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Recent climatic trends in Trinidad and Tobago, West Indies

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Abstract

Seawater level rise is one of the most prevalent adverse environmental impacts of the ongoing global warming process. Island nations are more vulnerable to the impact than the land masses. Two such islands impacted by global warming are Trinidad and Tobago, located in the Atlantic Ocean. However, there is minimal related research in this area in the context of the impact of climate variability. Therefore, it is timely and interesting to assess the climatic trends in islands that are extremely vulnerable like Trinidad and Tobago. This paper presents a detailed non-parametric statistical analysis for well-known climate gauges in Trinidad and Tobago, West Indies. Mann Kendall and Sen's slope tests were carried out on two identified rain gauges in Trinidad and Tobago. Monthly climatic data including cumulative rainfall and the average of the minimum and maximum atmospheric temperatures were processed to identify the trend analysis using the above stated non-parametric tests. Important results are found from the analysis; most importantly, there is no significant impact on the rainfall in the area due to the climate variability over 30 years. However, the atmospheric temperature behaves in a different way and it has a rising pattern across the total 12 months studied. This can be seen for both the minimum and maximum atmospheric temperatures. Therefore, the warm months are becoming warmer and the cold months are becoming less cold. This is a critical finding that must be considered for any future planning processes.

Keywords: Atmospheric temperature, Climate variability, Non parametric tests, Rainfall, Trinidad and Tobago

1. Introduction

The impact of the greenhouse effect on Earth has increased over the past several decades due to industrialization and deforestation. Eventually, this leads to climate variabilities and climate changes [1]. An increase of greenhouse gases (GHG) like carbon dioxide (CO_2), nitrous oxide (N_2O), chlorofluorocarbons (CFCs) and methane (CH_4) has altered the atmospheric greenhouse effect during the last century, thus resulting in global warming, ozone layer damage and sea-level rise [2,3]. The risks associated with these outcomes and the ability to manage them would affect the sustainability of living conditions and the development of the economy. It has been projected that extreme climatic events like droughts and floods will become more frequent and affect agriculture, infrastructure, water resources, etc., in the future [4,5].

The entire globe has been experiencing a surface warming pattern, with a mean surface temperature increment of 0.85 ˚C from the year 1880 to the year 2012 [6]. However, a temperature increment of 0 to 0.5 ˚C/ decade from 1971 to 2004 can be observed in small islands in the Caribbean, Mediterranean and Indian Ocean regions [4,5]. Out of these, the Caribbean region is known to have faced adverse impacts due to changes in precipitation and temperature, where global warming in this area has increased the propensity of vector-borne diseases, coral bleaching and damage to biodiversity [7]. It is also known that the small islands are having increasing threats from climate extremes and climate changes [8,9]. These conditions have been impacted further through limited land and other natural resources, highly compacted cities and coastal belts, and on the economic dependency on tourism [10,11].

Several studies on the climatic trends in the islands of West Indies can be found in literature. Neelin et al. [12] studied changes in rainfall due to anthropogenic activities in the Caribbean/ Central American region. Their studies utilized many global warming simulation techniques. They have showcased a decrease in the overall magnitude of the precipitation at convective zone margins. In addition, a significant summer drying was observed for some of the locations. McLean et al. [13] studied the extremes in future rainfall and atmospheric temperature for Caribbean regions. They have validated the rainfall trends and the minimum and maximum temperature extremes from a regional climate model (RCM) for five rainfall zones using the climatic data from 1979-1989. They have further explored the drying trends for Trinidad and northern Guyana. Therefore, the temperature indices suggested that warmer temperatures can be expected in the Caribbean region.

Beharry et al. [14], from their recent study, presented the precipitation trends in Trinidad. However, they have used the in-situ and gridded datasets for 1901 to 2010. This study was carried out using two statistical tests, Pettit test and Mann-Kendall test. It found that Southern Trinidad is becoming drier during the dry season. Furthermore, they found that the variations between the maximum rainfall months and the minimum rainfall months have increased .

Supporting the conclusions from Beharry et al. [14], Stone [15] found that Trinidad is becoming drier during the dry seasons. However, they further claimed that the wet season is becoming wetter. Five climatic gauging stations in Trinidad were statistically (auto-correlation and Wald- Wolfowitz test) analyzed to find trends, jumps and cycles in the data series. Furthermore, Jones et al. [16] presented variabilities in rainfall and atmospheric temperature in the Caribbean region. They used CRU TS 3.21 and GPCCv5 grid data sets for northern, eastern, southern and western regions. This study was carried out over three time periods (1901 to 2012, 1951 to 2012 and 1979 to 2012). The results of this study showed that there are no century-long climatic trends in the Caribbean islands. However, some decade-long trends of drier or wetter conditions were observed. Nevertheless, atmospheric temperature showed a significant increase for all considered periods.

Despite these studies, no proper recent study has been carried out in Crown point, Tobago and Trinidad since the 1980s. This paper reviews the trends in rainfall and temperature in Trinidad and Crown point, Tobago Island using commonly used statistical tests, Mann-Kendall test and Sens's slope estimator test.

2. Materials and methods

2.1 Mann-Kendall test

The Mann-Kendall test is a statistical test, which can be used to analyze climatic data series to find trends. Mann [17] originally introduced this test for trend analysis. However, a significant amount of time period was required to created improved versions (published in 1975). Hirsch et al. [18] have improved this non-parametric test with seasonal effects. This test is widely used to identify climatic trends, which are continuously (monotonically) increasing or decreasing. The test was famous as Mann-Kendall test among the researchers [19, 20]. The test can be formulated as Equation (1) to find the Mann-Kendall statistic S.

$$S = \sum_{i=1}^{m-1} \sum_{j=i+1}^{m} sgn\,(y_j - y_i) \tag{1}$$

where y_j and y_i are time series and m is the number of data points in the time series. The "sgn" sign function can be expressed as given in Equation (2).

$$sgn(y_j - y_i) = \begin{cases} +1, > (y_j - y_i) \\ 0, = (y_j - y_i) \\ -1, < (y_j - y_i) \end{cases} \tag{2}$$

Equation (3) presents the variance of the Mann-Kendall's test.

$$Variance(S) = \frac{m(m-1)(2m+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18} \tag{3}$$

where t_i is the number of ties up to sample i. Then, the Mann-Kendall's statistics Z_c is given by Equation (4).

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{Varience(S)}}, S > 0 \\ \frac{S-1^{0,S=0}}{\sqrt{Varience(S)}}, S < 0 \end{cases} \quad (4)$$

An upward trend is depicted through a positive Z_c value whereas a downward trend is given by a negative Z_c, which follows the standard normal distribution.

2.2 Sen's slope estimator test

Climatic trends' magnitude at a set time is assessed using Sen's slope; this is widely used for rainfall trend analysis [21-23]. The slope of a climatic trend is calculated using the following Equation (5).

$$d_k = \frac{y_j - y_i}{j-i}; for\ (1 \le i \le j \le m) \quad (5)$$

d_x - slope
y_i - data values at time i
y_j -data values at time j
m - number of data

The Sen's slope estimator (Q_i) is the median of d_k and given by Equation (6).

$$Q_i = \begin{cases} \frac{d_{m+1}}{2}, m\ is\ odd \\ \frac{1}{2}\left(d_{\frac{m}{2}} + d_{\frac{m+2}{2}}\right), m\ is\ even \end{cases} \quad (6)$$

Increasing climatic trends are given by the positive Q_i values whereas the decreasing trends are given by the negative Q_i values.

2.3 The study area; Trinidad and Tobago

The most southern Caribbean nation, the Republic of Trinidad and Tobago is located between 60˚ to 62˚ W longitudes and 10˚ to 11.5˚ N latitudes. Trinidad and Tobago are two separate islands. "Trinidad" is located in Trinidad island having a land area of 4862 km^2 and "Crown point" is in the Tobago island with a land area of 300.4 km^2. The small island Tobago is located 30 km to the northeast of Trinidad Island as shown in Figure 1. Two seasonal climates--tropical maritime and modified moist equatorial--exist in Trinidad [7,14,24-26]. Tropical maritime climate occurs during the dry season between the months of January and May, characterized by warm daytimes and cool night-times. Generally, daytime heat results in convectional rainfall at night. Hot, humid daytimes and night-times are usually influenced by the modified moist equatorial climate from June to December [24]. Despite Crown point, Tobago is more frequently affected by storms, as compared to Trinidad. Therefore, Trinidad is wetter than Tobago. Crown point, Tobago generally experiences its primary rainfall mode in November while Trinidad experience its primary mode in June [24].

Figure 1 Meteorological stations in Trinidad and Tobago (Crown point).

Rainfall and atmospheric temperature data for these two locations have been recorded by the Trinidad & Tobago Meteorological Service for the last 37 years. These climatic data are then processed for the non-parametric tests (Mann-Kendall test and Sen's slope estimator test) to identify any potential trends in the rainfall and atmospheric temperature.

3. Results and discussion

The annual rainfall variation in Trinidad and Crown point over the past 37 years, spanning from 1981 to 2017 are given by Figure 2. It is clear that the Crown point (Figure 2A) has received less rainfall as compared to Trinidad (Figure 2B) during this period, though drops and rises can be observed for both the rain gauge stations**.** Even though similar patterns are observed for most of the years in drops and rises for both stations, Trinidad rainfall station received its highest rainfall from 1981 to 1986 while Crown point received lower rainfall during this time period relative to its other years. However, these figures do not clearly depict any increasing or decreasing pattern in the change of rainfall over the years in either Trinidad or Crown point station.

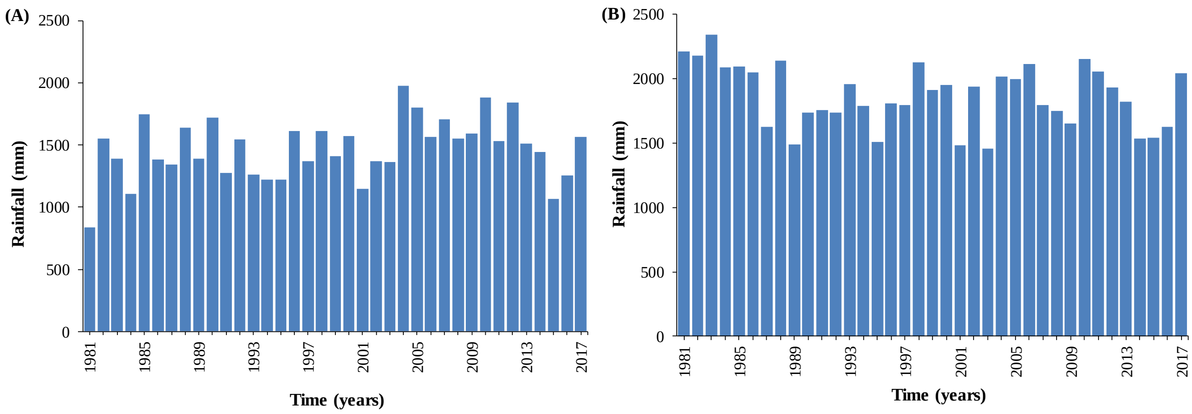

Figure 2 Annual rainfall variations from 1981 to 2017 (A) for Crown point and (B) for Trinidad.

Table 1 illustrates the Mann-Kendall trend analysis results for the two rain gauging stations. Similar to above Figure 2, test results suggest that a significant trend for annual rainfall for both stations cannot be identified.

Table1 Mann-Kendall trend analysis results for annual rainfall.

	Significant (Sig) /Insignificant (In-Sig)	Sen's slope (mm/year)
Crown point	In-Sig	0
Trinidad	In-Sig	0

Monthly cumulative rainfalls recorded at Crown point are shown in Figure 3 for different decades varying from 1981, 1991, 2001, 2011 and 2017. According to the figures, a similar pattern in monthly cumulative rainfall is visible for every year, except for 2011. Relatively higher rainfalls are observed during the first two quarters of the year 2011, while such observation is not available for other years. Figures clearly deduce the fact that Crown point receives its primary rainfall from October to December with higher monthly cumulative rainfalls in each year. However, it can be observed that monthly cumulative rainfall in Crown point for January, February and March have increased with no clear trend showing that Crown point has moved to wetter conditions throughout the year.

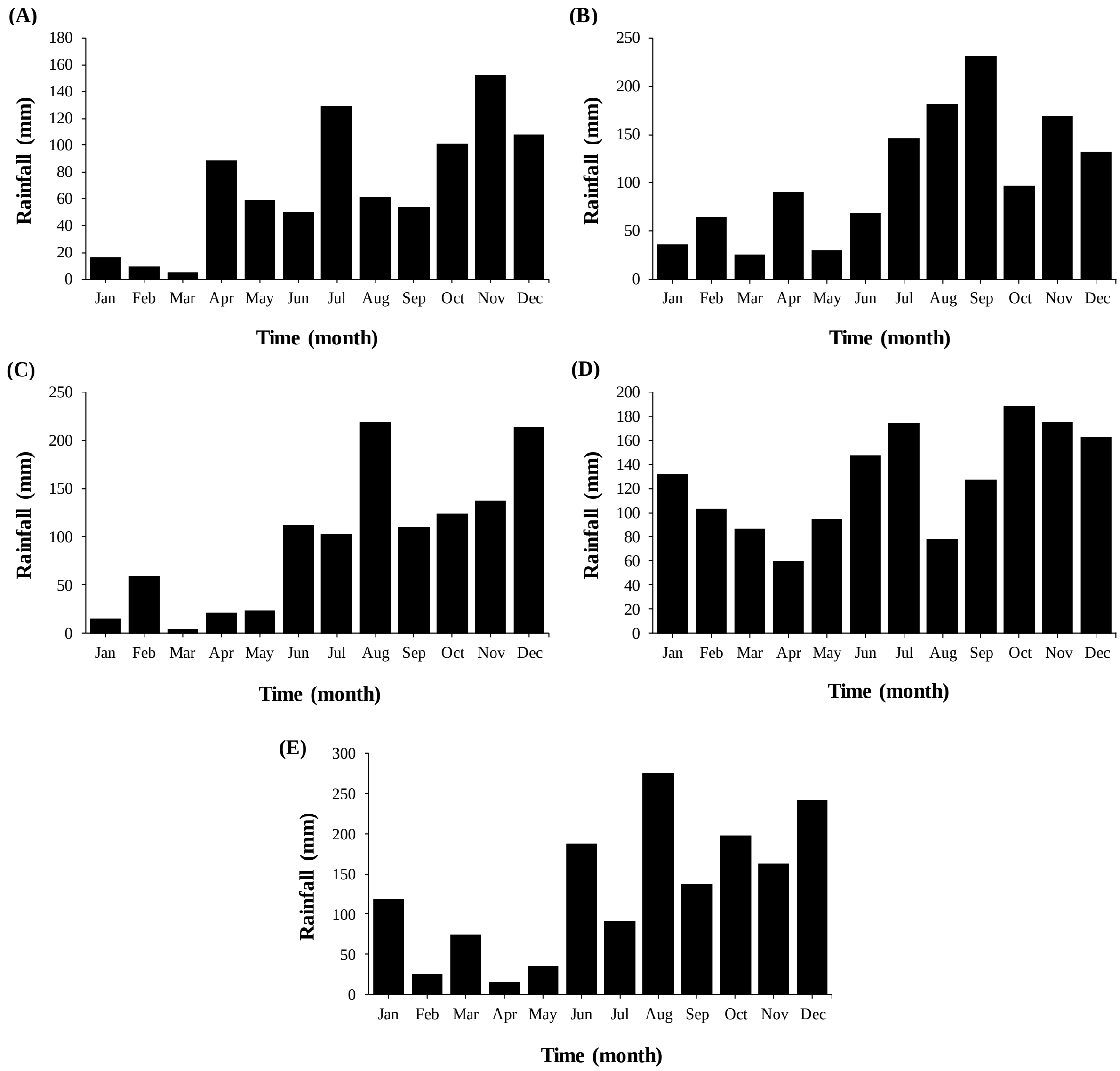

Figure 3 Monthly cumulative rainfall variations for Crown point (A) for 1981; (B) for 1991; (C) for 2001; (D) for 2011 and (E) for 2017.

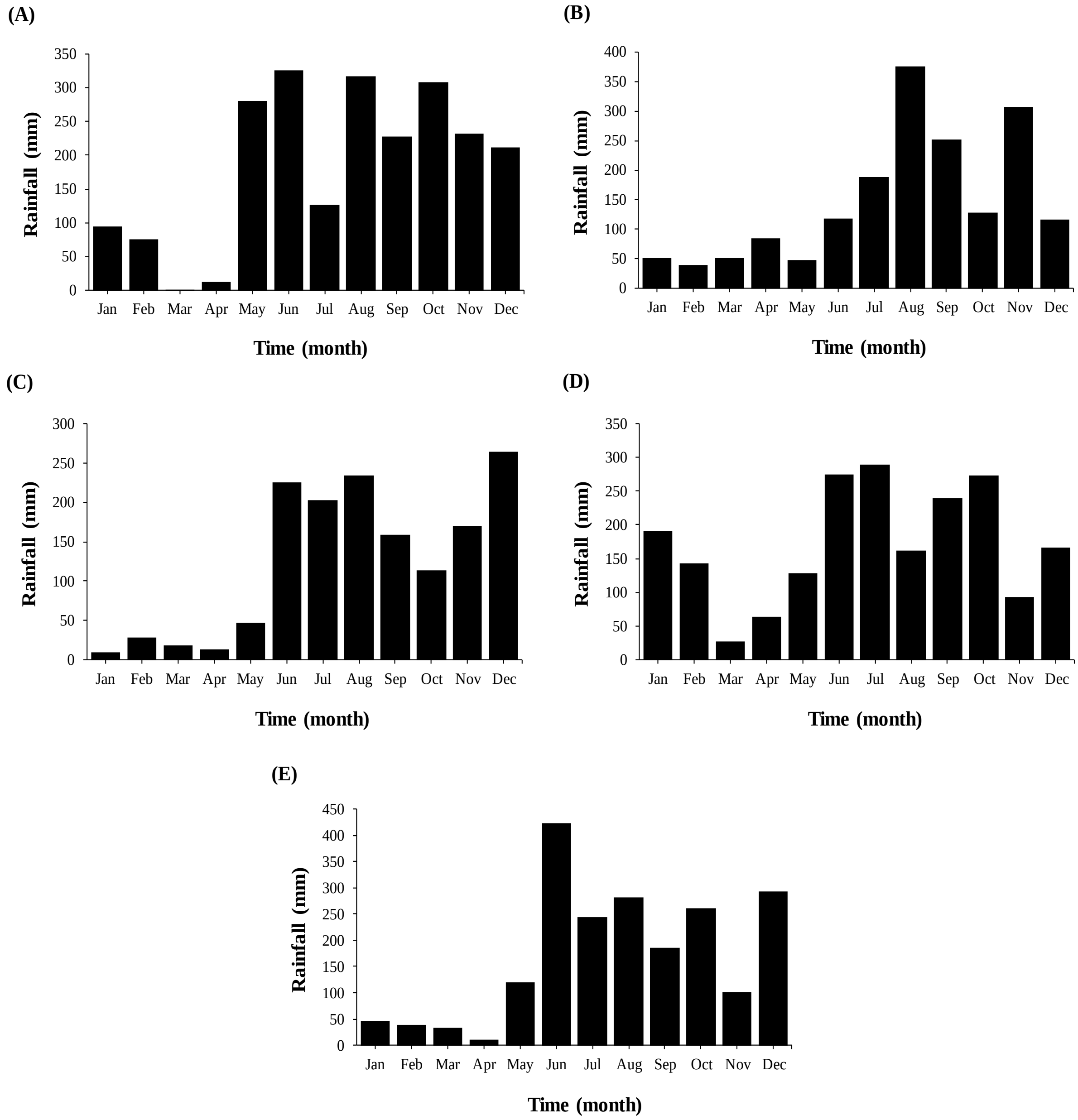

Figure 4 Monthly cumulative rainfall variations for Trinidad (A) for 1981; (B) for 1991; (C) for 2001; (D) for 2011 and (E) for 2017.

Similarly, Figures 4A to 4e show the monthly cumulative rainfall in Trinidad from 1981 to 2017. Based on these figures, apart from the representation for 2011, Trinidad has its driest months in the period from January to April. Data for Trinidad shows that the months around June are when its primary rainfall is received as mentioned in the literature [24]. These figures exhibit clues that Trinidad is getting drier at the end of the year with a reduction of cumulative rainfall in the months of October, November, and December from 1981 to 2017, despite the fact that a clear trend is not observed.

Rainfall variation in the driest and wettest months in Crown point and Trinidad is shown in Figures 5A-5D. It is noticeable that rainfall for March in Crown point has increased slightly over the years (refer Figure 5A). Despite this observation, a Zig-Zag pattern can be observed in the other three figures (Figures 5B-5D) where no definite pattern can be identified.

However, the rainfall variation in the starting months of the year 2011 could be due to an extreme case as given in Figures 5A and 5C, where there are some years with higher rainfalls during the driest month: March.

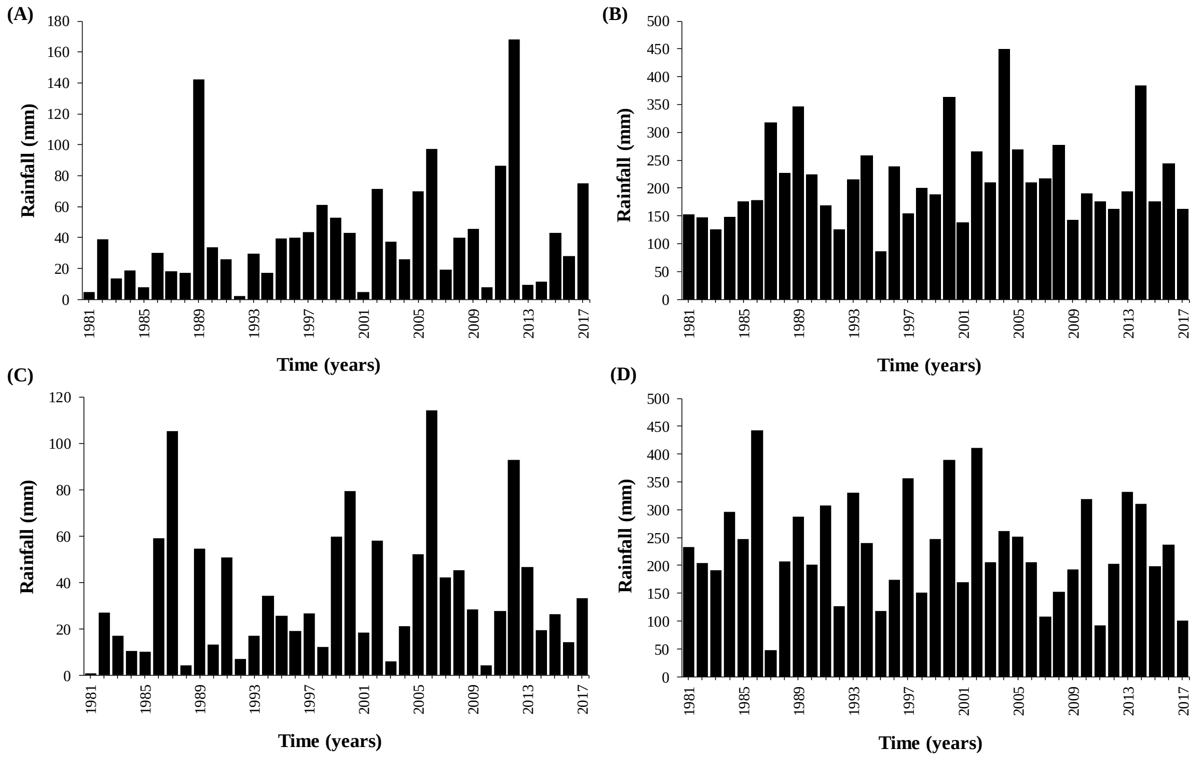

Figure 5 Rainfall variations during the driest and wettest months (A) for March (Crown point); (B) for November (Crown point); (C) for March (Trinidad) and (D) for November (Trinidad).

Table 2 gives the results of the trend analysis tests for Crown point, Tobago. The significant trends in monthly cumulative rainfall can be seen for January and March with rainfall increments of 1.8 mm/month and 0.8 mm/month. However, no significant trend was observed for any of the twelve months in terms of maximum daily rainfall. Similarly, Table 3 presents the Mann-Kendall and Sen's slope test results for Trinidad. These results clearly depict that there is no significant trend for monthly cumulative rainfall and maximum daily rainfall throughout the year except for the month of September (rainfall reduction of 2.1 mm/month).

Table 2 Mann-Kendall trend analysis results for rainfall for Crown point.

	Monthly cumulative rainfall		Maximum daily rainfall	
Month	Significant (Sig.) / Insignificant (In-Sig.)	Sen's slope (mm/month)	Significant (Sig.) / Insignificant (In-Sig.)	Sen's slope (mm/d)
Jan	Sig.	1.8	In-Sig.	0
Feb	In-Sig.	0	In-Sig.	0
Mar	Sig.	0.8	In-Sig.	0
Apr	In-Sig.	0	In-Sig.	0
May	In-Sig.	0	In-Sig.	0
Jun	In-Sig.	0	In-Sig.	0
Jul	In-Sig.	0	In-Sig.	0
Aug	In-Sig.	0	In-Sig.	0
Sep	In-Sig.	0	In-Sig.	0
Oct	In-Sig.	0	In-Sig.	0
Nov	In-Sig.	0	In-Sig.	0
Dec	In-Sig.	0	In-Sig.	0

Table 3 Mann-Kendall trend analysis results for rainfall for Trinidad.

Month	Monthly cumulative rainfall	Maximum daily rainfall	Month	Monthly cumulative rainfall
	Significant (Sig.) / Insignificant (In-Sig.)	Sen's slope (mm/month)	Significant (Sig.) / Insignificant (In-Sig.)	Sen's slope (mm/month)
Jan	In-Sig.	0	In-Sig.	0
Feb	In-Sig.	0	In-Sig.	0
Mar	In-Sig.	0	In-Sig.	0
Apr	In-Sig.	0	In-Sig.	0
May	In-Sig.	0	In-Sig.	0
Jun	In-Sig.	0	In-Sig.	0
July	In-Sig.	0	In-Sig.	0
Aug	In-Sig.	0	In-Sig.	0
Sep	Sig.	-2.1	In-Sig.	0
Oct	In-Sig.	0	In-Sig.	0
Nov	In-Sig.	0	In-Sig.	0
Dec	In-Sig.	0	In-Sig.	0

Furthermore, these rainfall trends were carried out for two seasons in Trinidad and Tobago. Dry season starts in January and ends in May of the year whereas the wet season starts in June and ends in December. Trend analysis results show that there are no trends in the dry season for neither Trinidad nor Tobago. However, there is a negative trend in the wet season for Trinidad (-8.5 mm/season). This is interesting as it is a reduction of rainfall even though the reduction rate is less than 1% of the total rainfall of the wet season rainfall. Despite the low percentage, this may lead to a significant impact.

Table 4 shows the results of trend analysis test results for the minimum and maximum of average temperature in Crown point. The results show a positive trend in the minimum of average temperature with increments in every month except for February, where no such observance is made. However, trends for the maximum of average temperature were observed only during July, September and November with temperature increments of 0.024, 0.024 and 0.018 ˚C/d in year respectively.

Table 4 Mann-Kendall trend analysis results for average daily temperatures for Crown point.

Month	Minimum of Average Temperature		Maximum of Average Temperature	
	Significant (Sig.) / Insignificant (In-Sig.)	Sen's slope (˚C/d in year)	Significant (Sig.) / Insignificant (In-Sig.)	Sen's slope (˚C/d in year)
Jan	Sig.	0.043	In-Sig.	0
Feb	In-Sig.	0	In-Sig.	0
Mar	Sig.	0.045	In-Sig.	0
Apr	Sig.	0.03	In-Sig.	0
May	Sig.	0.028	In-Sig.	0
Jun	Sig.	0.033	In-Sig.	0
July	Sig.	0.045	Sig.	0.024
Aug	Sig.	0.054	In-Sig.	0
Sep	Sig.	0.065	Sig.	0.024
Oct	Sig.	0.06	In-Sig.	0
Nov	Sig.	0.047	Sig.	0.018
Dec	Sig.	0.045	In-Sig.	0

Correspondingly, Table 5 presents the Mann-Kendall and Sen's slope estimator test results for average daily temperature in Trinidad. According to these results, it is observed that the minimum of average temperature has increased in all twelve months with increments varying in the range of 0.027 to 0.042 ˚C/d. Similarly, the maximum of average temperature has shown a positive trend with a rise in temperatures except for March where no such significant trend is observed. Based on these results, it can be adjudged that the minimum of average temperature has increased over the years in the islands Trinidad and Tobago. However, no such observance can be made with these results for maximum of average temperature.

Table 5 Mann-Kendall trend analysis results for average daily temperatures for Trinidad.

Month	Minimum of Average Temperature		Maximum of Average Temperature	
	Significant (Sig.)/ Insignificant (In-Sig.)	Sen's slope (˚C/ d in year)	Significant (Sig.)/ Insignificant (In-Sig.)	Sen's slope (˚C/ d in year)
Jan	Sig.	0.042	Sig.	0.03
Feb	Sig.	0.033	Sig.	0.033
Mar	Sig.	0.039	In-Sig.	0
Apr	Sig.	0.027	Sig.	0.035
May	Sig.	0.027	Sig.	0.041
Jun	Sig.	0.029	Sig.	0.045
Jul	Sig.	0.038	Sig.	0.05
Aug	Sig.	0.038	Sig.	0.057
Sep	Sig.	0.037	Sig.	0.058
Oct	Sig.	0.042	Sig.	0.051
Nov	Sig.	0.038	Sig.	0.04
Dec	Sig.	0.039	Sig.	0.033

Trend analysis results for the minimum and maximum temperatures in Crown point are shown in Table 6. The results show that there is a positive trend for the minimum temperature in which the minimum temperature has risen in the range of 0.04 to 0.059 ˚C/d for year, with the exception of the months of April and May. However, similar to the average of maximum temperature, no significant trends are observed in maximum temperature except for the months of July, August, November and December where temperature increments of 0.027, 0 0.029, 0.023 and 0.018 ˚C/d in year are observed.

Table 6 Mann-Kendall trend analysis results for minimum and maximum daily temperatures for Crown point.

Month	Minimum Temperature		Maximum Temperature	
	Significant (Sig.)/ Insignificant (In-Sig.)	Sen's slope (˚C/ d in year)	Significant (Sig.)/ Insignificant (In-Sig.)	Sen's slope (˚C/ d in year)
Jan	Sig.	0.055	In-Sig.	0
Feb	Sig.	0.046	In-Sig.	0
Mar	Sig.	0.04	In-Sig.	0
Apr	In-Sig.	0	In-Sig.	0
May	In-Sig.	0	In-Sig.	0
Jun	Sig.	0.047	In-Sig.	0
Jul	Sig.	0.056	Sig.	0.027
Aug	Sig.	0.056	Sig.	0.029
Sep	Sig.	0.059	In-Sig.	0
Oct	Sig.	0.05	In-Sig.	0
Nov	Sig.	0.054	Sig.	0.023
Dec	Sig.	0.054	Sig.	0.018

Minimum and maximum temperature trend analysis results for Trinidad is given in Table 7. The results clearly show that the minimum temperature has increased for all of the months in the considered time frame. Similarly, the maximum temperature has significant positive trends for all the months, showing a similarity in the average of maximum temperature in Trinidad. These minimum and maximum temperatures have increased in the range of 0.022 to 0.064 ˚C/ d in the year.

Table 7 Mann-Kendall trend analysis results for minimum and maximum daily temperatures for Trinidad.

Month	Minimum Temperature		Minimum Temperature	
	Significant (Sig.)/ Insignificant (In-Sig.)	Sen's slope (˚C/ d in year)	Significant (Sig.)/ Insignificant (In-Sig.)	Sen's slope (˚C/ d in year)
Jan	Sig.	0.043	Sig.	0.033
Feb	Sig.	0.055	Sig.	0.032
Mar	Sig.	0.05	Sig.	0.04
Apr	Sig.	0.036	Sig.	0.043
May	Sig.	0.022	Sig.	0.029
Jun	Sig.	0.026	Sig.	0.047
Jul	Sig.	0.038	Sig.	0.044
Aug	Sig.	0.037	Sig.	0.064
Sep	Sig.	0.031	Sig.	0.054
Oct	Sig.	0.036	Sig.	0.058
Nov	Sig.	0.05	Sig.	0.041
Dec	Sig.	0.05	Sig.	0.047

It has been stated that the usual pattern of rainfall to most of the Caribbean islands is convectional during the warmer months. This means that rainfall occurs during the evening due to warm periods in the morning hours. However, when it comes to trends analysis, there is no significant change in the rainfall patterns in the drier months (Jan-May). Even though there are trends in atmospheric temperature in the order of 1/100 ˚C, this may be not enough to make a big difference in the convectional rainfall in the dry months.

4. Conclusions

The outcome of this research is significant and critical. The trend analysis results show that there are no significant trends in monthly cumulative rainfalls for either station, thus it can be concluded that the Trinidad and Tobago are safer from abrupt rainfall trends. Nevertheless, there is a negative trend in the seasonal rainfall for the wet season in Trinidad. Therefore, more analysis should be carried out to observe this reduction. However, there is an impact in atmospheric temperature. Trend analyses for the minimum and the maximum atmospheric temperature exhibit positive trends throughout the year. This means that living beings would feel a temperature rise throughout the year. This conclusion was made available to the public in the early 1990s by some researchers; it has been further proved by this research. Consequently, these findings on atmospheric temperature can be potentially used for planning processes (for example-to predict the energy requirement for air-conditioning and so on). Therefore, the results can be thoroughly assessed by planners for various predictions. In addition, the impact of sea rise due to ongoing climate change or climate variability must be analyzed in detail.

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