Rainfall Analysis by Using Mann-Kendall Trend, Sen’s Slope and Variability at Six Stations of Andaman & Nicobar Islands

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ABSTRACT

On analysis of thirty five years rainfall data (1980-2015) of six stations of Andaman & Nicobar islands it was found through Mann-Kendall trend, Sen’s slope and Regression slope, that annual and monsoon rainfall at Mayabandar, Long Island, Port Blair and Carnicobar showed increasing trend while that of HutBay and Nuncowrie showed decreasing trend. The monsoon season (summer monsoon) rainfall variability of 49.78% in Mayabandar, 52.12% in Long Island, 24.09% in Port Blair, 49.39% in HutBay, 47.26% in Carnicobar and 51.91% in Nuncowrie has been recorded in this time span. The high coefficient of variation (CV) denoted that
the variability of rainfall is not equally distributed. A low standard deviation indicates that the data points tend to be close to the mean of the set, while a high standard deviation indicates that the data points are spread out over a wide range of values. High SD was reported at all the five stations of study in comparison to Port Blair which also had a low coefficient of variation. The rainfall distribution of different season viz. pre monsoon, monsoon, post monsoon and winter, it was observed that the highest present contribution of rainfall was observed during monsoon season followed by post monsoon in all the six stations of Andaman & Nicobar islands. Rainfall contribution during May to November was most in all the six stations studied, while in remaining months it was 5.3% in Mayabandar, 6.4% Long Island, 10.2% in Port Blair, 12.3% in HutBay, 16.9% in CarNicobar and 21.1% in Nuncowrie.

Key words- Mann-Kendall trend, Sen’s slope and rainfall variability.

1. Introduction

Determination of precipitation trend analysis on different spatial and temporal scales during the past century has been a major concerning area because of the attention given to global climate change from the scientific community. The researchers indicate a small positive global trend, even though large areas are instead characterized by negative trends (IPCC 1996). Shown in Table 1.

In recent years it has been observed that there is an increasing tendency of occurrence of extreme events. Scientific community are now focusing on hydro-meteorological conditions as it holds the key for efficient management of water resources, flood management (Mondal et al. 2012). Needless to say, that rainfall pattern governs the overall cropping pattern, productivity and sustainability of agriculture enterprise. The standard of living and well being of human is largely dependent on rainfall intensity and frequency. If information about its probability is known to us then we will be able to combat the adverse condition faced during the season. It is known about the vastness of the subject area of climate change, but the changing pattern of rainfall is a topic which needs riveted attention because it affects both the availability of fresh water and food production (Dore. 2005). Indian agriculture continues to be a gamble of the whimsicality of monsoon, rainfall being the most critical parameter because nearly 70% of the net sown area is still rain dependent (Narain et al. 2006).

According to Intergovernmental Panel on Climate Change (IPCC 2007), future climate change is likely to affect agriculture, increase the risk of hunger and water scarcity and lead to more melting of glaciers (Bhalme and Mooley 1980; Gregory and Parthsarthy 1986) studied large scale droughts over India. The rainfall distribution is extremely uneven and irregular in the areas located at the peripheral boundary of the main current of South-west monsoon as in south Gujarat, India (Kumar et al. 2017). Recent studies (Khan et al. 2000;
Shrestha et al. 2000; Mirza 2002; Lal 2003; Min et al. 2003; Dash et al. 2007) show that, in general, the frequency of more intense rainfall events in many parts of Asia has increased, while the number of rainy days and total annual amount of precipitation has decreased. Significant decline in rainfall from June to September was observed by (Wing Cheung et al. 2008) for the Baro-Akobo, Omo-Ghibe, Rift Valley and Southern Blue Nile watersheds located in southwestern and central parts of Ethiopia. (Longobardi and Villani 2009) reported the trend appears predominantly negative, both at the annual and seasonal scale, except for the summer period when it appears to be positive in Italy. In recent years, annual rainfall has decreased over the African continent (Morishima and Akasaka 2010). Batisani and Yarnal (2010) identified a trend towards decreased rainfall throughout the Botswana, which is associated with decrease in the number of rainy days. Parthasarathy (1984) found that the monsoon rainfall for the two subdivisions, viz., Sub-Himalayan West Bengal and Sikkim and the Bihar Plains are having decreasing trends while for the four subdivisions viz. Punjab, Konkan and Goa, West Madhya Pradesh and Telengana are having increasing trends. Using the network of 306 stations and for the period 1871-1984, Kumar et al. (1982) identified the areas having decreasing and increasing trends of monsoon rainfall. Analysis of rainfall data for the period 1871 to 2002 indicated a decreasing trend in monsoon rainfall and increasing trend in the pre-monsoon and post-monsoon seasons (Dash et al. 2007). According to Sinha Ray and Srivastava (1999), the frequency of heavy rainfall events during the southwest monsoon has shown an increasing trend over certain parts of the country, whereas a decreasing trend has been found during winter, pre-monsoon and post-monsoon seasons. Kumar et al. (2010) studied monthly, seasonal and annual trends of rainfall have been studied using monthly data series of 135 years (1871–2005) for 30 sub-divisions (sub-regions) in India. Half of the sub-divisions showed an increasing trend in annual rainfall, but for only three (Haryana, Punjab and Coastal Karnataka), this trend was statistically significant. Similarly, only one sub-division (Chhattisgarh) indicated a significant decreasing trend in annual rainfall. Jain et al. (2012) reported that rainfall has no clear trend for the region as a whole, although there are seasonal trends for some seasons and for some hydro-meteorological sub-divisions of North east India. Guhathakurta and Rajeevan (2007) observed significant decrease in pre-monsoon rainfall for the six sub-divisions viz. Gujarat region, west M.P. region, East M.P., Vidarbha, Chhattisgarh and Jharkhand. However during the post-monsoon season, rainfall is increasing for almost all the sub-divisions except for the nine divisions. Kumar et al. (2009) revealed that there are significant differences in rainfall trends at the regional level.
2. Materials and method

In Andaman & Nicobar islands six locations were chosen for assessment of scarce and excess rainfall intensity and frequency namely Mayabandar, Long Island, Port Blair, Hut Bay, Carnicobar and Nuncowrie. The monthly and annual rainfall data were used for 35 years (1980-2015). By using monthly rainfall data, monthly mean, seasonal averages, standard deviation (SD) and co-efficient of Variation (CV) were computed monthly and season-wise viz., Pre-monsoon (March-May), South-west monsoon (June-September), Post monsoon (October-December) and Winter (January-February). The data were subjected to find out long term trends. A linear trend line was added to the series for simplification of the trends.

2.1 Trend analysis

2.1.1 Mann–Kendall test.

The trend analysis and estimation of Sen’s slope are done using Kendall (1975) and Sen (1968) method respectively for the given data sets. Mann-Kendall test is a non-parametric test for finding trends in time series. This test compares the relative magnitudes of data rather than data values themselves (Gilbert, 1987). The benefit of this test is, that data need not to confirm any particular distribution. In this test, each data value in the time series is compared with all subsequent values. Initially the Mann–Kendall statistics (S) is assumed to be zero, and if a data value in subsequent time periods is higher than a data value in previous time period, S is incremented by 1, and vice-versa. The net results of all such increments and decrements give the final value of S. The Mann-Kendall statistics (S) is given as:

\[
S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sign} \left( x_j - x_i \right)
\]

where

\[
\text{sign} \left( x_j - x_i \right) = 1 \quad \text{if} \quad (x_j - x_i) > 0;
\]

\[
= 0 \quad \text{if} \quad (x_j - x_i) = 0;
\]

\[
= -1 \quad \text{if} \quad (x_j - x_i) < 0;
\]

A positive value of S indicates an increasing trend, and a negative value indicates a decreasing trend. However it is necessary to perform the statistical analysis for the significance of the trend. The test procedure using the
normal approximation test is described by Kendall (1975). This test assumes that there are not many tied values within the dataset. The variance ($S$) is calculated by the following equation:

$$Var(S) = \frac{1}{18} \left( n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p-1)(2t_p+5) \right)$$

where, $n$ is the number of data points, $g$ is the number of tied groups and $t_p$ is the number of data points in the $p^{th}$ group.

The normal Z-statistics is computed as:

$$Z = \begin{cases} 
\frac{S-1}{\sqrt{Var(S)}} & \text{, if } S > 0 \\
0 & \text{, if } S = 0 \\
\frac{S+1}{\sqrt{Var(S)}} & \text{, if } S < 0 
\end{cases}$$

The trend is said to be decreasing if $Z$ is negative and the computed $Z$–statistics is greater than the $z$–value corresponding to the 5 % level of significance. The trend is said to be increasing if the $Z$ is positive and the computed $Z$–statistics is greater than the $z$–value corresponding to the 5 % level of significance. If the computed $Z$- statistics is less than the $z$–value corresponding to the 5 % level of significance, there is no trend.

### 2.1.2 Sen’s Slope estimator

Simple linear regression is one of the most widely used model to detect the linear trend. However this method requires the assumption of normality of residuals (McBean and Motiee 2008). Viessman et al. (1989) reported that many hydrological variables exhibit a marked right skewness partly due to the influence of natural phenomena and do not follow a normal distribution. Thus Sen (1968) slope estimator is found to be powerful tool to develop the linear relationships. Sen’s slope has the advantage over the regression slope in the sense that it is not much affected by gross data errors and outliers. The Sen’s slope is estimated as the median of all pairwise slopes between each pair of points in the data set (Thiel 1950; Sen 1968; Helsel and Hirsch 2002). Each individual slope ($m_{ij}$) is estimated using the following equation:
\[ m_{ij} = \frac{Y_j - Y_i}{j - i} \quad (2) \]

where, \( i = 1 \) to \( n-1 \), \( j = 2 \) to \( n \), \( Y_j \) and \( Y_i \) are data values at time \( j \) and \( i \) (\( j > i \)), respectively. If there are \( n \) values of \( Y_j \) in the time series, there will be \( N = n(n-1)/2 \) slope estimates. The Sen’s slope is the median slope of these \( N \) values of slopes. The Sen’s slope is

\[ m = m \quad \text{, if } n \text{ is odd} \]
\[ m = \left[ \frac{n+1}{2} \right] \]

\[ m = \left( \frac{m \left[ \frac{n}{2} \right] + m \left[ \frac{n-1}{2} \right]}{2} \right) \quad \text{, if } n \text{ is even} \]

Positive Sen’s slope indicates rising trend while negative Sen’s slope indicates falling trend.

2.1.3 Linear regression analysis

Linear regression analysis is a parametric model and one of the most commonly used methods to detect a trend in a data series. This model develops a relationship between two variables (dependent and independent) by fitting a linear equation to the observed data. The data is first checked whether or not there is a relationship between the variables of interest. This can be done by using scatter plot. If there appears no association between the two variables, linear regression models will not prove a useful model. A numerical measure of this association between the variables is the correlation coefficient, which ranges between -1 to +1. A correlation coefficient value of \( \pm 1 \) indicates a perfect fit. A value near zero means that there is a random, non-linear relationship between the two variables. The linear regression model is generally described by the following equation:

\[ Y = mX + C \quad (3) \]

Where, \( Y \) is the dependent variable, \( X \) is the independent variable, \( m \) is the slope of the line and \( C \) is the intercept constant. The coefficients (\( m \) and \( C \)) of the model are determined using the Least-Squares method,
which is the most commonly used method, t-test is used to determine whether the linear trends are significantly different from zero at the 5% significance level.

3. Results and discussion

3.1 Annual rainfall features

Rainfall characteristics of Andaman and Nicobar are presented in Table 1 and 2. The Union Territory’s annual average rainfall is 2673.22 mm with SD, standard deviation is 1130.52 mm and co-efficient of variation is 42.29%. The highest mean annual rainfall recorded in this study is at Port Blair which is 2956.78 mm with SD (675.81 mm) and the CV (22.86%).

The comparatively low CV denotes that variability of rainfall in those areas is nearly equally distributed. The data shows that North Middle Andaman comprising of stations Mayabandar and Long Island and South Andaman comprising of stations Port Blair and HutBay, have high annual rainfall and Nicobar comprising of stations Carnicobar and Nuncowrie falls under relatively low annual rainfall. The rainfall distribution of different season viz. pre monsoon, monsoon, post monsoon and winter season shows that the highest contribution of rainfall is in monsoon season followed by post monsoon and pre monsoon. The corresponding results given in Table 2.

3.2 Pre monsoon

Rainfall characteristics of pre monsoon season of Andaman and Nicobar Islands are presented in Tables 1 and 2. The highest mean rainfall observed during pre monsoon season is 547.38 mm with percent contribution of annual rainfall is (21.13%) and CV (51.58%) at Carnicobar.

3.2.1 MAYABANDAR

The data analysis of Mayabandar showed that during pre monsoon season, rainfall in the month of May was 344.71 mm with percent addition of annual rainfall (11.81%) and CV (54.51%) with subsequent lower in month of April (52.12 mm) with percent contribution of annual rainfall (1.79%) and CV (131.53%). The lowest rainfall observed was in the month of March was 16.03 mm with per cent inclusion of annual rainfall (0.55%) and CV (196.58%).
3.2.2 LONG ISLAND

The data analysis of Long Island showed that during pre monsoon season, rainfall in the month of May was 275.23 mm with percent addition of annual rainfall (10.43%) and CV (56.88%) with subsequent lower in month of April (40.81 mm) with percent contribution of annual rainfall (1.55%) and CV (128.13%). The lowest rainfall observed was in the month of March was 18.26 mm with percent inclusion of annual rainfall (0.69%) and CV (258.12%).

3.2.3 PORT BLAIR

The data analysis of Port Blair showed that during pre monsoon season, rainfall in the month of May was 378.43 mm with percent addition of annual rainfall (12.80%) and CV (54.87%) with subsequent lower in month of April (70.34 mm) with percent contribution of annual rainfall (2.38%) and CV (115.32%). The lowest rainfall observed was in the month of March was 53.27 mm with percent inclusion of annual rainfall (1.80%) and CV (242.03%).

3.2.4 HUT BAY

The data analysis of Hut Bay showed that during pre monsoon season, rainfall in the month of May was 348.83 mm with percent addition of annual rainfall (13.26%) and CV (44.84%) with subsequent lower in month of April (91.05 mm) with percent contribution of annual rainfall (3.46%) and CV (94.73%). The lowest rainfall observed was in the month of March was 50.87 mm with percent inclusion of annual rainfall (1.93%) and CV (170.06%).

3.2.5 CAR NICOBAR

The data analysis of Car Nicobar showed that during pre monsoon season, rainfall in the month of May was 378.51 mm with percent addition of annual rainfall (14.61%) and CV (50.92%) with subsequent lower in month of April (111.25 mm) with percent contribution of annual rainfall (4.29%) and CV (92.98%). The lowest
rainfall observed was in the month of March was 57.62 mm with per cent inclusion of annual rainfall (2.22 %) and CV (127.21%).

3.2.6 NUN COWRIE

The data analysis of Nun Cowrie showed that during pre monsoon season, rainfall in the month of May was 296.72 mm with percent addition of annual rainfall (12.88 %) and CV (36.64 %) with subsequent lower in month of April (111.00 mm) with percent contribution of annual rainfall (4.82 %) and CV (81.93 %). The lowest rainfall observed was in the month of March was 56.81 mm with per cent inclusion of annual rainfall (2.47 %) and CV (96.67 %). The slopes of regression lines in Table 3, has been extracted from graphs (FIG 1 to 6).

FIG 1(a-e) & FIG 2 (a-e)

3.3 Monsoon season

Rainfall characteristics of monsoon season at Andaman and Nicobar islands are also presented in Tables 1 and 2. The union territory receives rain mainly under the influence of south west monsoon only during the four month from June to September. The highest mean rainfall observed during monsoon season is 1950.61 mm with percent contribution of annual rainfall is (66.83 %) and CV (49.78%) at Mayabandar.

3.3.1 MAYABANDAR

The data analysis of Mayabandar showed that during monsoon season, rainfall in the month of June was 520.66 mm with percent addition of annual rainfall (17.84 %) and CV (47.76%) with subsequent lower in month of August (503.90 mm) with percent contribution of annual rainfall (17.26 %) and CV (39.60 %) and in month of July (465.11 mm) with percent contribution of annual rainfall (15.93 %) and CV (41.19 %). The lowest rainfall observed was in the month of September was 460.93 mm with per cent inclusion of annual rainfall (15.79 %) and CV (52.78 %).

3.3.2 LONG ISLAND

The data analysis of Long Island showed that during monsoon season, rainfall in the month of August was 469.81 mm with percent addition of annual rainfall (17.81 %) and CV (53.98 %) with subsequent lower in month
of June (438.37 mm) with percent contribution of annual rainfall (16.62%) and CV (50.72%) and in month of September (422.02 mm) with percent contribution of annual rainfall (16.00%) and CV (53.62%). The lowest rainfall observed was in the month of July was 411.63 mm with percent inclusion of annual rainfall (15.60%) and CV (53.49%).

3.3.3 PORT BLAIR

The data analysis of Port Blair showed that during monsoon season, rainfall in the month of September was 454.00 mm with percent addition of annual rainfall (15.35%) and CV (38.46%) with subsequent lower in month of June (452.21 mm) with percent contribution of annual rainfall (15.29%) and CV (39.58%) and in month of August (424.84 mm) with percent contribution of annual rainfall (14.37%) and CV (35.17%). The lowest rainfall observed was in the month of July was 424.14 mm with percent inclusion of annual rainfall (14.34%) and CV (46.91%). It is observed that in Port Blair the rainfall distribution is nearly equal in all the monsoon months.

3.3.4 HUT BAY

The data analysis of Hut Bay showed that during monsoon season, rainfall in the month of September was 458.12 mm with percent addition of annual rainfall (17.41%) and CV (51.24%) with subsequent lower in month of July (335.43 mm) with percent contribution of annual rainfall (12.75%) and CV (57.13%) and in month of August (316.00 mm) with percent contribution of annual rainfall (12.01%) and CV (51.61%). The lowest rainfall observed was in the month of June was 302.33 mm with percent inclusion of annual rainfall (11.49%) and CV (52.75%).

3.3.5 CAR NICOBAR

The data analysis of Car Nicobar showed that during monsoon season, rainfall in the month of September was 349.80 mm with percent addition of annual rainfall (13.50%) and CV (60.93%) with subsequent lower in month of July (297.87 mm) with percent contribution of annual rainfall (11.50%) and CV (65.12%) and in month of June (277.50 mm) with percent contribution of annual rainfall (10.71%) and CV (54.13%). The lowest
rainfall observed was in the month of August was 276.43 mm with per cent inclusion of annual rainfall (10.67 %) and CV (40.95 %).

3.3.6 NUN COWRIE

The data analysis of Nun cowrie showed that during monsoon season, rainfall in the month of September was 259.59 mm with percent addition of annual rainfall (11.27 %) and CV (47.07%) with subsequent lower in month of July (245.30 mm) with percent contribution of annual rainfall (10.65 %) and CV (45.42 %) and in month of June (229.63 mm) with percent contribution of annual rainfall (9.97 %) and CV (46.14 %). The lowest rainfall observed was in the month of August was 226.30 mm with per cent inclusion of annual rainfall (9.82 %) and CV (44.21 %).

3.4 Post Monsoon season

Rainfall characteristics of post monsoon season at Andaman and Nicobar islands are also presented in Tables 1 and 2. The union territory receives rain under the influence of retreating south west monsoon and low pressure which later develops into cyclonic storm while moving towards the eastern coast of Indian subcontinent during this season. It was also seen that Nicobar Islands had more rainfall in November and less in October which was a opposite trend to that in Andaman Islands. The highest mean rainfall observed during post monsoon season is 760.67 mm with percent contribution of annual rainfall is (33.02 %) and CV (52.36%) at Nun cowrie.

3.4.1 MAYABANDAR

The data analysis of Mayabandar showed that during post monsoon season, rainfall in the month of October was 275.57 mm with percent addition of annual rainfall (9.44 %) and CV (69.65%) with subsequent lower in month of November (193.53 mm) with percent contribution of annual rainfall (6.63 %) and CV (39.60 %). The lowest rainfall observed was in the month of December was 66.06 mm with per cent inclusion of annual rainfall (2.26 %) and CV (119.90 %).
3.4.2 LONG ISLAND

The data analysis of Long Island showed that during post monsoon season, rainfall in the month of October was 240.90 mm with percent addition of annual rainfall (9.13 %) and CV (62.74 %) with subsequent lower in month of November (210.56 mm) with percent contribution of annual rainfall (7.98 %) and CV (74.88 %). The lowest rainfall observed was in the month of December was 81.54 mm with per cent inclusion of annual rainfall (3.09 %) and CV (135.71 %).

3.4.3 PORT BLAIR

The data analysis of Port Blair showed that during post monsoon season, rainfall in the month of October was 291.61 mm with percent addition of annual rainfall (9.86 %) and CV (47.59 %) with subsequent lower in month of November (231.25 mm) with percent contribution of annual rainfall (7.82 %) and CV (52.49 %). The lowest rainfall observed was in the month of December was 121.25 mm with per cent inclusion of annual rainfall (4.10 %) and CV (130.47 %).

3.4.4 HUT BAY

The data analysis of Hut Bay showed that during post monsoon season, rainfall in the month of October was 297.41 mm with percent addition of annual rainfall (11.30 %) and CV (49.13 %) with subsequent lower in month of November (249.49 mm) with percent contribution of annual rainfall (9.58 %) and CV (64.66 %). The lowest rainfall observed was in the month of December was 110.58 mm with per cent inclusion of annual rainfall (4.20 %) and CV (118.36 %).

3.4.5 CAR NICOBAR

The data analysis of Car Nicobar showed that during post monsoon season, rainfall in the month of November was 311.54 mm with percent addition of annual rainfall (12.02 %) and CV (63.86 %) with subsequent lower in month of October (261.49 mm) with percent contribution of annual rainfall (10.09 %) and CV (49.26 %). The
The lowest rainfall observed was in the month of December was 166.29 mm with per cent inclusion of annual rainfall (6.42 %) and CV (94.08 %).

### 3.4.6 NUN COWRIE

The data analysis of Nun Cowrie showed that during post monsoon season, rainfall in the month of November was 307.44 mm with percent addition of annual rainfall (13.35 %) and CV (55.01 %) with subsequent lower in month of October (253.32 mm) with percent contribution of annual rainfall (11.00 %) and CV (36.36 %). The lowest rainfall observed was in the month of December was 199.71 mm with per cent inclusion of annual rainfall (8.67 %) and CV (65.27 %).

The percentage contribution of winter rainfall to the annual are 0.69 % for Mayabandar, 1.10 % for Long Island, 1.88 % for Port Blair, 2.71 % for Hut Bay, 3.96 % for Car Nicobar and 5.10 % for Nun Cowrie.

FIG 5(a-e) & FIG 6 (a-e)

### 3.5 Winter season

Rainfall characteristics of winter season at Andaman and Nicobar islands are also presented in Tables 1 and 2. The highest mean rainfall observed during winter season is 117.49 mm with percent contribution of annual rainfall is (5.10%) and CV (79.88 %) at Nun cowrie.

### 3.5.1 MAYABANDAR

The data analysis of Mayabandar showed that during winter season, rainfall in the month of January was 11.49 mm with percent addition of annual rainfall (0.39 %) and CV (267.24%) with subsequent lower in month of February (8.76 mm) with percent contribution of annual rainfall (0.30 %) and CV (307.85 %).

### 3.5.2 LONG ISLAND

The data analysis of Long Island showed that during winter season, rainfall in the month of January was 16.92 mm with percent addition of annual rainfall (0.64 %) and CV (187.87%) with subsequent lower in month of February (12.03 mm) with percent contribution of annual rainfall (0.46 %) and CV (273.35 %).
3.5.3 PORT BLAIR

The data analysis of Port Blair showed that during winter season, rainfall in the month of January was 36.03 mm with percent addition of annual rainfall (1.22%) and CV (129.30%) with subsequent lower in month of February (19.41 mm) with percent contribution of annual rainfall (0.66%) and CV (234.81%).

3.5.4 HUT BAY

The data analysis of Hut Bay showed that during winter season, rainfall in the month of January was 43.05 mm with percent addition of annual rainfall (1.64%) and CV (177.71%) with subsequent lower in month of February (28.21 mm) with percent contribution of annual rainfall (1.07%) and CV (243.06%).

3.5.5 CAR NICOBAR

The data analysis of Car Nicobar showed that during winter season, rainfall in the month of January was 62.32 mm with percent addition of annual rainfall (2.41%) and CV (148.88%) with subsequent lower in month of February (40.28 mm) with percent contribution of annual rainfall (1.55%) and CV (110.31%).

3.5.6 NUN COWRIE

The data analysis of Nun Cowrie showed that during winter season, rainfall in the month of January was 64.41 mm with percent addition of annual rainfall (2.80%) and CV (82.84%) with subsequent lower in month of February (53.08 mm) with percent contribution of annual rainfall (2.30%) and CV (121.04%).
3.6 Annual Mann-Kendall and Sen’s slope trends of rainfall.

The study of trend analysis from scatter plot graph shows that mean annual rainfall has highest increasing trend for Mayabandar of 22.413 with $R^2$ (0.0760), followed by Port Blair of 7.499 with $R^2$ (0.0277) and Long Island of 5.133 with $R^2$ (0.0106). The highest decreasing trend for Car Nicobar of -4.989 with $R^2$ (0.0049) followed by Nun Cowrie of -2.519 with $R^2$ (0.0056) and then Hut Bay of -1.215 with $R^2$ (0.0003). The Mann-Kendall analysis and other statistics value given in Table – 3, shows annual basis increasing trend of rainfall in Mayabandar with Mann-Kendall tau co-efficient shows rising (0.1872) with Sen’s Slope (17.9107), then in Port Blair (0.1016) with Sen’s Slope (5.932), in Car Nicobar (0.0455) with Sen’s Slope (6.4186) and in Long Island (0.0313) with Sen’s Slope (3.5440). It also shows decreasing trend of rainfall in Nun Cowrie (-0.1237) with Sen’s Slope (-8.5881) and then in Hut Bay (-0.0099) with Sen’s Slope (-0.9594).

3.7 Pre monsoon

Rainfall characteristics of pre monsoon season as per Mann-Kendall analysis and other statistics of Andaman and Nicobar Islands are presented in Table 3, shows that mean pre monsoon rainfall has highest increasing trend for Port Blair of 7.812 with $R^2$ (0.1021), followed by Maya Bandar of 6.812 with $R^2$ (0.1356), Hut Bay of 3.566 with $R^2$ (0.0332), Nun Cowrie of 2.678 with (0.0389) and Long Island of 2.031 with $R^2$ (0.0271). The only decreasing trend is Car Nicobar of -1.926 with $R^2$ (0.0073). The Mann-Kendall analysis and other statistics value given in Table 3, shows pre monsoon increasing trend of rainfall in Mayabandar with Mann-Kendall tau co-efficient shows rising (0.3005) with Sen’s Slope (10.459), then in Port Blair (0.2095) with Sen’s Slope (6.7452), in Nun Cowrie (0.2081) with Sen’s Slope (4.9679), in Long Island (0.1054) with Sen’s Slope (2.7677) and in Hut Bay (0.0928) with Sen’s Slope (2.1388). It also shows one decreasing trend of rainfall in Car Nicobar (-0.0341) with Sen’s Slope (-1.2367).

3.8 Monsoon

Rainfall characteristics of monsoon season as per Mann-Kendall analysis and other statistics of Andaman and Nicobar Islands are presented in Table 3, shows that mean monsoon rainfall has highest increasing trend for Maya Bandar of 16.9070 with $R^2$ (0.1141), followed by Port Blair of 2.0196 with $R^2$ (0.0053) and Long Island of 0.9867 with $R^2$ (0.0007). The highest decreasing trend is for Hut Bay of -6.7131 with $R^2$ (0.0241), followed by Car Nicobar of -3.1698 with $R^2$ (0.0051) and by Nun Cowrie of – 1.6529 with $R^2$ (0.0067). The Mann-Kendall analysis and other statistics value given in Table 3, shows monsoon increasing trend of rainfall
in Mayabandar with Mann-Kendall tau co-efficient shows rising (0.1693) with Sen’s Slope (13.1500), then in Car Nicobar (0.0444) with Sen’s Slope (8.5618), in Port Blair (0.0118) with Sen’s Slope (0.7571) and in Long island (0.0028) with Sen’s Slope (1.6333). It shows decreasing trend of rainfall in Nun Cowrie (-0.1007) with Sen’s Slope (-5.3563) and in Hut bay (-0.0321) with Sen’s Slope (-3.8698). Shown in Table 3.

3.9 Post Monsoon

Rainfall characteristics of post monsoon season as per Mann-Kendall analysis and other statistics of Andaman and Nicobar Islands are presented in Table 3, shows that mean post monsoon rainfall has highest increasing trend for Maya Bandar of 4.7331 with $R^2 (0.0293)$ and followed by Hut Bay of 0.9657 with $R^2 (0.0030)$. The highest decreasing trend is for Nun Cowrie of -3.6390 with $R^2 (0.0324)$, followed by Port Blair of -3.3381 with $R^2 (0.0286)$, by Long Island of -1.6141 with $R^2 (0.0064)$ and by Car Nicobar of -1.2222 with $R^2 (0.0022)$. The Mann-Kendall analysis and other statistics value given in Table 3, shows post monsoon increasing trend of rainfall in Hut Bay with Mann-Kendall tau co-efficient shows rising (0.0667) with Sen’s Slope (1.1817) and then in Car Nicobar (0.0061) with Sen’s Slope (0.2423). It shows decreasing trend of rainfall in Nun Cowrie (-0.2282) with Sen’s Slope (-11.9972), in Port Blair (-0.1059) with Sen’s Slope (-66.1), in Long Island (-0.0769) with Sen’s Slope (-1.9875) and in Maya Bandar (-0.0265) with Sen’s Slope (-0.9909).

3.10 Winter

Rainfall characteristics of winter season as per Mann-Kendall analysis and other statistics of Andaman and Nicobar Islands are presented in Table 3, shows that mean winter rainfall has highest increasing trend for Car Nicobar of 4.4683 with $R^2 (0.1943)$, followed by Hut Bay of 2.1572 with $R^2 (0.0576)$, by Long Island of 1.0342 with $R^2 (0.0584)$, Port Blair of 1.0051 with $R^2 (0.0231)$ and Maya Bandar of 0.6793 with $R^2 (0.0418)$. The only decreasing trend is for Nun Cowrie -0.1775 with $R^2 (0.0006)$. The Mann-Kendall analysis and other statistics value given in Table 3, shows winter increasing trend of rainfall in Maya Bandar with Mann-Kendall tau co-efficient shows rising (0.3110) with Sen’s Slope (0.0649), in Car Nicobar (0.2748) with Sen’s Slope (2.4593), in Hut Bay (0.2434) with Sen’s Slope (1.6177), in Long Island (0.1348) with Sen’s Slope (0.0) in Port Blair (0.1329) with Sen’s Slope (11.6909) and in Nun Cowrie (0.00) with Sen’s Slope (0.0).
Conclusions

The rainfall behavior showed on basis of Mann-Kendall, Sen’s slope and regression slope that the annual and monsoon rainfall at Mayabandar, Long Island and Port Blair shows increasing trend which reveal that the North & Middle Andaman is showing increasing trend in rainfall whereas the Nicobar Islands show decreasing trend. The highest CV during annual (50.56%) and monsoon season (52.12%) has been recorded in Long Island and lowest CV during annual (22.96%) and monsoon season (24.09%) has been recorded in Port Blair. The high coefficient of variation denotes that variability of rainfall in these areas are not equally distributed. The highest SD during annual (1414.12 mm) and monsoon season (971.06 mm) is recorded at Mayabandar and lowest annual SD (675.81 mm) and monsoon season (422.91 mm) is recorded in again Port Blair. The contribution of monsoon rainfall was recorded as 66.83% in Mayabandar, as 66.03% in Long Island, as 59.36% in Port Blair, as 53.66% in Hut Bay, as 46.38% in Car Nicobar and as 41.71% in Nun Cowrie. The low standard deviation indicates that the rainfall were close to the mean rainfall in that region, from this it can be inferred that Port Blair receives mostly equally distributed season wise rainfall than other areas. This study has already revealed that North Middle Andaman receives more rainfall so accordingly policies can be framed for optimal use of this rainfall for different economic activities. As study of Andaman and Nicobar Islands has long been neglected so it goaded us to explore this area and use this research analysis for good water management which is bereft of fresh water though surrounded by ocean on all sides.

Acknowledgements

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References


Dore MHI (2005) Climate change and changes in global precipitation patterns, what do we know. Environment Int 31:1167-1181


Table 1
Monthly and seasonal means of rainfall (mm) over Mayabandar, Long Island and Port Blair for 1980 to 2015

<table>
<thead>
<tr>
<th>Months</th>
<th>Mayabandar</th>
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<th>Port Blair</th>
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</thead>
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<td>Std. Dev (%)</td>
<td>CV (%)</td>
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Table 2
Monthly and seasonal means of rainfall (mm) over Hut Bay, Car Nicobar and Nuncowrie for 1980 to 2015

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<th>Nun Cowrie</th>
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Figs. 1 (a-e). Annual and seasonal rainfall trends over Maya Bandar from 1980-2015
Figs. 2 (a-e). Annual and seasonal rainfall trends over Long Island from 1980-2015
PORT BLAIR ANNUAL RF

\[ y = 7.4991x + 2895.9 \]
\[ R^2 = 0.0277 \]

PORT BLAIR PRE MONSOON RF

\[ y = 7.6125x + 357.44 \]
\[ R^2 = 0.1021 \]

PORT BLAIR MONSOON RF

\[ y = 2.0196x + 1775.2 \]
\[ R^2 = 0.0053 \]

PORT BLAIR POST MONSOON RF

\[ y = -3.3381x + 727.17 \]
\[ R^2 = 0.0286 \]
Figs. 3 (a-e). Annual and seasonal rainfall trends over Port Blair from 1980-2015
HUT BAY ANNUAL RF
\[ y = -1.2151x + 2590.7 \]
\[ R^2 = 0.0003 \]

HUT BAY PRE MONSOON RF
\[ y = 3.566x + 397.85 \]
\[ R^2 = 0.0332 \]

HUT BAY MONSOON RF
\[ y = -6.7131x + 1524.4 \]
\[ R^2 = 0.0241 \]

HUT BAY POST MONSOON RF
\[ y = 0.9657x + 676.55 \]
\[ R^2 = 0.003 \]
CAR NICOBAR ANNUAL RF

\[ y = -4.9895x + 2617.9 \]

\[ R^2 = 0.0049 \]

CAR NICOBAR PRE MONSOON RF

\[ y = -1.926x + 579.92 \]

\[ R^2 = 0.0073 \]

CAR NICOBAR MONSOON RF

\[ y = -3.1698x + 1218.6 \]

\[ R^2 = 0.0051 \]

CAR NICOBAR POST MONSOON RF

\[ y = -1.2222x + 761.94 \]

\[ R^2 = 0.0022 \]
Figs. 5 (a-e). Annual and seasonal rainfall trends over Car Nicobar from 1980-2015
(a) NUN COWRIE ANNUAL RF

\[ y = -2.5189x + 2337.3 \]
\[ R^2 = 0.0056 \]

(b) NUN COWRIE PRE MONSOON RF

\[ y = 2.6783x + 414.23 \]
\[ R^2 = 0.0389 \]

(c) NUN COWRIE MONSOON RF

\[ y = -1.6529x + 994.25 \]
\[ R^2 = 0.0067 \]

(d) NUN COWRIE POST MONSOON RF

\[ y = -3.639x + 800.4 \]
\[ R^2 = 0.0324 \]
Figs. 6 (a-e). Annual and seasonal rainfall trends over Nun Cowrie from 1980-2015
Figures

Figure 1

(a-e). Annual and seasonal rainfall trends over Maya Bandar from 1980-2015
Figure 2

Figure 3

Figure 4

Figure 5

Figure 6