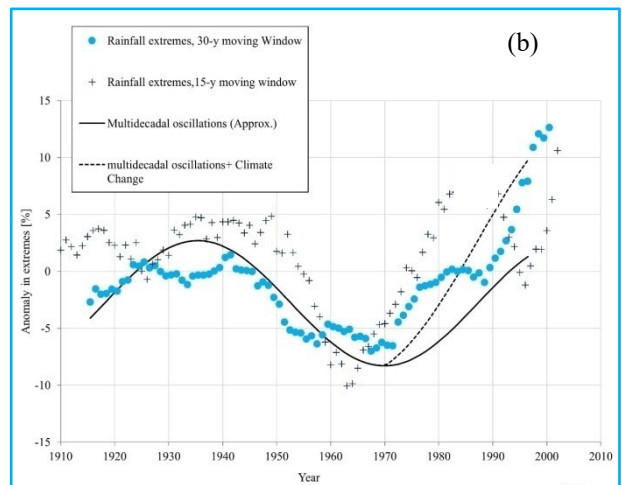
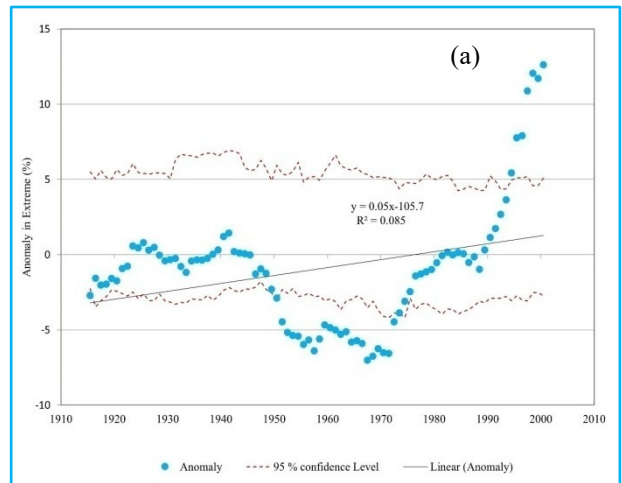


Fig. 3(a&b). (a) Anomalies in annual rainfall extremes using 30 years moving average and (b) The Identical change in rainfall extremes observed after 1970's onward (Source: Sam & Chakma, 2019)

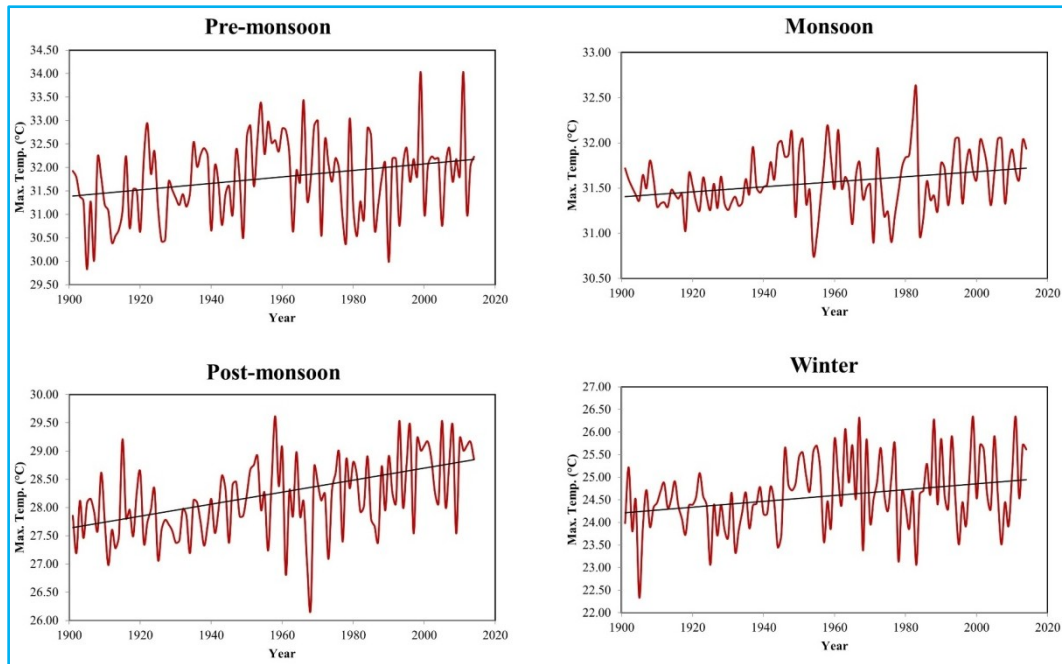


Fig. 4. Seasonal trend of maximum temperature (1901-2014) with Sen's trend line

The magnitude of the trend is examined by using Sen's slope estimator, which was proposed by Sen (1968). The magnitude is predicted by the slope (T_i) from all data pair computed as follows:

$$T_i = X_j - X_i / j - i \quad (4)$$

where, X_j and X_i are as rainfall values at the time of j and i ($j > i$). the median value of T_i represented as Sen's slope estimator. Sen's slope estimator is calculated as $Q_{med} = T(N+1)/2$ if N is odd and $Q_{med} = [T(N+1)/2 + T(N+1)/2]/2$ if N is even. Thereafter trend is tested 100 (1- α) % confidence interval.

4. Results and discussion

4.1. Multi-decadal oscillation of temperature and rainfall extreme

The climate of this region was damp due to heavy rainfall in the monsoon season and temperature is rarely excessive. In Fig. 2, the multi-decadal trends of average annual temperature go beyond the normal persistence from 1985s onward and R^2 value signifies the linear positive trend. On the other hand, lower extremes are found from 1920 to 1930 by considering more than 100 years of historical series. As this region is prone to flood and high extreme precipitation observed during monsoon season (June to August), henceforth, annual extreme rainfall is also taken under consideration in multi-decadal

oscillations analysis. Figs. 3(a&b) illustrate multi-decadal oscillations with higher rainfall quantiles for 1930-1940s and 1980s onwards and lower quantiles in 1960-1970 are observed. From this trend, it has observed that after 1970's trends of extremes events are not similar as approximate cyclic variations. Extreme precipitation quantiles are found to be around 5% higher than the previous cluster periods of the past decades, oscillation altitude increased as an effect of climate change reflects on rainfall extremes. The resultant recent cluster of extreme rainfall might be attributed to anthropogenic induced climate change, given that the change is in sign and order of magnitude consistent with the global warming impact predictions following regional climate model (Lenderink *et al.*, 2007; IPCC 2007a,b; Min *et al.*, 2011; Willems *et al.*, 2012).

4.2. Seasonal trend of temperature and rainfall

The Mann-Kendall and Sen's slope are estimated to analyse the trend and rate of change of seasonal temperature (1901-2014) and rainfall (1901-2015) of the studied region.

4.2.1. Pre-monsoon

During pre-monsoon period, a significant positive trend of maximum and minimum temperature is observed (Figs. 4&5) and both are found to be significant at 95% and 99% level of significance with a slope of 0.017

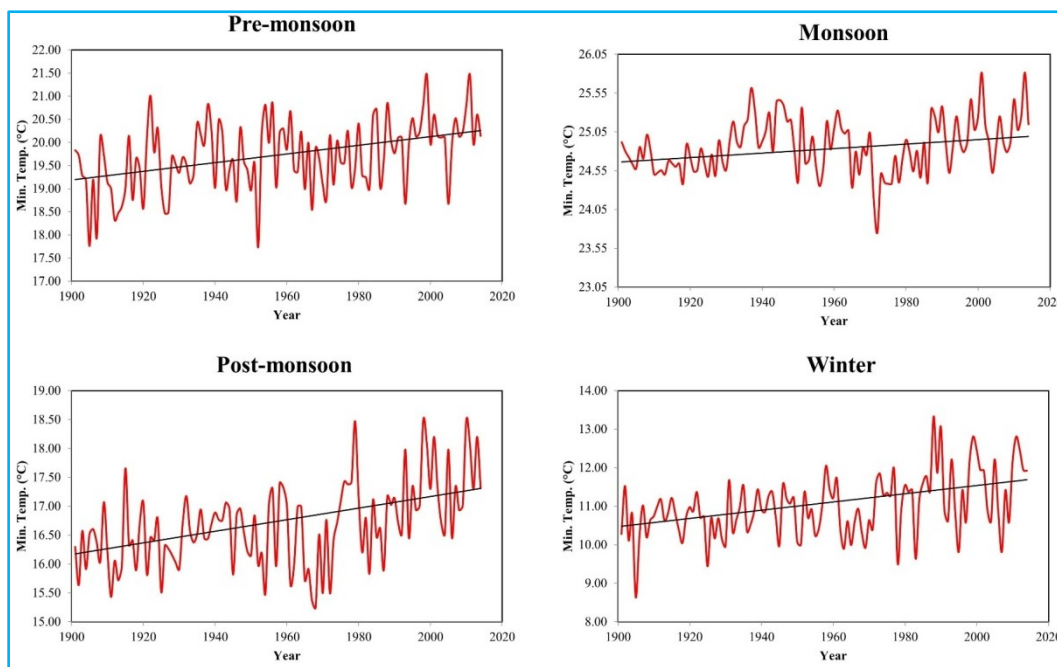


Fig. 5. Seasonal trend of minimum temperature (1901- 2014) with Sen's trend line

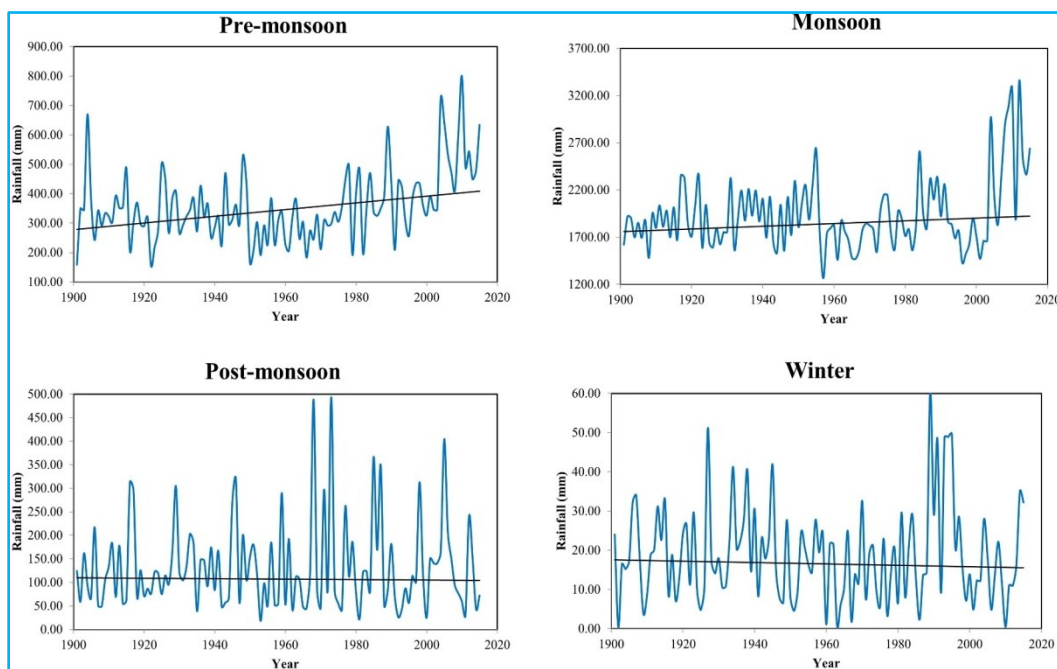


Fig. 6. Seasonal trend of rainfall (1901-2015) with Sen's trend line

and 0.018 respectively (Table 2). Whereas a significant positive trend is found during this season specially in the month of April and May in case rainfall (Fig. 6 & Table 3). The trend of rainfall is found to be significant at a 99% level of confidence (Tables 3&4).

4.2.2. Monsoon

The Bengal Duars region has received the highest amount of rainfall during this period. In this season, the trend of maximum and minimum temperature is found to

TABLE 1
Mann Kendall (Z) and Sen's Slope (Q) estimate of monthly temperature

Month	Z		Q		Significance	
	Max	Min	Max	Min	Max	Min
Jan	1.527	2.035	0.005	0.006	NS	*
Feb	2.888	4.458	0.011	0.014	***	***
Mar	1.579	3.134	0.007	0.011	NS	NS
Apr	1.645	2.307	0.006	0.007	*	*
May	2.356	2.859	0.007	0.008	*	*
Jun	2.489	2.275	0.005	0.004	*	*
Jul	-0.032	1.159	0	0.002	NS	NS
Aug	2	1.076	0.002	0.002	*	*
Sep	0.778	0.679	0.001	0.001	NS	NS
Oct	2.417	2.402	0.007	0.007	*	*
Nov	3.472	2.492	0.011	0.007	***	*
Dec	3.484	3.9	0.01	0.012	***	***

TABLE 2
Mann Kendall (Z) and Sen's Slope (Q) estimate of seasonal temperature

Season	Z		Q		Significance	
	Max	Min	Max	Min	Max	Min
Pre-monsoon	2.71	5.94	0.007	0.018	**	***
Monsoon	3.07	4.67	0.003	0.007	**	**
Post-monsoon	5.42	6.49	0.011	0.017	***	***
Winter	3.37	6.44	0.007	0.019	***	***

Note: significant at *** 99%, ** 95%, * 90% level of confidence and NS for not significant

be significant in the months of June and August (Table 1). However, increasing trend of temperature is observed at 90% confidence level in both cases (Table 2). But rainfall doesn't experience any significant trend during this period (Table 4).

4.2.3. Post-monsoon

An increasing trend of temperature has observed during the post-monsoon period (Figs. 4&5). From the month of October to December, the rate of change of maximum and minimum temperature is quite high. Maximum temperature with a Sen's slope of 0.011 in November and 0.010 in December. On the other hand, the

minimum temperature increased with Sen's slope 0.007 in November and 0.012 in December (Table 1). But in case of rainfall, no significant trend has found during this season (Table 4).

4.2.4. Winter

Change of temperature during the winter season is quite interesting in nature. The rate of change in maximum and minimum temperature is higher than the monsoon period (Table 2, Figs. 4&5). Especially in the month of February with a Sen's slope estimate of 0.011 and 0.014 respectively (Table 1). The high rate of the positive trend of minimum temperature is observed as an

TABLE 3

Mann Kendall (Z) and Sen's Slope (Q) estimate of monthly rainfall

Month	Z	Q	Significance
Jan	1.175	0.013	NS
Feb	-1.134	-0.025	NS
Mar	0.887	0.041	NS
Apr	3.275	0.42	**
May	2.796	0.711	**
Jun	0.234	0.098	NS
Jul	1.472	0.874	NS
Aug	0.945	0.356	NS
Sep	1.694	0.573	NS
Oct	-0.515	-0.084	NS
Nov	0.865	0.01	NS
Dec	-0.906	-0.001	NS

TABLE 4

Mann Kendall (Z) and Sen's Slope (Q) estimate of seasonal rainfall

Season	Z	Q	Significance
Pre-monsoon	3.782	1.138	***
Monsoon	1.583	1.444	NS
Post-monsoon	-0.176	-0.045	NS
Winter	-0.51	-0.017	NS

Note: significant at *** 99%, ** 95%, * 90% level of confidence and NS for not significant

indication of warming winter. It has also been found that there is an absence of any statistically significant trend of rainfall during this period (Table 4), though the Sen's slope is estimated at -0.017.

5. Conclusions

In conclusion, it may be stated that the temperature and rainfall conditions in the Bengal Duars region are changing. Long-term analysis of the climatic data exposed that the annual average temperature has increased at the rate of $0.0227^{\circ} \text{C}^{-1}$ and rainfall extreme also become 5% higher since the 1990's. Among the four seasons, the only significant rising trend of rainfall is observed in the pre-monsoon period. Moreover, the increasing trend of rainfall in monsoon and decreasing trend in post-monsoon and winter periods are observed in Bengal Duars though are not statistically significant. Through Sen's slope analysis, the significant rising trend of maximum and minimum temperature are found in all the four seasons. Seasonal shifting of temperature may cause disappearing of micro-

seasons like spring, autumn etc. due to overlapping of the main seasons. Different species may respond to different environmental cues may cause an adverse effect on the whole ecosystem of the Bengal Duars region.

Acknowledgements

The authors would like to acknowledge the University Grants Commission, New Delhi, India, for financial support to carry out the research work presented in this paper. We would also like to acknowledge IMD, Pune, India for providing climatic dataset. We are grateful to the anonymous reviewers for their valuable suggestions during the preparation of this work.

The contents & views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

References

- Gruning, J. F., 1911, "Eastern Bengal and Assam District Gazetteers, Jalpaiguri", WBDG, Govt. of West Bengal.
- IPCC (Climate Change), 2007a, "Synthesis Report; Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]", Geneva, Switzerland.
- IPCC (Climate Change), 2007b, "The Physical Science Basis", Cambridge University Press, Cambridge and New York.
- IPCC (Climate Change), 2014, "Synthesis Report; Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]", Geneva, Switzerland.
- Jana, M. M., 2002, "Management and Development of River Basins in North Bengal Using Remote Sensing Techniques", Photonirvachak, *J. Indian soc. Remote Sens.*, **25**, 2, 105-111.
- Kaur, S., Diwakar, S. K. and Das, A. K., 2017, "Long term rainfall trend over meteorological sub divisions and districts of India", *Mausam*, **68**, 3, 439-450.
- Laskar, S. I., Kotal, S. D. and Roy Bhowmik, S. K., 2014, "Analysis of rainfall and temperature trends of selected stations over North East India during last century", *Mausam*, **65**, 4, 497-508.
- Lenderink, G., Van Ulden, A., Van Den Hurk, B. and Keller, F., 2007, "A study on combining global and regional climate model results for generating climate scenarios of temperature and precipitation for the Netherlands", *Clim. Dyn.*, **29**, 2, 157-176.
- Min, S. K., Zhang, X., Zwiers, F. W. and Hegerl, G. C., 2011, "Human contribution to more intense precipitation extremes", *Nature*, **470**, 378-381.
- Ntegeka, V. and Willems, P., 2008, "Trends and multidecadal oscillations in rainfall extremes, based on a more than 100 years' time series of 10 minutes' rainfall intensities at Uccle, Belgium", *Water Resour. Res.*, **44**, 1-15.

- Pant, G. B. and Kumar, K. R., 1997, "Climates of South Asia", John Wiley & Sons Ltd., Chichester, UK
- Parthasarathy, B., Sontakke, N. A., Munot, A. A. and Kothawale, D. R., 1987, "Droughts/ Floods in the summer monsoon season over different meteorological subdivisions of India for the period 1871±1984", *J. Climatol.*, **7**, 57-70.
- Radhakrishnan, K., Sivaraman, I., Jena, S. K., Sarkar, S. and Adhikari, S., 2017, "A Climate Trend Analysis of Temperature and Rainfall in India", *Clim. Change Environ. Sustainability*, **5**, 2, 146-153.
- Rajendran, K., Sajani, S., Jayasankar, C. B. and Kitoh, A., 2013, "How dependent is climate change projection of Indian summer monsoon rainfall and extreme events on model resolution?", *Curr. Sci.*, **104**, 1409-1418.
- Ravindranath, N. H., Rao, S., Sharma, N., Nair, M., Gopalakrishnan, R., Rao, S. A., Malaviya, S., Tiwari, R., Sagadevan, A., Munsri, M., Krishna, N. and Bala, G., 2011, "Climate Change Vulnerability profiles for North East India", *Curr. Sci.*, **101**, 3, 384-394.
- Sam, K. and Chakma, N., 2019, "An exposition into the changing climate of Bengal Duars through the analysis of more than 100 years' trend and climatic oscillations", *J. Earth Syst. Sci.*, **128**, 67, 1-12, <https://doi.org/10.1007/s12040-019-1107-8>.
- Somorin, A. O., 2010, "Climate impacts, forest-dependent rural livelihoods and adaptation strategies in Africa: A review", *Afr. J. Environ. Sci. Technol.*, **4**, 13, 903-912.
- Willems, P., 2013a, "Multidecadal oscillatory behaviour of rainfall extremes in Europe", *Clim. Change*, **120**, 931-944.
- Willems, P., 2013b, "Revision of urban drainage design rules after assessment of climate change impacts on precipitation extremes at Uccle, Belgium", *J. Hydrol.*, **496**, 166-177.
- Willems, P., Olsson, J., Arnbjerg Nielsen, K., Beecham, S., Pathirana, A., Bulow Gregersen, I., Madsen, H. and Nguyen, V. T. V., 2012, "Practices and impacts of climate change on rainfall extremes and urban drainage", *Water Science & Technology*, **68**, 1, 16-28.
- Winstanley, D., 1973, "Recent Rainfall Trends in Africa, the Middle East and India", *Nature*, **243**, 464-465.
- Yue, S. and Hashino, M., 2003, "Temperature trends in Japan: 1900-1996", *Theor. Appl. Climatol.*, **75**, 15-27.
-