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Analysis of Long-Term Rainfall Trends in Sri Lanka Using CHRIPS Estimates.

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ABSTRACT:- For a country like Sri Lanka where food security and the economy depend on timely water availability, it is extremely important to study rainfall trends. In this work, monthly, seasonal and annual rainfall trends were studied using a series of 30-year (1989-2019) monthly data for 30 sub-visions (sub-regions) of Sri Lanka. The uniqueness of this study is the use of daily raster data generated by mixing satellite estimates and location data (CRIPS) instead of traditional spatial rainfall measurements. In addition, the study was conducted by dividing Sri Lanka into four main areas (sub-divisions) considering the climatic and geographical factors of the country rather than finding out whether there is a significant trend in rainfall by the district level. These sub-divisions were named as SD-01, SD-02, SD-03 and SD-04. The main statistical method used in the study was the Man-Kandall and Sen's slope, which looked at whether the incidence of annual, seasonal and monthly rainfall was significantly reduced or increased. According to this analysis, all sub-divisions show an increasing tendency for annual rainfall, all of which were statistically significant. That is to say, the most important factor reflected in the last 30 years is the increase in annual rainfall in all parts of Sri Lanka. The special feature of the monsoon (southwest and northeast) in Sri Lanka is that it shows a significant trend of southwest rainfall but cannot be identified during the northeast. The study further exaggerated the long-term precipitation trend for each month using only monthly rainfall data. In doing so, it appears that not all four major areas show a significant trend except few months. In this regard, significant trends can be identified in March, August and September for SD-01, while significant trends in SD-02 and SD-03 can be seen in March, but no significant trend in any of the months can be identified in SD-04. It is further suggested that a small scale study should be carried out to study the trend of monthly rainfall.

Key words: Rainfall, Satellite, Significant, Sub-Divisions, Trend

I. INTRODUCTION

Global average rainfall is forecast to increase, but increases and decreases on a regional and continental scale are expected (Dor, 2005). More or less rainfall or changes in its spatial and seasonal distribution will affect the spatial and temporal distribution of overflow, soil moisture and groundwater reserves, as well as the frequency of droughts and floods.

According to the forecasts of the Intergovernmental Panel on Climate Change (IPCC) changes of the global climate will affect agriculture, increase the risk of famine and water scarcity, and cause glaciers to melt more rapidly (IPCC, 2007, 2013 and 2014). Freshwater in some river basins in Sri Lanka have already been depleted due to climate change. This decline, along with population growth and rising living standards, could adversely affect many people in Sri Lanka by the 2050s.

Rapid glacial melting causes increased risk factors for flooding, slope destabilization, and reduced river flow (IPCC, 2007). Both Climate change or climate variability are not myths and there is ample evidence to support them (Adger, et al., 2002; Schuldt et al., 2011; Spence et al., 2011; Weber et al., 2011). Many researchers believe that human interactions have accelerated climate change (Chapin, et al., 2000; Hoegh-Guldberg and Bruno, 2010; Karl, 2003; Pearson and Dawson, 2003; Walther et al., 2002). Although climate variability is only one possibility, many as global warming (Schuldt et al., 2011), often refer to climate variability. Observations (Easterling et al., 2000; Knutti et al., 2002; Soja et al., 2007) and theoretical models (Karl, 2003; Kim et al., 2003; Tebaldi et al., 2007) are mainly used to understand current and future climate variables.

Climate variability can be identified as function of changes in rainfall and atmospheric temperature, slow winds, and acidification of the ocean. Atmospheric temperature and precipitation have also been identified by various studies as the two most sensitive factors for people. Changes in rainfall are one of the most important factors determining the overall impact of climate change, and it is clear that it affects society in a very big way.

Various researchers have predicted that warmer climates will intensify rainfall (Christensen and J. Christensen, 2004). This is most evident in the fact that more intense rainfall (precipitation) events can be identified after the onset of drier intervals. Other researchers have argued that the effects of climate change cannot be measured by regional rainfall over natural fluctuations (Chandler, 2001; Guowei and Jingpeng, 1999; Kundzewicz and Robson, 2000; Lindstrom, 1999; Lins, 1999; Robson, 2000; Robson, 2002; Robson, 1998). However, some cases show a strong correlation between human activity and climate change (Kawashima et al., 2004; Oreskes, 2004; Wang et al., 2007). Studies have shown that the unequal floods in England and Wales in the fall of 2000 were man-made (Jones and Reynard, 2006; Lorenzoni et al., 2007; Prudhomme et al., 2003).

Rainfall trend analysis was carried out in several important catchment areas of Sri Lanka. According to Jayawardena and others. The average annual rainfall in Colombo, Sri Lanka is a significant annual increase of 3.15 mm, while the other cities, Kandy and Nuwara Eliya, experience an annual decrease of 2.88 and 4.87, respectively (Jayawardene et al, 2005). Literature, It can be seen that a number of other researches have conducted precipitation research in many other important areas of Sri Lanka (Ampitiyawatta and Guo, 2010; Herath and Ratnayake, 2004; Jayawardene et al., 2015; Malmgren et al., 2003; Ranatunge et al., 2003; Suppiah, 1997; Wickramagamage, 2015).

However, the literature does not show that a precipitation trend analysis has been carried out based on satellite rainfall estimates at the district/regional level in Sri Lanka. Only (Alahacoon et al., 2018) done a basin level rainfall trend analysis using satellite estimated rainfall data. This study primarily focuses on conducting Sub-Division (SD-01 to SD-04) precipitation analysis using monthly rainfall data. Based on such studies, it is possible to identify if there is a shortage of water in the catchments.

In order to carry out homogeneity tests, it is important in daily rainfall measurements to ensure that data are recorded daily at the same time with the same equipment in the same location (Sahin and Cigizoglu, 2010: Perera et al., 2017; Wijemannage and Perera, 2018). However, recording daily rainfall measurements over long time intervals (such as 30 years or 100 years) can be tedious because the measurement patterns have changed over time, the measuring instruments have been re-installed, and so on. As literature explain by (Alexandersson and Moberg, 1997; Khaliq and Ouarda, 2007; Sahin and Cigizoglu, 2010; Wijngaard, 2003; Alexandersson, 1986; Buishand, 1982; Haylock et al., 2009) there are many homogeneity tests used to correct the rainfall data. The best answer to all the problems analyzed above is to use satellite estimate rainfall data.

Study Area

Sri Lanka is an island in the Indian Ocean southwest of the Bay of Bengal, between latitudes 5 ° and 10 N and longitudes 79 ° and 82 E. The island consists mostly of flat, rolling coastal plains and with south-central mountains. The rainfall pattern is affected by two monsoon winds in the Indian Ocean and the Bay of Bengal. Sri Lanka is divided into three main climatic zones, namely the "wet zone", the "dry zone" and the "semi-arid zone". The "wet zone" and southwesterly windy slopes of the country hills receive an average of 2,500 mm of rainfall each year. Most of the "dry zone" in the eastern, southeastern and northern parts of Sri Lanka receives between 1,200 and 1,900 mm of rainfall. This precipitation is mainly due to the northeast monsoon winds. Similarly, the semi-arid northwestern and southeastern coasts receive the minimum rainfall of 800 to 1200 mm.

Major monsoons are known as the Northeast Monsoon and the Southwest Monsoon distributed in December to February and May to September in each year. In addition, there are two intermittent monsoons between the two seasons: the 1st intermediate season from March to April and the 2nd intermediate monsoon from October to November. When consider the cultivation period it is aggregated as Yala (April to August) season and Maha season (October to February). 103 rivers are formed in Sri Lanka with the help of the monsoon winds and central mountains described above and cover 103 major and minor river basins. The longest of these rivers is the Mahaweli River which stretches for 335 km.

In terms of administration in Sri Lanka, It is divided into 9 provinces and 25 districts as the main administrative units. Each district is further subdivided into the Divisional Secretariat (DS-Divisions-256) and the Grama Niladhari Division (GN - approximately 16000).

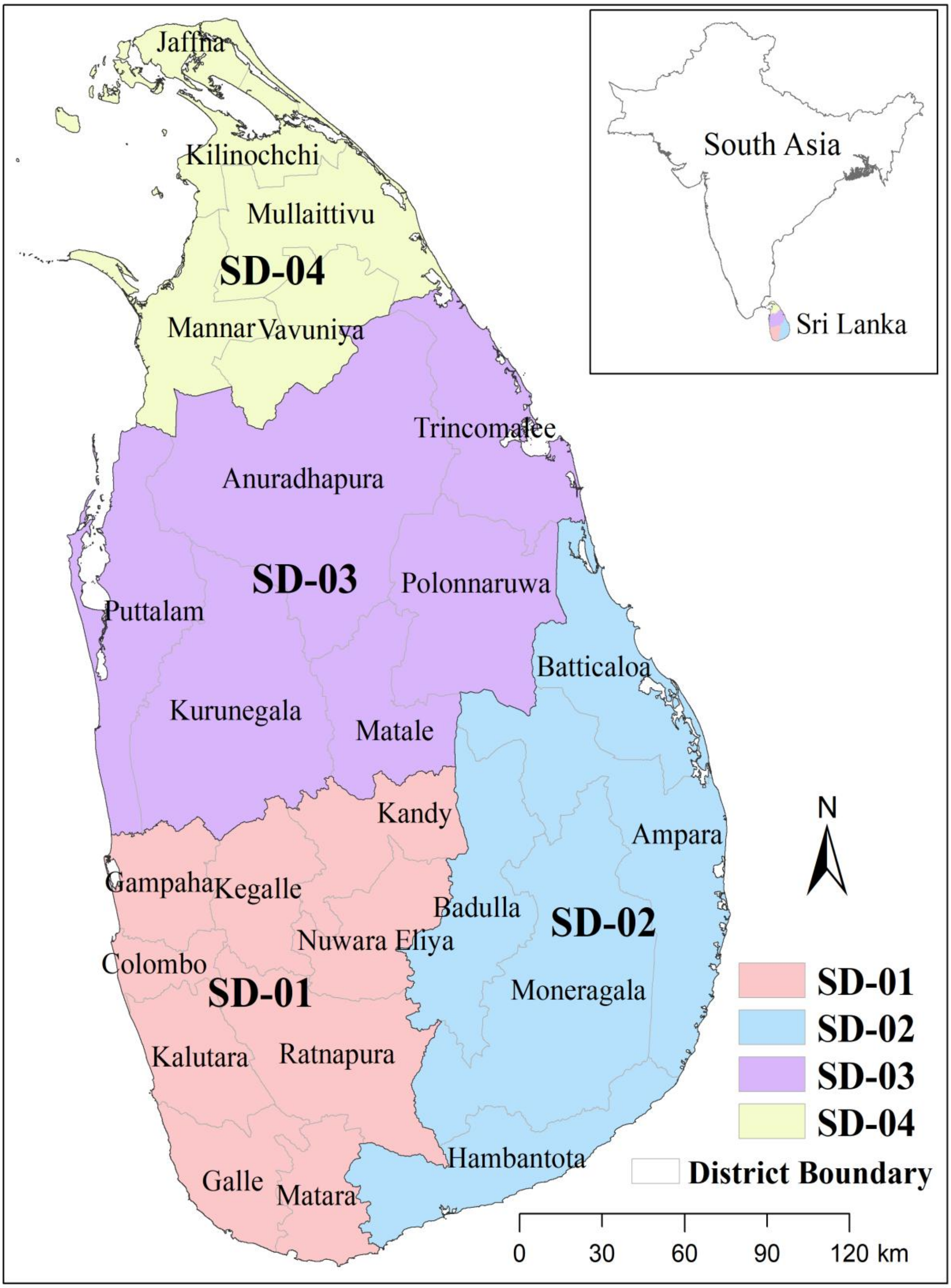

Figure 1: Sub-Division map of Sri Lanka used in this study.

As shown in Figure 1, the study initially divided Sri Lanka into four major regions, taking into account climatic distribution and geographical settings. These were named Sub-division 1 (SD1), Sub-division 2 (SD2), Sub-division 3 (SD3) and Sub-division 4 (SD4). Table 1 below shows the list of districts which are the administrative units included in these sub-divisions (SD1 to SD4).

Table 1: List of districts fallen in to four different sub-divisions

Sub-Division name	Districts
Sub-Division 01 (SD-01)	Colombo, Galle, Ganpaha, Kalutara, Kandy, Kegalle, Rathnapura, Nuvara-Eliya, Matara
Sub-Division 02 (SD-02)	Ampara, Badulla, Baticaloa, Hambantota, Monaragala
Sub-Division 03 (SD-03)	Anuradhapura, Matake, Kurunagala, Puttalam, Polonnaruwa, Trinco,alee
Sub-Division 04 (SD-04)	Jaffna, Kilinochchi, Mannar, Mullaitivu, Vavuniya

II. DATA AND METHODOLOGY

Mann, (1945) proposed an asymmetric test to analyze the tendencies, while (Kendall, 1975) executed the Mann test. In addition, (Harsh et al., 1982) Seasonal assessment was added to the test. This tendency is now more widely known as the Man-Kendall test for trend analysis. It tests statistically monotonic ups and downs of the climate trends over the time and that test is widely used around the world (Robson, 2002; Khaniya et al., 2018; Mondal et al., 2012).

Man-Kendall's statistics

Man-Kendall's statistics S is given by the following formula (1):

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sng(xj - xi) \qquad (1)$$

xj and xi are the time series and n is the number of data points in the time series. The sign function **"Sgn"** can be expressed as follows (2);

$$sgn\ (xj - xi) = \begin{Bmatrix} +1, > (xj - xi), \\ 0, = (xj - xi), \\ -1, < (xj - xi) \end{Bmatrix} \qquad (2)$$

The calculation of the variables in the Man-Kendall experiment is given by the following equation (3):

$$Var(s) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} ti(\, i)(i-1)(2i+5)}{18} \qquad (3)$$

Where it is the number of bonds specified in the sample i. then, Man-Kendall's statistics Zc are given by the following expressions (4);

$$Zc = \begin{Bmatrix} \frac{S-1}{\sqrt{Var(S)}}, & S > 0, \\ 0, & S = 0, \\ \frac{S+1}{\sqrt{Var(S)}}, & S < 0. \end{Bmatrix} \qquad (4)$$

Zc follows the standard normal distribution. A positive Zc value shows a high (upward) tendency and a negative Zc data gives a low (downward) tendency for the period.

Sen's slope estimation

The magnitude of given time trend can be found in Sen's Slope estimator (Sen, 1968). The test is widely used to estimate the magnitude of the propensity for rainfall ranges over time. Slope pairs can be calculated for all data using the following equation (5);

$$Ti = \frac{xj - xk}{j - k}\ for\ i = 1,2,3, \dots \dots . n, j > k, \qquad (5)$$

Where, Ti is the slope and xj and xk are the data values at time j and k, respectively.

The mean of the n values of Ti is encoded as Sen,s Slope estimator (Qi) and is calculated using following equation (6);

$$Zc = \begin{Bmatrix} (T(n+1/2), & n\ is\ 0dd, \\ & , \\ \frac{1}{2}(T(n/2)+T(n+2)/2, & n\ is\ even \end{Bmatrix} \qquad (6)$$

III. DATA

Climate Hazards Group Infra-Red Precipitation with Station Data provided (CHIPS) by the Climate Hazard Center, are the basic data used for this study. This data is available as Daily Grinding Rainfall and can be accessed (https://data.chc.ucsb.edu/products/CHIRPS-2.0/) from the web link from 1981 to the present. These data were then converted into monthly rainfall data using the method of daily accumulation sum at monthly basis. Geo-statistical Data Analysis method was apply to completed the above procedure. Finally, the monthly average rainfall value for each area used in the study was calculated by applying the zonal statistical method.

IV. RESULTS

Figure 2 shows the annual rainfall variation of by province. The spatial and temporal variation of rainfall can be clearly seen in this figure. All of this annual rainfall usually show different patterns with falls and rises and they show an increasing tendency. In addition, all regions except SD-01 received significantly less rainfall in 2016 compared to other years. Therefore, it can be considered as a drought year for them. Tests to show the homogeneity of rainfall data show that the data series are homogeneous for all four sub-divisions. As shown in Figure 2, all of these annual precipitates generally show more or less similar patterns with different annual accumulated rainfall values. For example, SD-01 has the highest annual rainfall and SD-04 shows the lowest annual rainfall. SD-02 and SD-03 represent more or less similar patterns except in 2015, with SD-03 receiving very good rainfall, the bumper crop year of Sri Lanka (Census and Statistics).

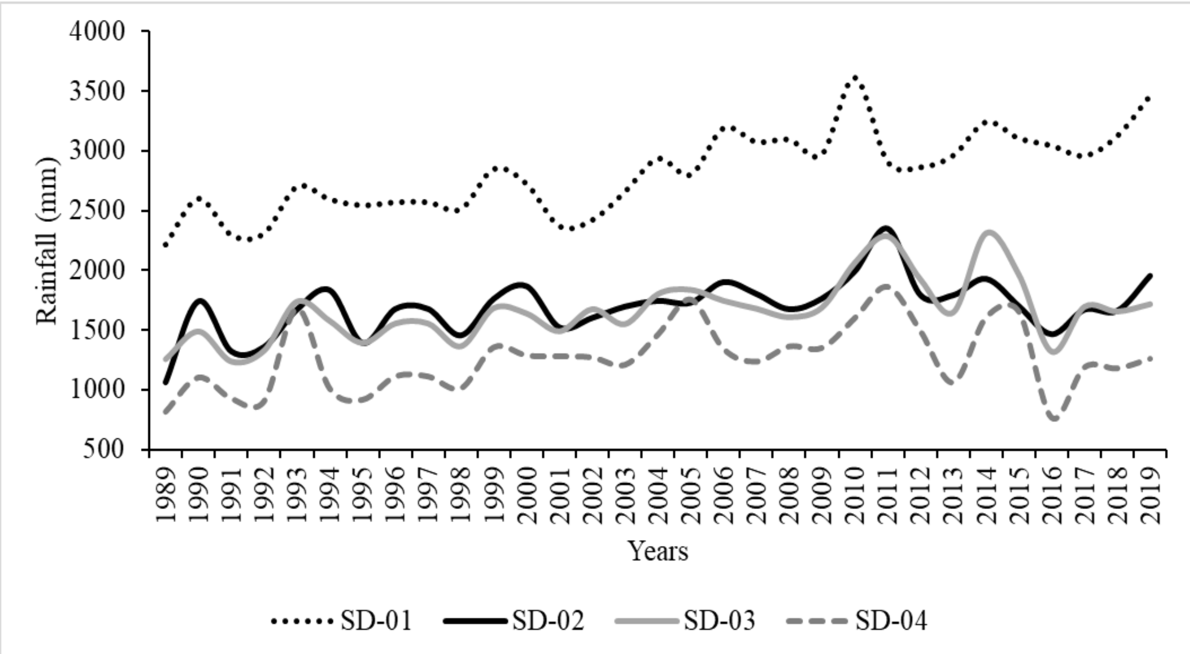

Figure 2: Representation of Annual rainfall distribution in identified four regions of Sri Lanka

Table 2: Mann-Kendall and Sen's slope calculation results for annual rainfall in four regions

Geographical region	Kendall's tau	P values (two-tailed)	Significant (Yes)/ Insignificant (No)	Sen's Slope (Qi – mm/year)
SD-01	0.589	< 0.0001	Yes	27.610
SD-02	0.290	0.0257	Yes	9.302
SD-03	0.419	0.0012	Yes	14.824
SD-04	0.276	0.0337	Yes	14.404

The results of the trend analysis (Mann-Kendall and Sen's slope) for the annual rainfall data are shown in Table 2. The table shows a very good trend in annual rainfall for SD-01, SD-02, SD-03 and SD-04 of all the rainfall zones. The most positive precipitation trends in SD-01rainfall measurements can be identified and the less values are shown in SD-03 and SD-04. Although the precipitation value is medium less in the SD-02 division. The annual potential rainfall increase for all of these regions is significant, and the annual precipitation values can be seen from the Sen's slope. The most important point here is that SD-01 represents about 90% of the wet zone and the highest annual precipitation increase can be identified in this region, which is 27.61 mm / yr. The other peculiarity is that the increase in potential rainfall in Sri Lanka is not negative from the trend analysis.

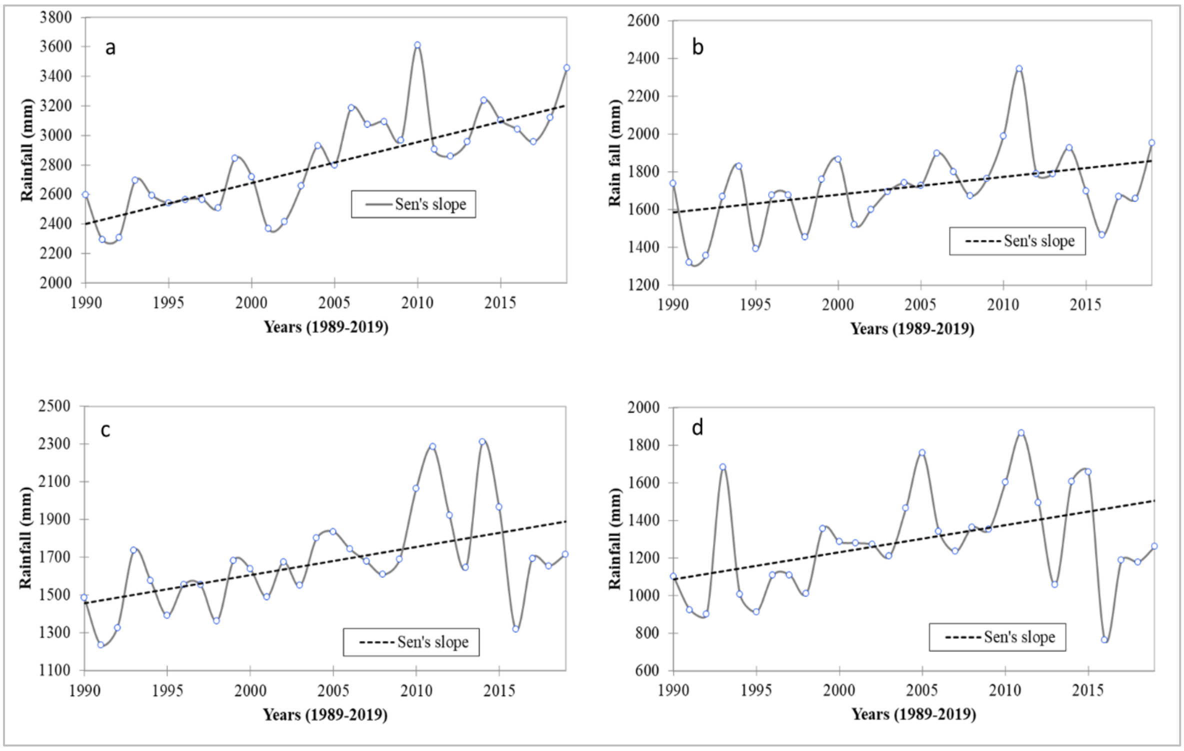

Figure 3: Temporal variation of Annual rainfall according to Mann-Crandall's and Sen's slope calculation, a. Sub-Division-01, b. Sub-Division-0, c. Sub-Division-03 and d. Sub-Division-04

This is an interesting finding identified in this study. According to the trend analysis, the catchment area of SD-01 is not subject to severe water scarcity. SD-01 is the main catchment area of Sri Lanka's major rivers Kalu Ganga, Mahaweli Ganga, Kelani Ganga and Walawe Ganga. However, due to the prevalence of this precipitation, SD-01 is most prone to floods. The area has been hit by three major floods (2016, 2017, 2018) in the last four years.

This analysis was expanded to identify the impact of seasonal rainfall in addition to the impact of annual rainfall on the water resources of the area in these study zones in Sri Lanka. SD-02 to SD-04, in particular, are famous for their irrigated agriculture and 90% of the total paddy cultivation in the country is done from these regions. Therefore, the analysis of seasonal rainfall trends will be an interesting topic for farmers in the area.

Table 3: Mann-Kendall and Sen's slope calculation results for seasonal rainfall in four regions

Geographical region	Rainfall season	Kendall's tau	P values (two-tailed)	Significant (Yes)/ Insignificant (No)	Sen's Slope (Qi –mm/year)
SD-01	Yala	0.354	0.006	Yes	12.513
	Maha	0.118	0.378	No	4.72
SD-02	Yala	0.299	0.021	Yes	3.184
	Maha	-0.034	0.807	No	-2.743
SD-03	Yala	0.35	0.007	Yes	6.164
	Maha	0.064	0.639	No	3.248
SD-04	Yala	0.331	0.011	Yes	3.016
	Maha	0.202	0.129	No	11.879

Statistics from Man-Kendall's test for seasonal rainfall and Sen's slope estimation are shown in Table 2. It is noteworthy that all divisions show significant trends for rainfall only during the Yala season. It is also important to note that SD-02 only shows a negative value (Figure 4) during the Maha season as this could exacerbate the drought.

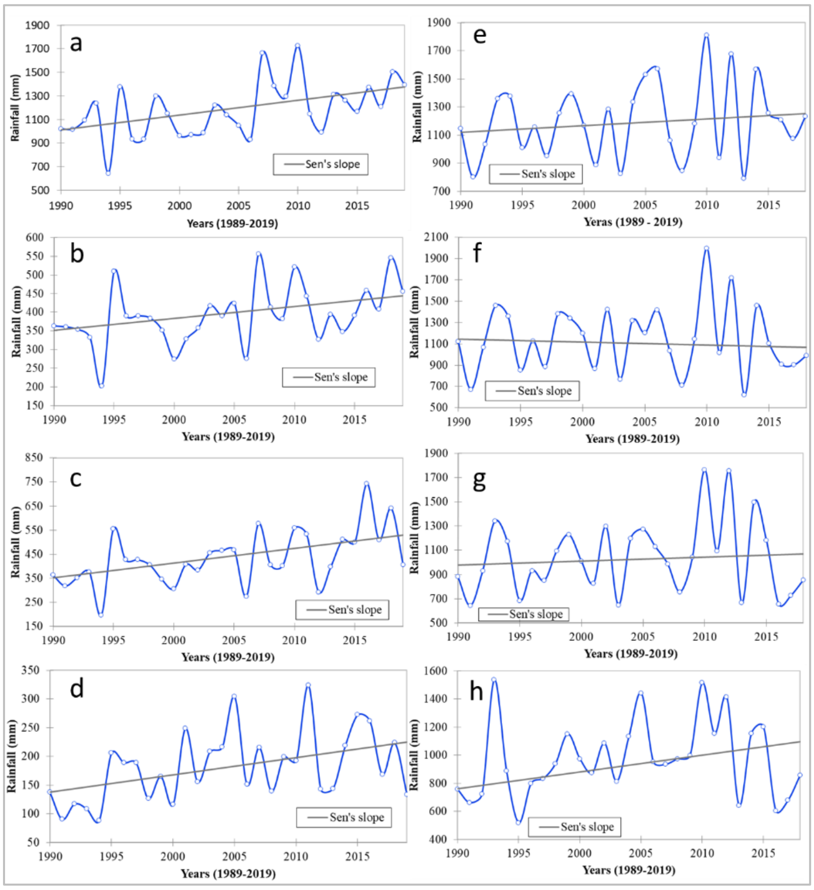

Figure 4: Temporal variation of Annual rainfall according to Mann-Crandall's and Sen's slope calculation, a-d Sub-Division 01, 02, 03 and 04 Yala season, e-h. Sub-Division-01, 02, 03 and 04 in Maha Season.

Furthermore, SD-02 and SD-04 are more closely related by geography and climatology, again, these rainfall trends and the slope of those divisions show similar variability. This is interesting and it will be interesting to study further the topographical contribution for this rainfall trends.

Table 4: Mann-Kendall and Sen's slope calculation results for monthly rainfall in four Regions

Region	Months	Kendall's tau	p-value (Two-tailed)	Sen's slope (Qi – mm/year)	Region	Months	Kendall's tau	p-value (Two-tailed)	Sen's slope (Qi – mm/year)
SD-01	Jan	-0.193	0.139	-2.597	SD-02	Jan	-0.170	0.193	-4.470
	Feb	0.147	0.261	1.492		Feb	0.147	0.261	1.737
	Mar	0.258	0.048	3.787		Mar	0.290	0.026	2.543
	Apr	0.133	0.309	2.946		Apr	0.078	0.556	1.050
	May	0.092	0.486	3.352		May	0.092	0.486	0.792
	Jun	0.074	0.580	0.761		Jun	-0.110	0.581	-0.009
	Jul	-0.078	0.556	-0.293		Jul	-0.009	0.957	-0.304
	Aug	0.350	0.007	4.358		Aug	0.203	0.121	1.034
	Sep	0.290	0.026	5.419		Sep	0.124	0.344	0.834
	Oct	0.170	0.193	4.139		Oct	0.207	0.112	2.749
	Nov	0.198	0.129	2.122		Nov	-0.037	0.789	-0.296
	Dec	0.060	0.656	0.784		Dec	0.041	0.762	1.080
SD-03	Jan	-0.170	0.193	-2.899	SD-04	Jan	-0.147	0.509	-1.090
	Feb	0.147	0.261	1.235		Feb	0.087	0.261	0.261
	Mar	0.216	0.097	1.625		Mar	0.184	0.159	0.967
	Apr	0.133	0.309	1.646		Apr	0.138	0.292	1.161
	May	0.175	0.203	1.635		May	0.060	0.656	0.194
	Jun	0.028	0.844	0.043		Jun	0.014	0.929	0.002
	Jul	-0.087	0.509	-0.281		Jul	0.115	0.382	0.077
	Aug	0.157	0.232	0.936		Aug	0.180	0.169	0.330
	Sep	0.041	0.762	0.385		Sep	0.018	0.901	0.156
	Oct	0.087	0.509	2.158		Oct	0.055	0.682	1.040
	Nov	0.028	0.844	1.023		Nov	0.041	0.762	0.929
	Dec	0.101	0.443	2.534		Dec	0.166	0.205	4.112

Monthly Trend Analysis Results for the four rain region areas are presented in Table 3. For SD-01, all months except January and July show a positive trend. However, the Sen's slope shows the highest values in August and September, with 4.35 and 5.41, respectively. This study shows that all four major areas show no significant trend except for a few months. In this regard, significant trends for SD-01 can be identified in March, August and September, while significant trends in SD-02 and SD-03 can be seen in March but no significant trend can be detected in any month SD-04.

V. CONCLUSIONS

Of paramount importance in this study is the division of Sri Lanka into four main regions and then the examination of rainfall trends using reconstructed precipitation data using satellite estimates and location data. The fact that the annual rainfall trend results show that no negative trends shows for any region of Sri Lanka Kendall's tau and Sen's flow and p values also represent that there is a significant positive trend everywhere in the country. When study the seasonal rainfall trend, It is clear that all zones show significant trends for rainfall only during the Yala season (Southwestern monsoon). Long-term (30 Years) precipitation studies show that there is no significant change in rainfall during the Maha season (Southwestern monsoon).

Furthermore, in terms of agricultural and seasonal rainfall trends, it is evident that the tendency to add more water to the river basins of all regions increases during the Yala season. This tendency is much higher in SD-01 compare to all other. In addition, droughts in SD-02, SD-03 and SD-04 regions can be minimized by utilizing the increased rainfall during the Yala season, especially during the Maha season. Finally, it is recommended that a detailed and fine-scale analysis be performed using satellite-estimated precipitation data that bias corrects with gauge data to achieve much better results.

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