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IMPACT OF CLIMATE CHANGE ON WATER RESOURCE ENGINEERING IN TRINIDAD AND TOBAGO

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ABSTRACT

The detection of rainfall trends is vital for water resource development in small island states such as Trinidad and Tobago. This study investigates whether climate change affects rainfall trends and conducts statistical analysis of annual, seasonal, and decadal cumulative rainfall data obtained from two meteorological stations in Trinidad and Tobago for the period 1990-2020. Using XLSTAT, the nonparametric Mann–Kendall's test was conducted at a 5% significance level to detect whether trends in the rainfall data existed, and the nonparametric Sen's slope estimator was used to detect the magnitude of the trends. The results showed no statistically significant trends in Trinidad and Tobago's annual, seasonal, or decadal rainfall over the 30 years considered. This result indicates that Trinidad and Tobago are safe from abrupt changes in rainfall trends due to climate change and highlights the significance of conducting localized climate studies rather than solely depending on the predictions of global climate models.

Keywords: Climate, Mann-Kendal test, Rainfall, Sen's slope estimator, Trinidad and Tobago.

INTRODUCTION

Climate variability directly results from human activities such as industrialization, burning fossil fuels, and land-use changes (Kouao et al., 2020; Nassa et al., 2021; Pang and Tan, 2023). According to the IPCC (2007), "It is projected that some extremes will become more frequent, widespread, and intense during the 21st century. These may include droughts or flooding events which can threaten water resources, agricultural production, and biodiversity."

In October 2018, the Caribbean Islands of Trinidad and Tobago experienced an extreme rainfall event that produced, according to government officials, an entire month's worth of rain for two days (Gunathilake et al., 2020; Karunanayake et al., 2020; Samarasinghe et al., 2023). This freak rainfall event caused flooding in approximately 80% of the country, displacing many individuals from their homes and businesses (Khaniya et al., 2021; Khaniya et al., 2019; Pawar et al., 2023). Although there have been studies conducted on the regional level about climate change and its possible effect on rainfall trends by Stephenson et al. (2013) and others conducted by Beharry et al. (2014) and Perera et al. (2020), on its effects on rainfall trends in Trinidad and Tobago specifically, these studies are very few and only used datasets from before 2017. This fact shows a deficiency in the number of studies conducted on recent rainfall data and highlights the need for a new localized study that evaluates rainfall datasets to date. This small-scale study will conduct annual, decadal, and seasonal rainfall trend analysis and is necessary for providing a significant understanding of the possible effects of climate change on rainfall variability. This study will also analyze the observed statistical trends to determine the implications on the overall rainfall patterns in Trinidad and Tobago.

Additionally, the rainfall data will only be obtained from two meteorological stations, one located in the northern region of Trinidad and the other located in the southern region of Tobago. Due to the small size of both islands, the rainfall trends detected, or lack thereof, would represent the trends across the entire island (Samarasinghe et al., 2022; Amin et al., 2023; O-brein et al., 2022).

LITERATURE REVIEW

An important part of effectively conducting this investigation is understanding the methods employed to analyze cumulative rainfall data to detect trends and variability. Stephenson et al. (2013) conducted a regional study on the "Changes in extreme temperature and precipitation in the Caribbean region 1961-2010." According to the researchers, "The daily maximum and minimum temperatures and precipitation data from 51 stations across the Caribbean and neighboring countries" were used (Stephenson et al. 2013). The researchers used RClimdex to correct errors from the 51 stations and visually inspect the time series to identify seemingly unrealistically high or low values. The researchers divided the annual total precipitation by the average total precipitation to produce a series not dominated by extremely high precipitation amounts and calculated the regional average indices using stations with less than 30% missing values. Statistical trends were computed if more than 80% of the values were presented in the time series, and the trend significance was assessed at the 5% level using the t test.

Beharry et al. (2014) conducted similar research on the variation in extreme temperature and precipitation on the island of Trinidad rather than the entire Caribbean, with rainfall data collected from Piarco Meteorological Services and UWI. Both Stephenson et al. (2013) and Beharry et al. (2014) agreed that in the Caribbean region, obtaining continuous daily time series metadata is a challenge. According to Beharry et al. (2014), "Due to the unavailability of data, only the Northern region of the island of Trinidad was represented by station data." First, the researchers assessed the dataset homogeneity using the RH test version 4 package and rather than using the RClimdex software to correct errors as Stephenson et al. (2013) did. These researchers used RClimDex software to detect annual and monthly precipitation trends. In addition to using RClimDex software, Beharry et al. (2014) also used Mann–Kendall's test and Sen's estimator to detect monthly and annual precipitation trends, later comparing the results of the two methods and finding them to be the same.

Furthermore, a study conducted by Perera et al. (2020) sought to examine climatic trends in Trinidad and Tobago; however, this time instead of UWI, the second data source was from the meteorological services in Crown Point Tobago, and the period was 1981-2017. Similar to Beharry et al. (2014), these researchers used the Mann–Kendall test to find trends in the data series and Sen's slope estimator to analyze the magnitude of those trends.

An earlier study conducted by R.J. Stone (2001) titled "Changing seasonal rainfall patterns in Trinidad: Myth or Reality?" examined rainfall data from five geographical locations, with more than 50 years of continuous monthly data from 1862 – 1996. This researcher used the sample autocorrelation function (ACF) to analyze the time series and test stationarity at a 5% significance level. The researchers also used the run test to detect departures in the randomness of the time series and the Wald-Wolfowitz test to check for independence at a 5% significance level. These methods used by R.J. Stone (2001) for detecting rainfall trends shared no similarities to the methods employed in later studies by Stephenson et al. (2013), Beharry et al. (2014), or Perera et al. (2020).

Outside of the Caribbean region, many researchers have also conducted studies on detecting precipitation trends. Ghosh (2018) analyzed rainfall trends and their spatial patterns in West Bengal, eastern India, using rainfall data from 12 stations from 1901-2002. Similar to Beharry et al. (2014), this researcher first assessed the data for homogeneity by applying the standard normal homogeneity test and Buishand's range test at 5% significance. Again, Mann–Kendall's statistical test was used for trend detection, and Sen's slope estimator was used to determine trend magnitude.

Meena (2020) conducted a similar study of detecting rainfall trends and variability in the Udaipur District, India, and similar to the previously mentioned researchers, first conducted a homogeneity test using Pettit's homogeneity test and then proceeded to use

Mann–Kendall's test for trend detection and Sen's slope estimator to identify the magnitude. Meena (2020) used the coefficient of variance to measure relative variability. Patakamuri et al. (2020) analyzed homogeneity, trends, and change points in the arid district of Ananthapuramu, India. These researchers conducted various homogeneity tests, used Mann–Kendall's and Spearman's rho tests to detect trends, and estimated the magnitude of these trends using Sen's slope estimator. Gao et al. (2020) examined rainfall trends in Shanxi Province of northern China and did not test for homogeneity but carried out the same tests used by Patakamuri et al. (2020) to identify trends and estimate their magnitude. Malik et al. (2019) conducted precipitation analysis in India, studying 13 districts, used the innovative trend analysis method (ITA), and compared its results with the Mann–Kendall test at a 5% significance level. The ITA method is more sensitive to changes.

As seen in the previous studies within the literature review, it was common for researchers, namely, Beharry et al. (2014), Ghosh (2018), Meena (2020), and Patakamuri et al. (2020), to conduct homogeneity tests on precipitation data before commencing the trend analysis. Patakamuri et al. (2020) pointed out that "If homogeneity is not tested before trend analysis, the results will indicate erroneous trends." The Mann–Kendall and Sen's slope estimator tests are the most widely used for detecting trends and trend magnitudes in precipitation data. According to Patakamuri et al. (2020), the test is a nonparametric test for detecting monotonic trends and is flexible to outliers in the data.

The research conducted by Stephenson et al. (2013) pointed out that in the Caribbean region for the 1961-2010 period studied, warm nights and very high temperatures increased, and there were fewer recorded cool days, nights, and cool temperatures. There were small positive trends in the annual total precipitation, max no. of consecutive dry days, daily intensity, and heavy rainfall events in 1986-2010." The researchers found that the most significant change was in heavy rainfall events generally on the rise. Beharry et al. (2014), who conducted similar research specific to Trinidad, pointed out, "There were no statistically significant trends for the annual precipitation indices for Trinidad which is in line with predictions from the Caribbean region's annual report."

However, the researchers did find precipitation changes in the decadal analysis, which showed that in the decade 1981 – 1990, Trinidad's annual precipitation was above average. The results from Beharry et al. (2014) showed that wet days (i.e., precipitation > or approx. 24 mm) increased from 2001 – 2010. The researchers stated, "There was a shift in the rainfall patterns; the number of wet days decreased, but the wet days received more rainfall than normal in the last decade." This finding corresponds to the regional study conducted by Stephenson et al. (2013) but contradicts the global trend, which shows the average daily intensity during the 1901 – 2010 decreasing and heavy precipitation days being less frequent.

Similar to the findings of Beharry et al. (2014), Perera et al. (2020), who also performed research specific to Trinidad and Tobago, concluded that over the 37 years studied, there was no significant trend in the monthly cumulative rainfall data for the two stations observed. Contrary to the findings of Beharry et al. (2014), who concluded that Trinidad is becoming drier, Perera et al. (2020) concluded that “There is no significant change in rainfall patterns in the driermonths (Jan-May), based on trend analysis there was no trend in the dry season for both Trinidad and Tobago.

” This is a contraction from the conclusion of Stephenson et al. (2013) and Beharry et al. (2014) that heavy rainfall events and wet days increased. Perara et al. (2020) found a negative trend in Trinidad’s rainfall during the wet season (-8.5 mm/season). The researchers pointed out that “This reduction rate of rainfall is only less than 1% of the total rainfall in the wet season but may have a significant impact.”

An older study conducted by R.J. Stone (2001) on Trinidad arrived at a different conclusion; the researcher stated, “The recent claims of changing seasonal rainfall patterns have no valid statistical basis and are therefore inaccurate.” Studies conducted outside of the Caribbean by Ghosh (2018), Meena (2020), and Patakamuri et al. (2020) on different districts in India all observed an overall increase in annual rainfall trends. These observations are different from those made by Stephenson et al. (2013) and Beharry et al. (2014) in the Caribbean, who found insignificant or no increase in the annual rainfall. Gao et al. (2020) conducted a study on trend analysis in Shanxi Province, northern China, and concluded that there were no significant precipitation trends detected in that region on an annual scale. This conclusion is similar to that drawn by Stephenson et al. (2013) and Beharry et al. (2014) of the Caribbean but different from the researchers who studied different districts in India.

Overall, the most commonly used tools for precipitation trend analysis by researchers are the Mann–Kendall test used to detect trends and Sen’s slope estimator, which determines the magnitude of those trends. Most of the researchers assessed the datasets for homogeneity before commencing the Mann–Kendall and Sen’s slope estimator tests using various methods, namely, the RH test, standard homogeneity test, and Pettit’s homogeneity test.

METHODOLOGY

This study is specific to Trinidad and Tobago and will evaluate rainfall trends. The study will use rainfall data over the past 30 years (1990 – 2020) from Trinidad and Tobago’s meteorological services in Piarco and Crown Point in Tobago, as illustrated in Fig. 1. Its findings will help guide the decisions made by water resource engineers on these islands when conducting vulnerability and adaptation studies.

The add-on XLSTAT 2021 with Microsoft Excel 2016 was used to carry out Pettit’s homogeneity test, Mann–Kendall’s statistical test, and Sen’s slope estimator test on the annual, seasonal, and decadal rainfall data from Trinidad and Tobago’s meteorological services.

Figure 1: Location of the Meteorological stations in Piarco (Trinidad) and Crown Point (Tobago)

With respect to Mann–Kendall's test, the test statistic represented by the p value is a measure of trend significance. If the computed p value exceeds the significance level (α=5%), there is an insignificant trend in the dataset. Kendall's τ is another parameter found when using the Mann–Kendall technique; this parameter measures correlation and the strength in the relationship between two variables whose value ranges from -1 to +1. A negative correlation suggests that the rank of one variable increases while the other decreases, and a positive correlation suggests that the rank of both variables increases together. The statistic of Sen's slope indicates an increasing trend whenever the value is positive and a decreasing trend when the value is negative.

DISCUSSION

Variations in the annual rainfall from 1990 – 2020 in Trinidad and Tobago are represented graphically in Fig. 2; Trinidad generally experienced more annual rainfall than Tobago. Trinidad experienced an average rainfall of 1796.7 mm/yr, while Tobago had an average rainfall of 1479.4 mm/yr. Although the annual variations in rainfall are shown in Fig. 2, these figures do not accurately depict any increasing or decreasing trends. The Mann–Kendall test statistic results seen in Table 1 and Table 2 give a much more precise interpretation. Table 1 shows that when conducting Mann–Kendall's test at a 5% significance level on Trinidad's annual rainfall data, a p value of 0.610 and a Sen's slope value of -2.775 were obtained. Since the obtained p value was more than 0.05, which was the chosen significance level, and Sen's slope value was negative, this indicates a decreasing trend in Trinidad's annual rainfall, which was statistically insignificant.

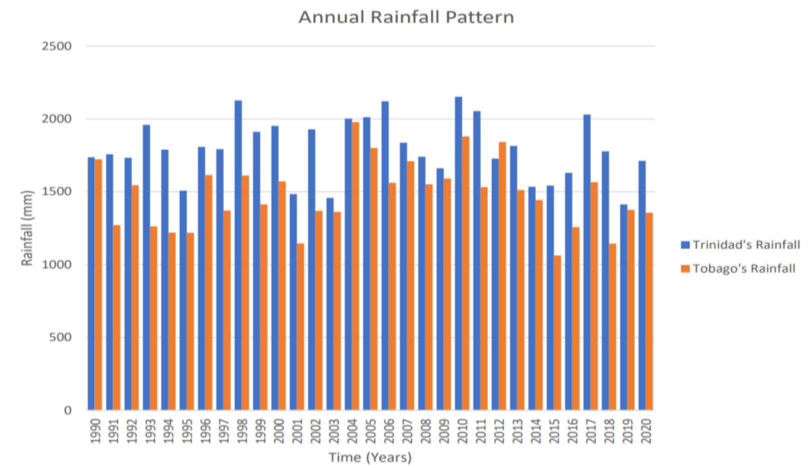

Figure 2: Annual rainfall pattern in Trinidad and Tobago from 1990 to 2020

Similarly, Tobago's annual rainfall data analysis yielded a p value of 0.683 and a Sen's slope value of - 1.517, indicating an insignificant decreasing trend in Tobago's annual rainfall. These findings are consistent with those made by Stephenson et al. (2013), who observed the same rainfall trends in the Caribbean region, and Beharry et al. (2014) also studied rainfall trends in Trinidad.

Table 1: Mann–Kendall test statistics and interpretation of trends in annual, decadal, and seasonal rainfall from 1990 to 2020, Trinidad

Period Examined	Kendall 's tau	Significanc e Level	Mann Kendall value two-tailed test p value	Sen's Slope	Test Interpretation
Annual	-0.067	0.05	0.610	-2.775	Insignificant decreasing trend
Decadal	0.074	0.05	0.461	-0.326	Insignificant decreasing trend
Wet-Season	-0.146	0.05	0.255	-2.652	Insignificant decreasing trend
Dry-Season	-0.019	0.05	0.892	-0.372	Insignificant decreasing trend

Note: I) If $p < 0.05$ (statistically significant); $p > 0.05$ (statistically insignificant). II) Sen's slope = +ve (increasing trend), Sen's slope = -ve (decreasing trend), Sen's slope = 0 (no trend)

Table 2: Mann–Kendall test statistic and interpretation of trends in annual, decadal, and seasonal rainfall from 1990 to 2020 in Tobago.

Period Examined	Kendall 's tau	Significance Level	Mann Kendall value two-tailed test p value	Sen's Slope	Test Interpretation
Annual	-0.054	0.05	0.683	-1.517	Insignificant decreasing trend.
Decadal	0.014	0.05	0.894	-0.628	Insignificant decreasing trend.
Wet-Season	-0.037	0.05	0.786	-0.891	Insignificant decreasing trend.
Dry-Season	0.058	0.05	0.659	0.946	Insignificant increasing trend.

Note: I) If $p < 0.05$ (statistically significant); $p > 0.05$ (statistically insignificant). II) Sen's slope = +ve (increasing trend), Sen's slope = -ve (decreasing trend), Sen's slope = 0 (no trend)

Caribbean islands experience two seasons: one dry and one wet season each year. According to the Caribbean Regional Climate Center, "the wet season runs from June to December, and the dry season during the other half of the year." The seasonal rainfall pattern from 1990-2020 in Trinidad and Tobago is represented graphically in Figs. 3 and 4. Trinidad experienced an average rainfall of 329.92 mm during the dry season and 1466.8 mm during the wet season. Similarly, Tobago experienced an average rainfall of 313.7 mm during the dry season and 1165.69 mm during the wet season. When Trinidad's wet season rainfall was examined at a 5% significance level, a p value of 0.255 and a Sen's slope value of -2.652 were obtained (seen in Table 1). As previously discussed, since this p value is more than the significance level and Sen's slope value is negative, this indicates an insignificant decreasing trend in Trinidad's wet season rainfall.

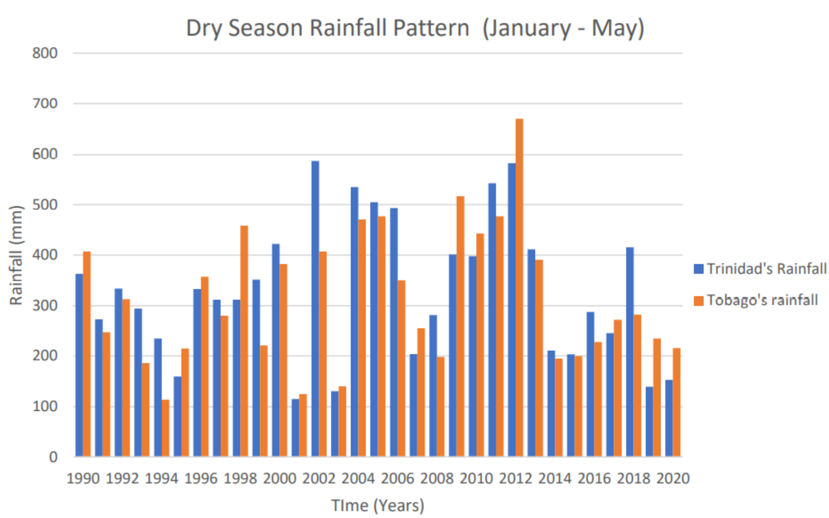

Figure 3: Dry season rainfall pattern in Trinidad and Tobago from 1990 – 2020

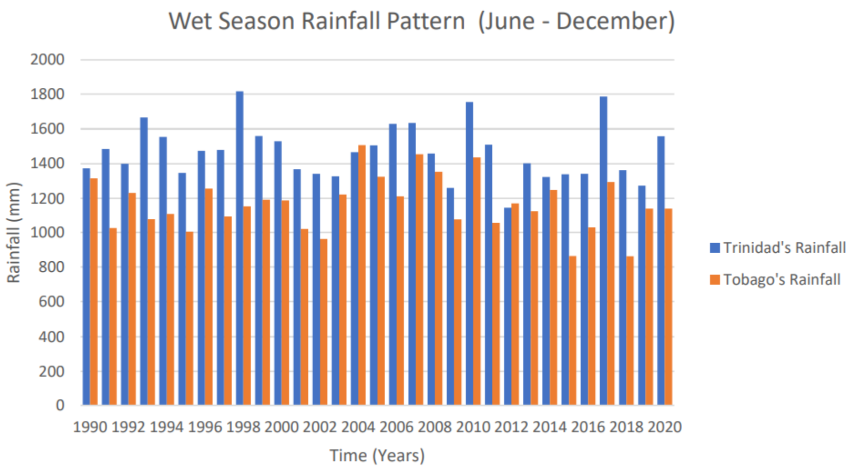

Figure 4: Wet season rainfall pattern in Trinidad and Tobago from 1990- 2020

Likewise, the p value obtained when analyzing Trinidad's dry season rainfall was 0.892, and Sen's slope estimator was -0.372, indicating an insignificant decreasing trend in rainfall during the dry season. When examined at the same significance level, Tobago's wet season rainfall yielded a p value of 0.786 and Sen's slope value of -0.891 (seen in Table 2), indicating that similar to Trinidad, there exists an insignificant decreasing trend in Tobago's rainfall during the wet season. Referring to the same table, the analysis of Tobago's dry season rainfall data yielded a p value of 0.659 and Sen's slope of 0.946, thus indicating an insignificant increasing trend in rainfall during this period. The findings on dry season rainfall patterns are similar to those of Perera et al. (2020), who also found in their study that there was no significant change in rainfall patterns in the drier months for Trinidad and Tobago. However, the findings on wet season rainfall patterns differ from those of Stephenson et al. (2013), who found a significant rise in heavy rainfall events in the Caribbean during the wet season, and Beharry et al. (2014), who found the same to be true from his study on Trinidad.

Trinidad's monthly cumulative rainfall for various decades (1990, 2000, 2010, 2020) is represented graphically in Fig. 5. In 2010, the island experienced its highest cumulative rainfall of 2152 mm and its lowest of 1712.3 mm in 2020. When statistically analyzed at 5% significance, a p value of 0.461 and Sen's slope of -0.326 (seen in Table 1) indicate that an insignificant decreasing trend exists. Similarly, Tobago's monthly cumulative rainfall for the same periods is represented graphically in Fig. 5; the island also experienced its highest cumulative rainfall of 1879.30 mm in 2010 and its lowest of 1356.4 mm in 2020. Upon performing the statistical analysis, a p value of 0.894 and Sen's slope of -0.628 (seen in Table 2) indicate that an insignificant decreasing trend also exists in Tobago's decadal rainfall patterns.

These decadal findings differ from those of Beharry et al. (2014), who found an increase in Trinidad's decadal rainfall. Since the results show that no statistically significant trends existed in Trinidad and Tobago's annual, seasonal, and decadal rainfall patterns from 1990 - 2020, the inference is that Trinidad and Tobago are safe from abrupt changes in rainfall patterns due to climate change. The global climate change models and IPCC predictions that rainfall will increase during the 21st century currently do not apply to Trinidad and Tobago, lending to the argument that global climate models do not provide a representative description of the local climate, thus highlighting the need for more localized studies such as this one to be done. These results can be valuable to water resources and agricultural management policymakers in Trinidad and Tobago, influencing the systems put in place to manage floods and droughts.

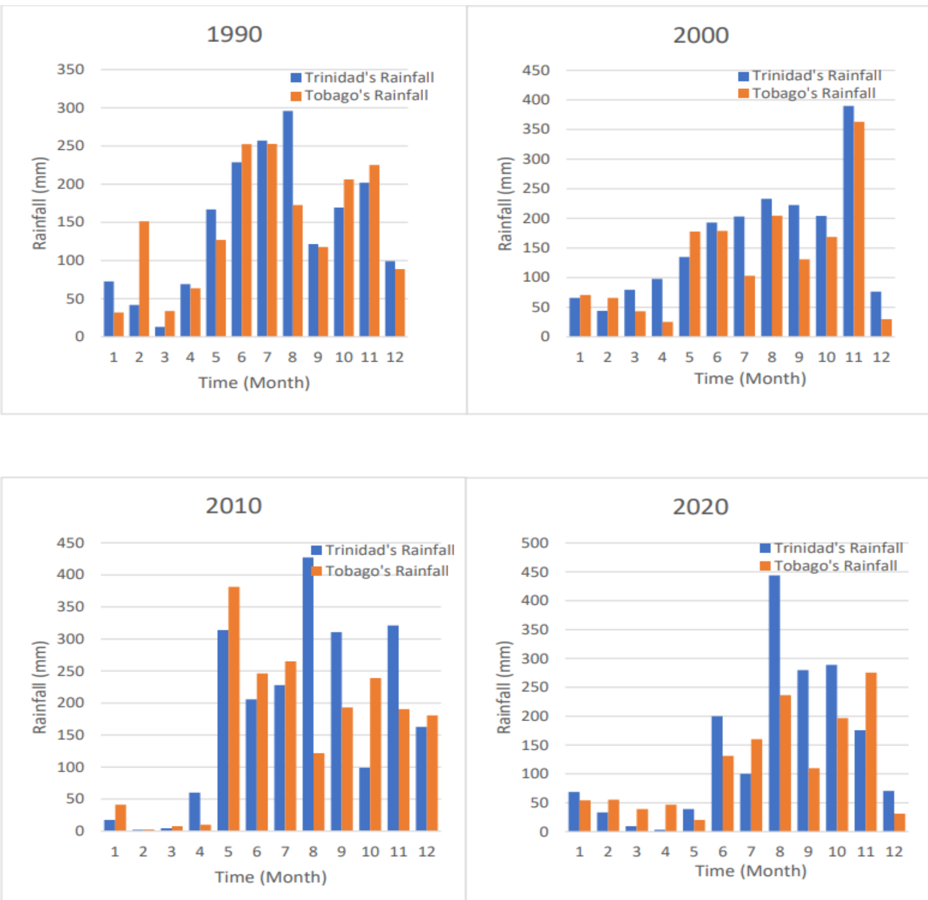

Figure 5: Decadal Rainfall pattern in Trinidad and Tobago from 1990 to 2020

CONCLUSION

This study concluded that there were insignificant trends with respect to the effect of climate change on the annual, seasonal, and decadal rainfall trends in Trinidad and Tobago from 1990 – 2020. The fact that insignificant trends exist in the rainfall data examined indicates that Trinidad and Tobago are generally safe from abrupt changes in rainfall trends due to climate change. This also highlights the significance of conducting localized climate studies that will help shape policies and adaptation strategies in small island states such as Trinidad and Tobago. However, these results do not correlate rainfall intensity which have negative impact from the drainage system. Future studies in this area required.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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