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Trend Analysis of Rainfall and Air Temperature in Andaman & Nicobar Islands, India

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Andaman and Nicobar Islands of India by its location in the Andaman Sea to the East and the Bay of Bengal to the West are one of the most vulnerable zones to climate change. Temporal trends of weather parameters such as rainfall and air temperature of Port Blair (11°40'0.01" N Latitude, 92°45'0" E Longitude and elevation 16 m above mean sea level) representing Andaman and Nicobar Islands were analysed by non-parametric modified Mann-Kendall and Sen's slope methods. Long term monthly rainfall and air temperature data of (1949-2019) was used to detect a trend. The results from trend analysis indicated that Port Blair receives a mean annual rainfall of 3079.1 mm (±487.3 mm) with a considerable variation (CV = 15.8%). The results revealed that total annual rainfall decreased non-significantly at the rate of 0.195 mm yr^{-1}. On an average 150 rainy days in a year were recorded in the region, whereas during the last ten years (2010-2019), the number of rainy days was reduced to 143 days. There was a significant increase in maximum, minimum and mean temperature of the region at the rate of 0.009, 0.015, and 0.012 ^{o}C yr^{-1}, respectively. This kind of information on long term trends of rainfall and temperatures are useful in evolving climate-resilient agricultural and water conservation plan for that region.

(***Key words:*** *Climate change, Coastal region, Island, Mann-Kendall test, Trend analysis)*

Climate change is being felt over the globe but small Islands are the most vulnerable to climate variability and long-term climate change impacts because of proximity to the sea (IPCC, 2007). It is projected that due to the rise of average global temperatures by 2-3^{o}C within the next 50 years, several adverse impacts will be witnessed in coastal areas and small Islands (IPCC, 2001). These changes broadly result in rising sea levels, saltwater intrusion, coastal erosion, increased 'storm surges', inundating low-lying areas, exposure to external shocks, reduction in off-season water supply, changes in cropping patterns, declining crop yields, increased heat stress and malnutrition, coral bleaching and breaching, ocean acidification, crippled the functionality of ecosystems, etc. (Anonymous, 2013). Andaman and Nicobar Islands face high levels of direct and indirect risks and threats mediated by climate change due to their peculiar features of small physical size, geographical exposure, remoteness from the mainland, and limited natural resources (McCarthy *et al*., 2001). The 2004 Tsunami is an example of a high level of devastation, which can be a comparable situation resulting from sea-level rise and intense tropical cyclone.

Though Andaman and Nicobar Islands receives very high rainfall, which is concentrated only in monsoon months. Consequently, most of the rainwater goes to waste as runoff into the sea and also creates widespread waterlogging at low lying agricultural fields. Since rainfed agriculture dominates the food grain production chain in Andaman and Nicobar Islands, any abrupt change in climate variables, particularly rainfall patterns pose a serious threat to food and environmental security of the entire island ecosystem. Knowing the trend of long-term weather variables responsible for the climate of the Andaman and Nicobar Islands holds importance for adaptation and mitigation strategies to sustain food production in this island ecosystem.

Although several researchers have explored the island in the context of saltwater intrusion, erosion, land-use changes, sea-level rise, etc. (Balaji *et al*., 2015; Pandey and Singh, 2009; Reddy *et al*., 2016; Roy and Sankar, 2014; Sahoo *et al*., 2013; Shankar and Dharanirajan, 2018). There is no comprehensive study on long term behaviour of climate variables responsible for climate change in Andaman Island. Velmurugan *et al*. (2015) studied the temporal changes and future

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projections of climatic pattern for the Nicobar Islands along with impacts and adaptation strategies. Rainfall and temperature are the key elements of weather in island ecosystem. Hence, analysis of their behaviour is vital for the understanding of climate variability in the islands.

Various parametric and non-parametric tests have been used for trend analysis of meteorological time series variables (Desai *et al*., 2019; Waghaye *et al*., 2018). Time series data of such variables have missing values, zero values, a non-normal distribution which limits the application of parametric tests. Mann-Whitney test, Kruskal-Wallis, Mood's median test, etc. are some of the non-parametric tests usually employed for trend analysis (Kisi and Ay, 2014). Such tests have been applied by various researchers for Indian region (Desai *et al*., 2019; Kale, 2020; Lunagaria *et al*., 2012; Mandal *et al*., 2019; Prabhakar *et al*., 2017; Waghaye *et al*., 2018; Yadav *et al*., 2014). Realizing the need to detect the direction of change (+/–) in climate variables, this study is planned to analyze long term (1949-2019) monthly climate variables (rainfall and temperature) of Port Blair using non-parametric modified Mann-Kendall and Sen's slope approaches.

MATERIALS AND METHODS

Study area

Situated about 1200 km from the Indian mainland, between 6° 45′ N to 13° 41′ N longitude, and 92° 12′ E and 93° 57′ E latitude, Andaman and Nicobar Islands are an archipelago in the Bay of Bengal, consisting of 306 named islands and 206 rocky outcrops endowed with outstanding natural beauty and ecological diversity. According to the provisional census of 2011, the total population of Andaman and Nicobar Islands is 379944 with a decadal increase growth of 6.68% over the 2001 population. The state of Andaman and Nicobar Islands is having 3 districts: South Andaman, North & Middle Andaman, and Nicobar with 38 inhabited Islands. Port Blair is the capital city of Andaman and Nicobar Islands in the South Andaman district, representing >50% population of whole Union Territory (including tourist population). The islands have a total land area of 8249 km^2, of which the Northern Andaman group constitutes 6408 km^2 and the Southern Nicobar 1841 km^2. The two island groups are separated by the 160 km wide 10° channel and are geologically and ecologically quite distinct. The location of the Andaman and Nicobar Islands is shown in Fig. 1.

Methodology

The climate of Andaman and Nicobar Islands is hot, humid, and tropical. Climatic data (rainfall and temperature) of Port Blair for 71 years (1949-2019) was collected from the Directorate of Economics and Statistics, Andaman and Nicobar Administration. The Islands receive rainfall from both the South-West and North-East monsoons. Andaman and Nicobar Islands has an average rainfall of about ≈ 3000 mm of which South-West monsoon contributes 60% and North-East monsoon contributes 17%. For trend analysis of climatic variables, monthly weather data for rainfall, rainy days, maximum and minimum air temperatures were used for the study. To study intra-annual variations of rainfall data, the year was divided into five different seasons: South-West Monsoon (SWM: June-September), North-East Monsoon (NEM: October-November), Post-Monsoon (Po-M: December-January), Summer (S: February-April) and Pre-Monsoon (Pr-M: May). Similarly, seasonal variation of temperature was studied for the rainy season (June-November) and summer season (December-May).

Mann-Kendall Test

The Mann-Kendall test statistic (S) is calculated as (Kendall, 1948; Mann, 1945):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\left(x_i - x_k\right) \quad \cdots (1)$$

where x = time series having an n number of data points, and

$$sign\left(x_i - x_k\right) = \begin{cases} +1 & \text{when} \left(x_i - x_k\right) > 0 \\ 0 & \text{when} \left(x_i - x_k\right) = 0 \\ -1 & \text{when} \left(x_i - x_k\right) < 0 \end{cases} \quad \cdots (2)$$

The significance of the trend is calculated using Z statistics as:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & \text{when } S > 0 \\ 0 & \text{when } S = 0 \\ \dfrac{S-1}{\sqrt{Var(S)}} & \text{when } S < 0 \end{cases} \quad \cdots (3)$$

where $Var(S)$ = variance of S. The negative value of Z

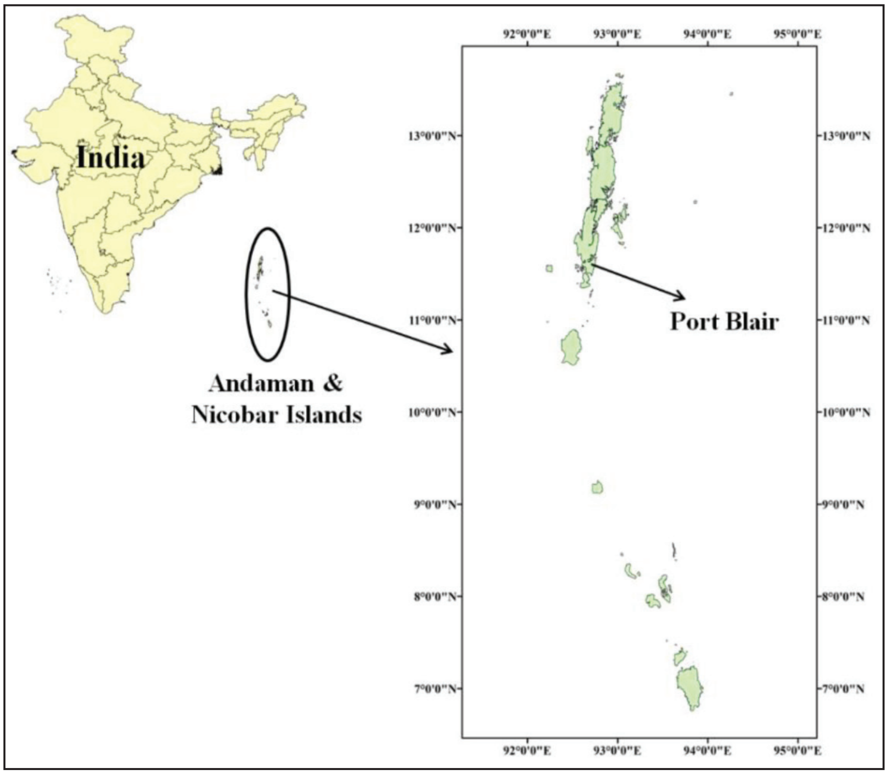

Fig. 1. *Location of the Andaman and Nicobar Islands*

indicates a decreasing trend and vice versa. At the 5% significance level, the null hypothesis of no trend is rejected if the absolute value of Z is greater than 1.96.

Modified Mann-Kendall test

A non-parametric monotonic trend test 'modified Mann-Kendall' was used over parametric test for identifying trends in the time series data as rainfall, rainy days and temperature data (Kendall, 1975; Mann, 1945; Yue *et al.*, 2002). The modified Mann-Kendall test applies a trend-free pre-whitening method to the series having a significant serial correlation. The pre-whitening procedure can be expressed as follows:

$$Y_i = x_i - (\beta \times i) \quad \cdots (4)$$

where β = Theil-Sen's slope of n pairs of data points.

The pre-whitening series are considered to be serially independent when the lag-1 autocorrelation coefficient of it is not significantly different from zero. In this case, the Mann-Kendall test shall be used on the original series. Otherwise, the pre-whitening is calculated before applying the Mann-Kendall test as in Eqs. (5) and (6).

$$Yi' = Y_i - r_i \times Y_{i-1} \quad \cdots (5)$$

$$Yi'' = Yi' + (\beta \times i) \quad \cdots (6)$$

where Yi'' = is the final series.

This test checks the statistical significance of the trend in data as null hypothesis (H_o) of no trend and the alternative hypothesis (H_1) of either increasing or decreasing trend based on the criteria of the computed value of $P>P_\alpha$ (H_o is rejected) at α level of significance. Positive, negative and zero value of modified Mann-Kendall statistic tau (τ) indicates increasing, decreasing and no trend, respectively.

Sen's slope estimator

The magnitude of the linear trend (change per unit time) was estimated by using a procedure developed by Sen (1968). The slope of trend gave the rate and direction of change for the considered data. The linear model f(t) can be described as:

$$f(t) = Q_t + B \quad \cdots (7)$$

where Q_t = slope, B = constant.

To derive an estimate of the slope Q_t the slopes of all data pairs was calculated as:

$$Q_t = \frac{x_j - x_k}{j - k}, i = 1, 2, 3 \ldots N, j > \quad \cdots (8)$$

where, x_j = magnitude of the sample at j^{th} time; x_k = magnitude of sample at k^{th} time; j = succeeding year of data; and k = preceding year of data.

If there are n number of sample values, we get x_j in time series as many as $N = n\ (n - 1)/2$ slope estimates of Q_t. The N number slope values of Q_t were ranked from the smallest to the largest and the Sen's estimator is the median of these N values of Q_t. Positive and negative values of Sen's slope indicate an increasing and decreasing trend, respectively in the time series.

$$Q_t = \begin{cases} Q_{\frac{N+1}{2}} & \text{if } N \text{ is odd} \\ \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+1}{2}}\right) & \text{if } N \text{ is even} \end{cases} \quad \cdots (9)$$

RESULTS AND DISCUSSION

Rainfall and temperature variability

The variation in annual rainfall (mm) from 1949 to 2019 is given in Fig. 2. The linear pattern showed a slight decreasing trend of rainfall in the long term and the rate of change of rainfall is about -0.83 mm per year. Wet, dry and normal years were observed in 1961, 1979 and 2001, respectively. In these 71 years annual data, maximum annual rainfall of about 4362 mm was observed in 1961 whereas a minimum of 1541 mm was observed in 1979. The average annual rainfall in Port Blair was 3079.1 mm. In the last seventy-one years, the highest monthly rainfall of 1122.9 mm was received in September in 1954. It was also observed that December-April months experienced <1 mm or no rainfall in some of the years during 1949-2019.

The annual rainfall deviation (%) from average annual rainfall for 1949-2019 period is shown in Fig. 3. As per IMD classification if rainfall deviation from mean is +19% to -19%, -20% to -59%, -60% to -99%, -100%, +20% to +59%, and +60% and above, it is considered as normal, deficient, large deficient, no rain, excess, and large excess, respectively (http://www.imdpune.gov.in/Weather/Reports/glossary.pdf). It is observed from Fig. 3 that there were five and seven events, which received 'deficient' (-20% to -50%) and excess (20-59%) rainfall, respectively. Remaining all rainfall events fall under the category of 'Normal'.

Fig. 4 shows the variation in maximum and minimum air temperatures (T_{max} and T_{min}) from 1949 to 2019. It was observed that the temperature in the long term has increased with the rate of change in 0.008°C maximum temperature and 0.014°C minimum temperature. From Fig. 4, the maximum and minimum temperature difference (TD = T_{max} - T_{min}) of 9.2°C and 5.9°C was observed in 1989 and 2018, respectively. The rate of change in a temperature difference of 0.006°C resulted from the long-term data analysis in Port Blair (Fig. 5).

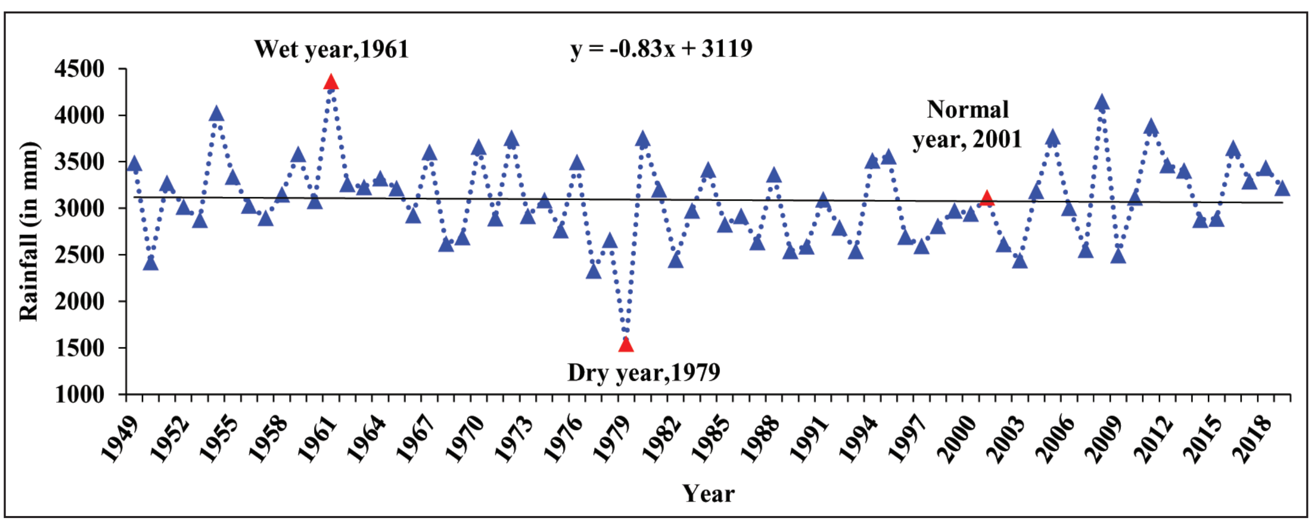

Fig. 2. *Annual rainfall variation in Port Blair*

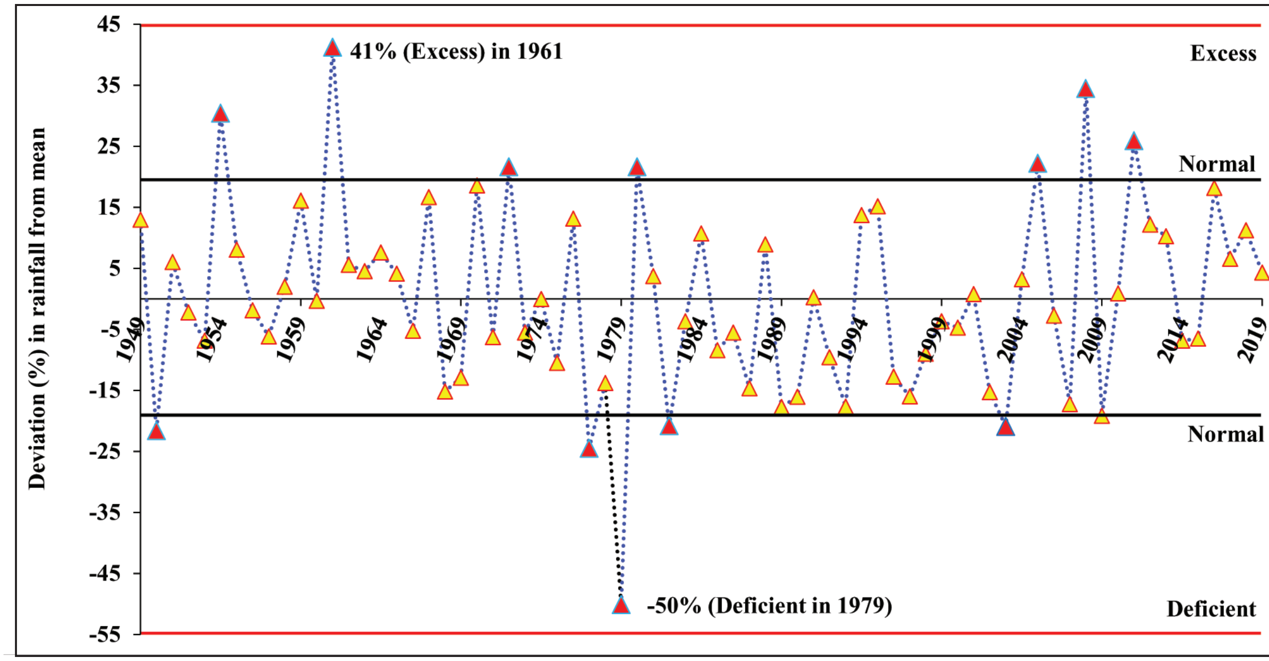

Fig. 3. Per cent deviation of annual rainfall from mean in Port Blair

Trend analysis for annual and seasonal rainfall

Long-term analysis of rainfall data (1949-2019) indicated that Port Blair received a mean annual rainfall of 3079±487.3 mm with a considerable variation (CV, 15.8%) in a total amount from as low as 1541 mm (-50%) in 1979 to as high as 4362 mm (+41.6%) in 1961 (Table 1). In this study, statistical significance was tested at various significance levels and results were showed at level of significance (α) = 0.05 with 95% confidence level due to not much difference. Modified Mann-Kendall test affirmed non-linear, non-significant annual marginal decreasing trend of total rainfall (τ =

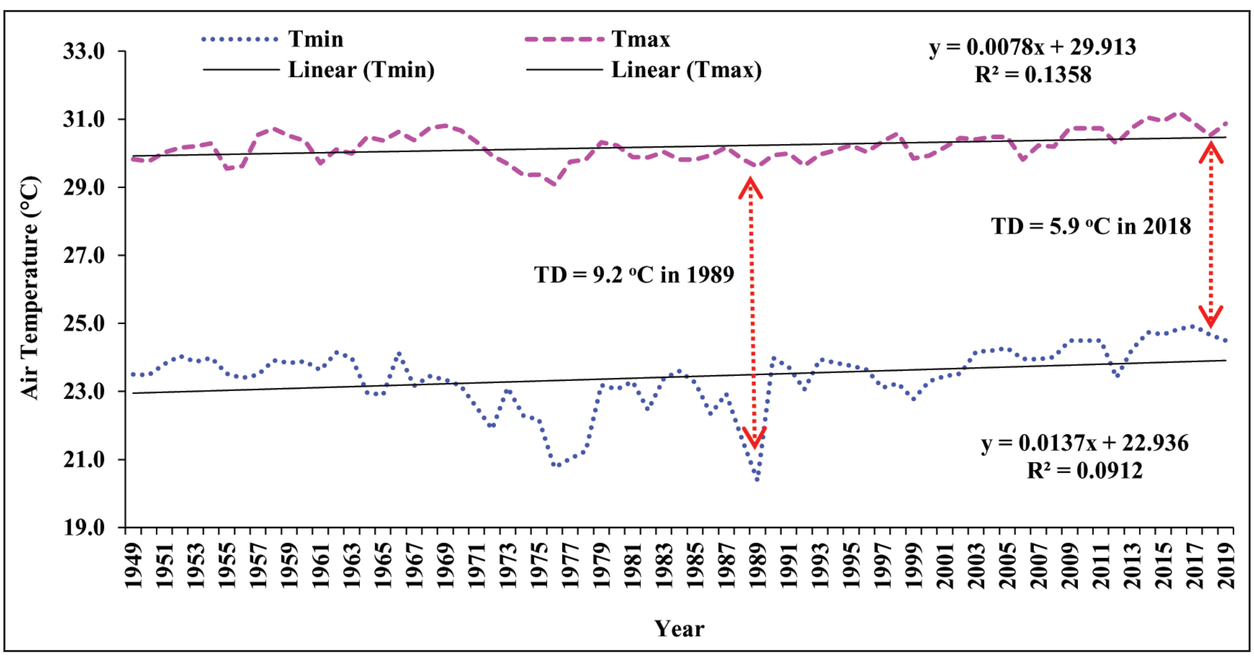

Fig. 4. Maximum and minimum temperature variation in Port Blair during 1949-2019

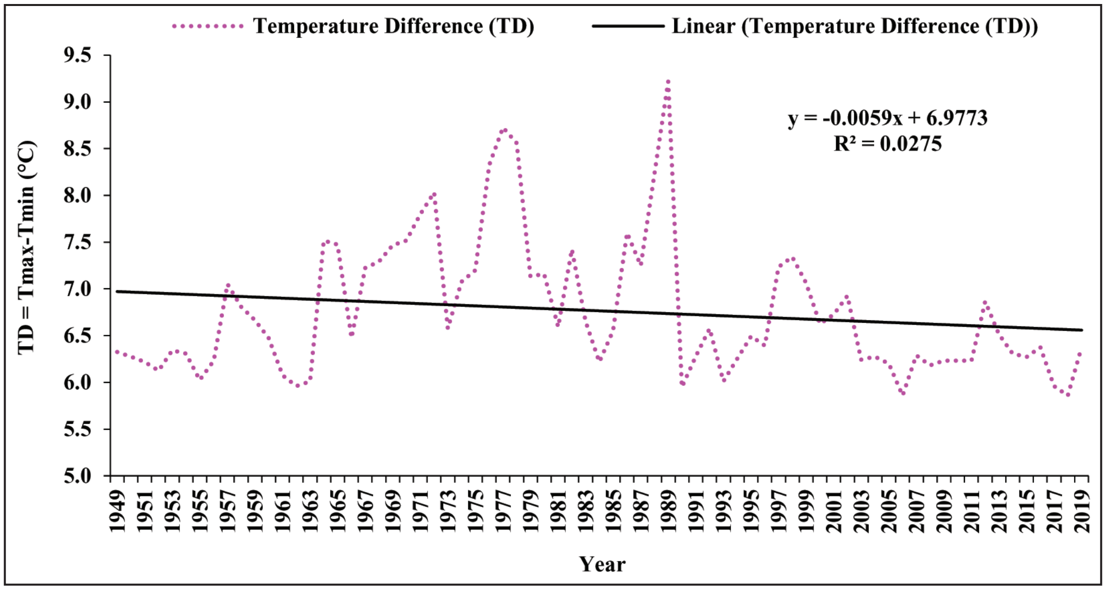

Fig. 5. *Temperature difference variation in Port Blair during 1949-2019*

-0.005) at the rate -0.195 mm yr^{-1}. Mean of 71 years monthly rainfall varied considerably and September received the highest (481.7±171.8 mm), whereas February received the lowest (19.7±40 mm) amount of rainfall. SWM months (June-Sep) received higher monthly rainfall (86.3-1008.8 mm) which contributed 2.78-32.7% of the total annual rainfall. The variability (CV, 18.6%) during SWM rainfall was relatively less as compared to NEM (CV, 31.5%), Po-M (CV, 103%), Summer (106%), and Pr-M (48%). Monsoon months: SW-NE (June-Nov) contributed 77.2% (2383.8 mm) with an average variability of 25.1% to the annual rainfall, whereas pre-monsoon (May) and post-monsoon (Dec-Jan) months contributed 12.9% and 6.0% of annual rainfall, respectively (Table 1). South-West, North-East, and post-monsoon rainfall showed a non-significant decreasing trend @ 0.05, 0.55 and 0.03 mm yr^{-1}, respectively but the summer and pre-monsoon months showed an increasing trend @ 0.16 and 0.25 mm yr^{-1}, respectively. Maximum, minimum and mean rainy days months from 71 years data were ~209, ~117, and ~150, respectively. Trend analysis of annual rainy days showed a significant increasing trend rate @ 1.056 days yr^{-1}.

Table 1. *Analysis for annual and seasonal rainfall trends at Port Blair (1949-2019)*

Statistical parameters	Total annual rainfall (mm)	Seasonal rainfall (mm)					Rainy days (No.)
		SWM	NEM	Po-M	S	Pr-M	
Minimum	1541.4 (1979)	1112.7 (1979)	179.8 (1979)	6.1 (1971)	0 (2014)	145.1 (1957)	117 (1979)
Maximum	4362.4 (1961)	3151.1 (1954)	889.5 (1972)	898.9 (1999)	587.8 (2011)	1060.6 (1961)	209 (1999)
Mean	3079.1	1851.0	532.8	186.9	118.8	398.2	150
SD	487.3	343.9	167.9	192.1	126.4	190.7	23.5
CV (%)	15.8	18.6	31.5	102.8	106.4	47.9	15.6
Man Kendall's Tau	-0.005	-0.024	-0.042	-0.003	0.0285	0.028	0.559
P value	0.959	0.768	0.605	0.975	0.730	0.730	<0.0001
Z value	-0.051	-0.294	-0.517	-0.030	0.346	0.346	6.844
Sen's Slope	-0.195	-0.048	-0.547	-0.028	0.156	0.245	1.056

Note: SD = Standard deviation (mm), CV = Coefficient of variation

Trend analysis for annual and seasonal air temperatures

Maximum monthly air temperature varied from 29.1 to 31.2°C with a long-term average of 30.2±0.4°C (Table 2). Similarly, minimum monthly air temperature varied from 20.4 to 24.9°C with a mean of 23.4±0.94°C. The highest monthly maximum temperature experienced by the Island region was 34.2°C (April, 2014) and the lowest monthly minimum temperature was 17.8°C during February, 1989. The mean maximum air temperature during summer (December-May) ranges from 29.5 to 31.9°C. The mean minimum temperature during winter (June-Nov) ranges from 21 to 27.1°C. Average annual variability of (CV) maximum, minimum and mean air temperatures were 1.4%, 4%, and 2.4%, respectively. Similarly, the average seasonal variability in mean air temperature of 2.3% and 2.7% was observed during rainy and summer seasons, respectively.

Modified Mann-Kendall trend statistics revealed a significant rising trend in monthly minimum (τ = 0.335 and Sen's slope = 0.015), monthly maximum (τ = 0.353 and Sen's slope = 0.009) and mean temperature (τ = 0.351 and Sen's slope = 0.012). The mean monthly temperature of rainy season and summer showed significant increasing trend @ of 0.123°C and 0.103°C, respectively. Though global warming is very prominent in other parts of the world including India, its effect in coastal island ecosystem is marginal.

Modified Man Kendall's and Sen's Slope non-parametric tests were used to study the long-term trend analysis for Andaman Island ecosystem. Seventy-one years (1949-2019) monthly rainfall and air temperature data from Port Blair, Andaman and Nicobar Islands was used to study the variations in climate. Trend analysis of 71 years of rainfall and temperatures in the Island region showed that temperature and rainy days exhibited a significant increasing trend whereas there was a non-significant decreasing trend for rainfall. A marginal decreasing trend of total rainfall at the rate -0.195 mm yr^{-1} and increasing trend of mean air temperature at the rate of 0.012°C yr^{-1} has resulted. The decadal increase in the temperature of 0.1°C was observed for the Andaman Islands and was projected to 1°C for the Century. It is matching with the IPCC temperature projections of 1-1.5°C for the islands. Though the trend in total rainfall indicated that no significant variations (2 mm per decade), variations in annual deviation were observed. Out of 71 years, 12 large deviations (7 excess and 5 deficient) in total rainfall were observed accounting for 10% variations. Thus, it was clear that total annual rainfall fairly remains the same, but annual variations were significant. The observed trend in rainfall and temperature projected for the Andaman Islands was not very prominent possibly due to the moderating effect of sea surrounding these Islands. Hence, more spatial observations are needed in a larger time frame.

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Table 2. *Statistical analysis of annual and seasonal temperature trends at Port Blair (1949-2019)*

Statistical parameters	Annual temperature (°C)			Seasonal temperature (°C)					
				Rainy season (June-Nov)			Summer (Dec-May)		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Minimum	29.1	20.4	24.9	27.5	21.0	24.8	29.5	19.7	24.9
Maximum	31.2	24.9	28.0	30.5	27.1	28.2	31.9	25.0	28.5
Mean	30.2	23.4	26.8	29.4	23.7	26.6	30.9	23.2	27.1
SD	0.44	0.94	0.63	0.48	1.00	0.62	0.56	1.05	0.73
CV (%)	1.4	4.0	2.4	1.6	4.2	2.3	1.8	4.5	2.7
Man Kendall's Tau	0.353	0.335	0.351	0.388	0.262	0.327	0.184	0.344	0.267
Z value	4.319	4.096	4.288	4.745	3.204	4.005	2.251	4.208	3.264
P value	<0.0001	<0.0001	<0.0001	<0.0001	0.0013	<0.0001	0.0244	<0.0001	0.0011
Sen's Slope	0.009	0.015	0.012	0.103	0.133	0.123	0.0065	0.017	0.103

Note: SD = Standard deviation (mm), CV = Coefficient of variation

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