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TRENDS OF EXTREME TEMPERATURE AND RAINFALL INDICES FOR ADDIS ABABA CITY, ETHIOPIA

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Abstracts: *The extreme temperature and precipitation index trend analysis for Addis Ababa city is presented in this study. The Bole and Tikur Anbesa observatories, two stations in the capital city of Addis Ababa, provide the temperature and rainfall variation used in this analysis. The RClim-Dex software has been used to find climate extreme indices for Addis Ababa city stations based on climate data for the period 1954 to 2019. The annual total precipitation trend (PRCPTOT) at the 5% significant level exhibits a positive slope at the Addis Ababa observatory and a negative slope at the Addis Ababa Bole station. SDII trends indicate an increase at the 5% significant threshold for both stations. At the 5% significance level, the trends for both stations' maximum and minimum temperatures show a positive slope. Conversely, both stations exhibit a negative slope in the diurnal temperature ranges. The RClim-Dex results indicate that, while rainfall intensity is decreasing, there is a tendency for annual rainfall indices to increase at the Addis Ababa observatory station, but to decrease at the Bole station. Additionally, there is an upward slope for consecutive wet days for all stations. Nevertheless, steady warming patterns are evident for both the maximum and minimum temperature indices. In contrast, declining trends are shown in the diurnal temperature ranges*.

Keywords: Temperature and rainfall, Trend Analysis, Extremes climate events, Climate Change, RClim-Dex, Addis Ababa, Ethiopia

1. Introduction

The high frequency of climate extreme events, such as flooding, droughts, sea level rise, and heat waves, is a clear indicator of climate change, according to the Intergovernmental Panel on Climate Change (IPCC) report [1]. Numerous studies have demonstrated that variations in the frequency and intensity of extreme weather events related to climate change, as well as variations in weather patterns, have a significant impact on both natural and human systems [2], [3]. Climate change is a major long-term factor contributing to social, economic, and environmental change. There are significant geographical variations in the worldwide impact of its alteration [4]. Unquestionably, rising air temperatures and altered precipitation patterns may have positive or negative effects on a range of facets of human existence, including energy use, agricultural goods, and human settlements [4]. As extreme events occur more frequently and with greater severity, future climate change may make the climate over East Africa more complicated [5]. There are hundreds of thousands of farmers, pastoralists, and other people who live in this region and manage their lives in harmony with the environment, which is heavily affected by the climate. Climate change consequently affects society, the economy, and the population. Future climate change may complicate the climate of East Africa as extreme events become more frequent and severe [6]. In this region, which is greatly influenced by the climate, there are hundreds of thousands of farmers, pastoralists, and other individuals who live in harmony with the nature. Consequently, society, the economy, and the population are impacted by climate change.

Alterations in extremes are the most direct result of climate change. Studies on the patterns and fluctuations in temperature and precipitation across Africa are numerous, both at the regional and national levels. The yearly mean minimum temperature in Ethiopia was shown to be rising, according to a study [7]. In contrast, there has been significant seasonal variability in the yearly rainfall throughout the same period. The combustion of fossil fuels releases gases into the atmosphere, which are then combined with fumes from factories, power plants, and cars, as well as toxic spills and paint and other chemical odors, to continuously contaminate the air in cities. One of the most populous cities in the world, Addis Ababa is susceptible to both drought and riverine flooding because of its dramatic weather patterns [8].

Additional research on variations in extremes across the Addis Ababa region uses straightforward indices to characterize the frequency, magnitude, and persistence of extremes over brief periods. Although the indices are simple to understand, they only cover a small portion of all potential extreme traits. This is the first study of its kind that uses the Rclimdex program to assess the temporal changes in extremes indices over the city using time series of temperature and rainfall data covering a long period of time (1954–2019). The software does this by utilizing statistically extreme value theory. Examining trends in extreme temperature and precipitation indices, which are based on recorded temperature and rainfall for the Addis Ababa observatory stations and Bole, is the aim of this study.

2. Materials and Methods

2.1. Description of the study area

2.1.1. Location

The largest and capital city of Ethiopia is Addis Ababa, which is situated at a height of 2,355 meters (7,726 feet) above mean sea level in the country's center at 9°1′48″N latitude and 38°44′24″E longitude. It is located in Ethiopia and covers an area of roughly 527 km^2. Eleven sub-cities comprise it. Addis Ketema, Akaky Kaliti, Arada, Bole, Guardele, Kirkos, Kolfe Keranio, Lidette, Nifas Silk-Lafto, Yeka, and Lemi Kura are the 11 sub cities. The headquarters of the African Union (AU), the United Nations Economic Commission for Africa (ECA), and several other continental and international institutions are located in Addis Ababa.

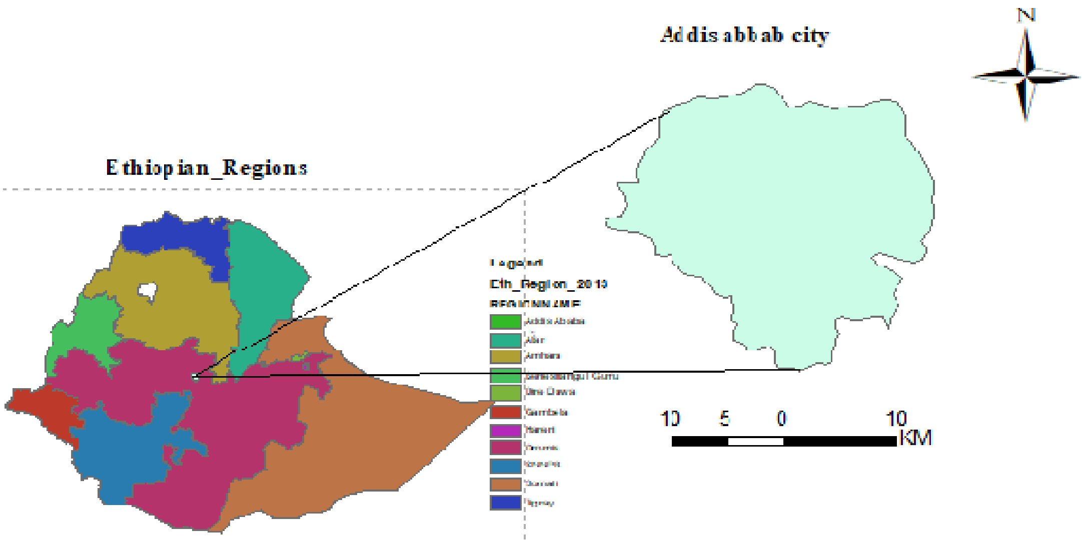

Figure 1: Location of Study Area

2.1.2. Population

Based on Ethiopian statistical service report of 2007 census, Addis Ababa has a total population of 2,738,248 which of 1,304,518 (47.6%) are male and 1,433,730 (52.4%) are female. Addis Ababa has an area of 527 km² with a population density of 5195.9. Everybody in the population resided in an urban area. However, according to Worldo-meter, 4,793,699 people will be achieved by 2024.

2.1.3. Climate

The monthly rainfall, maximum temperature, and minimum temperature statistics for Addis Ababa from 1981 to 2015 are displayed in Figure 2.

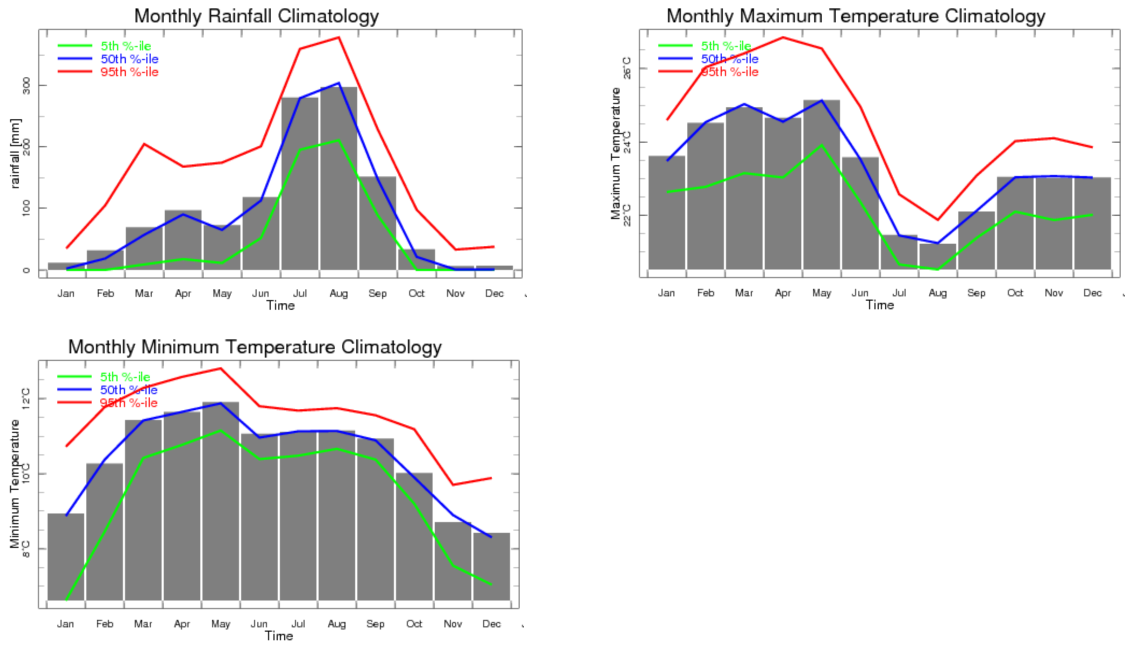

Figure 2: shows the climatology of Addis Ababa's monthly rainfall, maximum temperature, and lowest temperature

2.1.4. Topography

From a topographic perspective, Addis Ababa is primarily a flat city surrounded by a few hills and tiny mountains that rise to heights of 2,326 meters (7,631 feet) to 3,000 meters (9,800 feet) above sea level. Situated at the base of Mount Entoto, the city is a part of the Awash watershed.

2.1.5. Data Source

The Ethiopian Meteorological Institute, located in Addis Ababa, Ethiopia, provided all historical meteorological data. This research has made use of long-term historical daily rainfall, maximum (T_{max}), and minimum (T_{min}) temperature data for two stations: Addis Ababa-Bole and Addis Ababa-observatory. The Addis Ababa-observatory Meteorological Station and Addis Ababa-Bole data sets used in this study covered the years 1954 to 2019.

2.2. Methods

The visual examination of the data and the identification of anomalies on displayed graphs served as controls over its quality. It is important to thoroughly identify outlier values to ensure that they are anomalies and not just naturally extreme results. This work employed a standard outlier threshold, which is established using inter-quartile range (IQR). In mathematics, the following formula defines it:

$$\text{Threshold} = (Q1 - 3*IQR,\ Q3 + 3*IQR) \quad (1)$$

In this case, the first quartile is denoted by Q1, the third by Q3, and the inter-quartile range (IQR) is the difference between Q3 and Q1. The inter-quartile range approach is renowned for its ability to withstand outliers while retaining extreme data. After that, the identified outlier values were eliminated and replaced with the outlier threshold.

To analyze the historical meteorological raw data, RClimDex was utilized. This tool, which is based on Microsoft Excel, offers a user-friendly software package for computing climatic extreme indexes in order to track and identify climate change [9]. It has been utilized at CCl/CLIVAR workshops on climate indices since 2001 and was created by Byron Gleason at the National Climate Data Centre (NCDC) of NOAA.

Rclimdex.r 1.0, an R-based software program, was used to perform quality control (QC) on all variables, specifically checking maximum and minimum temperatures as well as rainfall. The Meteorological Service of Canada's Climate Research Division (CRD) is responsible for maintaining this on behalf of the Expert Team on Climate Change Detection and Indices (ETCCDI) [10]. This program may detect consecutive days with equal values, outliers, duplicate dates, and values that are out of range depending on a predetermined threshold. It can also detect coherence between highest and minimum temperatures (Tmax > Tmin). These represent daily statistics that fall outside of a user-defined threshold. Since this approach does not presuppose a distribution for the residuals and is resistant to the impact of outliers in the series, Kendall's tau-based slope estimator has been used to calculate the trends. Slope estimates should not be believed if slope inaccuracy exceeds slope estimate. A trend is considered significant at the 95% confidence level if the P Value is less than 0.05. Analysis was limited to trends that were determined to be statistically significant at the 0.05% level.

A set of 13 indices was selected for this study and their descriptions are provided in Table 1.

Table 1: List of the twelve climate indices analyzed in this paper

No.	Index	Descriptive name	Definition	units
1	PRCPTOT mm	Wet day precipitation	Annual total precipitation from wet days(>1mm)	mm
2	R20mm	Very heavy precipitation	Annual count of days when PR ≥20mm	days

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3	SU25	Hot days	Annual count when TX>25℃	days
4	TR20	Warm nights	Annual count when TN>20℃	days
5	TN10p	Cool nights	Percentage of days when TN < 10th percentile	Days
6	TX10p	Cool days	Percentage of days when TX < 10th percentile	Days
7	TN90p	Warm nights	Percentage of days when TN > 90th percentile	Days
8	TX90p	Warm days	Percentage of days when TX > 90th percentile	Days
9	WSDI	Warm spell duration Indicator	Annual count of days with at least 6 consecutive days when TX > 90th percentile	Days
10	DTR	Diurnal temperature Range	Monthly mean difference between TX and TN	˚C
11	SDII	Simple daily intensity Index	Annual total precipitation divided by the number of wet days (defined as PR ≥ 1.0 mm) in the yea	Mm/Day
12	CDD	Consecutive dry days	Maximum number of consecutive days with RR < 1 mm	Days
13	CWD	Consecutive wet days	Maximum number of consecutive days with RR ≥ 1 mm	Days

3. Results and Discussions

3.1 Trends in Temperature and Rainfall Extremes

Trend analysis of two stations' extreme temperature and rainfall indices for the years 1954 to 2019 was presented on this section.

Table 2: Trend analysis of the twelve extreme rainfall and temperature indices for the Addis Ababa observatory and Bole station

Station			Addis Ababa-Bole			Tikur Anbesa observatory		
Latitude			8.98108			9.01891		
Longitude			38.79871			38.7475		
Indices	Starting Year	Ending Year	Slope	STD_of _Slope	P-Value	Slope	STD_of_ Slope	P-Value

SU25	1954	2019	0.655	0.174	0	1.12	0.219	0
TX10p	1954	2019	-0.224	0.03	0	-0.237	0.038	0
TX90p	1954	2019	0.302	0.051	0	0.412	0.063	0
TN10p	1954	2019	-0.46	0.047	0	-0.732	0.083	0
TN90p	1954	2019	0.53	0.055	0	0.342	0.044	0
WSDI	1954	2019	0.37	0.079	0	0.648	0.148	0
DTR	1954	2019	-0.03	0.005	0	-0.008	0.007	0.24
SDII	1954	2019	0.004	0.006	0.517	0.01	0.007	0.142
R20mm	1954	2019	-0.007	0.024	0.775	0.032	0.028	0.255
R30mm	1954	2019	0	0.017	0.987	0.002	0.018	0.906
CDD	1954	2019	0.074	0.245	0.762	0.155	0.181	0.396
CWD	1954	2019	-0.034	0.036	0.347	0.054	0.043	0.221
PRCPtot	1954	2019	-0.289	1.181	0.807	1.081	1	0.284

3.2 Trends in Rainfall Extremes

The annual total precipitation (PRCPTOT) trend for the Addis Ababa Bole station exhibits a negative slope, whereas the Addis Ababa observatory displays a positive slope at the 5% significant level (Figure 3 and Figure 4). The presence of consecutive wet days (CWD) is a reliable indicator of sufficient water for agricultural systems (Figure *7* and Figure *8*). A reliable indicator of the possibility of insufficient water for agricultural systems is the occurrence of consecutive dry days, or CDD. At the 5% significant level, CDD trends revealed an increase in CDD, as shown in the example given for both stations (Figure *5* and Figure 6). Days with heavy precipitation of 20 mm (R_{20}) or 30 mm (R_{30}) of rain per day, respectively, are counted as heavy precipitation days. While Addis Ababa Bole station did not exhibit either increasing or decreasing trends, Figure 11 of the examples supplied for Addis Ababa observatory stations showed trends of increasing heavy precipitation (R_{30}), with a slope of 0.002 at 5% significant level. The ratio of the total yearly rainfall to the number of days when precipitation fell during the year is known as the "Simple Day Intensity Index for rain" (SDII). When there are more rainy days in a given year, the overall amount of precipitation falls, but the rain intensity index decreases. In addition, the number of rainfall days may have increased (or decreased) more than the yearly rainfall, leading to a decline. Similarly, a decrease in rainfall days without affecting the overall annual rainfall amount or a larger rise (smaller decrease) in the annual rainfall relative to the increase (decrease) in the number of rainy days could lead to an increase in this indicator. As a result, if the index falls, there will be, on average, less rain each day, and more rain each day, if the index rises. The SDII trends indicate a rise at the 5% significant level for both stations (Figure *13* and Figure *14*).

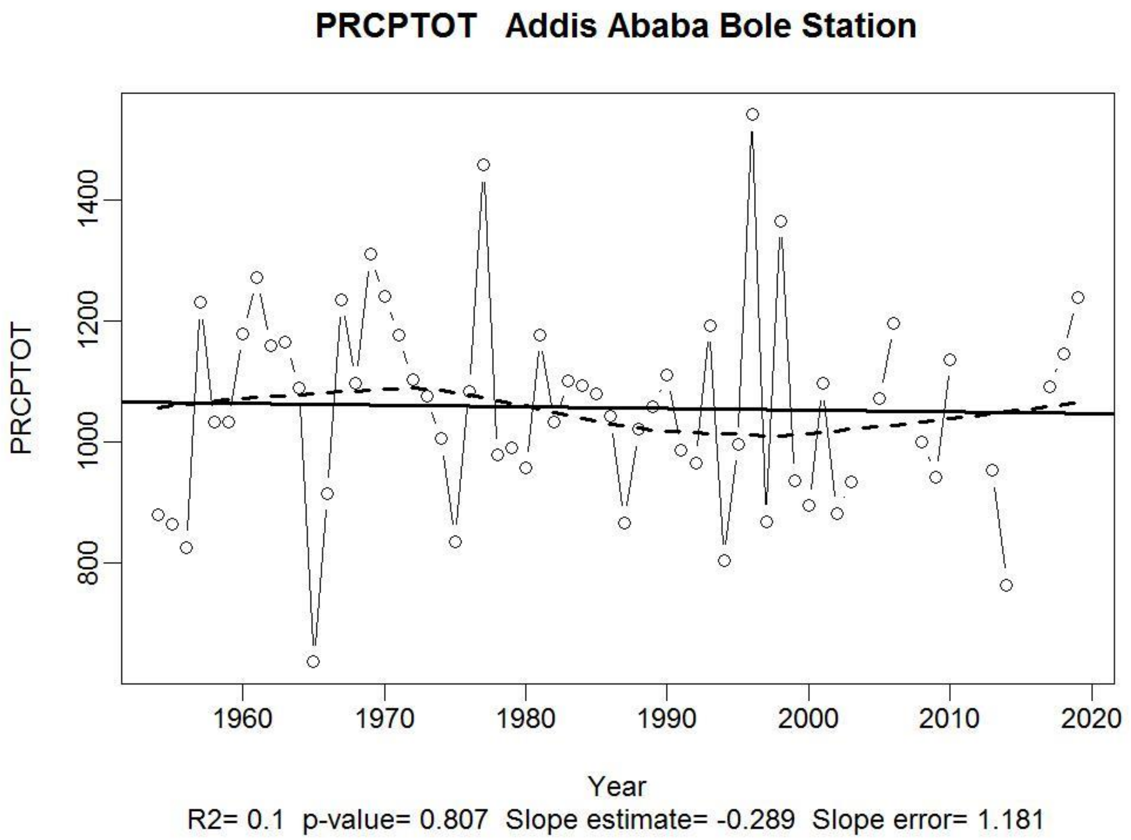

Figure 3: Addis Ababa Bole Station's yearly total precipitation in rainy days (rain greater than 1 mm).

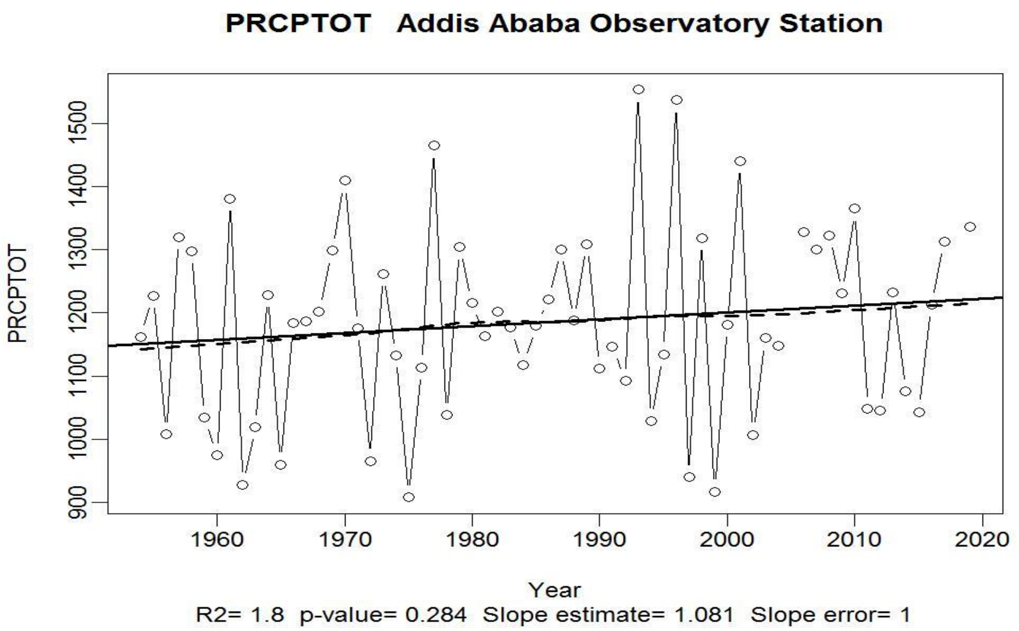

Figure 4: Annual total precipitation for Addis Ababa Observatory on wet days (rain greater than 1 mm)

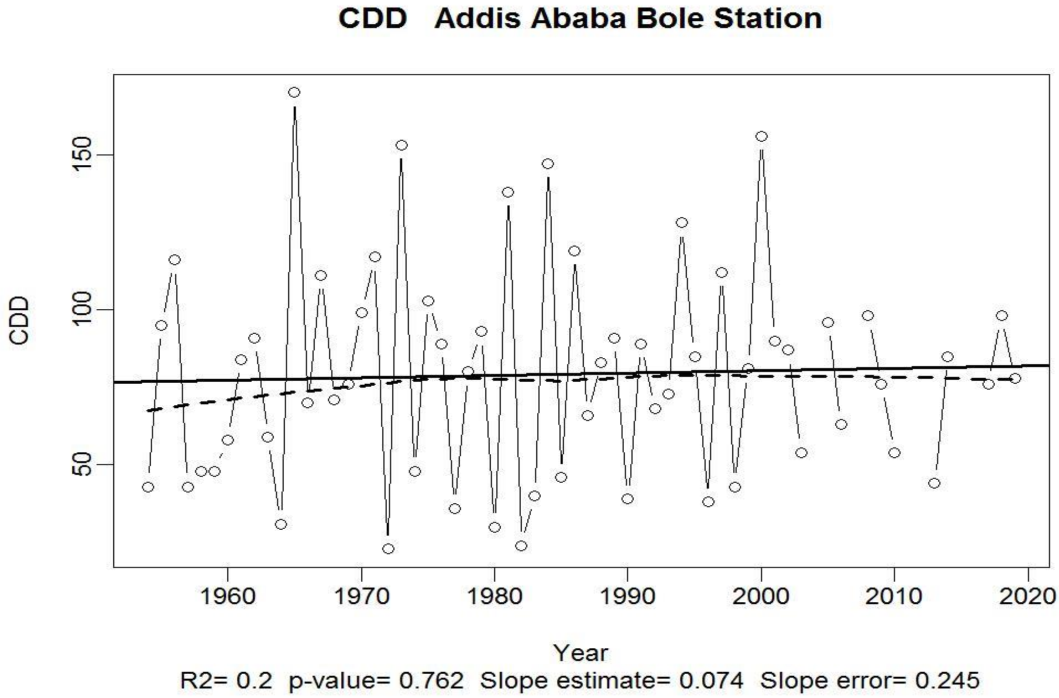

Figure 5: Addis Ababa Bole Station's maximum number of days without rain (rainfall less than 1 mm).

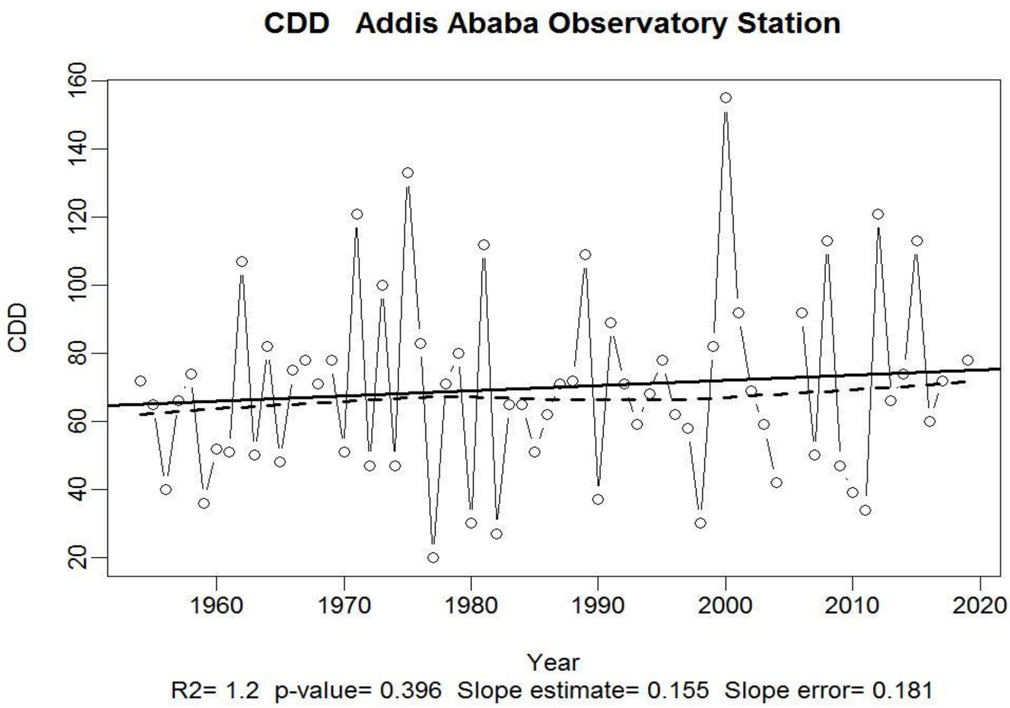

Figure 6: The Addis Ababa Observatory Station's maximum number of days without rain (rainfall less than 1 mm)

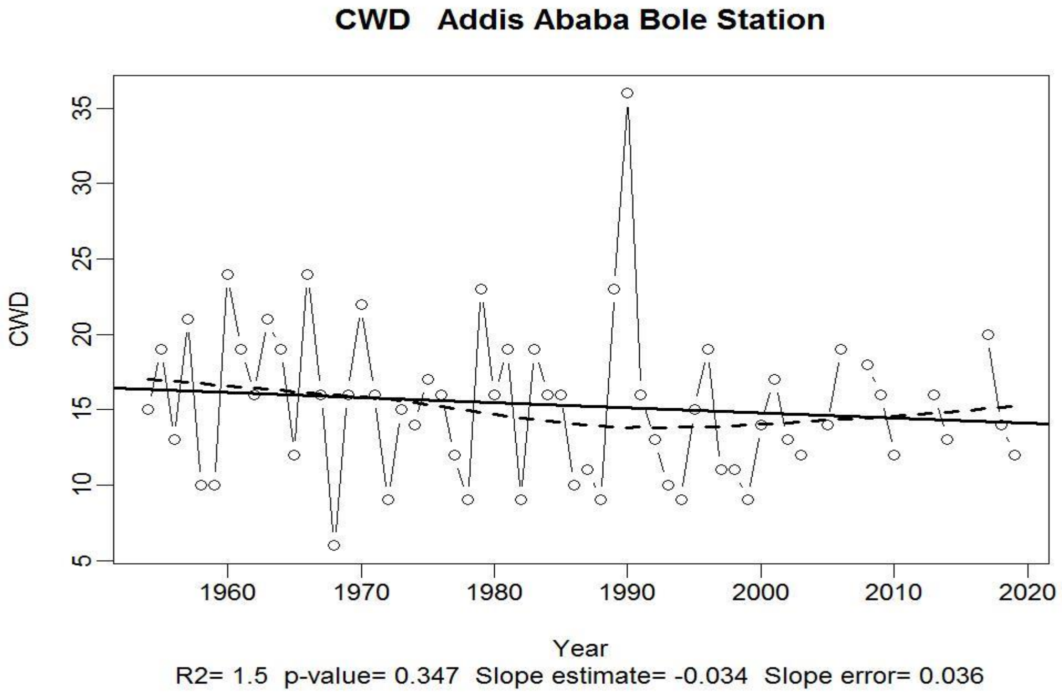

Figure 7: Addis Ababa Bole Station's maximum number of consecutive wet days (rainfall greater than 1 mm)

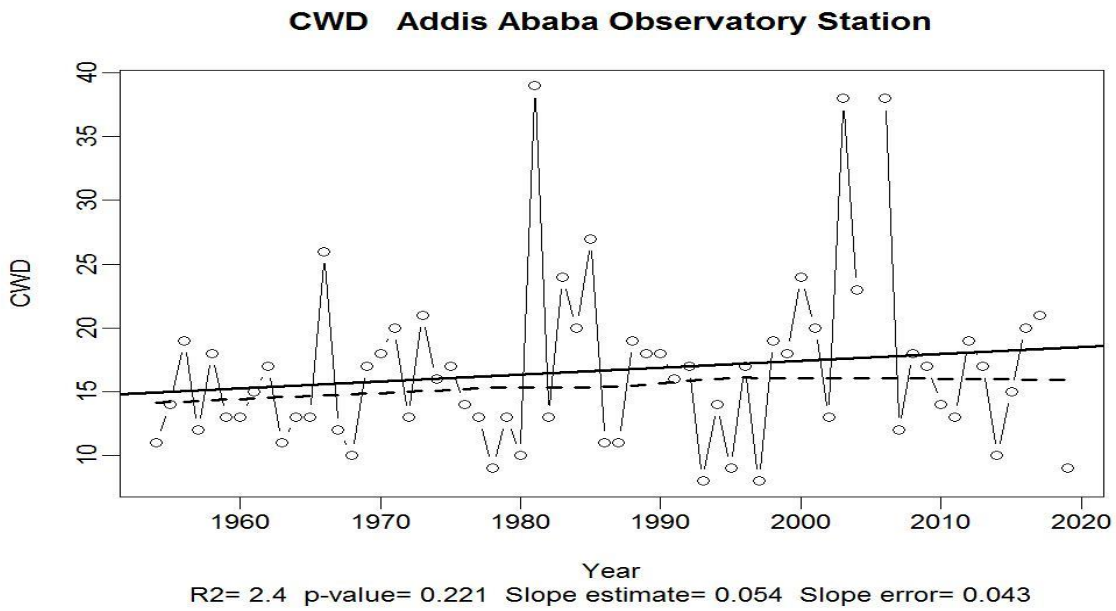

Figure 8: The Addis Ababa observatory station's maximum number of days with rain (more than 1 mm) in a row

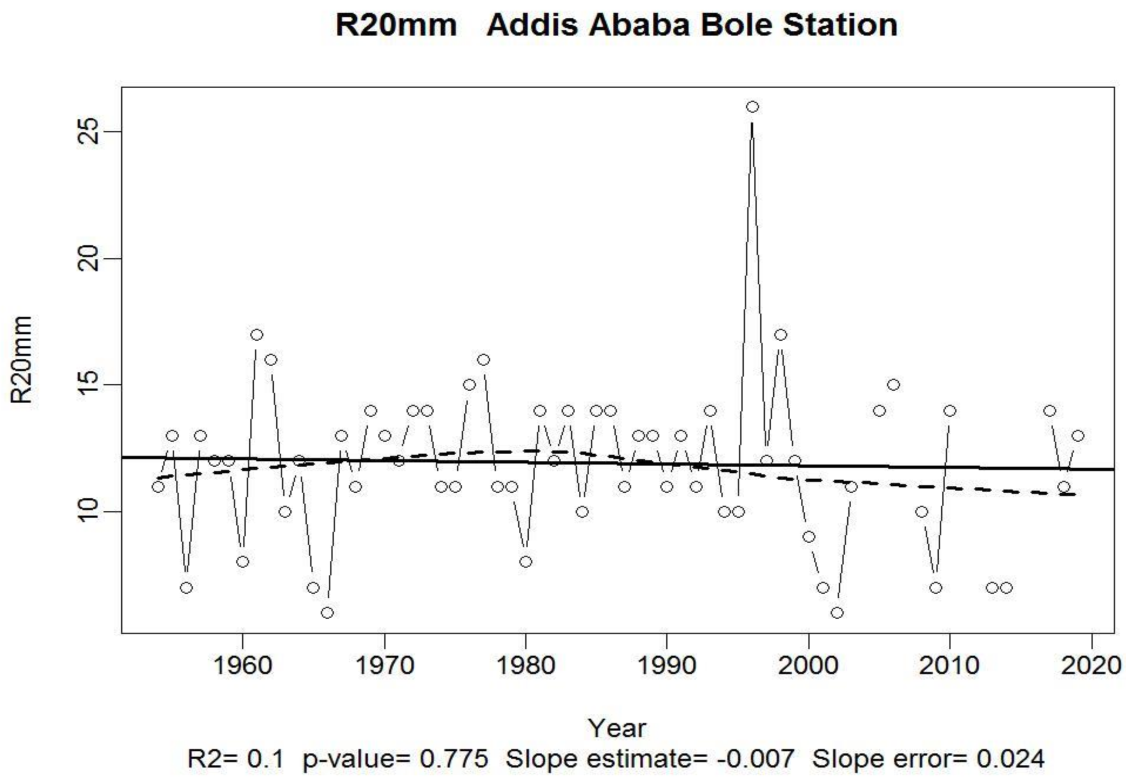

Figure 9: Heavy precipitation days for Addis Ababa Bole station (precipitation >20 mm

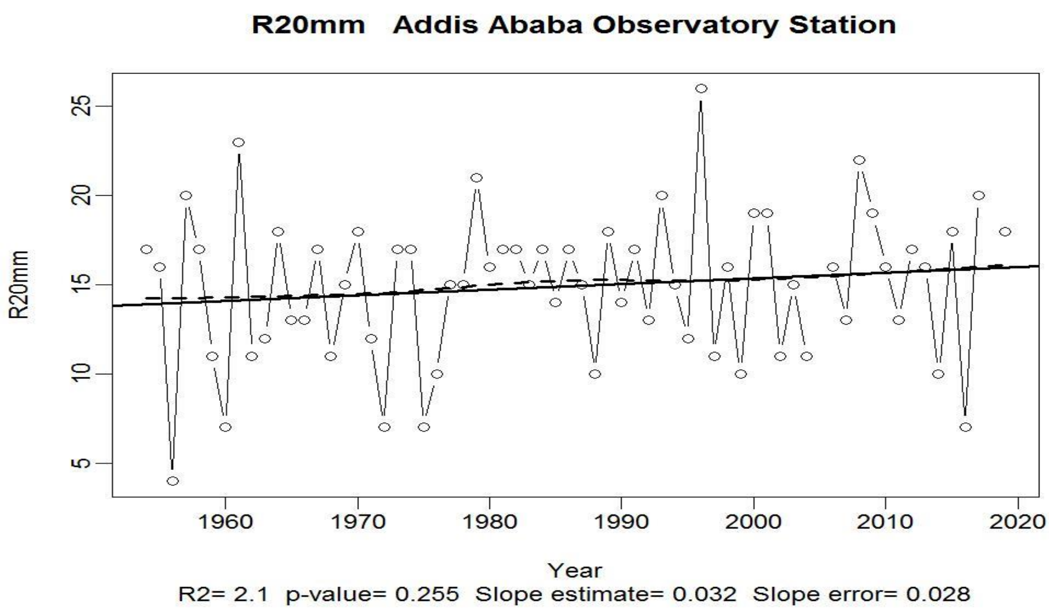

Figure 10: Heavy precipitation days for Addis Ababa observatory station (precipitation > 20 mm)

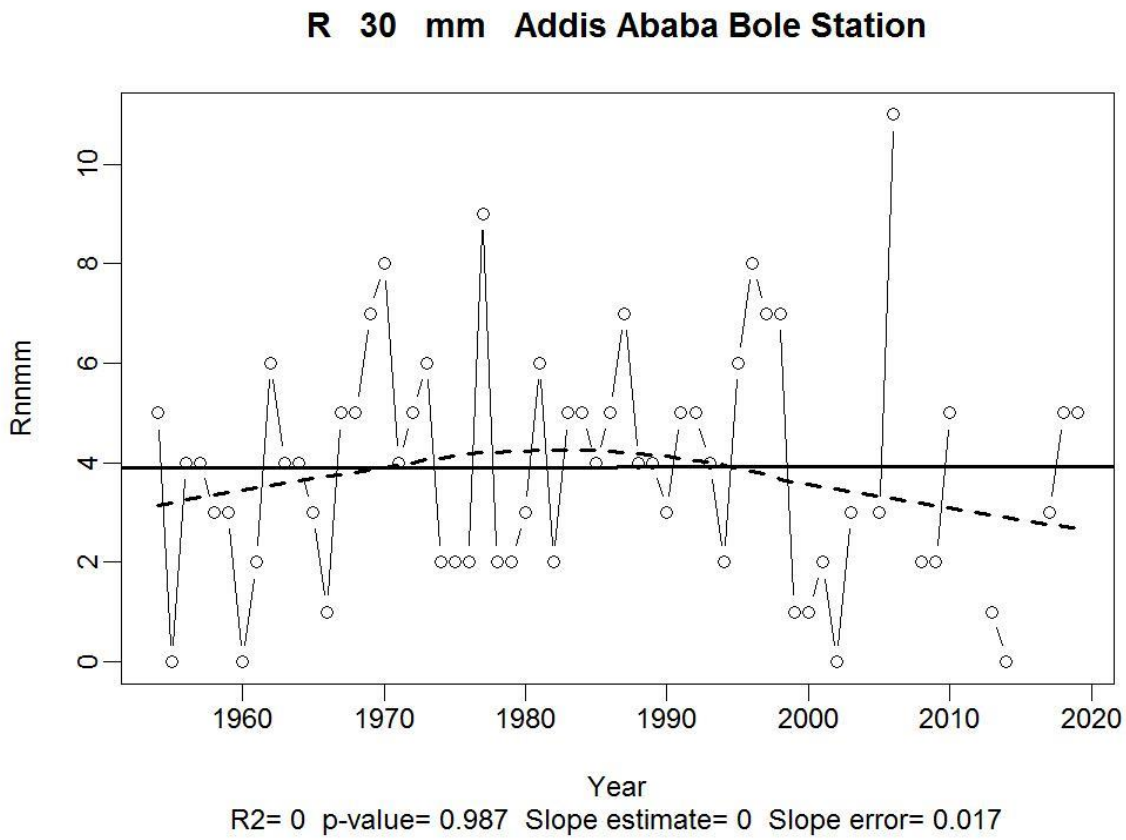

Figure 11: Heavy precipitation days for Addis Ababa Bole station (precipitation > 30 mm)

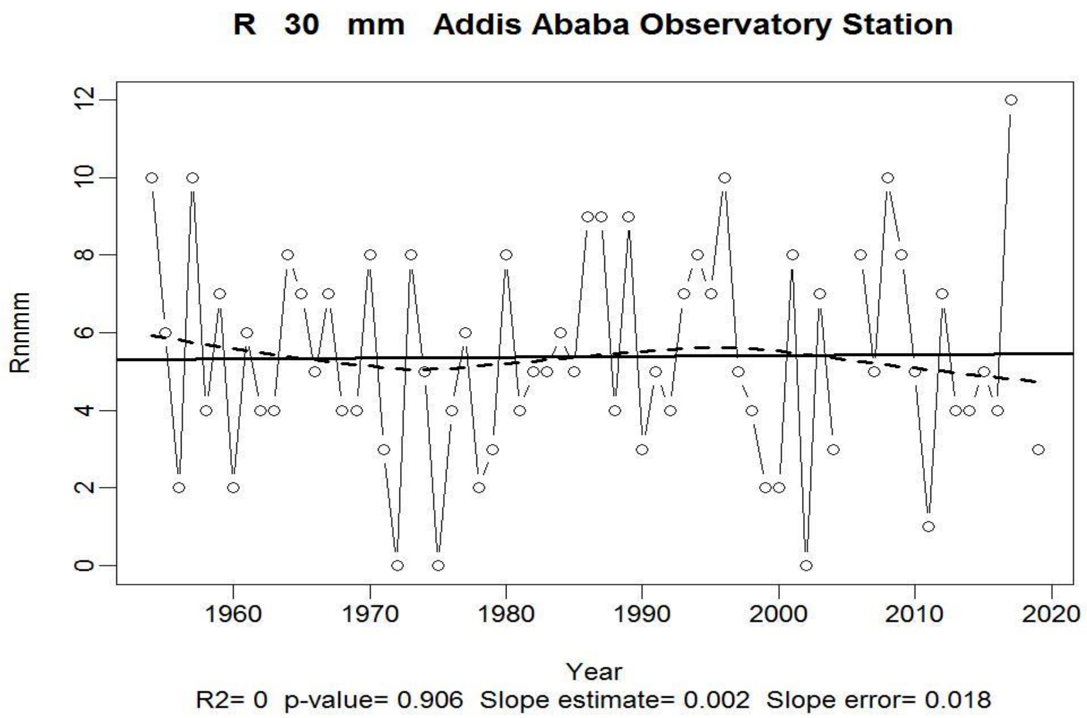

Figure 12: Heavy precipitation days for Addis Ababa observatory station (precipitation > 30 mm)

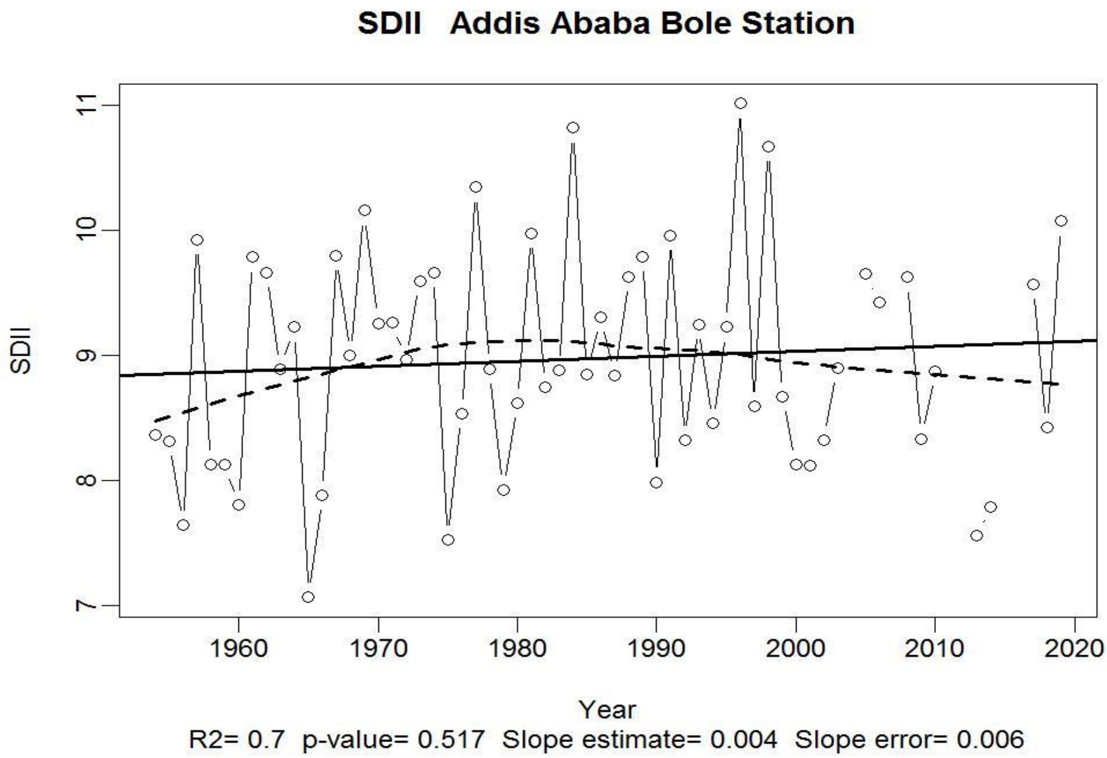

Figure 13: Simple rainfall intensity index for Addis Ababa Bole station

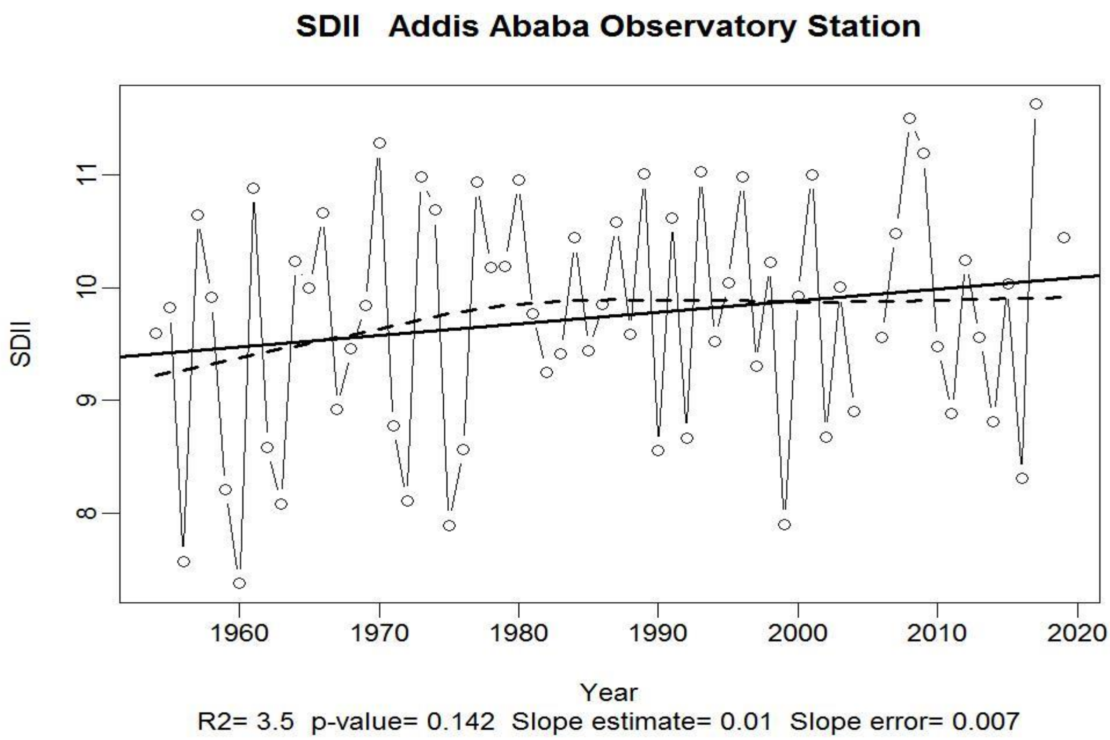

Figure 14: Simple rainfall intensity index for Addis Ababa observatory station

3.3 Trends in Temperature Extremes

When exposed to specific threshold temperatures during the day and night, plants develop to their maximum potential. Crop growth and development are determined by "Degree Days," which are defined as cumulative temperature values over particular limits. Increased respiration occurs at high temperatures, sometimes surpassing the rate of photosynthesis. This indicates that the rate at which photosynthesis produces its products is outpacing its use. Photosynthesis must outpace respiration in order for growth to occur. Conversely, low temperatures may cause inadequate growth. High daytime temperatures are a defining feature of Ethiopia's semi-arid and desert regions.

The number of warm days has continued to rise over Addis Ababa, Ethiopia, according to temperature trends analysis. The days are warmer, as shown by the index "summer days" (SUT_{max} >25˚C), based on an analysis of the extreme temperature trend on both stations. At a 5% significant level, the examples presented for the two stations (Figure *15* and Figure *16*) clearly show increasing trends in the number of days when the temperature exceeds 25˚C (SU25). The data below, which shows the Addis Ababa observatory stations (Figure *17* and Figure *18*) and the Addis Ababa bole, similarly indicates a declining trend in the frequency of days with T_{min} <10th percentile of daily lowest temperature "cold nights" (TNI0P) at the 5% level of significance.

Figure *19* and Figure *20* show a declining trend at the 5% significant level for the trend in days with T_{max} <10th percentile of daily maximum temperature, or "cold day times" (TXI0P). The Addis Ababa observatory sites (Figure *21* and Figure *22*) and the Bole of Addis Ababa, however, showed an increasing trend for warm day periods (TX90P) at the 5% significant level. Figure *23* and Figure 24 illustrate an increasing trend in warm nights (TN90P) at a significance level of 5%. These examples are from the Addis Ababa Bole and Addis Ababa observatory stations.

Furthermore, as demonstrated by the examples for Addis Ababa Bole and Addis Ababa Observatory (Figure *25* and Figure *26*) at the 5% significant level, respectively, there is an increasing trend in the annual count of days with at least 6 consecutive days when Tmax > 90th percentile "warm spell duration index" (WSDI). One reliable measure of the durability of the warm weather in the area is the WSDI's growing trend. On the other hand, the mean diurnal temperature range (DTR) showed declining trends, as shown in the example given for the Addis Ababa observatory station and the Addis Ababa bole, which have slopes of 0.008 and 0.03 at the 5% significant level, respectively (Figure *27* and Figure *28*).

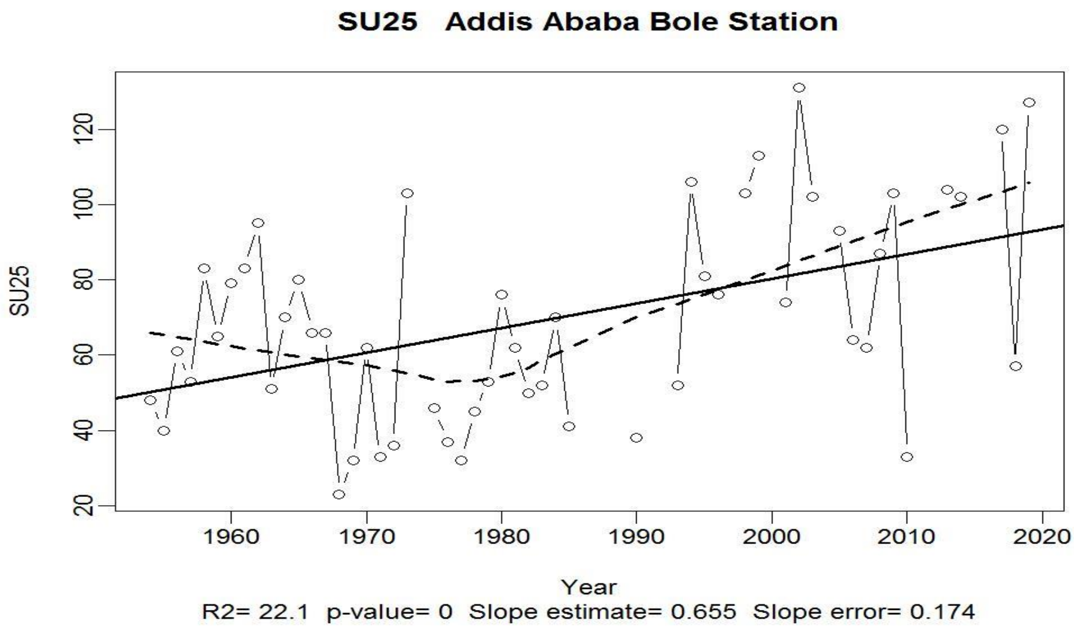

Figure 15: Frequency of days when Tmax > 25˚C for Addis Ababa Bole station

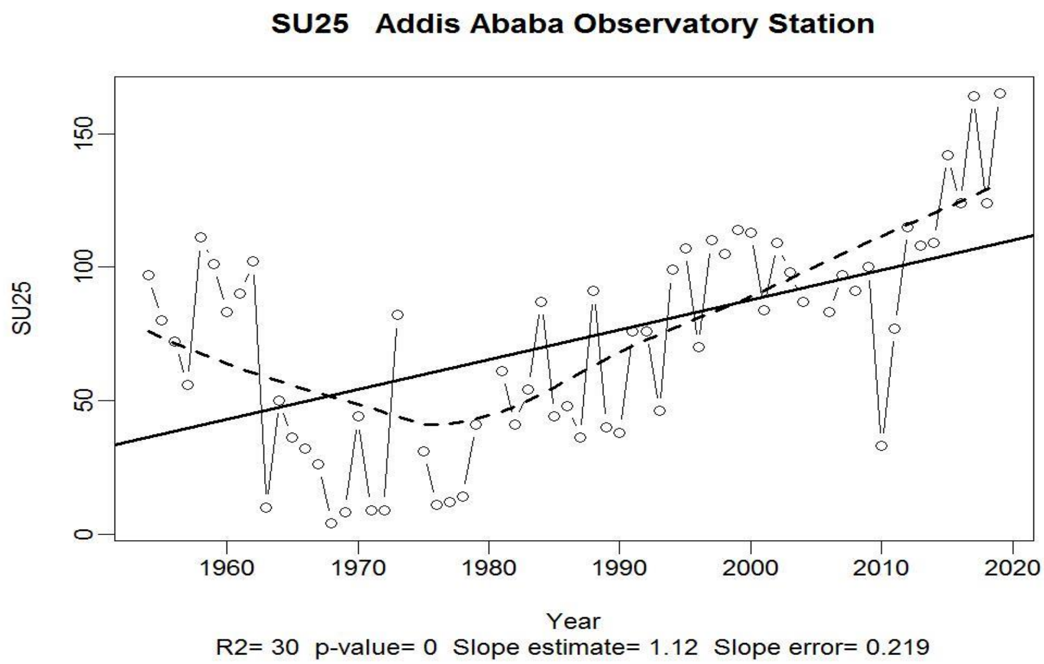

Figure 16: Frequency of days when Tmax > 25˚C for Addis Ababa observatory station

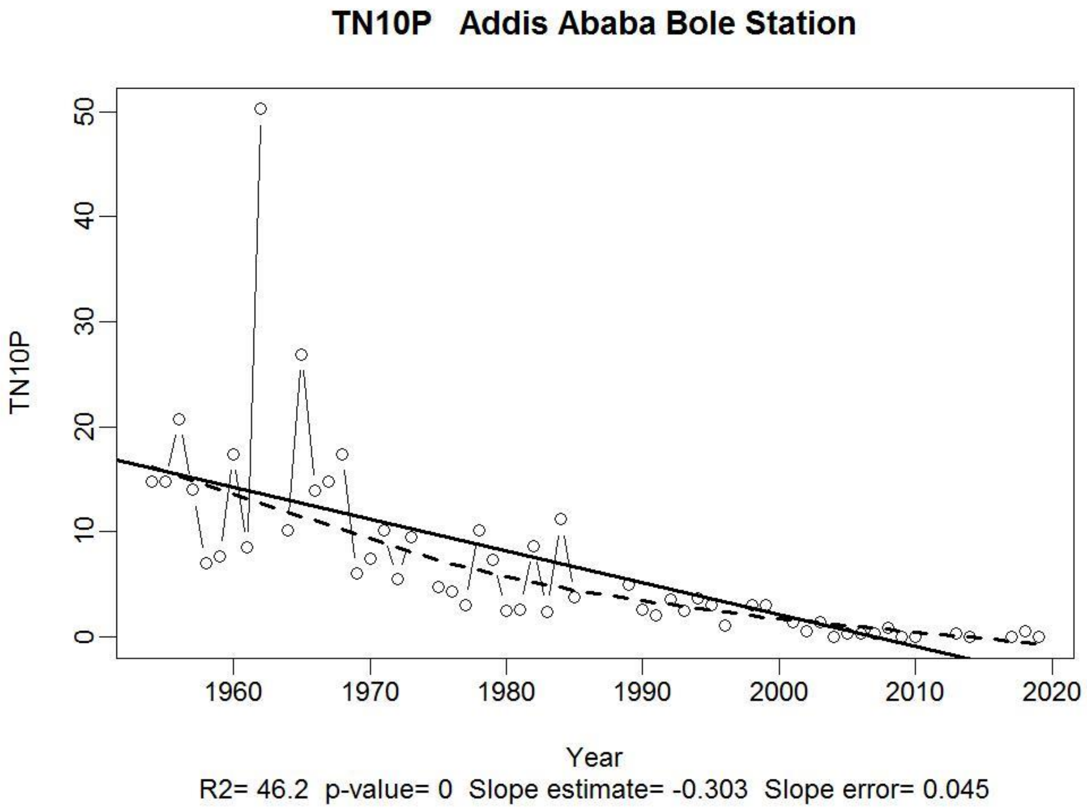

Figure 17: Days with T_{min} < 10th percentile of daily minimum temperature (cold nights)-Addis Ababa Bole

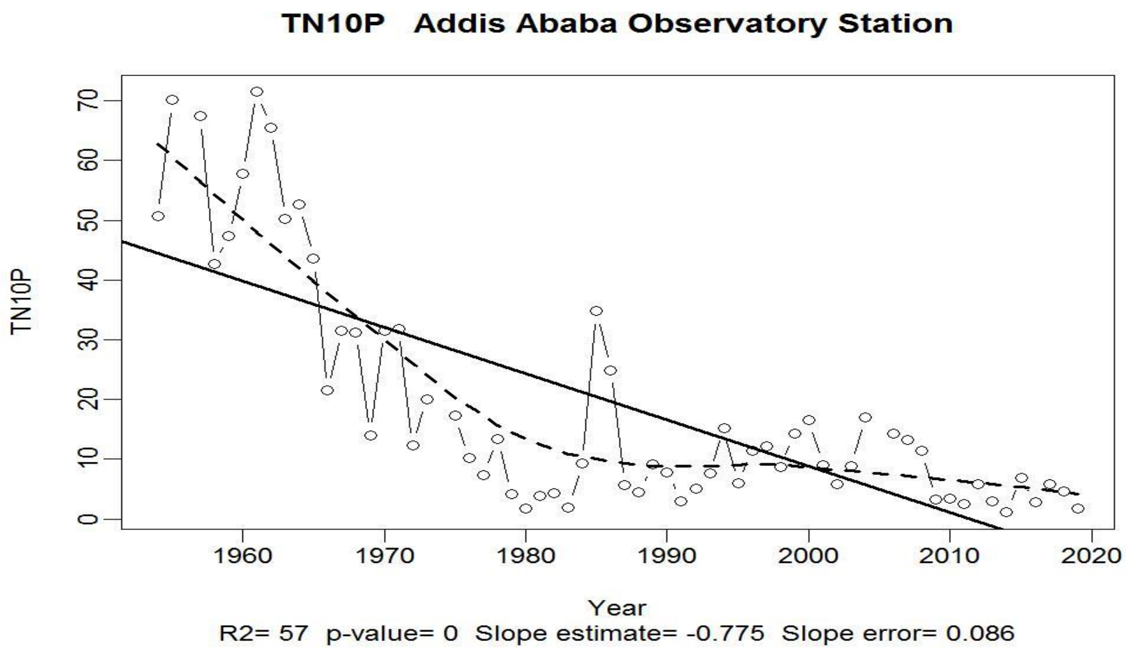

Figure 18: Days with T_{min} < 10th percentile of daily minimum temperature (cold nights)-Addis Ababa observatory station

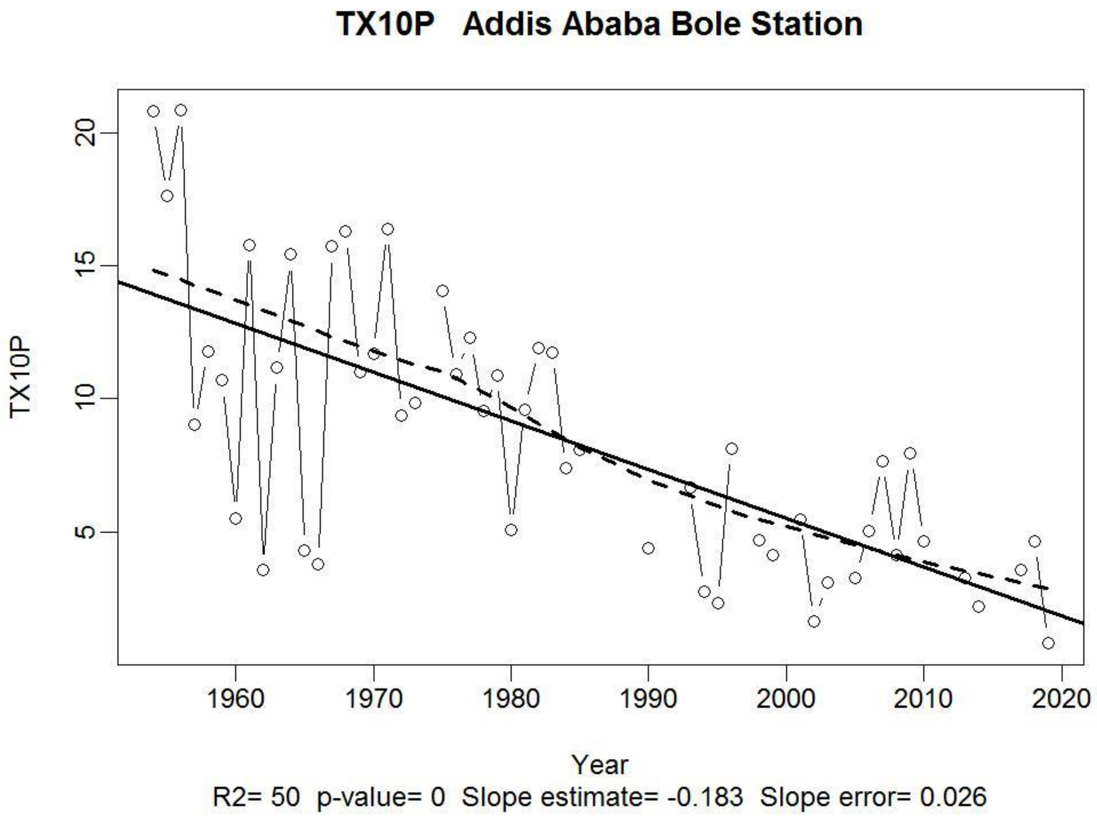

Figure 19: Days with T_{max} < 10th percentile of daily maximum temperature (cold day)-Addis Ababa bole station

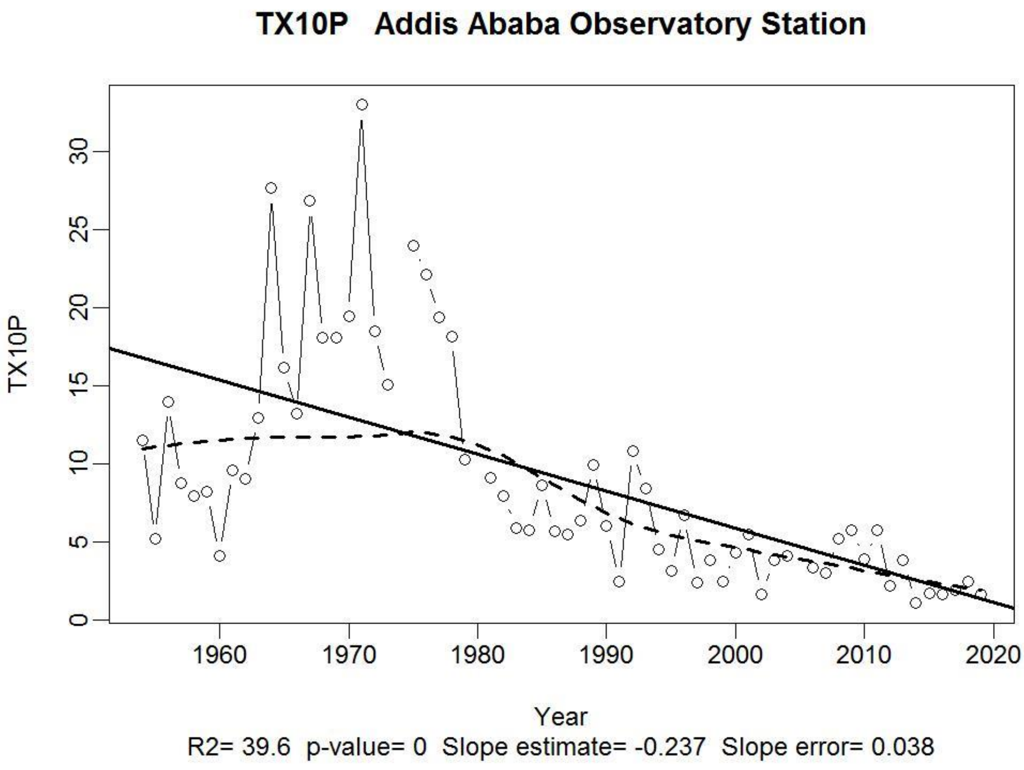

Figure 20: Days with T_{max} < 10th percentile of daily maximum temperature (cold day)-Addis Ababa observatory station

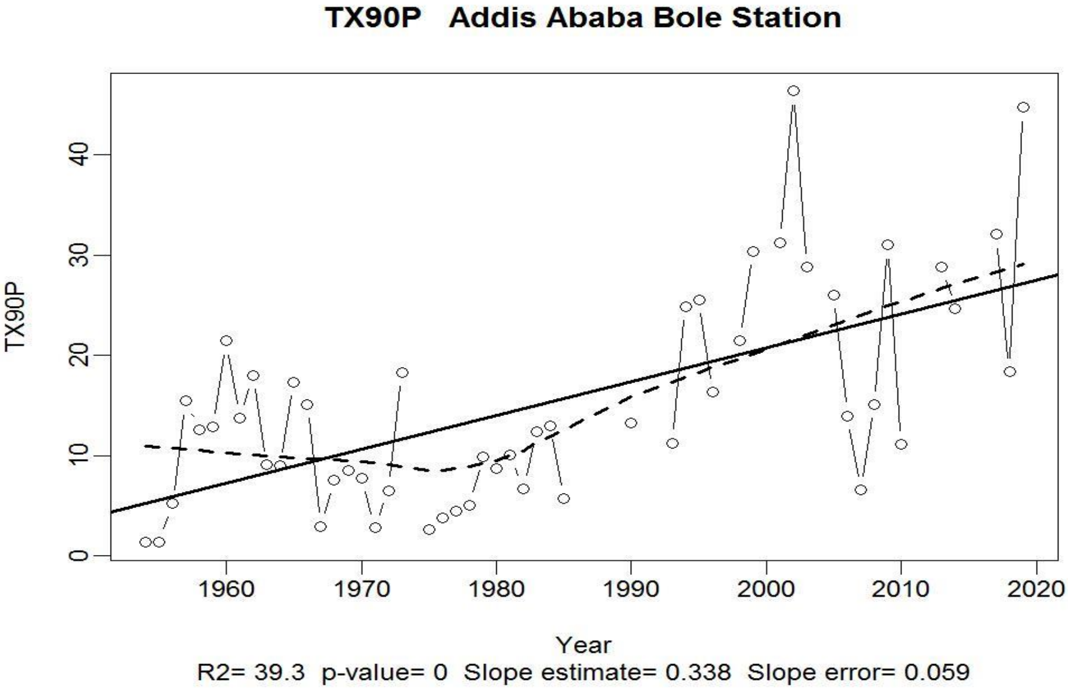

Figure 21: Days with Tmax > 90th percentile of daily maximum temperature (warm daytimes)-Addis Ababa Bole station.

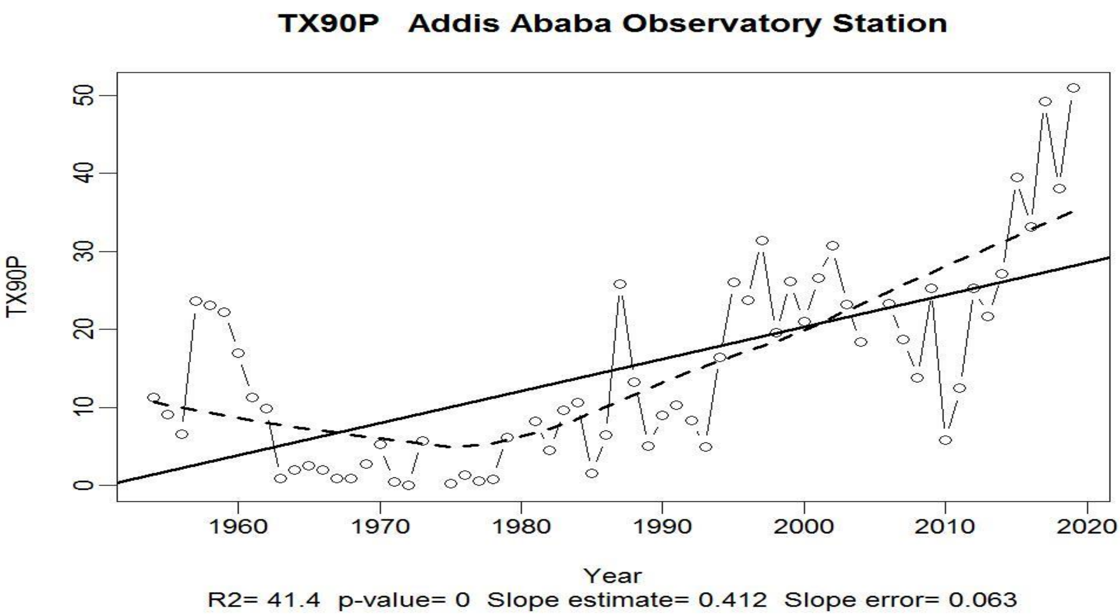

Figure 22: Days with T_{max} > 90th percentile of daily maximum temperature (warm day-times)-Addis Ababa observatory station

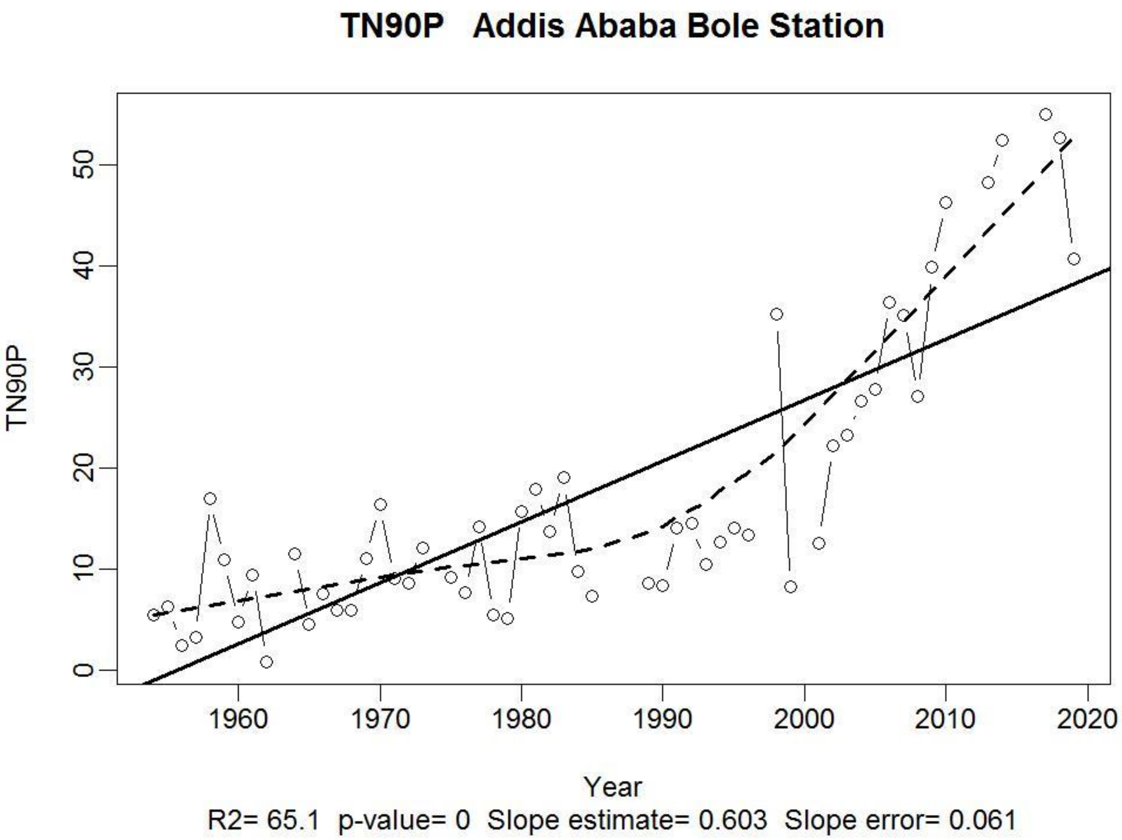

Figure 23: Days with T_{min} > 90th percentile of daily temperature (warm nights)-Addis Ababa-Bole station

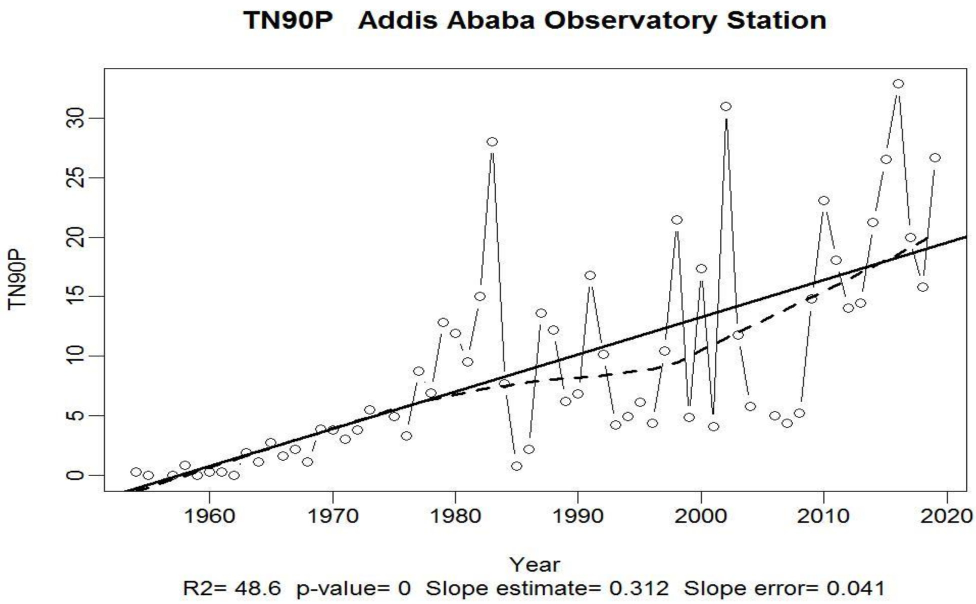

Figure 24: Days with T_{min} > 90th percentile of daily temperature (warm nights)-Addis Ababa-observatory station

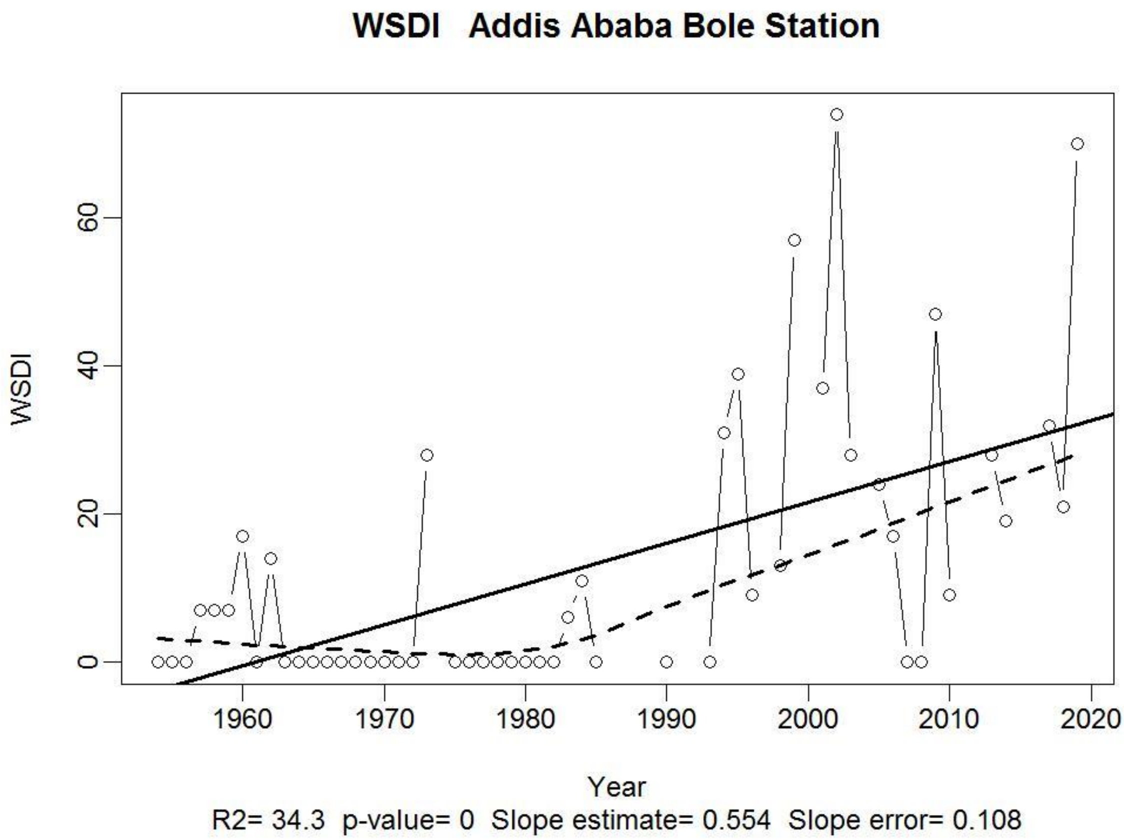

Figure 25: Warm spell duration (days)-Addis Ababa Bole station

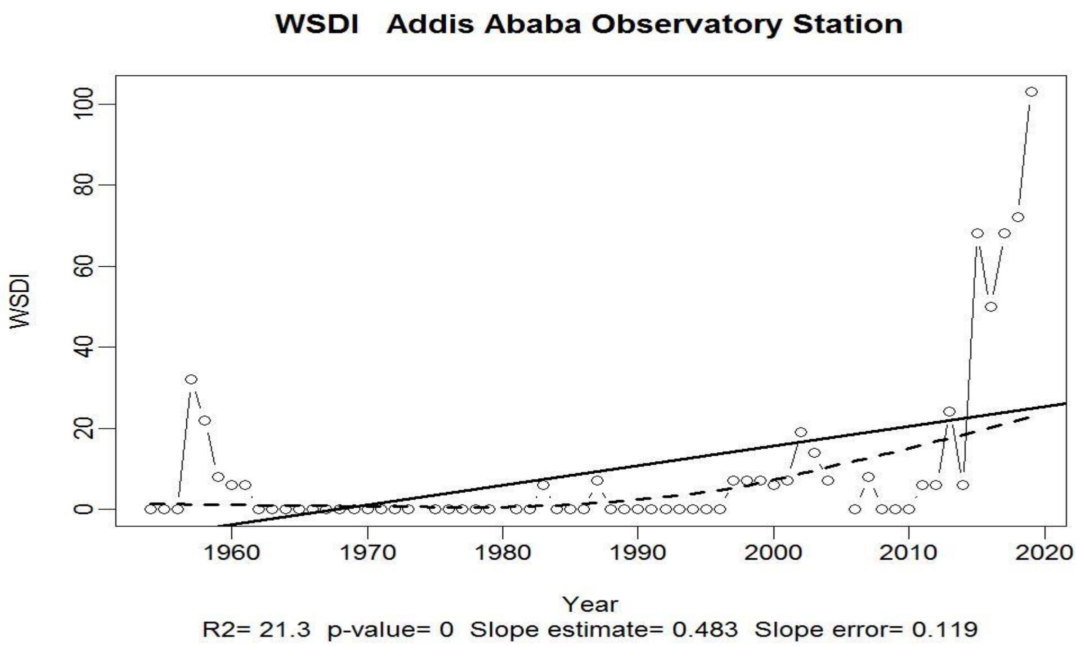

Figure 26: Warm spell duration (days)-Addis Ababa observatory station

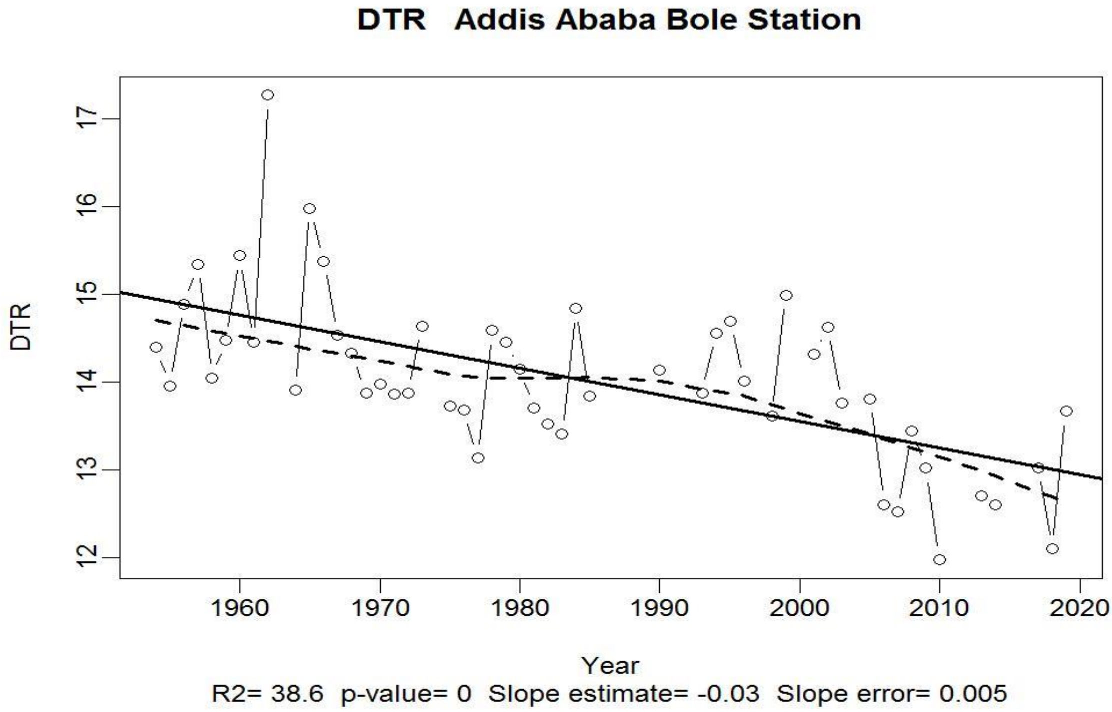

Figure 27: Mean of diurnal temperature range (˚C)-Addis Ababa Bole station

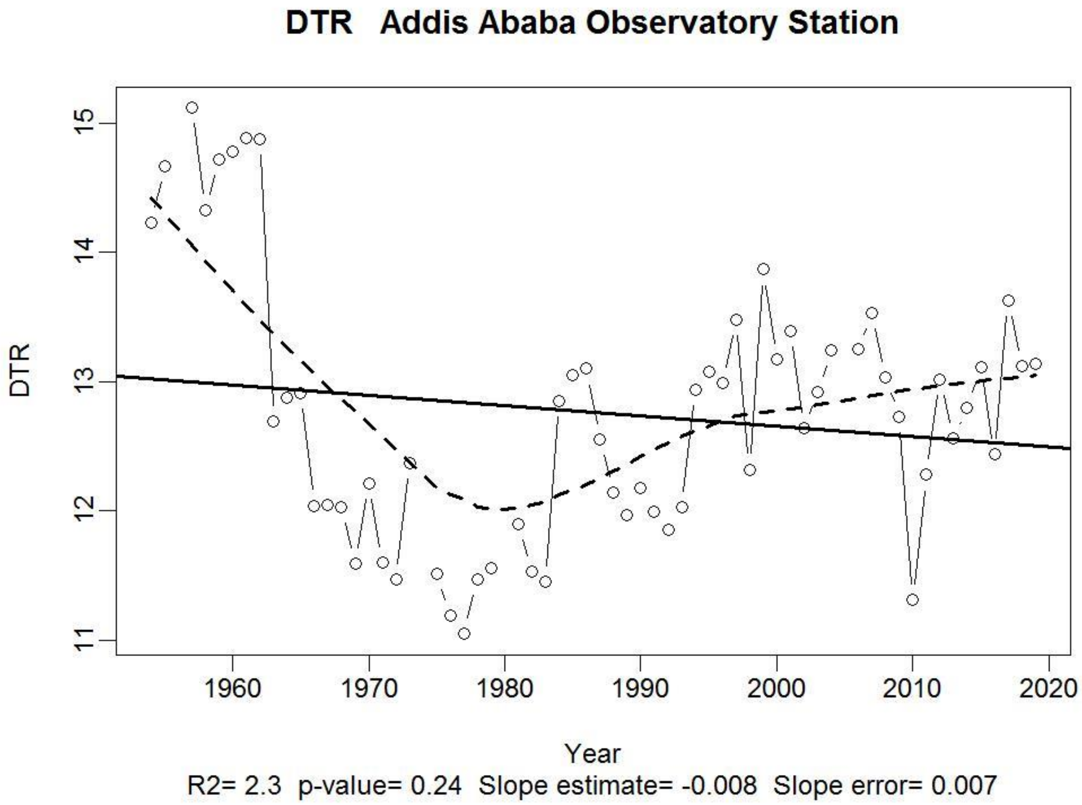

Figure 28: Mean of diurnal temperature range (˚C)-Addis Ababa observatory station

4. Conclusion and Recommendations

4.1. Conclusion

The number of consecutive rainy days on the Addis Ababa observatory station is increasing, while the number of wet days on the Addis Ababa bole station is dropping. However, the annual rainfall trend is increasing for both stations, according to these indices. For both the maximum and minimum temperature indices, consistent warming trends are apparent. Days with high temperatures are becoming more frequent on both stations. Conversely, there are trends toward decline in the diurnal temperature ranges.

However, it should be emphasized that in this field of study, the indices' magnitudes of change are location-specific, meaning that the data is more trustworthy when used for planning and decision-making at the particular sites under consideration. The information is significant because it shows that climate extremes may have an impact on society's capacity to adapt to them and the area's delicate ecosystem. Thus, careful and thorough mainstreaming of this knowledge at all decision-making stages would be necessary for agriculture planning and practice in these surrounding areas.

4.2. Recommendations

Extreme weather and climatic event hazards have a significant effect on the socioeconomic activities of the county. To find evidence of changes in these extremes at the smallest (localized) region feasible, it is imperative that all of Ethiopia be inspected, and the patterns found therein must be recorded.

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