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Application of Mann-Kendall Trend Test & Sen's Slope Estimator to Hydrological Data

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ABSTRACT

This paper is mainly concerned with Statistical analysis of the trend of hydrological data viz. rainfall data. The rainfall trend of a region plays a vital role in the charm of its climatic situation in respect of tourism as well as local livelihood. In this case study the monthly rainfall data (mm) of 67 years (1951 to 2017) of the Lakshadweep meteorological subdivision has been processed to analyze its trend by nonparametric Statistical analysis. The Mann-Kendall trend test and the Sen's Slope estimator are used to determine the monotonic trend of rainfall and its magnitude respectively. In this study, monthly and average annual trends have been considered. Winter, pre-monsoonal, monsoonal, post-monsoonal trend are taken into consideration. In this paper, results show the average annual rainfall is 130.67 mm whereas for winter season, pre-monsoon season, monsoon season and post-monsoon season, the average rainfall are 29.95 mm, 70.36 mm, 249.09 mm and 135.39 mm respectively. The trend of average annual rainfall is significantly upward, i.e. increasing similar to winter season and monsoon season. The decreasing trend is found in pre-monsoon and post-monsoon seasons. The impact of rainfall on local livelihood is also discussed here. R (Version 3.6.1) Statistical software is used for analysis purposes.

***KEYWORDS**: Rainfall Trend, Mann-Kendall Trend Test, Sen's Slope Estimator, Kendall's tau, Livelihood*

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I. INTRODUCTION

Climate change is a burning issue of recent days. The earth's climate is continuously changing its behavior over the past century due to variation of rainfall as well as temperature. The changing of precipitation patterns is one of the major impacts of climate change. Changes in behavior of rainfall influences the hydrological cycle too.

Moreover, the Climatic conditions like rainfall, temperature etc. are responsible for the economy and livelihood of a region like agricultural, fishing, irrigation, tourism, lumbering, industry etc. Many researchers have studied on different themes of climatic conditions. Pattanaik *et.al* (2007) [1] investigated the analysis of rainfall over different homogeneous regions of India. The study was done in relation to variability in westward movement frequency of monsoon depressions. Mondal *et.al.* (2012) [2] showed the trend analysis of rainfall of north-eastern part of Cuttack district of Odisha, India. Anie *et.al.* (2018) [3] has studied the pattern of rainfall in Vamanapuram River Basin of Kerala, India by using non-parametric Statistical trend analysis. The rainfall pattern of the districts of West Bengal has been studied by *Mukherjee* (2017) [4]. *Bhattacharya (2021)* [5] has studied about the surface air temperature of Kolkata district, West Bengal using Mann-Kendall trend test and Sen's slope estimator.

In view of the above, study of rainfall trend is a significant and interesting area of research today. Changing pattern of rainfall is not only an important global and national climatic scenario, but also an important scenario for an archipelago too. This present study is an attempt to analyze the trend of rainfall of Lakshadweep meteorological subdivision of India during 1951 to 2017. Lakshadweep, an archipelago, is the smallest and uni-district Union Territory of India which nowadays became one of the most attractive places of tourist's interest for its natural landscapes, sandy beaches, climate, flora & fauna and the absence of a rushed lifestyle. The economy and livelihood are directly depending upon rainfall. So, the rainfall trend analysis of Lakshadweep meteorological subdivision of India is an untouched area of research interest. A non-parametric Statistical trend test has been used to analyze the trend of average annual rainfall and average seasonal rainfall.

II. STUDY AREA

India covers 36 meteorological subdivisions. Lakshadweep meteorological subdivision is one of the smallest meteorological subdivisions in India. Lakshadweep, an archipelago consisting of 36 islands is India's smallest Union Territory with an area of 32 sq km consisting of total 64429 populations. It is situated in 8^0 – 12^0 13' North Latitude and 71^0 – 74^0 East Longitude and 200-400 km. distance to Malabar Coast. It is comprised of 12 atolls, three reefs, five submerged banks and ten inhabited islands in Arabian Sea.

III. MATERIALS USED

The monthly data on rainfall (mm) of Lakshadweep meteorological subdivision has been collected from the Indian Meteorological Department (IMD) through data.gov website (*https://data.gov.in/resources/sub-divisional-monthly-rainfall-1901-2017)* for the period 1951 to 2017. The Statistical analysis is done by using R (Version 3.6.1) Statistical software. The population data is collected from Census of India, 2011.

IV. METHODOLOGY

Statistical inference has basically two parts, one is Statistical estimation of parameter(s) and other is Statistical testing of hypothesis. Parametric testing and Non-parametric are the two commonly used testing procedures. A parametric Statistical test is a test where the model specifies certain conditions about the parameters of the population. In this case there must be a parent probability distribution form which the samples are to be drawn. But in reality, many situations arise where the assumptions about the parent probability distribution is known to us. Then we have to introduce non-parametric approach. A non-parametric test is a test where the model does not specify conditions about the parameters of the population or the parent probability distribution. But the most interesting fact is, in most of the non-parametric model, the test statistic follows a Normal Distribution asymptotically. The Mann-Kendall test is a non-parametric test which is widely used to detect monotonic trends in series of environmental data, climate data or hydrological data. This test is the result of the development of the test first proposed by Mann (1945) which is further studied by Kendall (1975).

Entire rainfall data (mm) from 1951 to 2017 are categorized in five temporal categories like average annual for the entire year, pre-monsoon (March to May), monsoon (June to September), post-monsoon (October-November) and winter season (December to February) for analysis. The trend analysis is also done for month- wise average data also.

In Mann-Kendall test, we are to test the null hypothesis (H_0): There is no significant trend in rainfall *against* the alternative hypothesis (H_1): There is a specific significant trend in rainfall at 5% level of significance [5].

The Mann-Kendall test statistic is denoted as S and is given by

$$S=\sum_{k=1}^{n-1}\sum_{j=k+n}^{n}\operatorname{sgn}(X_j-X_k) \quad (1)$$

Where, n is the number of data points; X_j, X_k are the data values for the time period j and k respectively; $\operatorname{sgn}(X_j-X_k)$ is signum function and is equal to 1, 0 or -1 if (X_j-X_k) is positive, zero or negative respectively.

Under the null hypothesis, the mean of S is zero and the variance of S is denoted by Var (S) and is given by

$$Var(S)=\{n(n-1)(2n+5)-\sum_{j=1}^{m}t_j(t_j-1)(2t_j+5)\}/18 \quad (2)$$

where m is the number of the tied groups in the data set and t_j is the number of data points in the j^{th} tied group. For $n\geq 10$ the statistic S is approximately normally distributed with mean 0 and variance Var(S) [5]. The normally distributed test statistic is defined by

$$Z=\begin{cases}\frac{S-1}{\sqrt{Var(S)}}, & if\ S>0\\ 0, & if\ S=0\\ \frac{S+1}{\sqrt{Var(S)}}, & if\ S<0\end{cases} \quad (3)$$

The Kendall's tau is denoted as τ and is given by

$$\tau=\frac{S}{[\frac{1}{2}n(n-1)-\frac{1}{2}\sum_{j=1}^{p}t_j(t_j-1)]^{1/2}[\frac{1}{2}n(n-1)]^{1/2}} \quad (4)$$

In situations where there is no tie(s) occur, then Var (S) and τ reduce to

$$Var(S)=\{n(n-1)(2n+5)\}/18 \quad (5)$$

and

$$\tau = \frac{S}{[\frac{1}{2}n(n-1)]} \qquad (6)$$

respectively.

Kendall's tau has been also calculated to show the nature of trend. The positive and negative τ value defines the increasing and decreasing trends respectively.

Now, for determining the hydro-meteorological magnitude of trend the Sen's slope estimator is used.

A set of linear slopes is calculated as follows

$$d_i = \frac{X_j - X_k}{j-k} \qquad (7)$$

For $(1 \le k \le j \le n)$, d is the slope and X_j, X_k are the data values for the time period j and k respectively.

The Sen's slope β is calculated as the median from all slopes.

The positive β value indicates upward trend and the negative β value indicates decreasing trend [5]. This Z value also play the significant role for taking decision about accepting or rejecting the null hypothesis. Skewness of a distribution or a data set is a measure of symmetry or asymmetry. A positive or a negative value of skewness of a data set states that a data set is skewed right or skewed left respectively. A measure of peakedness relative to Normal distribution is measured by Kurtosis. A positive or a negative value of kurtosis of a data set indicates the data set is heavy-peaked or light-peaked respectively. The Coefficient of Variation is used to measure the variability of rainfall.

V. RESULTS

The Mann-Kendall trend test is performed. The following tables are the summary of results of the test performed in R (Version 3.6.1) Statistical software.

Table 1: Mann-Kendall Trend Test Table (Month- wise Average)

Month	Min.	Max.	Mean	Coefficient of Variation	Z Value	Mann-Kendall Statistic (S)	Kendall's Tau (τ)	Sen's Slope (β)	Trend (At 95% level of confidence)
January	0.00	131.30	20.50	134.42	0.91	168	0.0762	0.053	**Upward**
February	0.00	114.90	13.38	169.31	-1.30	-240	-0.11	-0.038	**Downward**
March	0.00	120.70	12.71	182.23	0.85	158	0.073	0.008	**Upward**
April	0.00	315.40	40.73	114.13	-1.77	-329	-0.149	-0.326	**Downward**
May	15.30	497.10	157.65	65.81	-1.63	-302	-0.137	-1.023	**Downward**
June	125.60	604.30	328.78	31.36	0.12	24	0.011	0.087	**Upward**
July	29.40	537	287.49	41.57	0.14	26	0.012	0.125	**Upward**
August	43.70	466.10	213.18	45.01	1.10	204	0.092	0.797	**Upward**
September	36.60	457.50	166.89	51.59	0.49	93	0.042	0.314	**Upward**
October	28.90	452.40	155.51	46.18	-0.81	-150	-0.067	-0.31	**Downward**
November	12.20	378.10	115.22	66.13	0.50	94	0.043	0.197	**Upward**
December	1.20	320.60	55.96	110.10	0.67	124	0.056	0.157	**Upward**

N.B.: Table is computed by the author

Table 2: Mann-Kendall Trend Test Table (Season wise Average)

Season	Min.	Max.	Mean	Skewness	Kurtosis	Coefficient of Variation	Z Value	Mann-Kendall Statistic (S)	Kendall's Tau (τ)	Sen's Slope (β)	Trend (At 95% level of confidence)
Annual	82.72	196.80	130.67	0.41	0.71	16.83	0.17	34	0.02	0.023	**Upward**
Winter	3.50	109.37	29.95	1.57	2.62	80.28	0.67	124	0.06	0.078	**Upward**
Pre-Monsoon	15.17	195.27	70.36	0.92	0.58	56.13	-1.36	-253	-0.11	-0.302	**Downward**
Monsoon	134.30	438.30	249.09	0.36	1.31	21.31	0.68	127	0.06	0.26	**Upward**
Post-Monsoon	39	275.90	135.39	0.42	-0.04	39.75	-0.04	-9	-0.004	-0.038	**Downward**

N.B.: Table is computed by the author

The average annual rainfall (mm.) and average seasonal rainfall (mm) for each season are depicted as follows to show the actual trend.

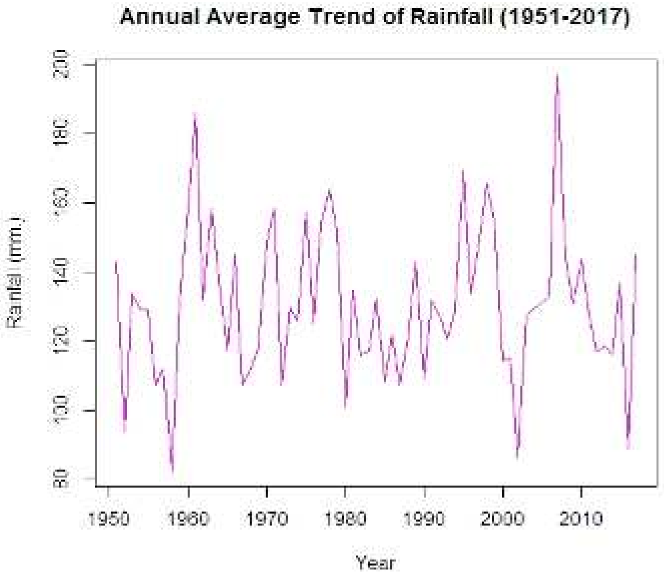

Figure 1: Average Annual Trend of Rainfall (1951-2017)

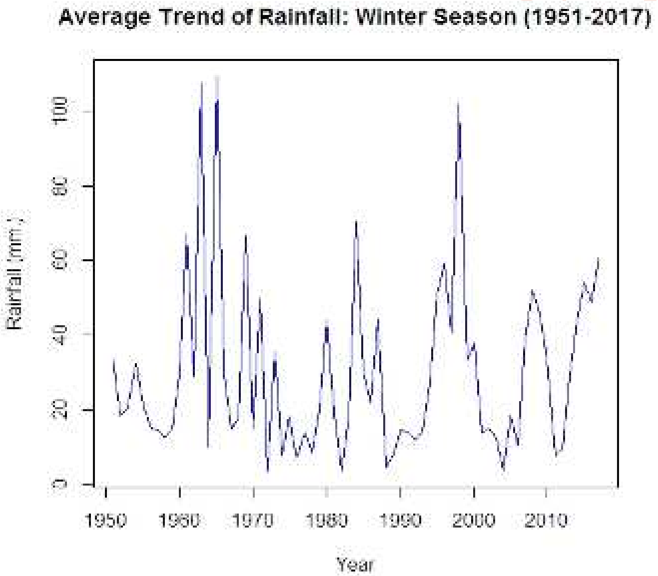

Figure 2: Trend of Rainfall: Winter Season (1951-2017)

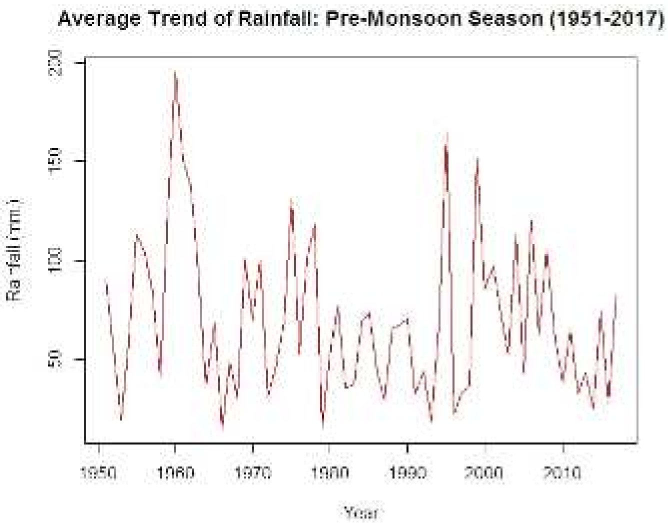

Figure 3: Trend of Rainfall: Pre-Monsoon Season (1951-2017)

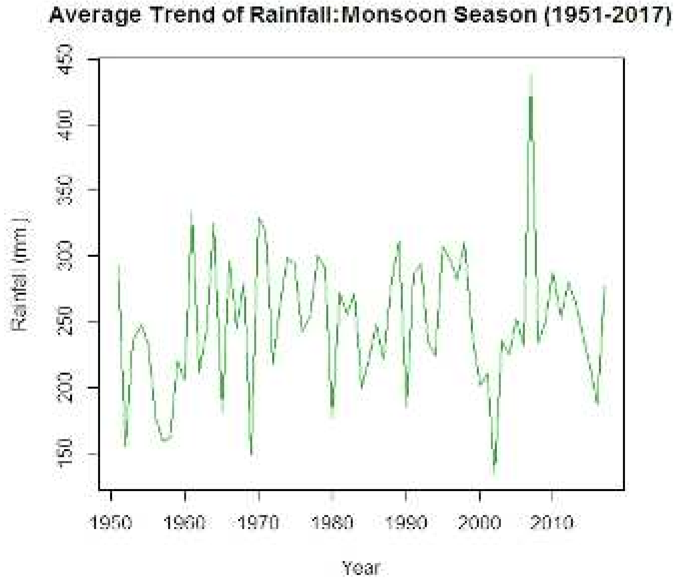

Figure 4: Trend of Rainfall: Monsoon Season (1951-2017)

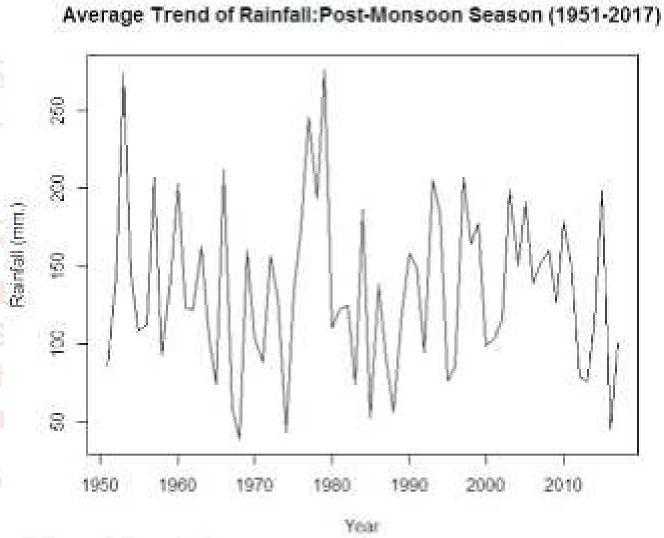

Figure 5: Average Trend of Rainfall: Post-Monsoon Season (1951-2017)

VI. DISCUSSION

A. Rainfall Distribution & Trend

From Table 1 and Table 2, the evidence of changing trend of rainfall in Lakshadweep meteorological subdivision is clear. In this study, the results show the average annual rainfall is 130.67 mm whereas for winter season, pre-monsoon season, monsoon season and post-monsoon season, the average rainfall are 29.95 mm, 70.36 mm, 249.09 mm and 135.39 mm respectively. It is observed that in the month of June, the maximum rainfall (604.30 mm.) occurs in year. The average monthly rainfall is least in the month of March (12.71 mm). On the other hand, the average rainfall is highest in the month of June (328.78 mm.). In the monsoon season, the rainfall occurs in maximum in June. During June to September, the amount of rainfall is very high. In winter season the amount of average rainfall (29.95 mm) is very low, moreover it is the least in amount. The average annual rainfall and all the seasonal average rainfall are skewed right. Post-monsoon average rainfall follows light-peaked distribution. But the data sets for average annual rainfall, average rainfall of winter, monsoon and pre-monsoon season are heavy-peaked in pattern. Figure 1, Figure 2, Figure3, Figure 4 and Figure 5 show the normal seasonal pattern of the rainfall of Lakshadweep meteorological subdivision.

Rainfall trend during the month of January, March, June, July, August, September November and December is upward. But the pattern of rainfall is downward during February, April, May and October. The overall trend of rainfall of Lakshadweep meteorological subdivision is significantly upward during last 67 years. The seasonal trend of the region is of mixture pattern. In winter season and monsoon season the trend of rainfall is significantly increasing during the past years whereas in pre-monsoon season the trend is downward. There is also significant downwards trend found in post-monsoon season. In this Coefficient of Variation measures the variability of rainfall. The Therefore from the long-term rainfall distribution it may be concluded that Lakshadweep meteorological subdivision has a beautiful mixture of different type of rainfall trend.

B. Impact of Rainfall and Climate Change

Lakshadweep is diverse in terms of its flora and fauna. In Lakshadweep Islands the soil is highly calcareous and sandy in nature, as opposed to Andaman & Nicobar Islands. Most of the area of Lakshadweep is rainfed. Thus, irrigation through tanks is lesser than even 500 hectares, while that from tube well is 1000 hectares. The government policy even allows Lakshadweep inhabitants to procure and distribute the frequently required farm machineries and implements at subsidized price.

The flora of Lakshadweep includes colocasia, banana, drumstick, breadfruit and wild almonds. However, coconut is the only cash crop that grows in this region. It is the main plantation crop with high yield. Due to the rise in sea level the arable land for crop production is short in supply and is likely to decrease even more in the coming decades. Salinization of cultivable land due to climate change also poses a huge threat to the sustainability of both subsistence and commercial agriculture. Being the dominant crop, the impact of climate change on coconut is of great significance. Moreover, these trees are the worst hit by cyclones, which are more frequent now on the island.

Lakshadweep has immense potential for the development of fisheries. Thus, marine fishery is an important means of subsistence for the people of the region. Tuna is the main fish found in Lakshadweep for commercial purpose. Climate induced changes cause problems in tuna fishery, as it affects their movement in the ocean currents and thus its cycle. This movement is also monsoon driven and thus changes productivity with changing monsoons.

Due to climate change, Lakshadweep has been highly affected. According to various studies, slow invasion of the sea into inhabited lands pose real threat for the people living there. Thus, for the island this could imply complete submergence. Climate change will have impacts on tourism, fisheries such as degeneration of coral reefs and lagoon ecosystem, changes in the seasonality and abundance of fish species, which can reduce the catch type, size and income for local fishermen. The absolute coral reef cover, which is a tourist attraction, has reduced by around 40 per cent due to climate change. The deteriorating health of Lakshadweep's reefs, also known as "rainforests of the ocean" is plainly catastrophic and requires policy measures to save it for the coming generations.

VII. CONCLUDING REMARKS

The study aims to give general idea about rainfall pattern of Lakshadweep meteorological subdivision. It is clear that there is a beautiful mixture of trend of rainfall of the region. The rainfall pattern is increasing in nature in most of the months in a year. The average annual rainfall is upward in trend. In post-monsoon season there is decreasing trend of rainfall. From month of June to month of September, the amount of rainfall in very high. In winter season and monsoon season the trend of rainfall is significantly increasing during the past years whereas in pre-monsoon season the trend is decreasing. The long-term trend analysis gives a clear idea about the climatic condition of the region in present era. Today Lakshadweep is very much interesting place of tourist attraction. The rainfall pattern helps the tourists for taking decision to travel there in respect of rainfall, temperature, humidity and other climatic variables. The livelihood of local people, water resource management, irrigation, industry of the region is also depending upon rainfall.

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